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ORIGINAL RESEARCH PAPER

Distribution and abundance of bee forage flora across an agricultural landscape – railway embankments vs. road verges

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Abstract
In this study, we evaluated if railway embankments and road verges create refuge habitats for bee flora across agricultural landscape. The survey was conducted in 2009–2012, in the Lublin Province, SE Poland. Data on the bee forage flora were obtained while making floristic charts along 60 transect plots × 300 m, with a total length of 18 000 m, for each type of linear structure. Forage bee flora was compared with respect to species richness, diversity, and evenness indices. The canonical correspondence analysis (CCA) was used to characterize relationship between species composition and environmental variables. The bee forage species richness and abundance were significantly greater on railway embankments than on road verges. The composition of species varied considerably; the number of bee forage species common to both habitats was only approximately 38% in entire data set. Most good-value bee forage species were recorded along the embankments of railways with an intermediate traffic volume. Bee forage species diversity benefits from the location of habitat elements (forests or meadows), primarily if the distance is <50 m. The lack of dense patches of valuable bee forage species in the road verges was related to the high density of non-nectariferous graminoids. Our results demonstrate how the value of man-made areas in an agricultural ecosystem can vary with respect to floral resources across the landscape, suggesting that it is inappropriate to generalize about agricultural systems as a whole without first addressing differences among habitats.

Keywords
nectar and pollen flora; food niche; pollinators

Introduction

The loss of pollinators worldwide represents a potential danger for ecosystems and human health [1]. The possible negative effect of the pollinator decline is reported for reproductive impairment of wild plant populations [2,3]. The decrease in the yield of cultivated plants has also been evidenced [1]. Therefore, reduction of incomes and harmful consequences for economic growth as well as future instability of human nutrition and health are expected [4].

The possible causes of the pollinator decline are multifactorial. These include (***i***) intensive farming with use of chemicals, (***ii***) diseases and parasites, (***iii***) climate change, (***vi***) monocultures with the dominance (>70%) of cereals, (***iv***) spread of invasive species, (***v***) habitat loss, (***vi***) simplification of the agricultural landscape structure, and (***vii***) disappearance of multi-flowering patches [1,5]. This can result in monotonous diet and a chronic scarcity of nutrition for pollinators [6,7].

The modern agricultural landscape is formed of the matrix, patches, and their interconnections [8]. The matrix is the dominant component of the landscape, the patches are created by small natural and semi-natural habitats, while interconnections (corridors) enhance structural and functional connectivity and support integration of the landscape system [3]. Corridors are elongated patches (= linear structures) that form networks across the landscape and connect other patches together. Linear structures (e.g., road verges, railways, field margins, and ditch and stream verges) are a part of the system [9]. Since land transport is one of the most dynamic sectors of the European economy, road networks and railway lines are still developing [10]. In the European Union, the overall length of railway lines amounts to 215 800 km while that of roads amounts to 10 582 700 km [11]. A disadvantage is that road and railway constructions cause a considerable loss of natural habitats [12] and impaired environment quality, i.e., they modify microclimatic and hydrological conditions and develop dispersal barriers to many terrestrial animals [13]. However, a growing body of evidence shows that linear structures may benefit rural areas by creating important zones for general diversity of fauna [2,14] and flora [15–17]. The ecological value of habitats along road verges and railway embankments for pollinators is related to a number of functions, i.e., sites for nesting, mating as well as food sources for larvae and adults [3,18,19].

To counteract the problem of the lack of the food base for pollinators, ecological integrity of a structurally complex agricultural landscape is required [3]. However, it is still arguable how many flower-rich patches are needed and how they should be spatially distributed to secure food niches for pollinators [3,20]. The knowledge of the food resources in various habitats (natural, semi-natural, and man-made) is necessary to provide effective conservation of pollinators on the landscape scale [21]. First and foremost, the biggest problem is the lack of good data on bee flora distributions and abundance. In spite of the growing interest in the role and function of linear structures [15,22,23], the bee forage flora on railway embankments and road verges remains insufficiently explored.

An understanding of the nectariferous and polleniferous flora distribution within linear structures may provide important data to support conservation of pollinators at a long term and large scale. In this study, we compared the composition, richness, and diversity of bee forage species between railway embankments and road verges. There were even more specific goals in this study: to determine vegetation diversity in railways and roads with regard to (***i***) the distance of these linear structures from habitat elements (forests, meadows), (***ii***) the type of railways and roads (distinguished by traffic volume). Based on Ellenberg's indicator values, we evaluated the ecological factors that have an impact on the occurrence of bee forage flora within linear structures [17].

Material and methods

Research area

The investigations were carried out in 2009–2012 in an agricultural landscape across the Lublin Province, SE Poland (22°21′–23°50′ E, 50°91′–51°63′ N; Fig. 1). The region is highly undulated at 148–199 m above sea level. The area is bordered by large rivers – the Vistula River in the west and the Bug River to the east, the North European Plain in the north and old mountains of Central Europe in the south. The area of the Lublin Province is 25 122 km^2 (8% of Poland's area), 62% of which has an agricultural-settlement character with islands or strips of forest (22.7% of the area), water-and-meadow or steppe environmental islands. Mesophilous deciduous forests (*Tilio-Carpinetum*), mixed coniferous forests (*Pino-Quercetum*), wet meadows (*Molinietalia*), fresh meadows (*Arrhenatheretalia*), and xerothermic grasslands (*Festuco-Brometea*) were noted in the study area. The farming and gardening build up the mosaic structure of the landscape characteristic for SE Poland. Most of the cultivated area was under cereals (50–72% of the crop structure) and ca. 12–16% of the crop structure was occupied by root crops (potato and sugar beet fields); therefore, the abundant nectar and pollen flow from crop plants was observed only in May, during orchard and/or rape blooming.

