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On the occurrence of the arctic-alpine and endemic species in the high-altitude vegetation of the Western Carpathians

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Abstract: This contribution brings the overall knowledge on quantitative distribution of endemic and relic arctic-alpine taxa of vascular plants in the high-altitude plant communities of the Western Carpathians. The occurrence of the phytogeographically relevant floristic elements in the high-mountain vegetation of the Western Carpathians was analysed based on the synoptic phytosociological tables. One of the most important conditions for the speciation of new taxa (incl. endemics), as well as for preservation of relic taxa (depending on the plasticity of individual taxa), is the diversity of the geological bedrock and the rugged relief, which directly influence the habitat diversity and in turn affect the diversity of the flora and vegetation. The data analysis revealed that the presence of both floristic elements in the analysed syntaxa increases with 1) increasing altitude, 2) increasing variability of the geological bedrock and 3) with more rugged relief. Both groups of geographical elements reach the highest proportion in extreme windward high-altitude habitats with low snow-cover (*Oxytropido-Elynion*, *Festucion versicoloris*, *Caricion firmae*), as well as in the habitats with a long-lasting snow cover that considerably shortens the vegetation season (*Arabidion caeruleae*, *Salicion herbaceae*).

Keywords: floristic elements, phytogeography, plant communities, sky islands, vegetation survey.

Introduction

Mountains are especially rich in endemic and relic species. The large number of endemics in these areas is connected with their isolation, as well as with the extreme diversity of environmental conditions (particularly edaphic and climatic). High mountains are not only places, where old relics could have survived, but also where intense speciation occurs at present giving rise to new endemic taxa (cf. PIĘKOŚ-MIRKOWA et al. 1996).

The peculiarity of flora of a particular region can be determined by species richness, the overall composition and its specific evolution. The endemic taxa constitute the most important particularities, which are specific and irreplaceable components of the flora, making it distinguishable from other floras of often geographically close areas. Conditions of the origin predetermine the distribution area of these species, restricted mainly to the high mountains (their parts, or even individual peaks) or less often to the "habitat islands" with specific substratum (saline habitats, eolian sands, serpentinites etc.).

Since the endemics belong to the most precious components of the natural heritage of each country, there is an extensive literature concerned with the analysis of endemism at various spatial levels; the regional (national) analyses, analyses of whole mountain ranges or European overviews (e.g., PAWŁOWSKI 1969, 1970; HENDRYCH 1982). To define the accurate boundaries of the distributional area, the taxonomical and chorological studies of individual taxa (e.g., HENDRYCH 1977, 1993, 1995; GOLIAŠOVÁ 1985; DVOŘÁKOVÁ 2003, etc.) are of a great value. Meanwhile, the studies dealing with the biology of individual taxa or endemics of certain regions are less frequent. Within the Western Carpathians, the first group of works is represented e.g., by the study of the biology of the stenoendemic of the Muránska Planina Mts – *Daphne arbuscula* (ERDELSKÁ & TURIS 1995, 1996) or the study about the phytosociology of the subendemic taxon of the Veľká Fatra Mts – *Cyclamen fatrense* (KANKA et al. 2008). An excellent example of the second group of works is the study by PIĘKOŚ-MIRKOWA et al. (1996) which includes the results of the population study of 33 endemic taxa of vascular plants and the study of their habitats in the Polish part of the Tatra Mountains. The overall study by KLIMENT (1999) contains the data on current distribution, as well as the basic information on ecological and coenotical valence, endangerment and further characteristics of the Carpathian endemics.

The relic arctic-alpine taxa represent another important element of the regional flora. They shifted to Central European flora from the North, together with the arctic and subarctic tundra, some of them during the last glacial cycle (~135 kyr, see HEWITT 1996). They are now distributed in arctic latitudes (zonal distribution in Scandinavia, Greenland, Alaska, arctic Siberia, and large mountain systems in Canada and the USA) and in the more southern mountain ranges, where they are restricted to the highest summits – in Europe they show an extrazonal distribution in the Alps, Carpathians, Pyrenees, Apennines, Dinarides and the Rilo–Rhodopean massifs (e.g., PETRÍK et al. 2005; HÁJKOVÁ et al. 2006). In the Western Carpathians, they have been preserved mainly at high altitudes on exposed stands, such as windward slopes and edges of rocky crests and peaks. Being part of the high-altitude vegetation threatened by climatic changes, they belong to the most endangered species. Many of them represent the threatened taxa included in the red lists (for the Western Carpathians see ČEŘOVSKÝ et al. 1999).

The rare and relic taxa have attracted the attention of botanists from the beginning. Of a great value are the studies dealing with the ecology, chorology and taxonomy of particular arctic-alpine species (see e.g., PAWŁOWSKI & STECKI 1925; KRAJINA 1938; ŠMARDA 1955; BERNÁTOVÁ & PETRÍK 1983 for studies concerning the Western Carpathians). There is also an extensive literature dealing with biogeographical definitions of floristic elements, including the arctic-alpine plants (e.g., PAWŁOWSKI 1929; MÁTHÉ 1940; WALTER & STRAKA 1970; PAWLOWSKA 1977; HENDRYCH & HENDRYCHOVÁ 1989; DOSTÁL & ČERVENKA 1991, 1992; AESCHIMANN et al. 2004). The statistical analysis of the distribution of geographical elements occurring in the high-altitude vegetation of the Western Carpathians was performed by ŠIBÍKOVÁ et al. (2010). The studies of high-altitude vegetation with the occurrence of arctic-alpine species have also been published recently (PETRÍK et al. 2005; ŠIBÍK et al. 2004, 2005; etc.). Based on long-lasting studies of West Carpathian montane to subnival vegetation, complete overview of the high-altitude vegetation of Slovakia has been prepared (KLIMENT & VALACHOVIČ 2007), forming part of the monographic series of the *Plant Communities of Slovakia*.

This contribution brings the overall knowledge on quantitative distribution of endemic and relic taxa in the high-altitude plant communities of the Western Carpathians, with the following specific aims: i) to compare the occurrence of the phytogeographically relevant floristic elements (endemic and arctic-alpine species) among the high-altitude vegetation units of the Western Carpathians and evaluate the relationships between the geomorphological and ecological parameters of the habitats and the quantity of relic and endemic taxa; and ii) to perform the data analysis based, contrary to ŠIBÍKOVÁ et al. (2010), on the data from the synoptic tables.

