Chorological and phytogeographical diversity of trees and shrubs as a mean to regionalization: Kaczawa Mountains, Sudetes, Poland

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Abstract

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The tree and shrub flora of the Kaczawa Mountains (Sudetes, Poland) consists of 240 taxa, of which over 70 % are native. The biodiversity and chorological differentiation are reflected in a number of biogeographical phenomena, such as differences in floristic richness of native and alien species, concentration of borderline species, and co-occurrence of various taxa. Concentration maps of particular groups of taxa in the investigated area together with the statistical analysis point to distinct relationships between the distribution of these groups and earlier recognized phytogeographical units of the rank of three subdistricts (Kaczawa Mountains, Western Kaczawa Plateau, Eastern Kaczawa Plateau), which include eight geobotanical sections. The distinguished phytochorions cover territories of various areas demarcated by natural borders and characterized by specific components of woody flora, concentration of taxa exhibiting particular types of local geographical range, as well as by altitude, relief, geological structure, and local climatic and hydrological parameters.

Additional key words: woody flora, geobotanical regionalization, biodiversity, hercynian mountains

Introduction

Maps of geobotanical regionalization represent a synthesis of present knowledge on spatial variation of flora (Matuszkiewicz 1993; Dahl 1998; Arita & Rodriguez 2004). The regionalization results from relations between the development of vegetation and abiotic components of environment. The leading criterion to determine borders of phytogeographical units are maps of species distribution (McLaughlin 1986; Zemanek 1991; Wohlgemuth 1996; Lahti & al. 1998; Lawesson & Skov 2002; Valdés & al. 2006; Finnie & al. 2007; Preston & al. 2013), while construction of regional divisions is based mainly on floristic criteria. Among the most often-used criteria there are local types of geographical range of endemic, borderline and mountain taxa and taxa of various ecological groups (e.g. Poldini & al. 1991; Korsch 1999; Pausas & Sáez 2000; Bruun & al. 2003; Kaplan 2012). Less often chorological differentiation of woody flora is taken into consideration (Ojeda & al. 1998; Gómez-González & al. 2004; Kosiński 2005; Abbate & al. 2012).

The Kaczawa Mountains and Kaczawa Plateau are a unique region of Poland in natural and landscape terms, with richness and diversity of flora not encountered in other parts of the Sudetes. Among numerous mountain, thermophilous and rock taxa that occur here, many attain the limit of their geographical range. This is also true for the tree and shrub flora. Therefore, the main objective of the present study was the revision of postulates concerning geobotanical regionalization of the Kaczawa Mountains and Kaczawa Plateau and its comparison with regionalization based on woody flora. In particular (1) a taxonomic diversity of dendroflora was studied; (2) its spatial structure was determined; and (3) rules of taxa distribution were searched for by identification of groups of species representing similar types of geographical range and distribution of localities on the background of mosaics of different habitats.

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Material and methods

1. Study area

The investigated area, located in south-western part of Poland, belongs to the Western Sudetes Mountains and Western Sudetes Plateau (Fig. 1). It is divided on the basis of physiographical (Staffa & al. 2000a, b) and geobotanical data (Kuczyńska 1997; Kwiatkowski 2007) into the Kaczawa Mountains and the Kaczawa Plateau. The territory, covering about 1300 km^2, extends between 51°15'52"N and 50°50'16"N and between 15°29'47"E and 16°13'00"E. The relative vertical height attains 588 m, from an altitude of 136 m near the confluence of the Nysa Szalona and Kaczawa rivers on the Kaczawa Plateau, to 724 m on the hill known as Skopiec in the Kaczawa Mountains.

The Kaczawa Mountains (Bober-Katzbach-Gebirge) represent a system of parallel mountain ridges separated by tectonic faults. They are characterized by asymmetry of hill slopes, a system of rivers, creeks and streams, rocky relief, and a mosaic geological structure (crystalline limestones, dolomites, diabases, keratophyres, serpentinites, etc. – Baranowski & al. 1990; Sawicki 1997). These traits influence the vegetation and flora, especially the richness of mountain, calciphilous and thermophilous taxa (Limpricht 1944; Kwiatkowski 2006), and well-developed forest formations: marshy forests (*Alnetum incanae*, *Carici remotae-Fraxinetum*, *Stellario nemorum-Alnetum glutinosae*), beech forests (*Cephalanthero longifoliae-Fagetum*, *Dentario enneaphylli-Fagetum*, *Luzulo luzuloidis-Fagetum*) and sycamore forests (*Arunco-Aceretum pseudoplatani*, *Lunario-Aceretum*), as well as thermophilous scrub (*Pruno-Ligustretum*) (Kwiatkowski 2009).

The Western Kaczawa Plateau (501 m) is a rather flat hillocky region with a few isolated hills. Sandstones, gravels and conglomerates dominate in its geological structure. Its location within the Sudetes, and environmental conditions cause the presence of a large number of subatlantic and boreal taxa, as well as oligotrophic and acidophilic plant communities (Kwiatkowski 2009), especially coniferous forests (*Dicrano-Pinetum sylvestris*, *Molinio caeruleae-Pinetum*), acidophilic oak forests (*Luzulo-Quercetum petraeae*) and acidophilic heaths (*Genisto germanicae-Callunetum*) with characteristic contribution of small shrubs.

The Eastern Kaczawa Plateau (468 m) comprises mainly volcanic hills built of basaltic formation rocks, such as basanites, nephelenites, trachytes, andesites, rhyoliths and greenstones (Grocholski & Jerzmański 1975; Kozłowska-Koch 1987). A diversified geological structure, rich hydrological network, and high variation of relief (canyons), are factors that create a unique mosaic of habitats. This leads to variation of natural deciduous forests that are represented by the associations *Aceri platanoidis-Tilietum platyphylli*, *Astrantio-Fraxinetum*, *Dentario enneaphylli-Fagetum*, *Fraxino-Alnetum*, *Galio sylvatici-Carpinetum*, *Luzulo luzuloidis-Fagetum*, *Luzulo-Quercetum petraeae*, *Querco-Ulmetum minoris*, *Scolopendrio-Fraxinetum* and *Sorbo torminalis-Quercetum* (Kwiatkowski 2009). The region is distinguished also by scrub (*Pruno-Ligustretum*, *Pruno-Rubetum raduleae*), with a high contribution of taxa from the genera *Crataegus*, *Rosa* and *Rubus*.

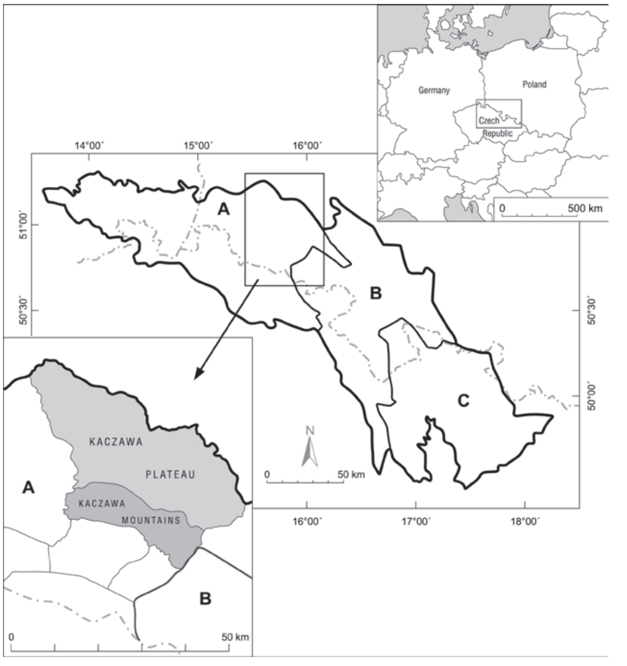

Fig. 1. Location of the investigated area in Central Europe (upper right), in the Sudetes (centre) and the investigated area (bottom left). In the central map, the western (A), central (B), and eastern (C) Sudetes Mountains are distinguished.

