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# The effect of the construction and renovation of a highway bypass in Central Poland on the carabid beetle fauna (Coleoptera: Carabidae)

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**Key words.** Coleoptera, Carabidae, roadsides, highway bypass renovation, landscape

**Abstract.** The aim of this research was to define the effect of the construction and renovation of a highway bypass around the town of Skępe on the environment and assemblages of carabid beetles. This four-year study was based on catching samples of beetles using pitfall traps. The traps were set first in 2008 and later from 2010 to 2012, after the renovation of the road, along roadside verges adjacent to two ca. 100-year-old pine forest stands, wet habitats and fallows of arable fields and inside these habitats about 25 m from the road (control plots). The carabids collected were identified to species and numbers of individuals and dominance values of each of the species were calculated for each study plot and each year. Furthermore, the dominance of the different species of plants was assessed. Numbers of species, numbers of individuals, percentage share of forest species and individuals, and Shannon diversity values of the carabid assemblages were analyzed. Multivariate statistical analyses (ordinations) were carried out using the dominance of the different species of carabids and using the ecological indicator values of plants as environmental factors. The construction of the bypass in 1987 resulted in more diversified carabid assemblages along the roadsides. Carabid fauna along the roadsides differed from that in the control plots in forests and in terms of some parameters from the control plots in wet habitats, but not statistical from the control plots in the fallow areas of arable fields. The renovation of the road 22 years after construction did not result in any significant changes in the characteristic parameters of the carabid assemblages along the roadsides, but gradient analysis indicated that it did have an effect. In terms of the environmental conditions of the habitats based on the plant associations occurring there the roadside habitats differed from the control plots in forests and wetlands. Since the number of sites studied is rather low, the results of this study have to be considered to be preliminary, but may provide research hypotheses for further research on highway roadsides.

## INTRODUCTION

The issue of an effect and importance of roads for wild organisms, biological diversity and the natural environment is widely discussed in the literature. A great part of this research refers to the fragmentation of the habitats of species due to the construction of linear infrastructures in the landscape and the reaction of populations, in particular, organisms with poor powers of dispersal, including insects. There have been attempts to analyse movements of insects in the vicinity of roads and railways, and determine whether they will cross hardened surfaces, in order to find out how much of a physical barrier roads are for small invertebrates (Mader, 1984; Mader et al., 1990; Koivula, 2002; Koivula & Vermeulen, 2005). Crossing roads by animals may result in an increase in their death rate due to collisions with cars (Saarinen et al., 2005; Mellis et al., 2010; Skórka et al., 2013). In addition, road construction may reduce gene flow between populations, lead to inbreeding issues and eventually the extinction of populations (Keller et al., 2005).

On the other hand, the consequences of the difficulties for individuals of various species, especially those with poor powers of dispersal, in crossing of roads, results in them migrating along roadsides if they provide suitable environmental conditions. Migration also makes it possible for invertebrates to find temporary habitats along roadsides. A range of studies refer to the positive aspects of roadsides as habitats promoting migration (Vermeulen, 1994; Vermeulen & Opdam, 1995; Koivula, 2002). It has been demonstrated many times that roadsides are sometimes habitats for species that are rare and in danger of extinction in degraded anthropogenic environments in which roadsides may function as secondary habitats important for the survival of endangered species (Ries et al., 2001; Koivula et al., 2005; Nordijk, 2009).

The effect of road construction on the physical and chemical attributes of the soil environment is reviewed by Trombulak & Frissell (2000). They conclude that road construction and operation result in the compacting of the soil, reduced drainage and water content of the soil along roads. Road construction increases light intensity in forest environments. Important is also the chemical alteration resulting from application of de-icing salts in winter and pollution from the traffic. This affects the acidity and nutrient levels in roadside soil and must also affect the plants communities (Auerbach et al., 1997; Lee et al., 2011; Neher et al., 2013).

