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ORIGINAL RESEARCH PAPER

Composition and structure of the flora in intra-urban railway areas

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Abstract

Railway areas are considered as large greenspaces and are recognized important in improving the biodiversity and dynamic of urban flora. In this study, we examined the flora composition and diversity along intra-city railway lines in Lublin, SE Poland and Lviv, W Ukraine. The flora has been analyzed in terms of species composition (multivariate ordination techniques), life span, life form, type of pollination mode, seed dispersal, life strategy sensu Grime, hemerophoby, urbanity degree, and in terms of habitat preferences using ecological indicator values. The multivariate analysis (CCA) clearly revealed that abiotic factors (topographical), weather elements (annual precipitation and air temperature), and soil attributes (moisture, trophy, pH, salinity) differed between two cities and impacted on the differences in railway flora composition. Plants growing on the intra-urban railway areas are mainly hemicryptophytes/perennials, C, CR, CRS-strategists, insect-, self-, or wind-pollinated, reproducing by seeds and mainly dispersed by wind. Intra-urban railway areas are predominated by native species, however the participation of invasive alien species is higher than their proportion in domestic floras. The share of invasive species is greater in railway areas of Lviv, ca. 12% (45 species) compared to 8% in Lublin (36 species). Spontaneous flora in intra-urban railway areas represent distinct adaptations to unique urban-industrial ecosystems with different degree of anthropogenic disturbance.

Keywords

railway flora; disturbed areas; functional traits; invasive alien species; Lublin; Lviv

Introduction

The rapid development of railway transport in Europe was induced by Industrial Revolution and started in the eighteenth century. Since then, railway lines are under continuous development and constitute important form of land transport [1]. Railway lines permeate both rural and urban areas and form networks. In a landscape, there are some environmental disadvantages of railways constructions, e.g., considerable loss of natural/semi-natural habitats or fragmentation, impairment of microclimatic and hydrological conditions, development of dispersal barriers to many non-flying terrestrial animals [2,3]. On the other, railway lines create artificial corridors and perform a number of functions that are associated with both natural and man-made corridors. The main functions of such corridors are habitat assurance, filter/barrier, source and sink for species [4–6]. Heterogeneous habitats (top beds, embankments, slopes, ditch, open flattish strips) and distinctive environmental conditions, i.e., highly polluted (coal dust deposition, diesel oils, heavy metals, herbicides), affect the flora and vegetation [7]. The distinctive flora of railway areas has been an interest since the nineteenth century [8,9]. Since then, railway transport has become one of the most important factor affecting the process of fragmentation of natural and semi-natural biotopes and flora synanthropization in various parts of the world [4,5]. Recently, the increasing movement and migration of humans promote the spread of plant species along railway tracks [10–12]. In urban ecology, the railway areas are considered as large greenspaces and are recognized important in improving the biodiversity and dynamic of urban flora [13–15].

The presented study deals with the composition and diversity of vascular flora along intra-city railway lines. We examined to what degree the railway flora differs between two cities located in the distance of ca. 220 km. The other question raised up in the paper was to examine the factors that determine the flora in the railway areas and describe the features of flora. We combined the flora recorded with data on biological and functional traits of plants (life form, life span, life strategy, type of pollination agent, type of reproduction, type of seed dispersal, etc.). We also analyzed the geographical-historical status and synecological groups of species. These analyses can be applied to study on the stability of railway vegetation, and to predict the possible impact on the vegetation in surrounding areas.

Material and methods

Study area

The floristic records of railway flora have been conducted in 2014–2015 in two cities – in Lublin (51°19′–51°10′ N and 23°36′–23°14′ E, 170–220 m a.s.l.), southeastern Poland and in Lviv (49°83′–49°50′ N and 24°00′–24°10′ E, 320–382 m a.s.l.), Western Ukraine. Lublin is located on the Lublin Upland. The Bystrzyca River divides the city into two diverse parts: the western side with a number of valleys and loess gorges and the flatter side on the east [16]. Lviv is developed at the intersection of four physiographic regions – Davydov Plateau, Lviv Plateau, Ukrainian Roztocze, and ridged Pobuzhya [17]. The city is located within the main European watershed, which separates drainage basins of the rivers Vistula, Dniester, and Dniepr. Lublin covers an area of 147 km^2 and has a population of approximately 349 000. Lviv covers an area of 182 km^2 with approximately 730 270 inhabitants. The distance between Lublin and Lviv is ca. 220 km. The long-term average weather data for Lublin/Lviv differ and are as follows: the annual average air temperature 8.0/8.9°C and precipitation 537.9/748 mm [18]. In both cities, the center is characterized by dense housing while the suburbs have many green areas subjected to different anthropopressures. The railway lines have been developed since the mid-nineteenth century, in both cities.