Material and methods

The data for survey were obtained from the Slovak National Vegetation Database (JAROLÍMEK & ŠIBÍK 2008; ŠIBÍKOVÁ et al. 2009) and from the private databases of the authors, stored in the Turboveg program (HENNEKENS & SCHAMINÉE 2001). The sources of data (the number of relevés, the name of the author, the year of publication and the relevé number or the number of the table in the original source) for each particular column of the synoptic table are identical to the sources of data published in Kliment & Valachovič (2007).

All relevés have been collected according to the principles of the Zürich-Montpelliér school (BRAUN-BLANQUET 1964; WESTHOFF & VAN DER MAAREL 1978). They were transformed into the nine-degree ordinal scale (VAN DER MAAREL 1979) in order to obtain data that can be compared by means of numerical classification. Taxa that were determined only at the genus level were excluded from the numerical analysis; some taxa were included into more broadly defined aggregates.

To evaluate their significance, we considered not only the number of the species belonging to both geographical elements studied, but also the proportion of their presence (the sum of the frequency in % = ∑Co) to the presence of all of the vascular plants ($\sum Co_{Vasc}$) in the individual syntaxon (Table 2).

The nomenclature of the plants follows the checklist of MARHOLD & HINDÁK (1998); rare exceptions are added with the author's citation. The names of the subspecies in the synoptic table are abbreviated and marked by an asterisk (*).

The header of the synoptic table carries the information on the number of the relevés per given column and an average number of taxa in a community. In a given column, the constancy values of a taxon are expressed in %. The upper index, accompanying the constancy values, is indicative of the weighted average value of the cover/abundance of a taxon in a given column (in ordinal scale 1–9). The taxa in the table are grouped according to their diagnostic value.

The Arctic-alpine elements were defined according to ŠIBÍKOVÁ et al. (2010) on the basis of following works: PAWŁOWSKI (1929, 1969), MÁTHÉ (1940), HESS ET AL. (1967, 1970, 1972), WALTER & STRAKA (1970), ČIHAŘ & POSPÍŠIL (1976), PAWLOWSKA (1977), HENDRYCH & HENDRYCHOVÁ (1989), DOSTÁL & ČERVENKA (1991, 1992), SIMON et al. (1992), ČEŘOVSKÝ et al. (1999), AESCHIMANN et al. (2004) and Flore Alpes (www.florealpes.com). The endemic taxa are in accordance with KLIMENT (1999). To simplify the analysis and avoid the taxonomic problems, all the endemics were merged into five categories: Carpathian endemics, Carpathian subendemics, East Carpathian endemics, West Carpathian endemics and West Carpathian subendemics.

Results

The presence of phytogeographically important taxa

The postglacial history and past environmental conditions of the high-altitude habitats resulted into the state that these sites host both, relic taxa, which have survived the past conditions in the refugia; and endemics, which have successfully adapted to changes in the environment. In the Western Carpathians, both geographical elements are represented by the high number of taxa (Table 1). According to their ecological characteristics, we can see that their presence in the analysed syntaxa increases with 1) increasing altitude, 2) increasing variability of the geological bedrock, and 3) with more rugged relief. The rugged relief affects the distinct changes seen in habitat conditions, even on a small scale. Both groups of geographical elements reach the highest proportion in extreme windward high-altitude habitats with low snow-cover (*Oxytropido-Elynion*, *Festucion versicoloris*, *Caricion firmae*), as well as in the habitats with a long-lasting snow cover that considerably shortens the vegetation season (*Arabidion caeruleae*, *Salicion herbaceae*). They reach the lowest proportion on the alluviums and the banks of montane streams (*Petasition officinalis*). The proportions of both of the geographical elements changed more distinctly in favour of the endemics (Table 2) in the plant communities that occurred on shallow carbonate soils on sunny slopes (*Astero alpini-Seslerion calcariae*), in the vegetation complexes of the tall-herb plant communities (*Calamagrostietalia villosae*, *Adenostyletalia alliariae*) and in the phytocoenoses of the subalpine deciduous shrubs (*Salicion silesiacae*). Despite the significant proportion of endemics, the arctic-alpine taxa prevails in the relic alpine plant communities, such as the communities of the strongly wind-exposed slopes and the edges of rocky crests (the class *Carici rupestris-Kobresietea*) and ecologically similar plant communities of the alliance *Caricion firmae* (*Elyno-Seslerietea*).

There is a total of 70 endemic taxa of the Carpathians present in the analysed syntaxa, and that 27 of them are the Carpathian endemics, 11 are the Carpathian subendemics, 28 are the West Carpathian endemics (including the subregion endemics), and 4 are the West Carpathian subendemics. The highest number of endemic species was recorded in the plant communities of the alliance *Seslerion tatrae* (42), while the lowest number of endemic species was recorded in the communities of the alliance *Loiseleurio-Vaccinion* (9). Based on the frequency, the highest proportion of the endemic species to the vascular plants is in the alliance *Arabidion caeruleae* (22.42) and the suballiance *Astero-Seslerienion* (21.55), while the lowest proportion is in the alliance *Petasition officinalis* (1.18).

From the comparison of marginal values, the significant differences between the overall count of the endemic taxa (often occurring only sparsely; see Table 1) and their real proportion of the community assembly can be observed. The Carpathian endemics are more often found in most of the alliances than the West Carpathian endemics with the exception of the class *Elyno-Seslerietea* and the alliance *Oxytropido-Elynion* (Table 2).

