

# Alpine–subalpine species richness of the Romanian Carpathians and the current conservation status of rare species

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Received: 26 February 2008 / Accepted: 18 September 2008 / Published online: 7 October 2008  
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**Abstract** In the context of global warming, alpine–subalpine plant species are some of the most threatened. The distribution of these species in the Romanian Carpathians is centralized and analyzed for the first time. A network with 472 grid cells of  $12.5 \times 11.5$  km ( $6'$  latitude  $\times$   $10'$  longitude) has been used to register the distribution of 550 selected high mountain taxa. The analysis starts with a brief description of the most important determinants of alpine–subalpine species richness, continues with a comparison between the different sub groups of the Romanian Carpathians and a discussion of their particularities. The purpose of the paper is to identify areas in need of protection as well as rare and vulnerable species outside the network of protected areas. A description of the current network of protected areas from the Romanian Carpathians is provided, with ideas for improvement.

**Keywords** Endemic species · Floristic diversity · Rare species · Romanian Carpathians · Subalpine–alpine taxa · Vulnerable taxa

## Abbreviations

HMT High mountain taxa  
EC Eastern Carpathians

**Electronic supplementary material** The online version of this article (doi:[10.1007/s10531-008-9488-z](https://doi.org/10.1007/s10531-008-9488-z)) contains supplementary material, which is available to authorized users.

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SC	Southern Carpathians
AM	Apuseni mountains
RSR	Range size rarity
RRSR	Relative range size rarity
SR	Species richness

## Introduction

Scientific interest in studying the alpine flora and vegetation has increased recently, as global warming threatens particularly the specific flora of the high mountains (Grabherr et al. 1994; Gottfried et al. 1999; Stanisci et al. 2005; Pauli et al. 2006). All the scenarios that concern the future of alpine species and the structure of subalpine–alpine ecosystems need long-term field observations to relay on. In this context, data existing in the literature on alpine–subalpine plant species ranges becomes very important. Although there are a few general studies related to the subalpine–alpine flora of the Romanian Carpathians (Pax 1909; Borza 1959; Boşcaiu 1971; Coldea 1991, 2003), until now there was no attempt for a centralization of alpine–subalpine plant species distribution.

The present study is the first on this subject in the Romanian Carpathians, and is based on data obtained in the IntraBioDiv project ([www.intrabiodiv.eu](http://www.intrabiodiv.eu)), 2004–2006.

Due to their geographic position, the Romanian Carpathians represent a crossroad of floristic elements of different origins (Central European, Balkanic and Asiatic), and are characterized by a large number of endemic taxa (Pax 1898; Borza 1959; Pawlowski 1970; Beldie 1967; Boşcaiu 1971; Dihoru and Pârnu 1987; Coldea 1990). Knowledge related to their subalpine–alpine vascular flora contributes to the efficiency of national efforts made to protect the region's rare and vulnerable species.

The first Romanian protective law for natural monuments was adopted in 1933. Since then, information regarding rare plants and locations of scientific interest has accumulated continuously. Currently, in the mountain-alpine area of the Romanian Carpathians there are 91 natural reserves of botanical interest and 10 national parks.

The network of protected areas presently covers approximately 5.5% of the 67,800 km<sup>2</sup> total area of the Romanian Carpathians, but as there was no centralization of plant species distributions, there was no way of knowing how well this network covers the increasing need of protection for alpine–subalpine plant species. This study will try to fill in some of the gaps, and recommend new areas for protection.

Also, a brief description of the most important determinants of alpine–subalpine species richness is considered and a comparison between different sub-groups of the Romanian Carpathians relating to species richness, rarity, similarity and number of endemics.

## Materials and methods

### Study area

The Romanian Carpathians (the Romanian Carpathians) are located between 44°48'–48°00' N and 22°00'–26°40' E, and have an area of about 67,800 km<sup>2</sup>, divided into three main groups, namely (i) the Eastern Carpathians (highest peak, Pietrosul Rodnei—2,305 m), (ii) the Southern Carpathians (highest peak, Moldoveanu—2,544 m) and (iii) the Apuseni

Mountains or the Romanian Western Carpathians (highest peak, Bihor—1,848 m) (Mihăilescu 1963). These mountain ranges differ also by their geological structure.

The relief is characterized by a prominent fragmentation (0.5–3 km/km<sup>2</sup>) and average relief energy of about 600 m.

The geologic substrate is composed mainly of crystalline schist, with numerous granite intrusions, and in certain points, with Mesozoic limestone deposits. On the western rim of the Eastern Carpathians the geologic substrate is mainly volcanic (Coldea 1991).

The climate of the Romanian Carpathians is continental-moderate, with average annual temperatures between +7 and –2°C, varying with altitude; precipitations have a yearly average of 900–1,350 mm (Coldea 2003).

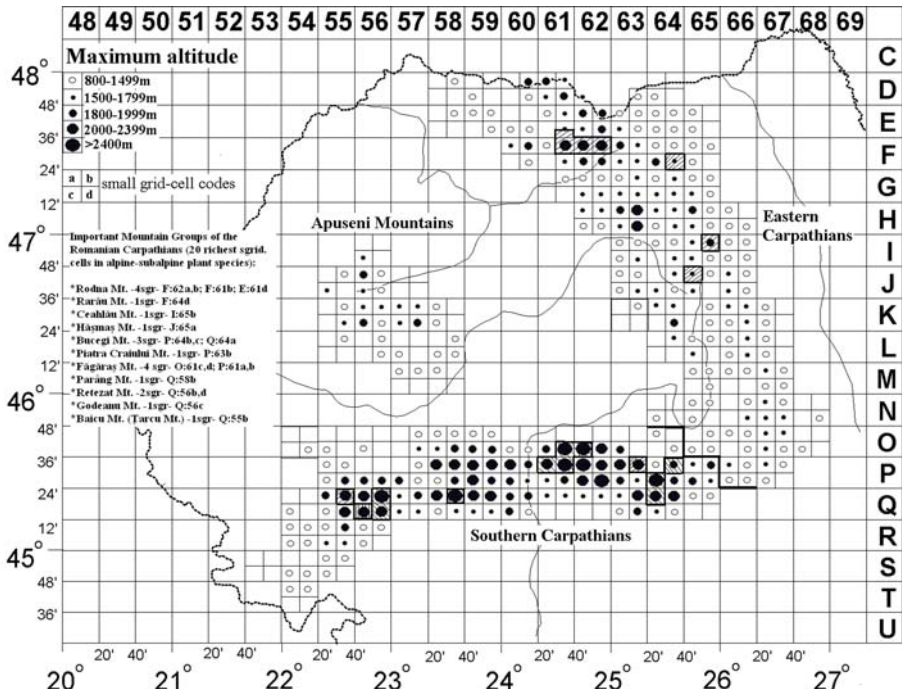
In the Carpathians there are three distinct vegetation belts: (i) the mountainous belt (750–1,650 m), with *Fagus sylvatica* and *Picea abies* forests; (ii) the subalpine belt (1,650–2,200 m) with *Pinus mugo*, *Alnus viridis* and *Rhododendron myrtifolium* shrubs and (iii) the alpine belt (2,200–2,540 m), with primary grasslands with *Carex curvula*, *Juncus trifidus* and *Festuca supina* (Coldea 1991).

