Tuexenia 35: 155–176. Göttingen 2015.
doi: 10.14471/2015.35.003, available online at www.tuexenia.de

Formalised classification and environmental controls of riparian forest communities in the Sudetes (SW Poland)

Formalisierte Klassifikation und Umweltfaktoren von Auwald- und Quellwaldgesellschaften in den Sudeten (Südwest-Polen)

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Abstract

The Cocktail method was applied to a small data set derived in a regional survey on riparian forest in the Polish part of the Sudetes. Formalised classification revealed the occurrence of seven associations. Considering the ecological character, three distinct groups emerged among them: i) alluvial forests (*Salicetum albae*, *Alnetum incanae*), ii) forests of small and medium mountain streams with only a narrow riparian zone (*Salicetum fragilis*, *Stellario nemorum-Alnetum glutinosae* and *Fraxino-Alnetum*) and iii) forests developed on waterlogged soils of spring-fed areas (*Carici remotae-Fraxinetum* and *Piceo-Alnetum*). The associations *Salicetum fragilis* and *Piceo-Alnetum* are reported for the first time from Poland. Analysis of GIS-derived environmental variables showed that average altitude, stream power index (SPI) and river order were significantly different among the associations, while there were no differences among average values of slope, solar radiation and topographic wetness index (TWI). Significant differences in species richness among the associations were also identified. Application of the Cocktail method in regional studies was also discussed.

Keywords: Cocktail method, formalised classification, mountain forest, phytosociology, riparian forest, spring-fed area, vegetation classification

Erweiterte deutsche Zusammenfassung am Ende des Artikels

1. Introduction

Although there is a long history of phytosociological surveys in the Polish part of the Sudetes, the diversity of forest communities is still poorly recognised and needs comprehensive ecological studies. The first relevés of riparian forests were published in the 1960s. MATUSZKIEWICZ & MATUSZKIEWICZ (1967) reported the occurrence of *Alnetum incanae* in the Karkonosze Mts., while FABISZEWSKI (1968) described *Carici remotae-Fraxinetum* in the Śnieżnik Massif. Much more data have been provided by vegetation surveys in the 1970s and later works (Table 1).

Despite a total of 142 relevés published so far, different syntaxonomic questions related to riparian forests in the Sudetes remained unresolved. The most important are the occurrence and floristic composition of *Alnetum incanae* and *Ficario-Ulmetum* as well as the

Manuscript received 16 October 2014, accepted 21 January 2015
Co-ordinating Editor: Erwin Bergmeier

Table 1. List of vegetation surveys in the Polish part of the Sudetes that provided relevés and descriptions of riparian forests.

Tabelle 1. Liste der Vegetationsübersichten im polnischen Teil der Sudeten mit Vegetationsaufnahmen und Beschreibungen von Au- und Quellwäldern.

Region	Syntaxon	Relevés no	Source
Karkonosze Mts.	*Alnetum incanae* Aich. et Sierg. 1930	1	MATUSZKIEWICZ & MATUSZKIEWICZ 1967
Snieżnik Massif and Bialskie Mts.	*Carici remotae-Fraxinetum* W. Koch 1926	3	FABISZEWSKI 1968
Opawskie Mts.	*Carici remotae-Fraxinetum* Koch 1926 *Fraxino-Alnetum* Mat. 1952 *Fraxino-Ulmetum* R. Tx. ap. Lohm. 1932 (Oberd. 1953)	4 17 12	KUCZYŃSKA 1972
Sowie Mts.	*Salicetum albo-fragilis* R. Tx. (1948) 1955 *Carici remotae-Fraxinetum* Koch 1926 *Fraxino-Alnetum* Mat. 1952	3 28 6	PENDER 1975
Kaczawskie Mts. and Izerskie Mts.	*Carici remotae-Fraxinetum* Koch 1926	7	KUCZYŃSKA & BERDOWSKI 1976
Kamienne Mts.	*Circaeo-Alnetum* Oberd. 1953 *Carici remotae-Fraxinetum* Koch 1926	7 9	KUCZYŃSKA & MACICKA 1984
Kamienne Mts. and Stołowe Mts.	ass. of *Salicion albae* R. Tx. 1955 *Carici remotae-Fraxinetum* Koch 1926 ass. of *Alno-Padion* Knapp 1942	6 5 5	MACICKA 1988
Karkonosze Foothills	*Alnetum incanae* Aich. et Siegr. 1930	4	ŚWIERKOSZ 1994
Kaczawskie Mts.	*Carici remotae-Fraxinetum* Koch 1926 *Stellario nemorum-Alnetum glutinosae* Lohm. 1957	8 8	KWIATKOWSKI 2003
Opawskie Mts.	*Carici remotae-Fraxinetum* Koch 1926	9	NOWAK & NOWAK 2010

diversity of submontane ash and willow riparian forests. Moreover, vegetation classification in neighbouring countries includes riparian forest communities that have never been documented in Poland (OBERDORFER 1992, NEUHÄUSLOVÁ 2003, DOUDA 2008, ONYSHCHENKO 2010, SLEZÁK et al. 2013, SLEZÁK et al. 2014) despite previous surveys. Previous observations also suggest clear differences between forest developed either on floodplains or in spring-fed areas, but this distinctiveness is rarely reflected in the vegetation classifications. None of the previous studies presented comprehensive analyses of riparian forests in the Sudetes, and what is probably the most important, all previous studies focused mostly on the syntaxonomic diversity of communities, but none of them tried to investigate differences in environmental controls among the units. It needs to be emphasized that understanding relations between vegetation patterns and the environment is one of the most important goals of current vegetation ecology and far exceeds the significance of regional vegetation surveys.

Formalised classification has become a standard in national vegetation classifications in many European countries (BRUELHEIDE & CHYTRÝ 2000, HÁJKOVÁ et al. 2006, CHYTRÝ 2007, DÍTĚ et al. 2007, ŠILC & ČARNI 2007, JANIŠOVÁ & DÚBRAVKOVÁ 2010, LANDUCCI et al. 2011, KĄCKI et al. 2013, ŠUMBEROVÁ & HRIVNÁK 2013). This type of vegetation classification was mostly based on large data sets containing thousands of relevés. The database usually contains not only the plots of analysed vegetation units, but also different vegetation types. This approach leads to the creation of more representative sociological groups of species, covering a significant part of their realized niches. It seems, however, that the advantages of supervised classification with detailed definitions of associations could also be incorporated in local studies, even if the sampled data set is limited to only one vegetation type. In this work I tried to use supervised classification and the Cocktail method in a local study to fill the gaps in the knowledge of riparian forests in the Polish part of the Sudetes. Contrary to other research based on large data sets, in this study I used a relatively small amount of data of riparian forests collected during fieldwork.

The research presented here was conducted to (1) recognise the diversity of riparian forest communities in the Sudetes and (2) understand the relationships between species composition of riparian forest communities and environmental factors related to hydrology and topography.

2. Methods

2.1 Study area

The area of vegetation sampling was limited to the Polish part of the Sudetes which covers about 4000 km^2 (Fig. 1). This mountain range spreads along the border between Poland and the Czech Republic. The altitudinal limit of the forest ecosystems is located at ca. 1250 m a.s.l.; however, deciduous forests reach their upper limits at ca. 950–1050 m a.s.l. Geological and climatic conditions in the Sudetes are remarkably diverse (see WOŚ 1999 & KONDRACKI 2000 for details), and thus vegetation composition varies considerably among the subranges of the Sudetes. However, the main patterns of natural vegetation are determined by elevation and may be simplified to the following zones: (i) forests of *Quercus robur*, *Tilia cordata* and *Carpinus betulus* at 300–500 m a.s.l.; (ii) forests dominated by *Fagus sylvatica* and *Acer pseudoplatanus* (formerly also with *Abies alba*) at 500–1000 m a.s.l.; (iii) coniferous forests of *Picea abies* at 1000–1250 m a.s.l.; (iv) dwarf formations of *Pinus mugo* at 1250–1500 m a.s.l.; and (v) natural grasslands and alpine dwarf shrub communities above 1500 m a.s.l. Some azonal forest communities also occur, like thermophilous oak forests on exposed rocky ground at lower altitudes, as well as riparian forests along streams or in spring-fed areas. This simple vegetation pattern has been heavily altered by different types of land use, including settlement, agriculture and forestry plantations of conifers.

The rivers and floodplains in the Sudetes have suffered from human alteration for many centuries. The channels of the main rivers were modified due to timber floating, while many streams were deforested. Many rivers are still subject to strong human pressure, caused mainly by inappropriate and anachronistic methods of flood control.

2.2 Vegetation sampling

Within the studied area, 100 river valleys with patches of well-preserved riparian forests were selected. ‘Well-preserved’ forests were defined as ones with low contribution (if any) of alien species, only slight anthropogenic disturbances and tree layer cover higher than 50%. Selected valleys were surveyed from the source (if located in the studied area) to either their mouth or the place where the river leaves the Sudetes (total length of investigated streams was ca. 870 km). All recognised fragments of well-preserved riparian forest were sampled. The fieldwork was conducted in 2006–2009, according to the methodology of the Central-European phytosociology (KENT & COKER 1992). Plots located in floodplains were rectangular (7.5 × 20 m), with the longer axis parallel to the river to minimise the

Fig. 1. Location of study area.

Abb. 1. Lage des Untersuchungsgebiets.

influence of a lateral gradient. Plots in spring-fed areas had no limitations regarding their shape due to smaller spatial gradients, however all the plots were 150 m^2. The vegetation of all plots was sampled by making a relevé and the Domin-Krajina scale was used for cover estimation (MUELLER-DOMBOIS & ELLENBERG 2003). All collected relevés (268) were entered into a Turboveg database (HENNEKENS & SCHAMINÉE 2001) and were then processed to obtain a more representative data set. To avoid an overrepresentation of regions with a high concentration of sample plots, a geographic stratification procedure was used with a 0.5 km square grid (one relevé was randomly selected if a square contained more than one sample plot). To reduce 'noise' in the data analysis, species names of critical taxa were substituted by their broader taxonomic concepts.

