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Multivariate Morphometric Study of the *Sempervivum montanum* Group (*Crassulaceae*) in the West Carpathians.

By

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With 8 Figures

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Summary

LETZ R. & MARHOLD K. 1998: Multivariate morphometric study of the *Sempervivum montanum* group in the West Carpathians. – Phyton (Horn, Austria) 38 (2): 323–336, 8 figures. – English with German summary.

Multivariate morphometric study of the *Sempervivum montanum* group based on material from the West Carpathians is presented. Methods used include principal components analysis, cluster analysis and discriminant analysis. The study confirmed the possibility to recognise two taxa on the subspecific level in the area studied. The correct names of these taxa, both different from *S. montanum* L. s. str., depend on the acceptance of the proposal to reject the name *S. carpathicum* WETTST. ex PRODAN. Therefore we treat them at present under informal designations, as "lowland" and "upland" taxon. The proposed subspecies differ in respect of the size of rosettes and rosette leaves and the colour of leaves. Both differ from *S. montanum* in the acuminate rosette leaves, their sparse, short glandular hairs, and in the petals which are usually longer (12–16 mm).

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Zusammenfassung

LETZ R. & MARHOLD K. 1998. Multivariate, morphometrische Studie der *Sempervivum montanum*-Gruppe (*Crassulaceae*) in den West-Karpaten. – Phyton (Horn, Austria) 38 (2): 323–336, 8 Abbildungen. – Englisch mit deutscher Zusammenfassung.

Eine multivariate, morphometrische Studie der *Sempervivum montanum*-Gruppe, basierend auf Material aus den West-Karpaten, wird vorgelegt. An Methoden wurden Hauptkomponenten-Analyse, Cluster-Analyse und Diskriminanz-Analyse angewendet. Die Studien bestätigen die Möglichkeit, im Untersuchungsgebiet zwei Sippen in der Rangstufe der Subspecies zu unterscheiden. Die Namen dieser Taxa, die beide von *S. montanum* s.str. verschieden sind, hängen von der Annahme des Vorschlages, den Namen *S. carpathicum* WETTST. ex PRODAN zu verwerfen, ab. Daher behandeln wir die beiden Sippen hier unter den Bezeichnungen Tieflagen- und Hochlagen-Taxon. Die vorgeschlagenen Subspecies unterscheiden sich in der Größe der Rosetten und Rosettenblätter und in der Farbe der Blätter. Beide unterscheiden sich von *S. montanum* durch die spitzen Rosettenblätter, die spärlichen, kurzen Drüsenhaare und durch die Petalen, die gewöhnlich länger (12–16 mm) sind.

1. Introduction

According to PARNELL 1988 *Sempervivum montanum* subsp. *carpathicum* "WETTST. ex HAYEK" [correctly (WETTST. ex PRODAN) WETTST. ex BERGER] represents a large flowered variant of *S. montanum* L. close to *S. montanum* subsp. *stiriacum* (WETTST.) WETTST. ex HAYEK. PARNELL & FAVARGER 1993 in the new edition of Flora Europaea, vol. 1, reported *S. montanum* subsp. *montanum* and *S. montanum* subsp. *carpathicum* for the Carpathians with the note that the latter taxon is diploid with 2n=42 and "somewhat intermediate in appearance" between *S. montanum* subsp. *burnatii* WETTST. ex HAYEK (2n=42) and *S. montanum* subsp. *stiriacum* (2n=84), and its status is uncertain. The same two subspecies (subsp. *montanum* and subsp. *carpathicum*) were reported by ZAHRADNÍKOVÁ 1984 in the Flora of Slovakia and this opinion is also shared by LIPPERT 1995 who underlines the need of further study of the West Carpathian populations of the *S. montanum* group.

In the course of the taxonomic revision carried out by the first author, on the genera *Sempervivum* L. and *Jovibarba* OPIZ in the Carpathians, particular attention was paid to the *S. montanum* group. The aim of the present paper is to present the results of the morphometric evaluation of Carpathian populations corresponding to the above mentioned "*S. montanum* subsp. *montanum*" and "*S. montanum* subsp. *carpathicum*".