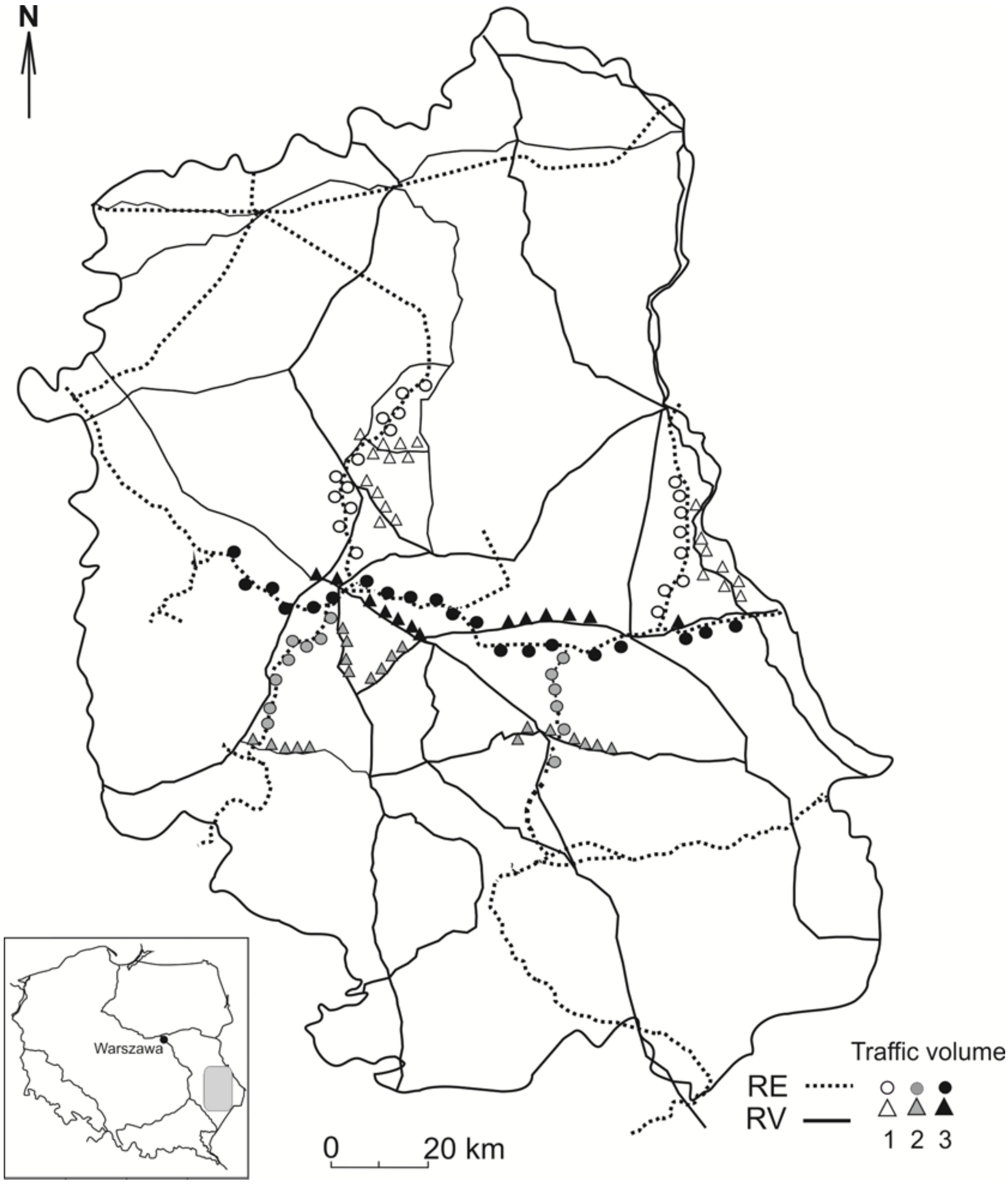

Fig. 1 Study sites on railway embankments (RE) and road verges (RV) located in the Lublin Province, SE Poland. The traffic volume categories comprised for railways were: 1 – low, <5 trains per 24 h; 2 – intermediate, 5–20 trains per 24 h; 3 – high, 21–50 trains per 24 h. The traffic volume categories comprised for roads were: 1 – ca. 30 vehicles per hour; 2 – ca. 150 vehicles per hour; 3 – >400 vehicles per hour.

Data collection and preparation

Floristic survey. The field survey was conducted from May to mid-August when spring flowers were still present and recognizable and seedlings of summer species were identifiable. We made walks along transects located on two types of linear structures, i.e., railway embankments and road verges. The embankments were adjacent to three types of tracks and the verges to three types of roads, categorized by the traffic volume. For every type, 20 transects were randomly selected (i.e., 60 transects for railways and 60 for roads; 120 in total), each transect was 300 m long. Transects were divided into 6 × 50 m long sections corresponding to the experimental plots. The distance between transects was ca. 1000–1800 m. We inspected ca. 18 000 m of railway embankments and ca. 18 000 m of road verges. The transects on the railway embankments were situated 2 m outside the edge of the railway track, i.e., beyond the layer of crushed stone. All road verges were located next to asphalt roads. Only areas with herbaceous vegetation (= without trees) were considered. The geographic position of each transect plot was recorded with a differential GPS.