On other hand, roadside verges are dynamic habitats kept at a young successional stage (Ranta, 2008), due to the construction of the road and subsequent successive modernisation works, permanent mowing of shoulders and roadsides and the disturbance of the vegetation by traffic. Consequently, roadsides and central reservations of highways favour open-habitat and eurytopic species of carabids (Koivual, 2002; Koivula et al., 2005). Roadsides should be considered as secondary habitats, where the species

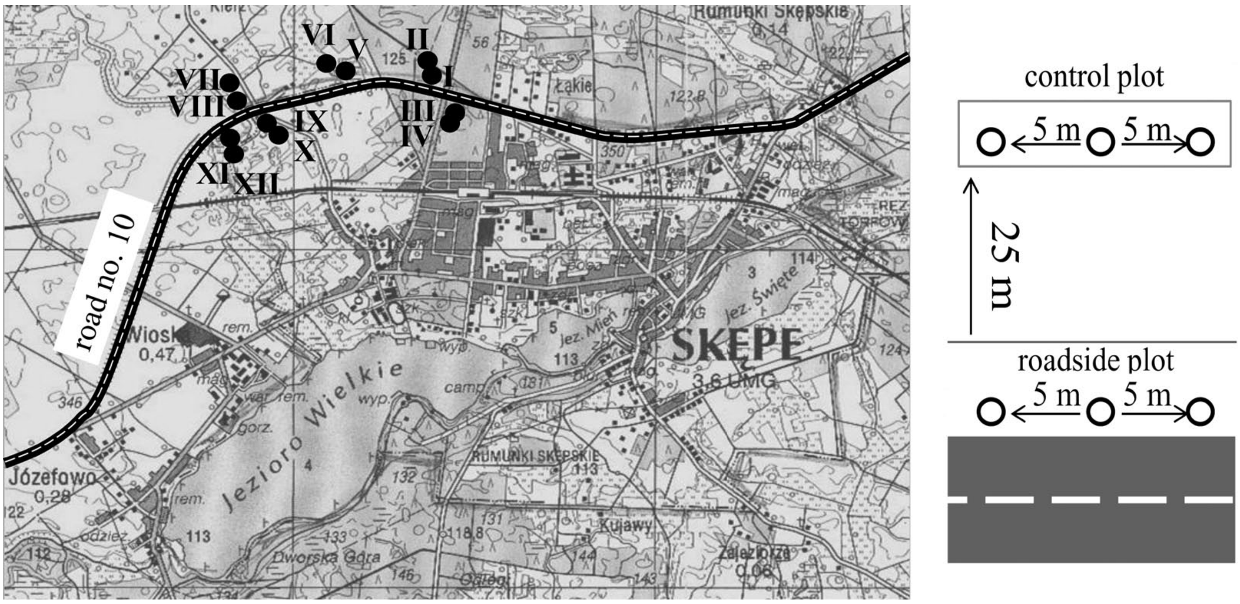


Fig. 1. Map of the bypass around the town of Skępe (road No. 10). Location of the study plots (filled circles) (left) and arrangement of the pitfall traps (open circles) in a roadside and corresponding control plot (right).

diversity can be high (Koivula et al., 2005; Melis et al., 2010). In addition, roadsides covered by grey-hair grass (*Corynephorus canescens*) are habitats and corridors for migration of stenotopic species of open and sandy habitats (Vermeulen, 1994).

All these studies focused on the issue of roads as elements of landscape that have a negative effect due to the resulting fragmentation of the environments of species and also their functioning as migration corridors connecting isolated sub-populations of species in a highly fragmented landscape. However, not much attention has been given to the dynamics of the environment of roadsides. Roadsides are technical elements that require maintenance, renovation and reconstruction. It is likely that the construction and renovation of roads causes changes in parameters of the roadside habitat. Therefore, it seems worthwhile determining what happens when a road that has existed in a landscape for a long time is modernized or renovated. Do habitat conditions along the roadsides change in such situations and do such changes affect assemblages of carabid beetles, a model group of epigeic invertebrates and bioindicators (Rainio & Niemelä, 2003)?

Therefore, a study was carried out on a highway bypass around the town of Skępe in central Poland (road No. 10), which was constructed in 1987 and renovated in 2009. The aim of the study was to describe the effect of (a) road construction on the carabid assemblages in different types of habitats and (b) roadside renovation 22 years after road construction in 2009 on the carabid assemblages. In addition, the environmental conditions in the habitats studied were analyzed in order to determine the differences between roadsides and control sites.

To do this I tested the following hypotheses:

(1) The carabid assemblages in the roadside plots differ in terms of the selected parameters from those in control plots in different types of habitats. Particularly, low numbers of forest species are expected along the roadsides. Roadside plots should be separated from control plots in indirect gradient analyses.

