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Polish Botanical Journal 59(1): 121–130, 2014
DOI: 10.2478/pbj-2014-0001

STRUCTURE OF THE FLORA OF RAILWAY AREAS UNDER VARIOUS KINDS OF ANTHROPOPRESSION

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Abstract. Floristic studies were carried out in NE Poland in 2007–2008 in three types of railway areas: operating tracks, tracks abandoned less than 10 years ago, and tracks abandoned more than 10 years ago. In the 41 sections of railway tracks surveyed, 338 species were recorded, including 22 species that occurred at >50% frequency, 27 species strongly associated with operating railway areas, and 4 species typical of railway areas in Poland. Comparative analysis of the flora of the 3 types of railway areas investigated showed significant differences in the richness and structure of their floras.

Key words: man-made habitats, railway flora, alien plants, therophytes, Poland

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Introduction

There have been many different approaches to research on species occurring in railway areas. As the flora of such extreme habitats is characterized by species with relatively low frequency of occurrence, some botanists have analyzed the group of plants that occur most frequently in railway areas (see e.g., Sendek 1973; Brandes 1983 and references therein; Jehlik 1986; Brandes 1993a, b; Wittig 2002a; Junghans 2005; Wrzesień & Święs 2006). A number of authors have published records of species new for a given area which had been transported accidentally by train (e.g., Hohla 1998; Hohla *et al.* 2002; Latowski & Pardoł 2004; Nobis & Nobis 2006).

Botanists have long been interested in plants occurring (almost) exclusively in railway areas. In German publications the terms '*Eisenbahnpflanzen*' and '*eisenbahntypische Arten*' refer to species typical of railway facilities (Kornaś *et al.* 1959; Zając & Zając 1969; Sendek 1973; Brandes 1983, 1993a; Hohla *et al.* 2000, 2002; Brandes 2005a, b; and references cited therein), whereas the terms '*Bahnhofspflanzen*' and '*typische Bahnhofspflanzen*' and their synonyms refer to plants typical of railway stations (Brandes 1983, 1993a, 2002, 2004a, b, 2005b; Hohla 1998; Hohla *et al.* 2002; Büscher *et al.* 2008).

Among the species typical of railway facilities, Brandes (2005b) distinguished '*Habitatsspezialisten*' (species closely associated with specific habitat conditions) and '*Eisenbahnwanderer*' (species spreading along railway lines). Botanists have employed the latter term and its synonyms very frequently (e.g., Mühlenbach 1979; Keil & Loos 2005; Brandes 1983, 2004b, 2005a, b; Kowarik 1987; Büscher *et al.* 2008). The analogous English terms used are 'railway-wandering plants' (Mühlenbach 1979) and 'railway migrating plant species' (Büscher *et al.* 2008).

All the above-mentioned groups of species were distinguished among plants occurring in railway areas as broadly defined, including tracks, platforms, stations, storehouse ramps, loading sidings, slopes of railway embankments, and

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railway wasteland. In the present work we examined a group of species associated with operating railway areas *sensu stricto* (the part between the rails, and the adjacent part of the rail bed shoulder). These areas are subjected to constant anthropopression.

The aims of our study were to assess the floristic diversity and character of the total flora of the operating and abandoned railway areas we examined, and to determine the groups of species best reflecting the specific character of the flora of operating and abandoned railway tracks. Our working hypothesis was that species associated with railway areas share some features in common, which are influenced by the environmental conditions prevailing in the railway areas and which determine the character of the flora.

Material and methods

Field studies and list of species

In 2007–2008 we made floristic studies of railway lines in northeastern Poland (Table 1). Unlike most studies of railway areas (e.g., Kornaś *et al.* 1959; Sendek 1973; Nobis & Nobis 2006; Brandes 1983, 2008), this study covered only railway areas *sensu stricto* (relatively homogenous habitats). We investigated the part between the rails (rail gauge) and the part of the rail bed shoulder between the ends of the railroad ties. This completely artificial habitat is under strong human pressure as long as the railway lines are still in use. Other areas associated with the railways, such as platforms, loading areas, pavements, roads and railway embankment slopes, were not investigated in this study.