To characterize the vegetation, the method of phytosociological relevés was employed. The species abundance in each transect plot was ascertained by the classical Braun-Blanquet [24] method, which means that the total coverage for each species in each transect plot was estimated visually and recorded using a cover-abundance scale within seven cover classes, i.e., r – 1 or 5 individuals; "+" – few individuals (<20) with cover <5%; 1 – many individuals (20–100) with cover <5%; 2 – 5–25% cover; 3 – 25–50% cover; 4 – 50–75% cover; 5 – 75–100% cover.

Different criteria were considered to characterize the flora, i.e., botanical family, type of forage – nectar and/or pollen, and life span (perennials, biennials, annuals), to make the flora analysis more complex. The relevant data were obtained from the BioFlor database [25]. The list of bee plants was established on the basis of data from literature [16,26] and according to own observations. The taxonomic system and plant nomenclature followed Mirek et al. [27].

Prior to statistical analyses, transects were subdivided based on: (***i***) the type of the habitat elements (forest vs. meadow) in the surrounding area, (***ii***) the distance from habitat elements, and (***iii***) the type of railway tracks and types of roads by the traffic volume. The distance from natural habitats (forests or meadows) was categorized as follows: (***i***) 0–50 m, (***ii***) 51–300 m, and (***iii***) >301 m. The traffic volume categories specified for the railways were (***i***) low – <5 trains per 24 h, (***ii***) intermediate – 5–20 trains per 24 h, and (***iii***) high – 21–50 trains per 24 h. The traffic volume categories for the roads were (***i***) low – ca. 30 vehicles per hour on local roads, (***ii***) intermediate – ca. 150 vehicles per hour on voivodeship roads, and (***iii***) high – >400 vehicles per hour on national roads. Information on the current traffic volume was established based on the data from the Polish central government authority, the General Directorship of National Roads and Motorways in Lublin, and for railways from Office of Rail Transport in Lublin. Information on the current transect distance from natural habitats (forests, meadows, none) was based on detailed digital cadastral data as well as high-resolution IR orthophotographs (taken on 12 July, 2009 and 23 May, 2012; pixel resolution 1 m).

Data analyses. The floristic data from the sampling periods were pooled separately for railway embankments and road verges. The flora on the transect plots was compared based on three types of indices focused on (***i***) species richness (= number of species – $S = n_i$, where n_i=species i), (***ii***) species diversity with the Shannon–Wiener index – $H' = -\sum p_i \log_2 p_i$, where p_i = frequency of the species i, and (***iii***) species evenness with the Pielou index – $J' = H'/\ln S$, defined as the ratio of the observed diversity to the maximum diversity, where: S = the number of species and $H_{max} = \ln S$). J' is constrained between 0 and 1; the lower the variation in communities between species, the higher J is. H' is high when the relative abundance of different species in the sample is even and decreases when a few species are more abundant than others. To calculate the indices, the MVSP package was used [28]. The mean and *SD* (standard deviation) were computed and the values obtained were compared to assess the significance of differences by non-parametric tests. The two-side test (the Mann–Whitney *U* test) was used to analyze the differences in the species richness and diversity indices between the railway embankments and road verges. The Kruskal–Wallis test was employed to assess (***i***) the effect of the distance from habitat elements and (***ii***) the effect of the traffic volume on bee flora within each linear structure [29]. Pearson's correlation coefficient (r) was applied to measure the strength of the relationship between the forage species richness and the distance of the railway embankments and road verges from habitat elements. Statistica software package version 10 developed by StatSoft Kraków was applied for these analyses.

Multivariate analysis was used to examine the differences in the flora composition between the railway embankments and road verges and to characterize and visualize the relationship between floristic composition of vegetation in transects and environmental variables (habitat, distance, traffic, and ecological indicators). The cover-abundance values were log transformed. The species noted only once were excluded from the analysis. The species data showed a clear unimodal response (length of the gradient 3.7), enabling us to use the canonical correspondence analysis (CCA). The significance of the environmental variables was calculated using a Monte Carlo test (499 permutations). Canoco for Windows 5.0 was used for the ordination [30]

The ecological indicator values (EIV) were calculated for all the species recognized in each transect, using the Ellenberg system adopted for Polish conditions by Zarzycki et al. [31]. We took into account six environmental variables related to ecological indicator values describing the most typical habitat conditions within agriculturally transformed areas – light (L), temperature (T), soil moisture (W), soil/water pH (R), salinity – resistance to the NaCl content in soil (S), and the trophy value (Tr). The share of species with a specific indicator value in each transect plot was determined using a modified formula for the weighted averages:

$$W_A = \frac{\sum_{i=1}^{n}(A_i^2 I_i)}{\sum_{i=1}^{n} A_i^2}$$

where: W_A – weighted average, A_i – abundance of cover of the i-th species in a given field margin transect, I_i – ecological indicator value for the i-th species, n – number of species in the field margin transect.

The data from the sampling periods were pooled. The level of statistical significance to measure the differences between the means for all the analyses was at $p = 0.05$.