Data collection

In each city, the flora occurring on railway tracks, cargo yards, ridges, platforms, embankments, trenches has been investigated. The floristic records were made along 60 transect plots randomly selected. Each transect was ca. 300 m long and ca. 2–3 m wide, i.e., 18 000 m of railways in each city was explored. The field survey was conducted from the beginning of May to the end of September. To make the flora analysis more complex, we completed different characteristics of plant species: the botanical family, geographical-historical status, synecological groups [19–23], and their functional traits, i.e., life form (phanerophyte, chamaephyte, hemicryptophyte, geophyte, therophyte), life span (annuals, biennials, perennials, shrubs, and trees), type of pollination agent (insect-, wind-, self-pollination), reproduction (seeds, vegetative, mixed), type of seed dispersal (auto-, anemo-, zoo-, hydro-, anthropochory), life strategy according to Grime's classification, i.e., C – competitors, S – stress tolerant, R – ruderal, and mixed types – CR, SR, CS, and CSR. In order to analyze the human impact on the flora in intra-urban railway areas, we calculated the frequency of the species according to their hemeroby values: H1 – oligohemerobic (very weakly influenced), H2 – mesohemerobic (moderately influenced), H3 – euhemerobic (strongly influenced), and H4 – polyhemerobic (very strongly influenced). We also calculated the frequency of the species according to their urbanofoby value, which reflects the affinity of plant species towards urban areas. The following urbanofoby values were employed U1 – urbanophobic (species restricted to non-urban areas), U2 – moderately urbanophobic (species restricted predominantly to non-urban areas), U3 – urbanoneutral (species with no preference to urban or non-urban areas), U4 – moderately urbanophilic (species occurring predominantly in urban settlements), U5 – urbanophilic (species restricted to urban settlements).

Data considering the species traits were taken from BiolFlor [24] and LEDA Traitbase [25]. To assess plants preferences towards climatic and edaphic conditions, ecological indicator values were assigned to each species [26]. We took into account eight environmental variables describing the most typical habitat conditions – light tolerance (L), temperature (T), soil moisture (W), soil/water pH (R), trophy (Tr) and continentality (K), organic matter (H), and soil salinity (S). The mean values were calculated [27].

Data analysis

The multivariate analyses and the forward selections procedure available in the CANOCO 5.0 package [28] was used to group the transect plots on the basis of the presence or absence of plant species. These ordination techniques helped to characterize variation in railway flora composition between Lublin and Lviv. The constrained ordination CCA (canonical correspondence analysis) was used to characterize and visualize the relationship between floristic composition and physico-chemical habitat parameters (Tab. 1). For each city, the data from the sampling periods were pooled. Differences in mean values for ecological indicators recorded in Lublin and Lviv were analyzed with Tukey HSD test for unequal sample size. Statistica software package version 10 developed by StatSoft (Cracow, Poland) was applied for these analyses. The level of statistical significance to measure the differences between the means for all the analyses performed was at $p = 0.05$.

Tab. 1 Variables used in the CCA analyses.

Variable	Variable code
Environmental variables	
Altitude (m a.s.l.)	Altitude
Annual mean temperature (°C)	Temperature
Annual precipitation (mm/year)	Precipitation
Climatic and edaphic criteria based on indicator values	
Light	L
Temperature	T
Continentality	K
Soil moisture	W
Soil/water pH	R
Trophy	Tr
Organic matter	H
Salinity	S

Results

Overall, we recorded 502 plant species in the total dataset. More species was identified in the railway flora in Lublin (447 species) than in Lviv (364 species). Most recorded species grew in both cities (296 species); 151 species were noted exclusively in Lublin and 68 species were recorded only in Lviv. The number of species in the particular transect plots ranged from 42 to 109 (mean = 74.4 ±35.2 *SD*).

The CCA analysis showed significant impact of the environmental factors studied (altitude, temperature, precipitation) and climatic and edaphic conditions (L, T, W, R, Tr, S, H, K) on the floristic composition of railway areas in the Lublin and Lviv. The biplot diagram clearly distinguished two major specifically concentrated sets of data (opposite sides of axis 2). The eigenvalues of the first two ordination CCA axes were 0.30 and 0.21, respectively. The first two axes explained 31.8% of the variance in the species composition (Fig. 1, Tab. 2).

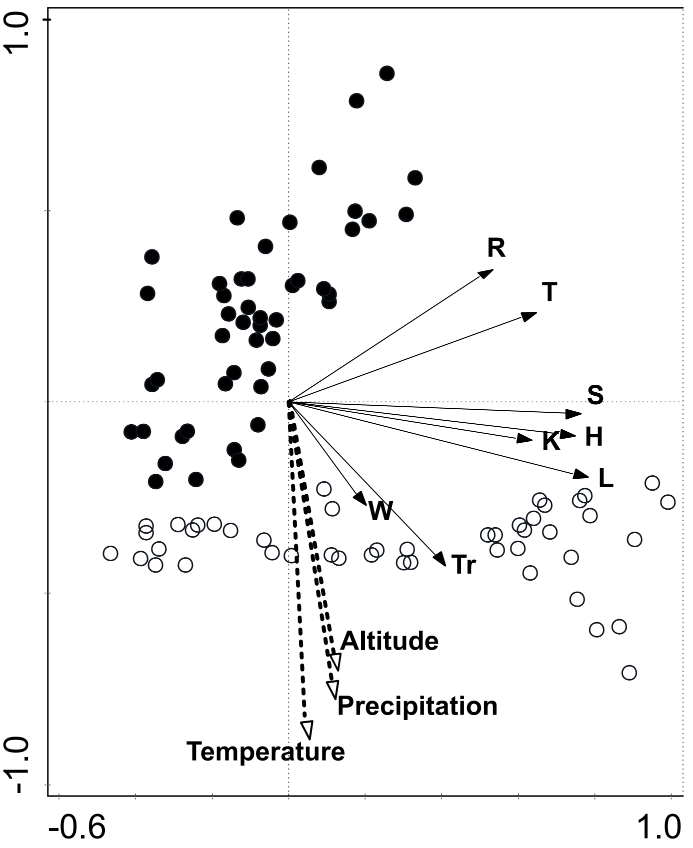

Fig. 1 Ordination biplot diagram of the canonical correspondence analysis (CCA) for the years 2014–2015 based on species matrix comprising the flora occurred in Lublin (white circles) and Lviv (black cicrcles) railway areas. Vector labels refer to environmental variables, climatic and edaphic criteria (see Tab. 1 for definition). Eigenvalues: axis 1 – 0.30, axis 2 – 0.21. The diagram explains 31.8% of total variance.