2.3 Environmental variables

Most previous research suggested that riparian forests are mainly influenced by hydrology and geomorphology. A set of six environmental variables related to these factors was calculated on the basis of digital data in GIS (Fig. 2). Primary topographic attributes (elevation and slope) were derived from a 10 m resolution digital elevation model (DEM) and generated in ArcGIS (version 10.0, ESRI Inc., Redlands CA, US). Secondary topographic attributes, including topographic wetness index (TWI) and stream power index (SPI), were generated in SAGA (System for Automated Geoscientific Analyses, version 2.1.0, Hamburg, Germany). TWI describes the tendency of a map cell to accumulate water, while SPI is a measure of the erosive power of flowing water (for calculation formulas and detailed information see MOORE et al. 1991, QUINN et al. 1991, GRUBER & PECKHAM 2009, KOPECKÝ & ČÍŽKOVÁ 2010). In addition, DEM was used to calculate a model of potential solar radiation following the upward-looking hemispherical viewshed algorithm (RICH et al. 1994, FU & RICH 2002). Radiation maps were generated using the Spatial Analyst extension in ArcGIS by considering the measurements in discrete 30-minute intervals during the day and 14-day intervals during the year. Finally, a digital river network (Map of Hydrographic Division of Poland, MPHP) was used to calculate the stream river order according to Strahler's classification (STRAHLER 1957). Stream order is the method for classifying streams according to size and a generalization for size-related hydrological and morphological features (discharge, contributing area, stream power, accumulation and erosion ratio, etc.) in the river network.

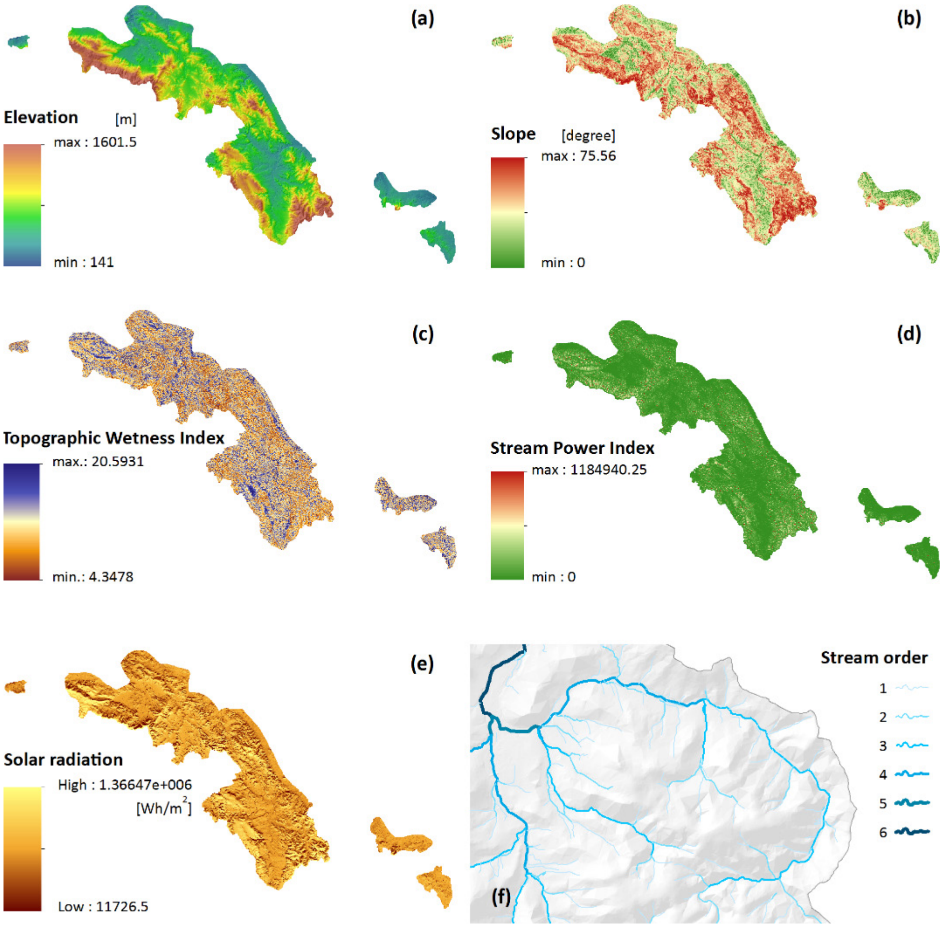

Fig. 2. Maps of environmental variables derived from digital data (digital elevation model and digital river network) and calculated in GIS. **a)** Elevation, **b)** Slope, **c)** Topographic Wetness Index (TWI), **d)** Stream Power Index (SPI), **e)** Potential solar radiation, **f)** Stream order.

Abb. 2. Karten der aus digitalen Daten (digitales Höhenmodel und digitales Fließgewässernetzwerk) abgeleiteten und in GIS berechneten Umweltvariablen. **a)** Höhe, **b)** Neigung, **c)** Topographischer Nässe-Index (TWI), **d)** Strömungskraft-Index (SPI), **e)** Potenzielle Sonneneinstrahlung, **f)** Fließgewässer-Ordnungszahl.

2.4 Data analysis

Classification of riparian forests was performed using the Cocktail method (BRUELHEIDE 2000, BRUELHEIDE & CHYTRÝ 2000). Most of the riparian forest associations published previously from the Sudetes have been used as the target groups in this work (Table 2) (MATUSZKIEWICZ 1976, OBERDORFER 1992, POTT 1992, MATUSZKIEWICZ & MATUSZKIEWICZ 1996, MORAVEC et al. 2000, MATUSZKIEWICZ 2001a, MATUSZKIEWICZ 2001b, NEUHÄUSLOVÁ 2003, GERŽA 2007, DOUDA 2008). Hardwood riparian forest dominated by oak, ash and elms (*Ficario-Ulmetum minoris*) was not considered as a target group, as it is typical of the lowland floodplains of large rivers (related forms of this community type sporadically occur in the Sudeten Foreland) and was erroneously reported from the Polish part of the Sudetes (KUCZYŃSKA 1972).

Ten species were subjectively selected to create sociological groups. According to expert knowledge, selected species are usually either dominant or exclusive species in one or more of the target associations. The procedure of creating the sociological groups of species was based on statistical measures of co-occurrence and has been described in many recent papers (BOUBLÍK et al. 2007, CHYTRÝ 2007, ROLEČEK 2007, ŠILC & ČARNI 2007, DOUDA 2008). In this work, the number of species in each group was fixed at four to six and – following other authors (CHYTRÝ 2007, DOUDA 2008) – a group was recorded in a relevé when that relevé contained at least half of the group's species. Selected main species and their sociological groups are described in Table 3. The formal definitions were constructed on the basis of expert knowledge and former descriptions of the target associations. Qualitative (presence or absence of the sociological groups) and quantitative (cover criteria of some species) conditions were combined and joined with logical operators (AND, OR, NOT) to create formal definitions of the target groups (Table 4) (BRUELHEIDE 1997). Relevés classified ambiguously were then assigned to one of the target groups on the basis of statistical measure of similarity: frequency-positive fidelity index (FPFI) was used for this purpose (TICHÝ 2005).

Diagnostic species were selected on the basis of their concentration in the target associations. As a statistical measure of this concentration, the phi coefficient (ϕ) was used and calculated after the size equalization of the groups (CHYTRÝ et al. 2002, TICHÝ & CHYTRÝ 2006). In addition, Fisher's exact test (p = 0.001) was calculated to test the significance of the concentration measures (CHYTRÝ et al. 2002, TICHÝ & CHYTRÝ 2006). Only species with a phi value higher than 0.25 were considered as diagnostic species. Constant and dominant species were also selected following percentage thresholds proposed in similar studies (CHYTRÝ 2007). Constant species were defined as those with a frequency over 80%, while dominant species were those that occurred with a cover value exceeding 25% in at least 20% of relevés. Finally, a synoptic table was generated to show differences among associations.

Table 2. List of plant associations selected as target groups in formalised classifications of riparian forests in the Sudetes.

Tabelle 2. Liste der als Zielgruppen in formalisierten Klassifikationen der Au- und Quellwälder der Sudeten verwendeten Assoziationen.

No	Association - target group	Remarks
1	*Salicetum albae* Issler 1925 (syn. *Salicetum albo-fragilis* Tx. ex Moor 1958 p.p.)	-
2	*Salicetum fragilis* Passarge 1957 (syn. *Chaerophyllo hirsuti-Salicetum fragilis* Müller & Görs 1958)	Not reported from Poland, but well documented in Germany and the Czech Republic.
3	*Alnetum incanae* Lüdi 1921	Only one relevé from Karkonosze Mts. Relevés from the Chojnik Mt. referred to spring forest dominated by *Alnus incana*. Well documented in the Czech Republic.
4	*Stellario nemorum-Alnetum glutinosae* Lohm. 1953	Poorly recognised in Poland; lack of relevés.
5	*Fraxino-Alnetum* W.Mat. 1952	-
6	*Piceo-Alnetum* Mráz 1959	Not recognised in Poland, although well documented in the Czech Republic and Slovakia. The name *Piceo-Alnetum* as used in some Polish sources refers to a different community (details in discussion).
7	*Carici remotae-Fraxinetum* Koch 1926	-

Table 3. List of sociological groups used for defining the associations.