Results

Overall, 411 plant species were sampled and identified in the total dataset, of which 321 species (78.1%) were identified as bee forage plants. Almost 71.5% more bee forage species were recorded on the railway embankments (307 species) compared to the road verges (179 species). The number of bee forage species in the particular transect plots ranged from 20 to 195 (mean = 75.4 ±35.2 *SD* on the railway embankments; mean = 25.0 ±5.4 *SD* on the road verges). Species yielding both nectar and pollen predominated (293 species – 95.4% along the railways and 176 species – 98.3% along the roads); pollen as floral reward (= no nectar) was offered by 17 species (5.3%) of the bee flora noted.

The location of the linear structures in relation to habitat elements in the landscape affected the richness of bee forage species only on the railway embankments (Kruskal–Wallis test for the habitat effect: $H = 7.95$, $p = 0.018$), but not on the road verges ($H = 2.95$, $p = 0.318$; Tab. 1). The same trends were recorded for the H' and J indices. A greater influence of the distance from habitat elements on bee plant diversity on the railway embankments was recognized when the distance from the forest or meadow was less than 50 m. The mean number of bee forage species on embankments in the distance category 51–300 m from forests was still higher than on embankments located >301 m from forests. The surroundings of meadows in the distance category 51–300 m had no significant effect on the richness of bee forage species compared with embankments located >301 m from meadows. The Pearson's correlation between the richness of bee forage species and the distance from natural habitats was $r = -0.338$, $p < 0.05$ for the embankments and $r = 0.180$, $p > 0.05$ for the road verges (Fig. 2).

The richness and diversity of bee forage species differed between the types of railway tracks ($H = 12.07$, $p = 0.021$ for species richness; $H = 21.14$, $p = 0.038$ for H' index; $H = 18.10$, $p = 0.041$ for J index) and between the types of roads ($H = 9.03$, $p = 0.034$ for species richness; $H = 11.38$, $p = 0.043$ for H' index; $H = 32.14$, $p = 0.043$ for J index). However, no differences in the bee forage species richness and diversity were noted between the voivoideship (traffic volume ca. 150 vehicles per hour) and national roads (>400 vehicles per hour; Tab. 2). The richness of bee forage plants was the highest along railways with an intermediate traffic volume (103.7 species, on average). The number of bee forage species identified along railways with a low traffic volume was approximately 25% lower. The species richness along railways with a high traffic volume was the lowest (only 49.6 species, on average; Tab. 2). Within the road verges, the number of bee forage species appears to be the highest along local roads with low traffic intensity (40.3 species). The richness of bee forage species in verges adjacent to the national and voivoideship roads was similar.

Tab. 1 Comparison of species richness (*S*) and diversity indices (*H′*, *J*) calculated for bee-flora noted in railway embankments (RE) and road verges (RV) located at different distances from habitat elements (forests and meadows).

Distance from natural habitat (m)	Species richness (*S*)		Shannon–Wiener index (*H′*)		Evenness index (*J*)	
	type of linear structure (mean ±*SD*)					
	RE	RV	RE	RV	RE	RV
Forests						
0–50	105.2 ᵃ ±36.5	26.0 ᵃ ±3.6	1.9 ᵃ ±0.1	1.4 ᵃ ±0.1	0.996 ᵃ ±0.00	0.994 ᵃ ±0.01
51–300	85.5 ᵇ ±32.5	25.8 ᵃ ± 6.2	1.8 ᵃ ±0.2	1.4 ᵃ ±0.1	0.998 ᵇ ±0.01	0.991 ᵇ ±0.00
>301	63.2 ᶜ ±31.5	24.2 ᵃ ±5.5	1.7 ᵇ ±0.2	1.4 ᵃ ±0.1	0.996 ᵃ ±0.0	0.993 ᵃ ±0.00
Mean	84.6 ᴬ ±19.7	25.3 ᴬ ±4.2	1.8 ᴬ ±0.1	1.4 ᴬ ±0.1	0.996 ᴬ ±0.0	0.993 ᴬ ±0.01
Meadows						
0–50	74.1 ᵃ ±15.4	23.6 ᵃ ±1.3	1.8 ᵃ ±0.0	1.3 ᵃ ±0.2	0.996 ᵃ ±0.00	0.988 ᵃ ±0.00
51–300	57.8 ᵇ ±16.2	21.2 ᵃ ±2.1	1.7 ᵇ ±0.0	1.3 ᵃ ±0.0	0.996 ᵃ ±0.01	0.982 ᵇ ±0.01
>301	59.5 ᵇ ±11.7	24.6 ᵃ ±1.4	1.7 ᵇ ±0.0	1.3 ᵃ ±0.1	0.996 ᵃ ±0.01	0.987 ᵃ ±0.01
Mean	63.8 ᴮ ±21.5	23.1 ᴬ ± 1.8	1.73 ᴬ ±0.2	1.3 ᴮ ±0.1	0.996 ᴬ ± 0.01	0.991 ᴮ ± 0.01

The values indicated by the same small letters within columns are not significantly different between distances, according to Kruskal–Wallis test; values indicated with the same capital letter are not significantly different between forest–meadow habitats, according to the Mann–Whitney *U* test.