The main phyto-geographic elements recorded in the Romanian Carpathians are:

- circumpolar (arctic-alpine) (*Androsace chamaejasmae*, *Arctostaphylos uva-ursii*, *Arenaria tenella*, *Astragalus frigidus*, *Draba fladnitzensis*, *Carex rupestris*, *Carex lachenali*, *Juncus castaneus*, *Juncus triglumis*, *Lomatogonium carinthiacum*, *Kobresia simpliciscula*, *Primula farinosa*, *Salix alpina*, *Saxifraga cernua*, *Saxifraga hieracifolia*, *Thalictrum alpinum*),
- eurasian (arctic-alpine) (*Arenaria biflora*, *Astragalus alpinus*, *Astragalus penduliflorus*, *Carex parviflora*, *Carex fuliginosa*, *Comostoma tenellum*, *Saussurea discolor*, *Saxifraga aizoides*, *Saxifraga stellaris* ssp. *robusta*, *Ranunculus glacialis*),
- alpine-european (*Crepis conyzifolia*, *Draba aizoides*, *Gentiana frigida*, *Gentiana orbicularis*, *Geum reptans*, *Linaria alpina*, *Oxytropis halleri*, *Oxytropis neglecta*, *Phleum hirsutum*, *Primula intricata*, *Rumex scutatus*, *Ranunculus alpestris*, *Ranunculus thora*, *Saussurea discolor*, *Saxifraga bryoides*, *Saxifraga retusa*),
- alpine-carpathic (*Arabis soyeri*, *Armeria alpina*, *Callianthemum coriandrifolium*, *Gentiana frigida*, *Leontodon croceus*, *Trifolium pallescens*),
- carpathic-balcanic (*Arabis hornungiana*, *Centaurea kotschyana*, *Leontodon rilaensis*, *Plantago gentianoides*, *Potentilla haynaldiana*, *Saxifraga luteoviridis*, *Saxifraga rotundifolia* ssp. *heucherifolia*),
- endemic for South-Eastern Carpathians (*Alopecurus laguriformis*, *Andryala levitomentosa*, *Aquilegia nigricans* ssp. *suscaposa*, *Aquilegia transsilvanica*, *Asperula carpatica*, *Centaurea carpatica* agg., *Dianthus callizonus*, *Draba dorneri*, *Festuca nitida* ssp. *flaccida*, *Festuca versicolor* ssp. *domini*, *Hesperis oblongifolia*, *Nigritella carpatica*, *Pedicularis baumgarteni*, *Silene nivalis*, etc.) (Appendix 1),
- pancarpathic endemics (*Achillea schurii*, *Campanula carpatica*, *Campanula serrata*, *Chrysosplenium alpinum*, *Dianthus spiculifolius*, *Festuca carpatica*, *Heracleum carpaticum*, *Melampyrum saxosum*, *Phyteuma wagneri*, *Oxytropis carpatica*, *Pulmonaria filarszkyana*, etc.) (Appendix 1).

#### Grid cells

The grid cell network for the subalpine–alpine area of the Romanian Carpathians was set up following the method used to map the Central Europe Flora (Ehrendorfer and Harmann 1965).



**Fig. 1** Maximum altitudes of the small grid cells from the Romanian Carpathians and the 20 richest cells in HMT species (highlighted in black)

According to the EU-INTRABIODIV common methodology for the alpine and subalpine taxa from the Alps and Carpathians (Gugerli et al. submitted), the area with altitudes above 1,000 m from the Romanian Carpathians covers 118 large grid cells of 25 × 23 km. To increase the accuracy of the records location and to enhance the statistical data processing, each large grid was subdivided into 4 parts making a total of 472 small grid cells of 12.5 × 11.5 km, (10' longitude and 6' latitude) (Fig. 1).

**Environmental data**

In order to reveal the influence of environmental factors on alpine–subalpine species richness (SR) and on endemic alpine–subalpine species richness, we have taken into consideration the following environmental variables: geological substrate and altitude.

*The geological substratum* for every grid cell has been established using the geological maps of Romania scale 1:200,000 (Murgeanu et al. 1966–1970). Three groups of limestone frequencies (0, 1, 2) were used for showing the presence of limestone patches. Grid cells with limestone frequency “2” have consistent calcareous patches, clearly delimited, occupying more than 15% of the surface of a grid cell. Grid cells with limestone frequency “1” have some calcareous patches, but their spread is between 5 and 15% of the grid surface. Grid cells with limestone frequency “0” have no limestone (below 5% spread).

*Altitude* as geo-morphological factor, which influences indirectly the chorology of HMT, was extracted from Gauss topographic maps of Romania, on the scale of 1:100,000. Maximum altitude of the grid cell was considered.

## Floristic data

The unitary list of the alpine and subalpine taxa (HMT) from the Alps and the Carpathians was established by a specialized collective (Englisch et al. in prep.) and will be published in a special issue.

Approximately 85% of the floristic database has been compiled from existing botanic and phytocoenologic literature, as well as chorological data from the most important herbariums in the country—Cluj, Sibiu, Iasi (electronic appendix). About 15% of the grid cells were not researched for floristic data, so field researches were carried out between 2004 and 2006 by our specialists.

## Diversity measures

The most used diversity indicator of flora is SR, which for the high mountains is strongly influenced by the energy availability, geologic substrate and the interaction of available energy and water, which can be included as continental aspect of the climate (Wohlgemuth 2002a, b; Birks 1996; Moser et al. 2005; Grytnes et al. 1999; Krauss et al. 2004).

Two of the most important factors that influence the distribution patterns, altitude and substrate, were taken into consideration for a regression model. Another indicator to be investigated is the number of endemic species and its relations to altitude, substrate and SR (Heikkinen and Neuvonen 1997; Bruun et al. 2003).