A map of the railroad network in NE Poland and the location of the study sites is given by Galera *et al.* (2013). We surveyed the vascular flora along 41 railway sections:

– 11 sites along operating tracks (called 'operating' here),

– 14 sites on tracks abandoned less than 10 years ago ('abandoned <10'),

– 16 sites on tracks abandoned more than 10 years ago ('abandoned >10').

At each site we investigated 6 small sample areas covering 20 m^2 each, totalling *ca* 120 m^2. Each site included the area within the rail gauge and extending to the ends of the ties.

The following groups of species were identified within the flora of the investigated areas:

– species occurring at frequency greater than 50% (species found at 21 or more sites),

– plants typical of railway facilities (species occurring almost exclusively in railway areas),

– species associated with the three types of railway areas we examined (species strongly concentrated in 'operating', 'abandoned <10' or 'abandoned >10' railway areas).

In distinguishing groups of species associated with 'operating', 'abandoned <10' and 'abandoned >10' tracks we considered only species recorded from at least 5 of the 41 sites studied; extremely rare species that occurred temporarily and accidentally were omitted from the analysis. We determined the occurrence of species in the three types of railway areas based on their presence in 246 small sample areas (20 m^2 each). To verify whether the occurrence of a given species depended on a particular railway type we used the chi-square test of independence (Sokal & Rohlf 1995). Statistical analyses were performed using SAS/STAT7 software (2002–2003).

The tables present the following groups of species: species most frequently encountered at the investigated sites; 'plants typical of railways' recorded within the investigated area; and species associated with operating railway areas.

For each species the following information is given: life form (Raunkiaer 1934), synanthropic status following the geographical-historical classification scheme developed by Kornaś (1981), habitat preferences for environmental factors such as light, temperature and substrate moisture conditions (Lindacher 1995), and data on frequency of occurrence in 'operating', 'abandoned <10' and 'abandoned >10' tracks.

Floristic analyses

The floristic analyses yielded the following information on the total flora of the railway areas studied: frequency of species occurrence, spectrum of life forms (Raunkiaer 1934), and the groups of synanthropes (Kornaś 1981). Autochthonous species were divided into euapophytes and ephemeral apophytes – native species vulnerable to anthropopression which occur very rarely in anthropogenic habitats.

We compared the data on the flora and species groups associated with the three types of railway areas. The floristic richness and role of alien plants and therophytes in the flora were determined; those groups of plants are typical of areas under strong anthropopression (e.g., Gilbert 1989; Hill *et al.* 2002; Wittig 2002b).

Table 1. Characteristics of the study sites.

