POLISH JOURNAL OF ECOLOGY (Pol. J. Ecol.)	54	1	69–90	2006

Regular research paper

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EFFECT OF SNOW PATCHES ON VEGETATION IN THE HIGH-MOUNTAIN NIVAL GULLIES (TATRA MTS. POLAND)

ABSTRACT: The purposes of the present paper are: a) to characterise the spatial pattern of vegetation in the high mountain nival gullies, b) to assess the factors determining the differentiation of vegetation in the gullies with particular consideration of the role of snow patches, and c) to present the similarities and the differences of relations between plant species composition and thickness and duration of snow patches existing in the gullies and in their vicinities.

The studies have been carried out in the Polish part of Tatra Mountains (19°45'36"–20°08'00"E and 49°10'42"–49°20'05"N), in two nival gullies, located above the upper timberline (i. e. 1500 m a.s.l) . The coverage of each plant species was correlated with the thickness of a snow patch on the basis of the sample plots of 0.25 m^2 (n = 889), located along the vertical transects in the gullies. The relations between variables were established based on the Spearman rank correlation analysis. In order to present the general character of relations between the features analysed the PCA method was applied.

The differentiation of vegetation reflects the habitat conditions, which result from the terrain topography, morphometry of the relief forms, as well as from the thickness and duration of the snow patch. In the nival niches there are the species which positively or negatively correlate with the snow patch thickness. It is manifested through the decrease in the number of species as the snow thickness increases. Two species, *Luzula alpino-pilosa* (Chaix) Breistr. and *Festuca picta* Kit., can be accepted as indicators of the sites with the long persistent snow cover. The negative correlation of the plant species coverage with the snow patch thickness is not so unambiguous, since the role of the snow patch depends upon the duration of its persistence. The study showed the effect of factors featuring the high-mountain vegetation at different spatial scale, i. e. according to altitude, local sites and micro-site factors connected with the place inside the gully with the snow patch.

KEY WORDS: subalpine vegetation, alpine vegetation, snow patches, Tatra Mountains

1. INTRODUCTION

Snow cover in high mountains strongly affects the biotic and abiotic environment and this influence is reflected through the differentiation of vegetation composition and pattern. Snow can influence on the plants by reducing the duration of growing season, increasing soil moisture due to the supply of meltwater, changing thermal conditions of the ground layer and protecting against frost (Daubenmire 1973). This refers especially to such places as the snow beds, which distinctly determine the development of plant communities. On the basis of a study in the

Rocky Mts. (USA) Helm (1982) listed the following factors determining alpine snow patch vegetation: insulation, a shortened growing season, meltwater and soil movement. Harrison *et al.* (2001) pointed up also: reduction in available photosynthetically active solar radiation, the mechanical effects of snow accumulation on steep slopes, reduction of the amplitude of temperature fluctuation and protection against damage by frost, desiccation or wind.

Diversity of plant communities due to different duration of snow cover is revealed in the typology of mountain vegetation. The principles of the Braun-Blanquet approach (Braun-Blanquet 1964) were used for the vegetation of the Tatra Mts. (Pawłowski 1956, 1972, Balcerkiewicz 1984, Matuszkiewicz 2001) and the Central Europe (Ellenberg 1986). Some communities described by these autors, especially those of snow-bed communities (*Salicetea herbaceae*) as well as tall-herb communities and avalanche meadows (*Betulo-Adenostyletea*), occur in places where snow cover lasts for a long time.

According to the Scandinavian typology (European vegetation types: the Nordic countries, 1998) on the basis of the duration of snow cover the high mountain plant communities belong to three units: 1.1 snowfree exposed mountain heath; 1.2 snowcovered vegetation occuring on firm ground with early thaw like tall herb and avalanche meadows; 1.3 snowfield vegetation (on loose ground) – this group consists of snow-bed vegetation. The Scandinavian typology reflects particularly the role of snow in the high mountain vegetation differentiation, especially for the northern European communities (Gjaerevoll and Bringer 1965). It refers also to the lists of chionophobous and chionophilous species (e.g. Eurola and Virtanen 1991).

The influence of the snow cover duration on the vegetation is observed both in the mountain massifs as well as in the case of small areas, such as nival gullies or nival niches with snow patches (Ostler *et al.* 1982, Palacios and García Sánchez-Colomer 1997). It is well known that the places where the snow patches are formed in winter are easily recognised also in summer on the basis of plant communities or indicative plant species. The distribution of the vegetation types and the species indicators according to the locations of snow patches could be different in the case of small-scale spatial distribution of vegetation inside the nival gully. The same vegetation types may form diverse spatial patterns, depending upon the local site conditions (Gerdol and Simarglia 1990, Påhlsson 1998, Kozłowska and Rączkowska 2002).

The purpose of the present study is to show the influence of the snow patches on the differentiation of vegetation cover in relation to the topographical conditions in selected nival gullies of the Tatra Mts. Particularly the following items will be analysed:

- the site conditions of the nival gullies;
- the plant communities and the spatial pattern of the selected plant species;
- the factors determining the differentiation of the vegetation in the gullies, with particular attention paid to the impact of the snow patch persistence and thickness;
- correlation between plant species composition and coverage and snow cover site conditions.

The study constitutes the continuation of the research performed by the authors on the indicative role of plants in relation to the long-lasting snow patches (Kozłowska and Rączkowska 1996).

2. STUDY AREA

The study was carried out in the upper part of the Sucha Woda valley, in the Tatra Mountains (19°45’36”–20°08’00”E and 49°10’42”–49°20’05”N), the highest mountain group of the alpine character in the Carpathian arc (Fig. 1).

Two elongated nival gullies with compact vegetation cover, on the granite substratum have been selected for the study (Fig. 1). Snow patches usually occupied these gullies from May till July. Both gullies are located above the timberline (1500 m a.s.l.). One of the gullies is on the northern slope of Beskid Mt. (1750–1850 m a.s.l.) and the other on the eastern slope of Uhrocie Kasprowe Mt. (1650–1700 m a.s.l.). The study objects were selected as the typical slopes for the studied area of the Tatra Mountains.