(2) Changes in carabid assemblages in the roadside plots after roadside renovation should occur in terms of the parameters selected. In the indirect gradient analyses roadside plot samples from 2008 should differ from those from 2010, 2011 and 2012.

(3) The environmental conditions in terms of plant indicator values for the roadside plots should differ from those of the control plots in terms of their granulometric composition, trophy, moisture, acidity of the soil and light conditions. In the indirect gradient analyses roadside plots should differ from control plots and correlate differently with the indicator values.

## MATERIALS AND METHODS

### Study sites and field methods

The highway bypass around Skępe (Kujawsko-Pomorskie Voivodship, Poland), main road No. 10, was constructed and opened in 1987. This road was renovated in 2009 and the roadsides reconstructed, which included widening the road and its shoulders, replacing the substratum (soil) and partly paving the shoulders. The average 2010 traffic flow was 7092 cars per day according to the General Directorate for National Roads and Motorways in Poland (GDDKiA, 2010).

Sampling sites chosen are representative of the composition of the local landscape, which is dominated by forest, wetlands and arable fields. For each of these three types of habitats two sites were chosen along the road. At each site two study plots were established: one on the sand and gravel part of the roadside, ca. 1 m in width, covered partly by grasses and herbaceous plants and a control plot at a right angles in a straight line ca. 25 m from the edge of the roadside. Thus, altogether 12 plot were established (Fig. 1). Forest plots were in about 100-years-old pine stands in previously agricultural areas. Plots in the wetlands were in small depressions in low moor with sedges and reed fields. Plots in fal-

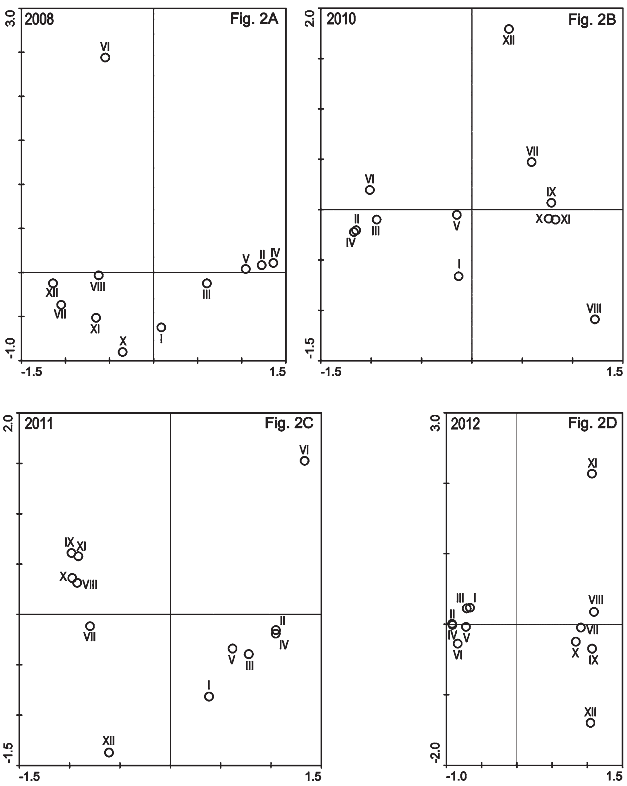


Fig. 2. Ordination plots based on correspondence analyses (CA) of control and roadside plots in 2008 (Fig. 2A), 2010 (Fig. 2B), 2011 (Fig. 2C) and 2012 (Fig. 2D). Control plots: II, IV – forests; VI, XII – wet habitat; VII, X – fallow parts of arable field. Roadside plots: I, III – roadside close to forest; V, XI – roadside close to wet habitats; VIII, IX – roadside close to arable land.

low areas were at the edges of arable fields with wheat and corn, on sandy loam soils.

Three pitfall traps of the type used by Barber (1931) and modified by Szyszko (1985) were set in each plot. The three 10 cm diameter traps each containing 50 ml of ethylene glycol were set in a row parallel to the edge of the road at intervals of 5 m in each plot (Fig. 1). The traps were set from May 15 to September 15 in 2008, the year preceding the road modernization. Subsequently, the collection of beetles continued after the modernization in three consecutive years, i.e. 2010–2012.