Locality	Coordinates	Type of railway track
Białystok Fabryczny Station (sample 1)	53°06′32,0″N; 23°12′20,9″E	operating
Białystok Fabryczny Station (sample 2)	53°08′12,0″N; 23°11′39,5″E	operating
Hajnówka (sample 1)	52°37′36,0″N; 23°39′17,0″E	operating
Iława (sample 1)	53°35′09,4″N; 19°34′39,7″E	operating
Iława (sample 2)	53°34′67,5″N; 19°34′34,0″E	operating
Iława (sample 3)	53°34′55,0″N; 19°34′26,1″E	operating
Lewki (sample 1)	52°40′55,9″N; 23°12′03,5″E	operating
Nowosady (sample 1)	52°46′53,2″N; 23°37′36,0″E	operating
Nowosady (sample 2)	52°36′35,4″N; 23°36′27,7″E	operating
Siemianówka	52°52′38,8″N; 23°56′09,2″E	operating
Sokoły (sample 1)	52°58′43,6″N; 22°44′13,9″E	operating
Czarny Kierz	54°04′53,3″N; 20°39′41,0″E	abandoned <10
Czerniki	54°05′05,6″N; 21°25′58,6″E	abandoned <10
Gierłoż	54°04′45,2″N; 21°29′39,7″E	abandoned <10
Iława (sample 4)	53°34′49,0″N; 19°34′20,1″E	abandoned <10
Kołaki	53°00′58,1″N; 22°21′21,8″E	abandoned <10
Pogorzel (sample 1)	54°13′32,2″N; 22°24′59,3″E	abandoned <10
Pogorzel (sample 2)	54°13′49,1″N; 22°25′00,9″E	abandoned <10
Puchałowo	53°21′56,5″N; 20°44′53,6″E	abandoned <10
Sokoły (sample 2)	52°58′23,2″N; 22°43′44,6″E	abandoned <10
Suchy Las	53°23′04,0″N; 20°55′46,5″E	abandoned <10
Tolniki	54°04′02,4″N; 20°42′49,2″E	abandoned <10
Waliły	53°05′09,4″N; 23°38′11,6″E	abandoned <10
Wielbark	53°22′34,0″N; 20°51′41,6″E	abandoned <10
Zubki Białostockie	53°03′33,6″N; 23°55′03,7″E	abandoned <10
Białowieża Pałac Station (sample 1)	52°41′32,3″N; 23°50′04,3″E	abandoned >10
Białowieża Pałac Station (sample 2)	52°41′32,3″N; 23°50′04,3″E	abandoned >10
Białowieża Towarowa Station	52°41′45,3″N; 23°50′39,8″E	abandoned >10
Białystok Fabryczny Station (sample 3)	53°06′53,2″N; 23°11′18,9″E	abandoned >10
Hajnówka (sample 2)	52°37′35,4″N; 23°39′12,9″E	abandoned >10
Lewki (sample 2)	52°42′04,0″N; 23°12′21,3″E	abandoned >10
Narewka (sample 1)	52°49′10,9″N; 23°45′01,9″E	abandoned >10
Narewka (sample 2)	52°13′21,6″N; 23°44′56,5″E	abandoned >10
Nerwiki	54°10′49,1″N; 20°30′45,9″E	abandoned >10
Nowa Wieś Wielka	54°10′49,1″N; 20°30′45,9″E	abandoned >10
Nowe Kiejkuty (sample 1)	53°39′27,4″N; 21°02′16,1″E	abandoned >10
Nowe Kiejkuty (sample 2)	53°38′53,9″N; 21°02′03,6″E	abandoned >10
Nowosady (sample 3)	52°46′53,2″N; 23°37′36,0″E	abandoned >10
Nowosady (sample 4)	52°46′53,2″N; 23°37′36,0″E	abandoned >10
Olecko	54°01′21,3″N; 22°30′33,9″E	abandoned >10
Straszewo	53°03′17,9″N; 23°55′05,3″E	abandoned >10

Results

flora of the investigated areas

We recorded 338 species at the 41 sites studied. As expected, most of these species occurred at low frequency; *ca* 50% of the species were considered rare (found at only 1–4 sites). The high percentage of these plants is a characteristic feature of the flora of railway areas. Species found at 21 or more sites (>50% of the sites studied) made up only 8% of the total flora (Fig. 1A).

Hemicryptophytes, a typical element of the temperate zone, dominated the spectrum of life forms (49% of the flora) in the investigated areas. A strikingly high number of woody plants was recorded. Altogether 50 species of phanerophytes were detected but most of these species were represented by seedlings or juveniles. Plants with short life cycles (therophytes) comprised 24% of the total flora (Fig. 1B). Native species dominated among the geographical-historical groups of species (euapophytes and ephemeral apophytes constituted 76% of the total flora). Among the alien plants, archaeophytes were slightly more numerous (11%) than kenophytes (10%) (Fig. 1C).

The following groups of species dominated among the 22 species occurring at >50% frequency (Table 2):

– native grassland species (only *Bromus tectorum* is an archaeophyte, and the native *Artemisia vulgaris* occurs naturally in forests),

– hemicryptophytes (15 species),

– light-preferring plants heliophilous plants (21 species with light indicator values L> 6),

– plants preferring dry habitats (18 species with moisture indicator values F< 6).