Tabelle 3. Liste der für die Definition der Assoziationen verwendeten sozioloigschen Gruppen.

Group	Species
Group Phalaris arundinacea	*Calystegia sepium*, *Glechoma hederacea*, *Lamium maculatum*, *Phalaris arundinacea*
Group Chaerophyllum hirsutum	*Chaerophyllum hirsutum*, *Chrysosplenium alternifolium*, *Myosotis palustris* s.l., *Senecio nemorensis* s.l.
Group Melandrium rubrum	*Aconitum variegatum*, *Anthriscus nitida*, *Campanula latifolia*, *Melandrium rubrum*
Group Veratrum lobelianum	*Cardaminopsis halleri*, *Doronicum austriacum*, *Ranunculus platanifolius*, *Veratrum lobelianum*
Group Asarum europaeum	*Asarum europaeum*, *Euphorbia dulcis*, *Galeobdolon luteum*, *Mercurialis perennis*, *Pulmonaria officinalis*, *Ranunculus lanuginosus*
Group Carex vesicaria	*Carex flava*, *Carex vesicaria*, *Carex paniculata*, *Frangula alnus*, *Scirpus sylvaticus*, *Valeriana dioica*
Group Chaerophyllum aromaticum	*Aegopodium podagraria*, *Anthriscus sylvestris*, *Chaerophyllum aromaticum*, *Petasites hybridus*
Group Calamagrostis villosa	*Betula pendula*, *Calamagrostis villosa*, *Galium palustre* s.l., *Vaccinium myrtillus*
Group Carex remota	*Carex remota*, *Carex sylvatica*, *Equisetum sylvaticum*, *Juncus effusus*, *Lysimachia nemorum*, *Veronica beccabunga*
Group Filipendula ulmaria	*Angelica sylvestris*, *Caltha palustris*, *Equisetum arvense*, *Filipendula ulmaria*, *Geum rivale*, *Valeriana sambucifolia*

Formalised classification, determination of diagnostic species and generation of the synoptic table were performed using the Juice software (TICHÝ 2002). The plant species' names in the table, as well as in the whole paper, follow MIREK et al. (2002).

Differences in the ecological character of associations were investigated by comparing average values of environmental variables. The Kruskal-Wallis nonparametric test was applied to test the significance of the differences. This test was also used to compare plant species richness among the associations.

3. Results

The classification based on formal definitions distributed the relevés among all seven target groups. The synoptic table (Supplement S1) presents the differences in species composition of riparian forest communities. Considering the ecological characters, three distinct groups emerged among these seven associations. Alluvial forests are common along bigger rivers, either at lower altitudes or typically mountain ones, but generally with extensive floodplains where the accumulation process predominates over erosion. *Salicetum albae* and *Alnetum incanae* represent this type of forest. The second type constitutes the forests of small and medium mountain streams, with only a narrow riparian zone. This type is represented by *Salicetum fragilis*, *Stellario nemorum-Alnetum glutinosae* and *Fraxino-Alnetum*, depending on altitude, stream power and local moisture. Finally, the third group is formed by forests developed on waterlogged soils of spring-fed areas and is represented by *Carici remotae-Fraxinetum* and *Piceo-Alnetum*.

Table 4. Formal definitions of the associations based on contribution of sociological species groups as well as on dominance of selected species.

Tabelle 4. Formale Definitionen der Assoziationen basierend auf dem Beitrag soziologischer Artengruppen wie auch der Dominanz ausgewählter Arten.

Association	Formal definition
Salicetum albae	*Salix fragilis* > 25% AND Group Phalaris arundinacea NOT (Group Chaerophyllum hirsutum OR (Group Melandrium rubrum OR Group Veratrum lobelianum)
Salicetum fragilis	*Salix fragilis* > 25% AND Group Chaerophyllum hirsutum
Alnetum incanae	(((*Alnus glutinosa* > 25% OR *Alnus incana* > 25%) AND (Group Melandrium rubrum OR Group Veratrum lobelianum)) OR (*Alnus incana* > 25% AND (Group Phalaris arundinacea OR (Group Chaerophyllum aromaticum OR Group Chaerophyllum hirsutum>25%)))) NOT (Group Carex remota OR Group Calamagrostris villosa)
Stellario nemorum-Alnetum glutinosae	(*Alnus glutinosa* > 25% OR *Fraxinus excelsior* > 25%) AND (Group Asarum europaeum NOT (Group Carex remota OR (Group Filipendula ulmaria OR (Group Carex vesicaria OR Group Melandrium rubrum))))
Fraxino-Alnetum	(*Alnus glutinosa* > 25% OR *Fraxinus excelsior* > 25%) AND ((Group Carex vesicaria OR Group Chaerophyllum aromaticum) NOT (Group Asarum europaeum OR (Group Veratrum lobelianum OR Group Melandrium rubrum)))
Piceo-Alnetum	(*Alnus glutinosa* > 25% OR *Alnus incana* > 25%) AND Group Calamagrostis villosa
Carici remotae-Fraxinetum	Group Carex remota NOT (Group Calamagrostis villosa OR (Group Carex vesicaria OR (Group Chaerophyllum aromaticum OR Group Asarum europaeum)))

A comparison of environmental variables revealed that average altitude (H = 41.60, p = 0.000), river order (H = 86.92, p = 0.000) and stream power index (H = 31.94, p = 0.000) were significantly ($p < 0.01$) different among riparian forest associations, whereas no significant differences were detected among average values of slope, solar radiation and topographic wetness index (H = 14.05, p = 0.03; H = 15.36, p = 0.018; H = 10.30, p = 0.112, respectively) (Fig. 3). In addition, there were significant differences in species richness among the associations (H = 48.01, p = 0.000) (Fig. 4).

3.1 Descriptions of riparian forest associations

3.1.1 *Salicetum albae* Issler 1925 (syn. *Salicetum albo-fragilis* Tx. ex Moor 1958 p.p.)

Diagnostic species: *Calystegia sepium*, *Galium aparine*, *Glechoma hederacea*, *Lamium maculatum*, *Phalaris arundinacea*, *Salix fragilis*, *Urtica dioica*
Constant species: *Aegopodium podagraria*, *Phalaris arundinacea*, *Salix fragilis*, *Urtica dioica*
Dominant species: *Salix fragilis*, *Urtica dioica*

Typically, willow alluvial forest occurs on the floodplains of large lowland rivers, and in the Sudetes it reaches its altitudinal limit and grows only in the lowest part (mainly below 400 m a.s.l.) along the biggest rivers (5.–6. order reaches). Compared to other riparian forest

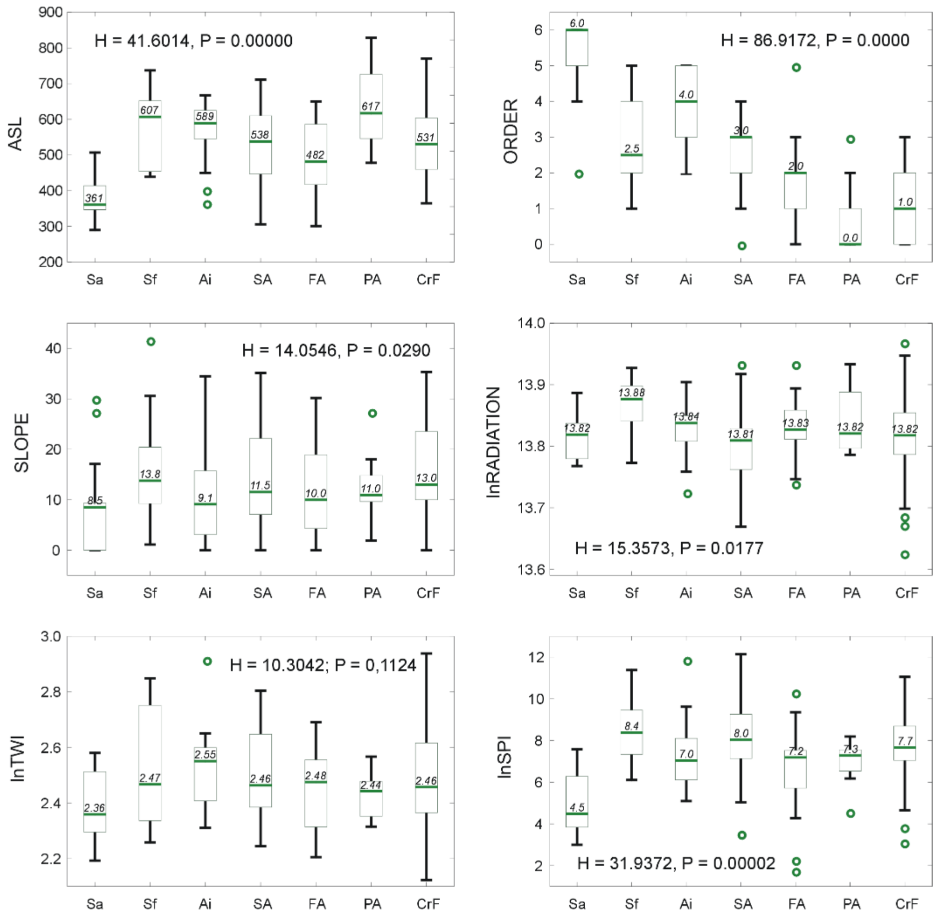

Fig. 3. Comparison of six environmental variables among seven riparian forest associations. Outliers are represented by the circles. Variable abbreviations: ASL – altitude, ORDER – stream order, SLOPE – slope calculated from DEM, lnRADIATION – potential solar radiation transformed using logarithm function, lnTWI – topographic wetness index transformed using logarithm function, lnSPI – stream power index transformed using logarithm function. Association abbreviations: Sa – *Salicetum albae*, Sf – *Salicetum fragilis*, Ai – *Alnetum incanae*, SA – *Stellario-Alnetum*, FA – *Fraxino-Alnetum*, PA – *Piceo-Alnetum*, CrF – *Carici remotae-Fraxinetum*.