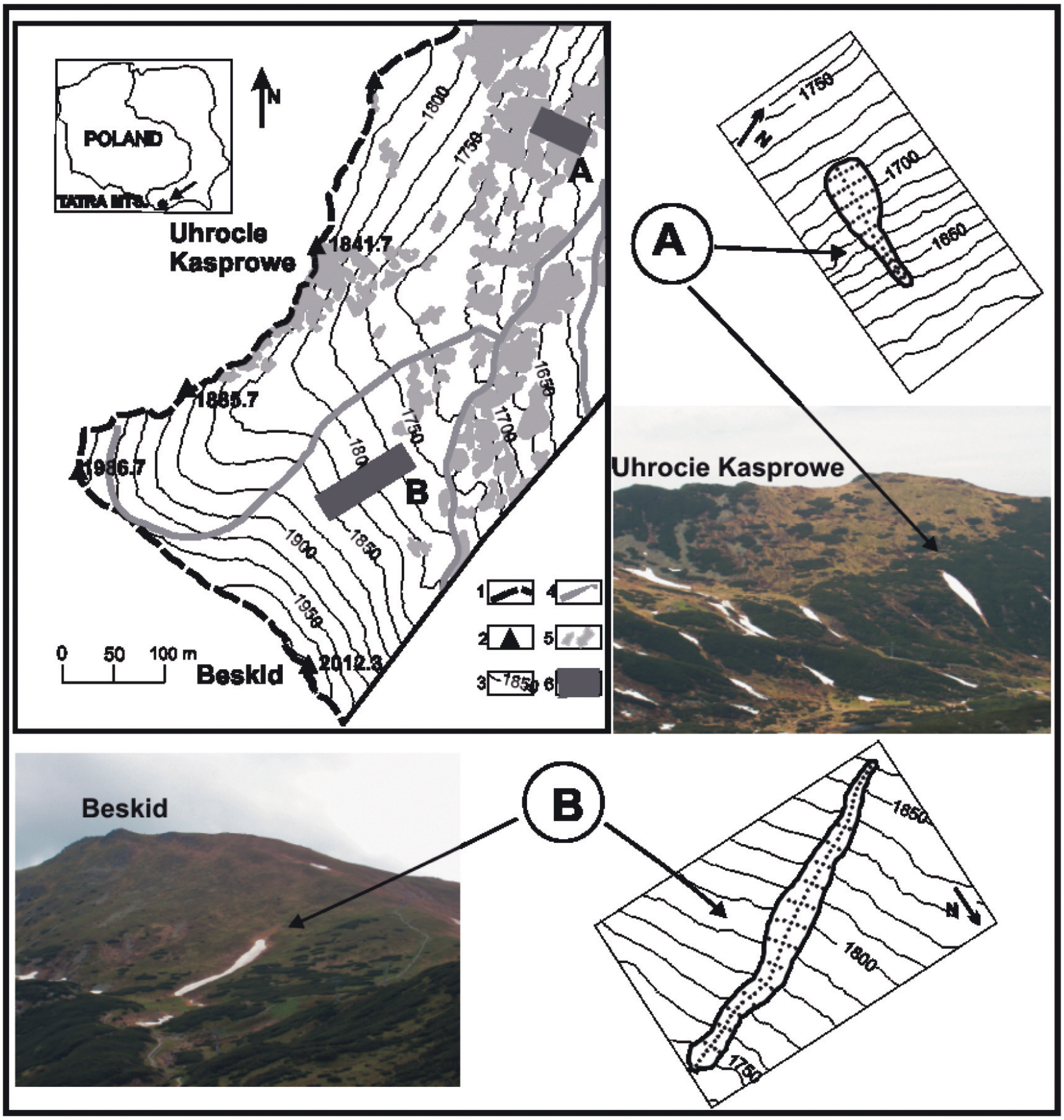

Fig. 1. Location of study areas. A – Uhrocie Kasprowe Mt. (1650–1700 m a.s.l.), B – Beskid Mt. (1750–1850 m a.s.l.) in the Tatra Mts. with indication of snow patches under study (Photos – Z. Rączkowska). View of both study areas in the end of spring. The dots inside the outline of snow patches indicate sample plots.
Explanation of symbols: 1. ridges; 2. summits; 3. contour lines; 4. tourist trails; 5. *Pinus mugo* scrubs; 6. study areas.

The gully on the Uhrocie Kasprowe Mt. (study area A – Fig. 1) has the shape of a small basin narrowing downwards the line of the outcrop of more resistant layers, recognised as small rock walls. The entire niche is located in the subalpine belt, between 1650 and 1710 m a.s.l. and is 7–23 m wide and 110 m long. The gully on Beskid Mt. (study area B – Fig. 1) is longer, and extends between 1750 and 1875 m a.s.l., partly in the alpine belt. It has the form of a weakly developed, 20–40 m wide and 250 m long trough of a uniform longitudinal profile.

Both gullies are located on smooth, mature slopes, stabilised by grassland communities with patches of dwarf mountain pine. The slopes are covered with a weathering mantle composed of large boulders and small amounts of finer fractions. Because the geological substratum is uniform, one can expect the soil conditions dependent on substratum to be similar in both nival gullies, although soils have not been studied in detail. The soils are poor developed leptosols like: lithosols, regosols, rankers and tangel rankers. More detailed characterizations are provided by Komornicki and Skiba (1996) and Degórski (1999).

The topoclimatic conditions of the mountain areas determine both the formation of snow patches and the vegetation. These conditions are characterised using the data from the meteorological stations located in the area on the Kasprowy Wierch Mt. (1987 m a.s.l.) and on Hala Gąsienicowa Valley (1520 m a.s.l.). The mean temperature of January varies from –9°C at about 2000 m a.s.l. to –6.3 °C at 1500 m a.s.l. The mean temperature of July is from 7.3 °C to 10.7 °C respectively. The growing season (i.e. days with mean daily air temperature > 5°C) is 140 days long at the altitude of about 1600 m a.s.l. , while the length of period without the ground frost varies from 49 days per year at about 2000 m a.s.l. to 72 days at 1500 m a.s.l. Mean totals of precipitation at 1500 m a.s.l. amount 70 mm for January, 247 mm for July and 1664 mm as the annual one. The annual total of precipitation at about 1900 m a.s.l. is 1889 mm (Niedźwiedź 1992). Most of water reaches the ground in the summer season. Snowfall happens during the whole year in the area above timberline (1500 m a.s.l.). Snow cover persists for 228–236 days at the altitude about 2000 m a.s.l., where its maximum depth is 320 cm. At timberline it reaches only 237 cm and this maximum usually occurs in March (Hess 1965).

The gullies studied differ as to the potential values of solar radiation (Baranowski 2003). The eastern slopes of Uhrocie Kasprowe Mt. have the most advantageous radiation conditions (>120 MJ m^{-2}) The values of radiation on the northern slopes of Beskid Mt. are much lower (40–80 MJ m^{-2}). This means that the habitat of the gully on Uhrocie Kasprowe Mt. is drier and warmer than that of the gully on Beskid Mt.

3. MATERIAL AND METHODS

Preliminary investigations of the differentiation of vegetation in the studied areas, i.e. inside the nival niches and in their closest surroundings, have been performed (Kozłowska 2001). On the basis of phytosociological relevés and the published data (Balcerkiewicz 1984), completed by geobotanical and geomorphological mapping, plant communities occurring there have been identified.

Quantitative studies of vegetation were carried out in sample plots. These square plots, 0.5 × 0.5 m, were designated along the vertical transect, parallel to the long axis of the trough, and along the series of cross-profiles, perpendicular to the transect (Fig. l). 13 cross-profiles, distanced by 20 meters, have been established in the bigger gully (on Beskid Mt.), while in the case of the smaller gully (on Uhrocie Kasprowe Mt.) – 10 cross-profiles, 10 meters apart. The plots along the cross-profiles are located 0.5 meter apart. The total numbers of plots are 591 in the case of Beskid Mt. and 298 in the case of Uhrocie Kasprowe Mt. The number of the samples allow the application of statistical methods.

For each plot, the cover of vascular plants, bryophytes, plant litter, rocks, gravels and finer materials and slope inclination were determined, as well as plant species occurring in a plot have been recorded. The names of the vascular plant species were used after Mirek *et al.* (2002). The mosses were distinguished by Dr Anna Rusińska from the Institute of Environmental Biology (University of Adam Mickiewicz in Poznań), while lichens – by Dr Janina Zielińska (Institute of Botany, University of Warsaw). The cover of the species (in %) was estimated using the cover-class method (Daubenmire 1968). Plants were studied in August 1991.

The survey of the phases of snow patch disappearance, was made in three subsequent seasons. The thickness of snow patches was measured every 1 meter along the longitudinal profiles of vertical transects in nival gullies. The thickness of each patch was also measured every 1 meter along the cross-profile. The measurements were made with an avalanche measuring rod. The vertical profiles of snow and the cross-profiles corresponding to them were measured in the same places, where plant profiles were studied.

Following parameters have been calculated:

- mean number of species for the sample plot of $0.25m^2$ for both gullies,
- frequency of plant species for each gully,
- mean values (±SD) of coverage by herbaceous plants, bryophytes, litter, rocks, gravels and finer materials,
- sum of covering in per cent for all the species of a given ecological group for the area of $0.25\ m^2$. A group was distinguished on the basis of the character-species: for the snow-beds – *Salicetea herbaceae*, for the alpine swards – *Caricetea curvulae*, for the subalpine communities – *Nardion* and *Loiseleurio-Vaccinion*, for the avalanche meadow species – *Betulo-Adenostyletea*.

In order to present the general character of relations between the parameters analysed and to reduce the number of variables the Principal Component Analysis was applied.

The relations between the variables (plant species coverage, frequency, species richness) and the maximum thickness of the snow patch were established on the basis of the Spearman rank correlation analysis. The variability was determined of the correlation parameters between the variables for the parts of the gullies situated at various altitudes a.s.l.

4. RESULTS

4.1. Dynamics of disappearance of snow patches

The pattern of snow patch disappearance is presented in selected, different five cross-profiles for each gully (Figs 2 and 3).

In the initial period, just after a snow patch has been separated from the compact snow cover it fills up the whole gully, and sometimes extends even outside the gully's boundaries. In the case of study area A (Uhrocie Kasprowe Mt.) the maximum thickness of the studied patch at the moment of its separation is 200 cm, while on study area B (Beskid Mt.) it reaches 250–280 cm. This thickness is partially associated with the depth of the gully. In the final phase of the snow patch disappearance the snow thickness does not exceed 25–30 cm.

The particular phases of snow patch disappearance occur in the two gullies at different times. Initial phase usually turns up at the end of April or beginning of May on Uhrocie Kasprowe Mt. (study area A) and at half of May on Beskid Mt (study area B). Intermediate phase appears at half of May on Uhrocie Kasprowe Mt. and at first decade of June on Beskid. The remnants of patches exist on Uhrocie Kasprowe Mt. till half of June and on Beskid Mt. till last decade (end) of June. Frequently, the initial phase of the patch disappearance on Beskid Mt. takes place at the same time when the patch on Uhrocie Kasprowe Mt. is already in the terminal phase. This phenomenon is most likely due to the occurrence of the patches at different altitude belts and on slopes of various exposure.