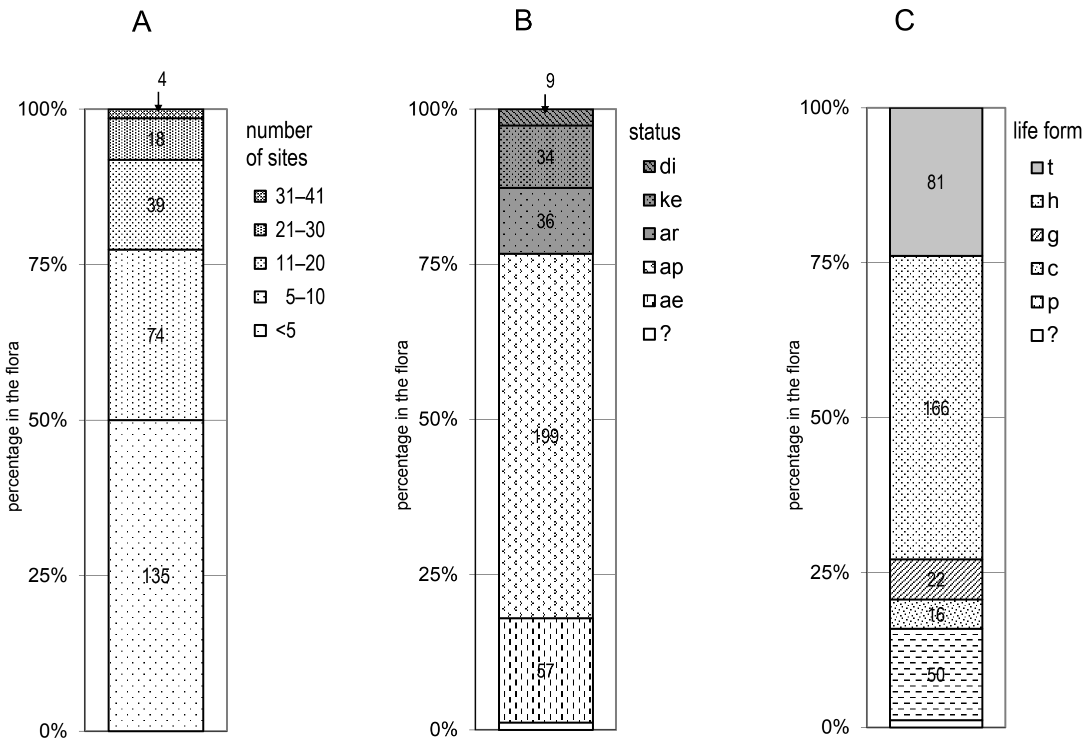

Fig. 1. Analysis of the total flora of the investigated railway areas with respect to: A – frequency of particular species, B – spectrum of groups of synanthropic species (di – diaphytes, ke – kenophytes, ar – archeophytes, ap – euapophytes, ae – ephemeral apophytes), C – spectrum of life forms (t – therophytes, h – hemicryptophytes, g – geophytes, c – chamaephytes, p – phanerophytes, ? – life form unknown). Number of species is given in diagrams.

Table 2. Characteristics of species most frequently encountered in the investigated areas. Life form and status (group of synanthropic species) – for abbreviations see Fig. 1. Ecological indicator values: L – light, T – temperature, F – substrate moisture (x – species with a wide amplitude, '–' – no data). Frequency on tracks: operating – active railway areas, <10 – railway areas abandoned less than 10 years ago, >10 – railway areas abandoned more than 10 years ago.

Species	Life form	Status	Ecological values			Frequency on tracks		
			L	T	F	operating	<10	>10
Achillea millefolium L.	h	ap	8	x	4	4	10	14
Arenaria serpyllifolia L.	t	ap	8	x	4	9	7	5
Arrhenatherum elatius (L.) P. Beauv. *ex* J. Presl & C. Presl	h	ap	8	5	5	3	13	14
Artemisia campestris L.	c	ap	9	6	2	10	8	11
Artemisia vulgaris L.	h	ap	7	6	6	8	10	12
Bromus tectorum L.	t	ar	8	6	3	10	7	4
Cardaminopsis arenosa (L.) Hayek	h	ap	9	x	4	8	12	7
Convolvulus arvensis L.	g	ap	7	6	4	3	9	11
Dactylis glomerata L.	h	ap	7	x	5	7	10	11
Daucus carota L.	h	ap	8	6	4	6	8	9
Festuca rubra L.	h	ap	x	x	6	6	10	11
Galium mollugo L.	h	ap	7	6	4	0	12	13
Hieracium pilosella L.	h	ap	7	x	4	5	8	11
Knautia arvensis (L.) J. M. Coult.	h	ap	7	6	4	0	11	11
Medicago falcata L.	h	ap	8	6	3	4	6	14
Medicago lupulina L.	t	ap	7	5	4	7	10	15
Poa angustifolia L.	h	ap	8	6	x	1	12	12
Poa compressa L.	h	ap	9	x	3	6	13	13
Rumex acetosa L.	h	ap	8	x	x	5	11	13
Sedum acre L.	c	ap	8	6	2	7	8	10
Taraxacum sp. sect. *Vulgaria* Dahlst.	h	ap	7	x	5	10	13	13
Vicia cracca L.	h	ap	7	5	5	4	9	9

The flora of the examined railway areas had a high proportion of native species and hemicryptophytes, which are not usually found in habitats transformed by man (Gilbert 1989; Hill *et al.* 2002; Wittig 2002b).