The three subgroups of the Romanian Carpathians are compared related to their no. of species, altitudes, no. of large grid cells and small grid cells, geographic distance between grids and Sorensen similarity between grids.

Qian et al. (2005), considering Vellend (2001) have defined a measure of beta-diversity based on turnover: “the slope of the relationship between turnover of species (the natural logarithm of the Sorensen index of floristic similarity) and geographic distance”. Considering this definition, beta-diversity is estimated for the Romanian Carpathians sub-groups. According to both Qian et al. (2005) and Vellend (2001), the best similarity coefficient to be used in turnover studies is Sorensen. Past Software (Hammer et al. 2001) was used to obtain the Sorensen similarity matrices for the three mountain groups. The Geographic Distance Matrix Generator (Ersts 2008) was used for the geographic distance matrices (respectively the distance in km between the centers of each grid cells). Sorensen similarity was then log transformed (Vellend 2001; Qian et al. 2005). Zero values of Sorensen similarity were assigned a value of 0.05 to allow log transformation (Vellend 2001). Individual values of log transformed Sorensen similarity were plotted against the Geographical distances between each pair of grid cells; straight lines were fit to the data using linear regression.

ANCOVA analysis is used to determine if there is a significant difference between the Romanian Carpathians sub-groups regarding beta-diversity (Qian et al. 2005).

## Rare and endangered species

In order to determine rare and vulnerable species, the HMT distribution in the grid cells was analyzed for the three important ranges of the Romanian Carpathians, respectively the Eastern Carpathians (219 grid cells), the Southern Carpathians (133 grid cells) and the Apuseni Mountains (38 grid cells). In the analysis we have considered as “rare species” the taxa that occur in less than 3% of the total number of grid cells, separately for each of the three mountain ranges (Williams 2000). Some of these species match the IUCN criteria for vulnerable and endangered species proposed by Mace and Lande (1991).

## Rarity analysis

As Levin et al. (2007) notice, quantifying rarity can be measured using several estimates (Izco 1998), but given the restriction to a mountain chain (Romanian Carpathians) rather than considering the entire distribution of species, a relative range size rarity index is needed. This index (RSR range size rarity) is calculated as the sum of the inverse of the range sizes of all the species occurring in each quadrat (sensu Williams et al. 1996; Williams 2000, Levin et al. 2007). RSR has high values in the grid cells with many species, so in order to get a more real estimate, RRSR (relative range size rarity) was used, an index that uses the species number in each grid cell to weigh RSR (Levin et al. 2007). Even the weighed RRSR is a biased measure of rarity, as grid cells with the highest RRSR values usually have small number of species (Williams 2000).

A real comparison of rarity is possible only between grid cells with a similar number of species. In our case, the 20 richest small grid cells were tested for correlation of rarity with altitude and SR. Comparisons are made between the most important mountain massifs of the Romanian Carpathians with regards to both HMT richness and rarity, highlighting the small grid cells of special interest.

## Results

### Species diversity

Out of the 472 small grid cells, only in 390 were found subalpine–alpine taxa.

We have identified in the Romanian Carpathians 550 high mountain taxa (HMT)—446 species and 104 subspecies. The number of taxa that have their distribution limited only to the alpine belt is 47.

The repartition of the 550 taxa in the three mountainous ranges of Romanian Carpathians is different: in the Eastern Carpathians we find 475 taxa (86.5% of the total taxa), in the Southern Carpathians 515 taxa (93.8%) and in the Apuseni Mountains only 230 taxa (41.9%) have been identified.

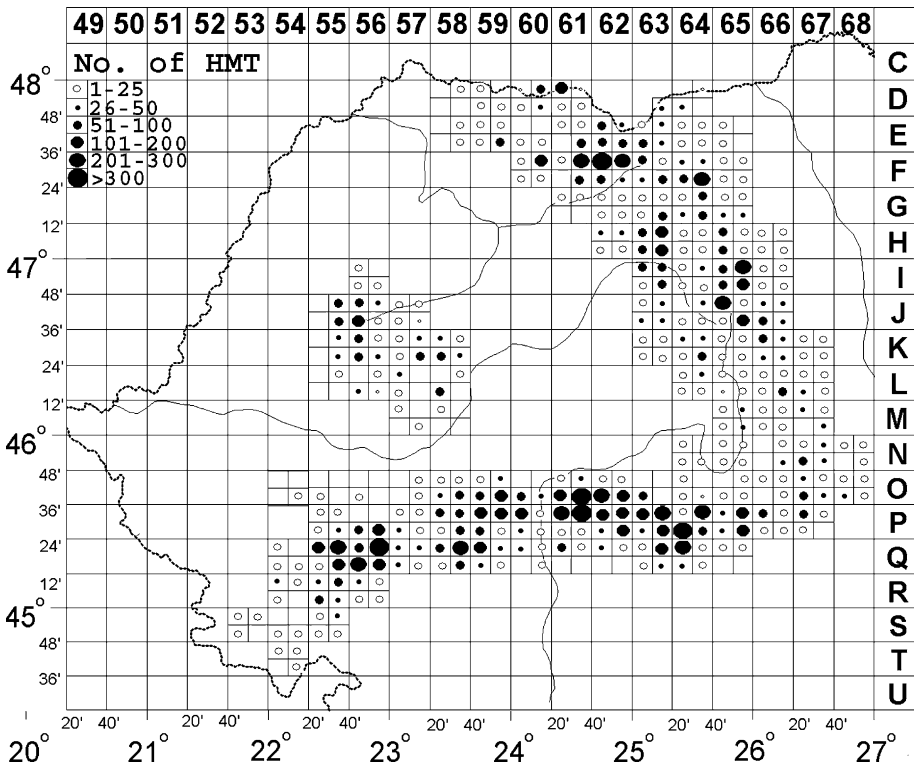
The highest number of taxa recorded on the surface of one  $6' \times 10'$  ( $\approx 140 \text{ km}^2$ ) grid cell has been recorded in the Southern Carpathians, namely 357 taxa (grid cells P-64/c; O-61/d) in the Bucegi and Fagaras Mountains and 314 taxa (Q-56/b) in the Retezat Mountains, respectively. In the Eastern Carpathians the maximum number of identified taxa was 307 taxa (F-62/a) in Rodna Mountains and 261 taxa (I-65/b) in the Ceahlau Mountains. In the Apuseni Mountains the maximum number of 106 taxa was found in the Vladeasa Massif (J-56/c).

A representation of SR on the grid cell network from the Romanian Carpathians is presented in Fig. 2.