Abb. 3. Vergleich von sechs Umweltvariablen von sieben Au- und Quellwald-Assoziationen. Ausreißer sind durch Kreise markiert. Abkürzungen der Variablen: ASL – Höhe, ORDER – Fließgewässer-Ordnungszahl, SLOPE – Neigung, berechnet aus dem digitalen Höhenmodell (DEM), lnRADIATION – logarithmisch transformierte potenzielle Sonneneinstrahlung, lnTWI – logarithmisch transformierter topographischer Nässe-Index, lnSPI – logarithmisch transformierter Strömungskraft-Index. Abkürzungen der Assoziationen: Sa – *Salicetum albae*, Sf – *Salicetum fragilis*, Ai – *Alnetum incanae*, SA – *Stellario-Alnetum*, FA – *Fraxino-Alnetum*, PA – *Piceo-Alnetum*, CrF – *Carici remotae-Fraxinetum*.

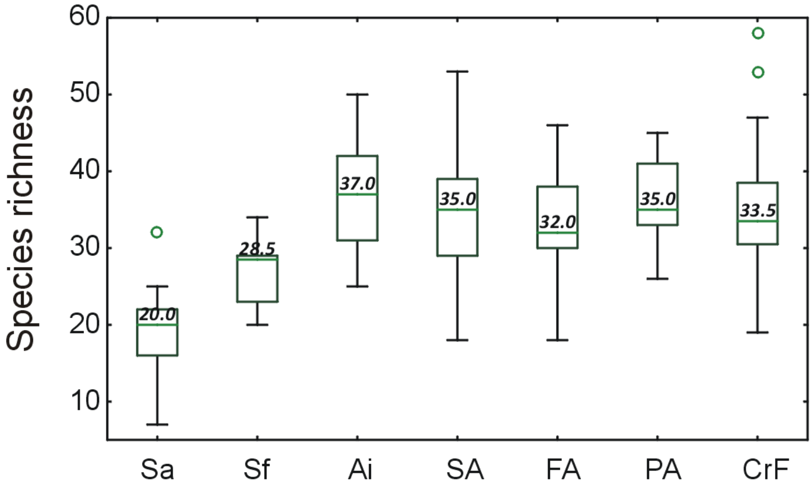

Fig. 4. Comparison of average species richness (medians) among seven riparian forest associations. Outliers are represented by the circles. Abbreviations: Sa – *Salicetum albae*, Sf – *Salicetum fragilis*, Ai – *Alnetum incanae*, SA – *Stellario-Alnetum*, FA – *Fraxino-Alnetum*, PA – *Piceo-Alnetum*, CrF – *Carici remotae-Fraxinetum*.

Abb. 4. Vergleich des mittleren Artenreichtums (Mediane) von sieben Au- und Quellwald-Assoziationen. Ausreißer sind durch Kreise markiert. Abkürzungen: Sa – *Salicetum albae*, Sf – *Salicetum fragilis*, Ai – *Alnetum incanae*, SA – *Stellario-Alnetum*, FA – *Fraxino-Alnetum*, PA – *Piceo-Alnetum*, CrF – *Carici remotae-Fraxinetum*.

communities, *Salicetum albae* is not very rich in species (ca. 20 species per sample plot). The tree layer is dominated by *Salix fragilis*, and other species occur only sporadically. The herb layer is dominated by plants characterized by high nitrogen demands, e.g. *Aegopodium podagraria*, *Glechoma hederacea*, *Phalaris arundinacea* and *Galium aparine*. Vines are also among the frequent species (*Calystegia sepium* and *Humulus lupulus*).

The submontane character of sites localized at the topmost part of the altitudinal range is marked by a lack of *Salix alba*, typically a lowland species, as well as by the sporadic presence of montane species that migrate along the rivers from higher altitudes.

3.1.2 *Salicetum fragilis* Passarge 1957 (syn. *Chaerophyllo hirsuti-Salicetum fragilis* Müller & Görs 1958)

Diagnostic species: *Petasites hybridus*, *Salix fragilis*
Constant species: *Aegopodium podagraria*, *Cirsium oleraceum*, *Petasites hybridus*, *Salix fragilis*, *Urtica dioica*
Dominant species: *Chaerophyllum aromaticum*, *Petasites hybridus*, *Salix fragilis*, *Urtica dioica*

The tree layer is dominated by *Salix fragilis*, with frequent admixture of *Alnus glutinosa*, *Fraxinus excelsior* or *Acer pseudoplatanus*. The morphology of some old willow trees, with creeping and deformed trunks, reflects unfavourable conditions that are due to the strong impact of the high stream power of the mountain rivers and damage caused by the transport of coarse material. The shrub layer is formed by *Salix fragilis* and *Prunus padus*, whereas the herb layer is dominated by nitrophytes and tall-herb species (*Petasites hybridus*, *Chaerophyllum aromaticum* and *Urtica dioica*). A few montane species also occur, e.g. *Carduus personata*, *Chaerophyllum hirsutum* and *Senecio nemorensis* s.l.

This association is typical for the mid-reaches of mountain streams (usually 2.–4. order) in foothills and lower mountain zone (440–740 m a.s.l.). In Poland it has not been reported so far; however, similar communities with domination by *Salix fragilis* were recognised in the Carpathians and were classified as the initial phase of *Alnetum incanae*.

3.1.3 *Alnetum incanae* Lüdi 1921 (Fig. 5)

Diagnostic species: *Aconitum variegatum*, *Alnus incana*, *Angelica sylvestris*, *Anthriscus nitida*, *Campanula latifolia*, *Cardaminopsis halleri*, *Doronicum austriacum*, *Elymus caninus*, *Galeopsis speciosa*, *Geranium sylvaticum*, *Melandrium rubrum*, *Ranunculus platanifolius*, *Stellaria nemorum*, *Valeriana sambucifolia*, *Veratrum lobelianum.*
Constant species: *Acer pseudoplatanus*, *Senecio nemorensis* s.l., *Stachys sylvatica*, *Stellaria nemorum*.
Dominant species: *Alnus glutinosa*, *A. incana*.

This mountain forest occurs along medium and big mountain rivers (usually 4.–5. order reaches) in the mountain zone (450–670 m a.s.l.). It is not present in the Sudetes very often, because there are only a few big rivers at higher altitudes. Typically, the tree layer is dominated by *Alnus incana*, but quite often *A. glutinosa* may dominate. *Salix fragilis* and *Fraxinus excelsior* are the most common admixture. The shrub layer is well developed and, in spite of canopy species, formed by *Acer pseudoplatanus*, *Prunus padus*, *Salix caprea* and *Sorbus aucuparia*. Species of mountain tall-herb communities are the most characteristic part of the herb layer in *Alnetum incanae* (*Aconitum variegatum*, *Anthriscus nitida*, *Campanula latifolia*, *Doronicum austriacum*, *Melandrium rubrum*, *Thalictrum aquilegifolium*, *Valeriana sambucifolia* and *Veratrum lobelianum*). Plants with high trophic demands are also frequent (e.g. *Phalaris arundinacea*, *Galium aparine*, *Glechoma hederacea*, *Urtica dioica*, *Aegopodium podagraria* and *Stachys sylvatica*) and are common with another alluvial forest type, *Salicetum albae*.

3.1.4 *Stellario nemorum-Alnetum glutinosae* Lohm. 1953 (Fig. 6)

Diagnostic species: *Acer platanoides*, *A. pseudoplatanus*, *Allium ursinum*, *Asarum europaeum*, *Corylus avellana*, *Dryopteris filix-mas*, *Euphorbia dulcis*, *Festuca altissima*, *Fraxinus excelsior*, *Galeobdolon luteum*, *Geranium robertianum*, *Lilium martagon*, *Luzula luzuloides*, *Mercurialis perennis*, *Mycelis muralis*, *Paris quadrifolia*, *Petasites albus*, *Polygonatum verticillatum*, *Prenanthes purpurea*, *Pulmonaria officinalis*, *Ranunculus lanuginosus*, *Ulmus glabra*.
Constant species: *Acer pseudoplatanus*, *Aegopodium podagraria*, *Athyrium filix-femina*, *Fraxinus excelsior.*
Dominant species: *Acer pseudoplatanus*, *Fraxinus excelsior*.

Species rich riverine forests most often dominated by *Fraxinus excelsior* and *Acer pseudoplatanus*, but sometimes also by *Alnus glutinosa*. *Ulmus glabra* may also occur as an admixture. The cover by the shrub layer is not very high (ca. 10% on average) and is built by *Fraxinus excelsior*, *Acer pseudoplatanus*, *Corylus avellana* and *Fagus sylvatica*. A rich herb layer is characterized by a significant contribution of forest mesophytes, e.g. *Asarum europaeum*, *Euphorbia dulcis*, *Festuca altissima*, *Mercurialis perennis*, *Milium effusum*, *Pulmonaria officinalis* or *Ranunculus lanuginosus*. Plants typical for waterlogged soils are very

Fig. 5. *Alnetum incanae* along Czarna Woda River near Stronie Śląskie (Śnieżnik Massif) (Photo: R. Pielech, June 2008).

Abb. 5. *Alnetum incanae* entlang des Czarna Woda-Flusses bei Stronie Śląskie (Śnieżnik Massif) (Foto: R. Pielech, Juni 2008).

Fig. 6. *Stellario nemorum-Alnetum glutinosae* along Dańczówka River (Stołowe Mts. National Park) (Photo: R. Pielech, May 2012).