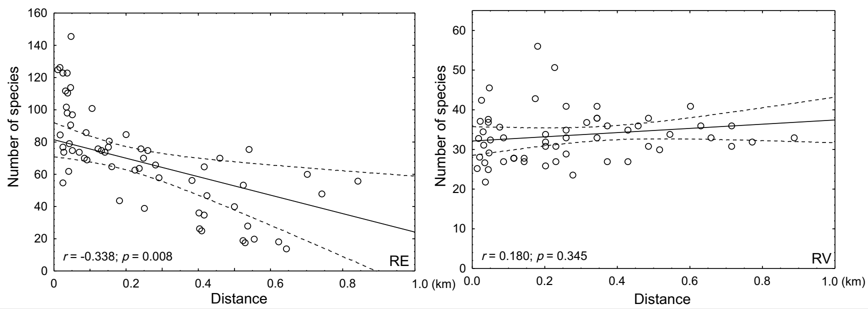

Fig. 2 The Paerson's correlation between the bee forage species richness and the distance from habitat elements calculated separately for railway embankments (RE) and road verges (RV).

Tab. 2 Comparison of species richness (*S*) and diversity (*H′*, *J*) indices calculated for bee-flora noted in embankments (RE) and verges (RV) adjacent to different types of railways and roads categorized by traffic volume.

Traffic volume	Species richness (*S*)		Shannon–Wiener index (*H′*)		Evenness index (*J*)	
	type of linear structure (mean ±*SD*)					
	RE	RV	RE	RV	RE	RV
1	76.5 ᵃ ±27.2	40.3 ᵃ ±5.8	1.8 ᵃ ±0.2	1.3 ᵃ ±0.1	0.996 ᵃ ±0.010	0.989 ᵃ ±0.01
2	103.7 ᵇ ±3.5	32.8 ᵇ ±2.9	1.9 ᵇ ±0.1	1.5 ᵇ ±0.1	0.996 ᵃ ±0.010	0.993 ᵃ ±0.01
3	49.6 ᶜ ±20.5	29.4 ᵇ ±2.9	1.6 ᶜ ±0.2	1.4 ᵇ ±0.1	0.993 ᵇ ±0.020	0.992 ᵃ ±0.01
Mean	76.6 ᴬ ±35.0	34.2 ᴮ ±8.1	1.8 ᴬ ±0.2	1.4 ᴮ ±0.1	0.995 ᴬ ±0.008	0.991 ᴮ ±0.02

The values indicated by the same small letters within columns are not significantly different between types of linear structures categorized by traffic volume, according to Kruskal–Wallis test; values indicated with the same capital letter are not significantly different between linear structures, according to Mann–Whitney *U* test. For traffic volume categories see Fig. 1.

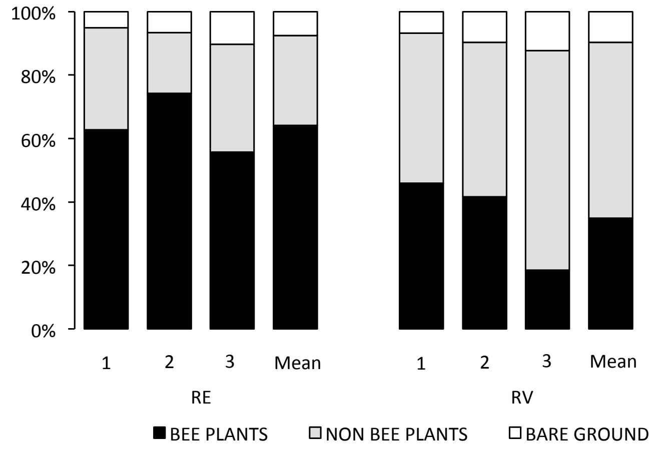

Fig. 3 Cover of bee forage species, non-bee forage species and bare ground noted in embankments (RE) and verges (RV) adjacent to different types of railways and roads categorized by traffic volume. For traffic volume categories (1–3) see Fig. 1.

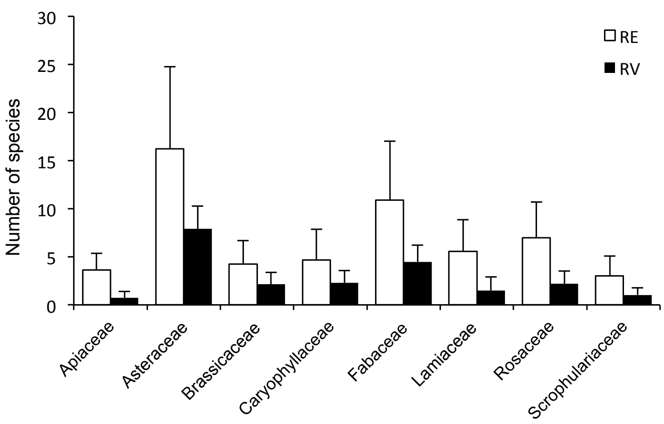

Fig. 4 The botanical families richest in high value bee forage species. The richness of bee forage species is calculated separately for transects in railway embankments (RE) and road verges (RV). Means (bars) and ±*SD* (whiskers) are given.

The cover of bee forage species was considerably higher on the railway embankments (75% of the transect plots, on average) compared to the road verges (41% of transect plots, on average; Mann–Whitney test $Z = 8.69$, $p = 0.000$; Fig. 3). The other area of transect plots comprised bare ground or was covered by anemophilous plants. Among them, representatives of Poaceae, Amaranthaceae, and Polygonaceae, as well as *Artemisia vulgaris* (Asteraceae), *Amaranthus retroflexus* (Amaranthaceae), or *Urtica dioica* (Urticaceae), were noted most frequently.