4.2. General characteristics of vegetation

The character of vegetation occurring in both of the nival gullies is rather similar. In both sites, in the deepest hollows at the vertical axis of a gully *Luzuletum alpino-pilosae* or *Festuca picta*-community occur. Toward the outer parts of the gullies there is a transition from these communities to swards or dwarf shrub communities, depending on the altitude a.s.l. of the slope. In case of the upper part of the gully at Beskid Mt. this is the alpine sward *Oreochloo distichae-Juncetum trifidi*, while in the lower parts of this gully and in the case of Uhrocie Kasprowe Mt. these are the subalpine grasslands of anthropogenic origin and *Vaccinium myrtillus*-community as well as *Empetro-Vaccinietum*. In the gully on Uhrocie Kasprowe Mt. the avalanche meadow – *Calamagrostietum villosae* occurs as well. The grassland communities on Uhrocie Kasprowe Mt. are surrounded by compact mountain pine shrubs, while in the vicinity of the gully on Beskid Mt. – only small clumps of this species grow.

Both the alpine and subalpine grasslands change in accordance with the moisture conditions, i.e. from the wet form with *Luzula alpino-pilosa* to fresh forms, and in the extreme cases to dwarf shrubs with large

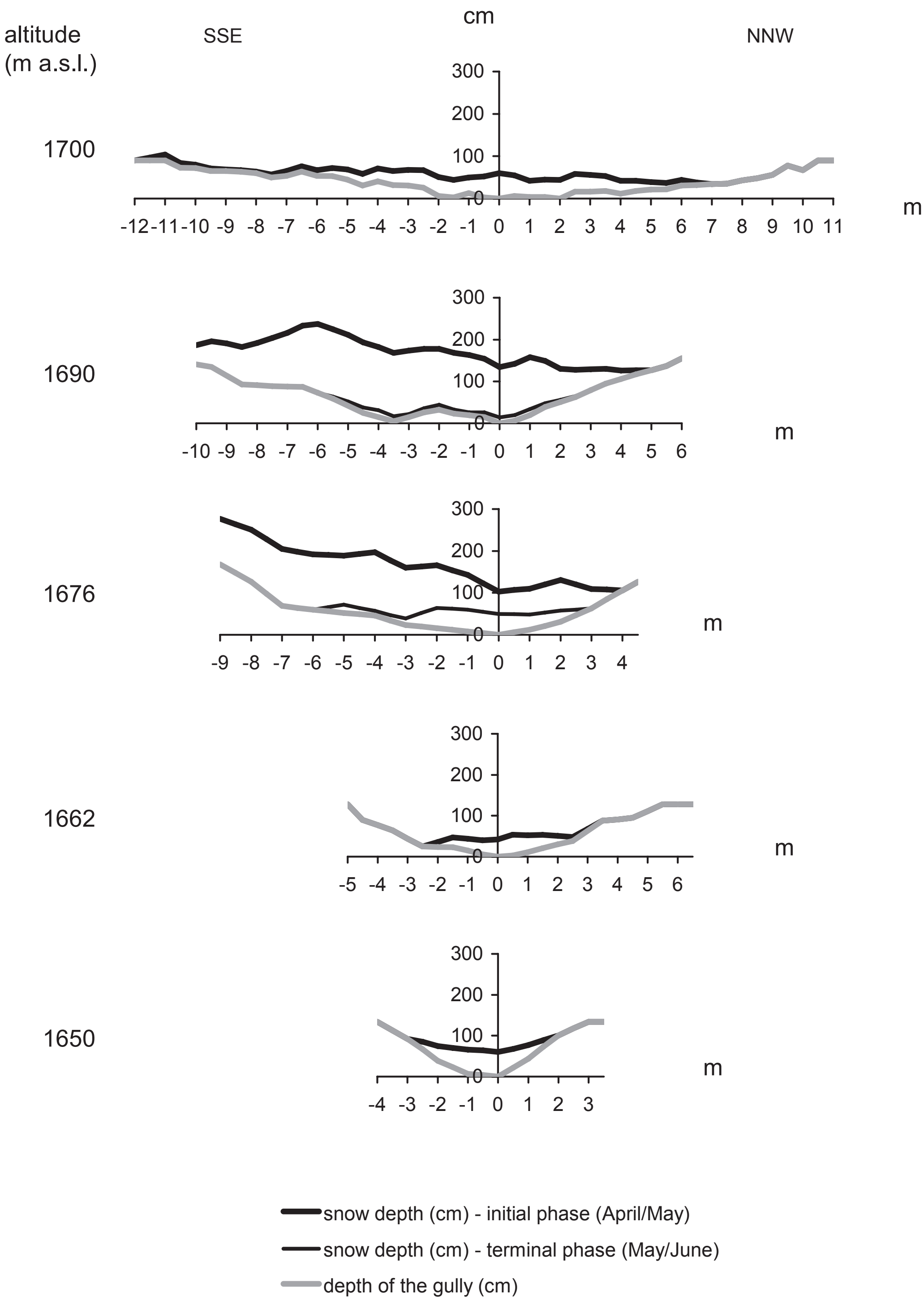

Fig. 2. Thickness and disappearance of snow patch in the gully on the E-slope of Uhrocie Kasprowe Mt. – study area A (see Fig. 1 for localisation).
Values below 0 indicate distance to the SSE-side, values above 0 – distances to the NNW-side – from the axis of the gully.

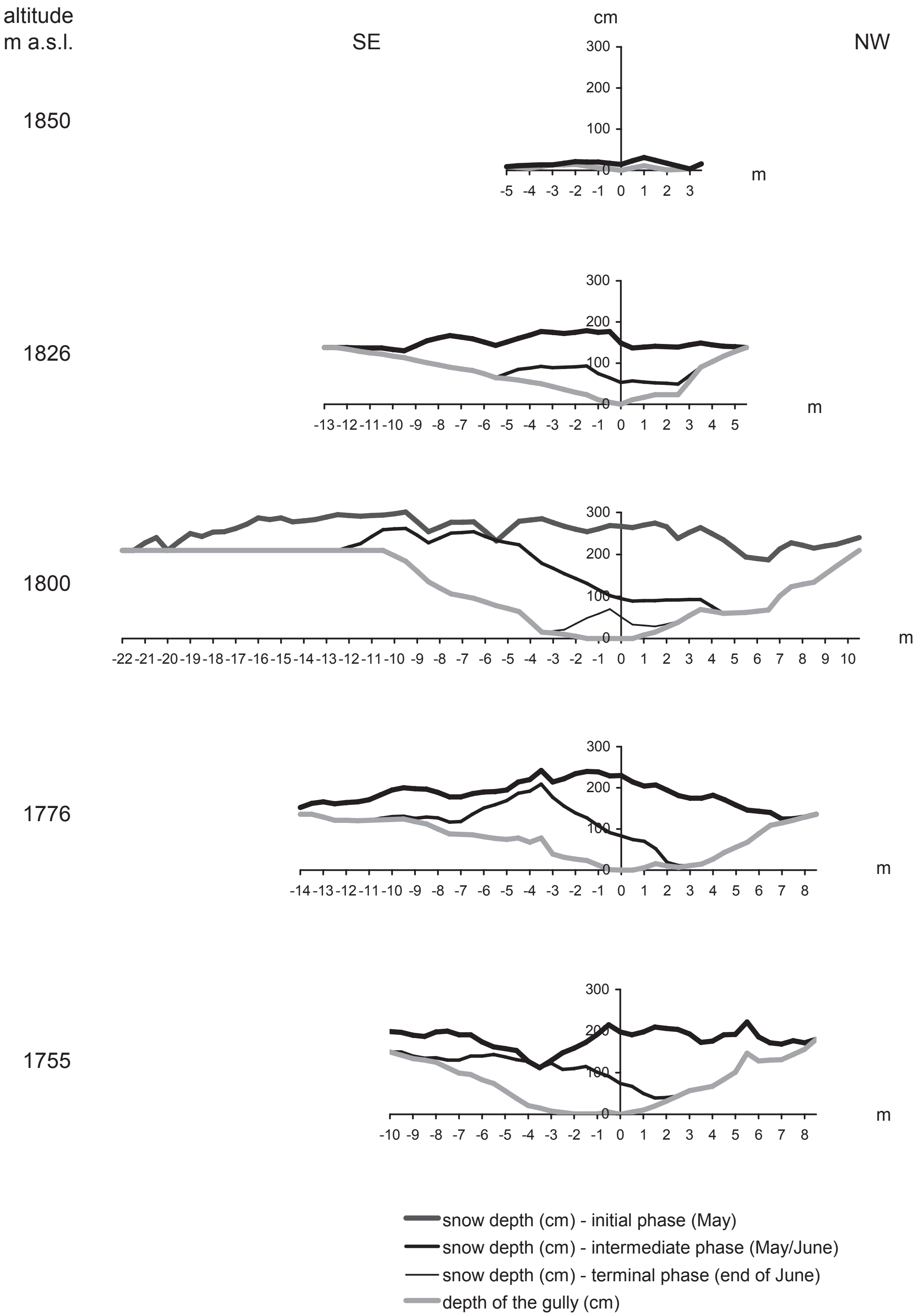

Fig. 3. Thickness and disappearance of snow patch in the gully on the N-slope of Beskid Mt. – study area B (see Fig. 1 for localisation). Values below 0 indicate distance to the SE-side, values above 0 – distances to the NW-side – from the axis of the gully.

