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Original Article

RAILWAY EMBANKMENTS – REFUGE AREAS FOR FOOD FLORA, AND POLLINATORS IN AGRICULTURAL LANDSCAPE

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A b s t r a c t

In a modern agricultural landscape the assurance of food resources is a key issue in the maintaince and control of food niche for pollinators. In the present study we evaluated bee forage flora composition and diversity within railway embankments located in the agricultural landscape, SE Poland. We also analysed the abundance of pollinators that use food resources along railway embankments and recognized insect visitors preference for selected plant species. Railway embankments represent valuable refuge areas for bee forage flora (307 species, i.e. 76.1% of total flora) and pollinators (in total 4172 insect visits from 9 taxonomic groups). However, the richness and abundance of bee forage flora significantly differed between types of the railway distinguished by traffic volume. The highest diversity of bee forage flora is noted along the railway with intermediate traffic volume. Approx. 25% and 40% less bee forage species was identified along railways with low and high traffic volume. Likewise, bee forage flora differed considerably between microhabitat types, i.e. top vs. slope vs. bottom of the embankment. Providing support (e.g. mowing) seems to be an important management type in order to strengthen the native bee forage flora particularly on railway embankments along low and high traffic volume tracks. Such activity is crucial to counteract the spread of aggressive non-forage species (e.g. *Calamagrostis epigejos, Artemisia vulgaris, Phragmites communis*) and invasive species (e.g. *Bunias orientalis, Solidago gigantea*).

Keywords: bee-flora richness, bee-flora abundance, bee-pasture

INTRODUCTION

Numerous studies conducted across the world indicate that pollinators and the pollination service they provide are still under threat (e.g. Potts et al., 2010). This is true despite multiple strategies and actions undertaken to support and protect pollinating insects (e.g. Vanbergen, 2013). The reason for pollinator reduction is that the pollinators face multiple interacting anthropogenic pressures from land-use intensification, i.e. urbanisation and increasing agricultural intensification (Hülsmann et al., 2015). In the modern agricultural landscape, pollinators suffer from an acute scarcity of flowering plants and are under nutrition stress. These factors can bring on a number of complications, including a weakening of the pollinators immunological system (Moroń et al., 2009, 2014). Several studies indicate that the population dynamics of bees, hoverflies, dipterans, and butterflies favour habitats with a mosaic structure of vegetation in an area (Wratten et al., 2012).

During the last century, logistics and land transport became very dynamic sectors of the European economy. Railway lines have been under continuous development and create important structures in the modern agricultural landscape (Spiekermann, 2015). In the European Union, the overall length of railway lines amounts to 215 800 km (The World Factbook, 2013-2014); in Poland they comprise