2. Data analysis

The objects of the present investigation were all native and permanently established taxa of trees and shrubs reported from the Kaczawa Mountains and Kaczawa Plateau. Floristic data were gathered directly during field investigations with the aid of the cartogram method ATPOL (Zając 1978). The investigated area was divided into 346 basic squares each with a side of 2 kilometres. Two classifications of species frequency in the investigated area were used: one based on the percentage of localities in which the taxon occurs with respect to all the squares of the investigated area; the other using equal intervals of locality numbers.

The chorological analysis of native and alien dendroflora was performed on the basis of literature data (Kwiatkowski 2006), supplemented with results of field investigation from the years 2010–2013, together with analysis of groups of mountain, thermophilous, basaltic bedrock, river valley and stream taxa (Drude 1902; Zemanek 1988; Zając 1996; Mucina 1997; Matuszkiewicz 2002), as well as taxa from the genus *Rubus*, which have distributions restricted to certain parts of the investigated area. The data are presented as synthetic concentration maps of taxa prepared with the aid of the software DMAP for Windows v. 7.2a (Morton 2003). Diameters of circles shown in concentration maps increase with the number of taxa occurring within the cartogram unit. Equal ranges of numbers of taxa per unit were used to define classes of taxa concentration. On the basis of the concentration maps, phytogeographical units were identified, which are characterized by generally uniform tree and shrub flora. The units were the subject of cluster analysis using the Jaccard similarity coefficient, performed with the aid of Matlab (The Mathworks, Natick, MA, U.S.A.).

The geographical-historical status of each taxon was determined taking into account the general distribution of individual taxa and the hierarchical system of phytogeographical elements (Zając & Zając 2009). Names of species, subspecies and varieties are according to Mirek & al. (2002), while hybrid taxa are according to Kubát & al. (2002) and Rothmaler & al. (2005). Syntaxon nomenclature is after Matuszkiewicz (2002) and Kwiatkowski (2009).

Results

1. Chorological diversity

Nearly 13 000 records for cartogram units were gathered for the investigated area, recording the occurrence of 240 tree or shrub taxa, including 190 species, 26 subspecies and varieties, and 24 hybrid taxa (see Appendix). Individual taxa differ both in the total number of localities and the type of local geographical range.

The contribution of taxa representing different categories of occurrence frequency (Fig. 2, upper graph), as in Kwiatkowski (2006), shows that the first three categories, which comprise generally rare taxa, are dominating. Their domination in the tree and shrub flora becomes still more apparent when equal ranges of locality numbers are used to define frequency categories (Fig. 2, lower graph). As much as 71.25 % of species have the smallest number of localities, i.e. not more than 50. They occur in habitats of both natural and modified character. Analysis of the origin (geographical-historical spectrum) of the whole tree and shrub flora shows that native species (172 taxa) are dominating over alien (68).

The regions of the highest richness of native species are the central parts of the Kaczawa Mountains, the N and S parts of the Eastern Kaczawa Plateau, the isolated hill Grodziec (389 m a.s.l.) of the Western Kaczawa Plateau, and part of the river Kaczawa valley, where from 57 to 74 taxa per cartogram unit were noted. The distribution of alien tree and shrub taxa is not uniform. In the majority of the investigated area the contribution of these taxa is low, while in N parts of the Western Kaczawa Plateau and the Eastern Kaczawa Plateau (in towns: Bolesławiec, Bolków, Świerzawa, Wojcieszów, Złotoryja) their concentration is the highest, from 11 to 15 taxa per cartogram unit.

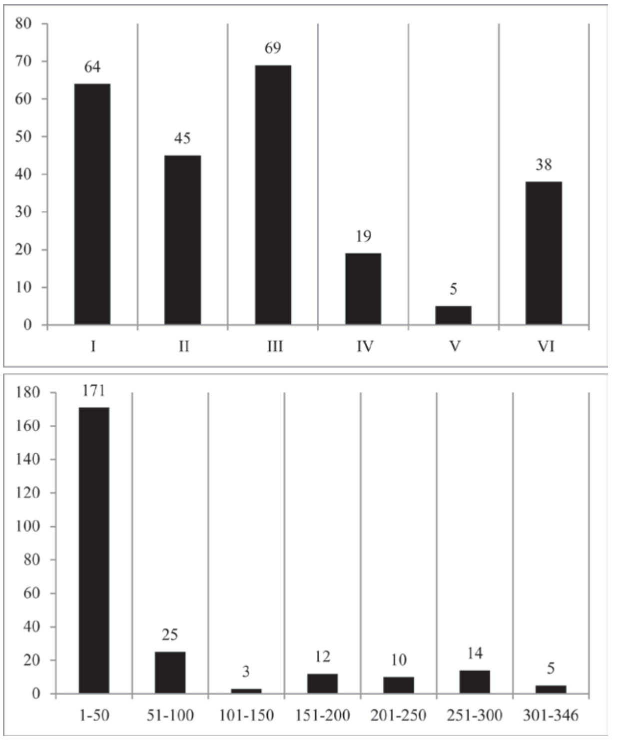

Fig. 2. Numbers of taxa representing different occurrence frequencies. – Upper graph: numbers of taxa belonging to frequency categories 1: very rare (1–3 localities, < 1 % of cartogram units); II: rare (4–10 localities, 1.1–2.9 %); III: relatively frequent (11–51 localities, 3–14.9 %); IV: frequent (52–103 localities, 15–29.9 %); V: very frequent (104–173 localities, 30–49.9 %); VI: common (174–346 localities, > 50 %). – Lower graph: numbers of taxa belonging to frequency categories with equal intervals of locality numbers.

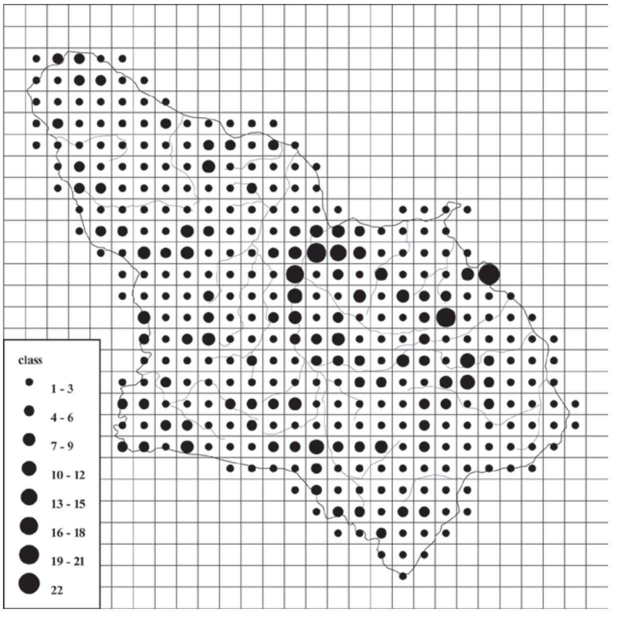

Fig. 3. Concentration map of species from the genus *Rubus*. Concentration classes are represented by circles of different sizes; the concentration range for each circle size is specified in the lower left corner of the plot.