Samples of vegetation from each of the plots, both at the roadside and the controls were collected between June and July 2012 and used to describe the edaphic conditions in the reconstructed roadsides compared to those in the control plots. Three surveys of the vegetation were undertaken in an area of 5 × 5 m at the roadside and open areas and 15 × 15 m in forest plots. Plant species occurring there were described using the 5-grade Braun-Blanquet cover-abundance scale (Braun-Blanquet, 1964).

**Data processing and statistical methods**

The carabids were identified to species. Determination and nomenclature follows that of Freude et al. (2004). Numbers of individuals and dominance values of the species were calculated for each plot and year. Dominance values were calculated by dividing the number of individuals of a given species collected by the total number of carabids in a sample. In addition, for each sample the percentage of forest species, numbers of individuals of forest species and the Shannon diversity index (Magurran, 1988) were calculated. Designation of species as forest species was based on Burakowski et al. (1973, 1974), Hůrka (1996) and Freude et al. (2004).

Furthermore, the dominance values for the different species of plants were determined based on the Braun-Blanquet cover scale assuming the following average percentage covers: 5 – 87.5% cover; 4 – 62.5% cover; 3 – 37.5%; 2 – 17.5%; 1 – 5%; + – 0.1%, r – 0% (Braun-Blanquet, 1964).

Next, for the species compositions of the associations recorded in each plot the average ecological indicator values of the vascular plants were calculated (Zarzycki et al., 2002). The 5-grade scale of ecological values according to Zarzycki is a modification of the method of ecological values of vascular plants according to Ellenberg (Ellenberg, 1974) adapted to the conditions of the Polish climate. Average values describing soil conditions were calculated: fertility (called "trophy" by Zaczycki et al., 2002), humidity at ground level, granulometric composition, acidity and light conditions for each plot. Environmental conditions of the roadsides and, for the sake of comparison, of individual control plots were described with the help of these values.

In order to study the effect of the road construction on carabid assemblages for each of the three types of habitats studied the roadside plots were compared with the control plots in terms of numbers of species, numbers of individuals, percentage share of forest species and individuals and Shannon diversities, using the Wilcoxon rank sum test for paired samples (Sachs, 1984). Additionally, for each of the study years an indirect gradient analysis was carried out using the full set of study sites for each year.

The influence of the roadside renovation on the carabid assemblages along the roadside was analyzed by comparing numbers of species, numbers of individuals, percentage share of forest species and individuals, and Shannon diversities recorded in 2008 with those recorded after the renovation of the roadside using non-parametric ANOVA for paired samples (Friedman test). In addition, the results for all the samples from the roadside plots were subjected to an indirect gradient analysis.

Table 1. Results of Wilcoxon rank sum tests for paired samples of comparisons of roadside and control plots located in three types of habitats along the bypass around the town of Skępe (significant results are in bold).

| Parameter of carabid fauna | Forest | Fallows of arable fields | Wetlands |
|---|---|---|---|
| No. of individuals | **z = –2.103**<br>**p = 0.035** | z = –1.352<br>p = 0.176 | **z = –2.380**<br>**p = 0.017** |
| No. of species | **z = –2.383**<br>**p = 0.017** | z = –1.690<br>p = 0.091 | **z = –2.521**<br>**p = 0.012** |
| Percentage share of forest species | **z = –2.521**<br>**p = 0.012** | z = –0.338<br>p = 0.735 | **z = –2.521**<br>**p = 0.012** |
| Percentage share of individuals of forest species | **z = –2,521**<br>**p = 0.012** | z = –1.521<br>p = 0.128 | z = –1.540<br>p = 0.123 |
| Shannon-Weaver index of similarity | z = –2.521<br>p = 0.012 | z = –1.183<br>p = 0.237 | z = –1.540<br>p = 0.123 |