### Environmental predictors of subalpine–alpine plant species richness

One of the first things tested is the correlation with altitude ( $R^2 = 0.70$ ,  $P < 0.001$ ), which is found to be quite consistent, but considered normal as we have a list of selected high mountain taxa.

Even if grid cells have equal size, the cover of high mountains inside each grid cell may differ, causing hidden species-area effects—so we tested the correlation between SR and high mountain area in each grid. We considered high mountain area to be the area above 1,400 m



**Fig. 2** The HMT floristic richness in the Romanian Carpathians, HMT = High Mountain Taxa

a.s.l. The correlation ( $R^2 = 0.27, P < 0.001$ ) reveals that even though area above 1,400 m a.s.l. in a grid cell influences SR, altitude is a much better predictor (maximum altitude is more important than area above 1,400 m in the determination of alpine–subalpine plant SR).

In order to analyze the combined effect of altitude and area above 1,400 m a.s.l., we used multiple regression. The adjusted  $R^2$  is in this case 0.71 while  $F = 73.92, P < 0.001$ . Multicollinearity is, however, problematic in this model, as  $R^2$  between the two predictors is 0.53,  $P < 0.001$  (the two predictors are not independent—generally, the higher a peak is, the larger the area above 1,400 m surrounding it). The regression coefficient of area above 1,400 m is negative in this context and it has failed the significance test ( $P > 0.05$ ), for this reasons, in the following analysis, only altitude will be used.

Substrate is also an important environmental factor to be considered.

A multiple regression that has SR as dependent variable and altitude and limestone presence as predictors has the adjusted  $R^2 = 0.567$  while  $F = 217.056, P < 0.001$ . Multicollinearity is not a problem in this regression as  $R^2$  of the two predictors is 0.087 ( $P < 0.001$ ), meaning that they are independent.

The regression coefficients are both positive and significant at the 0.001 level (Table 1).

### Endemics analysis

Out of the 85 Romanian plant endemics (Dihoru and Pârnu 1987), 48 (56%) are localized in the alpine–subalpine belts of the Romanian Carpathians.

**Table 1** Multiple regression of species richness with altitude and limestone as variables

Predictor	Coefficient	Standard deviation	<i>t</i> -ratio	<i>P</i>
Constant	−161.948	10.832	−14.951	0.000
Altitude	0.128	0.007	17.994	0.000
Limestone	16.882	3.571	4.727	0.000

An analysis of endemic species distribution, related to grid cell altitude and SR shows that the number of these species increases with altitude ( $R^2 = 0.33$ ,  $P < 0.001$ ), similarly to the results recorded in the southern Europe (Giménez et al. 2004). There is also a strong relation to the total number of taxa per grid cell— $R^2 = 0.82$  (Kull et al. 2002).

As for the Carpathic endemics distribution in relationship with the nature of the geological substrate, most of them seem to be calcicole (57.5%), the rest being acidophile (42.5%) (Csürös et al. 1967; Ellenberg et al. 1992).

#### Measures of habitat heterogeneity and beta-diversity

##### *Measures of habitat heterogeneity*

As already mentioned, the Romanian Carpathians are divided in three main groups: Eastern, Southern and Apuseni (Romanian Western). We considered a comparison between the three groups with respect to spread, similarity, altitude and no. of grid cells (Table 2).

##### *Measures of beta-diversity*

The comparison of HMT, endemics and rarity between the three groups was considered only in small grids (Table 3), as these provide better resolution, the large grid cells hiding small numbers of HMT.

The three mountain ranges were considered for separate regressions of distance versus similarity (Qian et al. 2005). Their linear fits were: Eastern Carpathians:  $\text{LnS} = -1.838 - 0.001 \times \text{Dist}$  ( $R^2 = 0.034$ ,  $P < 0.001$ ); Southern Carpathians:  $\text{LnS} = -1.750 - 0.003 \times \text{Dist}$  ( $R^2 = 0.129$ ,  $P < 0.001$ ); Apuseni Mountains:  $\text{LnS} = -1.935 - (4.308E - 5) \times \text{Dist}$  ( $R^2 = 0.002$ ,  $P < 0.001$ ).

The slope is representative for beta-diversity. ANCOVA analysis was used to see if there is a significant difference between the slopes. In the comparison of Eastern and Southern Carpathians, the null hypothesis that the slopes are identical was dismissed ( $P < 0.001$ ), so we can declare that the beta-diversity of the Eastern Carpathians is higher than that of the Southern Carpathians.

#### Rare and vulnerable species

Out of the 550 cormophyte taxa recorded in the Romanian Carpathians, 291 are considered to be rare in the three mountain ranges (the Eastern Carpathians, the Southern Carpathians and the Apuseni Mountains), which means that 52% of the taxa occur in less than 3% of the total number of grid cells of one chain of mountains. These taxa can be considered rare for the region (Stace 1991; Kull et al. 2002, Williams 2000).

**Table 2** Habitat heterogeneity measures between the three main groups of the Romanian Carpathians

Mountain Group	Distance between large grid cells (km)		Sorensen similarity (St. Dev.)	Altitude (m)		Number of grid cells	
	Mean (St. Dev.)	Maximum		Mean	Maximum	Small cells	Large cells
Eastern Carpathians	143.95 (84.02)	432.2	0.151 (0.065)	1,436.76 (272.58)	2,305	219	63
Southern Carpathians	162.98 (104.47)	449.4	0.144 (0.097)	1,725.02 (419.76)	2,544	133	41
Apuseni Mountains	55.02 (23.84)	113.19	0.160 (0.068)	1,454.31 (214.82)	1,849	38	11
Total (Romanian Carpathians)	NA	NA	NA	NA	2,544	390	115

**Table 3** Differences in species richness and rarity between the three main groups of the Romanian Carpathians

Mountain group	No. of HMT	Average no. of HMT in small grids		No. of endemic HMT	Average no. of endemic HMT in small grids		Rarity RRSR in small grids	
		Mean (Std. Dev.)	Maximum		Mean (Std. Dev.)	Maximum	Mean (Std. Dev.)	Maximum
Eastern Carpathians	475	35.22 (49.164)	307	35	3.25 (4.14)	22	0.1128 (0.057)	0.5
Southern Carpathians	515	67.34 (82.24)	357	40	5 (5.36)	25	0.1071 (0.044)	0.199
Apuseni Mountains	230	32.66 (25.82)	106	10	2 (0.96)	5	0.1028 (0.041)	0.173
Total (Romanian Carpathians)	550	45.92 (62.86)	357	48	3.79 (4.55)	25	0.1099 (0.052)	0.5

## Rarity analysis

The 20 grid cells that are richest in species are taken into consideration for a comparison regarding their rarity index—RRSR (Tables 3, 4). RRSR was found to be unrelated to no. of species ( $R^2 = 0.038$ ,  $P < 0.001$ ), or altitude ( $R^2 = 0.016$ ,  $P < 0.001$ ).