Abb. 6. *Stellario nemorum-Alnetum glutinosae* entlang des Dańczówka-Flusses (Nationalpark Stołowe-Gebirge) (Foto: R. Pielech, Mai 2012).

rare. *Stellario nemorum-Alnetum glutinose* usually occurs along small and medium streams (2.–3. order reaches) in deep and narrow mountain valleys. Plants typical for upslope forests of *Acerion* and *Fagion* alliances (e.g. *Allium ursinum*, *Galium odoratum*, *Lilium martagon*, *Luzula luzuloides*, *Paris quadrifolia*, *Polygonatum verticillatum*, *Prenanthes purpurea*, *Lunaria rediviva*, *Polystichum aculeatum*, *Actaea spicata* or *Lonicera nigra*) may constitute an admixture in the herb layer, due to lateral downslope migration of their propagules. In addition, riverine nitrophytes are frequent, e.g. *Aegopodium podagraria*, *Stachys sylvatica*, *Stellaria nemorum* and *Urtica dioica*. The association was recorded at altitudes 310–710 m a.s.l.

3.1.5 *Fraxino-Alnetum* W. Mat. 1952

Diagnostic species: *Caltha palustris*, *Carex flava*, *C. paniculata*, *C. vesicaria*, *Equisetum fluviatile*, *Frangula alnus*, *Lysimachia vulgaris*, *Scirpus sylvaticus*, *Valeriana dioica.*
Constant species: *Alnus glutinosa*, *Crepis paludosa.*
Dominant species: *Alnus glutinosa*.

Alnus glutinosa dominated the forest with frequent admixtures of *Fraxinus excelsior*. The association is common in lowlands, and in the Sudetes occurs at the margins of its altitudinal range. It was recorded along small streams (1.–2. order reaches) up to 650 m a.s.l. The shrub layer is formed by *Frangula alnus*, *Prunus padus*, *Viburnum opulus*, *Salix caprea* and *S. cinerea*, together with canopy species. Due to waterlogged soil, the herb layer is dominated by a group of wetland species (e.g. *Caltha palustris*, *Carex flava*, *C. panicea*, *C. paniculata*, *C. vesicaria*, *Cirsium rivulare*, *Crepis paludosa*, *Equisetum fluviatile*, *Filipendula ulmaria*, *Juncus effusus*, *Lycopus europaeus*, *Lysimachia vulgaris*, *Scirpus sylvaticus*, *Solanum dulcamara* and *Valeriana dioica*), whereas nitrophytes are less frequent compared to other riverine forest communities.

3.1.6 *Piceo-Alnetum* Mráz 1959 (Fig. 7)

Diagnostic species: *Alnus incana*, *Betula pendula*, *Calamagrostis villosa*, *Deschampsia flexuosa*, *Equisetum sylvaticum*, *Galium palustre* s.l., *Myosotis palustris* s.l., *Picea abies*, *Vaccinium myrtillus*.
Constant species: *Acer pseudoplatanus*, *Athyrium filix-femina*, *Calamagrostis villosa*, *Crepis paludosa*, *Dryopteris austriaca* s.l., *Equisetum sylvaticum*, *Galium palustre* s.l., *Myosotis palustris* s.l., *Oxalis acetosella*, *Picea abies*, *Rubus idaeus*, *Senecio nemorensis* s.l.
Dominant species: *Alnus glutinosa, A. incana*.

This association is typical for spring-fed areas with nutrient-poor, and usually acid, bedrocks. The tree layer is formed by either *Alnus glutinosa* or *A. incana* together with *Picea abies*. The canopy is often open, because treefall gaps are common on the unstable heavily waterlogged ground. The shrub layer is rather poorly developed and formed mainly by canopy species. Two distinct species groups are typical in *Piceo-Alnetum*: species of springs (e.g. *Carex remota*, *Cardamine amara*, *Crepis paludosa*, *Equisetum palustre*, *E. sylvaticum*, *Galium palustre* s.l., *Juncus effusus*, *Myosotis palustris* s.l., *Ranunculus flammula*, *Stellaria alsine* and *Viola palustris*) and acidophytes (*Calamagrostis villosa*, *Deschampsia flexuosa*, *Maianthemum bifolium*, *Solidago virga-aurea* and *Vaccinium myrtillus*). The moss layer is well developed in some sites and dominated by *Sphagnum* spp. This association has never been recognised in Poland before, and it occurs in the montane zone of the Sudetes at altitudes 480–830 m a.s.l.

3.1.7 *Carici remotae-Fraxinetum* Koch 1926 (Fig. 8)

Diagnostic species: *Ajuga reptans*, *Athyrium filix-femina*, *Carex remota*, *C. sylvatica*, *Circaea lutetiana*, *Fraxinus excelsior*, *Lysimachia nemorum*, *Veronica beccabunga*, *V. montana.*
Constant species: *Acer pseudoplatanus*, *Athyrium filix-femina*, *Carex sylvatica*, *Fraxinus excelsior*, *Senecio nemorensis* s.l., *Stachys sylvatica.*
Dominant species: *Alnus glutinosa*, *Fraxinus excelsior.*

The tree layer is dominated by *Alnus glutinosa* or *Fraxinus excelsior* (or both species) and an admixture of *Acer pseudoplatanus*, but *A. incana* may also dominate sporadically. The canopy is usually open as a result of waterlogged soils and frequent treefall. The shrub layer is built by *Acer pseudoplatanus*, *Alnus glutinosa*, *Corylus avellana*, *Fagus sylvatica*, *Fraxinus excelsior* and *Sorbus aucuparia*. The herb layer is dominated by species of spring-fed areas, like *Ajuga reptans*, *Caltha palustris*, *Cardamine amara*, *Carex remota*, *Chrysosplenium alternifolium*, *Circaea intermedia*, *C. lutetiana*, *Crepis paludosa*, *Equisetum sylvaticum*, *Filipendula ulmaria*, *Juncus effusus*, *Lysimachia vulgaris*, *Myosotis palustris*, *Veronica beccabunga* and *V. montana*. Contrary to the *Piceo-Alnetum* association, forest species with higher nutrient demands are frequent, e.g. *Anemone nemorosa*, *Athyrium filix-femina*, *Dryopteris austriaca* s.l., *D. spinulosa* s.l., *Carex sylvatica*, *Festuca gigantea*, *Galeobdolon luteum*, *Geranium robertianum*, *Impatiens noli-tangere* or *Stachys sylvatica*. Some part of the bare ground usually remains unvegetated on the forest floor due to the very high level of the groundwater table. *Carici remotae-Fraxinetum* is typical for places with heavily waterlogged soils and occurs in nutrient-rich spring-fed areas, at valley slopes with groundwater discharge or sometimes along small headwater streams, in foothills and lower montane zone (360–770 m a.s.l.).

4. Discussion

4.1 Methodological consideration

Methods of formalised classification are usually applied to large data sets at broad geographic scales. If applied at the local scale, at least the formal definitions and sociological groups have been created on the basis of large databases (Dítě et al. 2007, Landucci et al. 2011). In this study, I applied this method to a data set of sample plots collected in a local vegetation survey. In addition, this data set covered only one broad vegetation type (riparian forests). While this approach appeared to be satisfactory for detecting syntaxonomical diversity, some limitations must be highlighted here. When sociological species groups are generated on the basis of one vegetation type, only a part of the whole realized niche of the species is taken into consideration, and this applies particularly to species with relatively broad ecological spectra. Thus, the sociological groups used here may not be directly used in studies on other vegetation types. The same situation refers to diagnostic species distinguished on the basis of their fidelity in particular associations. The fidelity measures are calculated in riparian forest associations, but some of the diagnostic species may also frequently occur in other vegetation types. The best examples are species that are typically frequent in *Fagion* and *Acerion* forests (e.g. *Mercurialis perennis*, *Luzula luzuloides*, *Pulmonaria officinalis*, *Ranunculus lanuginosus*, *Lilium martagon*, *Allium ursinum*, *Paris quadrifolia*, *Festuca altissima* and *Lunaria rediviva*), but due to specific landscape configuration they may also

Fig. 7. *Piceo-Alnetum* in spring-fed area near Jagniątków (Karkonosze Mts.) (Photo: R. Pielech, August 2009).

Abb. 7. *Piceo-Alnetum* in einem quelligen Bereich bei Jagniątków (Karkonosze-Gebirge) (Foto: R. Pielech, August 2009).

Fig. 8. *Carici remotae-Fraxinetum* with occurrence of *Equisetum telmateia* in extensive spring-fed area near Wieściszowice (Rudawy Janowickie Mts.) (Photo: R. Pielech, July 2009).

Abb. 8. *Carici remotae-Fraxinetum* mit Vorkommen von *Equisetum telmateia* in einem großflächigen Quellbereich bei Wieściszowice (Rudawy Janowickie-Gebirge) (Foto: R. Pielech, Juli 2009).

occur in one of the riparian forest types (*Stellario-Alnetum*). Due to the narrow geographical context of the analysis and by considering riparian forests only, we have to be aware that these are differential, not character, species.

4.2 Environmental drivers of vegetation diversity

The supervised classification revealed the occurrence of seven riparian forest associations in the Polish part of the Sudetes. The main factors driving the diversity of riparian forest types are related to geomorphology and hydrology. Altitude and river size (in this study represented by river order) are probably the most important. Constant species turnover along the altitudinal gradient is an essential feature of mountain vegetation, and in this study is reflected by significant differences in the altitudinal ranges of the seven riparian forest types. Considering the mountain riparian forest, however, it is difficult to distinguish between altitude-related and hydrology-related gradients because altitude is negatively correlated with stream size. There is a constant change in environmental conditions in river valleys from higher altitudes with headwaters to lower altitudes. This change results in variation of light availability, stream flow, soil moisture, dissolved constituents inputs (e.g. carbon or nitrogen), flood magnitude and duration, erosion and accumulation rates (NAIMAN et al. 1987, GREGORY et al. 1991, NADEAU & RAINS 2007, HUANG et al. 2013). Upstream-downstream interactions have been recognised as a longitudinal gradient, which is considered to be one of the most important dimensions of riverine ecosystems (WARD 1989). Thus, distinguishing between three types of riparian forest: i) alluvial forest of big rivers, ii) forests of the mid-reaches of mountain streams and iii) forests of spring-fed areas may be explained by the existence of altitudinal and longitudinal gradients.