Some of the arctic-alpine taxa survived the last glaciations also in extreme high-altitude habitats with a very short vegetation season. During the post-glaciations period, no other plants could spread to replace them in such habitats, coping with the adversity selection, which might be together with stochastic processes the comparatively stronger factors than interspecific competition (WIENS 1977). Several adverse factors affect there the vegetation season, such as the harsh, high-altitude clime of the peaks, the rugged relief, as well as the thick and long-lasting snow cover. These arctic-alpine plants are in fact in refugia now; they had a broad distribution in unglaciated parts of the Central Europe at least during the last Glacial period. It seems that more important limiting factor was the existence of good sites for these species and vegetation during the climatic optimum in Holocene period (Krahulec, in lett.). Thus, the highest occurrence of the arctic-alpine taxa is on strongly wind-swept slopes or in the ecosystems of the snow beds in the alpine belt. The calculated values support this observation as well. There are, overall, 49 arctic-alpine taxa, and the majority of them are grouped in the plant communities of the alliances

Oxytropido-Elynion (34) and *Caricion firmae* (33) while the least occur in the plant communities of the alliances *Salicion silesiacae* (2) and *Petasition officinalis* (2). Based on the frequency, the arctic-alpine taxa (contrary to the endemics) retain the marginal values in these plant communities: *Oxytropido-Elynion* (26.23), *Caricion firmae* (23.92), *Festucion versicoloris* (21.99); *Salicion silesiacae* (0.21), *Petasition officinalis* (0.19). Despite the lower occurrence (22 and 16 species), the arctic-alpine taxa reach an important rate in the overall composition of the vascular plants in the communities of the snow beds of the alliances *Arabidion caeruleae* (23.25) and *Salicion herbaceae* (20.85), too. Similar results were obtained from the statistical analysis of more than 5 000 individual relevés of high-altitude vegetation of the Western Carpathians (ŠIBÍKOVÁ et al. 2010).

Discussion

One of the most important conditions for the speciation of new taxa (including endemics), as well as for preservation of relic taxa (with various genesis, age and ecological conditions), is the diversity of the geological bedrock and the rugged relief, which directly influence the habitat diversity and in turn affect the diversity of the flora and vegetation. The various edaphic and climatic conditions are provided for by the strongly basiphilous carbonate bedrock (limestone, dolomite), as well as bedrock rich in lime or potassium (mylonites, marly limestone, hornstone, Allgäu-Schiefer, etc.), which have slightly acidic to alkaline reaction. The majority of the West Carpathian endemics and many of the arctic-alpine taxa are found on such bedrock. Other important factor is the complex effect of altitude since the proportion of arctic-alpine element in the plant communities distinctly decreases with decreasing altitude and less extreme habitats. In addition, a significant role in sense of the evolutionary differentiation of arctic-alpine species played the small size of their populations during the periods of their refugial distribution (i.e. during interglacials and the Holocene). These small and considerably isolated populations are the most suitable for rapid evolution and fixation of specific feature combinations. This fact is clearly related also to the distribution on calcareous bedrock, which was common during the glacial also in lower altitudes (Krahulec, in lett.).

The long-lasting isolation and specific conditions of the refugia might (mainly within small populations) lead to the formation of the steno-endemic species. For example, specific plant communities have arisen during the postglacial period (cf. BERNÁTOVÁ et al. 2003a, b) that include the steno-endemic taxa described as *Poa margilicola* (BERNÁTOVÁ & MÁJOVSKÝ 1997), *P. sejuncta* and *P. babiogorensis* (BERNÁTOVÁ et al. 1999). These specific communities arose from the populations of an arctic species *Poa glauca* Vahl that have survived on isolated and exposed habitats in the Veľká Fatra Mts (Mt. Borišov), Západné Tatry Mts (Mt. Osobitá) and the Oravské Beskydy Mts (Mt. Babia hora).

The high occurrence of endemic species in the plant communities of the extreme windward high-altitude habitats (*Oxytropido-Elynion*) and habitats with long-lasting snow cover that shortens the vegetation season (*Arabidion* *caeruleae*), is caused by the isolation of high-altitude plant communities in the individual mountain ranges representing the sky islands and also, primarily by the strong pressure of adaptive selection during the evolution of the individual species.

Climatic extremes, as well as the adversity selection (WHITTAKER 1975), have played a key role in the evolution of the alpine taxa. The extreme conditions have increased selection pressures and thus also the necessity of adaptation. Hence, a new, endemic species might have arisen more easily than in less extreme conditions. On the other hand, a flat or slightly rugged relief does not provide many possibilities to form the refugia for relic species or suitable habitats for speciation. On the siliceous bedrock, this is enhanced by the predominantly low diversity of species of the stands, too. This fact explains why these stands are poor in both geographical elements. PAWŁOWSKI (1970) reached similar results when he compared the rate of endemism within the overall diversity of species of the plant communities on the basiphilous and siliceous bedrock.

The endemics are only sparsely present on the siliceous bedrock; the higher occurrence is only typical of species with a wide ecological and coenological amplitude (e.g., *Soldanella carpatica* in communities of the alliance *Nardion strictae*). In addition, the arctic-alpine taxa behave similarly. The proportion of the arctic-alpine taxa to the vascular plants is in the alliance *Nardion strictae* only 2 %.

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Tab. 1. Occurence of endemic and arctic-alpine species in the high-altitude vegetation of the Western Carpathians (a brief synoptic table)