## Discussion

### Environmental predictors of subalpine–alpine plant species richness

According to the regression model described in the results, if the two predictors used (altitude and limestone presence) would be the only determinants of alpine–subalpine plant SR we would expect an increase of about 13 alpine–subalpine plant species for every 100 m of maximum altitude gained on similar substrate. Limestone was not ruled out as a predictor of alpine–subalpine plant SR, as an increase of one frequency unit will add about 17 species (if the altitude is constant).

Considering limestone for this analysis even if there was no digitized substrate map at our disposal was needed to underline an obvious trend: grid cells from mountainous massifs higher than 2,000 m with limestone areas have the highest number of taxa (P-64/c, O-61/d—357 taxa), while grid cells from high mountain massifs without limestone in their geological substratum contain much lower number of taxa (H-63/b—192 taxa). The lowest number of HMT (1–3 taxa) was found in grid cells from lower altitudes (1,000–1,200 m) with exclusively acid geologic substratum (I-63/c, L-66/c).

However the regression model is not complete and further studies on the environmental determinants of alpine–subalpine plant species are needed, especially in the context of global warming (Grabherr et al. 1994; Gottfried et al. 1999; Stanisci et al. 2005).

For now, the results prove that alpine–subalpine SR is determined by both altitude and geologic substrate, similar to results from other parts of Europe (Heikkinen 1996; Birks 1996; Wohlgenuth 2002a, b).

### Endemics analysis

Even though richness in endemic species shows a strong correlation with total HMT species richness ( $R^2 = 0.82$ ,  $P < 0.001$ ), there is only weak correlation with altitude ( $R^2 = 0.33$ ,  $P < 0.001$ ), in contradiction with the strong correlation between total HMT species richness and altitude ( $R^2 = 0.70$ ,  $P < 0.001$ ). This suggests that for the alpine–subalpine endemic species, altitude is not the most important predictor, and other factors are involved (substrate, climate, exposition, species history during glaciation cycles, etc.).

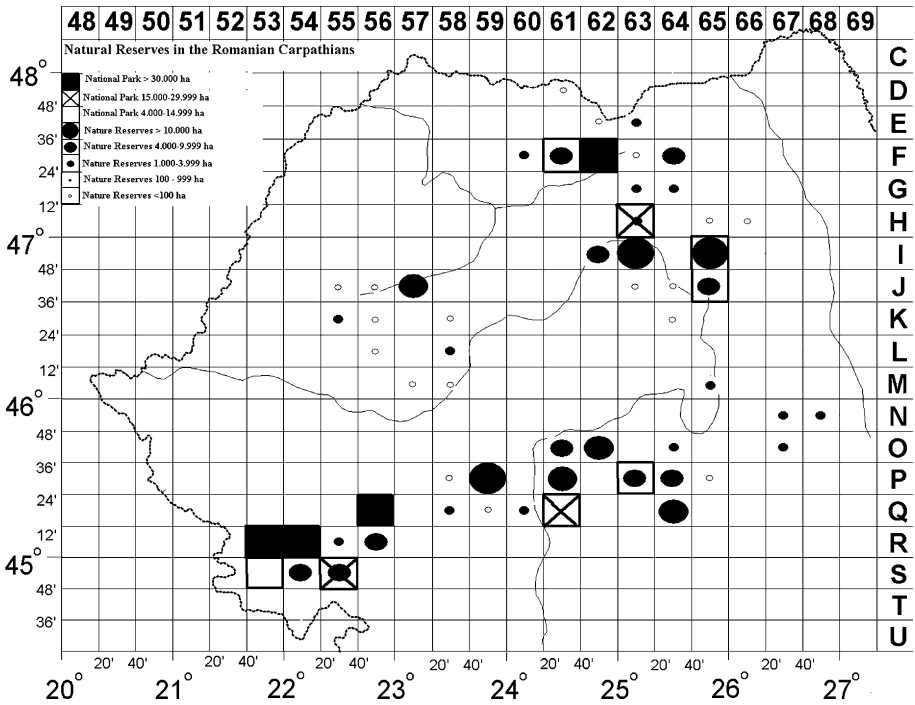
### Measures of habitat heterogeneity and beta-diversity

#### *Measures of habitat heterogeneity*

As we can see in the comparison between the three groups of the Romanian Carpathians (Table 2), the Apuseni Mountains have obvious lower values for almost all of the characteristics used in the comparison (explained by the small spread  $55.02 \pm 23.84$  km and low altitudes  $1,454.31 \pm 214.82$  m). Even if the average altitude of the Apuseni Mountains appears higher than that of the Eastern Carpathians, this is only a bias caused by the fact