COMPARISON OF THE FLORA OF THE THREE TYPES OF RAILWAY TRACKS

Species richness differed between the three types of railway areas (Fig. 2A). As anticipated, operating railway areas had the fewest species (172 species found at 11 sites). We recorded 226 species (14 sites) in railway areas abandoned less than 10 years ago, and 256 species (16 sites) in track areas abandoned more than 10 years ago. The obvious inference is that species diversity increases following the closure of railway lines. The structure of the flora also changed through time (Fig. 2A), with a decline in the shares of allochthonous species (37% for 'operating', 17% for 'abandoned >10') and therophytes (40% and 15% respectively); at the same time the share of perennial plants increased (47% and 77%).

The data for species associated with only one type of railway area show that the share of therophytes and alien plants in the flora of abandoned railway areas was much lower than for operating tracks (Fig. 2B): 27 species were associated with operating railway lines, 47 with 'abandoned <10', and 48 species with 'abandoned >10'. The 27 species closely associated with operating railway areas (Table 3) show the following patterns:

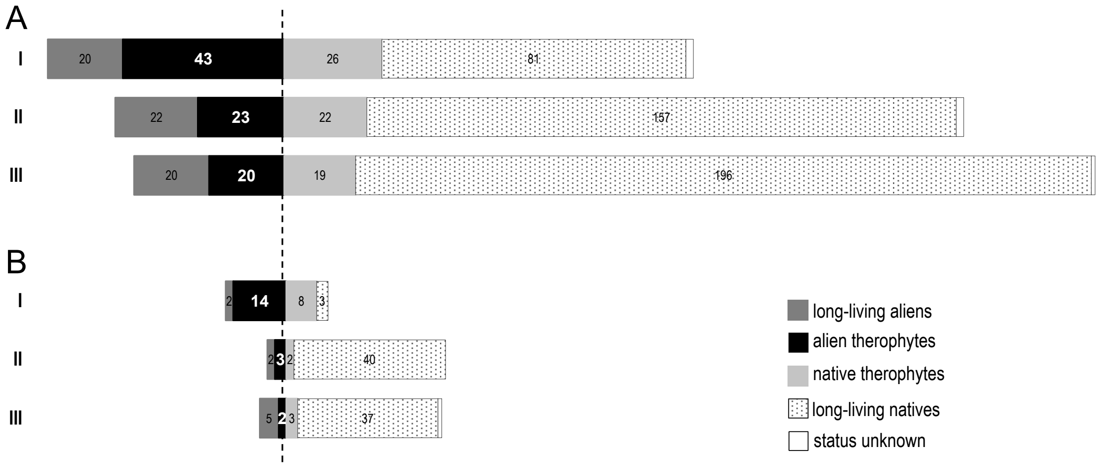

Fig. 2. Comparison of the flora of operating railway areas (I), railway areas abandoned less than 10 years ago (II) and railway areas abandoned more than 10 years ago (III) with regard to: A – species richness, B – number of species strongly associated with one type of railway track. Vertical broken line separates alien species from native species.

– dominance of annual plants (22 species of therophytes),

– dominance of light-preferring plants (21 species with light indicator values L>6),

– dominance of plants preferring dry habitats (18 species with moisture indicator values F<6),

– dominance of allochthonous plants (16 species of anthropophytes, most originating from regions with warmer climate).

Plants typical of railway areas recorded in the investigated area

In the present study we recorded only four species of the group closely associated with railway lines in Poland but rarely found outside railway areas (see Table 4). This finding may be the result of our delimitation of the types of areas investigated (railway areas *sensu stricto*, including 11 sites on operating tracks). All of those species were alien therophytes, and three were heliophilous (light indicator value L = 8) plants occurring in warm (temperature indicator values T>6) and dry habitats (moisture indicator values F<5, see Table 4). There are no data available for *Dracocephalum thymiflorum* regarding its ecological indicator values. Published reports of its preferred natural habitats suggest that *D. thymiflorum* has habitat requirements similar to those of the other three species 'typical of railway areas' recorded in the investigated area (Shishkin 1954; Gams 1964). Since the only four recorded species typical of railway areas were found at low frequency, these plants cannot be considered characteristic of the flora of the areas we studied.