The bee forage species belonged to 42 botanical families. Representatives of 42 families occurred on the railway embankments, while the bee flora of the road verges was grouped in 38 families. Botanical families that were the richest in bee forage species accounted for approximately 68.0% of plant species, with Asteraceae and Fabaceae families presenting the greatest number of flowering species (Fig. 4).

The ratio of actinomorphic to zygomorphic flowers was approximately 2:1, an average of 157 ±11.3 *SD* vs. 68 ±7.3 *SD* in the entire bee flora. The ratio of perennials to biennials to annuals was approximately 6:1:1.5 on the railway embankments and 5:1:2.5 on the road verges. Perennial plants dominated along all types of the investigated railway embankments and road verges. However, the number of perennial species differed between the types of the railway tracks (Kruskal–Wallis test: $H = 17.22$, $p = 0.034$). Most perennials were noted along railways with intermediate traffic (169 perennials in total, mean 60.5 ±19) and along roads with low traffic (83 perennials in total, mean 20.5 ±4.5).

The CCA analysis confirmed the impact of the environmental factors studied (habitat, distance, traffic) on the composition and diversity of bee forage plants noted on the railway embankments and road verges. The biplot diagram clearly distinguished two major specifically concentrated sets of data (opposite sides of axis 2). Within each set, the subsets are distinguished, indicating differences in the composition of bee forage flora depending on the railway and road types. The first two axes displayed in the ordination diagram explained 13.6% of the variation, and the total variation explained by all the axes was 19.9% (Fig. 5). Among environmental factors related to the ecological criteria studied, light and trophy did not exert a significant impact on the occurrence of bee flora species on the railway embankments and road verges.

Discussion

Estimation of the richness, diversity, and abundance of bee forage flora is an important step in any kind of inventory or evaluation of habitats for the pollinator fauna. Our survey provides evidence that the composition, richness, and abundance of bee forage species varies widely between railway embankments and road verges. Most importantly, we have revealed that railway embankments create particularly important habitats for bee flora in the agricultural landscape.

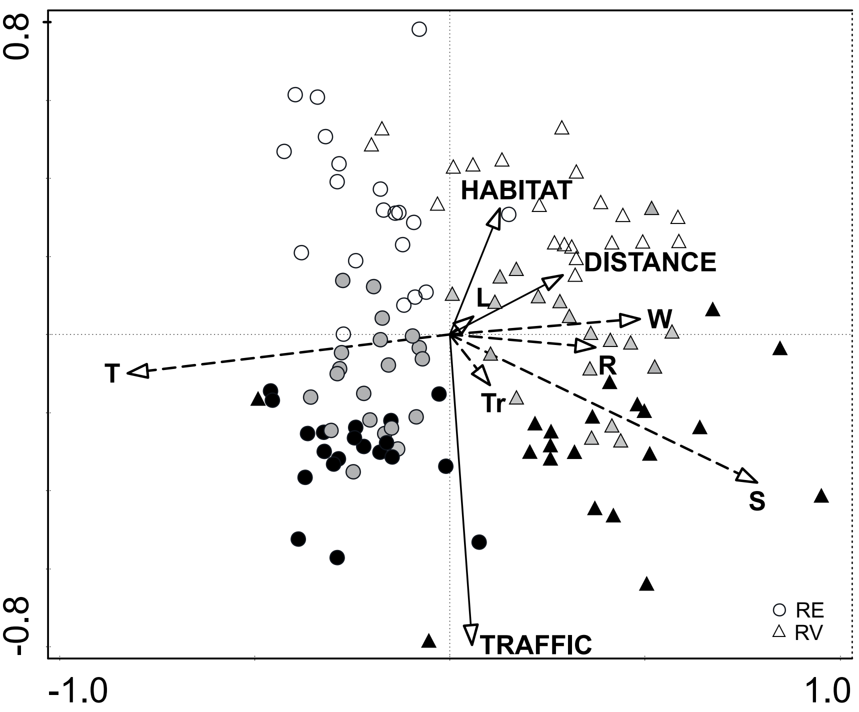

Fig. 5 Ordination biplot diagram of the canonical correspondence analysis (CCA) for the years 2009–2012 based on species matrix comprising the bee forage flora occurred on railway embankments and road verges. Black, grey, and white points correspond to the traffic volume categories (see Fig. 1 for definition). Eigenvalues: axis 1 – 0.115, axis 2 – 0.022. The diagram explains 19.9% of total variance. Simple term effects: T – 5.6%, p = 0.002; S – 5.6%, p = 0.002; W – 2.7%, p = 0.002; TRAFFIC – 2.0%, p = 0.002; R – 1.8%, p = 0.002; DISTANCE 1.5%, p = 0.026; HABITAT – 1.4%, p = 0.042; Tr =1.0%, p = 0.380; L = 0.9, p = 0.512. Conditional effects: T – 5.6%, p = 0.002; S – 3.0%, p = 0.002; TRAFFIC – 1.9%, p = 0.002; R – 1.9%, p = 0.002; HABITAT – 1.3%, p = 0.006. W = 1.1, p = 0.078; Tr = 0.9%, p = 0.246; L = 0.9, p = 0.296. RE – railway embankments; RV – road verges; L – light; T – temperature; R – soil pH; Tr – trophy; W – soil moisture; S – salinity.