4.3 Syntaxonomical diversity

In this study, two forest associations new to Poland are reported for the first time. *Salicetum fragilis* is well documented in many European countries (OBERDORFER 1992, NEUHÄUSLOVÁ 2003, WILLNER & GRABHERR 2007, NIEMEYER et al. 2010, CHYTRÝ 2013), and it is dominated by *Salix fragilis* and has many species common to lowland alluvial willow forests (e.g. nitrophytes: *Urtica dioica*, *Lamium maculatum*, *Galium aparine*, *Phalaris arundinacea*, *Aegopodium podagraria* and *Chaerophyllum aromaticum*). Thus, this association is included into the *Salicetea purpureae* class, but contrary to other lowland communities of this class, mountain species typically occur here (e.g. *Senecio nemorensis* s.l., *Carduus personata* and *Chaerophyllum hirsutum*). Species from mountain tall-herb communities, which are common to the *Alnetum incanae* association, may also occur (e.g. *Anthriscus nitida*, *Angelica sylvestris* and *Campanula latifolia*). This community is developed in diverse locations, but most often it occurs in contact with *Alnetum incanae* and vegetation of gravel deposits of rivers dominated by *Phalaris arundinacea* and *Petasites hybridus*. The second species had the highest concentrations in sample plots of *Salicetum fragilis* and it is recognised as its diagnostic species. This community appears to represent a seral stage on riverine gravel deposits in succession towards *Alnetum incanae*. In other localities along smaller mountain streams, but with a significant stream gradient (stream slope) and relatively large contributing area, mechanical damage caused by floodwaters and flood-transported coarse material may halt a succession at the level of the disturbance-resistant community of *Salix fragilis*.

Piceo-Alnetum is the second newly recognised riparian forest association in Poland, however, some detailed explanation must be provided here. The name "*Piceo-Alnetum*" was used for the first time in Poland by SOKOŁOWSKI (1980). On the basis of previously collected data (SOKOŁOWSKI 1968, SOKOŁOWSKI & KAWECKA 1970), he described a new spruce-alder-birch riverine forest with a boreal character and named it "*Piceo-Alnetum* ass. nova". However, the name "*Piceo-Alnetum*" had already been used in Germany and the Czech Republic with a different meaning referring to mountain spruce-alder forests in spring-fed areas (*Piceo-Alnetum* Rubner ex Oberdorfer 1957; *Piceo-Alnetum* Mráz 1959) (MORAVEC et al. 2000). In spite of the fact that the name given by Sokołowski is invalid (PRIEDITIS 1997, 1999) (article 5 of International Code of Phytosociological Nomenclature (WEBER et al. 2000)), it was repeated by other authors (KUPRYJANOWICZ 2007, ŁASKA 2008, MATUSZKIEWICZ et al. 2012), leading to syntaxonomical misunderstandings. Communities representing the *Piceo-Alnetum* Mráz 1959 association are typically forests growing in spring-fed areas with waterlogged soils underlain by nutrient-poor bedrocks. For this reason, *Piceo-Alnetum* was most often recorded within the area of the granitoid Karkonosze-Izera Massif. In other parts of the Sudetes, *Piceo-Alnetum* is very rare and limited to higher altitudes, whereas at lower altitudes in nutrient-rich spring-fed areas, forests of *Carici remotae-Fraxinetum* are usually developed. These two associations are distinctly different from riverine forests and are characterized by the presence of spring species (e.g. *Carex remota*, *Juncus effusus*, *Cardamine amara*, *Crepis paludosa*, *Filipendula ulmaria*, *Veronica beccabunga*, *Lysimachia vulgaris*, *Equisetum sylvaticum* and *Myosotis palustris* s.l.).

This study significantly improves the knowledge of the mountain alluvial forest *Alnetum incane* in the Polish part of the Sudetes. Up to now this association was documented by only one relevé (MATUSZKIEWICZ & MATUSZKIEWICZ 1967), and was considered as almost completely destroyed within the studied area. However, fragments of this community were recorded along a few mountain rivers (Dzika Orlica, Bóbr and Czarna Woda). Some transitional comunities between two types of alluvial forests (*Salicetum albae* and *Alnetum incanae*) were also observed and characterised by the canopy being formed by *Alnus incana* and the dominance of alluvial nitrophytes in the herb layer, while mountain species were rare. The association of *Alnetum incanae* is traditionaly considered to be dominated by *Alnus incana*, but this species is relatively rare in the Sudetes, except for areas with alkaline to neutral rocks, where it occurs more frequently. Thus, the tree layer of the mountain alluvial forests *Alnetum incanae* in the Sudetes is often dominated by *Alnus glutinosa*, which has also been shown by other studies (GERŽA 2007).

The association *Stellario nemorum-Alnetum glutinosae* has never been reported before from the Polish part of the Sudetes, but it has been recognised in Poland (MATUSZKIEWICZ 2001a). It usually occurs along the mid-reaches of small mountain streams with a narrow floodplain zone in deep valleys, where errosion preveils over accumulation. As the tree layer is often dominated by *Fraxinus excelsior*, in literature this type of forest was often erroneously classified as *Carici remotae-Fraxinetum*, or less often as *Ficario-Ulmetum*. However, wetland species are absent in *Stellario-Alnetum* because the soil is not waterlogged due to the high stream gradient.

Erweiterte deutsche Zusammenfassung

Einleitung – Ziele dieser Studie waren, (1) die Auwald- und Quellwaldgesellschaften der Sudeten zu ermitteln und (2) die Beziehungen zwischen den Waldgesellschaften und hydrologischen und topographischen Umweltfaktoren zu erfassen.

Material und Methoden – Die Untersuchungen wurden auf den polnischen Teil der Sudeten beschränkt, ein Gebiet von etwa 4000 km². In diesem Gebiet wurden hundert Bachtäler mit gut erhaltenen Auwaldbeständen ausgewählt. Diese Bachtäler wurden von der Quelle (falls im Untersuchungsgebiet) bis zur Mündung oder bis zu dem Ort untersucht, wo der Bach die Sudeten verlässt. Die Gesamtlänge der untersuchten Fließgewässer betrug 870 km. Alle gefundenen gut erhaltenen Auwaldfragmente wurden erfasst. Dabei wurden 268 Vegetationsaufnahmen angefertigt.

Auf der Grundlage von digitalen GIS-Daten wurden sechs Umweltvariablen berechnet. Primäre (Meereshöhe, Hangneigung) und sekundäre (Topographic Wetness Index TWI, Stream Power Index SPI) topographische Attribute wurden mittels eines digitalen Höhenmodells (DEM) mit 10 m Auflösungsvermögen erhoben. Zudem wurde mittels DEM die potenzielle Solarstrahlung errechnet, und ein digitales Fließgewässernetz diente dazu, die Größenordnung des Baches gemäß der Flussordnungszahl nach Strahler zu bestimmen.

Die Auwaldgesellschaften wurden mit der Cocktail-Methode klassifiziert. Als Zielgruppen wurden die bisher aus den Sudeten bekannten Auwaldassoziationen verwendet. Die formalen Definitionen der Cocktail-Gruppen wurden auf der Grundlage von Expertenwissen und früheren Beschreibungen der Vegetationseinheiten erstellt. Zehn Pflanzenarten wurden aufgrund von Expertenwissen subjektiv soziologischen Artengruppen zugeordnet. Qualitative (Vorkommen oder Fehlen der soziologischen Gruppen) und quantitative (Kriterien der Deckung einiger Arten) Bedingungen wurden kombiniert und mit logischen Operatoren (Und, Oder, Nicht) verknüpft, um die Vegetationseinheiten formal zu definieren. Vegetationsaufnahmen mit zweifelhaftem Klassifikationsergebnis wurden dann anhand ihrer statistischen Ähnlichkeit einer der Einheiten zugeordnet. Diagnostische Arten sind aufgrund ihrer Treue zu den Gesellschaften bestimmt worden. Nach Angleichung der Gruppengrößen wurde der phi-Koeffizient (ϕ) als statistisches Treuemaß berechnet. Zusätzlich wurde mit dem Exakten Fisher-Test die Signifikanz ($p = 0{,}001$) des Treuemaßes ermittelt. Nur Arten mit einem phi-Wert größer als 0,25 wurden als diagnostische Arten gewertet. Konstante (stete) und dominante Arten wurden ebenfalls bestimmt, wobei die Prozentschwellenwerte in Anlehnung an ähnliche Arbeiten gewählt wurden. Schließlich wurde eine synoptische Tabelle angefertigt, um die Unterschiede zwischen den Assoziationen aufzuzeigen. Ökologische Unterschiede zwischen den Assoziationen wurden anhand der Durchschnittswerte der Umweltvariablen verglichen. Der nicht-parametrische Kruskal-Wallis-Test wurde verwendet, um die Signifikanz der ökologischen Unterschiede zu testen sowie um den Artenreichtum der Assoziationen zu vergleichen.