From the chorological perspective, the investigated area is distinguished by a high diversity of taxa in the genus *Rubus*. Among 48 taxa reported from this region, some are rare components of the vascular flora of Poland, e.g. *R. acanthodes*, *R. chaerophyllus*, *R. lignicensis*, *R. lusaticus*, *R. mollis*, *R. nemorosus*, *R. praecox* and *R. scaber*. Species richness of *Rubus* in the investigated area is not uniform. From 16 to 22 taxa were noted in some cartogram units (Fig. 3), especially those of the Eastern Kaczawa Plateau (including, e.g., the rocky hills Bazaltowa Góra, 367 m, Kozia Góra, 373 m, Wilcza Góra, 363 m, and Żarek, 205 m).

2. Ecological differentiation

Individual tree and shrub taxa of the Kaczawa Mountains and the Kaczawa Plateau are attached to different habitats and represent various ecological groups. They also have distinctly different and characteristic geographical ranges, as shown in concentration maps of mountain taxa, thermophilous taxa, taxa of basaltic bedrock, and those of the larger river valleys (Fig. 4–7).

Variation in the absolute altitude of the investigated area results in limited vertical ranges of mountain tree and shrub taxa. Their concentration within the area is not uniform (Fig. 4). The number of taxa per cartogram unit generally decreases from south to north, i.e. along the decreasing absolute altitude. Thus, the highest concentration of these species (5–7 species per unit) is in the Kaczawa Mountains. On the other hand, where local conditions are preferable also at lower altitudes (e.g. on the hill Grodziec), colonies of mountain taxa have persisted, comprising shrubs especially. Most of mountain taxa of the tree and shrub flora are components of natural deciduous forests (*Querco-Fagetea*: *Alno-Ulmion*, *Fagion sylvaticae*, *Tilio platyphylli-Acerion pseudoplatani*). It also has to be noted that in the investigated area some of these taxa attain extreme values of their vertical range in the Sudetes. This is true for, e.g., *Lonicera nigra* (< 450 m), *Ribes alpinum* (< 300 m) and *Rosa pendulina* (< 400 m – cf. Boratyński 1991; Kwiatkowski 2007).

Localities with thermophilous species occur mostly on the limestone hills of the central part of the Kaczawa Mountains, especially near Podgórki and Wojcieszów, as well as on basaltic hills in the N part of the investigated

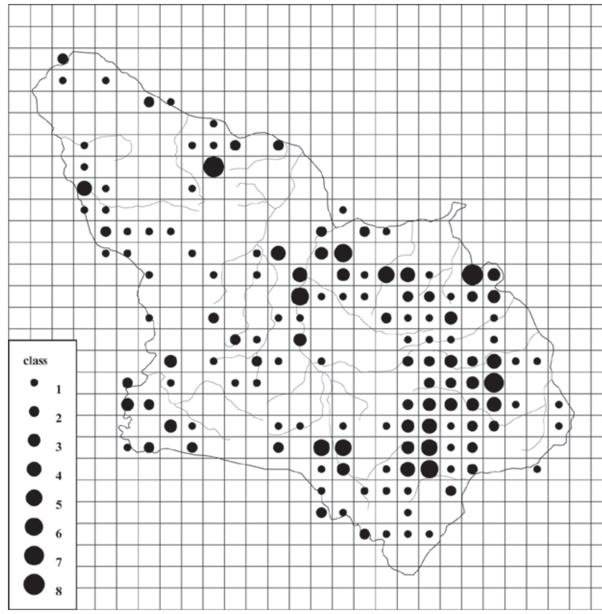

Fig. 5. Concentration map of thermophilous species of trees and shrubs. Labelling as in Fig. 3.

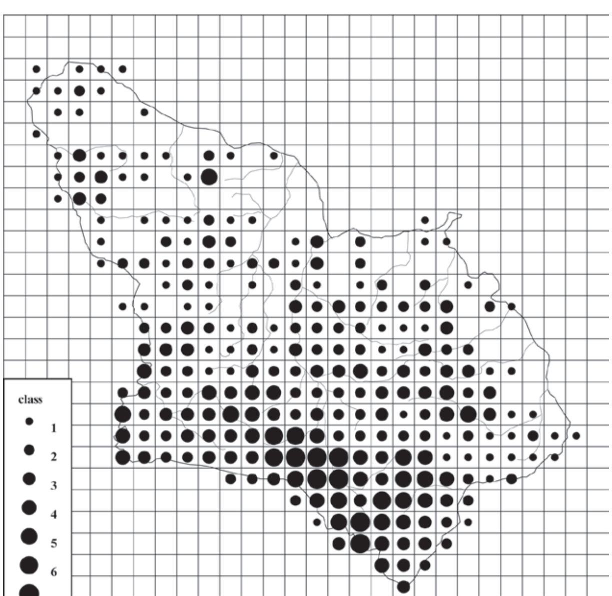

Fig. 4. Concentration map of mountain taxa of trees and shrubs. Labelling as in Fig. 3.

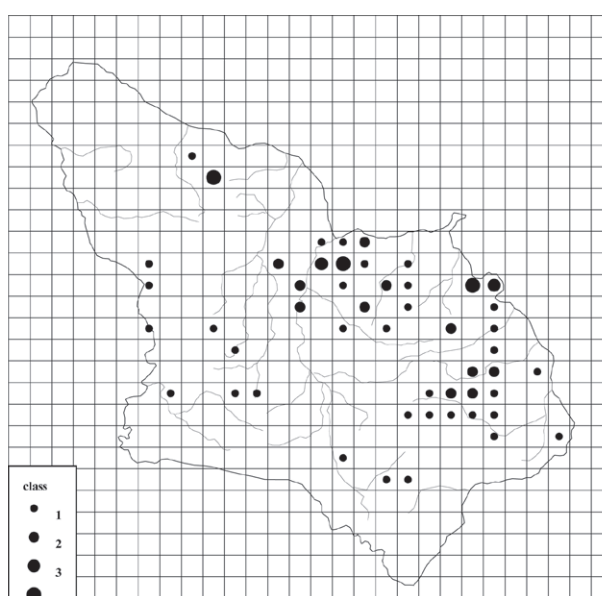

Fig. 6. Concentration map of species of trees and shrubs of basaltic bedrock. Labelling as in Fig. 3.

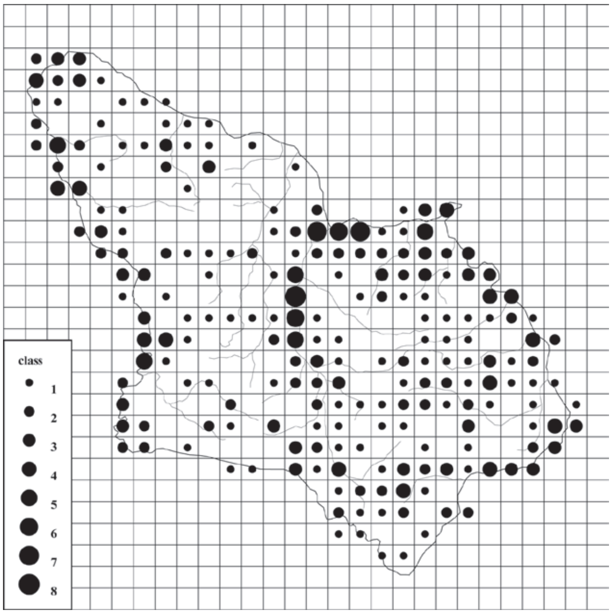

Fig. 7. Concentration map of tree and shrub species of rivers and streams. Labelling as in Fig. 3.