2. Material and Methods

The present study is based on 17 populations samples (170 plants altogether, approximately ten plants per locality; for localities see Table 1) collected in the West Carpathians and cultivated in the same conditions. Population samples were

Table 1

Origin of the population samples studied.

Population	Phytogeographical district	Locality	Altitude (ca.)	Geological substratum
1	Slovenské stredohorie, Štiavnické vrchy	Psiare, Mt. Krivín (Krásna skala)	280 m	andesite
2	Slovenské stredohorie, Vtáčnik	Podhradie, Sivý Kameň	600 m	andesite
3	Nízke Tatry	Mt. Král'ova skala	1650 m	crystallic slate
4	Slanské vrchy	Zámutovské skaly, near Čulkov	750 m	andesite
5	Slovenské stredohorie, Vtáčnik	Makovište	620 m	andesite
6	Slanské vrchy	Hermanovské skaly	500 m	andesite
7	Slovenské rudohorie	Klenovský Vepor	1250 m	andesite
8	Slovenské stredohorie, Štiavnické vrchy	Sitno	1000 m	andesite
9	Slovenské stredohorie, Štiavnické vrchy	Lehôtka pod Brehmi, Szabóova skala	300 m	rhyolite
10	Tatry, Západné Tatry	Smutná dolina Valley	1760 m	granodiorite
11	Nízke Tatry	between Prašivá and Krupova hol'a	1600 m	granodiorite
12	Nízke Tatry	near Malužiná	750 m	melaphyre
13	Západné Beskydy	Mt. Babia Hora	1700 m	flysch
14	Krivánska Malá Fatra	Hoskora Valley, under Krivé	450 m	auto-metamorphic granite
15	Tatry, Vysoké Tatry	near Vel'ké Hincovo pleso Lake	1950 m	granodiorite
16	Tatry, Vysoké Tatry	between Štrbské pleso and Popradské pleso Lakes	1500 m	granodiorite
17	Tatry, Vysoké Tatry	Malá Studená dolina Valley	1650 m	granodiorite
18	Hohe Tauern	Oberes Sulzbachtal, near Gamseck Fall	1600 m	granite

collected in order to represent as much as possible different altitudes and substrata. There are only diploid chromosome numbers (2n=42) reported for the *S. montanum* group from the area of Slovakia for both lower and higher altitudes (cf. LETZ & al., in press) and we can safely expect that all our samples from the West Carpathians are diploid as well. For comparison, one population sample of *S. montanum* L. subsp. *montanum* (in the sense of the recent lectotypification by LETZ & MARHOLD 1996) was collected in the Hohe Tauern Mts (Austria).

2.1. Cultivation

The plants of the genus *Sempervivum* are succulent and therefore any morphometric evaluation must be done on the living material. Moreover they perform a large amount of plasticity in the quantitative characters depending mainly on the local light and moisture conditions. In order to avoid this bias as much as possible and to evaluate taxonomically important variation, the plants were cultivated for one year in the same conditions at the experimental field of the Institute of Botany of the Slovak Academy of Sciences in Bratislava, Slovakia (at the altitude 200 m a. s. l.). Plants were cultivated in an open field without shadow and regularly watered.

2.1. Collection of material and characters studied

Vegetative propagation plays a great role in the *S. montanum* group (as in the whole genus *Sempervivum*) and individual "populations" are composed usually of several more or less uniform clones. This pattern of variability was taken into account in the collecting of material in such a way that the individuals for the purpose of the cultivation and further morphometric evaluation were collected from different parts of the localities and in order to represent different morphotypes present at the given locality. Usually 15–20 individuals were collected at each locality from which usually 10 were randomly selected after one year of cultivation for the morphometric purposes.

The genus *Sempervivum* has a monocarpic life cycle and that is why, especially in the conditions of the experimental cultivation, it is not easy to have a reasonable amount of flowering specimens for the morphometric purposes at hand. This is the main reason why in course of the present study only vegetative characters on the sterile and well developed rosettes were measured or scored. However, it was already shown by SMITH 1971, 1984 that these characters can reflect the taxonomic differences quite well.