Table 1. Characteristics of vegetation per sample plot (0.25 m^2) and frequency of species (> 5%) of study areas on the slopes of Uhrocie Kasprowe Mt. (study area A, 1650–1700 m a.s.l.) and Beskid Mt. (study area B, 1750–1850 m a.s.l.), Tatra Mts. (n = 298 and 591).

	A		B	
Total number of species per study area	45		51	
Number of common species	27			
Average characteristics:	mean	SD	mean	SD
species number	7	2	8	3
herb layer cover (%)	79	14	80	14
bryophyte layer cover (%)	<1	3	3	9
plant litter (%)	16	10	13	9
rocks (%)	2	7	3	9
gravel. finer material (%)	3	6	<1	3
Character-taxa of the *Caricetea curvulae:*				
Campanula alpina Jacq.	<1		39	
Agrostis rupestris All.	33		39	
Hieracium alpinum L.	30		36	
Juncus trifidus L.	16		33	
Character-taxa of the *Salicetea herbaceae:*				
Luzula alpino-pilosa (Chaix) Breistr.	28		73	
Polytrichum sexangulare Floerk.	0		14	
Cerastium cerastoides (L.) Britton	0		5	
Character-taxa of the *Betulo-Adenostyletea:*				
Festuca picta Kit.	70		60	
Calamagrostis villosa (Chaix) J. F. Gmel.	8		0	
Character-taxa of the *Nardion, Loiseleurio-Vaccinion*:				
Homogyne alpina (L.) Cass.	39		79	
Vaccinium myrtillus L.	86		56	
Nardus stricta L.	34		51	
Vaccinium gaultherioides Bigelow	7		2	
Vaccinium vitis-idaea L.	3		5	
Calluna vulgaris (L.) Hull	6		6	
Luzula luzulina (vill.) Dalla Torre & Sarnth.	0		32	
Pinus mugo Turra	0		9	
Other species:				
Mutellina purpurea (Poir.) Thell.	72		61	
Deschampsia flexuosa (L.) Trin.	52		69	
Anthoxanthum alpinum A. Löve & D. Löve	51		28	
Soldanella carpatica Vierh.	33		12	
Carex sempervirens Vill.	23		29	
Geum montanum L.	16		8	
Potentilla aurea L.	11		11	
Luzula sudetica (Willd.) DC.	8		0	
Cetraria islandica (L.) Ach.	8		2	
Campanula polymorpha Witasek	0		10	

amounts of lichens (mainly *Cetraria islandica* (L.) Ach.), along the line from the centre to the edges of the gullies. These latter driest forms of communities, especially *Empetro-Vaccinietum*, occur in habitats, which are characterised by the shortest duration of snow cover when compared with other parts of the gullies.

The species composition in both gullies is similar although the frequency of the particular species often differs in each studied area (Table 1). The frequency and the number of species of the snowbed and alpine sward species are bigger in case of the gully on Beskid Mt. than on Uhrocie Kasprowe Mt., as opposed to the species characteristic for *Betulo-Adenostyletea* and *Nardion*, *Loiseleurio-Vaccinion* (Fig. 4).

4.3. Spatial distribution of ecological groups of plant species

The gullies considered, as well as their individual parts (cross-profiles situated at various altitudes a.s.l.), differ among themselves in terms of the contribution (share in per cent of sum of species covering) of ecological groups of species characteristic for the alpine swards habitat, subalpine grasslands, snowbeds and avalanche meadows (Figs 5 and 6). These groups form different spatial patterns of vegetation patches.

The upper, weakly incised parts of both gullies are characterised by a mosaic of various ecological groups of species, proper for the location in terms of altitude. The differences between the centre and the edge of the gully are weakly pronounced in these parts. The species of the zonal communities dominate there. On Uhrocie Kasprowe Mt. (study area A), at the altitude of 1700 m a.s.l., these are the species of the subalpine communities, although a permanent, but limited contribution of the species of the alpine belt is also observed. On Beskid Mt. (study area B), at the altitude of 1850 m a.s.l., in the lower part of the alpine belt, these are the species of the alpine, but also of the subalpine swards. The species of the avalanche meadows and snow-beds are a constant element of the upper part of the gully on Beskid Mt., while on Uhrocie Kasprowe Mt. in the analogous place there are no snowbed species. On the other hand, there is a high contribution of the avalanche meadow species, especially in the left-hand part of the gully (Figs 5 and 6).

The highest diversity of the ecological groups of species and the variability of their percentage share in the cover of the basic plots of 0.25 m^2, as well as a mosaic of clusters, occur in the middle-upper part of both gullies . The snow-bed species dominate in the nival niches of both gullies. The species of the alpine belt are observed in both gullies close to the depression with the snowbed communities. They are noted on study area A (Uhrocie Kasprowe Mt.) down to the altitude of 1670 m a.s.l. (it is – in the subalpine belt).

The lower parts of Beskid Mt. gully are dominated by the snow-bed species, while on Uhrocie Kasprowe Mt. – by the avalanche meadow species (Figs 5 and 6). The diversity of the species clusters decreases, especially on the study area A (on Uhrocie Kasprowe Mt.), where it is determined by the avalanche meadow species along with the species of the alpine belt. One can observe a bigger diversity in the lower part of the study area B (on Beskid Mt.), which is situated higher.

It seems that the differences between the gullies should not be caused only by climatic conditions resulting in altitude differentiation of vegetation but also by microclimate and moisture conditions related to the presence of snow patches.

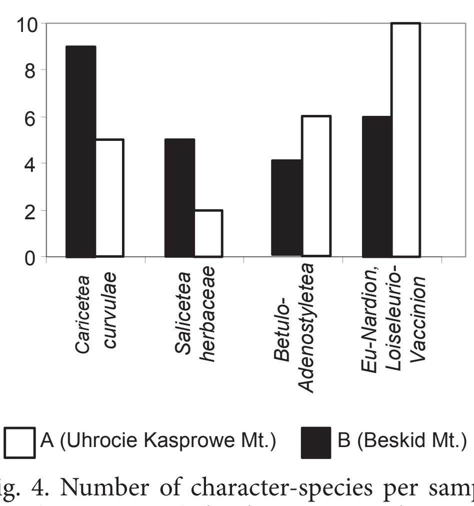

Fig. 4. Number of character-species per sample plot (area 0.25 m^2) for four groups of syntaxonomic units and two study areas (A and B, see Fig. 1).