Class			1						2		3			4		5			6		7	8	
Order			11			12		13	21	31				41		51		52	61		71	81	
Alliance	111	112	113	114	115	121	121	131	211	311	311	312	313	411	412	511	512	521	611	612	711	811	812
Suballiance						1211	1212			3111	3112												
Number of relevés	159	131	148	63	97	129	82	355	54	41	364	123	304	114	248	181	217	27	192	204	752	138	500
Average number of taxa	24	27	41	43	40	20	34	29	49	35	37	44	37	61	43	15	18	41	21	19	21	19	23
Number of column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Mulgedio-Aconitetea																							
Aconitum firmum [C]	13^{2}	76^{5}	2^{2}	6^{3}	32^{3}	36^{3}	48^{4}	11^{3}	6^{2}	2^{2}	$+^{2}$	6^{2}	1^{2}	8^{2}	3^{2}	1^{1}	1^{2}	11^{2}	.	3^{2}	$+^{2}$	.	$+^{2}$
Calamagrostietalia villosae																							
Campanula serrata [C]	11^{2}	2^{2}	71^{2}	24^{2}	28^{2}	4^{1}	18^{2}	1^{2}	61^{2}	2^{2}	16^{2}	24^{2}	1^{2}	.	2^{2}	.	2^{2}	.	.	8^{2}	1^{2}	5^{2}	24^{2}
Linum extraaxillare [Cs]	1^{2}	.	39^{3}	17^{3}	38^{3}	.	6^{2}	.	19^{3}	27^{3}	4^{3}	37^{3}	1^{1}	9^{4}	3^{3}	.	.	.	.	2^{2}	$+^{2}$	.	1^{2}
Cyanus mollis [Cs]	.	.	27^{4}	37^{2}	18^{3}	.	10^{2}	$+^{1}$	17^{4}	.	6^{2}	4^{3}	.	.	.	.	.	.	.	.	.	.	$+^{5}$
Calamagrostion villosae																							
*Sempervivum *carpathicum* [C]	23^{2}	3^{2}	.	.	1^{2}	3^{2}	.	.	.	.	.	1^{2}	.	.	4^{2}	.	12^{2}	.	4^{1}	3^{1}	5^{2}	4^{2}	.
Trisetion fusci																							
Trisetum fuscum [C]	3^{2}	33^{4}	.	.	11^{3}	10^{2}	5^{2}	.	.	.	.	.	.	.	1^{2}	1^{2}	3^{3}	41^{3}	.	.	.	.	.
Rhodiola rosea [AA]	14^{2}	64^{4}	1^{2}	2^{2}	31^{3}	21^{2}	28^{3}	$+^{2}$	7^{4}	17^{3}	.	24^{2}	17^{2}	53^{2}	45^{2}	2^{3}	5^{2}	59^{2}	.	2^{2}	1^{2}	.	.
Cardaminopsis neglecta [C]	.	14^{2}	.	.	.	1^{2}	.	.	.	.	.	.	.	.	25^{2}	6^{2}	2^{2}	7^{2}	.	.	$+^{2}$	.	.
Festucion carpaticae																							
Festuca carpatica [C]	.	.	7^{3}	10^{3}	100^{8}	1^{2}	27^{3}	.	56^{4}	12^{3}	2^{3}	19^{3}	.	1^{2}	.	.	.	.	.	.	.	.	.
Elyno-Seslerietea, Seslerietalia coerulae																							
Thymus pulcherrimus [C]	.	.	1^{2}	32^{3}	10^{3}	.	1^{3}	.	9^{2}	71^{3}	67^{3}	39^{3}	9^{2}	25^{3}	.	1^{3}	.	7^{2}	.	3^{2}	$+^{3}$	.	.
*Carex *tatrorum* [CW]	.	.	27^{3}	33^{3}	35^{3}	.	1^{2}	.	17^{2}	51^{3}	41^{6}	96^{6}	14^{2}	.	.	.	.	22^{3}	.	.	.	.	.
Veronica fruticans [AA]	.	.	1^{2}	2^{2}	1^{2}	.	.	.	.	37^{2}	8^{2}	11^{2}	$+^{2}$	.	.	.	.	7^{2}	.	.	.	.	.
Gentianella fatrae [CW]	.	.	.	8^{2}	1^{2}	.	.	.	2^{1}	15^{2}	21^{2}	18^{2}	1^{2}	.	.	.	.	.	.	.	.	.	5^{2}
*Dianthus *nitidus* [CW]	.	.	.	2^{2}	9^{2}	.	.	.	.	2^{2}	22^{3}	24^{3}	32^{2}	.	.	.	.	.	.	5^{2}	.	.	.
Astragalus alpinus [AA]	.	.	.	.	6^{4}	.	.	.	.	12^{3}	.	12^{4}	$+^{2}$	8^{3}	.	.	.	.	.	.	.	.	.