The mean ecological indicator values revealed that the plants growing along railways in Lublin and Lviv differed in terms of their demands for moisture, trophy, pH, and salinity (Tukey HSD test for unequal n, $p < 0.05$; Tab. 3).

The species belong to 63 botanical families of which the most abundant were Asteraceae, Poaceae, Brassicaceae, Fabaceae, and Rosaceae (Fig. 2). The members of Asteraceae, Poaceae, Brassicaceae, Fabaceae, Rosaceae, Lamiaceae, Scrophulariaceae, Caryophyllaceae, Apiaceae, and Boraginaceae made up 67.5% of the flora registered. The most frequently found on railway areas in Lublin were *Achillea millefolium*, *Artemisia vulgaris*, *Bromus tectorum*, *Cerastium arvense*, *Dactylis glomerata*, *Elymus repens*, *Equisetum arvense*, *Poa pratensis*, *Rumex acetosa*, and *Sonchus arvensis*, whereas *Acer negundo* (seedlings), *Achillea millefolium*, *Artemisia vulgaris*, *Arrhenatherum elatius*, *Aegopodium podagraria*, *Ballota nigra*, *Calamagrostis epigejos*, *Galium aparine*, *Poa compressa*, and *Trifolium arvense* were the most frequently recorded species on railways in Lviv.

Most of the species occurred at low frequency; ca. 40% of the species were found at only 1–5 plots. In both cities, the railway flora was dominated by native species (Fig. 3). Alien species were represented by archaeophytes (i.e., those aliens that arrived prior to 1500), which constituted 15% of the railway flora in Lublin and 17% in Lviv; the participation of neophytes (i.e., those aliens that arrived after 1500) was 19 and 21%, respectively. A large group of neophytes was noted in both cities, however several alien species were

Tab. 2 Simple and conditional term effects obtained from the summarize effects of explored variables.

Variable	Simple effect			Conditional effect		
	explains	pseudo-F	p	explains	pseudo-F	p
Light (L)	5.5	2.2	0.002	5.5	2.2	0.002
Organic matter (H)	5.4	2.2	0.002	3.3	1.4	0.002
Salinity (S)	5.3	2.1	0.002	4.1	1.7	0.002
Temperature (T)	4.6	1.8	0.002	2.9	1.3	0.040
Soil/water pH (R)	4.5	1.8	0.002	2.8	1.2	0.040
Continentality (K)	4.4	1.8	0.002	2.4	1.0	0.390
Annual mean temperature	4.4	1.7	0.002	4.3	1.8	0.002
Annual mean precipitation	4.4	1.7	0.002	4.1	1.7	0.002
Altitude	4.4	1.7	0.002	4.1	1.7	0.002
Trophy (Tr)	4.1	1.6	0.002	3.0	1.3	0.026
Soil moisture (W)	3.6	1.4	0.008	3.4	1.4	0.006

Tab. 3 Mean ecological indicator values calculated for railway flora noted in Lublin and Lviv.

Factor	Lublin mean	Lublin *SD*	Lviv mean	Lviv *SD*
Light	4.35 [a]	0.12	4.45 [a]	0.21
Temperature	3.91 [a]	0.10	3.89 [a]	0.10
Continentality	2.91 [a]	0.09	3.05 [a]	0.10
Moisture	2.91 [a]	0.14	2.99 [b]	0.13
Trophy value	3.14 [a]	0.13	3.23 [b]	0.09
Organic matter	4.06 [a]	0.11	3.97 [a]	0.14
Soil reaction	2.04 [a]	0.06	2.07 [b]	0.11
Salt	1.02 [a]	0.05	1.90 [b]	0.06

The values indicated by the same small letter are not statistically different, according to the Tukey HSD test.

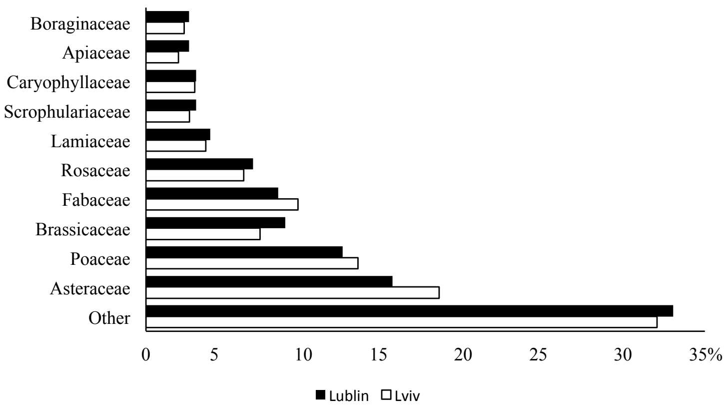

Fig. 2 Spectrum of the botanical families in the spontaneous flora of railway areas in Lublin and Lviv.