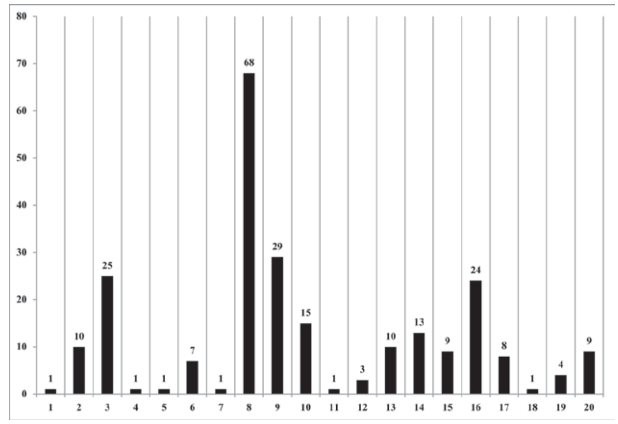

Fig. 8. Numbers of taxa belonging to different geographical elements. – Native species: 1: Arctic-Alpine; 2: Circumboreal; 3: Eurosiberian; 4: Eurosiberian-Mediterranean; 5: Eurosiberian-Irano-Turanian; 6: Eurosiberian-Mediterranean-Irano-Turanian; 7: Eurosiberian-Mediterranean-Irano-Turanian-Asiatic; 8: European-temperate; 9: European-temperate-Mediterranean; 10: European-temperate-Mediterranean-Irano-Turanian; 11: European-temperate-Mediterranean-Irano-Turanian-Asiatic; 12: European-temperate-Pontic-Pannonian; 13: of unknown origin. – Alien species: 14: European; 15: Asiatic; 16: American; 17: European-Asiatic; 18: European-Asiatic-American; 19: European-Asiatic-African; 20: anthropogenic origin.

area (Fig. 5). These species exhibit specific temperature and humidity preferences (*Rhamno-Prunetea*: *Berberidion vulgaris*, *Querco-Fagetea*: *Quercetalia pubescenti-petraeae*).

Distinctive elements of the natural environment of the investigated area are hills built of basaltic rocks and their metamorphic formations (Grocholski & Jerzmański 1975; Kozłowska-Koch 1987). Habitats that developed in such places are characterized by higher temperatures. Taxa preferring this type of bedrock occur mainly in the N part of the Eastern Kaczawa Plateau (Fig. 6). These are not only some of the thermophilous taxa but also species from the genus *Rubus*.

Certain tree and shrub taxa were noted almost exclusively in river valleys. Their localities in the investigated area are concentrated mostly along the rivers Bóbr, Kaczawa and Nysa Szalona. Therefore, along some parts of these rivers from 5 to 8 of these taxa were noted per cartogram unit (Fig. 7). Richest in these taxa are the middle and lower portions of the river Kaczawa valley, separating the Western Kaczawa Plateau from the Eastern Kaczawa Plateau, where numerous patches of natural marshy forests (*Querco-Fagetea*: *Alno-Ulmion*; *Salicetea purpureae*) are preserved.

Table 1. Tree and shrub species attaining one of their geographical range limits in the investigated area. (E) = endemic to Poland.

Species name	Sudetes	Poland	Europe
Chamaecytisus ratisbonensis	W	W	.
Cotoneaster integerrimus	NW	NW	N
Erica tetralix	SE	.	.
Lonicera nigra	N	N	.
Ononis arvensis	NW	.	.
Rosa pendulina	N	N	N
Rubus acanthodes	NE	.	.
Rubus angustipaniculatus	NW	NW	.
Rubus capitulatus	NW	(E)	.
Rubus chaerophyllus	N	.	.
Rubus crispomarginatus	NW	NW	.
Rubus lignicensis	NE	NE	NE
Rubus lusaticus	NE	.	.
Rubus mollis	N	N	N
Rubus scaber	.	.	NE
Rubus seebergensis	NW	(E)	.
Rubus silesiacus	N	NW	.
Salix silesiaca	N	N	.
Staphylea pinnata	NW	NW	NW

3. Phytogeographical analysis

Species representing the European-temperate subelement (68 taxa, Fig. 8), with geographical ranges centred on Central Europe, are the largest group among the native species. Among other elements, taxa with wider geographical ranges, e.g. Eurosiberian and European-temperate-Mediterranean, are more common. These three groups together comprise over 70 % of the native tree and shrub flora. Among alien taxa, in turn, American species dominate.

Important from the phytogeographical perspective is the contribution of native species that are borderline with respect to the whole of the Sudetes, attaining one of their geographical range limits within the Kaczawa Mountains and the Kaczawa Plateau. Most of these species attain their N and NW limits in Poland and some their N, NE or NW limits in Europe (Table 1). The occurrence of these species is distinctly connected to the highest parts of the Kaczawa Mountains and the Eastern Kaczawa Plateau.

Discussion

In comparison with other parts of the Sudetes (Boratyński 1991; Kosiński & Bednorz 2003; Świerkosz & Boratyński 2002), the tree and shrub flora of the Kaczawa Mountains and the Kaczawa Plateau appears to be one of the richest (240 taxa). The major part of this flora comprises taxa that are common and widely distributed in the Sudetes, especially in the lower and middle mountain ranges. The investigated area is distinguished by richness in taxa preferring dry, highly insolated and partly rocky habitats. This group is represented among others by taxa rare in the Sudetes, such as *Chamaecytisus ratisbonensis*, *C. supinus*, *Cotoneaster integerrimus*, *Crataegus rhipidophylla* var. *lindmanii*, *Ononis repens*, *O. spinosa* and *Rosa gallica* (Białobok & al. 1963–1981; Kaźmierczakowa & Zarzycki 2001; Zając & Zając 2001). Dry, highly insolated and partly rocky habitats are preferred also by *Sorbus torminalis* and *Staphylea pinnata*, for which the investigated area is the centre of distribution in the Sudetes (cf. Boratyński & Kwiatkowski 1998; Kwiatkowski 2003; Bednorz 2004). The region of the Kaczawa Plateau is also a regional diversity centre for the genus *Rubus* (cf. Zieliński 2004; Zieliński & al. 2004; Oklejewicz 2006). A good example is provided by the basaltic hill Wilcza Góra (363 m), where as many as 21 *Rubus* taxa (!) were found. An analogous phenomenon of *Rubus* attached to basaltic bedrock has been observed in the Lusatia Mountains (Weber 1987). On the other hand, because of the relatively low absolute altitude of the Kaczawa Mountains, high-mountain taxa (*Betula pubescens* subsp. *carpatica*, *Empetrum hermaphroditum*, *Pinus mugo*, *Ribes petraeum* – Boratyński 1991, 1994) were not reported from the region. Other taxa not present there are boreal or boreal-mountain shrub species that are components of mires and peat-bog ecosystems (*Andromeda polifolia*, *Betula nana*, *Oxycoccus palustris*, *Salix lapponum* – Boratyński 1991).

The richness of native flora in some cartogram units of the investigated area may be explained by the diversity of habitats (mosaic of geological structure, relief, hydrological system), developed plant communities, and human activity. The paucity of other cartogram units may be caused by special vegetation characteristics (complexes of weed communities, monocultures of forests) or a small surface area (only several %) lying within the investigated area, while the larger portion belongs to other geographical regions of the Sudetes, as is the case in some border cartogram units. The highest contribution of alien species is in turn typical for urbanized and industrialized sites, and vast forest complexes of the monoculture type. The presence of these species on the isolated hill Grodziec can be explained by historical introductions of some species that have persisted until the present day (e.g. *Euonymus latifolia*, *Laburnum anagyroides*, *Physocarpus opulifolius*, *Populus ×canadensis*, *Salix ×pendulina*, *Symphoricarpus albus* and *Syringa josikaea*; some of them being typical urbanophilous species), development of anthropogenic habitats, and deep changes in floristic structure within forest ecosystems. In forest ecosystems, a number of alien tree species (e.g. *Larix decidua* subsp. *decidua*, *Padus serotina*, *Pseudotsuga menziesii*, *Quercus rubra*, *Robinia pseudoacacia*) occur at secondary localities. It is worth noting that in the investigated area there is also a number of alien tree and shrub taxa (e.g. *Cotoneaster horizontalis*, *C. lucidus*, *Rubus armeniacus*, *R. laciniatus*, *Spiraea tomentosa*), the localities of which enlarge their secondary geographical ranges in Central Europe (cf. Zieliński 1991; Weber 1993, 1995; Zieliński 2004; Kott 2009; Dickoré & Kasperek 2010).