The following characters on well developed rosettes were measured or scored (Fig. 1):

RD – rosette diameter [mm]

NL – number of leaves on transversal section in the middle of rosette

HL – marginal leaf hair (cilia) length [1– length $\geq$ 0.2 mm; 2 – length $<$ 0.2 mm]

CL – length comparison of the marginal hairs with the leaf surface ones [1 – marginal hairs $\leq$ surface hairs; 2 – marginal hairs $>$ surface hairs]

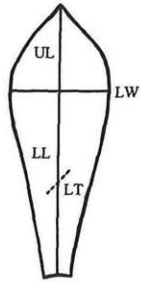

Fig. 1. The characters measured on the rosette leaves (LT – leaf thickness, LW – leaf width, LL – lower leaf length, UL – upper leaf length).

LT – leaf thickness [mm]

LW – leaf width [mm]

LL – lower part of leaf length (distance of the maximal leaf width from the leaf base) [mm]

UL – upper part of leaf length (distance of the maximal leaf width from the leaf apex) [mm]

IG – intensity of the green colour of the leaves [1 – light green, 2 – medium light green, 3 – green, 4 – medium dark green, 5 – dark green; assessed by comparing the plants with a set of 5 selected standard clones].

Among them there are characters reported by several authors (e.g. ZAHRADNÍKOVÁ 1984, SMITH 1971, 1984) as useful for the taxonomic differentiation of this group and those which appeared to be useful during the collecting and cultivation of material. Quantitative leaf characters were measured on the enlarged (2x) xerocopies of the fresh leaves from the marginal part of rosettes. These leaves were later dried and stored as vouchers in the herbarium SAV (representative copies of the leaves are on Fig. 2).

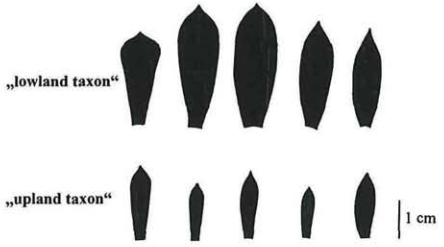

Fig. 2. Representative copies of the rosette leaves of the "lowland" and the "upland" taxa.

2.1. Morphometric analysis

The morphometric analysis was performed in the following steps:

(a) Analysis of pattern of variation – search for the hypothesis about the taxonomic structure of the group: principal components analysis (PCA) (SNEATH & SOKAL 1973, KRZANOWSKI 1990), based on correlation matrix; cluster analysis (CA), UPGMA (average linkage) (EVERITT 1986), based on the squared Euclidean distance and characters standardised to the zero mean and unit variance. As OTU's populations, characterised by the average values of characters in both cases were used, PCA was carried out on the individual plants as OTU's as well.

(b) Testing the hypothesis, based on PCA, CA as well as on the distribution data: canonical and classificatory discriminant analysis, the latter analysis was performed using the cross validation and both parametric and non-parametric k-nearest neighbours method were used (KLECKA 1980, KRZANOWSKI 1990, SAS Institute 1990b).

(c) Exploratory data analysis (TUKEY 1977, SAS Institute 1990a) – descriptive statistics of characters for the pooled matrix of all individuals and for the groups of populations recognised in the step (a), Pearson and Spearman correlation coefficients (the latter one, non-parametric was used because the distribution of most of characters was not strictly normal).

Cluster analysis and part of principal components analyses were performed using the SYN-TAX 5.02 package (PODANI 1993, 1994). Remaining numerical analyses were computed on the mainframe computer of the University of Vienna, Austria, using procedures CANDISC, CORR, DISCRIM, and UNIVARIATE, available in the SAS package (SAS Institute 1990a,b).