specific only for Lublin, e.g., *Aegilops cylindrica*, *Hyoscyamus niger*, *Lepidium campestre*, *Potentilla intermedia*, *Rapistrum perenne*, *Vicia grandiflora*, whereas exclusively in Lviv occurred: *Amaranthus powellii*, *Ambrosia artemisiifolia*, *Amorpha fruticosa*, *Dodartia orientalis*, *Geranium pyrenaicum*, *G. sibiricum*, *Heracleum sosnowskyi* (Fig. 4). Alien species classified as invasive by Tokarska-Guzik [23] comprised 36 species, i.e., 8% of the recorded railway flora in Lublin, and classified as invasive by Protopopova et al. [22] constituted 45 species, i.e., 12% of the railway flora noted in Lviv. In Lublin, *Acer negundo*, *Bunias orientalis*, *Echinocystis lobata*, *Helianthus tuberosus*, *Impatiens parviflora*, *Quercus rubra*, *Reynoutria japonica*, *Prunus serotina*, *Robinia pseudoacacia*, *Rosa rugosa*, and *Solidago gigantea*, were the most aggressive. In Lviv, *Acer negundo*, *Amaranthus albus*, *Ambrosia artemisiifolia*, *Amorpha fruticosa*, *Centaurea diffusa*, *Echinocystis lobata*, *Galinsoga parviflora*, *Geranium sibiricum*, *Lepidium densiflorum*, *Helianthus tuberosus*, *Heracleum sosnowskyi*, *Impatiens parviflora*, and *Reynoutria japonica* were the most frequently noted.

Irrespective of the city, perennials predominated among species recorded in the studied areas, ca. 55% (Fig. 5). Annuals constituted ca. 26%, biennials contributed to lesser extent, ca. 10%. Considering life form, hemicryptophytes predominated along railways, ca. 50%, on average, followed by therophytes ca. 25%, on average (Fig. 5). Phanerophytes constituted ca. 10%, on average. The least frequent were geophytes 8% and chamaephytes 7%. More than half of the plant species recorded in intra-urban railway flora was insect-pollinated, ca. 55% (Fig. 5). They were followed by self- and wind-pollinated species. Five categories of seed dispersal were represented by railway species, anemochorous species predominated and constituted ca. 34% of the flora (Fig. 5). Anthropochorous, zoochorous, and autochorous strategies were represented by a similar number of species.

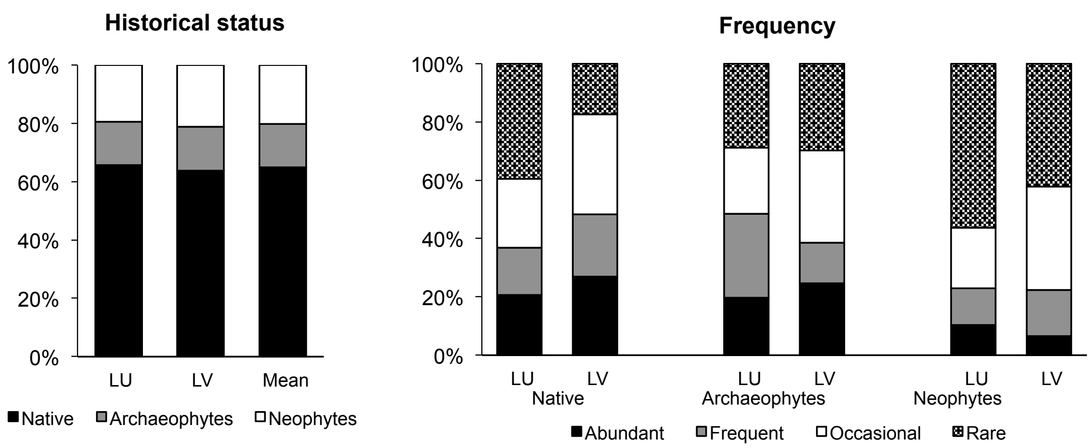

Fig. 3 Participation of native and alien plant species and their frequency in railway areas flora of Lublin and Lviv. Scale of frequencies: abundant – >50.1% of transects, frequent – 30.1–50.0%, occasional – 10.1–30.0%, rare – ≤10%.

Fig. 4 Alien species noted for intra-urban railway areas in Lublin: *Vicia grandiflora* (**a**), *Aegilops cylindrica* (**b**), *Sisymbrium wolgense* (**c**) and in Lviv: *Ambrosia artemiisifolia* (**d**), *Geranium sibiricum* (**e**), *Geranium pyrenaicum* (**f**).

Taking into consideration the phytosociological spectrum, a considerable participation of species from ruderal, segetal, meadow, xerothermic, and sandy grasslands communities (*Artemisietea vulgaris*, *Stellarietea-mediae*, *Molinio-Arrhenatheretea*, and *Festuco-Brometea* classes) were recorded (Fig. 6). The species associated with waterside therophytes and alluvial willow forests and thickets, and riparian tall-herb fringe communities with climbers (*Bidentetea tripartiti*, *Isoëto-Nanojuncetea*, *Salicetea purpureae*) were less frequently noted.

The spontaneous flora of intra-urban railway habitats is formed with species associated with transformed habitats (Fig. 7). We identified ca. 20% of the species sensitive to disturbance (H1), ca. 35% species were restricted to weakly affected sites (H2). Next, 25% are limited to moderately (H3) affected sites and ca. 15% to strongly affected habitats (H4). Most frequently, moderately urbanophobic species (U2) were noted, i.e., 38.03/35.98% LU/LV and urbanoneutral (U3), ca. 40 % in both cities. Moderately urbanophobic species (U1) accounted for 12.31/7.69 % LU/LV. Moderately urbanophilic (U4) and urbanophilic species (U5) were less frequently documented, ca. 9% and 3.8%, respectively (Fig. 8).