Ergebnisse und Diskussion – Mittels Klassifikation auf der Grundlage formaler Definitionen wurden die Vegetationsaufnahmen auf sieben Zielassoziationen verteilt. Diese Assoziationen ließen sich nach ökologischen Gesichtspunkten auf drei Gruppen verteilen. Wälder auf Schwemmböden sind an den größeren Bächen häufig, entweder in den tieferen Lagen oder an Bergbächen, aber stets in ausgedehnten Auen, wo die Sedimentation wirksamer ist als die Erosion. *Salicetum albae* und *Alnetum incanae* repräsentierten diese Gruppe. Die zweite Gruppe umfasst die Wälder an kleinen und mittleren Bergbächen mit nur schmaler Uferzone. Sie war repräsentiert durch *Salicetum fragilis*, *Stellario nemorum-Alnetum glutinosae* und *Fraxino-Alnetum*, abhängig von Meereshöhe, Fließgeschwindigkeit und Feuchte des Standorts. Die dritte Gruppe schließlich bildeten Wälder auf wassergesättigten Böden in Quellgebieten, repräsentiert durch *Carici remotae-Fraxinetum* und *Piceo-Alnetum*. Die Assoziationen *Salicetum fragilis* und *Piceo-Alnetum* wurden das erste Mal für Polen nachgewiesen.

Beim Vergleich der Umweltvariablen erwiesen sich mittlere Meereshöhe, Größenordnung des Baches und Stream Power Index als signifikant verschieden zwischen den Auwaldassoziationen, während für Hangneigung, Solarstrahlung und Topographic Wetness Index keine signifikanten Unterschiede bei den Mittelwerten gefunden wurden. Ein Vergleich der mittleren Artenzahlen belegte signifikante Unterschiede im Artenreichtum der Assoziationen.

Acknowledgements

I gratefully acknowledge the staff of the Department of Botany (Institute of Environmental Biology, University of Wrocław), especially Jadwiga Anioł-Kwiatkowska and Ewa Szczęśniak for their help in conducting the research, and Zygmunt Dajdok for insightful comments on the manuscript. I also thank Jan Douda and Michal Gerža for sharing informations on riparian forests in the Czech Republic, and Krzysztof Zając for his assistance with field surveys. This research was partly funded by a grant from the Ministry of Science and Higher Education, Republic of Poland (N N304 074736).

Supplements

Supplement S1. Combined synoptic table of frequency (%) and fidelity for seven associations of riparian forests in the Polish part of the Sudetes.

Beilage S1. Übersichtstabelle der Stetigkeit (%) und Treue für sieben Assoziationen von Auwäldern und Quellwäldern im polnischen Teil der Sudeten.

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Supplement S1. Combined synoptic table of frequency (%) and fidelity for seven associations of riparian forests in the Polish part of the Sudetes. Diagnostic species ($\varphi > 0.25$) are marked by a grey background and are sorted according their diagnostic value in each group. Significant values of fidelity (phi coefficient multiplied by 100) are given in superscript. Species noted in less then three associations are listed at the end of table. Abbreviations: Sa – *Salicetum albae* , Sf – *Salicetum fragilis* , Ai – *Alnetum incanae* , SA – *Stellario-Alnetum* , FA – *Fraxino-Alnetum* , PA – *Piceo-Alnetum* , CrF – *Carici remotae-Fraxinetum* .

Beilage S1. Übersichtstabelle der Stetigkeit (%) und Treue für sieben Assoziationen von Auwäldern und Quellwäldern im polnischen Teil der Sudeten. Diagnostische Arten ($\varphi > 0.25$) sind durch einen grauen Hintergrund markiert und gemäß ihrem diagnostischen Wert in jeder Gruppe sortiert. Signifikante Treue-Werte (phi-Koeffizient multipliziert mit 100) sind als hochgestellte Zahl dargestellt. Arten in weniger als drei Assoziationen sind am Ende der Tabelle aufgeführt. Abkürzungen: Sa – *Salicetum albae* , Sf – *Salicetum fragilis* , Ai – *Alnetum incanae* , SA – *Stellario-Alnetum* , FA – *Fraxino-Alnetum* , PA – *Piceo-Alnetum* , CrF – *Carici remotae-Fraxinetum* .

No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Association	**Sa**	**Sf**	**Ai**	**SA**	**FA**	**PA**	**CrF**
No. of relevés	**15**	**10**	**23**	**37**	**21**	**11**	**56**
D.S. *Salicetum albae*							
Calystegia sepium	47 $^{65.5}$	.	.	.	.	.	.
Glechoma hederacea	53 $^{44.1}$	10	26	8	5	.	2
Phalaris arundinacea	87 $^{43.4}$	60	57	11	14	9	12
Galium aparine	80 $^{38.1}$	60	35	19	29	9	16
Lamium maculatum	60 $^{36.7}$	60	17	16	.	.	4
Urtica dioica	100 $^{29.2}$	100	70	70	33	45	45
D.S. *Salicetum fragilis*							
Petasites hybridus	20	90 $^{64.4}$	39	3	10	.	2
D.S. *Alnetum incanae*							
Ranunculus platanifolius	.	.	35 ^{56}	.	.	.	.
Melandrium rubrum	20	10	61 $^{54.3}$	3	5	.	2
Aconitum variegatum	.	.	26 $^{48.2}$	.	.	.	.
Doronicum austriacum	.	.	30 $^{47.5}$	.	5	.	.
Cardaminopsis halleri	7	.	43 $^{43.5}$	8	.	9	7
Geranium sylvaticum	7	10	35 $^{40.8}$	.	.	.	4
Veratrum lobelianum	.	.	39 $^{40.4}$	11	10	.	9
Valeriana sambucifolia	7	10	65 $^{38.3}$	19	24	27	21
Anthriscus nitida	.	30	48 $^{37.8}$	16	5	.	5
Galeopsis speciosa	.	10	30 $^{37.6}$	.	5	.	4
Angelica sylvestris	7	30	57 $^{33.2}$	5	43	9	7
Elymus caninus	33	.	35 $^{28.9}$	5	10	.	.
Campanula latifolia	.	20	22 $^{27.2}$	.	.	.	.
Stellaria nemorum	80	70	96 $^{27.1}$	76	19	45	61
D.S. *Stellario nemorum-Alnetum glutinosae*							
Asarum europaeum	.	.	13	76 $^{69.5}$	.	.	16
Mercurialis perennis	.	.	9	73 $^{61.8}$	10	9	16
Corylus avellana	7	.	.	57 $^{48.8}$	5	.	34
Ulmus glabra	7	10	4	51 $^{48.6}$	5	.	9
Dryopteris filix-mas	.	20	13	65 $^{48.4}$	10	.	23
Pulmonaria officinalis	.	.	13	46 $^{45.1}$	5	9	5
Ranunculus lanuginosus	.	10	17	46 $^{43.3}$	.	.	9
Luzula luzuloides	.	.	.	22 $^{39.5}$	.	.	4
Galeobdolon luteum	13	10	39	76 $^{38.6}$	19	9	55
Euphorbia dulcis	.	.	13	38 $^{38.4}$	14	.	4
Prenanthes purpurea	.	.	4	30 $^{38.2}$	5	.	7
Lilium martagon	.	.	.	16 $^{37.7}$	.	.	.
Allium ursinum	7	.	.	24 $^{35.2}$	.	.	5
Petasites albus	.	.	9	49 $^{34.7}$	5	27	29
Geranium robertianum	7	10	17	57 $^{32.3}$	24	9	39
Paris quadrifolia	.	.	4	19 $^{32.1}$	.	.	4
Festuca altissima	.	.	4	19 $^{32.1}$	.	.	4
Polygonatum verticillatum	.	.	13	35 ^{30}	10	9	14
Acer platanoides	20	30	35	59 ^{28}	29	.	27
Acer pseudoplatanus	27	30	87	97 $^{26.9}$	48	82	93 ^{23}
Mycelis muralis	.	20	.	24 $^{25.2}$	5	.	5
D.S. *Fraxino-Alnetum*							
Carex vesicaria	.	.	.	.	33 $^{54.8}$	.	.
Valeriana dioica	.	.	.	3	38 $^{46.8}$	9	4
Scirpus sylvaticus	.	.	17	3	43 $^{41.5}$	.	14
Carex flava	.	.	.	.	24 $^{40.1}$	.	5
Caltha palustris	7	10	13	5	57 ^{40}	18	21
Frangula alnus	.	.	4	3	33 $^{39.7}$	9	4
Equisetum fluviatile	.	.	.	.	19 $^{38.6}$	.	2
Lysimachia vulgaris	.	10	13	5	62 $^{34.1}$	45	43
Carex paniculata	.	.	.	.	19 $^{31.2}$	9	.
D.S. *Piceo-Alnetum*							
Calamagrostis villosa	.	.	.	3	.	82 $^{82.2}$	9
Equisetum sylvaticum	.	.	4	8	38	100 $^{62.9}$	57 $^{24.6}$
Vaccinium myrtillus	.	.	.	3	.	45 $^{60.8}$	2
Galium palustre s.l.	7	10	13	.	29	82 $^{58.8}$	14
Betula pendula	.	10	9	3	14	64 $^{54.4}$	9
Deschampsia flexuosa	.	.	.	.	.	27 $^{49.3}$	.
Picea abies	.	.	26	46	29	82 $^{46.3}$	27
Myosotis palustris s.l.	.	40	43	5	57	91 $^{40.4}$	57
D.S. *Carici remotae-Fraxinetum*							
Lysimachia nemorum	7	10	13	27	19	45	80 $^{46.5}$
Carex remota	.	.	4	11	29	73	73 $^{42.4}$
Carex sylvatica	.	10	26	62	43	27	86 ^{42}
Rubus spp.	13	.	4	22	19	36	57 $^{35.1}$
Circaea lutetiana	.	.	4	16	10	.	30 $^{31.6}$
Veronica beccabunga	.	10	.	3	14	9	30 $^{29.1}$
Veronica montana	.	.	4	11	.	9	25 $^{28.7}$
Ajuga reptans	7	.	26	22	19	36	52 $^{27.8}$
Athyrium filix-femina	13	40	61	89	48	82	93 $^{26.8}$
D.S. common for more than one vegetation type							
Salix fragilis	87 ^{49}	90 $^{51.9}$	35	.	5	.	2
Alnus incana	13	10	70 $^{37.2}$	3	10	73 ^{40}	21
Fraxinus excelsior	27	50	65	97 $^{30.1}$	62	36	93 $^{26.3}$