3. Results and Discussion

3.1. Morphometric analysis

The results of the cluster analysis and principal components analysis (Fig. 3, 4) of the Carpathian populations, together with a sample of *S. montanum* s. str. from the Eastern Alps indicate that it is possible to recognise two groups of populations within the Carpathian material studied. The first of them represents with one exception populations collected above the timberline ("upland" group of populations), while the other one those from the lower altitudes, mostly below 1000 m a.s.l. ("lowland" group of populations). On the dendrogram of the cluster analysis (Fig. 4) two groups are visible, while population from the Alps is separately clustered. Similar picture is provided by the PCA ordination diagram (Fig. 3). The first two axes account for the 81.7 % of variation

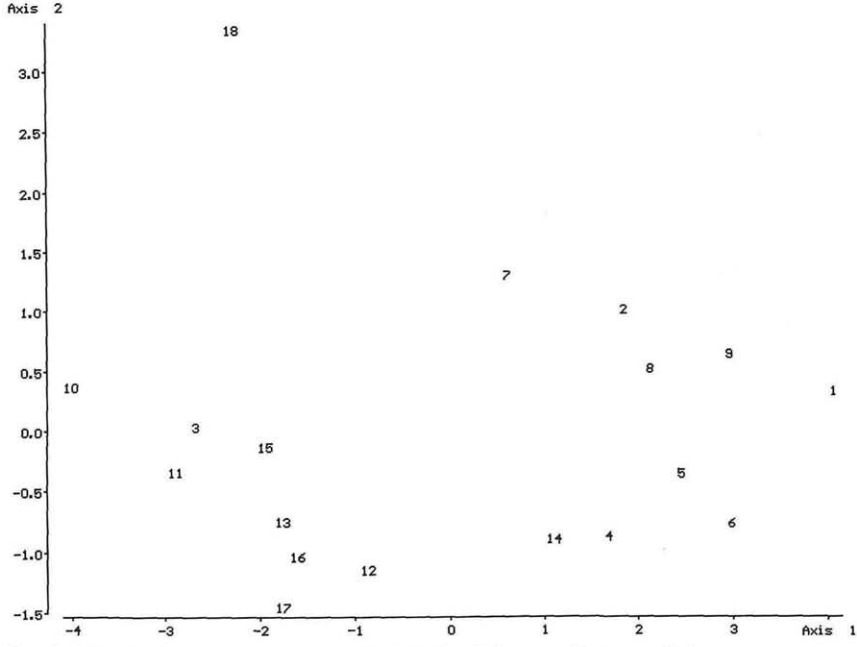

Fig. 3. Principal components analysis (PCA) of the populations of the *Sempervivum montanum* group in the West Carpathians (the "lowland" taxon: 1, 2, 4, 5, 6, 7, 8, 9, 14 and the "upland" taxon: 3, 10, 11, 12, 13, 15, 16, 17) and one population of *S. montanum* L. from the Eastern Alps (18).

among the populations. Two groups of populations from the West Carpathians are separated along the first axis, while population from the Alps is separated from the rest along the second one. The characters RD, LT, LW, LL, UL and IG are most correlated with the first axis while the

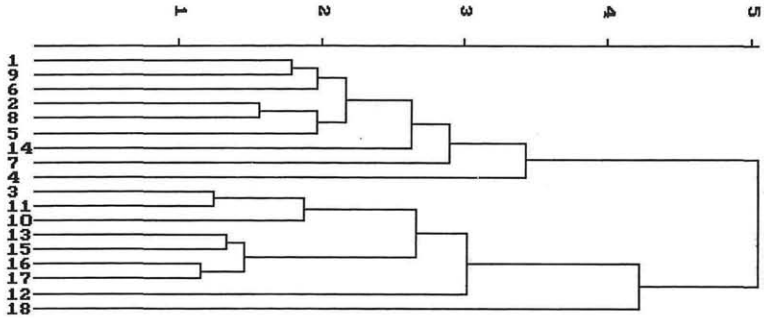

Fig. 4. Cluster analysis of the populations of the *Sempervivum montanum* group in the West Carpathians (the "lowland" taxon: 1, 2, 4, 5, 6, 7, 8, 9, 14 and the "upland" taxon: 3, 10, 11, 12, 13, 15, 16, 17) and one population of *S. montanum* L. from the Eastern Alps (18).