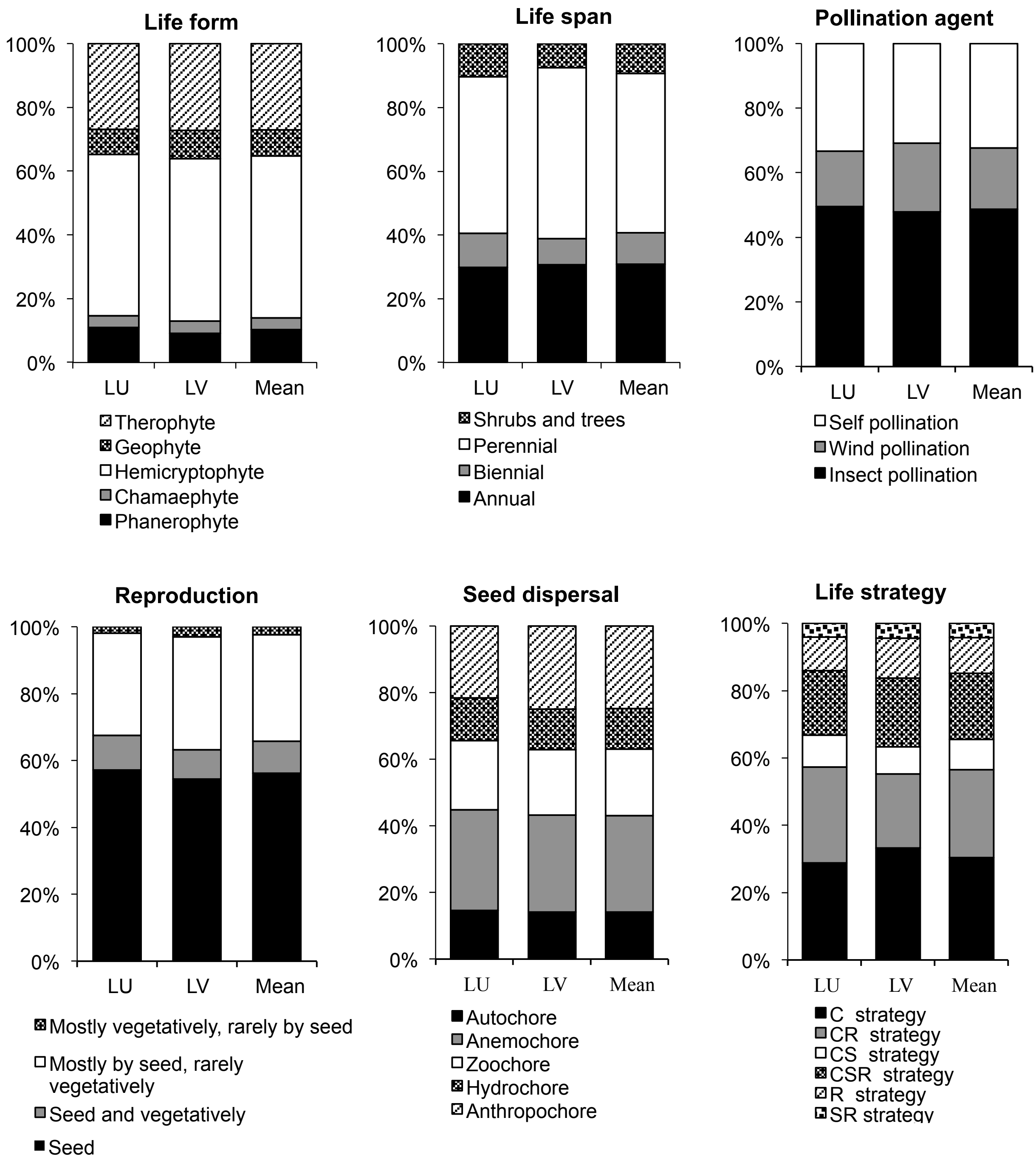

Fig. 5 The functional structure of the spontaneous flora of railway areas in Lublin and Lviv..

Discussion

It is widely accepted that the flora composition on man-made habitats, e.g., on railway areas or within cities is under pressure of the complexity of factors that determine species richness and composition [14,15,29]. Our results show that the flora on railway areas in Lublin and Lviv is species-rich. In general, high species richness of the flora along railway tracks has been revealed by several authors (i.e., [4,30,31]). However, it is important to note that the species richness results are difficult to compare as different method were used to describe the floras. Overall, species richness is influenced by many factors. Primary, the number of species depends on the area at which the species are sampled. The species–area relationship can explain the disparity in species richness reported in our study and identified for railway areas by Galera et al. [31] (338 species per 4920 m^2) or documented by Wrzesień and Święs [30] (668 species