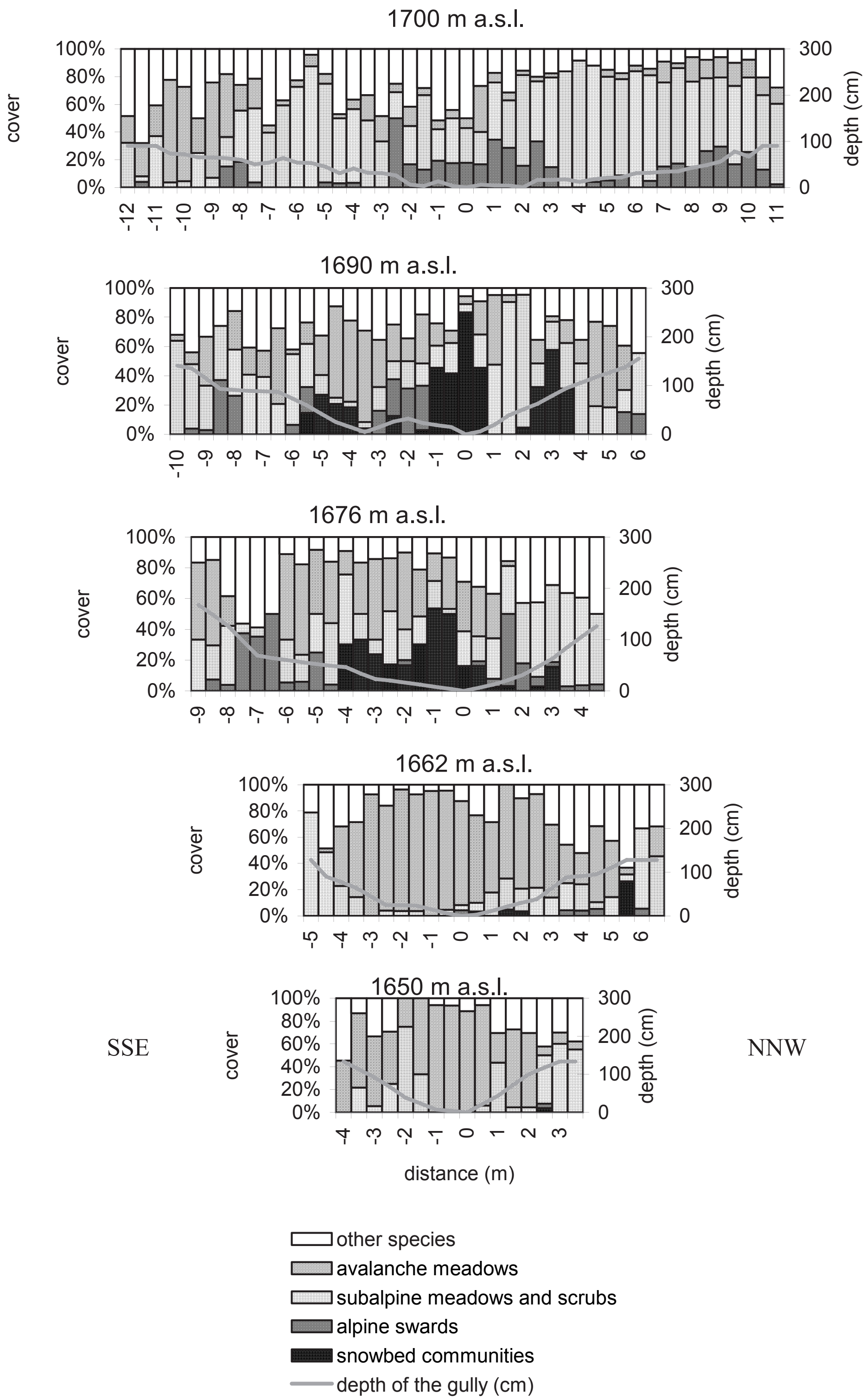

Fig. 5. Cover (%) according to distance and depth of gully (Fig. 2) of ecological groups of plant species on study area A (Uhrocie Kasprowe Mt.), see Fig. 1 for localisation. Values below 0 indicate distance to the SSE-side, values above 0 –distance to the NNW-side – from the axis of the gully.

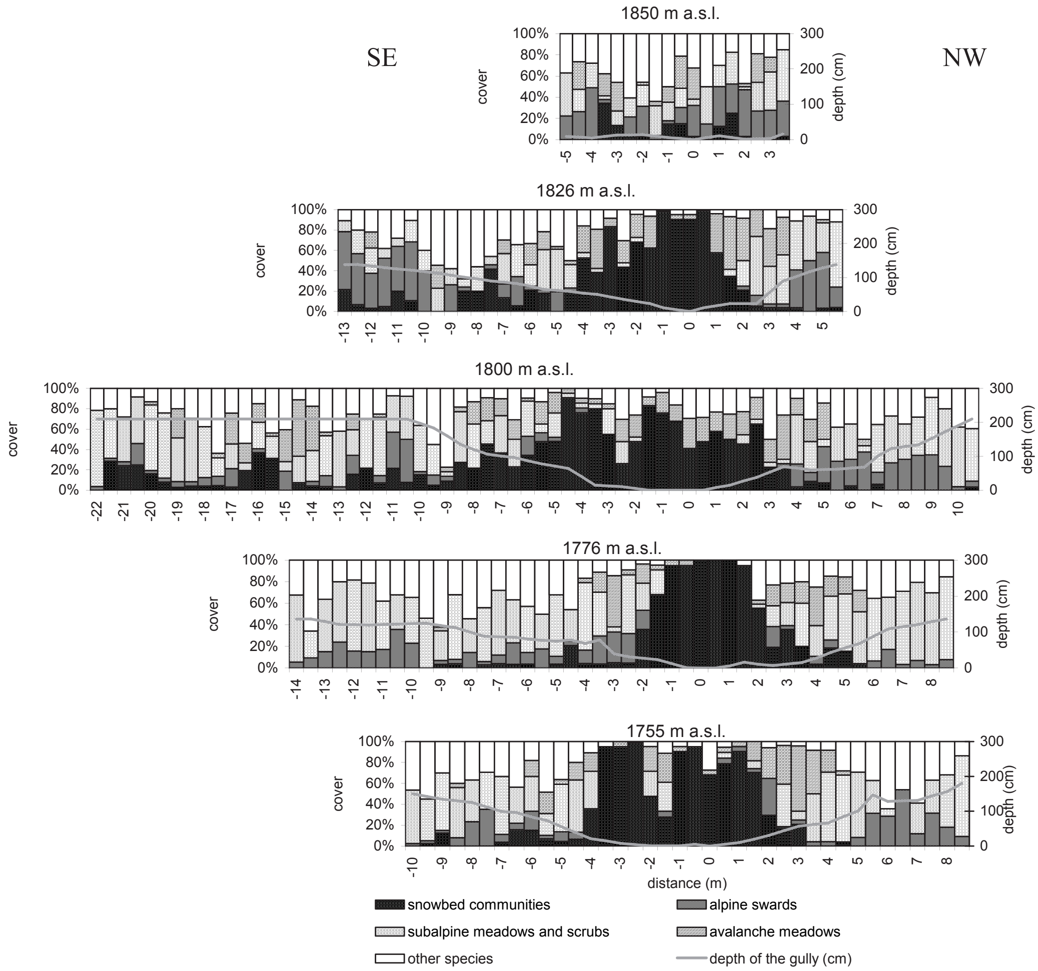

Fig. 6. Cover (%) according to distance and depth of gully (Fig. 3) of ecological groups of plant species on study area B (Beskid Mt.), see Fig. 1 for localisation. Values below 0 indicate distance to the SE-side, values above 0 – distance to the NW-side – from the axis of the gully.

4.4. Factors influencing the vegetation characteristics of the gullies

The analysis of the relations between the environmental variables and vegetation characteristics in the studied gullies, carried out with the help of the Principal Component Analysis indicates the similarity of the factors determining the composition and cover of plant species (Figs 7 and 8, Tables 2 and 3). There exist numerous factors of feature variability, with two most important ones being responsible for roughly 16% of variability. The variables forming the second factor on the study area A (depth of the gully – c01, and the presence of the snow patch – c02, c03; Fig. 7), form the first factor on the study area B (Fig. 8). The number of species (c12) is situated at the other end of this axis in the case of the study area B (Fig. 8). This parameter for the study area A (Fig. 7) does not play such a role. The coverage by the herb layer (c07) and the moss layer (c08) is the most important factor influencing the vegetation on the study area A (Fig. 7). The long persistence of the snow patch (c04, c05), together with the covering of the moss layer (c08) are located on the same side of the factor space, opposite to the position of the herb layer (c07) which is the second factor for the study area B (Fig. 8).

The coverage and frequency of majority of the species in both gullies are poorly correlated with the features mentioned above and form in both cases compact clusters near to 0 on both axes, with only few species clearly

Table 2. Factor loadings – relationship between species cover and site variables on study area A (Uhrocie Kasprowe Mt.) according to Principal Component Analysis (rotation: Varimex normalized). Most important factor loadings marked in bold.

Variable name	Variable symbol	Factor loadings	
		Factor 1	Factor 2
depth of the gully	c01	0.02	-0.79
snow depth initial phase (1)	c02	0.02	-0.84
snow depth terminal phase (2)	c03	-0.01	-0.71
slope	c06	-0.01	0.04
herb layer cover	c07	-0.33	-0.02
moss layer cover	c08	0.85	0.01
litter cover	c09	-0.11	0.04
stones cover	c10	0.21	-0.16
gravel, finer material cover	c11	0.15	0.14
species number	c12	0.06	-0.03
Agrostis rupestris	s01	0.27	-0.02
Anthoxanthum alpinum	s02	0.07	-0.24
Avenula versicolor	s04	-0.06	0.06
Calamagrostis villosa	s05	-0.01	0.16
Calluna vulgaris	s06	-0.04	0.21
Campanula alpina	s07	0.00	0.05
Campanula polymorpha	s08	-0.05	-0.06
Carex sempervirens	s09	-0.09	0.15
Cerastium cerastoides	s11	0.03	0.06
Cetraria islandica	s12	0.07	-0.02
Cladonia rangiferina	s13	0.07	0.02
Deschampsia caespitosa	s14	-0.01	0.06
Deschampsia flexuosa	s15	-0.03	0.11
Empetrum hermaphroditum	s16	-0.02	-0.01
Festuca picta	s18	-0.13	-0.28
Gentiana asclepiadea	s20	0.01	0.05

Table 3. Factor loadings – relationship between species cover and site variables on study area B (Beskid Mt.) according to Principal Component Analysis (rotation: Varimex normalized). Most important factor loadings marked in bold.