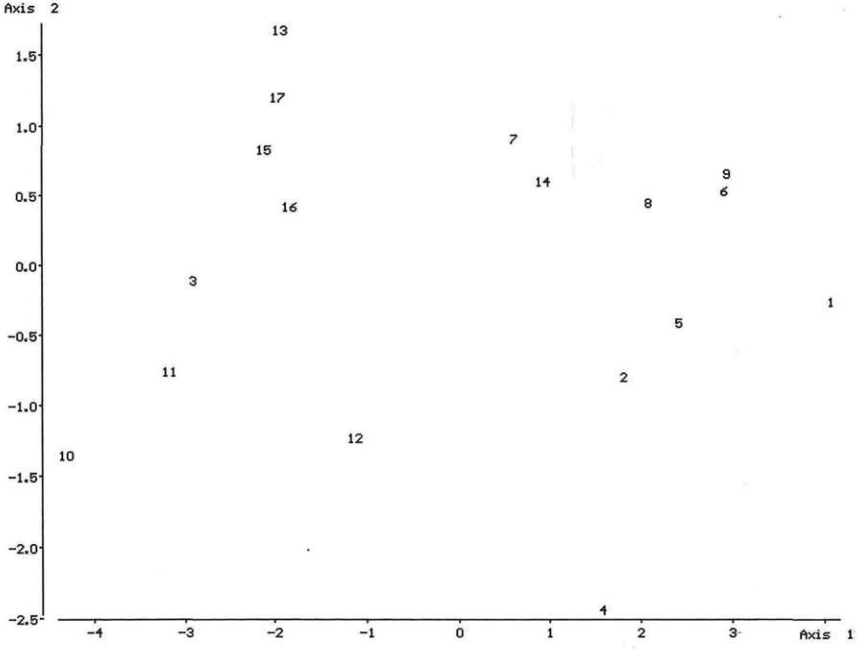

Fig. 5. Principal components analysis (PCA) of the populations of the *Sempervivum montanum* group in the West Carpathians (the "lowland" taxon: 1, 2, 4, 5, 6, 7, 8, 9, 14 and the "upland" taxon: 3, 10, 11, 12, 13, 15, 16, 17).

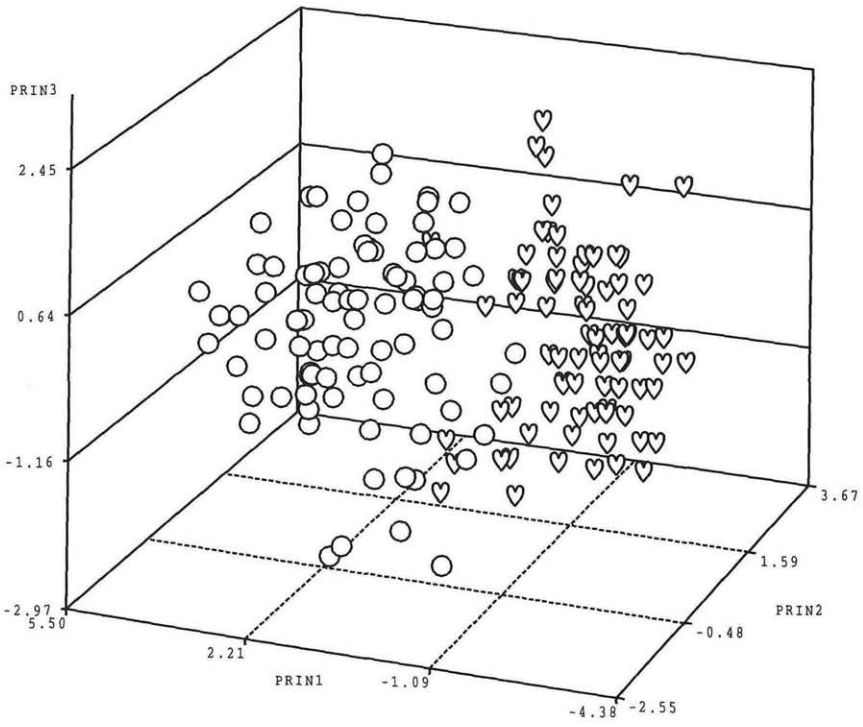

Fig. 6. Principal components analysis (PCA) of the individual plants of the *Sempervivum montanum* group in the West Carpathians. Balloon – the "lowland" taxon, heart – the "upland" taxon.

character NL most contribute to the separation of the population from the Alps. In addition to these analyses, separate PCA was carried out on the samples from the West Carpathians only (Fig. 5). The same two groups of populations are visible as on the previous ordination diagrams and the dendrogram, however slightly intermediate position of populations no. 12 (Malužiná, 750 m) of the "upland" population group and population no. 7 (Klenovský Vepor, 1250 m) of the "lowland" population group is visible. Indeed a more close look on the plants from these localities reveals the fact that they are intermediate, especially in respect of characters RD, LW, LL, and UL. The same characters contribute to the separation of these two groups, as in the first PCA analysis, in addition the contribution of characters HL and CL is higher here. Only the character NL accounts for the variation within both groups.