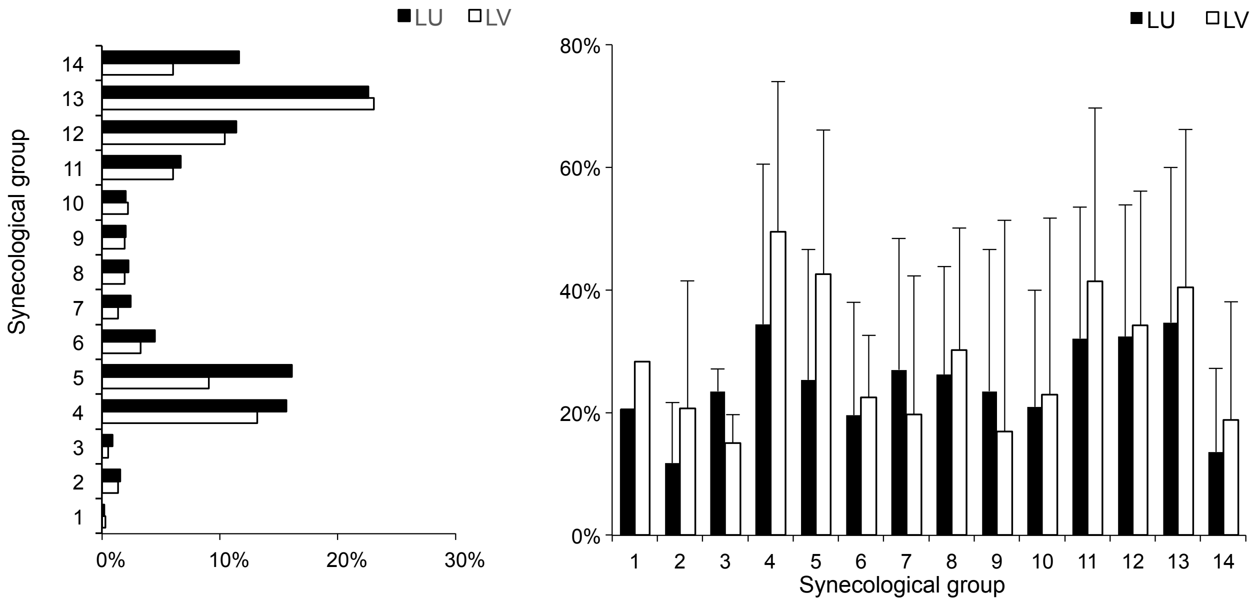

Fig. 6 Contribution of synecological groups to the flora of Lublin and Lviv railway areas and their frequency in plots. Explanations: 1 – mesotrophic bogs' communities; 2 – waterside therophytes; 3 – reed and sedge's communities; 4 – meadows and pastures; 5 – psammophilous and xerothermic grasslands; 6 – termophilous oak forests; mesophilous deciduous forests and nitrophilous shrub communities; 7 – acidophilous heathlands and baceous communities developing in the forest gaps and clearings; 8 – poor pine stands and acidophilus oak forests; 9 – alluvial willow forests and thickets as well as neighboring fertile tall-b communities; 10 – boggy and riparian alder forests and thickets; 11 – termophilous oak forests, mesophilous deciduous forests, and nitrophilous shrub communities; 12 – segetal communities; 13 – ruderal communities; 14 – species of undetermined phytosociological status.

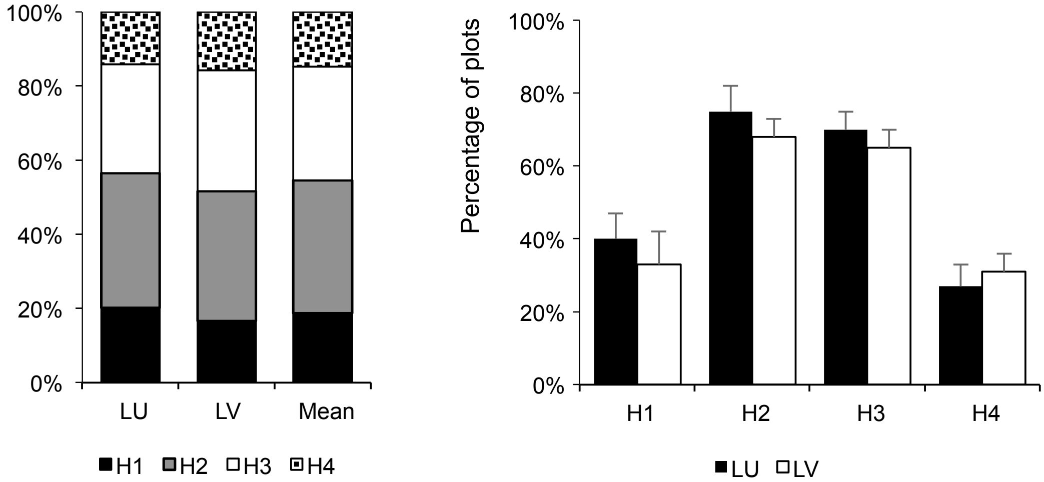

Fig. 7 The spectrum and frequency of the species in railway areas of Lublin and Lviv according to the hemeroby value of the species. Human impact: H1 – oligohemerobic, H2 – mesohemerobic, H3 – euhemerobic, H4 – polyhemerobic.

per 300 km). The linear species–area increase is one of the "fundamental nature laws" [32]. Moreover, variation in biotops, anthropogenic disturbance, or biotic interactions (e.g., pollination, herbivory) may impact on species richness [2]. Considerable temporal fluctuations in the microhabitat related to constant disturbance and/or succession are frequently noted on railway areas [33]. The richness of species on railway habitats can be even higher compared to grasslands [34,35] recognized as one of the most species-rich plant community type in Central Europe [36].

The multivariate analyses clearly revealed that railway flora composition differed between Lublin and Lviv. It is accepted that railway flora may reveal regional differences in species composition related to the local flora history [30,35], the type of vegetation in the surrounding area [4], disparity in abiotic factors across regions [37], or across railway microhabitats [38].