Factors affecting flowering plants – railway embankments vs. road verges

The multivariate ordination techniques unequivocally demonstrated interaction of multiple environmental properties (surrounding habitat elements, the type of track with regard to traffic volume, distance from habitat elements, abiotic environmental factors) on the composition of bee forage plants in man-made linear structures. The combined effects of different factors on the occurrence of bee-flora in agricultural landscape were found earlier for road verges in Denmark and the UK [18,21] as well as for field margins in Poland [23]. Generally, anthropogenic pressures (landscape fragmentation, land management practices, and agricultural intensity (i.e., farm practice) are assumed to be the main predictors for the richness and diversity of flowering plants in man-made habitats within agricultural landscape [15,32,33].

The number of species common to the embankments and road verges was low and accounted for only 38% in the entire data set. This may result from the habitat attributes that vary between railways and roads, i.e., soil structure, temperature, moisture, and chemical properties. Using Ellenberg's indicator values adopted for Polish conditions by Zarzycki et al. [31], we evidenced considerable differences in soil moisture, temperature, and salinity between the habitats of the embankments and road verges. Our survey evidenced many drought tolerant species occurring along the embankments (W indicator value 2.71). On the contrary, species tolerating drought were noted sporadically in the roadside areas, where an increase in soil moisture is caused by water run-off from the road (W indicator value 3.23). The special conditions on the road verges are related to high soil salinity, which creates habitat homogeneity [17]. Habitat homogeneity, a distinctive feature of road verges, may partly explain the uniformity and low diversity of bee flora along roads. We frequently recorded tall grasses (*Agrostis capillaris*, *Alopecurus pratensis*, *Apera spica-venti*, *Arrhenatherum elatius*, *Dactylis glomerata*), which in most transects constituted 30–100% of the vegetation cover. Due to their morphological and physiological properties, these grasses are highly competitive species and they grow and spread rapidly. Therefore, we assume that graminoids are responsible for replacement of zoogamous plants. Several studies reported reduction of floral diversity in response to aggressive Poaceae spread, for example, on thermophilous grasslands [23,33].

However, a few reports on the flora in road verges consider these linear structures as good refuge habitats for bee forage species in Norway [34] or in the United States [35]. No doubt, the diversity of bee forage flora in road verges in these countries is strongly influenced by managing strategies that have been incorporated to support pollinators (e.g., planting of native wildflowers) [35,36]. Such activity is supported in many EU countries through the agri-environmental programs [1]. In Poland, some bee plants (*Trifolium pratense*, *T. repens*, *Vicia cracca*, *Medicago* spp.) are currently sown to support pollinators along motorways; however, motorways were not included in our study as this type of road has just been under construction in the region of our survey.

In our study, the richness and abundance of bee forage plants on the railway embankments was considerably higher, compared to that on the road verges. The classical niche theory demonstrates a positive relationship between species richness and habitat heterogeneity [37]. Indeed, diverse spatial configuration of microenvironmental factors is reported between south-facing and north-facing sides, or between the bottom and the top of the embankments [38]. Considerable temporal fluctuations in the microhabitat related to constant disturbance and/or succession are also frequently noted [39]. This mosaic of habitats seems to be responsible for the richness of bee forage species evidenced in our inventory. Interestingly, in the same geographical region, the richness and diversity of bee forage species was even higher on railway embankments compared with the species richness documented in grasslands (152 species) [40], recognized as one of the most species-rich plant community type in Central Europe [41].

High richness of forage bee species on railway embankments signalizes great potential for increasing local bee-flora biodiversity. In general, plant diversity is considered a good predictor for pollinator diversity [2] and the higher plant species richness and abundance the more attractive a community is for pollinators [42]. Positive effects of flower abundance on the pollinator population size have been demonstrated for bumblebees [43], solitary bees [44], and butterflies [45]. According to Moroń et al. [19], in an agricultural landscape, railway embankments support the diversity and abundance of pollinators (bees, butterflies, hoverflies) even better than typical habitats for these insects, i.e., semi-natural grasslands. In fact, nutrient diversity enhances insect life cycles, protects them from many chronic diseases, and thus is decisive for their abundance [7].

We have documented that railway embankments and road verges constitute refugia for grassland, forest, and ruderal species. This observation is in accordance with the surveys conducted in other geographical regions, where road verges offer alternative habitats, for example for 70% of forest herbs in the USA [46] and for 80% of grassland flora in Central Europe [47]. In Poland, railway embankments have been recognized as refuge areas for ca. 20% of forest species and ca. 30% of meadow species [48].

Our survey has revealed that the location of the linear structures in relation to habitat elements in the landscape affected the richness of bee forage species only on the railway embankments. In several studies, the species diversity declined significantly with increasing distance from the nature reserves, however different distances for the decline are reported. For example, Kohler et al. [49] documented the drastic decline in forb species in field margins in the first 75 m from habitat elements. In our study, the maximum effect was noted in the 0–50 m distance from habitat elements. A possible explanation is that the 0–50 m distance categories represent a transitional area between forest and/or meadow edges and other habitats [50]. Among forest plant species recognized as a valuable food resource for insect visitors [51] several, namely, *Ajuga reptans*, *Asperula odorata*, *Melamphyrum pratense*, *Viola reichenbachiana*, or *Vinca minor* formed particularly dense patches on the embankments. Interestingly, within the 0–50 m distance, these forest species are able to migrate and establish new populations on railway embankments but not on road verges. Presumably, the habitat conditions (salinity, competition from large grasses) suppress the species migration to road verges located close to the forest-to-road segment.