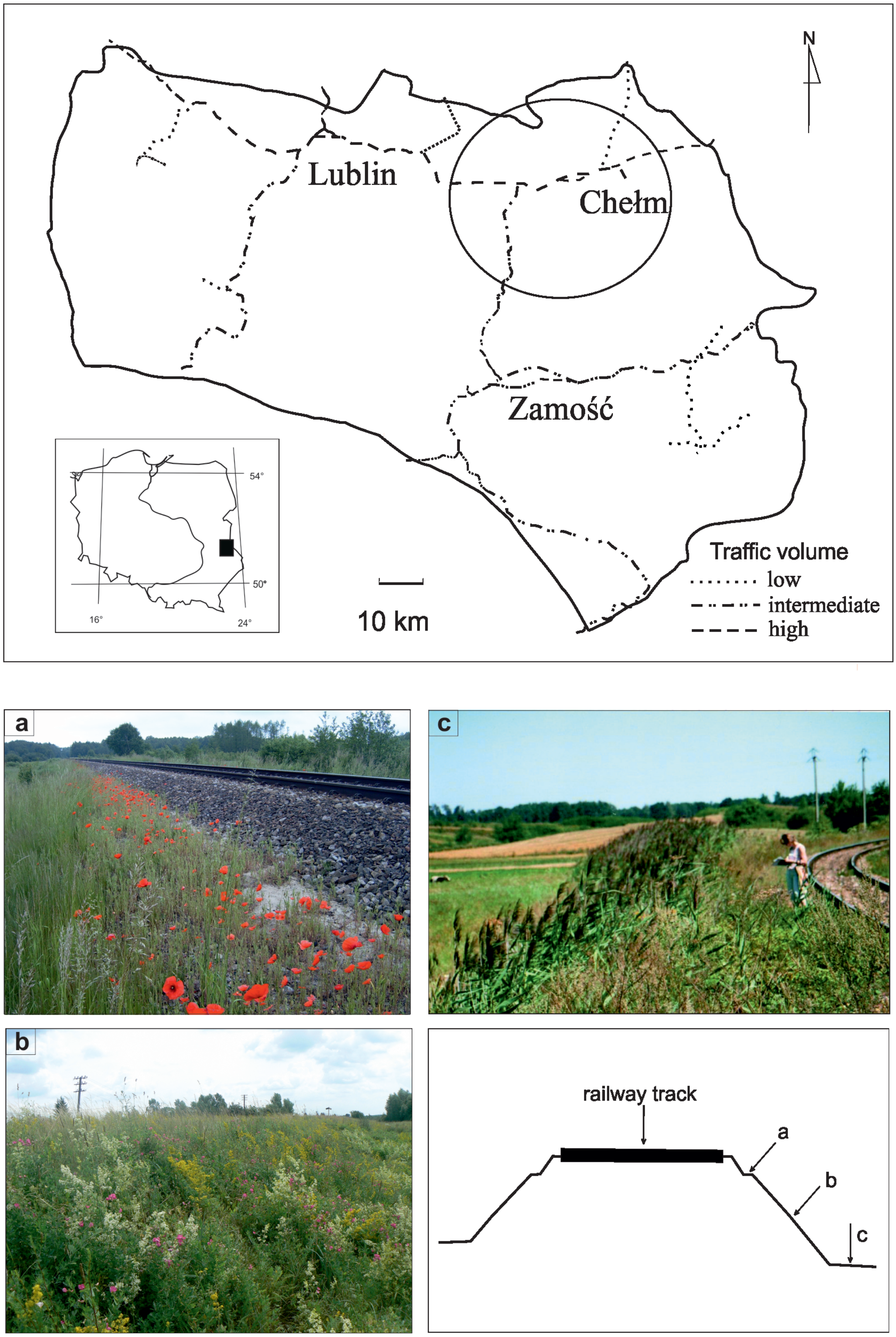

Fig. 1. Location of three types of railway categorized by traffic volume and view of transect plots and diagram (cross-section) of railway embankment with microhabitats location at the (a) - top, (b) - slope, and (c) - bottom

18 533 km (Falkowski & Pytel, 2014). There are some environmental disadvantages of railway constructions, e.g. considerable loss of natural habitats, impairment of microclimatic and hydrological conditions, development of dispersal barriers to many non-flying terrestrial animals (Fahrig, 2003). On the other hand, there is a lot of evidence that railway lines create important biotops for general diversity of fauna (e.g. Moroń et al., 2014; Kalarus & Bąkowski, 2015) and flora (Wrzesień, 2009).

In this study, we evaluated the bee forage flora distribution, richness, and diversity along railway embankments in relation to (i) the type of railway with regard to the traffic volume, and (ii) the microhabitats along an embankment cross section. We analysed the abundance of pollinators that use food resources along railway embankments. We also recognised the pollinators preference for several plant species.

MATERIAL AND METHODS

Study area

The investigations were carried out in the 2012–2013 time period, across two macroregions (Lublin Upland and Volhynia Woodlands) located between the Wieprz River and the middle reach of the Bug River (51°19´- 51°10´N, 23º36´- 23°14´E) (Fig. 1). It is the borderland between maritime Western Europe and continental Eastern Europe. The region is highly undulated at 180–300 m above sea level. The average annual precipitation in the research area is 572 mm, with a mean annual temperature of 7.2°C. The area has an agricultural-settlement character, arable lands constitute 50.94% of the region. The large monocultures of intensive farming systems as well as small farms are characteristic of the area. The existing railway lines are divided into three categories (i) unit 7 Warszawa–Dorohusk is an intensely exploited, high speed railway (ii) unit 69 Rejowiec–Hrebenne is medium-exploited, and (iii) unit 81 Chełm–Włodawa is a rarely-exploited tourist track. The railway tracks largely run through rural areas and natural habitats, i.e. mesophilous deciduous forests (*Tilio-Carpinetum*), mixed coniferous forests (*Pino-Quercetum*), wet meadows (*Molinietalia*), fresh meadows (*Arrhenatheretalia*), xerothermic grasslands (*Festuco-Brometea*), and peat bogs (*Scheuchzerio-Caricetea nigrae*).

1. Data collection and preparation

1.1. Floristic inventory and insect visitor survey

Flora resources and flower insect-visitors were quantified during walks along transects located on embankments along three types of railways categorised by traffic volume as (i) low < 5 trains per day, (ii) intermediate 5-20 trains per 24 h, and (iii) high 21-50 trains per 24 h. Within each type of railway, the transect plots were randomly selected and located in three microhabitats of the embankment cross section (i) at the top, (ii) at the slope, and (iii) at the bottom. We surveyed a total of 60 transect plots (= 18000m length), each was 300 m long. The width of the transects was 1.2 m (we used the stick to assign the transect width). The field survey was conducted from the beginning of May to the end of August. Each year 30 transect plots were visited, approximately every three weeks (= 8 observation rounds in 2012 and 6 rounds in 2013, i.e. 14 rounds total). The geographic position of each transect plot was recorded with a differential GPS. The method of phytosociological relevés was employed for flora records. The frequency and abundance of each vascular plant species in a particular transect plot was evaluated according to Braun–Blanquet (1964). To make the flora analysis more complex, we considered different characteristics of plant species: the botanical family, type of forage – nectar and/or pollen, flower symmetry (actinomorphic vs. zygomorphic), structural flower classes (umbel, umbel-head, brush, head, bowl, bell, tube, gullet, flag), pollination system (entomophilous vs. anemophilous), life-form (annuals, biennials, perennials), geographical status (native vs. alien). The relevant data were obtained from Klotz et al. (2002). The list of bee forage species was established on the basis of literature data (Kołtowski, 2006; Denisow & Wrzesień, 2007; Denisow, 2011) and according to our own observations. The taxonomic system and plant nomenclature followed Mirek et al. (2002).