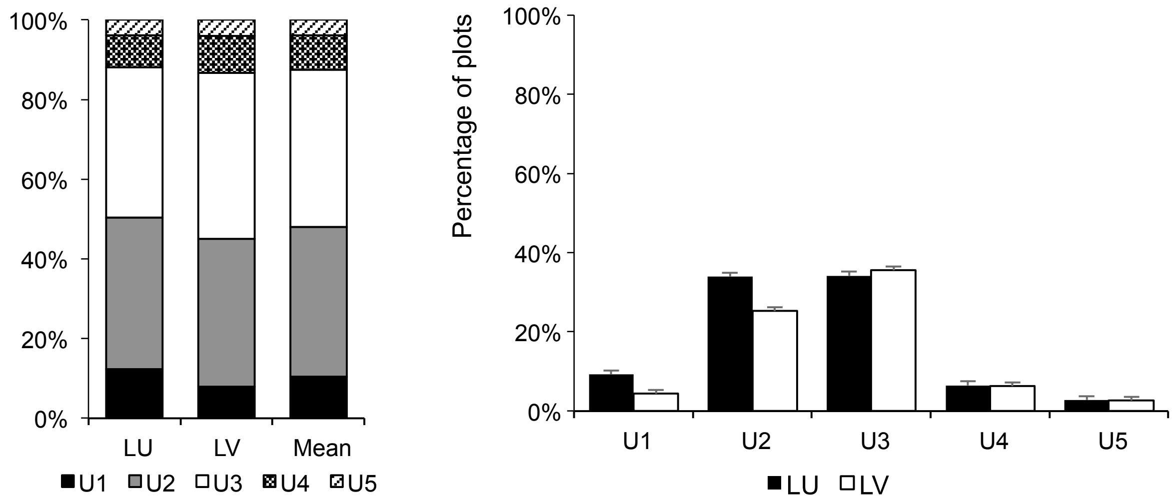

Fig. 8 The spectrum and frequency of the species in railway areas of Lublin and Lviv according to the urbanofoby value of the species. Urbanity: U1 – urbanophobic, U2 – moderately urbanophobic, U3 – urbanoneutral, U4 – moderately urbanophilic, U5 – urbanophilic.

Our survey clearly indicated that several abiotic factors (topographical), weather elements (annual precipitation and air temperature) differed between analyzed cities. In addition, using ecological indicator values, we evidenced the disparities in several soil attributes (moisture, trophy, pH, salinity) between railway habitats across Lublin and Lviv. Almost certainly, all these environment related factors interacted and evidently impacted on the diversity in the flora composition.

On the contrary, the movement of airflow, the air pushed aside by moving trains as well as functioning of the railway infrastructure create a very special environment in the vicinity of railways and restrict growth of certain plants. In both cities, the vegetation along the railway tracts shares some common characteristics which determine the character of the flora. It is generally accepted that the life form, life span, life strategy, pollination mode, or pattern of seed dispersal are important to increase the chance of both colonizing and survival under specific environmental stressors [6]. Considering life-form pattern, we documented the predominance of hemicryptophytes/perennials, which is in accordance with the findings of Galera et al. [31], who reported 49% of hemicryptophytes in the railways network in NE Poland. Biological traits of hemicryptophytes (rosettes, buds very close to the ground, long taproots) allow the survival of species in harmful habitat conditions and under anthropogenic disturbance, e.g., frequent construction repairs, mowing, or herbicide application [39,40]. The occurrence of therophytes/annuals was also similar to that noted in man-made habitats across railway areas [30] and urban areas [41]. Such species are clearly adopted to colonize areas of bare ground (non-vegetated) frequently found along railways [29]. Interestingly, we documented relatively high proportion of phanerophytes and chamaephytes, however, in the form of seedlings. The occurrence of trees and shrubs reflects the potential of the species from the surrounding vegetation for migration (seed rain). The significance of microsites among railway areas for woody species was emphasized in several previous study [14,30,33]. Among seedlings, we observed native and invasive alien species. Most frequent were young individuals of *Acer negundo*, *Robinia psedacaccia*, *Quercus robur* in Lublin and *Acer negundo*, *Amorpha fruticosa*, *Fraxinus pensilvanica* in Lviv. The seedlings of cultivable species, e.g., planted along streets or across urban greenery areas *Fraxinus excelsior*, *Prunus domestica*, *Malus domestica*, occurred in both cities and *Rhus typhina* exclusively in Lviv.

We assume that the co-occurrence of short-lived and long-lived plants on railway areas reflects the mosaic of seral stages of vegetation. Early successional stages of vegetation are dominated by annuals, mid-successional stages by biennials and perennials [42]. Intermediate stages of ecological succession are common on man-made habitats due to different levels of habitat disturbances that create multiple appropriate habitats for species that represent various life strategies.

The participation of different pollination modes creates a distinctive pattern of vegetation characteristic for the region [43]. Moreover, according to Grime [44], the pollination modes pattern is related to both environmental conditions and phylogeny. We recorded a high proportion of insect-pollinated species, which reflected a high participation of insect-pollinated Asteraceae, Brassicaceae, Fabaceae, and Rosaceae species. These species produce nectar and pollen and support food resources for divers pollinators (bees, butterflies, hoverflies), therefore, currently flower-rich patches on railway areas are considered as valuable "novel habitats" for the maintenance of food niche and conservation of pollinators [45]. Such areas help to protect pollinators in crisis [46]. We also recorded self-pollinated and wind-pollinated species (ca. 50%, of the total flora). It is widely accepted that autogamy and anemophily are advantages in colonizing man-made habitats. Self-pollinated and wind-pollinated species do not depend on mutualistic relationship with pollinators [47], therefore, their chances of reproduction and survival increase. Dense stands of wind-pollinated Poaceae recorded in our study were also observed along railways worldwide [48,49].

Considering the dispersal mode, we documented that anemochorous species (34%) were the most frequently occurring along the railways. It is in accordance with Hansen and Clevenger [5] who indicated that linear structures (railway tracks and road verges) harbor wind-dispersed species which can be easily carried by vehicles and trains and are the most likely to move along and dispersed to long-distance sites. In general, anemochory is considered to be an adaptation for the colonization of pioneer habitats and open territories [42]. We noted a relatively high proportion of anthropochorous species, which is not surprising for man-made railway habitats. However, overrepresentation of plant species dispersed by animals (zoochorous) and water (hydrochorous) is remarkable. The possible explanation is that the species noted in our study area may be dispersed in different ways.