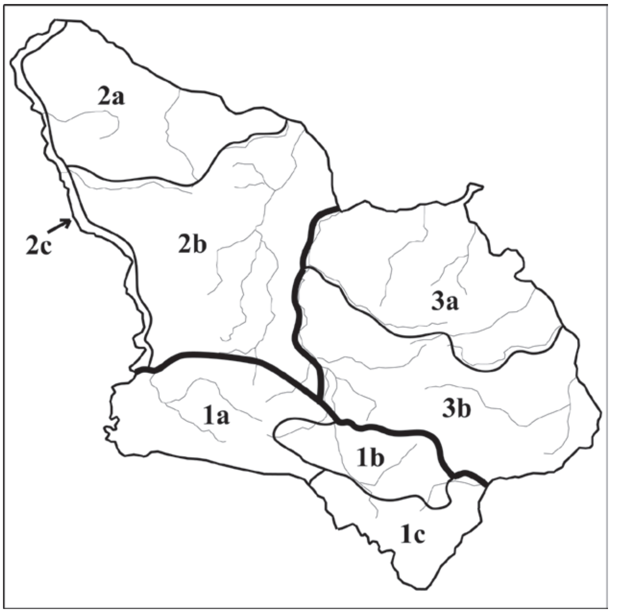

Fig. 9. Phytogeographical units of the investigated area. – 1: subdistrict Kaczawa Mountains; 1a: section Western; 1b: section Central; 1c: section Eastern. – 2: subdistrict Western Kaczawa Plateau; 2a: section Bolesławiec Plateau; 2b: section Central-southern; 2c: section Valley of River Bóbr. – 3: subdistrict Eastern Kaczawa Plateau; 3a: section Northern; 3b: section Southern.

The presence of taxa that attain their geographical range limits is one of the phytogeographical phenomena that distinguishes the investigated area in the whole of the Sudetes mountain range. It results from several factors: (1) a location for the Sudetes generally, and especially the investigated region, extremely north with respect to other mountain ranges of Central Europe, between the provinces "Mountains Central European" and "Lowland Central European" (as in case of distribution of *Lonicera nigra*, *Rosa pendulina* and *Rubus mollis*); (2) a small distance from European refugia exhibiting a subatlantic character (*Erica tetralix*, *Rubus lignicensis*, *R. lusaticus*); (3) the existence of habitats adequate for development of thermophilous vegetation (*Chamaecytisus ratisbonensis*, *Cotoneaster integerrimus*, *Staphylea pinnata*); and (4) the unique richness of the genus *Rubus*. Absolute Euro-

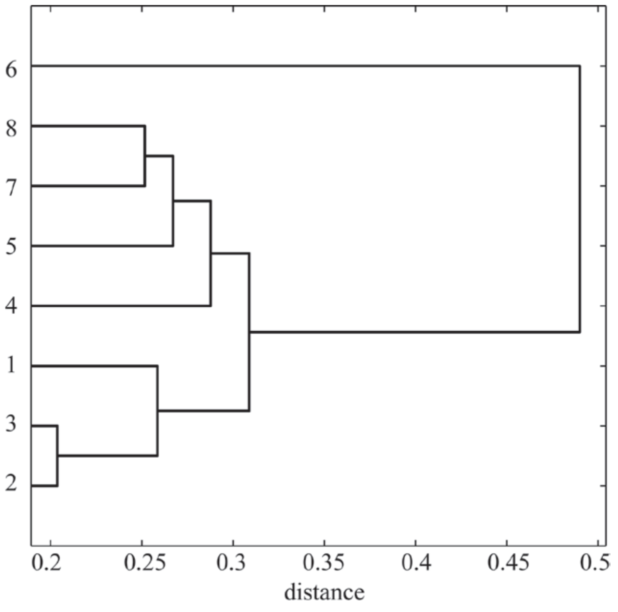

Fig. 10. Cluster analysis of tree and shrub flora of phytogeographical units distinguished in the investigated area (the distance is computed as one minus Jaccard similarity coefficient). Phytogeographical units are as follows. – Subdistrict Kaczawa Mountains: 1: section Western; 2: section Central; 3: section Eastern. – Subdistrict Western Kaczawa Plateau: 4: section Bolesławiec Plateau; 5: section Central-southern; 6: section Valley of River Bóbr. – Subdistrict Eastern Kaczawa Plateau: 7: section Northern; 8: section Southern.

Table 2. Tree and shrub species diagnostic for phytogeographical units of the investigated area.

Subdistrict	Section
1. Kaczawa Mountains:	1a. Western:
Lonicera nigra	*Ononis repens*
Ononis repens	*Salix eleagnos*
Ribes alpinum	1b. Central: –
Salix eleagnos	1c. Eastern: –
Salix silesiaca	
2. Western Kaczawa Plateau:	2a. Bolesławiec Plateau:
Chamaecytisus ratisbonensis	*Chamaecyt. ratisbonensis*
Erica tetralix	*Erica tetralix*
Genista pilosa	*Genista pilosa*
Lembotropis nigricans	*Lembotropis nigricans*
Rubus seebergensis	*Vaccinium vitis-idaea*
Vaccinium vitis-idaea	2b. Central-southern: –
	2c. Valley of River Bóbr:
	Salix dasyclados
	Salix triandra
	Ulmus laevis
3. Eastern Kaczawa Plateau:	3a. Northern:
Chamaecytisus supinus	*Rubus capitulatus*
Rubus capitulatus	*Rubus lignicensis*
Rubus lignicensis	*Rubus radula*
Rubus radula	*Rubus sulcatus*
Rubus sulcatus	3b. Southern:
Sorbus torminalis	*Chamaecytisus supinus*
	Sorbus torminalis
1. Kaczawa Mountains and 3. Eastern Kaczawa Plateau:	
Rosa pendulina	
2. Western Kaczawa Plateau and 3. Eastern Kaczawa Plateau:	
Rubus macrophyllus	
Rubus scaber	

pean range limits are attained by *Rosa pendulina* (Kurtto & al. 2004) and *Staphylea pinnata* (Meusel & al. 1978), among others.

Among the borderline taxa, the presence of species from *Rubus* ser. *Hystricopses* H. E. Weber (*R. capitulatus*, *R. seebergensis*) is especially worth mentioning since they are an endemic element of the Polish vascular flora (Weber 1995; Zieliński 1993; Mirek & Piękoś-Mirkowa 2009), as well as *R. scaber* from *R.* ser. *Pallidi* W. C. R. Watson, a subatlantic species with a disjunct geographical range in Europe (British Isles and, after a gap, Germany, the Czech Republic and SW Poland – Holub 1995; Ranft 1995; Weber 1995; Zieliński 2004). The only localities of *R. scaber*, a hercynic postglacial migration element (Weber 1987) in Poland are in the Kaczawa Plateau, where they set the absolute NE limit of this species in Europe.