In the PCA carried on the individual plants as OTU's two above-mentioned groups are not so clearly visible, however, they overlap only slightly (Fig. 6). Inspite of the slight overlap of the "upland" and "lowland"

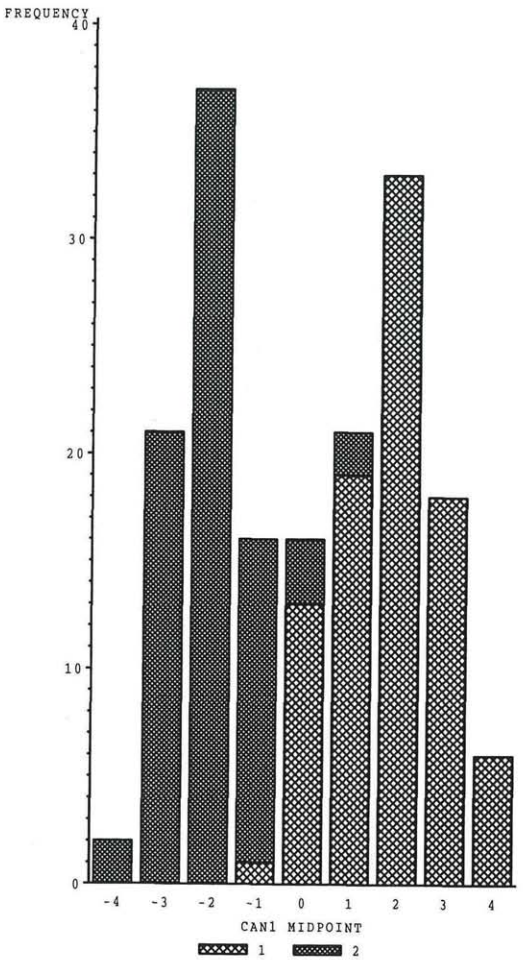

Fig. 7. Canonical discriminant analysis of the *Sempervivum montanum* group in the West Carpathians. 1 – the "lowland" taxon, 2 – the "upland" taxon.

population groups their separation is visible. The first three component axes account for 54.3, 13.1 and 11.9 % of the total variation respectively. Among the characters most correlated with the first axis, separating "upland" and "lowland" population groups are again RD, LT, LW, LL, UL, and IG, while character NL is most correlated with the second axis and characters HL and CL with the third one. Both the second and the third axis reflect variation within the above mentioned groups.

Similar results were provided by the classificatory and canonical discriminant analysis. There is only slight overlap among the groups in the histogram (Fig. 7) and percentage of correctly classified plants was more

Table 2

Results of the exploratory data analysis of the two groups of populations of *S. montanum* group in the West Carpathians. – lowl. = "lowland" taxon, upland = "upland" taxon; for character abbreviations see material and methods.

Character	Group	Mean	Standard deviation	5 % percentile	95 % percentile	Cv
RD	lowl.	46.633	8.269	34	60	17.731
	upland	33.025	7.258	21	42.5	21.978
NL	lowl.	13.656	1.944	11	17	14.236
	upland	14.950	2.037	11.5	18	13.625
LT	lowl.	2.690	0.344	2.1	3.3	12.794
	upland	1.779	0.360	1.3	2.45	20.234
LW	lowl.	8.158	1.676	5.75	11	20.551
	upland	4.864	1.112	3.5	6.875	22.862
LL	lowl.	12.908	3.356	7.5	19.25	25.998
	upland	8.872	2.754	4.25	13.875	31.050
UL	lowl.	8.831	2.251	5.5	12.75	25.495
	upland	5.769	1.394	3.875	8.375	24.171

Table 3

Frequency of the states of characters HL, CL and IG in the two groups of populations of *S. montanum* group in the West Carpathians. For character abbreviations see material and methods.