The proportion of life strategies revealed that biological plant traits are related to each other, which supports the concept of Grime [44]. For example, perennials/hemicryptophytes are more often insect-pollinated, reproduce both by seeds and vegetatively and are usually classified as C, CR, CRS-strategists. By contrast, annuals/therophytes are more often self-pollinated, reproduce by seeds, constitute persistent seedbanks, and are categorized as R-strategists.

As for the family spectrum, the richest families recorded from the embankment are the same as in the whole Central Europe flora [19]. The phytosociological spectrum revealed that railway flora in both cities is highly "ruderalized". The richest group of species was from *Artemisietea vulgaris* class, i.e., the ruderal communities and *Stellarietea* mediae class, i.e., the annual, ruderal communities (according to Matuszkiewicz [20]). These groups of plants are recognized as typical of areas under strong anthropopression, e.g., railway sides [30,50]. Ruderal species may constitute up to 50% of the flora along railway lines in Central and East Europe [14,49]. However, in the Mediterranean region, the species from *Artemisietea vulgaris* class constituted only ca. 6.6% of the railway flora [37]. This indicates that biological adaptation of species to the climatic conditions is very important for the flora composition even across man-made habitats.

We have documented that railway embankments constitute refugia for grassland, forest as well as boggy and riparian species. Our observation is in accordance with the surveys conducted by Wrzesień [51] and Wrzesień and Święs [30] who emphasize that railways offer alternative habitats, example for ca. 15 % of forest and ca. 30% of meadow species.

We found 11 species from red list plants that occur on Lublin Upland [51,52]. It has been documented that man-made and highly disturbed habitats can serve as complementary or alternative habitats for rare plants, including threatened species (*Androsace septentrionalis*, *Asperugo procumbens*, *Cerasus fruticosa*, *Clematis recta*, *Elymus hispidus* ssp. *hispidus*, *Festuca rupicola*, *Galeopsis angustifolia*, *Lithospermum officinale*, *Myosotis ramosissima*, *Potentilla inclinata*, *Salvia nemorosa*). Man-made habitats are important for survival of the species across the areas where natural habitats are destroyed or unavailable. An updated red list has not been compiled for Lviv region yet.

High percentage of the species which occur with low frequency as well as high share of native species were previously reported for railway flora [30,31,38]. In our study, the participation of anthropophytes on railway areas was higher than their participation in native floras, i.e., in Lublin 38% while ca. 30% is reported for Poland [23]; along railway in Lviv, anthropophytes constitute 40% while ca. 20% is noted for Ukrainian flora [21].

In both cities, invasive alien species were recorded among anthropophytes. This is not surprising as railway areas are considered both as entry for invasive species and the habitats that accelerate the dispersal of propagules and migration of invasive plant species [29,49,53,54]. In particular, open areas and air movement support species migration along railway areas [14,30,38].

In this study we analyzed the human impact (degree of hemeroby and urbanophoby) on the flora. This analysis acknowledged the occurrence of the species associated with urban-industrial areas and connected to habitats with different degree of anthropognic disturbance. This accords with the investigations of the flora of Poznań, Wien, and Warsaw [41,55]. High participation of urbanophobic and moderately urbanophobic species in both cities indicate that on railway areas the semi-natural vegetation is developed. The species represent distinct adaptations to unique urban-industrial ecosystems [56].

Conclusions

- Intra-urban railway flora is species-rich, however flora composition differs between cities. The differences are related to disparities in abiotic factors (topographical), weather elements (annual precipitation and air temperature) or soil attributes.
- Plants growing on the intra-urban railway areas are mainly hemicryptophytes/perennials, C, CR, CRS-strategists, insect-, self-, or wind-pollinated, reproducing by seeds and mainly dispersed by wind.
- Native species predominate in intra-urban railway flora, however, the participation of alien species is higher than their participation in native floras. The share of invasive species differ between intra-urban railway floras.
- Spontaneous flora in intra-urban railway areas represents distinct adaptations to unique urban-industrial ecosystems with different degree of anthropogenic disturbance.

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Kompozycja i struktura flory terenów kolejowych obszarów zurbanizowanych

Streszczenie

Inwentaryzację florystyczną siedlisk terenów kolejowych występujących w obrębie aglomeracji Lublina (Polska) i Lwowa (Ukraina) wykonano w sezonie wegetacyjnym 2014–2015. Flory obu miast analizowano pod względem trwałości biologicznej, sposobu rozmnażania i rozsiewania nasion, rodzaju strategii życiowej sensu Grime, klasy hemerobii, przywiązania do siedlisk miejskich, preferencji siedliskowych i synekologicznych. Analiza CCA wykazała, że czynniki topograficzne, elementy pogody (temperatura powietrza, opady) i cechy gleby (wilgotność, trofizm, pH, zasolenie) różniły się pomiędzy terenami kolejowymi miast i miały wpływ na kompozycję gatunków. Rośliny występujące na terenach kolejowych przebiegających w obrębie miast są głównie hemikryptofitami, reprezentują strategię C, CR, CRS, są zapylane przez owady, samopylne lub anemofilne. Dyspersja nasion odbywa się głównie przy udziale wiatru. We florach terenów kolejowych obu miast przeważają gatunki rodzime. Udział gatunków obcych jest wyższy we florze Lwowa (około 12%, 45 gatunków) niż Lublina (8%, 36 gatunków). Flora terenów kolejowych przebiegających przez aglomeracje miejskie wykazuje specyficzne cechy adaptacji do warunków abiotycznych siedlisk antropogenicznie przekształconych o różnym stopniu zaburzeń.