Monitoring of insect visitors was conducted simultaneously to the floristic survey. All insects visiting flowers of different plant taxa, were counted by walking very slowly along a transect once, at each census of observation. The observation time was usually between 9:00 and 16:00 h EET (GMT +2). The weather conditions were quite constant, i.e. sunny bright, max daily temperature in spring was 14-18°C, while in summer 23-28°C, no precipitation, wind speed < 10 km·h-1. Insects were identified in the field and grouped according to higher taxonomic and pollination-functional groups (Proctor et al., 1996). The following groups of pollinators were distinguished: 1. *Apis mellifera*, 2. *Bombus* spp., 3. solitary bees, 4. non-syrphid Diptera, 5. Syrphidae, 6. Lepidoptera, 7. Vespidae, 8. Heteroptera, 9. Coleoptera. The procedure enabled us to establish both the visitation intensity (to plant taxa and transect plots) and the proportion of pollinators (to plant taxa).

Data analyses

The flora on the transect plots was compared based on three types of indices, focusing on (i) species richness – S = ni, where ni = species i, (ii) species diversity with the Shanon–Wiener index

$$H' = -\sum_{i=1}^{s} p_i \log_2 p_i$$

where pi = frequency of the species i, and (iii) species evenness with the Pielou index – J' = H'/lnS, defined as the ratio of the observed diversity to the maximum diversity, where: S = the number of species and H max= lnS). J' is constrained between 0 and 1; the less variation in communities between the species, the higher J' is. To calculate the indices, the MVSP package was used (Kovach, 2005).

The mean values of indices and the SD (standard deviation) were computed and the values obtained were compared. The Kruskal–Wallis non-parametric test was employed to test the significance of differences in the above-mentioned indices between type of railways and mi-

Table 1

Environmental variables used in the CCA analyses

Variable	Variable code
Transects location	
The type of railway track categorised by traffic volume	TRAFFIC
Microhabitats at cross-section of embankment	M_HABITAT
Ecological criteria based on indicator values (EIV)	
Light	L
Temperature	T
Soil moisture	W
Soil/water pH	R
Trophy	Tr

crohabitats (Stanisz, 2007).
Multivariate ordination techniques were used to examine the differences in the flora composition on the railway embankments. To identify the general pattern of variation in the species composition within the entire data-set of bee forage flora, an indirect ordination method (Detrended Correspondence Analysis, DCA) was used (a unimodal response model; environmental gradient > 3). Redundancy Analysis (RDA) with forward selection, and associated Monte Carlo significance permutation tests (499 permutations), were employed to relate differences in the species composition with environmental variables (Canoco 5.0, ter Braak & Šmilauer, 2012). Two environmental variables describing the location of the railway embankments, i.e. TRAFFIC and M_HABITAT were tested (Table 1). We also identified ecological factors that had an impact on the species composition among the railway embankments. The ecological indicator values (EIV) were calculated for all the species recognised in each transect, using the Ellenberg system adopted for Polish conditions by Zarzycki et al. (2002). We took into account 5 environmental variables related to ecological indicator values describing the most typical habitat conditions – light (L), temperature (T), soil moisture (W), soil/water pH (R), and the trophy value (Tr). The Tr value indicates the content of different nutrients, particularly N, K, Mg, Ca, and P, showing how the fertility of the habitat varied. The share of species with a specific indicator value in each transect plot was determined using a modified formula for the weighted averages:

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

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

Table 2

Comparison of bee forage species richness (S), the values of diversity indices (H’, J’) calculated and the number of insect individuals noted on railway embankments. Means ± SD (standard deviation) are shown

Feature	Traffic volume			Microhabitat		
	low	intermediate	high	top	slope	bottom
	mean ±SD	mean ±SD	mean ±SD	mean ±SD	mean ±SD	mean ±SD
Species richness (S)	76.2_b ±26.3	103.2_c ±30.4	46.7_a ±19.7	63.6_b ±3.4	89.3_c ±17.3	67.4_b ±8.5
Shannon-Wiener index (H’)	1.84_b ±0.15	1.98_c ±0.12	1.62_a ±0.19	1.69_b ±0.21	1.96_c ±0.14	1.78_b ±0.08
Evenness (J’)	0.996_c ±0.001	0.983_b ±0.008	0.996_c ±0.013	0.996_c ±0.005	0.966_b ±0.007	0.946_a ±0.015
Insect visitors (number) per transect per m^2	0.002_b ±0.0004	0.006_c ±0.0002	0.001_a ±0.0001	0.003_b ±0.0002	0.005_c ±0.0001	0.001_a ±0.0002

The values indicated by the same small letter are not statistically different between traffic volumes or microhabitats, according to the Kruskal-Wallis test.