The alien therophytes were most strongly associated with operating railway areas (Fig. 2), as indicated by the structure of the total flora of operating railway sites (Fig. 2A) and by our analysis of the combination of the most frequent species (Table 2), species associated with operating railway areas (Fig. 2B and Table 3) and plants typical of railway areas (Table 4).

Discussion

Diversity and richness of the flora of railway areas

A number of botanists investigating the flora of railway areas have noted that the flora of these areas is particularly rich in species (for historical data see Mühlenbach 1979; for contemporary data see, e.g., Brandes 2004a, 2005a). In this study we identified 338 vascular plant species from railway sites totalling 4920 m^2 in area. Railway

Table 3. Characteristics of species associated with operating railway areas investigated in the study. See Table 2 and Figure 1 for abbreviations.

Species	Life form	Status	Ecological values			Frequency on tracks:		
			L	T	F	operating	<10	>10
Acer negundo L.	p	ke	5	6	6	6	3	4
Anchusa officinalis L.	t	ar	9	7	3	2	4	2
Arenaria serpyllifolia L.	t	ap	8	x	4	9	7	5
Bromus japonicus Thunb.	t	di	8	7	4	3	2	1
Bromus tectorum L.	t	ar	8	6	3	10	7	4
Capsella bursa-pastoris (L.) Med.	t	ar	7	x	5	8	1	1
Centaurea stoebe L.	h	ap	8	7	2	6	3	5
Cerastium semidecandrum L.	t	ap	8	6	3	9	5	4
Chaenorhinum minus (L.) Lange	t	ke	8	6	4	4	1	0
Chenopodium album L.	t	ap	x	x	4	5	0	4
Conyza canadensis (L.) Cronquist	t	ke	8	6	4	10	4	5
Erigeron annuus (L.) Pers.	t	ke	7	6	6	3	1	2
Galium aparine L.	t	ap	7	6	x	6	3	3
Geranium robertianum L.	t	ap	5	x	x	7	7	3
Lactuca serriola L.	t	ar	9	7	4	9	6	2
Leontodon autumnalis L.	h	ap	7	x	5	2	5	1
Matricaria maritima subsp. *inodora* (L.) Dostal	t	ar	7	6	x	6	3	0
Melandrium album (Mill.) Garcke	h	ar	8	6	4	5	3	6
Myosotis stricta Link. *ex* Roem. & Schult.	t	ap	8	6	3	7	2	0
Poa annua L.	t	ap	7	x	6	4	1	1
Polygonum aviculare L.	t	ap	7	x	x	6	1	0
Senecio vernalis Waldst. & Kit.	t	ke	7	6	4	6	2	1
Senecio vulgaris L.	t	ar	7	x	5	7	0	0
Tragopogon dubius subsp. *major* (Jacq.) Vollm.	h	ap	–	–	–	8	5	3
Veronica arvensis L.	t	ar	7	6	4	4	1	4
Vicia tetrasperma (L.) Schreb.	t	ar	6	6	5	6	3	7
Viola arvensis Murray	t	ar	6	5	x	10	4	3

tracks withdrawn from use over 10 years ago (1920 m^2 area) yielded 226 species. Skomorowska (2000) identified 325 vascular plant species found growing along the abandoned Orlanka-Hajnówka-Białowieża railway line (1425 m^2 area). That site partially overlapped with the railway area we surveyed. The flora of the railway areas examined in this study comprised a relatively small number of species. Other Polish authors have given quite different results from railway areas *sensu lato* (Latowski & Pardoł 2004; Puchałka 2004; Wrzesień & Święs 2006; Wrzesień & Denisow 2006). The disparity probably reflects differences in the size of the studied areas and the great variability of habitats in the areas they investigated.