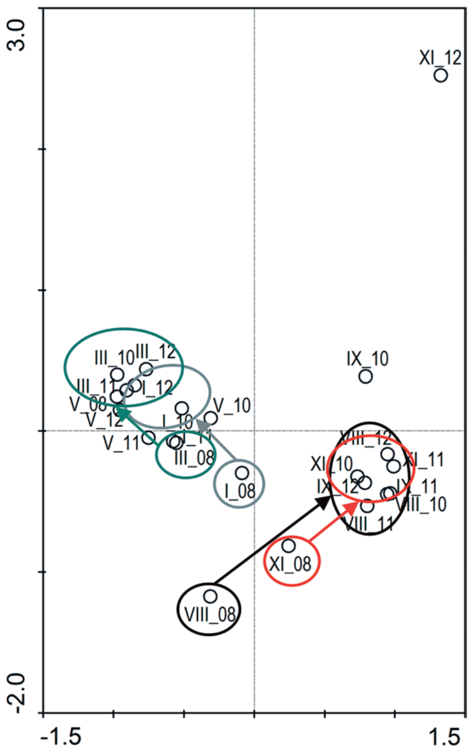


Fig. 3. Ordination plot based on correspondence analysis (CA) of roadside plots (circles) in 2008 compared with 2010, 2011 and 2012. Number of plots as in Fig. 2 with the year of study (08 = 2008, 10 = 2010, 11 = 2011, 12 = 2012) indicated. Ovals and arrows indicate location of roadside plots before renovation (2008) and after renovation (2010, 2011, 2012).

In order to determine the effect of the differences in the environmental conditions of the plots on their carabid assemblages a direct gradient analysis was carried out using the samples collected in 2012.

Gradient analyses were carried out using the species dominance of the carabids. The ecological indicator values of plants were used as environmental factors in direct gradient analysis. After DCA and DCCA to select the appropriate statistical model based on the longest gradient (Lepš & Šmilauer, 2003), Correspondence Analyses (CA) was carried out in the case of indirect gradient analysis and Canonical Correspondence Analysis (CCA) in the case of direct gradient analysis. Since dominance values were used, species data were not subjected to transformation. In the case of the CCA analyses, Monte Carlo permutation tests were carried out with 499 permutations; statistical significance was calculated using automatic forward selection of environmental variables. All ordination analyses were conducted using the Canoco package for Windows 4.56 (ter Braak & Šmilauer, 2002).

## RESULTS

### General results

4860 individuals of 93 species of carabid beetles were collected during the four years of this study. In the wetlands, dominant species were *Pterostichus niger* (Schaller, 1783) (25%), *Pterostichus strenuus* (Panzer, 1796) (13%), *Pterostichus melanarius* (Illiger, 1798) (12%) and *Epaphius secalis* (Paykull, 1790) (9%). In the forest the dominant species were *Pterostichus niger* (Schaller, 1783) (72%), *Carabus arvensis* (Herbst, 1784) (10%) and *Carabus nemoralis* (O.F. Müller, 1764) (7%). In fallow areas of arable fields *Harpalus rufipes* (De Geer, 1774) (24%), *Pterostichus melanarius* (Illiger, 1798) (15%) and *Carabus cancellatus* (Illiger, 1798) (14%) were most frequently collected. Along roadsides the dominant species were *Pterostichus niger* (Schaller, 1783) (24%), *Harpalus rufipes* (De Geer, 1774) (17%) and *Carabus cancellatus* (Illiger, 1798) (6%).

Table 2. Ecological indicator values calculated on the basis of the vascular plants present in plots located in the vicinity of the Skępe bypass, road No. 10, Kujawsko-Pomorskie Voivodship, Poland.

| Plot. No. | Soil granulometric composition | Soil acidity | Light conditions | Soil trophy | Soil moisture |
|---|---|---|---|---|---|
| I | 3.7 | 4.0 | 4.6 | 3.4 | 2.8 |
| III | 3.8 | 3.8 | 4.0 | 3.4 | 3.0 |
| V | 3.4 | 3.9 | 4.7 | 3.1 | 2.6 |
| VIII | 3.7 | 4.0 | 4.6 | 3.5 | 2.8 |
| IX | 3.9 | 4.0 | 4.3 | 3.7 | 3.0 |
| XI | 3.7 | 4.2 | 4.4 | 3.4 | 2.9 |
| II | 3.6 | 3.3 | 3.5 | 2.9 | 3.3 |
| IV | 3.5 | 3.2 | 3.9 | 2.8 | 3.2 |
| VI | 4.0 | 4.0 | 4.0 | 3.6 | 4.1 |
| XII | 3.9 | 4.1 | 4.0 | 3.9 | 3.6 |
| VII | 3.9 | 4.1 | 4.4 | 3.7 | 3.0 |
| X | 3.7 | 4.0 | 4.5 | 3.4 | 3.0 |