Knautia kitaibelii [CWs]	.	1^2	2^2	33^2	6^3	.	.	.	.	.	23^2	28^3	.	.	.	.	.	.	.	.	.	.	1^2
Astero alpini-Seslerion calcariae																							
*Dianthus *praecox* [CW]	.	.	.	5^2	2^2	.	.	.	.	68^3	23^2	3^2	4^2	.	.	.	.	.	.	$+^2$	.	.	.
Aster alpinus [AA]	.	.	.	.	.	.	.	.	.	56^3	26^3	1^2	8^3	16^3	.	.	.	.	.	$+^2$	.	.	.
Festuca tatrae [C]	.	.	5^3	37^2	10^4	.	1^2	.	15^2	46^4	50^3	15^2	$+^2$	.	.	.	.	.	.	.	.	.	.
Astero alpini-Seslerienion calcariae																							
*Oxytropis *tatrae* [C]	.	.	.	.	.	.	.	.	.	22^4	.	1^2	1^3	1^2	.	.	.	.	.	.	.	.	.
Campanula tatrae [CW]	33^2	19^2	1^2	5^2	15^2	.	1^2	.	.	39^2	.	37^2	9^2	79^2	58^2	1^1	12^2	33^2	12^2	5^2	9^3	16^2	9^2
Pulsatillo slavicae-Caricenion humilis																							
Pulsatilla slavica [CW]	.	.	.	25^2	.	.	.	.	.	12^5	50^2	1^2	1^2	.	.	.	.	.	.	.	.	.	.
Erysimum witmannii [C]	.	.	.	13^2	.	.	.	$+^1$	.	.	28^2	.	.	.	.	.	.	.	.	.	.	.	.
Koeleria tristis (reg.) [CW]	.	.	.	.	.	.	.	.	.	.	9^3	.	.	.	.	.	.	.	.	.	.	.	.
Bromus monocladus (reg.) [CWs]	.	.	.	.	.	.	.	.	.	.	7^3	1^2	.	.	.	.	.	.	.	.	.	.	.
Daphne arbuscula (reg.) [CW]	.	.	.	.	.	.	.	.	.	.	2^4	.	.	.	.	.	.	.	.	.	.	.	.
Seslerion tatrae																							
Sesleria tatrae [CWs]	1^3	.	7^3	6^3	56^3	.	9^3	.	46^2	29^3	2^2	99^4	30^2	61^2	1^2	.	$+^2$	85^2	.	4^2	$+^2$	.	.
*Trifolium *kotulae* [C]	.	.	.	.	.	.	.	.	.	12^2	.	21^2	.	.	.	.	1^2	.	.	.	.	.	.
*Cerastium *glandulosum* [CW]	.	2^4	.	.	5^2	.	2^2	.	.	.	.	22^2	4^2	18^2	12^2	.	2^2	89^4	.	$+^2$	$+^2$	1^3	.
Caricion firmae																							
Pinguicula alpina [AA]	.	.	.	.	.	.	.	.	.	.	1^2	6^2	43^2	11^2	3^2	.	.	22^2	.	1^2	.	.	.
Saxifraga aizoides [AA]	.	1^5	.	1^2	.	.	.	.	.	.	1^2	10^3	48^2	44^2	5^2	.	.	74^3	.	3^2	$+^2$	.	.
Carici rupestris-Kobresietea bellardii																							
Bistorta vivipara [AA]	3^2	26^2	3^3	.	19^2	.	.	.	.	7^2	7^3	59^3	69^2	97^4	70^2	7^2	7^2	93^3	11^2	11^2	21^2	4^1	4^2
Silene acaulis [AA]	.	2^3	.	.	.	.	.	.	.	.	$+^2$	18^2	44^3	93^6	76^4	3^2	$+^2$	37^2	1^2	2^3	7^2	.	.
Pedicularis oederi [AA]	1^3	8^2	.	.	.	.	.	.	.	.	.	24^2	43^2	89^3	53^2	1^2	1^2	81^2	1^2	1^2	5^2	.	.
Lloydia serotina [AA]	.	1^2	.	.	.	.	.	.	.	.	.	2^2	18^2	82^3	58^2	1^7	.	37^2	.	.	2^2	.	.
Dryas octopetala [AA]	.	.	.	.	.	.	.	.	.	5^2	2^3	15^4	78^5	51^4	6^4	.	.	7^2	.	8^2	$+^5$	.	.
*Luzula *mutabilis*	.	.	.	.	.	.	.	.	.	.	.	2^2	$+^2$	46^2	44^2	.	$+^1$	4^1	.	.	2^1	.	.
Elyna myosuroides [AA]	.	.	.	.	.	.	.	.	.	.	.	.	.	11^5	1^4	.	.	.	.	.	.	.	.
Carex rupestris [AA]	.	.	.	.	.	.	.	.	.	.	.	.	4^6	.	$*1^2$	.	.	.	.	.	1^8	.	.
Oxytropido-Elynetalia																							
*Festuca *versicolor* (reg.) [Cs]	.	.	2^3	2^5	3^2	.	.	.	.	95^6	5^3	63^5	98^4	97^5	49^5	2^2	.	33^2	2^2	15^2	4^4	.	$+^5$

Tab. 1. – cont.

Class			1						2		3			4		5			6		7	8	
Order			11			12		13	21	31				41		51		52	61		71	81	
Alliance	111	112	113	114	115	121	121	131	211	311	311	312	313	411	412	511	512	521	611	612	711	811	812
Suballiance						1211	1212			3111	3112												
Number of relevés	159	131	148	63	97	129	82	355	54	41	364	123	304	114	248	181	217	27	192	204	752	138	500
Average number of taxa	24	27	41	43	40	20	34	29	49	35	37	44	37	61	43	15	18	41	21	19	21	19	23
Number of column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Minuartia pauciflora [C]	.	.	.	.	.	.	.	.	.	.	.	3^{3}	25^{2}	82^{3}	22^{2}	.	.	11^{2}	.	.	$+^{2}$	.	.
Saxifraga moschata [CW] [1]	.	5^{2}	.	.	1^{2}	.	.	.	.	10^{2}	.	14^{2}	9^{2}	72^{3}	56^{2}	2^{2}	$+^{2}$	26^{2}	.	2^{2}	2^{2}	.	.
Carex atrata [AA]	.	.	.	.	2^{3}	2^{2}	.	.	.	.	.	11^{6}	6^{2}	54^{3}	25^{2}	1^{2}	.	33^{2}	2^{2}	2^{2}	10^{2}	4^{3}	.
Saussurea alpina [AA]	.	3^{3}	.	.	6^{3}	.	.	.	.	.	.	6^{2}	1^{2}	37^{3}	2^{3}	.	.	.	.	.	1^{2}	.	.
*Antennaria *carpatica* [C]	.	1^{2}	.	.	.	.	.	.	.	.	.	2^{2}	2^{2}	32^{2}	23^{2}	.	.	.	.	.	1^{2}	.	.
Saxifraga oppositifolia [AA]	.	.	.	.	.	.	.	.	.	.	.	1^{2}	5^{2}	24^{3}	26^{3}	.	.	7^{2}	.	.	$+^{1}$	.	.
Gentiana nivalis [AA]	.	1^{1}	.	.	.	.	.	.	.	2^{2}	.	2^{2}	2^{2}	16^{2}	$+^{2}$	.	.	.	.	.	$+^{2}$	.	.
Oxytropido-Elynion																							
Androsace chamaejasme [AA]	.	.	1^{2}	2^{2}	.	.	.	.	.	17^{2}	.	24^{2}	39^{2}	86^{3}	$+^{2}$	.	.	7^{2}	.	3^{2}	$+^{2}$	.	.
Comastoma tenellum [AA]	.	.	.	.	.	.	.	.	.	2^{2}	.	.	6^{2}	38^{2}	.	.	.	.	.	.	.	.	.
Pyrola carpatica [C]	.	.	.	.	.	.	.	.	.	.	.	1^{2}	12^{3}	34^{3}	1^{2}	.	.	.	.	$+^{2}$	.	.	.
Dactylina madreporiformis (E_0)	.	.	.	.	.	.	.	.	.	.	.	.	13^{3}	31^{2}	.	.	.	.	.	.	.	.	.
Oxytropis carpatica (reg.) [C]	.	.	.	.	.	.	.	.	.	7^{3}	.	1^{3}	11^{3}	26^{3}	.	.	.	.	.	.	.	.	.
Astragalus frigidus [AA]	.	.	.	.	4^{4}	.	.	.	.	.	.	3^{4}	1^{3}	20^{3}	.	.	.	.	.	.	.	.	.
Erigeron hungaricus (reg.) [C]	.	.	.	2^{2}	4^{3}	.	.	.	.	5^{2}	.	7^{3}	1^{2}	18^{2}	$+^{3}$	.	.	.	.	.	.	.	.
Astragalus norvegicus [AA]	.	.	.	.	1^{2}	.	.	.	.	.	.	3^{3}	$+^{2}$	11^{3}	.	.	.	.	.	.	.	.	.
*Cardaminopsis *tatrica* [CW]	1^{4}	2^{2}	12^{3}	2^{2}	16^{4}	7^{2}	18^{3}	1^{2}	.	.	.	22^{3}	.	32^{2}	.	.	$+^{1}$	.	.	.	.	.	1^{2}
Arenaria tenella [CW]	.	.	.	2^{2}	.	.	.	.	.	10^{2}	.	2^{1}	36^{2}	31^{3}	2^{2}	.	.	.	.	$+^{2}$	.	.	.
Festucion versicoloris																							
Salix retusa s. l.[2]	5^{2}	10^{2}	.	.	3^{4}	.	.	.	.	2^{2}	.	4^{2}	7^{2}	25^{2}	$*63^{5}$	$*3^{2}$	$*1^{2}$	30^{3}	9^{3}	1^{4}	$*5^{2}$	.	.
Erigeron uniflorus [AA]	.	.	.	.	.	.	.	.	.	.	.	2^{1}	$+^{2}$	.	19^{2}	.	.	.	.	.	$+^{4}$	.	.
Oxyria digyna [AA]	.	2^{2}	.	.	.	2^{2}	1^{2}	.	.	.	.	.	.	1^{2}	18^{2}	4^{2}	1^{4}	26^{3}	.	.	$+^{2}$	.	.