**Table 4** A multiple comparison of the 20 small grid cells richest in HMT

Sgrid	Sp. richness		RSR		RRSR		Altitude		Endemics		Mt. group	Lime stone	Surface of protected areas (ha)	Mountain Massif	
	No. sp	Rank	Indice	Rank	Indice	Rank	(m)	Rank	No. sp	Rank				National park	Name
O:61d	357	1	49.49723269	1	0.138648	10	2,507	5	22	1	S	2	1,927.3	No	Făgăraș Mt.
P:64c	357	1	44.73027228	3	0.125295	16	2,505	6	25	3	S	2	1634	No	Bucegi Mt.
Q:56b	314	3	46.95246146	2	0.14953	3	2,508	4	15	11	S	2	1629.4	Yes	Retezat N.P.
P:61b	312	4	41.93375034	5	0.134403	14	2,535	2	19	6	S	2	4247.3	No	Făgăraș Mt.
F:62a	307	5	42.38517121	4	0.138062	12	2,188	12	22	3	E	2	1200	Yes	Rodna N.P.
O:62c	291	6	41.22602619	6	0.14167	9	2,544	1	18	8	S	2	4247.3	No	Făgăraș Mt.
P:63b	286	7	35.50741719	10	0.124152	17	2,238	11	23	2	S	2	1459	Yes	P. Craiului N.P.
F:62b	279	8	41.18854088	7	0.147629	5	2,280	10	19	6	E	2	2893.1	Yes	Rodna N.P.
I:65b	261	9	36.17567285	9	0.138604	11	1,900	16	20	5	E	2	371	Yes	Ceahlău N.P.
P:64b	259	10	31.5152203	15	0.12168	19	1,843	17	15	11	S	2	1025	No	Bucegi Mt.
Q:64a	252	11	28.07842539	17	0.111422	20	2,100	15	17	9	S	2	4991	No	Bucegi Mt.
P:61a	243	12	36.32520714	8	0.149486	4	2,366	7	10	16	S	2	1747.3	No	Făgăraș Mt.
Q:56c	232	13	32.90631013	14	0.141838	8	2,291	9	10	16	S	1	—	No	Godeanu Mt.
F:61b	227	14	34.07750361	11	0.150121	2	2,305	8	12	14	E	2	3300	Yes	Rodna N.P.
F:64d	226	15	33.15514237	12	0.146704	7	1,650	19	16	10	E	2	1361.3	No	Rarău Mt.
Q:58b	217	16	26.58499338	20	0.122511	18	2,518	3	8	18	S	1	200	No	Parâng Mt.
J:65a	212	17	26.68301056	19	0.125863	15	1,772	18	14	13	E	2	800	Yes	Hășmaș N.P.
Q:55b	205	18	27.82021661	18	0.135708	13	2,150	13	8	18	S	1	—	No	Baicu Mt.
E:61d	200	19	32.98393955	13	0.16492	1	1,599	20	11	15	E	1	1370	Yes	Rodna N.P.
Q:56d	197	20	29.03691772	16	0.147396	6	2,114	14	8	18	S	2	280	Yes	Retezat N.P.



**Fig. 3** The existing protected areas network from Romania

that in the Apuseni Mountains there are many gaps in the altitude data (altitude was recorded only in the small grid cells with floristic data).

The most interesting comparisons are among Southern Carpathians (SC) and Eastern Carpathians (EC).

In the distance comparison, we see that the SC are more significantly more spread compared to the EC— $t = 3.176$ ,  $df = 819$ ,  $P < 0.01$ . This conclusion is supported by the higher number of grid cells present in the EC compared to the SC (63 vs. 41 for large grids, 219 vs. 133 for small grids). The SC are more spread even if they have a smaller number of grid cells. These results are caused by the pronounced latitudinal range of SC.

The latitudinal range of the SC is completed by the significantly higher altitude ( $t = 4.905$ ,  $df = 107$ ,  $P < 0.001$ ). The standard deviation of altitude in the SC is almost double than that of EC, reflecting a higher fragmentation of the relief forms.

*Measures of beta-diversity*

In this context it is not a surprise that SC have larger number of alpine–subalpine plant species compared to EC (total number, mean per small grid cell and maximum per small grid cell, total endemics, mean endemics—Table 3).

However, according to the analysis of the slope of the relationship between similarity and distance, Eastern Carpathians have larger beta-diversity. These results are in opposition with the results of Qian et al. (2005), who prove that the higher number of plant species in Eastern South Asia (EAS) compared to Eastern North America (ENA) is caused

by the higher beta-diversity of EAS. The results suggest that, in the case of the alpine–subalpine plant species from the Romanian Carpathians, the relationship described by Qian et al. (2005) is not valid.

To support this theory, it is worth noticing that in the rarity analysis (Table 3) four of the seven small grid cells from the EC have altitudes below 2,000 m a.s.l. (and as low as 1,599 m!), while only one of the 13 that belong to SC is below 2,000 m a.s.l., This may be a consequence of the unapparent higher beta-diversity of the EC compared to the SC. Spread and altitude data that create the idea of higher beta-diversity in the SC are not the only data responsible for beta-diversity. Important factors such as substrate, climate, exposition or species history have not been considered in this analysis, so it is possible that EC has higher beta-diversity compared to SC.

### Rarity analysis

The fact that the weighed rarity index RRSR is not related to the number of species ( $R^2 = 0.038$ ,  $P < 0.001$ ) or altitude ( $R^2 = 0.016$ ,  $P < 0.001$ ) suggests that for declaring biodiversity hot-spots regarding the alpine–subalpine plant species in the Romanian Carpathians, rarity analysis should be taken into consideration, together with SR.

From our analysis (Table 4) we derive the importance of Făgăraș Mt. with regards to SR, as it is spread on three of the top six richest grid cells, and the importance of Rodna Mt. with regards to rarity, as it spreads on three of the six small grid cells that have the biggest rarity index.

We can also notice for the Bucegi Mt. the discrepancy between the high scores of SR (1st and 10th and 11th) and the low scores of rarity (16th, 19th and 20th). Although this discrepancy may be partly caused by the vulnerability of the rarity index to the high values of SR, we notice that the Făgăraș Mountains that occupy also the 1st place for SR are 10th for rarity.

Regarding the situation of the National Parks, 11 of the 20 richest small grid cells in subalpine–alpine plant species are not part of a National Park, situation that should be taken into consideration by the decision-taking factors, in the context of global warming effects on these species (Grabherr et al. 1994; Gottfried et al. 1999; Stanisci et al. 2005).

### Rare and vulnerable species

As stated in the results, 291 of the 550 taxa recorded in the Romanian Carpathians are considered to be rare in the three mountain ranges. An analysis of rare taxa from the Romanian Carpathians, based on IUCN 2001 criteria, which takes into consideration the area occupied by each species in the region, the number of localities, the size of the population, the number of mature individuals and their extinction rate in time (Mace and Lande 1991; Pultin 2002), reveals that out of the total number of 291 rare taxa, 59 (20%) can be considered vulnerable taxa (Appendix 2). These require special measures of “in situ” protection, by including them into the network of natural reserves.

The vulnerable subalpine–alpine taxa phyto-geographic elements are:

- carpathic endemics (*Andryala levitomentosa*, *Draba dornerii*, *Hesperis oblongifolia*, *Nigritella carpatica*, *Pedicularis baumgarteni*, *Primula baumgarteniana*),
- arctic-alpine taxa (*Astragalus frigidus*, *Astragalus penduliflorus*, *Atocion rupestris*, *Carex bigelowii*, *Carex parviflora*, *Kobresia simpliciscula*, *Primula farinosa*, *Woodsia alpina*).

### Species conservation

The current level of “in situ” conservation of the rare and vulnerable plant species from the Romanian Carpathians is shown by the map of existing network of protected areas (10 national parks and 91 natural reserves) (Fig. 3).