Character	State	Frequency in the group "lowland" taxon	"upland" taxon
HL	1	27	77
	2	63	3
CL	1	15	50
	2	75	30
IG	1	23	2
	2	21	2
	3	25	11
	4	19	23
	5	2	42

than 90 % in both parametric and non-parametric classificatory analyses (Table 5). There are only slight differences between the results of the parametric and non-parametric method. Among the characters most correlated with the canonical axis are again RD, LT, LW, UL, IG, but also HL (Table 4). One would expect that the wrongly classified plants would be confined to the "intermediate" populations nos. 7 and 12, however this is not the case. Wrongly classified plants are spread into populations nos. 4, 7, 9, 11, 14, 16 and 17 in the parametric analysis and nos. 4, 5, 7, 9, 14,

Table 4

Total canonical structure and standardized canonical coefficients obtained in the canonical discriminant analysis of the two groups of populations of the *S. montanum* group in the West Carpathians. For character abbreviations see material and methods.

Character	Total canonical structure	Standardized canonical coefficients
RD	0.745	0.851
NL	–0.351	–0.525
HL	0.767	0.530
CL	0.532	0.249
LT	0.896	0.854
LW	0.853	0.384
LL	0.620	–0.591
UL	0.712	–0.237
IG	–0.718	–0.307

Table 5

Results of the classificatory discriminant analysis of the two groups of populations of the *S. montanum* group in the West Carpathians.

Actual group		Predicted group membership (number of observations/percentage classified into groups)	
		"lowland" taxon	"upland" taxon
"lowland" taxon	Parametric method	85/94.44	5/5.56
	Nonparametric method	84/93.33	6/6.67
"upland" taxon	Parametric method	7/8.75	73/91.25
	Nonparametric method	2/2.50	78/97.50

and 17 in the non-parametric one which confirms the correct classification of the populations no. 7 and 12 into "lowland" and "upland" population groups respectively.

A closer look at the results of the exploratory analysis (Table 2, 3) reveals that no individual character enables clear identification of plants into the above-mentioned groups and that more characters must be taken into consideration.

The question of proper names for these two groups of populations (taxa) still remains open and it depends on the acceptance of the proposal to reject the name *S. carpathicum* WETTST. ex PRODAN (LETZ 1998). The

current usage of the name *S. montanum* subsp. *carpathicum* is incorrect, based on the misapplication of a name with epithet "*carpathicum*" (cf. LETZ 1998). An usage of names with epithet "*carpathicum*" in the correct original sense (i.e. for the "upland" taxon, following the neotypification published by LETZ 1998) could be confusing and is prevented by the Art. 57 of the CODE. Thus the correct epithet for the "lowland" taxon should be "*heterophyllum*", based on the name *S. montanum* "ß" *heterophyllum* HAZSL., while if the proposal to reject the name *S. carpathicum* would be approved, the "upland" taxon remains to be described anew; in the case that the proposal fails, the name *S. carpathicum* should be applied here. Therefore, we treat both the taxa of the *S. montanum* group in the Carpathians at present under informal designations, as "lowland" and "upland" taxon.

Following the results of the morphometric analysis we suggest to treat the "lowland" and "upland" taxa on the level of subspecies of the as yet unnamed Carpathian species from the *S. montanum* group. They can be identified according to the following key:

1a Rosettes (2–)3–6(-9) cm in diameter, rosette leaves light (yellowish) green, often spathulate, rounded near apex, 6–11 mm wide, 2–3.5 mm thick
"lowland" taxon

1b Rosettes (1.5–)2–4(-5) cm in diameter, rosette leaves deep (dark) green, usually neither spathulate nor rounded near apex, 3–6.5 mm wide, 1–2.5 mm thick
"upland" taxon

Note: For the identification, attention should be paid to ecological conditions. The plants from extreme conditions and too young ones are not suitable for identification.