175 species of plants were recorded during the inventory of the plant cover in 2012. The wet habitats were dominated by the common reed (*Phragmites australis* (Cav.) Trin. ex Steud), common nettle (*Urtica dioica* L.), black alder (*Alnus glutinosa* Gaertn.), black sedge (*Carex nigra* Reichard) and slender tufted-sedge (*Carex gracilis* Curtis). In the Scots pine forest (*Pinus sylvestris* L.), common beech (*Fagus silvatica* L.), bilberry (*Vaccinium myrtillus* L.), and wavy hair-grass (*Deschampsia flexuosa* (L.) Trin.) were dominant, whereas fallow areas between arable fields were dominated by red fescue (*Festuca rubra* L. s. s.), redtop (*Agrostis gigantea* Roth), couch grass (*Elymus repens* (L.) Gould) and common horsetail (*Equisetum arvense* L.). Plants most numerous along the roadsides included red fescue (*Festuca rubra* L. s. s.), redtop (*Agrostis gigantea* Roth) and couch grass (*Elymus repens* (L.) Gould).

### Effect of road construction on carabid assemblages

The Wilcoxon rank sum tests for paired samples (Table 1) revealed significant differences in terms of all the parameters studied between the roadsides near forests and the forest control plots. There were significantly fewer individuals, more species, fewer forest species and individuals, and a higher Shannon diversity along the roadsides. In roadside plots near wet habitats there were significantly more individuals and species and significantly fewer forest species compared to the control plots. There were no significant differences between the roadside plots and control plots in agricultural areas in terms of the parameters studied.

In the correspondence analyses of the results for all the plots in 2008, 2010, 2011 and 2012, respectively (Fig. 2a, b, c, d), roadside plots adjacent to forest were regularly lo-

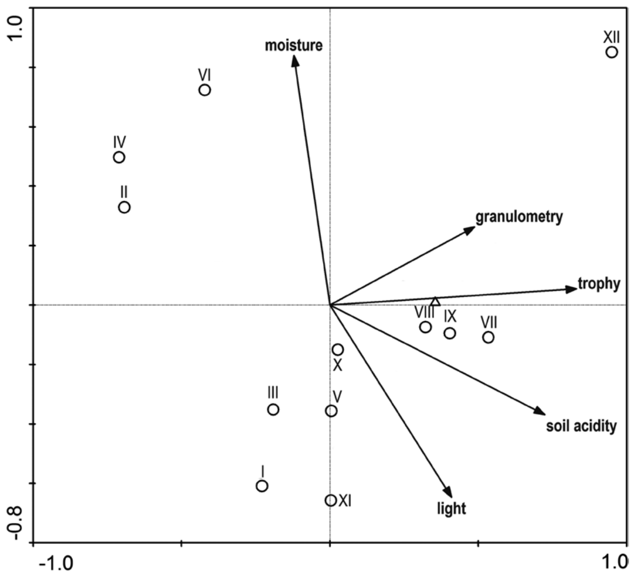


Fig. 4. Ordination plot based on canonical correspondence analysis (CCA) of control and roadside plots (circles), distribution and environmental factors (arrows) for 2012. Numbering of plots as cited in Fig. 2.

cated close to the control plots in forests and those adjacent to agricultural areas were located close to the control plots in fallow areas of arable fields. However, the roadside plots adjacent to those in wet habitats were not closely located, with plot V located close to the forest plots and plot XI close to the agricultural plots. The location of the control plots in wet habitats changed in the ordination diagrams from year to year.

### Effect of road renovation on the carabid assemblages in the roadside plots

In terms of the parameters studied the Friedman tests revealed no significant effect of roadside renovation on the carabid assemblages. However, the Correspondence Analysis of just the distribution of carabid assemblages along roadsides (Fig. 3), resulted in the samples for the year 2008 being slightly differently located compared to the samples collected in the years after reconstruction (2010, 2011, 2012).