The entire network of protected areas of 3,730 km<sup>2</sup>, represents 5.5% of the total area of Romanian Carpathians (67,800 km<sup>2</sup>). This network covers 53 vulnerable taxa (90%), out of the total 59 taxa existing in the area. It should be stressed that all taxa included in the IUCN red list taxa and in the European red list taxa are already included in the Romanian botanical reserves, except for the species *Draba simonkaiana*. Moreover, some taxa from the European red list such as *Achillea schurii*, *Arnica montana*, *Campanula abietina*, *Campanula serrata*, *Gentiana lutea*, *Tozzia alpina* ssp. *carpatica*, are found in large number in protected areas (10–15 reserves) from the Romanian Carpathians. It is scientifically supported that these taxa are well protected in this region. Also, in a similar situation we have most of the subalpine–alpine taxa included in the Romanian red list (Olteanu et al. 1994).

Nevertheless, some of the very rare taxa for the Romania flora, such as *Atocion rupestris*, *Cardamine glauca*, *Carex bigelowii*, *Nigritella carpatica* and *Potentilla haynaldiana*, are not protected “in situ”, so far.

In the Apuseni Mountains area, where because of the low altitudes (1,848 m) there is no alpine belt, several arctic-alpine species are very rare. However, these species, which are quite frequent in the South and Eastern Carpathians, are very important for the biogeography of the Apuseni Mountains, proving similar postglacial history of vegetation in the three studied Carpathian ranges. Nevertheless, species such as *Saxifraga stellaris*, *Carex rupestris*, *Carex atrata*, *Carex bigelowii* and *Nigritella nigra* are not yet included in the network of protected areas.

Based on the results of this study, five new locations for natural reserves have been proposed to the Romanian Ministry of Environment. The new protected areas will be also included in the “Natura 2000” network.

### Conclusions

The detailed analysis of the distribution of the subalpine–alpine species in the Romanian Carpathians reveals that subalpine–alpine plant taxa have an uneven distribution; SR on small grid cells (12.5 × 11.5 km) is positively correlated to altitude and geological substratum.

Grid cells above 2,000 m altitude, with frequent limestone substrate, show the highest number of taxa (357 taxa), while grid cells from lower altitudes (1,000–1,200 m a.s.l.), with only acid, silicate substratum, show the lowest number of taxa (1–3 taxa).

Out of the total number of 85 endemic taxa from Romania, 46 are subalpine–alpine taxa. The number of endemic species increases proportionally to the SR and to the altitude of grid cells.

The Southern Carpathians are more spread along one axis compared to the Eastern Carpathians. They have higher altitudes and a more pronounced fragmentation. All these attributes justify the higher number of HMT, the higher mean of HMT per small grid and the higher maximum of HMT per small grid in the SC. The HMT totals are higher in the SC even if they have fewer grid cells compared to the EC.

The Qian et al. (2005) distance vs. similarity slope test shows higher beta-diversity of the EC compared to the SC, which could be expressed in the surprisingly high number of HMT species in small grid cells with low altitude characteristic to the EC. This result may be a reflection of the environmental factors not considered in the analysis.

Rarity analysis should be taken into consideration for conservation purposes. Even if the Făgăraş Mt. are richest in HMT, Rodna Mt. have the best rarity index. Bucegi Mt. appear to have a discrepancy between the high SR and low rarity scores.

Out of the 550 subalpine–alpine taxa present in the Romanian Carpathians, 291 (53%) are rare; from these, 59 taxa (20%) are considered to be vulnerable, 10 taxa from the latter, (16%), requiring special “in situ” conservation measures.

The network of protected areas covers 53 of the 59 vulnerable taxa (90%). In-situ conservation of very rare taxa is, however, deficient. The fact that 53% of the 550 HMT are rare in at least one of the three Carpathian groups is an important sign for the need of conservation of these species, in the context of global warming.

About 11 of the 20 richest small grid cells in subalpine–alpine plant species are not included in National Parks, situation that should be also taken into consideration by the decision-taking factors.

Based on the results of this study, five new locations for natural reserves have been proposed to the Romanian Ministry of Environment. The new protected areas will be also included in the “Natura 2000” network.

**Acknowledgments** The authors acknowledge the financial support of the IntraBioDiv project ([www.intrabiodiv.eu](http://www.intrabiodiv.eu)) No GOCE-CT-2003-505376 and of the Romanian Education and Research Ministry project no. 51/09.2004. Our consideration for all the specialists involved in floristic data collection in Romanian botanics, as well as a referee for comments and suggestions.

## Appendix 1

The list of the Carpathic Endemic HMT present in Romania

1	<i>Achillea schurii</i>	43	<i>Leontodon kulczynskii</i> <sup>a</sup>
2	<i>Alopecurus laguriformis</i> <sup>a</sup>	44	<i>Leontodon pseudotaraxaci</i>
3	<i>Andryala levitomentosa</i> <sup>a</sup>	45	<i>Melampyrum herbichii</i>
4	<i>Anthemis carpatica</i> subsp. <i>pyrethriiformis</i> <sup>a</sup>	46	<i>Melampyrum saxosum</i>
5	<i>Aquilegia nigricans</i> subsp. <i>subscaposa</i> <sup>a</sup>	47	<i>Minuartia oxypetala</i> <sup>a</sup>
6	<i>Aquilegia transsilvanica</i>	48	<i>Nigritella carpatica</i>
7	<i>Asperula carpatica</i> <sup>a</sup>	49	<i>Noccaea dacica</i> subsp. <i>banatica</i> <sup>a</sup>
8	<i>Campanula carpatica</i>	50	<i>Noccaea dacica</i> subsp. <i>dacica</i>
9	<i>Campanula serrata</i>	51	<i>Oxytropis carpatica</i>
10	<i>Carduus kernerii</i> subsp. <i>kernerii</i>	52	<i>Papaver alpinum</i> subsp. <i>corona-sancti-stephani</i> <sup>a</sup>
11	<i>Carduus kernerii</i> subsp. <i>lobulatiformis</i> <sup>a</sup>	53	<i>Pedicularis baumgartenii</i> <sup>a</sup>
12	<i>Centaurea carpatica</i> subsp. <i>carpatica</i>	54	<i>Phyteuma vagneri</i>
13	<i>Centaurea carpatica</i> subsp. <i>rarauensis</i> <sup>a</sup>	55	<i>Plantago atrata</i> subsp. <i>carpatica</i>
14	<i>Centaurea pinnatifida</i> <sup>a</sup>	56	<i>Poa granitica</i> subsp. <i>disparilis</i> <sup>a</sup>
15	<i>Centaurea pseudophrygia</i> subsp. <i>retezatensis</i> <sup>a</sup>	57	<i>Poa molineri</i> subsp. <i>glacialis</i> <sup>a</sup>
16	<i>Cerastium transsilvanicum</i> <sup>a</sup>	58	<i>Poa rehmannii</i>
17	<i>Chrysosplenium alpinum</i>	59	<i>Primula auricula</i> subsp. <i>serratifolia</i> <sup>a</sup>