Salicetea herbaceae																							
*Luzula *obscura* [C]	31^3	52^2	.	.	.	55^3	7^3	.	.	.	.	2^2	.	27^2	54^2	85^3	85^6	19^3	14^2	10^2	47^2	.	.
Salix herbacea [AA]	1^1	8^2	.	.	.	.	.	.	.	.	.	.	.	.	20^2	51^6	5^2	11^3	18^5	.	17^5	.	.
Sagina saginoides [AA]	.	2^2	.	.	.	.	.	.	.	.	.	.	.	.	.	3^2	1^2	11^2	.	.	.	.	.
Salicetalia herbaceae																							
Omalotheca supina [AA]	1^1	3^2	.	.	.	1^1	.	.	.	.	.	.	.	.	1^2	57^3	21^3	.	1^1	.	5^2	2^2	.
*Leucanthemopsis *tatrae* [CW]	1^2	2^1	.	.	.	.	.	.	.	.	.	.	.	.	21^2	24^2	24^2	.	4^2	1^2	23^2	1^1	.
Poa granitica [CW]	1^3	5^2	.	.	.	15^3	.	.	.	.	.	.	.	.	$+^2$	7^2	9^2	.	.	.	.	.	.
Salicion herbaceae																							
Dichodon cerastoides [AA]	.	2^3	.	.	.	.	.	.	.	.	.	.	$+^2$	.	$+^2$	50^4	9^3	.	.	.	1^2	1^2	.
Festucion picturatae																							
Ranunculus pseudomontanus [Cs]	36^2	24^2	5^2	5^2	12^3	29^2	1^1	.	2^2	.	12^2	28^2	4^2	6^2	27^2	12^2	52^2	11^2	6^2	5^2	24^2	17^2	7^2
Soldanella carpatica [CW]	69^2	49^2	26^2	16^3	57^3	52^2	43^2	1^2	35^3	.	6^2	59^2	44^2	52^3	61^2	18^2	58^2	96^3	25^2	25^2	34^2	57^2	16^3
Arabidetalia caeruleae, Arabidion caeruleae																							
Saxifraga wahlenbergii [CW]	.	.	.	.	.	.	2^2	.	.	.	.	2^2	18^2	48^2	5^2	1^2	.	100^5	.	$+^3$	$+^2$	.	.
Salix reticulata [AA]	.	.	.	.	8^2	.	.	.	.	.	.	19^3	35^3	62^5	11^3	.	.	81^4	.	3^3	$+^2$	.	.
*Plantago *carpatica* [C]	.	.	.	.	.	.	.	.	.	.	.	2^2	.	1^2	.	.	$+^2$	11^4	.	.	.	.	.
Leontodon pseudotaraxaci [C]	1^2	3^2	.	.	2^3	.	.	.	.	.	.	20^2	7^2	25^2	15^2	2^2	1^2	63^3	.	$+^2$	1^2	.	.
Juncion trifidi																							
Juncus trifidus [AA]	18^2	7^2	.	.	.	.	.	.	.	.	.	3^2	1^2	41^3	51^2	12^2	13^2	.	88^3	17^3	72^5	17^2	.
Nardetea strictae, Nardetalia strictae																							
Crocus discolor [CW]	.	.	.	.	.	.	.	.	.	.	$+^2$	.	.	.	.	.	.	.	.	.	.	7^3	3^2
Species of contact phytocoenoses with higher abundance in analysed syntaxa; naturally rare taxa																							
Leucanthemum rotundifolium [Cs]	7^3	22^3	.	2^3	10^3	11^3	20^4	8^3	.	.	.	2^2	.	.	$+^2$	.	.	4^2	.	$+^2$	.	1^2	.
Hylotelephium argutum [C]	4^2	1^2	15^2	8^2	2^2	4^3	17^2	2^2	2^2	.	.	1^2	.	.	.	.	.	.	.	.	.	.	.
*Hesperis *nivea* [C]	.	.	5^2	2^3	3^2	.	2^2	6^2	2^2	.	.	.	.	.	.	.	.	.	.	.	.	.	.
*Primula *hungarica* [CWs]	.	.	1^2	2^2	.	.	.	.	.	63^4	40^2	7^2	45^2	9^2	.	.	.	4^1	.	.	.	.	.
Pedicularis verticillata [AA]	.	2^2	.	.	14^2	.	.	.	.	37^2	9^2	45^2	44^2	39^2	48^2	.	1^2	19^2	2^1	5^2	5^2	.	.
Potentilla crantzii [AA]	.	.	3^2	.	7^2	.	.	.	.	17^3	1^2	25^3	3^2	23^3	16^2	1^7	.	4^1	.	1^2	1^3	.	$+^1$

Tab. 1. – cont.