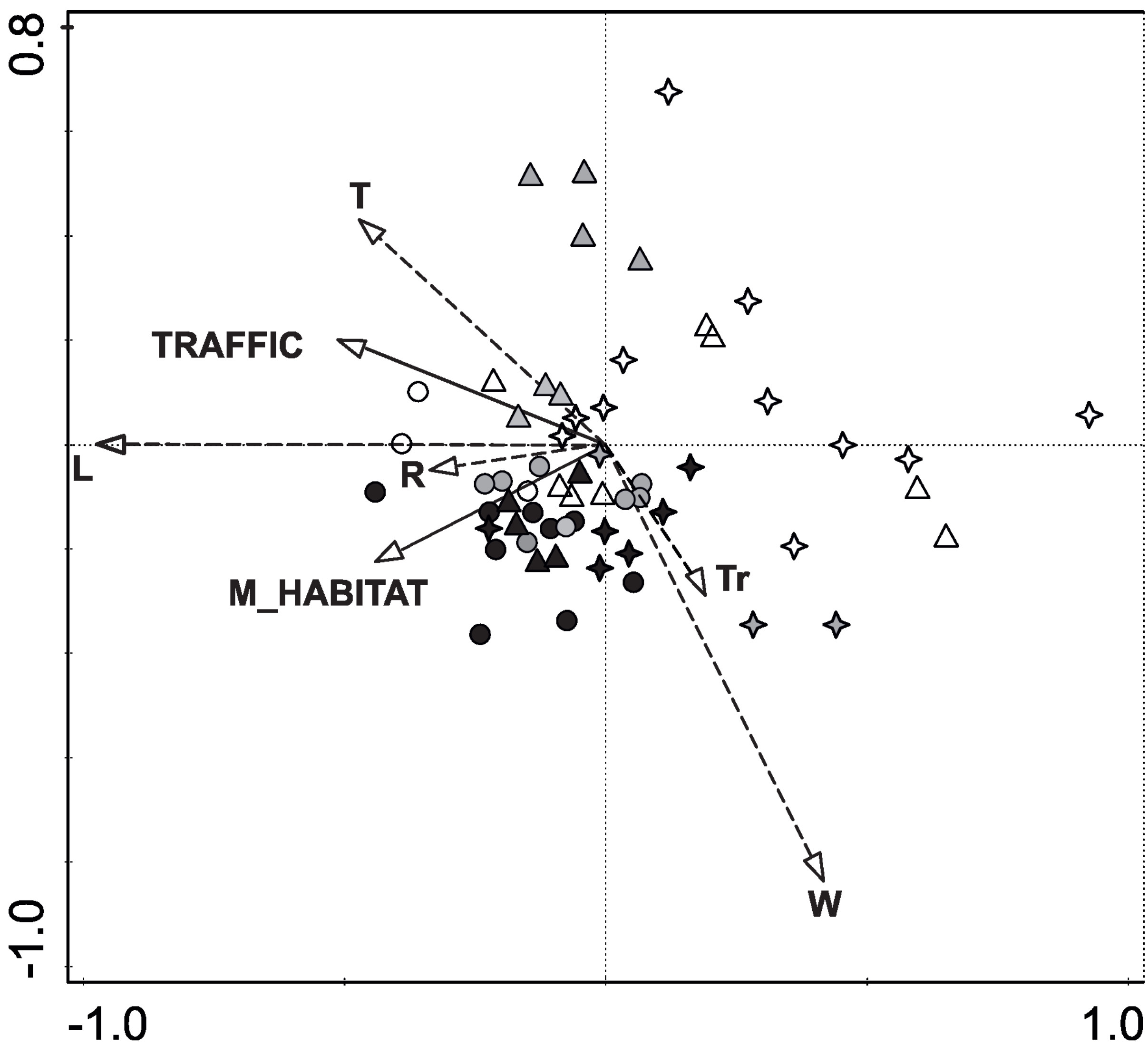

Fig. 2. Ordination biplot diagram of the canonical correspondence analysis (CCA) for the years 2012-2013 based on species matrix comprising the bee flora occurred on railway embankments. Each point refers to the traffic volume categories:✧ low < 5 trains per 24 h, △ - intermediate 5-20 trains per 24 h, and ○ - high 21-50 trains per 24 h. Colours of points correspond to the location of study plots in three microhabitats: white - at the top, grey - at the slope, black - at the bottom. Vector labels refer to environmental variables (see Table 1 for definition). Eigenvalues: Axis 1 - 0.208, Axis 2 - 0.156. The diagram explains 24.1 % of total variance. Simple term effects: L - 7.0%, P = 0.002; W - 5.3%, P = 0.002; T - 4.2%, P = 0.002; TRAFFIC - 4.1%, P = 0.002; M_HABITAT - 2.7%, P= 0.006; R - 2.2%, P = 0.004; Tr -1.9%, P=0.158; Conditional effects: L - 7.0%, P = 0.002; W - 4.8%, P = 0.002; TRAFFIC - 3.0%, P = 0.002; T - 2.7%, P = 0.002; M_HABITAT - 2.0%, P = 0.032; R - 1.8%, P=0.072; Tr - 1.4%, P=0.694.

To define the classes of plant species, based on similarities in relation to preferences of insect visitors, the hierarchical cluster analysis was performed (Stanisz, 2007). Insect preferences were measured based on frequency and proportion of visitors to particular plant species. The following plant traits were taken into account for computing: (i) structural flower classes (umbel, umbel-head, brush, head, bowl, bell, tube, gullet, flag), (ii) abundance of flowering (= cover in plot), (iii) flowering season, (iv) quantity of floral reward per flower (on a 1-5 scale adopted based on literature data). The homogeneity of the plant species was evaluated by Ward's dendrite method, with the Euclidean distance as a measure of similarity (Stanisz, 2007). The cut-off point for defining separate plant clusters was set at a level of 80. For clarity of data presentation, we analysed only 33 plant species which were most frequently visited. The data from the sampling periods were pooled.

Differences in the attractiveness of plant species to insect visitors were explored using the Kruskal–Wallis test, on the subset of 13 plant species selected based on the total number of recorded insect visitors >50 during sampling periods.