Concentration maps of selected groups of species and the statistical analysis show that a distinct relationship exists between the species distributions and the phytogeographical units recognized at the rank of three subdistricts and eight geobotanical sections (Fig. 9). The units comprise territories of different surface areas demarcated by natural borders and represent characteristic distributions of habitats as well as tree and shrub flora.

Comparative analysis of the distribution of all the native tree and shrub taxa (cluster analysis, Fig. 10) confirms the existence of significant differences between the recognized phytogeographical units, especially those of the rank of subdistrict. The obtained dendrogram shows that the units are grouped into two clusters. The first one is the subdistrict Kaczawa Mountains (Fig. 10; phytogeographical units 1–3). It distinctly differs from the remaining part of the investigated area by the presence of a number of mountain and thermophilous species, which do not occur or are very rare in the remaining regions. The striking feature of the second cluster is the close similarity of the tree and shrub flora of the N and S sections of the subdistrict Eastern Kaczawa Plateau (units 7 and 8). This is, among others, the effect of the occurrence of special taxa attached to basaltic bedrock and species of the genus *Rubus*. These phytogeographical units are somewhat similar to the subdistrict Western Kaczawa Plateau, especially to its geobotanical section Bolesławiec Plateau and the section Central-southern (units 4 and 5). On the other hand, the section Valley of River Bóbr (unit 6) exhibits distinct separateness from the other phytogeographical units. It results from partial regulation of the river bed, significant devastation of natural forest vegetation, and floristic paucity (the occurrence of only a few tree and shrub taxa per cartogram unit).

The borders and sizes of the phytochorions (subdistricts and geobotanical sections) used in the present investigation are different from the previously proposed geobotanical regionalizations of the Kaczawa Mountains: by Kuczyńska (1997), whose regionalization was in agreement with physico-geographical units of the Sudetes in Kondracki's (1988) system; and by Matuszkiewicz (1993), whose method was based on variation of potential landscape phytocomplexes and vegetation landscapes. They, however, generally overlap with the regionalization based on the analysis of vascular flora (Kwiatkowski 2007). The main difference in the present regionalization is that a part of the River Bóbr valley has been excluded from the W section of the subdistrict Kaczawa Mountains with a resulting change in the subdistrict border.

The list of taxa diagnostic for individual phytochorions, prepared on the basis of similarities and differences in local tree and shrub flora, includes groups of taxa representing different geographical ranges and habitat preferences (Table 2). The Kaczawa Mountains are distinguished by mountain taxa (*Lonicera nigra*, *Ribes alpinum*, *Salix eleagnos*, *Salix silesiaca*), the Western Kaczawa Plateau by subatlantic species (*Erica tetralix*, *Genista pilosa*), and the Eastern Kaczawa Plateau by thermophilous species (*Chamaecytisus supinus*, *Sorbus torminalis*) and the genus *Rubus* (e.g. *Rubus capitulatus*, *R. lignicensis*, *R. radula*). At the same time, the similarities between some subdistricts are manifested in several common diagnostic species.

Conclusions

The main conclusion of the present investigation is that the regionalization based on the results of geobotanical analysis of the dendroflora to a large extent overlaps with the earlier proposed regionalization based on the analysis of the whole vascular flora of the investigated region (Kwiatkowski 2007). Borders separating the Kaczawa Mountains from the Western Kaczawa Plateau and Eastern Kaczawa Plateau run mostly along natural relief forms, and along the contact of units representing different geological structures. Their location and the size of the distinguished subdistricts and geobotanical sections are confirmed by concentrations of taxa representing various types of local range, statistical comparison of local flora, and physico-geographical conditions, especially the relief and geological structure.

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Appendix: Catalogue of tree and shrub taxa of the investigated area

Symbols and abbreviations:

* = alien taxa according to Mirek & al. (2002).

Frequency classes: I = very rare (1–3 localities); II = rare (4–10 localities); III = relatively frequent (11–51 localities); IV = frequent (52–103 localities); V = very frequent (104–173 localities); VI = common (174–346 localities).

Geographical elements (after Zając and Zając 2009, modified): A-A = Arctic-Alpine; AM = American; anthr = anthropogenic origin; AS = Asiatic; CB = Circumboreal; CE = European-temperate; CE-M = European-temperate-Mediterranean; CE-M-IR = European-temperate-Mediterranean-Irano-Turanian; CE-M-IR-AS = European-temperate-Mediterranean-Irano-Turanian-Asiatic; CE-PAN-PONT = European-temperate-Pontic-Pannonian; ES = Eurosiberian; ES-M = Eurosiberian-Mediterranean; ES-IR = Eurosiberian-Irano-Turanian; ES-M-IR = Eurosiberian-Mediterranean-Irano-Turanian; ES-M-IR-AS = Eurosiberian-Mediterranean-Irano-Turanian-Asiatic; EUR = European; EUR-AS = European-Asiatic; EUR-AS-AFR = European-Asiatic-African; EUR-AS-AM = European-Asiatic-American; nn = of unknown origin.

References to Fig. 3–7 are given when concentration maps include a taxon.

GYMNOSPERMS

Cupressaceae

Juniperus communis L. subsp. *communis* – III/46 localities; CB.
**Thuja occidentalis* L. – III/13 localities; AM.
**Thuja plicata* Donn ex D. Don – II/5; AM.

Pinaceae

Abies alba Mill. – III/43; CE; Fig. 4.
**Larix decidua* Mill. subsp. *decidua* – VI/183; EUR.
**Larix kaempferi* (Lamb.) Carrière – II/9; AS.
Picea abies (L.) H. Karst. – VI/253; CE.
**Pinus nigra* J. F. Arnold – II/7; EUR-AS-AFR.
**Pinus strobus* L. – II/5; AM.
Pinus sylvestris L. – VI/228; ES.
**Pseudotsuga menziesii* (Mirb.) Franco – III/72; AM.

Taxaceae

Taxus baccata L. – III/32; CE-M-IR.

ANGIOSPERMS

Aceraceae

Acer campestre L. – III/28; CE-M-IR; Fig. 7.
**Acer negundo* L. – III/12; AM.
Acer platanoides L. – VI/303; CE-M.
Acer pseudoplatanus L. – VI/288; CE-M.
**Acer saccharinum* L. – I/1; AM.

Apocynaceae

Vinca minor L. – IV/90; CE-M.

Araliaceae

Hedera helix L. – VI/263; CE-M.

Berberidaceae

Berberis vulgaris L. – III/42; CE-PAN-PONT; Fig. 5.
**Mahonia aquifolium* (Pursh) Nutt. – I/2; AM.

Betulaceae

**Alnus aschersoniana* Callier – I/2; AM.
Alnus glutinosa (L.) Gaertn. – VI/246; ES-M.
Alnus incana (L.) Moench – VI/191; A-A; Fig. 4.
Alnus pubescens Tausch – II/6; nn.
**Alnus rugosa* (Du Roi) Spreng. – II/8; AM.
**Alnus ×silesiaca* Fiek – I/1; nn.
Betula ×aurata Borkh. – I/3; ES.
Betula obscura Kotula – II/4; ES.
Betula pendula Roth – VI/346; ES.
Betula pubescens Ehrh. subsp. *pubescens* – V/154; ES.

Caprifoliaceae

**Lonicera caprifolium* L. – II/6; EUR.
Lonicera nigra L. – III/19; CE; Fig. 4.
Lonicera periclymenum L. – III/31; CE.
**Lonicera tatarica* L. – II/4; EUR-AS.
Lonicera xylosteum L. – IV/53; ES.
Sambucus nigra L. – VI/332; CE-M.
Sambucus racemosa L. – VI/226; CE; Fig. 4.
**Symphoricarpos albus* (L.) S. F. Blake – IV/60; AM.
**Viburnum lantana* L. – II/6; EUR-AS-AFR.
Viburnum opulus L. – VI/225; ES.