Unlike *S. montanum* L. s.str., rosette leaves of both these taxa are acuminate on the apex, sparsely pubescent to glabrous, with shorter glandular hairs (0.05–0.2 mm); and petals are usually longer (12–16 mm). Rosette leaves of *S. montanum* L. s.str. are obtusely acute, densely pubescent, with longer glandular hairs (0.2–0.5 mm); and petals are 9–13(–15) mm long. Unlike tetraploid *S. stiriacum* WETTST., leaves of both taxa studied are not tipped with red; and petals are shorter (in *S. stiriacum* they are 16–20 mm long).

3.2. Notes on the distribution and ecology

While the "upland" taxon is distributed in the montane and subalpine to alpine belt of the whole Carpathians, the "lowland" one is endemic to the West Carpathians (Fig. 8). This is clearly visible also on the maps, published by MEUSEL & al. 1965: 199 and ZAHRADNÍKOVÁ 1984: 199–200 (in both publications as *S. montanum* subsp. *carpaticum* [sic!]). However, on these maps populations from the Krivánska Malá Fatra Mts. are wrongly identified as *S. montanum* subsp. *montanum* ("upland" type). According to the results of the present study, plants from this area (population no. 14 – Hoskora Valley) belong to the "lowland" type although, unlike the other

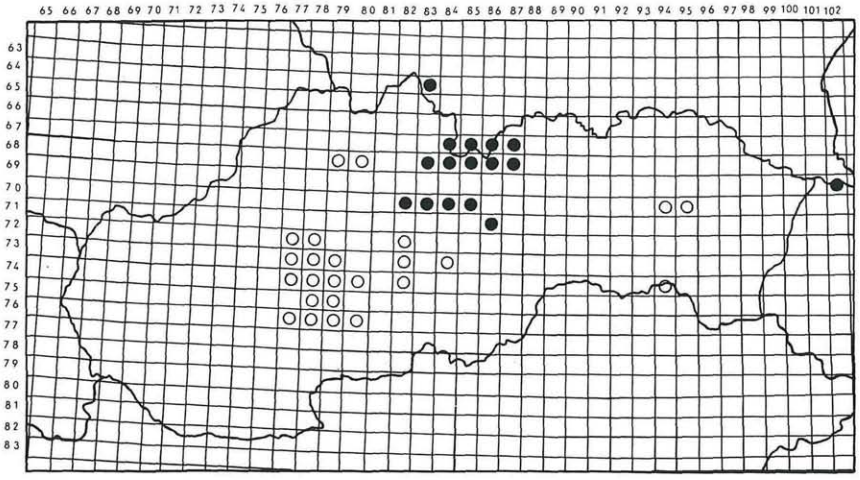

Fig. 8. Distribution map of the *Sempervivum montanum* group in the West Carpathians: the "upland" taxon (full dots) and the "lowland" taxon (empty dots). (The square 102–69 belongs to the East Carpathians.)

populations of this taxon, they do not grow on andesite or rhyolite (cf. Table 1), but on autometamorphic granite. It seems that the "lowland" type is restricted to andesite, rhyolite, and autometamorphic granite substrates, more rich in minerals in comparison with flysch, granite or crystallic slate substrates characteristic for the localities of the "upland" type. The altitude, characteristic for the "lowland" type, often as low as 300–600 m, is unique for the *S. montanum* group.

JÁVORKA 1924: 456, apart from the West Carpathian localities for his "*S. montanum* * *heterophyllum*" notes: "nagymarosi Ördög-hegyen [Hungary]; Erd. [Transylvania]: Tusnád [Tuşnad, Romania]". In the case of these localities this taxon was confused with the plants from the *S. marmoreum* group (cf.: Tuşnad – RAYNS 1901 BPU, KOVÁCS 1905 BP, SERBAN 1938 CL, NYÁRÁDY 1951 SIB; Nagy Maros – BOROS 1918 BP). Locality "Tuşnad, Solyomkö" is cited also by SOÓ 1930: 246, 1943: 28 as well as in the Flora of Romania (RĂVĂRUŢ 1956: 78), where four other localities for *S. montanum* subsp. *carpaticum* from Romania are also mentioned. All these data are most probably based on misidentifications as there are no herbarium data for this taxon either from the area of Romania or Ukraine.

4. Acknowledgments

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