Statistica software package version 10 developed by StatSoft Krakow was applied for these analyses. The level of statistical significance to measure the differences in average ranks among groups for all the analyses performed was at P=0.05.

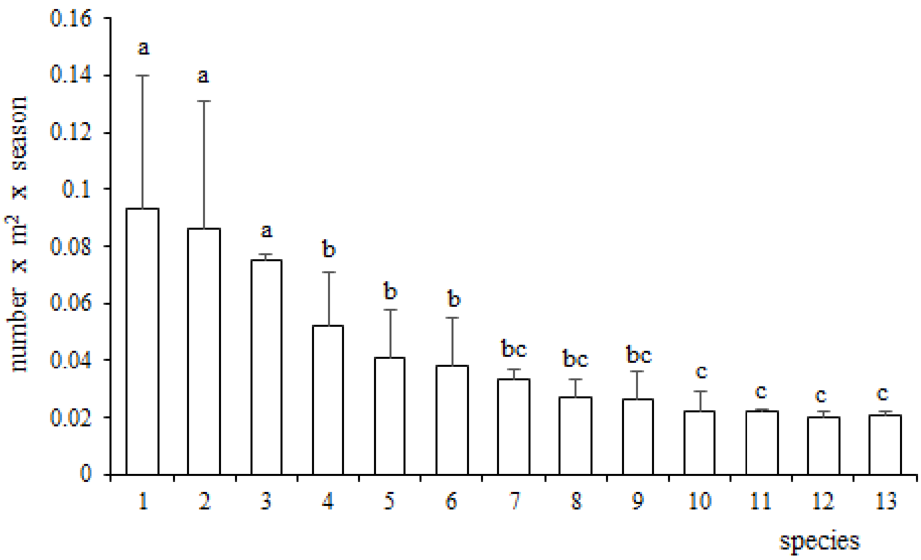

Fig. 3. Mean flower-visitor abundance per 1 m^2 per season for the following plant species 1 - *Pastinaca sativa*, 2 - *Berteroa incana*, 3 - *Cirsium arvense*, 4 - *Bunias orientalis*, 5 - *Melilotus officinalis*, 6 - *Convolvulus arvensis*, 7 - *Vicia cracca*, 8 - *Echium vulgare*, 9 - *Melilotus alba*, 10 - *Anthriscus sylvestris*, 11 - *Medicago falcata*, 12 - *M. sativa*, 13 - *Solidago gigantea* noted on railway embankments. Results are calculated on the base of plant species frequency and abundance in total transect plots area. Whiskers indicate standard deviation (SD).

RESULTS

The total number of plant species found was 401, of which 305 species (76.1%) were identified as visited by insects. The number of bee forage species in the particular transect plots ranged from 20 to 195 (mean = 75.4±35.2). Species yielding both nectar and pollen predominated (284 species – 93.1%). Pollen as floral reward (= no nectar) was offered by 21 species (6.9%) of the bee forage flora noted.

Bee forage species richness and abundance significantly differed between types of railways (Kruskal–Wallis test: H=11.09, df=2, P=0.026 for species richness (S); H=18.44, P=0.029 for H' index; H=17.10, P=0.042 for J' index). The species richness was the highest on the embankments along the railway with intermediate traffic volume (Table 2). Along railways with low and high traffic volume, we identified approx. 25% and 40% fewer bee forage species, respectively. Likewise, bee forage flora differed considerably between microhabitats, i.e. top vs. slope vs. bottom of the embankment (H=13.09, P=0.034 for species richness (S); H=19.52, P=0.039 for H' index; H=20.14, P=0.045