Celastraceae

Euonymus europaea L. – VI/258; CE-M.
**Euonymus latifolia* (L.) Mill. – I/2; EUR-AS-AFR.

Cornaceae

**Cornus alba* L. – III/12; EUR-AS.
Cornus sanguinea L. subsp. *sanguinea* – VI/225; CE-M.

Corylaceae

Carpinus betulus L. – VI/267; CE-M.
Corylus avellana L. – VI/299; CE-M-IR.

Eleagnaceae

**Eleagnus angustifolia* L. – I/1; EUR-AS.

Empetraceae

Empetrum nigrum L. s. str. – I/1; CB.

Ericaceae

Arctostaphylos uva-ursi (L.) Spreng. – I/1; CB.

Calluna vulgaris (L.) Hull – V/144; ES.
Erica tetralix L. – I/3; CE.
Oxycoccus palustris Pers. – I/2; CB.
Vaccinium myrtillus L. – VI/268; ES.
Vaccinium uliginosum L. – I/1; CB.
Vaccinium vitis-idaea L. – III/43; CB.

Fabaceae
**Chamaecytisus glaber* (L. f.) Rothm. – I/1; EUR.
Chamaecytisus ratisbonensis (Schaeff.) Rothm. – I/2; CE-PAN-PONT; Fig. 5.
Chamaecytisus supinus (L.) Link – I/1; CE; Fig. 5.
**Colutea arborescens* L. – I/1; EUR.
Genista germanica L. – IV/67; CE; Fig. 5.
Genista pilosa L. – III/28; CE.
Genista tinctoria L. – VI/177; CE-M.
**Laburnum anagyroides* Medik. – I/3; EUR.
Lembotropis nigricans (L.) Griseb. – II/10; CE.
Ononis arvensis L. – III/77; ES-IR.
Ononis repens L. – I/1; CE-M; Fig. 5.
Ononis spinosa L. – I/2; CE; Fig. 5.
**Robinia pseudoacacia* L. – IV/80; AM.
Sarothamnus scoparius (L.) W. D. J. Koch – IV/92; CE.
**Ulex europaeus* L. – I/2; EUR.

Fagaceae
Fagus sylvatica L. subsp. *sylvatica* – VI/214; CE.
Quercus petraea (Matt.) Liebl. – VI/282; CE-M.
Quercus robur L. – VI/257; CE-M.
Quercus ×rosacea Bechst. – I/1; CE-M.
**Quercus rubra* L. – III/78; AM.

Grossulariaceae
Ribes alpinum L. – III/50; CE; Fig. 4.
**Ribes aureum* Pursh – II/5; AM.
Ribes nigrum L. – III/25; ES.
**Ribes rubrum* L. s. l. – III/16; EUR.
Ribes spicatum Robson – IV/85; CE-PAN-PONT.
Ribes uva-crispa L. subsp. *uva-crispa* – V/158; CE-M.

Hippocastanaceae
**Aesculus hippocastanum* L. – III/42; EUR.

Hydrangeaceae
**Philadelphus coronarius* L. – III/24; EUR-AS.

Juglandaceae
**Juglans regia* L. – I/1; AS.

Loranthaceae
Viscum album subsp. *abietis* (Wiesb.) Janch. – II/6; CE.
Viscum album L. subsp. *album* – II/5; CE-M-IR-AS.
Viscum album subsp. *austriacum* (Wiesb.) Vollm. – I/1; CB.

Moraceae
**Morus alba* L. – I/2; AS.

Oleaceae
Fraxinus excelsior L. – VI/300; CE-M-IR.
**Fraxinus pennsylvanica* Marshall – I/1; AM.
Ligustrum vulgare L. – IV/74; EUR-AS-AFR.
**Syringa josikaea* J. Jacq. ex Rchb. – I/1; EUR.
**Syringa vulgaris* L. – III/20; EUR.

Platanaceae
**Platanus hispanica* Mill ex Münchh. 'Acerifolia' – II/4; anthr.

Pyrolaceae
Chimaphila umbellata (L.) W. P. C. Barton – I/1; CB.

Rhamnaceae
Frangula alnus Mill. – VI/209; ES.
Rhamnus cathartica L. – III/57; ES-M-IR.
**Rhamnus saxatilis* Jacq. subsp. *saxatilis* – I/1; EUR.

Rosaceae
**Amelanchier spicata* (Lam.) K. Koch – II/4; AM.
Cerasus avium (L.) Moench – V/170; CE-M.
**Cerasus vulgaris* Mill. subsp. *vulgaris* – III/11; EUR-AS.
**Cotoneaster horizontalis* Decne. – I/1; AS.
Cotoneaster integerrimus Medik. – II/9; CE-M; Fig. 4, 5.
**Cotoneaster lucidus* Schltdl. – I/3; AS.
**Crataegus flabellata* (Bosc ex Spach) K. Koch – I/3; AM.
Crataegus laevigata (Poir.) DC. – VI/191; CE-M.
Crataegus ×macrocarpa Hegetschw. – III/15; CE.
Crataegus ×media Bechst. – IV/65; CE-M.
Crataegus monogyna Jacq. – VI/310; CE-M-IR.
**Crataegus pedicellata* Sarg. – I/1; AM.
Crataegus rhipidophylla var. *lindmanii* (Hrabětová) K. I. Chr. – II/6; CE-M-IR; Fig. 5.
Crataegus rhipidophylla Gand. var. *rhipidophylla* – III/18; CE; Fig. 5, 6.
**Malus domestica* Borkh. – III/15; anthr.
Malus sylvestris Mill. – III/70; CE-M.
Padus avium Mill. – VI/194; ES.
**Padus serotina* (Ehrh.) Borkh. – III/37; AM.
**Physocarpus opulifolius* (L.) Maxim. – I/2; AM.
**Prunus domestica* L. subsp. *domestica* – III/25; anthr.
Prunus spinosa L. – VI/262; CE-M-IR.
**Pyrus communis* L. – III/60; anthr.
Rosa agrestis Savi – III/15; CE-M.
Rosa canina L. var. *canina* – VI/290; CE-M-IR.
Rosa canina var. *corymbifera* (Bork.) Boulenger – III/9; CE-M-IR.
Rosa canina var. *scabrata* Capin – III/8; CE-M-IR.
Rosa dumalis var. *coriifolia* (Fries) Boulenger – II/6; CE-M.
Rosa dumalis Bechst. emend. Boulenger var. *dumalis* – III/12; CE-M; Fig. 5.
Rosa gallica L. – I/2; CE-M; Fig. 5.
**Rosa glauca* Pourr. – I/1; EUR.
Rosa inodora Fr. – III/16; CE; Fig. 5.
Rosa jundzillii Besser – II/4; CE; Fig. 5.