### State of the environmental conditions and their effect on the carabid assemblages

The environmental conditions in the control plots, measured using the ecological indicator values of vascular plants, varied. The values for light conditions ranged from 3.3, indicating half-shaded conditions in the forests, to 4.5, indicating almost full light in the arable field (light value from 3.5 to 4.5) (Table 2). Soil granulometric composition also varied. There were sandy soils in the forests and argillaceous clay soils in the wet habitats (values from 3.5 to 4.0). The values for soil moisture indicate fresh soils in the agricultural land and moist soils in the wet habitat No. VI (values from 3.0 to 4.1). The soils were moderately acid ($5 < pH < 6$) to neutral, with a pH of from 6 to 7 (soil acidity values from 3.1 to 4.0). Soil trophy varied from mezotrophic soils close to poor oligotrophic soils in the forests to mezotrophic and close to eutrophic soils in the wet habitats (values from 2.8 to 3.9). The environmental conditions along the roadsides were more uniform. The light values were higher compared the control plots, from moderate to almost full light (values from 4.3 to 4.7). Granulometric soil composition indicates clayey-sandy soils to clay soils (values from 3.6 to 3.9) with the exception of plot No. V, with a newly constructed, artificial embankment along the roadside. Indicator values for soil acidity reveal neutral soils (comparatively higher soil acidity values, from 3.8 to 4.2). However, the moisture values were lower than those recorded in the control plots, from dry to fresh soils (values from 2.6 to 3.0). One factor only, trophy, varied more along the roadside compared to the control plots. There were mezotrophic soils in the majority of the roadside plots, with the exception of those located close to arable land. Here the fertility was higher, tending to eutrophic soils (value from 3.1 to 3.7).

The Canonical Correspondence Analysis (CCA) of the distribution of carabid assemblages in 2012 using gradients of environmental factors defined on the basis of ecological indicator values of the vascular plants calculated for the year 2012 (Fig. 4), shows that factors with the strongest links to the ordination axes are the fertility of the soils with the first axis and the humidity of soils with the second axis. It means that the humidity and fertility are factors that most strongly affect the distribution of carabid species. However, the Monte-Carlo permutation test indicated that the correlation of data with the first ordination axis is statistically insignificant ($p = 0.12$). On the other hand, the correlation with both ordination axes is statistically significant ($p = 0.01$). Forward selection of environmental variables indicated that the fertility of soils is the only statistically significant parameter ($p = 0.01$). Additionally, soil fertility accounts for 52% of the variation in carabid assemblages. Thus, I assumed that soil fertility is a significant environmental factor, which was changed by the reconstruction of the road and resulted in marked changes in the roadside carabid assemblages.

## DISCUSSION AND CONCLUSIONS

The construction of the bypass in 1987 resulted in diversified carabid assemblages occurring along the roadsides. There were significant differences between roadsides and forest habitats in terms of all the parameters measured. The wet habitats differed significantly in terms of the numbers of individuals, numbers of species and percentage share of forest species.

Lower numbers of individuals trapped along roadsides compared to in adjacent forest are reported by Melis et al. (2010), with the number of individuals increasing with distance from a busy road. They account for this in terms of a higher mortality of beetles along roadsides due to collisions with cars. However, the opposite was recorded at Skępe in the wet habitats adjacent to roadsides. This might be due to the low numbers of individuals trapped in the wet habitats, where pitfall traps were periodically flooded.

The higher total numbers of species trapped along roadsides than in adjacent forest are in accordance with the results of the study by Knapp et al. (2013), which indicates that species diversity decreases with increasing distance from a highway in forest habitats, and the study by Melis et al. (2010). The higher number of species trapped along roadsides can be explained in terms of an edge effect or that a roadside is an ecotonal zone, which determines the beetle assemblages recorded there, i.e. both forest and open and sandy habitat species occur there (Senft, 2009). On the other hand, Nordijk (2009) shows that factors that influence species diversity are productivity and mowing regime, with the highest species diversity along roadsides of medium and high productivity, which are mown twice a year and from which the cut biomass is removed. This type of roadside habitat is present at Skępe.

Several studies indicate that there is an increase in open habitat species along roadsides, for example Koivula et al. (2005) indicate this is the case in the central reservations of highways in Helsinki (more than 90% eurytopic species and specialists of open habitats) and Nordijk (2009) for carabids along roadsides adjacent to nature reserves (73% of species of open habitats and natural heathland reserves). Thus, at Skępe the percentage share of forest species and individuals along the roadside is much lower than in the adjacent forests. Knapp et al. (2013) also report an increase in the number of forest species with distance from the highway in a forest environment. This is confirmed also by Vermeulen (1994), Vermeulen & Opdam (1995) and Koivula (2003), who show that roadsides can function as migration corridors, especially for open habitat species.