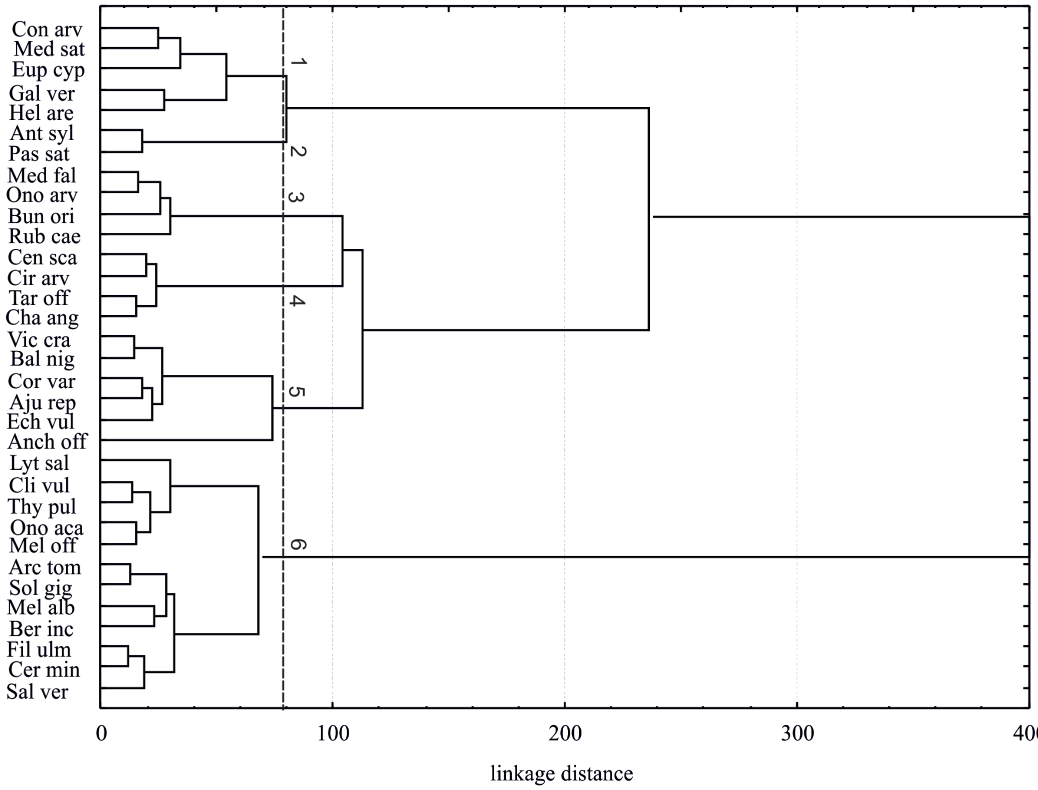

Fig. 4. Similarity of 33 bee forage species providing food resources for insect visitors on railway embankments. Cut point for plant species clusters (1-6) are at the level of 80 – dotted line (----); abbreviations of plant species: Con arv - *Convolvulus arvensis*, Med sat - *Medicago sativa*, Eup cyp - *Euphorbia cyparissias*, Gal ver - *Galium verum*, Hel are - *Helichrysum arenarium*, Ant syl - *Anthriscus sylvestris*, Pas sat - *Pastinaca sativa*, Med fal - *Medicago falcata*, Ono arv - *Ononis arvensis*, Bun ori - *Bunias orientalis*, Rub cae - *Rubus caesius*, Cen sca - *Centaurea scabiosa*, Cir arv - *Cirsium arvense*, Tar off - *Taraxacum officinale*, Cha ang – *Chamaenerion angustifolium*, Vic cra - *Vicia cracca*, Bal nig - *Ballota nigra*, Cor var - *Coronilla varia*, Aju rep - *Ajuga reptans*, Ech vul - *Echium vulgare*, Anc off – *Anchusa officinalis*, Lyt sal - *Lythrum salicaria*, Cli vul - *Clinopodium vulgare*, Thy pul - *Thymus pulegioides*, Ono aca - *Onopordium acanthium*, Mel off - *Melilotus officinalis*, Arc tom - *Arctium tomentosum*, Sol gig - *Solidago gigantea*, Mel alb - *Melilotus alba*, Ber inc - *Berteroa incana*, Fil ulm - *Filipendula ulmaria*, Cer min - *Cerinthe minor*, Sal ver - *Salvia verticillata*

for J' index). Most of the bee forage species were observed in the slope section of the embankment. The bee forage species identified at the top and at the bottom sections were of a similar number, but there were approx. 25% fewer species than at the slope.

Multivariate ordination techniques showed that bee forage flora composition differed according to the type of railway; traffic volume explained 4.1% of the flora. Four of the biotope conditions (light, soil moisture, temperature, and soil pH) restricted the composition of bee forage flora on railway embankments (Fig. 2). In general, plant species demanding light (L indicator value mean = 4.45) and tolerating drought (W indicator value mean = 3.03) grew mainly along the railways. However, the soil moisture differed between microhabitats across embankment sections (Kruskal-Wallis test: $H = 31.74$, $P < 0.05$). Wetter soil was characteristic for the bottom section compared to the top section of the embankment (W indicator value 3.15 vs 2.17, respectively).

The bee forage species belonged to 43 botanical families. Total number of "structural blossom classes" (*sensu* Faegri and van der Pijl 1979) did not differ either between railway types or microhabitats across embankment microhabitats. The ratio of actinomorphic to zygomorphic flowers was approximately 2:1, an average of 137 vs. 78 in the entire forage flora. The richest–in–bee plant species comprised the families Asteraceae (59 species – 15.73%), Fabaceae (36 species – 11.8 %), Rosaceae (29 species – 9.5 %), Caryophyllaceae (24 species – 7.7 %), Lamiaceae (23 species – 7.5 %), Brassicaceae (18 species – 5.9 %), and Apiaceae (11 species – 3.6 %). The ratio of perennials to biennials to annuals was approximately 5.5:1:2 (averaged 44.81±21.96 vs. 7.9±4.05 vs. 17.2±7.67 SD species in the entire bee flora, respectively). Native plant species predominated. In total, we found 234 - 76.7% of native bee forage plants vs. 71 – 23.3% of alien bee forage plant species, including 23 – 32.4% invasive species.

In total, we counted 4172 insect visits to the flowers during our observations (data pooled from the years of study, railway types, and microhabitats). Bumblebees were most abundant with 1924 visits (46.1%), followed by *Apis mellifera* with 754 visits (18.1%), solitary bees with 393 visits (9.4%), Syrphidae with 360 visits (8.6%), non-syrphid Diptera flies with 305 visits (7.3%), Coleoptera with 242 visits (5.8%), Lepidoptera with 105 visits (2.5%), Vespidae with 45 visits (1.1%), and Heteroptera with 44 visits (1.0%). The number of insect individuals documented on transect plots differed between types of railways (Kruskal-Wallis test: $H = 27.47$, $P < 0.05$). The highest abundance of insect visitors was noted along the railways with intermediate traffic volume; an approximately 40% lower abundance was recognised along railways with low traffic volume, and the lowest number of insect visitors was documented along railways with high traffic volume. Likewise, insects reacted differently to flora across microhabitats on railway embankments ($H = 17.41$, $P < 0.05$).