In the present study, the effects of different types of railways and roads on bee flora along these linear structures categorized by traffic volume varied. It is accepted that many harmful direct and indirect effects of railways and roads on wildlife usually increase with the volume of traffic [9]. However, the management strategy to provide safety traffic appears to be an important determinant for the richness and abundance of bee forage species along linear transport structures. In Poland, the roadside or embankment management policies differ between the types of railway tracks and between the types of roads. The differences relate to the frequency and height of mowing as well as application of herbicides. For example, spraying of herbicides along national roads (traffic volume >400 cars per hour) and railway embankments (traffic volume

>40 trains per day) was possibly responsible for the considerable reduction in the richness of forage bee species in these stands. Exposure to herbicides is a significant driver of changes in the composition and diversity of vegetation across agricultural landscapes [52]; however, differences in herbicide tolerance make some species disappear and others remain more-or-less intact [53].

In our survey, high richness of bee forage species was evidenced in road verges adjacent to local roads (traffic volume <50 cars per hour). Limited hand cutting operations are performed to maintain roadsides along local roads in Poland. Several studies have shown that the mowing frequency [43] as well as well-timed mowing, e.g., early summer and/or late summer [6], has the potential to harbor diversity of flowering plants. Mowing protocols for maintenance of bee-flora are used in conservation of pollinator biodiversity across the United States [54]. On the contrary, the reduction of bee plants noted along railways with a low traffic volume may be associated with extensive mowing frequency, only every 4–5 years. In such conditions, tall graminoids (e.g., *Calamagrostis epigejos*) spread, which leads to a lack of zoogamous species.

Food resources

Several interesting bee forage species were found on both the railway embankments and road verges. The large share of Asteraceae among the high-value bee plants was revealed in our inventory. Similarly, Asteraceae predominated among the nectar and pollen plants in road verges in Denmark [18] and on field margins in Poland [22]. Asteraceae are recognized as valuable bee plants due to the high value of nectar and pollen [26]. Some studies have reported that Asteraceae plants are among the most frequently visited plant families by several insect groups such as Hymenoptera (honeybees, bumblebees, solitary bees), Diptera, and Coleoptera [32]. However, the only Asteraceae species that created dense patches along the road verges was *Taraxacum officinale*. The species attracts a variety of nectarivorous insects [55] as well as pollen demanding ones [26], however, for a short period, limited to early spring.

We have recorded some Fabaceae species (*Coronilla varia*, *Medicago falcata*, *Melilotus albus*, *Trifolium medium*, *T. repens*, *Vicia cracca*). Again, these species formed dense patches more frequently along the railways and were only sporadically noted along the road verges. Leguminous plants offer a high value of nectar and pollen [27], and are particularly important for bumblebees [43]; however, they also support a food niche for a variety of wild bees, e.g., Megachilidae, Anthophorinae, Colletidae, and Halictidae [56].

Some Brassicaceae species (e.g., *Synapis arvensis* present in road verges and *Berteroa incana* along both linear structures) provide food sources for an array of insect visitors, not only Apoidea [26,43]. Frequent and abundant occurrence of Apiaceae species (*Anthriscus sylvestris*, *Pastinaca sativa*, and *Daucus carota*) was noted particularly on road verges. Especially flies, beetles, and wasp species feed on nectar and pollen of Apiaceae species [26,57]. We frequently observed *Knautia arvensis*, *Cirsium arvense*, *Centaurea scabiosa*, *Origanum vulgare*, and *Campanula* spp. along the railways. These plants are recognized as particularly important for butterflies [58,59]. In addition, *Knautia arvensis* is a food resource for specialized bee *Andrena hattorfiana* [5]. The occurrence of *Euphorbia cyparissias*, an important pollen source for beetles [60] or dense patches of *Anchusa officinalis* and *Echium vulgare* are worth noting. These plants support bumblebees, honeybees, solitary bees as well as dipterans [26,43].

Finally, we have documented the occurrence of invasive species; some of them provide a valuable food niche for pollinators. For example, *Bunias orientalis* is a good source of pollen for solitary bees. *Solidago* spp., *Helianthus tuberosus*, and *Aster salignus* supply nectar and pollen for a broad array of pollinators [26]. Therefore, invasive species may positively influence the size of pollinator populations. However, when invasive plants form dense patches, they compete with native species and impoverish plant biodiversity, and may indirectly impair the diversity and population size of wild bee species [35,61]. In our study area, *B. orientalis*, *H. tuberosus*, and *A. salignus* created mono-specific stands (absolute cover >50%) along the railways and the species from the genus *Solidago* were observed along both the railways and roads.

Conclusions

Our study is a step towards correctly managed areas within an agricultural landscape to provide a full range of food reserves for pollinators. We have revealed that railway embankments and road verges create suitable habitats for bee flora. However, floral resources varied considerably between these habitats. Therefore, it is inappropriate to generalize about agricultural systems as a whole without first addressing the differences among habitats. Embankments provide an excellent habitat for bee flora and these areas are a prerequisite for providing a food niche for pollinators and, consequently are important for protection and enhancement of pollinator biodiversity in the surroundings of farms. The flora present in man-made linear structures could provide supplemental forage resources between the bloom time of cultivated plants. Due to lack of dense bee-species patches, the promotion of sowing of nectar- and pollen- rich bee species seems to be a reasonable management activity across road verges, which may potentially contribute to pollinators' nutrition and to support conservation of pollinators in the surroundings of farms.

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