Variable name	Variable symbol	Factor loadings	
		Factor 1	Factor 2
depth of the gully	c01	**-0.85**	0.12
snow depth initial phase (1)	c02	**-0.88**	0.19
snow depth intermediate phase (2)	c03	**-0.74**	0.25
snow depth terminal phase (3)	c04	-0.30	**0.76**
snow depth terminal phase (4)	c05	-0.13	**0.84**
slope	c06	-0.08	-0.03
herb layer cover	c07	0.04	-0.34
moss layer cover	c08	0.05	0.62
litter cover	c09	0.00	-0.08
rocks cover	c10	-0.10	0.03
gravel, finer material cover	c11	0.06	0.10
species number	c12	0.43	0.05
Agrostis rupestris	s01	0.60	0.08
Anthoxanthum alpinum	s02	0.14	-0.03
Athyrium distentifolium	s03	-0.08	0.16
Avenula versicolor	s04	0.06	-0.01
Calluna vulgaris	s06	0.06	-0.01
Campanula alpina	s07	0.13	-0.05
Carex sempervirens	s09	0.37	-0.05
Cerastium cerastoides	s10	-0.35	0.57
Cetraria islandica	s11	0.18	0.03
Deschampsia flexuosa	s15	0.63	-0.01
Festuca airoides	s17	0.08	0.00
Festuca picta	s18	-0.35	-0.15
Galium anisophyllon	s19	-0.08	-0.01
Gentiana punctata	s21	-0.04	-0.04
Geum montanum	s22	0.00	-0.11
Gnaphalium supinum	s23	-0.10	0.00
Hieracium alpinum	s25	0.13	-0.04
Homogyne alpina	s26	0.31	-0.10

Variable name	Variable symbol	Factor loadings	
		Factor 1	Factor 2
Gentiana punctata	s21	0.01	0.03
Geum montanum	s22	0.01	-0.17
Gnaphalium supinum	s23	0.09	0.02
Hepaticae indet.	s24	-0.07	-0.01
Hieracium alpinum	s25	-0.03	-0.18
Homogyne alpina	s26	-0.05	0.29
Hypericum maculatum	s28	-0.06	0.10
Juncus trifidus	s29	0.23	-0.37
Juniperus communis subsp. alpina	s30	0.01	0.08
Lophocolea sp.	s33	0.08	-0.03
Luzula alpino-pilosa	s35	-0.09	-0.55
Luzula luzulina	s36	-0.01	0.53
Mutellina purpurea	s38	-0.12	0.07
Nardus stricta	s39	-0.11	0.17
Pinus mugo	s42	-0.04	0.08
Pogonatum urnigerum	s44	0.81	-0.04
Polytrichum juniperinum	s51	0.51	0.07
Potentilla aurea	s54	-0.03	-0.05
Pseudorchis albida	s56	-0.01	-0.06
Pulsatilla alpina	s57	0.01	0.06
Rhacomitrium sp.	s58	0.82	0.00
Soldanella carpatica	s60	-0.10	-0.12
Solidago alpestris	s61	-0.03	0.00
Thymus alpestris	s65	0.01	-0.09
Vaccinium gaultherioides	s66	0.05	-0.14
Vaccinium myrtillus	s67	-0.17	0.09
Vaccinium vitis-idaea	s68	0.06	0.10
Veratrum lobelianum	s69	0.06	0.18
Eigenvalue		4.75	3.98
% of total variance		8.79	7.37

Variable name	Variable symbol	Factor loadings	
		Factor 1	Factor 2
Huperzia selago	s27	0.01	0.04
Juncus trifidus	s29	-0.15	-0.13
Kiaeria starkei	s31	-0.10	0.03A
Leucanthemopsis alpina	s32	0.04	0.00
Lophocolea sudetica	s34	0.06	0.00
Luzula alpino-pilosa	s35	-0.57	-0.03
Luzula sudetica	s37	0.26	0.02
Mutellina purpurea	s38	-0.17	0.08
Nardus stricta	s39	0.24	0.01
Oreochloa disticha	s40	0.24	0.03
Phleum commutatum	s41	-0.01	0.02
Pleurozium schreberii	s43	-0.12	0.02
Pohlia drummondii	s45	-0.10	0.01
Pohlia ludwigii	s46	0.02	0.05
Polytrichum formosum	s47	-0.10	-0.04
Polytrichum sudeticum	s48	0.04	0.00
Polytrichum alpinum	s49	0.08	-0.03
Polytrichum commune	s50	0.03	-0.01
Polytrichum sexangulare	s52	0.11	**0.74**
Polytrichum strictum	s53	-0.02	-0.04
Potentilla aurea	s54	0.22	0.03
Primula minima	s55	-0.02	0.00
Pulsatilla alpina	s57	0.04	-0.02
Rhacomitrium sudeticum	s59	0.05	-0.01
Soldanella carpatica	s60	-0.04	0.08
Solidago alpestris	s61	0.13	0.01
Sphagnum girgensohnii	s62	-0.06	-0.03
Sphagnum quinquefarium	s63	0.02	0.00
Taylordia cfr. serrata	s64	0.01	-0.01
Vaccinium gaultherioides	s66	0.17	0.00
Vaccinium myrtillus	s67	0.53	-0.04
Vaccinium vitis-idaea	s68	0.13	0.00
Eigenvalue		6.59	3.74
% of total variance		10.63	6.03

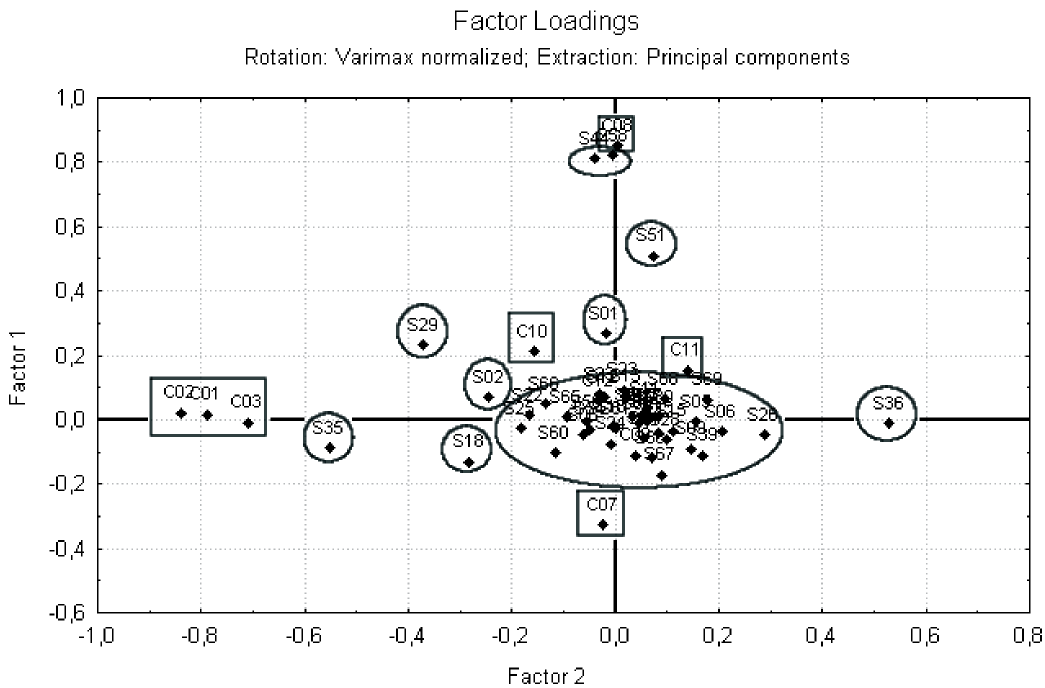

Fig. 7. The results of Principal Component Analysis for environmental variables and cover of plant species on the study area A (Uhrocie Kasprowe Mt.). Variables descriptions – see Table 2.

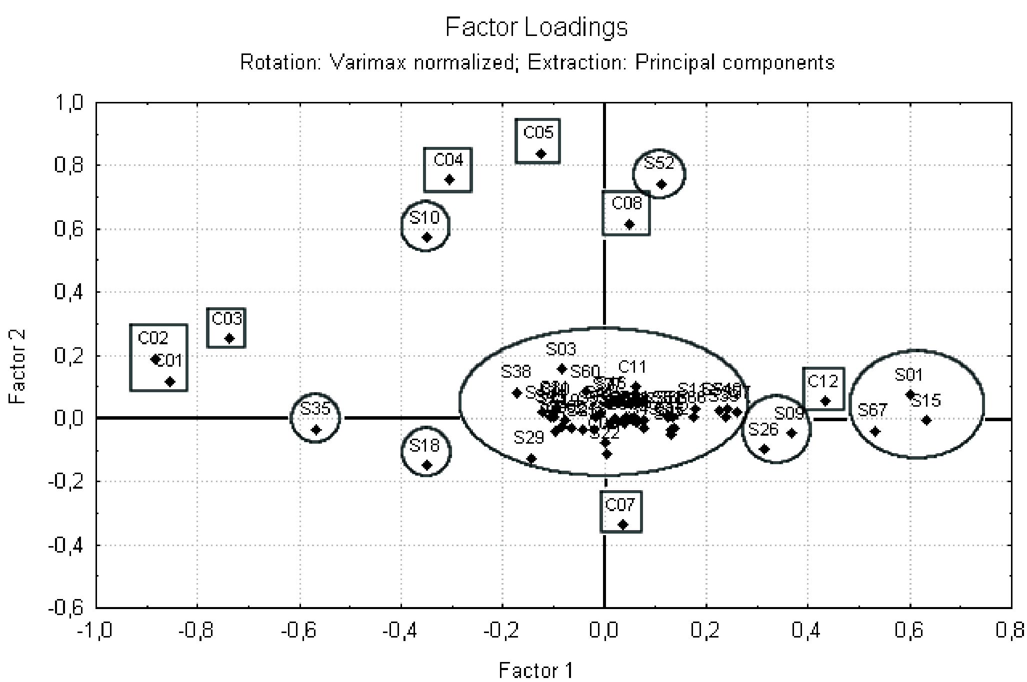

Fig. 8. The results of Principal Component Analysis for environmental variables and cover of plant species on the study area B (Beskid Mt.). Variables descriptions – see Table 3.