Considering the abundance of insect visitors to flowers of particular plant species, the highest abundance (from 0.075 to 0.093 insects per 1m^2 per season) was observed for *Pastinaca sativa*, *Cirsium arvense*, and *Berteroa incana* (Fig. 3). They were followed by *Bunias orientalis*, *Melilotus alba*, and *Convolvulus arvensis* (from 0.038 to 0.052 insects per 1m^2 per season). The lowest abundance was observed in *Anthriscus sylvestris, Medicago falcata, M. sativa, Solidago gigantea* (from 0.021 to 0.027 insects per 1m^2 per season).

Based on the agglomeration schedule, 6 clusters of bee forage plant species were distinguished (Fig. 4). The differences in the proportion of insect visitors to particular plant species are presented in Fig. 5. Non-syrphid Diptera and Syrphideae were present on flowers of all clusters (1-6). However, the highest proportion of these insects was noted for plants categorised in clusters 1 and 2. Plant species in cluster 3 were classified as highly attractive for solitary bees (e.g. *Bunias orientalis, Ononis arvensis, Rubus caesius*). A great proportion of *Bombus* species was associated with plant species in clusters 4 and 5. The plant species classified in cluster 6 were highly attractive to *Apis mellifera*.

DISCUSSION

In a landscape of vast monocultures of mass-flowering entomophilous crops, food resources for pollinators are often abundant but limited to a relatively short time during the season. This makes the flora present in non-cropped areas particularly important for food supplementation between the bloom of crop plants. Our study has unequivocally revealed that railway embankments are important refugial zones for nectariferous and polleniferous taxons. The importance is typified by the occurrence of 305 vascular plant species identified as bee forage plants; approximately 1/3 of the regional flora (Fijałkowski, 2003). This is in agreement with the study of Tikka et al. (2000) who consider these linear structures as good refuge habitats for flowering species.

In our study, the richness and abundance of bee forage species on railway embankments differed along tracks, and were categorised by traffic volume. A possible explanation is that diversity in vegetation management systems (important for maintaince of infrastructure, fire prevention or traffic safety) may clearly influence the richness and abundance of flowering species along these linear transport structures. For example, application of herbicides along those railway embankments with high traffic volume as well as extensive mowing (every 2-3 years; Wrzesień & Święs, 2006) along the railway embankments with low traffic volume, were possibly responsible for the considerable reduction in the richness of flowering species in these stands compared to the medium traffic volume stands (every year mowing; personal observations). For a long time, mowing control has been the recommended management approach to support wild-flower species richness on people-made habitats (Fussel & Corbet, 1992; Kleijn & van Langevelde, 2006). In general, native plants benefit from time-controlled, at least once-per-year mowing. Mowing prevents successional changes of vegetation and minimises the tall graminoids, other non-nectariferous plants, or invasive plants (Holzchuh et al., 2007). In our study, transects with low coverage of bee forage species were covered by, e.g. *Calamagrostis epigejos, Bromus tectorum, Artemisia vulgaris*. These are highly competitive species, which are recognised as restricting the diversity of flowering bee species, for example on field margins (Denisow & Wrzesień, 2015).

Using the multivariate ordination models and Ellenberg's indicator values adapted for Polish conditions by Zarzycki et al. (2002), we documented heterogeneity of the flora across railway embankments by both traffic volume and microhabitats. In accordance with Tikka et al. (2000), railway embankments are covered mainly by light-demanding and drought-tolerant plants. Bee forage flora was most abundant on the railway slopes, indicating that the most favourable conditions were on the slopes. Covers of crushed stones or gravel, and/or a highly dry area at the top (W indicator value 2.17), restricted the richness and abundance of bee forage plants. Whereas, the increase in soil moisture at the bottom of railway track (W indicator value 3.15) was advantageous for several aggressive plants (e.g. *Phragmites communis, Urtica dioica, Chenopodium album* or *Atriplex nitens*). These anemophilous species are not attractive for pollinators and they reduce the occurrence of wild-flowering species.

In general, plant species diversity is a main predictor for pollinator diversity (Ebeling et al., 2008). The limitation in our study was that we did not survey the richness of insect species. We did record 9 taxonomic groups of pollinators, though. The importance of railway habitats for attracting a diversity of pollinators was recently stressed by Moroń et al. (2014) and Kalarus & Bąkowski (2015), who indicated nest sites and diet variety as major determinants of habitat quality for richness of pollinator species and their abundance in railway embankments. The relationship between plant and pollinator richness is explained by increasing heterogeneity of floral rewards (nectar traits, i.e. chemical composition of nectar, sugar concentration, the rate of nectar secretion, and pollen production). Moreover, the richness of flowering species increases the diet diversity, and therefore enhances insect life cycles, preventing the insects from many chronic diseases and certainly having an impact on insect abundance (e.g. Alaux et al., 2015).