## Appendix 1 continued

18	<i>Dianthus callizonus</i> <sup>a</sup>	60	<i>Primula baumgarteniana</i> <sup>a</sup>
19	<i>Dianthus glacialis subsp.gelidus</i> <sup>a</sup>	61	<i>Primula leucophylla</i> <sup>a</sup>
20	<i>Dianthus spiculifolius</i>	62	<i>Pulmonaria filarszkyana</i>
21	<i>Dianthus tenuifolius</i> <sup>a</sup>	63	<i>Pyrola carpatica</i>
22	<i>Draba dorneri</i> <sup>a</sup>	64	<i>Ranunculus carpaticus</i>
23	<i>Draba haynaldii</i> <sup>a</sup>	65	<i>Salix kitaibeliana</i>
24	<i>Draba kotschyi</i> <sup>a</sup>	66	<i>Saussurea porcii</i>
25	<i>Draba simonkaiana</i> <sup>a</sup>	67	<i>Saxifraga mutata subsp.demissa</i> <sup>a</sup>
26	<i>Eritrichium nanum subsp.jankae</i> <sup>a</sup>	68	<i>Scabiosa lucida subsp.barbata</i> <sup>a</sup>
27	<i>Festuca bucegiensis</i> <sup>a</sup>	69	<i>Silene dinarica</i> <sup>a</sup>
28	<i>Festuca carpathica</i>	70	<i>Silene nivalis</i> <sup>a</sup>
29	<i>Festuca nitida subsp.flaccida</i> <sup>a</sup>	71	<i>Silene nutans subsp.dubia</i> <sup>a</sup>
30	<i>Festuca porcii</i>	72	<i>Silene zawadskii</i> <sup>a</sup>
31	<i>Festuca saxatilis</i>	73	<i>Soldanella angusta</i> <sup>a</sup>
32	<i>Festuca tatrae</i>	74	<i>Soldanella hungarica s.str.</i> <sup>a</sup>
33	<i>Festuca versicolor subsp.dominii</i> <sup>a</sup>	75	<i>Soldanella marmarossiensis</i>
34	<i>Festuca versicolor subsp.versicolor</i>	76	<i>Soldanella oreodoxa</i> <sup>a</sup>
35	<i>Gentiana phlogifolia</i>	77	<i>Soldanella rugosa</i> <sup>a</sup>
36	<i>Gypsophila petraea</i>	78	<i>Thesium kernerianum</i> <sup>a</sup>
37	<i>Heracleum carpaticum</i>	79	<i>Thymus bihoriensis</i> <sup>a</sup>
38	<i>Heracleum sphondylium subsp.transsilvanicum</i> <sup>a</sup>	80	<i>Thymus pulcherrimus subsp.pulcherrimus</i>
39	<i>Hesperis moniliformis</i> <sup>a</sup>	81	<i>Trisetum fuscum</i>
40	<i>Hesperis nivea</i>	82	<i>Trisetum macrotrichum</i> <sup>a</sup>
41	<i>Hesperis oblongifolia</i> <sup>a</sup>	83	<i>Viola declinata</i>
42	<i>Hypericum richeri subsp.transsilvanicum</i> <sup>a</sup>		

<sup>a</sup> Romanian Endemic HMT

## Appendix 2

Vulnerable HMT from Romania according to IUCN 2001 criteria

1	<i>Androsace obtusifolia</i>	31	<i>Jasione orbiculata</i>
2	<i>Androsace levitomentosa</i>	32	<i>Juncus castaneus</i>
3	<i>Arabidopsis neglecta</i>	33	<i>Kobresia simpliciuscula</i>
4	<i>Arabis sudetica</i>	34	<i>Lilium carniolicum subsp.jankae</i>
5	<i>Asperula carpatica</i>	35	<i>Linaria alpina</i>
6	<i>Astragalus depressus</i>	36	<i>Lomatogonium carinthiacum</i>
7	<i>Astragalus frigidus</i>	37	<i>Luzula luzulina</i>
8	<i>Astragalus penduliflorus</i>	38	<i>Minuartia oxypetala</i>
9	<i>Atocion rupestris</i>	39	<i>Nigritella rhellicani</i>
10	<i>Aubrieta columnae subsp.croatica</i>	40	<i>Nigritella carpatica</i>
11	<i>Barbarea vulgaris subsp.lepuznica</i>	41	<i>Nigritella nigra s.str.</i>
12	<i>Betula nana</i>	42	<i>Oxytropis neglecta</i>

## Appendix 2 continued

13	<i>Bupleurum ranunculoides</i>	43	<i>Pedicularis baumgartenii</i>
14	<i>Callianthemum coriandrifolium</i>	44	<i>Petasites paradoxus</i>
15	<i>Cardamine glauca</i>	45	<i>Polygala alpina</i>
16	<i>Carduus kernerii subsp.lobulatiformis</i>	46	<i>Potentilla haynaldiana</i>
17	<i>Carex bicolor</i>	47	<i>Primula baumgarteniana</i>
18	<i>Carex bigelowii</i>	48	<i>Primula farinosa</i>
19	<i>Carex lachenalii</i>	49	<i>Primula intricata</i>
20	<i>Carex parviflora</i>	50	<i>Pseudorchis frivaldii</i>
21	<i>Centaurea carpatica subsp.rarauensis</i>	51	<i>Ranunculus glacialis</i>
22	<i>Centaurea pseudophrygia subsp.retezatensis</i>	52	<i>Saxifraga cernua</i>
23	<i>Cirsium acaule</i>	53	<i>Saxifraga cymbalaria</i>
24	<i>Dianthus callizonus</i>	54	<i>Silene acaulis subsp.exscapa</i>
25	<i>Draba doreri</i>	55	<i>Sorbus chamaemespilus</i>
26	<i>Draba fladnizensis</i>	56	<i>Thalictrum alpinum</i>
27	<i>Draba haynaldii</i>	57	<i>Trinia glauca subsp. carniolica</i>
28	<i>Draba simonkaiana</i>	58	<i>Woodsia alpina</i>
29	<i>Gagea fistulosa</i>	59	<i>Woodsia glabella</i>
30	<i>Hesperis oblongifolia</i>		

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