Class			1						2		3			4		5			6		7	8	
Order			11			12		13	21	31				41		51		52	61		71	81	
Alliance	111	112	113	114	115	121	121	131	211	311	311	312	313	411	412	511	512	521	611	612	711	811	812
Suballiance						1211	1212			3111	3112												
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Average number of taxa	24	27	41	43	40	20	34	29	49	35	37	44	37	61	43	15	18	41	21	19	21	19	23
Number of column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Chamorchis alpina [AA]	.	.	.	.	.	.	.	.	.	.	.	2^{2}	21^{2}	11^{2}	.	.	.	.	.	$+^{2}$	.	.	.
Saxifraga hieraciifolia [AA]	.	.	.	.	.	.	1^{1}	.	.	.	.	1^{1}	1^{2}	30^{2}	17^{2}	.	.	11^{2}	.	.	$+^{2}$	.	.
Knautia slovaca [CW]	.	.	.	11^{3}	.	.	.	.	.	.	$+^{2}$	.	.	.	.	.	.	.	.	.	.	.	.
Pulsatilla subslavica [CW]	.	.	.	.	.	.	.	.	.	.	6^{2}	.	.	.	.	.	.	.	.	.	.	.	.
Campanula xylocarpa [CW]	.	.	1^{2}	.	.	.	.	.	.	.	5^{2}	.	.	.	.	.	.	.	.	.	.	.	.
Draba fladnicensis [AA]	.	.	.	.	.	.	.	.	.	.	.	.	.	8^{2}	.	.	.	.	.	.	.	.	.
Tofieldia pusilla [AA]	.	.	.	.	.	.	.	.	.	.	.	.	.	4^{3}	.	.	.	.	.	.	.	.	.
Carex atrofusca [AA]	.	.	.	.	.	.	.	.	.	.	.	.	.	3^{2}	.	.	.	.	.	.	.	.	.
Arctous alpina [AA]	.	.	.	.	.	.	.	.	.	.	.	.	.	2^{5}	.	.	.	.	.	.	.	.	.
Juncus triglumis [AA]	.	.	.	.	.	.	.	.	.	.	.	.	.	1^{2}	.	.	.	.	.	.	.	.	.
Ranunculus glacialis [AA]	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8^{2}	.	$+^{2}$	.	.	.	$+^{3}$	.	.
Sibbaldia procumbens [AA]	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1^{3}	.	.	.	.	.	.	.
Ranunculus pygmaeus [AA]	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1^{2}	.	.	.	.	.	.	.
Papaver tatricum [CW]	.	.	.	.	.	.	.	.	.	.	.	.	$+^{2}$	.	$+^{2}$	.	.	30^{2}	.	.	.	.	.
Saxifraga cernua [AA]	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7^{4}	.	.	.	.	.
Carpathian (sub)endemics																							
Euphrasia tatrae [C]	3^{2}	4^{2}	1^{2}	.	7^{2}	.	1^{2}	.	.	.	1^{2}	18^{2}	$+^{2}$	7^{2}	16^{2}	1^{2}	2^{1}	.	8^{1}	$+^{1}$	4^{2}	1^{3}	.
Soldanella hungarica [Cs]	1^{2}	.	1^{2}	.	7^{4}	2^{6}	2^{2}	.	.	.	$+^{2}$	.	.	.	.	.	.	.	.	3^{2}	$+^{2}$	1^{5}	19^{2}
*Primula *platyphylla* [Cs]	.	.	.	.	.	.	.	.	.	2^{3}	.	2^{2}	.	2^{3}	.	.	.	.	$+^{2}$	.	.	.	.
Campanula carpatica [C]	.	.	.	3^{3}	.	.	.	1^{2}	.	.	19^{2}	.	.	.	.	.	.	.	.	.	.	.	.
*Pilosella *ullepitschii* [C]	1^{1}	.	.	.	.	.	.	.	.	.	.	.	.	.	6^{2}	.	.	.	3^{2}	.	.	.	.
Aconitum moldavicum [Cs]	.	.	3^{2}	5^{1}	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Dentaria glandulosa [Cs]	.	.	.	.	.	.	1^{2}	1^{2}	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Symphytum cordatum [Cs]	.	.	.	.	.	.	.	1^3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sempervivum matricum [Cs]	.	.	.	.	.	.	.	.	.	.	1^2	.	.	.	.	.	.	.	.	.	.	.	.
Aconitum lasiocarpum [CE]	.	.	3^2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tithymalus sojakii [CE]	.	.	3^2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
West Carpathian endemics																							
Delphinium oxysepalum	.	11^3	.	.	6^3	.	7^4	$+^2$	.	2^2	.	.	2^2	19^2	2^2	.	$+^3$	22^3	.	$+^2$	.	.	.
Erysimum wahlenbergii	.	.	1^6	.	6^2	.	1^2	1^3	.	2^2	.	2^2	.	.	.	.	.	.	.	.	.	.	.
Cochlearia tatrae	.	1^2	.	.	.	.	.	.	.	.	.	.	.	.	2^2	.	.	.	.	.	.	.	.
*Thlaspi *tatrense*	.	.	1^2	.	.	.	1^1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
*Silene *sillingeri*	.	.	.	2^1	.	.	.	.	.	.	1^2	.	.	.	.	.	.	.	.	.	.	.	.
Taraxacum nigricans	.	.	.	.	2^3	.	.	.	.	.	.	2^2	.	.	.	.	.	.	.	.	.	.	.
Poa margilicola	.	.	.	.	.	.	.	.	.	.	$+^2$	.	.	.	.	.	.	.	.	.	.	.	.
Arctic-alpine taxa																							
Bartsia alpina	8^2	3^2	1^2	.	33^2	.	.	.	.	24^3	12^2	55^3	55^3	40^2	49^2	1^2	4^2	48^2	4^2	11^2	4^2	4^2	$+^2$
Arabis alpina	1^2	11^3	.	3^4	16^3	2^3	24^3	6^2	.	5^2	1^2	7^2	2^2	.	2^2	.	1^3	70^2	.	$+^1$	$+^3$	.	.
Epilobium annagalidifolium	.	5^2	.	.	.	1^2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Diphasiastrum alpinum	.	.	.	.	.	.	.	.	.	.	.	.	$+^3$	.	.	.	.	.	3^4	2^4	1^4	1^2	.
Kobresia simpliciuscula	.	.	.	.	.	.	.	.	.	.	.	.	9^4	4^2	.	.	.	.	.	.	.	.	.