In addition to the richness of plant species, the quantity of available food resources is considered to have a strong positive effect on pollinators (e.g. Potts et al., 2010). According to the resource threshold hypothesis, the resource availability has an impact on the size of pollinator populations (Fahrig, 2003). Differences in the abundance of bee forage plants between the types of railways may explain the variations in the abundance of insect visitors noted between transect plots located along different railways. Our results agree with the findings of Steffan-Dewenter and Tscharntke (2000), and Ebeling et al. (2012), that insect abundance could be best explained by blossom cover. However, contrasting results were also achieved (Holzschuh et al., 2007). For example, floral richness not flower abundance increased the abundance of both solitary bees and hoverflies (Ebeling et al., 2008).

The majority of plant species present on railway embankments are perennials. This observation is in agreement with earlier reports showing the predominance of perennials in vegetation developed on people-made habitats (e.g. Wrzesień & Denisow, 2007; Denisow & Wrzesień, 2015). In the opinion of many authors, perennials provide multi-seasonal sources of nectar and pollen, they bloom over a long period, i.e. more than two months in a season (Denisow, 2011) and by that means are particularly valuable food resources for pollinators.

The present study also focused on the composition of insect-visiting flowers of studied plant species. The bee forage species noted on railway embankments generally attracted different taxonomic groups of pollinators, and the composition of floral visitors to our study species differed considerably. Various factors are expected to influence this disparity. Apart from flower morphology, nectar and pollen characteristics had an impact on insect visitors to the flowers, for example - the type of carbohydrates or other compounds, i.e lipids, phenols, alkaloids or organic acids (Nicolson & Thornburg, 2007), the amount of sugars produced per unit area, or even absence/presence of starch or proteins in pollen (Denisow 2011). These nectar and pollen traits are highly species-specific (Nicolson & Thornburg, 2007, Denisow & Wrzesień, 2015).

The majority of insect visitors to the flora on railway embankments were bumblebees. These insects exhibited preferences for long-flowering perennials with zygomorphic flowers (clusters 3, 4, 5). This confirms the observations made by other authors (e.g. Osborne et al., 1999; Hülsmann et al., 2015), who reported that perennial species found in people-made habitats are useful for active restoration of bumblebee populations.

Apis mellifera was frequently observed visiting species with both actinomorphic and zygomorphic flowers, but they were species that flowered abundantly (cohort 6). The preference of honeybees to species which flowered abundantly resulted in a high nectar and/or pollen yield per unit area over a short period of time, and was noted by e.g. Steffan-Dewenter & Tscharntke (2000), Denisow (2011), and Jędrzejewska-Szmek & Zych (2013).

We documented the presence of small non-syrphid Diptera (flies), hoverflies (Syrphidae), and solitary bees among the visitors to most of the flora studied. These insect visitors were clearly associated with small, actinomorphic flowers, and with easily accessible floral reward. The advantageous role these pollinators play has been highlighted by Kearns (2001), who reported that if weather conditions are not suitable for honeybee flights, flies and solitary bees may contribute as the main pollinators to seed/fruit production of many crops. Accordingly, railways, as longitudinal landscape structures, seem to be crucial for the enhancement of pollination services for diverse entomophilous crops in an agricultural landscape. But this prediction needs further experimental testing. Small dipterans, hoverflies (Syrphidae), and solitary bees are also involved in other valuable ecosystem services (Wratten et al., 2012). For example, approx. 40% of these insects have zoophagous larvae (Kearns, 2001); natural enemies of insect pests (e.g. aphids, beetles). As can be seen, the flowering plant species diversity context is broader than just the maintenance of pollinators. Biocontrol is no less important in both agriculture and forestry.

Within plant species, the Apiaceae are considered the most generalised; the reward in umbel flower types is easily accessible for many insect visitor groups. In our study the Apiaceae species, *Pastinaca sativa* (cluster 2) was visited by a large number of individuals and the reward was shared by 9 taxonomic groups of floral visitors. The high attractiveness of *P. sativa* is presumably related to both its high frequency and abundance on railway embankments. A positive dependence between plant abundance and the number of established links with insect visitors was revealed, for example, by Jędrzejewska-Szmek and Zych (2013). The important role of the Apiaceae species as a food resource for a variety of insect visitors especially for flies, beetles, and the wasp species was stressed in several studies (e.g. Zych, 2007; Denisow, 2011).

The flora of railway embankments is dominated by native wild-flowers. However, we documented the occurrence of alien invasive species as well. Among the invasive species, we noted that *Bunias orientalis* and *Solidago gigantea* were a good source of pollen and nectar (Denisow, 2011). Strong competition from invasive plants often place native plant species at a disadvantage (Vanbergen, 2013) and may even impair the population size of wild bee species (Moroń et al., 2009). In our study, the attractiveness of the invasives for insect visitors differed. Attractiveness was relatively higher for *B. orientalis* compared to *S. gigantea*. Apart from differences in the floral reward traits, the reasons may include the plant abundance along railways (higher for *B. orientalis* than for *S. gigantea*) or the blooming phenology (spring vs. late summer). Railway embankments are important habitats which support a variety of taxonomic and functional pollinator groups. However, the bee forage flora richness and abundance differ considerably between railway types. As railways embankments cover about 4 million hectares (~10 million acres) in Poland, they represent an opportunity for management to promote native wildflowers. We assume that the management of flora (e.g. mowing) to strengthen the bee forage flora particularly on railway embankments along low and high traffic volume tracks should be considered. The important point of such management is to counteract a substantial spread of non-forage plants (e.g. C*alamagrostis epigejos, Artemisia vulgaris*) as well as non-native species, including invasive species.

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