correlated with the factors represented by the axes. On the study area A (Fig. 7) the duration of the snow patch is accompanied, similarly as on the study area B, with the occurence of *Luzula alpino-pilosa* (s35) and *Festuca picta* (s18), as well as with the species which do not occur on the study area B, like *Juncus trifidus* (s29) and *Anthoxanthum alpinum* (s02). On the opposite extreme (Fig. 7) *Luzula luzulina* (s36) is occuring, the species associated with the similar habitats as *Deschampsia flexuosa* and *Vaccinium myrtillus* on the study area B. The extreme of the second, transversal axis (Fig. 7) is formed – along with the coverage of the moss layer (c08) – by *Pogonatum urnigerum* (s44), *Rhacomitrium* sp. (s58) and *Polytrichum juniperinum* (s51). In the case of the study area B (Fig. 8) *Luzula alpino-pilosa* (s35), *Festuca picta* (s18) and *Cerastium cerastoides* (s10) are the species associated with the snow patches having the largest reach and thickness. On the opposite end of the aAxis the species *Vaccinium myrtillus* (s67), *Agrostis rupestris* (s01) and *Deschampsia flexuosa* (s15) are situated. The longest duration of the snow patches (c04, c05) is accompanied with *Cerastium cerastoides* (s10) and *Polytrichum sexangulare* (s52).

4.5. Correlation between snow variables and vegetation composition

The data provided above suggest that the role of snow and its influence on the plant species are different in the two gullies. This is even clearly visible from Tables 4 and 5, presenting the statistically significant ($P < 0.05$) Spearman rank correlation coefficients between the maximum snow thickness *versus* the coverage of plant species of frequencies exceeding 1%; they are calculated for the individual transversal profiles of both gullies.

On the study area A (Uhrocie Kasprowe Mt.) there is no species strongly negatively correlated with snow (see Table 4). A persistent negative correlation is observed for *Cetraria islandida, Calluna vulgaris, Campanula*

Table 4. Spearman rank correlation coefficients (P <0.05) between the maximal thickness of snow patch and the cover of species on different altitude a.s.l. on the E-slope of Uhrocie Kasprowe Mt. (study area A). Positive correlations marked in bold.

Species	Altitude m a.s.l.									
	1650	1656	1662	1668	1670	1676	1683	1690	1895	1700
Festuca picta		**0.67**	**0.77**		**0.51**	**0.53**	**0.53**	**0.27**		
Luzula alpino-pilosa				**0.78**	**0.48**		**0.68**	**0.46**		
Juncus trifidus								**0.33**	**0.57**	**0.4**
Soldanella carpatica								**0.18**		**0.35**
Potentilla aurea								**0.15**		**0.38**
Geum montanum		**0.49**						**0.18**		
Anthoxanthum alpinum								**0.24**	**0.37**	**0.59**
Hieracium alpinum								**0.14**	**0.50**	
Agrostis rupestris									**0.54**	
Nardus stricta		-0.5							**0.49**	
Vaccinium vitis-idaea		-0.49			-0.45			-0.19	**0.34**	
Pogonatum urnigerum							-0.71		**0.37**	
Pinus mugo				-0.48						**0.37**
Deschampsia flexuosa	-0.75				-0.81	-0.48				**0.33**
Calamagrostis villosa	**0.59**							-0.19	-0.4	
Mutellina purpurea				**0.47**		-0.68				
Vaccinium myrtillus	-0.66			-0.77			**0.37**			
Cetraria islandica		-0.49						-0.11		
Luzula luzulina								-0.36		-0.68
Homogyne alpina								-0.17		-0.46
Calluna vulgaris								-0.24		-0.47
Campanula polymorpha		-0.56								

Table 5. Spearman rank correlation coefficients ($P<0.05$) between the maximal thickness of snow patch and the cover of species on different altitude (a.s.l.) on the N-slope of Beskid Mt. (study area B). Positive correlations marked in bold.

Beskid

Species	Altitude m a.s.l.												
	1755	1760	1768	1776	1784	1792	1800	1809	1818	1826	1834	1842	1850
Luzula alpino-pilosa	**0.75**	**0.54**	**0.69**	**0.90**	**0.84**	**0.71**	**0.65**	**0.71**	**0.64**	**0.78**	**0.29**	**0.53**	
Festuca picta	**0.58**	**0.46**	**0.52**	**0.53**			**0.43**		**0.30**	**0.63**	**0.49**	**0.51**	
Cerastium cerastoides		**0.29**	**0.37**			**0.58**	**0.51**	**0.26**					
Mutellina purpurea			**0.45**	-0.52		**0.50**		**0.52**	**0.38**				
Kiaeria starkei		**0.35**	-0.34										
Juncus trifidus		**0.56**						-0.36					
Soldanella carpatica							**0.35**	-0.45					
Anthoxanthum alpinum		**0.44**			-0.36			-0.50	-0.29	-0.35	**0.27**		
Geum montanum												**0.57**	
Lophocolea sudetica	-0.37												
Polytrichum commune	-0.69												
Polytrichum strictum			-0.50										
Avenula versicolor				-0.34									
Polytrichum sudeticum				-0.30									
Solidago alpestris								-0.28					
Luzula sudetica										-0.57			
Polytrichum alpinum													-0.48
Oreochloa disticha			-0.31								-0.31		
Polytrichum sexangulare								-0.28	-0.37	-0.49	-0.38		
Potentilla aurea							-0.28	-0.49	-0.27				
Hieracium alpinum	-0.43					-0.38	-0.46	-0.59					
Vaccinium vitis-idaea	-0.47	-0.32	-0.68	-0.33									
Cetraria islandica	-0.36	-0.35	-0.64				-0.26			-0.38			
Campanula alpina	-0.37		-0.31		-0.47			-0.59	-0.33				
Carex sempervirens	-0.29		-0.58	-0.44	-0.59	-0.31	-0.39	-0.33	-0.58				
Nardus stricta			-0.40	-0.52	-0.46	-0.24	-0.36	-0.55	-0.38				
Homogyne alpina					-0.49	-0.64	-0.36	-0.65	-0.40	-0.35		-0.53	
Vaccinium gaultherioides	-0.48		-0.31	-0.59	-0.42		-0.42			-0.34			
Agrostis rupestris	-0.67	-0.60	-0.62	-0.54	-0.73	-0.31	-0.37	-0.83	-0.65	-0.74	-0.62	-0.66	
Vaccinium myrtillus	-0.58	-0.36	-0.63	-0.75	-0.84	-0.82	-0.74	-0.77	-0.49	-0.54	-0.32		
Deschampsia flexuosa	-0.60	-0.65	-0.46	-0.67	-0.83	-0.82	-0.55	-0.54	-0.67	-0.56	-0.37		