Explanations:

1 *Saxifraga moschata* = subsp. *dominii* [CW] and subsp. *kotulae* [CW]
2 values marked with asterisk – *Salix kitaibeliana* [C]; columns 1, 2, 18–20: *Salix retusa* and *S. kitaibeliana*
reg. – diagnostic taxon from the regional point of view, in another area it should have different status or it does not occur
+ – occurence with frequency lower than 0.5 %
[AA] – arctic-alpine taxon
[C] – Carpathian endemic, [Cs] – Carpathian subendemic, [CE] – East Carpathian endemic, [CW] – West Carpathian endemic, [CWs] – West Carpathian subendemic

Classes: 1 = *Mulgedio-Aconitetea*, 2 = *Betulo carpaticae-Alnetea viridis*, 3 = *Elyno-Seslerietea*, 4 = *Carici rupestris-Kobresietea bellardii*, 5 = *Salicetea herbaceae*, 6 = *Loiseleurio-Vaccinietea*, 7 = *Caricetea curvulae*, 8 = *Nardetea strictae*.

Orders: 11 = *Calamagrostietalia villosae*, 12 = *Adenostyletalia alliariae*, 13 = *Petasito-Chaerophylletalia*; 21 = *Alnetalia viridis*; 31 = *Seslerietalia coerulae*; 41 = *Oxytropido-Elynetalia*; 51 = *Salicetalia herbaceae*, 52 = *Arabidetalia caeruleae*; 61 = *Rhododendro-Vaccinietalia*; 71 = *Caricetalia curvulae*; 81 = *Nardetalia strictae*.

Tab. 1. – cont.

Alliances: 111 = *Calamagrostion villosae*, 112 = *Trisetion fusci*, 113 = *Calamagrostion arundinaceae*, 114 = *Calamagrostion variae*, 115 = *Festucion carpaticae*, 121 = *Adenostylion alliariae*, 131 = *Petasition officinalis*; 211 = *Salicion silesiacae*; 311 = *Astero alpini-Seslerion calcariae*, 312 = *Seslerion tatrae*, 313 = *Caricion firmae*; 411 = *Oxytropido-Elynion*, 412 = *Festucion versicoloris*; 511 = *Salicion herbaceae*, 512 = *Festucion picturatae*, 521 = *Arabidion caeruleae*; 611 = *Loiseleurio-Vaccinion*, 612 = *Vaccinion myrtilli*; 711 = *Juncion trifidi*; 811 = *Nardion strictae*; 812 = *Nardo-Agrostion tenuis*.

Suballiances: 1211 = *Adenostylenion alliariae*, 1212 = *Delphinienion elatae*; 3111 = *Astero alpini-Seslerienion calcariae*, 3112 = *Pulsatillo slavicae-Caricenion humilis*.

Tab. 2. The occurrence of arctic-alpine and endemic taxa in the analysed syntaxa.
(For number of columns and abbreviations see Tab. 1)

Number of column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
∑C+Cs	13	12	16	16	18	11	16	10	10	12	14	24	15	17	17	9	11	11	6	14	15	6	7
∑CW+CWs	6	10	10	14	14	3	10	4	4	12	18	18	15	10	12	6	9	10	3	11	7	5	6
∑End	19	22	26	30	32	14	26	14	14	24	32	42	30	27	29	15	20	21	9	25	22	11	13
$\sum_{AA}$	8	18	6	4	14	6	3	2	2	13	11	27	33	34	28	16	14	22	10	18	26	7	3
$\sum Co_{C+Cs}$	135	235	190	205	298	156	167	31	189	303	211	319	173	401	251	111	161	218	37	52	89	29	51
$\sum Co_{CW+CWs}$	106	97	79	150	217	74	85	3	100	303	258	439	249	421	220	53	105	507	41	42	72	82	34
$\sum Co_{End}$	241	332	269	355	515	230	252	34	289	606	469	758	422	822	471	164	266	725	78	94	161	111	85
$\sum Co_{AA}$	47	151	10	9	149	29	53	6	9	238	68	391	603	1111	614	196	69	752	128	72	155	33	4
$\sum Co_{Vasc}$	2086	2316	3956	4113	3747	1809	3175	2876	4617	2812	3325	4061	2521	4235	2792	940	1508	3234	1456	1334	1412	1646	2188
$\sum(Co_{C+Cs} / \sum Co_{Vasc}) \times 100$	6.5	10.2	4.8	5.0	8.0	8.6	5.3	1.1	4.1	10.8	6.3	7.9	6.9	9.5	9.0	11.8	10.7	6.7	2.5	3.9	6.3	1.8	2.3
$\sum(Co_{CW+CWs} / \sum Co_{Vasc}) \times 100$	5.1	4.2	2.0	3.7	5.8	4.1	2.7	0.1	2.2	10.87	7.8	10.8	9.9	9.9	7.9	5.6	7.0	15.7	2.8	3.2	5.1	5.0	1.6
$\sum(Co_{End} / \sum Co_{Vasc}) \times 100$	11.6	14.3	6.8	8.6	13.7	12.7	7.9	1.2	6.3	21.6	14.1	18.7	16.7	19.4	16.9	17.4	17.6	22.4	5.4	7.1	11.4	6.7	3.9
$(\sum Co_{AA} / \sum Co_{Vasc}) \times 100$	2.3	6.5	0.3	0.2	4.0	1.6	1.7	0.2	0.2	8.5	2.1	9.6	23.9	26.2	22.0	20.9	4.6	23.3	8.8	5.4	11.0	2.0	0.2

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