CHARACTERISTICS OF SPECIES MOST FREQUENTLY ENCOUNTERED IN ANTHROPOGENIC HABITATS

The lists of species noted along railway tracks in different regions of Europe cannot be compared directly, as the differences in species composition may be due to location-related differences and variation of habitat diversity across the region. Nevertheless, here we have attempted to distinguish groups of species occurring along railway tracks.

The species most frequently encountered in the 41 investigated areas (22 species having >50% frequency) were plants preferring light and dry habitats, among which native hemicryptophytes dominated. The latter group of species is

Table 4. Characteristics of plants typical for railway facilities investigated in the study. See Table 2 for abbreviations.

Species	Life form	Status	Ecological values			Frequency on tracks:		
			L	T	F	operating	<10	>10
Amaranthus albus L.	t	ke	8	8	2	2	0	0
Bromus japonicus Thunb.	t	di	8	7	4	3	2	1
Dracocephalum thymiflorum L.	t	di	–	–	–	1	0	0
Galeopsis angustifolia (Ehrh.) Hoffm.	t	ke	8	7	2	2	5	4

a characteristic element of the flora of temperate climate. Most of these species usually occurred on abandoned railway tracks and therefore were not subjected to strong anthropopression as prevails along operating tracks.

The characteristics of the most frequent species do not always reflect the quality of habitat conditions in an area, especially when the investigated area is a mosaic of varied ecological conditions. Among the most frequently noted plants in cities are species that have a wide range of ecological preferences. Such species are able to persist under conditions extremely unfavorable for plant growth and under high interspecific competition, particularly in less extreme habitats. Native plants were the most frequently occurring species in the 41 investigated areas (see Table 2) and are the most frequently occurring ones in cities as well (Sudnik-Wójcikowska 1998; Hill *et al.* 2002; Wittig 2002b).

Alien therophytes – a characteristic element of the flora of operating railway areas

The character of the flora of operating railway areas is indicated by species occurring exclusively within railway areas (plants typical of railway facilities) and by species strongly concentrated in these areas (plants closely associated with operating railway lines). We recorded only four species typical of railway areas. All these species were heliophilous, thermophilous and xerophilous therophytes (Table 4). The group of 27 species associated with operating railway lines was also dominated by plants preferring light and dry habitats and anthropophytes with a short life cycle. The temperature requirements of these plants have not been well established, however (Table 3).

In habitats where the plant cover regenerates after strong anthropogenic disturbance, species characteristic of initial stages of plant succession are frequently encountered (for railway areas see, e.g., Kowarik & Tietz 1986; Kowarik 1987; Brandes 1993a; for colliery spoil heaps see Rostański 2006). This also applies to pioneer tree species, represented mostly by juvenile specimens not capable of further development (e.g., Kobendza 1949; Brandes 1993a; Galera & Sudnik-Wójcikowska 2000a, b; Sudnik-Wójcikowska & Galera 2005; Rostański 2006). Pioneer species tolerate various adverse abiotic factors but do not tolerate direct competition with other plants. These species are therefore largely limited to harsh, stressful environments where the conditions do not favor plant growth but there is no competition with other plant species.

Our study confirms that plants with the above characteristics play a significant role in the structure of the flora of operating railway areas (cf. Galera *et al.* 2013). Alien therophytes originating from regions with warmer and drier climate proved to be a characteristic element of that flora. Most of these species are xerophilous plants that have higher light requirements. Note, however, that the above-mentioned characteristics are also typical of plants associated with open habitats under strong anthropopression. All the species we identified as associated with operating railway lines have also been found to occur commonly in other anthropogenic habitats (e.g., Gilbert 1989; Hill *et al.* 2002; Wittig 2002b).

Conclusions

The group of species occurring at high frequency in the studied railway areas (operating and abandoned tracks) contained mainly native hemicryptophytes. The plants typical of railway facilities and species strongly concentrated in operating railway areas were mainly therophytes. The above groups of species were dominated by light-preferring plants adapted to dry habitats. Plant characteristics such as short life cycle and the ability to persist under dry conditions and high insolation enable these plants to grow and thrive along operating rail tracks.

ACKNOWLEDGEMENTS. We are grateful to Professor Dietmar Brandes (Braunschweig, Germany) for helpful remarks on the manuscript. This work was funded by the Polish Ministry of Science and Higher Education (grant no. N305 076 32/2694).

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Received 19 February 2013