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Fortsetzung auf der Rückseite

No.	1	2	3	4	5	6	7
Association	**Sa**	**Sf**	**Ai**	**SA**	**FA**	**PA**	**CrF**
No. of relevés	**15**	**10**	**23**	**37**	**21**	**11**	**56**
Other species							
Ranunculus repens	20	20	13	5	52	45	55 [22.3]
Senecio nemorensis s.l.	7	70	87	78	67	100	82
Stachys sylvatica	73	50	83	76	57	18	84
Cirsium oleraceum	40	90	78	24	52	64	39
Chrysosplenium alternifolium	7	50	22	16	10	9	38
Salix capraea	7	10	26	3	19	18	2
Rumex subgen. *Rumex* sect. *Rumex*	13	20	22	8	14	18	23
Dactylis glomerata	20	50	26	11	10	9	12
Alnus glutinosa	40	40	78	35	90	64	71
Festuca gigantea	40	40	48	27	24	9	48
Impatiens noli-tangere	7	20	61	62	29	45	66
Deschampsia cespitosa	13	30	61	30	76	73	50
Rubus idaeus	27	60	74	54	71	82	59
Geum urbanum	60	30	22	54	10	27	38
Aegopodium podagraria	87	100	78	86 [19.4]	52	18	23
Chaerophyllum aromaticum	53	50	22	24	24	9	4
Poa trivialis	33	40	35	11	33	45	23
Geum rivale	7	20	43	5	52	27	23
Chaerophyllum hirsutum	13	70	65	51	48	55	45
Impatiens parviflora	20	20	35	49	19	18	34
Scrophularia nodosa	7	10	35	11	5	18	12
Primula elatior	7	30	57	24	38	36	36
Filipendula ulmaria	27	60	74	32	62	36	52
Dryopteris spinulosa s.l.	.	10	13	51	57	73	68 [24.3]
Crepis paludosa	.	20	52	41	86	91	73
Oxalis acetosella	.	20	30	65	33	82	62
Heracleum sphondylium	7	40	22	8	10	.	4
Equisetum arvense	.	20	39	8	48	55	39
Thalictrum aquilegifolium	.	10	26	14	14	9	7
Dryopteris austriaca s. l.	.	10	26	32	24	82	45
Sorbus aucuparia	7	.	35	24	62	73	45
Glyceria fluitans	.	10	13	8	14	36	20
Epilobium montanum	7	10	26	11	19	.	21
Poa nemoralis	.	30	17	41	5	9	23
Prunus padus	20	30	26	8	33	.	16
Agrostis stolonifera	.	30	4	3	14	18	4
Cardamine amara	.	10	9	.	43	36	43 [23.2]
Juncus effusus	.	.	4	5	52	64	48 [22.1]
Circaea intermedia	.	.	13	22	10	18	27
Carduus personata	20	40	35 [22.6]	5	5	.	.
Milium effusum	7	.	4	30	10	.	12
Fagus sylvatica	.	.	22	46	19	55	43
Calamagrostis arundinacea	.	.	13	5	14	9	21
Poa remota	.	20	22	11	.	18	5
Anthriscus sylvestris	27	30	17	3	5	.	.
Brachypodium sylvaticum	7	.	17	22	10	.	18
Galeopsis tetrahit s.l.	.	.	17	3	5	27	5
Viola reichenbachiana	.	.	4	27	14	9	12
Anemone nemorosa	.	.	9	27	29	18	23
Dactylorhiza fuchsii	.	.	4	3	5	9	5
Galium odoratum	.	.	4	41	14	.	34
Circaea alpina	.	.	.	3	5	9	4
Populus tremula	.	.	4	3	.	18	2
Melica nutans	.	.	4	11	14	.	7
Veronica chamaedrys	.	10	13	5	.	9	.
Cirsium palustre	.	.	4	.	24	36	4
Carex pallescens	.	.	.	3	24	9	12
Quercus petraea	.	.	4	3	.	9	12
Viburnum opulus	.	.	4	.	19	9	18
Carex echinata	.	.	.	3	19	18	4
Alchemilla spp.	.	10	13	.	5	.	2
Fragaria vesca	.	.	.	5	14	9	7
Campanula patula	.	10	.	5	5	9	.
Hypericum maculatum	.	10	9	14	.	.	7
Hordelymus europaeus	.	.	4	11	10	.	14
Vicia sepium	.	20	17	5	.	.	2
Maianthemum bifolium	.	.	.	8	5	27	7
Sambucus nigra	13	.	9	5	.	.	7
Galeopsis pubescens	.	10	22	3	.	.	5
Carex brizoides	13	.	22	.	10	.	4
Daphne mezereum	.	.	.	8	10	9	12
Lapsana communis	.	10	4	8	.	.	2
Artemisia vulgaris	7	20	4	.	.	.	.
Phegopteris connectilis	.	.	.	5	.	18	2
Lysimachia nummularia	7	.	9	3	.	.	.
Prunus avium	.	.	.	3	5	.	2
Ribes uva-crispa	.	.	.	14	5	.	2
Lunaria rediviva	.	.	9	14	.	.	4
Ranunculus flammula	.	.	.	.	10	18	2
Solidago virgaurea	.	.	.	3	.	18	2
Phyteuma spicatum	.	.	13	22	.	.	4
Crataegus laevigata	.	.	.	3	5	.	4
Scutellaria galericulata	.	10	.	.	.	9	2
Salix viminalis	7	10	4	.	.	.	.
Salix purpurea	27	10	9	.	.	.	.
Rumex sect. *Acetosa*	.	20	17	.	.	18	.
Taraxacum officinale	7	.	.	3	.	.	5
Alliaria petiolata	13	20	.	5	.	.	.
Rubus caesius	.	.	.	3	.	18	2
Stellaria holostea	7	.	4	14	.	.	.
Sambucus racemosa	13	.	.	.	5	.	2
Betula pubescens	.	.	9	3	5	.	.
Symphytum officinale	20	.	22	.	5	.	.
Cornus sanguinea	7	.	.	.	5	.	2
Gymnocarpium dryopteris	.	.	.	11	.	9	4
Holcus mollis	.	.	.	3	10	.	5
Carex canescens	.	.	4	.	5	.	2
Sanicula europaea	.	.	.	16	.	9	9
Luzula pallescens	.	.	.	3	5	.	2
Stellaria uliginosa	.	.	4	.	10	.	11
Geranium phaeum	7	20	.	8	.	.	.
Poa palustris	.	10	4	.	.	.	2
Prunella vulgaris	.	.	4	5	5	.	.

Species noted in one or two groups only (frequencies are given in brackets)**:** *Ficaria verna* 4(3), 7(11); *Viola palustris* 5(10), 6(18); *Calamagrostis canescens* 6(18), 7(2); *Carex panicea* 5(14), 7(2); *Humulus lupulus* 1(13), 7(2); *Impatiens glandulifera* 1(13), 3(9); *Ribes alpinum* 2(10), 4(3); *Ranunculus acris* 5(10), 7(2); *Chrysosplenium oppositifolium* 3(9). 7(7); *Actaea spicata* 4(16), 7(4); *Lychnis flos-cuculi* 5(10), 7(2); *Mentha ×verticillata* 6(9), 7(2); *Cirsium rivulare* 5(14), 6(9); *Lonicera nigra* 4(3), 7(2); *Vinca minor* 4(3), 7(2); *Tanacetum vulgare* 1(13), 3(4); *Anthoxanthum odoratum* 5(10), 6(9); *Sanguisorba officinalis* 2(10), 5(5); *Cardamine hirsuta* 3(9), 7(2); *Euonymus europaea* 4(8), 7(2); *Agrostis capillaris* 3(4), 5(5); *Phragmites australis* 1(7), 6(9); *Solanum dulcamara* 1(13), 5(19); *Tilia cordata* 4(11), 7(4); *Glyceria nemoralis* 5(10), 7(4); *Equisetum palustre* 5(14), 6(18); *Carex pendula* 6(9), 7(4); *Lonicera xylosteum* 4(11), 5(10); *Tilia platyphyllos* 4(3), 5(5); *Polygonatum multiflorum* 4(3), 7(2); *Alopecurus pratensis* 2(20); *Myrrhis odorata* 3(9); *Cirsium arvense* 1(13); *Agrostis canina* 5(5); *Campanula trachelium* 4(11); *Salix cinerea* 5(14); *Ulmus laevis* 4(5); *Reynoutria japonica* 1(13); *Lycopus europaeus* 5(10); *Equisetum telmateia* 7(5); *Chamaenerion angustifolium* 3(4); *Stellaria uliginosa* 6(18); *Epilobium palustre* 2(10); *Moehringia trinervia* 4(8); *Cardamine trifolia* 7(2); *Stellaria media* 4(3); *Dentaria bulbifera* 4(8); *Rosa pendulina* 4(8); *Dactylis polygama* 7(2); *Mulgedium alpinum* 6(9); *Polygonum bistorta* 5(5); *Cardamine flexuosa* 6(9); *Agrostis gigantea* 3(9); *Crataegus ×macrocarpa* 7(2)