Rosa majalis Herrm. – I/1; ES.
Rosa micrantha Borrer ex Sm. – III/19; CE-M; Fig. 5.
**Rosa multiflora* Thunb. – I/2; AS.
Rosa pendulina L. – III/34; CE; Fig. 4.
Rosa rubiginosa L. – III/22; CE-M; Fig. 5.
**Rosa rugosa* Thunb. – III/35; AS.
Rosa sherardii Davies – II/9; CE; Fig. 5.
**Rosa spinosissima* L. – I/2; EUR-AS.
Rosa tomentosa Sm. – II/10; CE-M; Fig. 5.
Rosa villosa L. – II/4; CE-M.
Rubus acanthodes (H. Hofm. ex Focke) E. Barber – I/1; CE; Fig. 3.
**Rubus allegheniensis* Porter – I/1; AM; Fig. 3, 4.
Rubus angustipaniculatus Holub – II/10; CE; Fig. 3.
Rubus apricus Wimm. – III/14; CE; Fig. 3.
**Rubus armeniacus* Focke – I/2; AS; Fig. 3.
Rubus caesius L. – VI/198; ES-M-IR; Fig. 3.
Rubus camptostachys G. Braun – II/4; CE; Fig. 3.
Rubus capitulatus Utsch – II/4; CE; Fig. 3, 6.
Rubus chaerophyllus Sagorski & Wilh. Schulze – III/19; CE; Fig. 3.
Rubus constrictus P. J. Müll. & Lefèvre – I/1; CE; Fig. 3.
Rubus corylifolius Sm. agg. – III/33; CE; Fig. 3.
Rubus crispomarginatus Holub – I/2; CE; Fig. 3.
Rubus dollnensis Sprib. – I/2; CE; Fig. 3.
Rubus fabrimontanus (Sprib.) Sprib. – III/19; CE; Fig. 3.
Rubus fasciculatus P. J. Müll. – II/7; CE; Fig. 3.
Rubus gothicus Frid. & Gelert ex E. H. L. Krause – I/2; CE; Fig. 3.
Rubus grabowskii Weihe ex Günther & All. – III/26; CE; Fig. 3.
Rubus gracilis J. Presl & C. Presl – III/16; CE; Fig. 3.
Rubus guentheri Weihe – IV/58; CE; Fig. 3, 4.
Rubus hercynicus G. Braun – I/1; CE; Fig. 3.
Rubus hirtus Waldst. & Kit. agg. – IV/74; CE; Fig. 3.
Rubus idaeus L. – VI/284; CB; Fig. 3.
Rubus koehleri Weihe – III/16; CE; Fig. 3.
Rubus kuleszae Ziel. – II/8; CE; Fig. 3.
**Rubus laciniatus* Willd. – II/5; anthr; Fig. 3.
Rubus lignicensis Figert – I/1; CE; Fig. 3, 6.
Rubus lusaticus Rostock – II/8; CE; Fig. 3, 6.
Rubus macrophyllus Weihe & Nees – III/13; CE; Fig. 3.
Rubus mollis J. Presl & C. Presl – I/2; CE; Fig. 3.
Rubus montanus Lib. ex Lej. – III/17; CE; Fig. 3.
Rubus nemorosus Hayne & Willd. – I/3; CE; Fig. 3.
Rubus nessensis Hall. subsp. *nessensis* – III/32; CE; Fig. 3.
Rubus orthostachys G. Braun – III/12; CE; Fig. 3.
Rubus pedemontanus Pinkw. – III/37; CE; Fig. 3.
Rubus pericrispatus Holub & Trávníček – I/3; CE; Fig. 3.
Rubus plicatus Weihe & Nees – III/35; CE; Fig. 3.
Rubus praecox Bertol. – I/2; CE-M-IR; Fig. 3.
Rubus ×pseudidaeus (Weihe) Lej. – II/10; nn; Fig. 3.
Rubus pyramidalis Kaltenb. – I/2; CE; Fig. 3.
Rubus radula Weihe – III/18; CE; Fig. 3, 6.
Rubus saxatilis L. – II/8; ES; Fig. 3.
Rubus scaber Weihe – II/8; CE; Fig. 3.
Rubus schleicheri Weihe & Tratt. – III/13; CE; Fig. 3.
Rubus seebergensis Pfuhl ex Sprib. – I/1; CE; Fig. 3.
Rubus silesiacus Weihe – II/9; CE; Fig. 3.
Rubus sulcatus Vest – III/14; CE; Fig. 3.
Rubus tabanimontanus Figert – II/8; CE; Fig. 3.
Rubus wahlbergii Arrh. – II/4; CE; Fig. 3.
**Sorbaria sorbifolia* (L.) A. Braun – I/1; AS.
Sorbus aria (L.) Crantz – I/1; CE-M.
Sorbus aucuparia L. subsp. *aucuparia* – VI/334; CE.
**Sorbus intermedia* (Ehrh.) Pers. – II/6; EUR.
Sorbus torminalis (L.) Crantz – III/19; CE-M-IR; Fig. 5, 6.
**Spiraea chamaedryfolia* L. emend. Jacq. – II/6; EUR-AS.
**Spiraea salicifolia* L. – III/23; EUR-AS-AM.
**Spiraea tomentosa* L. – I/1; AM.
**Spiraea ×vanhouttei* (Briot) Carrière – II/5; anthr.

Salicaceae
Populus alba L. – IV/63; ES-M-IR; Fig. 7.
**Populus berolinensis* (K. Koch) Dippel – III/15; anthr.
**Populus ×canadensis* Moench – II/8; anthr.
**Populus nigra* L. s. str. – VI/177; AM.
**Populus nigra* L. ‘Italica’ – III/8; anthr.
Populus tremula L. – VI/248; ES-M-IR-AS.
Salix alba L. – VI/193; ES-M-IR.
Salix ×ambigua Ehrh. – I/3; nn.
Salix aurita L. – IV/80; CE.
Salix caprea L. – VI/247; ES-M-IR.
Salix ×capreola J. Kern. – II/5; nn.
Salix cinerea L. – IV/60; ES.
Salix ×dasyclados Wimm. – II/4; ES; Fig. 7.
Salix ×dichroa Döll – I/3; nn.
Salix eleagnos Scop. – II/7; CE; Fig. 4, 7.
Salix fragilis L. – VI/212; CE-M-IR.
Salix ×meyeriana Rostk. ex Willd. – I/1; nn.
Salix ×multinervis Döll – I/3; nn; Fig. 7.
Salix myrtilloides L. – I/1; CB.
**Salix ×pendulina* Wender. – III/15; anthr.
Salix pentandra L. – IV/58; ES.
Salix ×pontederana Willd. – I/2; nn.
Salix purpurea L. – IV/83; ES-M-IR.
Salix ×reichardtii A. Kern. – I/3; ES; Fig. 7.
Salix repens L. subsp. *repens* – III/12; ES.
Salix repens subsp. *rosmarinifolia* (L.) Hartm. – III/22; ES.
Salix ×rubens Schrank – III/49; nn; Fig. 7.
Salix silesiaca Willd. – III/14; CE; Fig. 4.
Salix ×smithiana Willd. – III/49; ES; Fig. 7.
Salix ×subcaprea Anderss. – II/8; nn.
Salix triandra L. – IV/73; ES-M-IR; Fig. 7.
Salix viminalis L. – IV/65; ES; Fig. 7.
Salix ×wimmeriana Gren. & Godr. – I/3; ES.

Solanaceae
**Lycium barbarum* L. – III/26; EUR-AS.

Staphyleaceae
Staphylea pinnata L. – II/9; CE; Fig. 5.

Thymelaeaceae

Daphne mezereum L. – V/121; ES.

Tiliaceae

Tilia cordata Mill. – VI/280; ES.
Tilia platyphyllos Scop. – VI/199; CE.

Ulmaceae

Ulmus glabra Huds. – IV/105; CE-M.
Ulmus laevis Pall. – III/50; CE; Fig. 7.
Ulmus minor Mill. emend. Richens var. *minor* – IV/63; CE-M-IR; Fig. 7.
Ulmus minor var. *suberosa* (Moench) Soó – III/19; CE-M-IR; Fig. 5.

Vitaceae

**Parthenocissus inserta* (A. Kern.) Fritsch – III/14; AM.