However, at Skępe, the roadsides located in the vicinity of forests hosted some forest species. Therefore, the carabid assemblages of roadsides located near the forests differ from those in the vicinity of arable fields. Thus, carabid assemblages in similarly developed roadsides differ from one another. Accordingly, roadside plots were located closer to their respective control plots in indirect gradient analyses, indicating an influence of the adjacent habitats on the roadside fauna.

For all three types of habitats studied at Skępe the Shannon diversity was higher for the roadsides then the control plots. However, this was statistically significant only for the forest habitats. It is assumed that the high Shannon diversities recorded for the roadsides are mainly due to the increased number of species. The study of Koivula et al. (2005) in Helsinki indicates that species richness decreases with increase in the age of the roadsides, thus Shannon diversity will probably also decrease.

The study at Skępe did not reveal any significant differences in terms of the parameters studied between roadsides and control plots located in agricultural land, indicating that roadsides are similar to arable land. Accordingly, Varchola and Dunn (1999) show that richness of the assemblages along complex (colonized by native prairie grasses and herbaceous plants) and simple roadsides (covered by dominant *Bromus inermis*) and adjacent crops of corn are similar, but the degree of similarity depends on both the type of roadside and maturity of the corn, i.e. time of year.

Contrary to expectations, the renovation of the roadside did not lead to significant changes in the parameters of the carabid assemblages. However, the CCA (Fig. 3) indicates an influence of the renovation on the carabid assemblages along on the roadsides. Koivula et al. (2005) report that along a new highway ring-road there was a higher number of species and that the small and macropterous species were more abundant than along older ring roads. They explain this in terms of more hostile conditions along older roadsides, resulting in the extinction of species less tolerant of contamination. Succession may also be a reason for the difference between young and old roadsides. At Skępe the reconstruction might have lead to the restoration of slightly younger successional stages and reduced the degree of contamination of these habitats.

Based on the plant indicator values the environmental conditions of the roadside plots are more similar than those of the control plots, where the spectrum of conditions in the three types of habitat is broader. The light intensity is higher and the soil drier in the roadside plots than the control plots in all three types of habitat. This confirms the results reported by Trombulak & Frissell (2000), who also stress the problems associated with soil compaction along roads, which were not recorded in this study, as well as changes in soil chemical parameters. At Skępe the fertility of the roadside soils varied from mesotrophic close to forest habitats to eutrophic in the fallow habitat, but Lee et al. (2011) report the appearance of nitrogen-tolerant plants due to the increase in the nitrogen content of roadside soils resulting from contamination with the $NH_3$ and $NO_2$ emissions from traffic, which also causes the alkalinization of the roadside environment (Lee et al., 2011; Neher et al., 2013). At Skępe the new substrate of the unpaved shoulders and reconstructed roadsides has an almost neutral but slightly alkaline pH. However, the pH values of the roadsides will probably increase in future due to emissions from cars and increase in traffic.

However, Fig. 4 indicates that most of the roadsides in this study were more similar to plots located in the fallow parts of arable fields. Both represent early successional stages resulting from road management and agricultural practices, respectively. Following Ranta (2008) roadside verges are early successional stage habitats, due to, among others, management directed towards road safety and mowing. Ranta (2008) indicates that the majority of the plants growing along Finnish roadsides are species occurring in urban environments, i.e. plants that can survive mowing and standard road management. In addition, Nordijk (2009) indicates that fertility and mowing are important factors affecting the species composition of carabids present in open roadside verges in the Netherlands. Indeed, the study at Skępe confirms that fertility is a statistically significant factor determining the carabid assemblages present along roadsides. However, the effect of mowing was not included in the statistical analyses, because the bypass at Skępe is uniformely mown twice a year.

This study confirms most of already published results on carabids present along roadsides but also the importance of road renovation on carabid assemblages. This effect, revealed by the gradient analysis, needs further study at the species level to identify the response of individual species. Since few sites were studied, the results are preliminary and additional studies of many more sites are necessary to confirm the results. However, the results may be useful in developing research hypotheses for further research on highway roadsides.

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