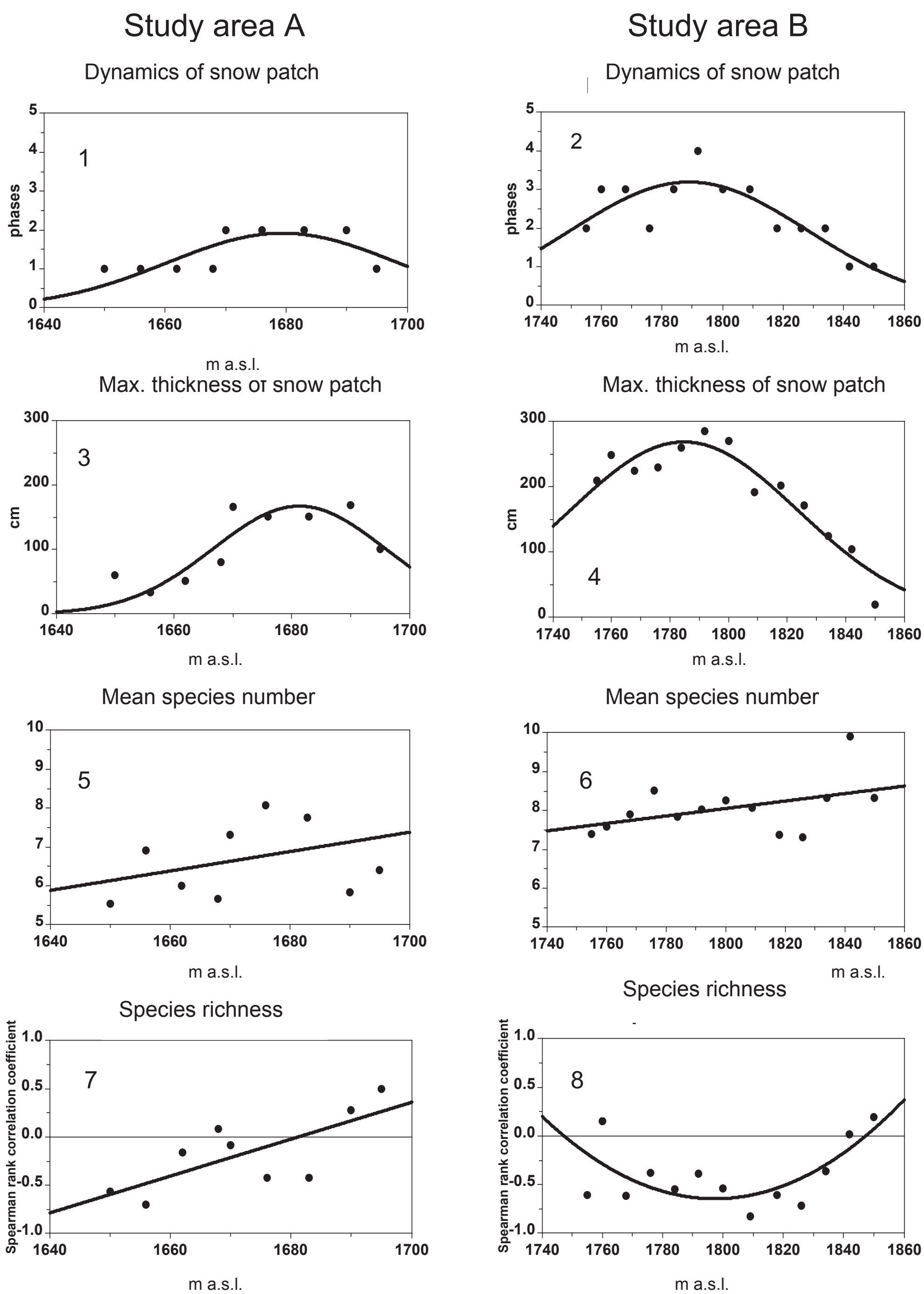

Fig. 9. Vertical (altitude) differentiation of snow cover features and richness of plant species on two study areas - A (Uhrocie Kasprowe Mts.) and B (Beskid Mts.), see Fig. 1 for localisation. Phases of snow dynamics Figs 2, 3.

Functions according to the models:

1. y=a*exp((-(b-x)^2)/(2*c^2); a = 1.92; b = 1679.35; c = 10.00; r = 0.76.
2. y=a*exp((-(b-x)^2)/(2*c^2); a = 3.20; b = 1788.85; c = 39.20; r = 0.85.
3. y=a*exp((-(b-x)^2)/(2*c^2); a = 167.63; b = 1681.24; c = 14.60; r = 0.86.
4. y=a+bx+cx^2; a = -170578.63; b = 191.43; c = 0.96.
5. y=a+bx; a = -34.95; b = 0.02; r = 0.42. 6. y=a+bx; a = -9.23; b = 0.01; r = 0.44.
7. y=a+bx; a = -32.12; b = 0.02; r = 0.78. 8. y=a+bx+cx^2; a = 833.53; b = -0.93; c = 0.00; r = 0.69.

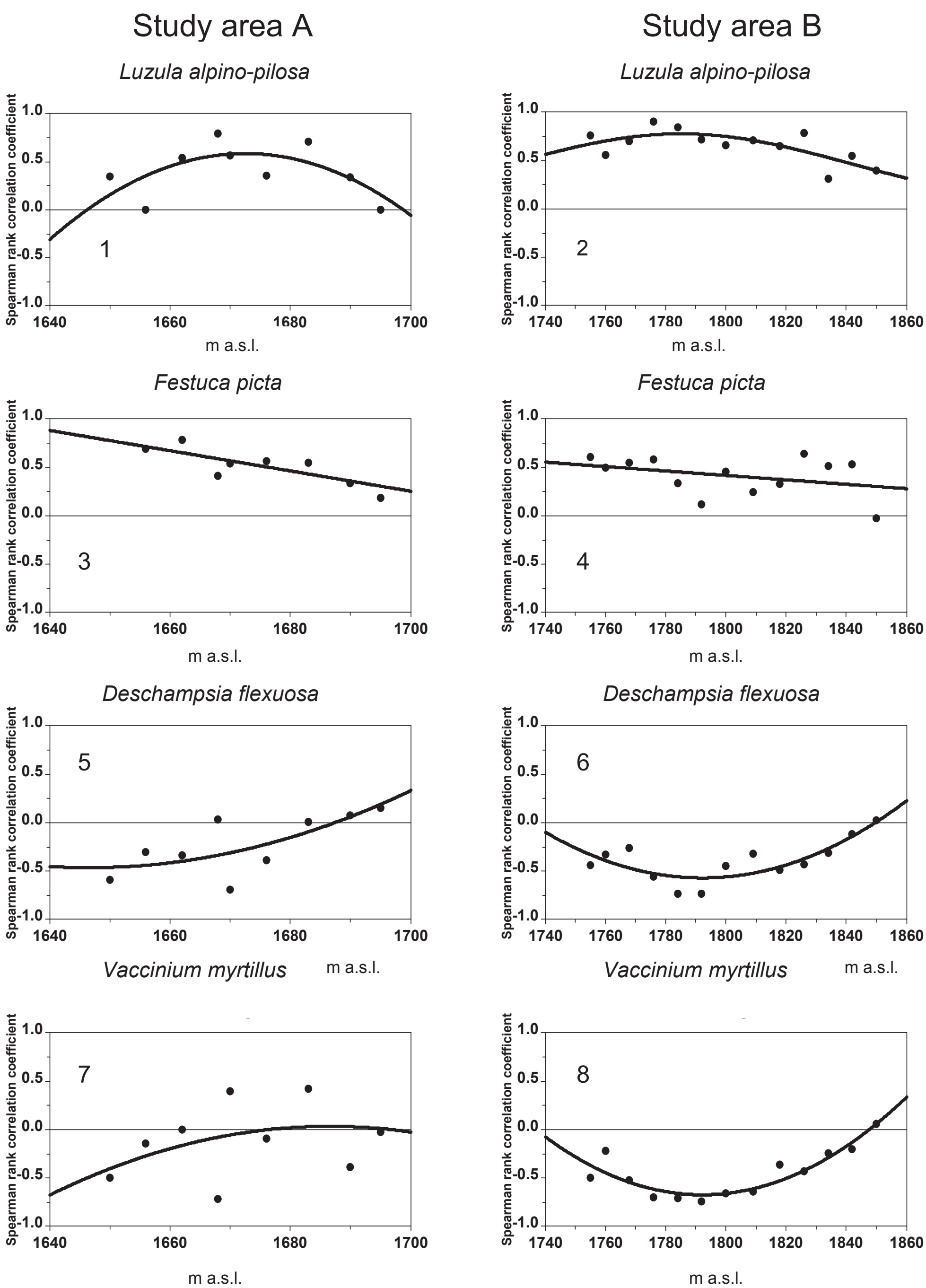

Fig. 10. Vertical (altitude) differentiation of relation between most sensitive plant species and maximum depth of snow patch on two study areas - A (Uhrocie Kasprowe Mts.) and B (Beskid Mts.), see Fig. 1 for localisation.

Functions according to the models:

1. y=a+bx+cx^2; a = 2374.00; b = 0.02; c = 0.00; r = 0.75.
2. y=a*exp((-(b-x)^2)/(2*c^2); a = 0.78; b = 1784.94; c = 56.18; r = 0.74.
3. y=a+bx; a = 18.05; b = -0.01; r = 0.83. 4. y=a+bx; a =4.52; b = 0.00; r = 0.36.
5. y=a+bx+cx^2; a = 754.28; b = -0.92; c = 0.00; r = 0.81.
6. y=a+bx+cx^2; a = 556.32; b = -0.62; c = 0.00; r = 0.82.
7. y=a+bx+cx^2; a = -2013.37; b = 2.40; c = 0.00; r = 0.80.
8. y=a+bx+cx^2; a = 703.93; b = -0.79; c = 0.00; r = 0.92.

polymorpha, Luzula luzulina and *Homogyne alpina*. These species are associated with the subalpine belt meadows. There exists a broad group of species, including also the commonly appearing *Deschampsia flexuosa, Vaccinium myrtillus, Nardus stricta, Mutellina purpurea*, which changes the character of correlation along the altitude within the gully. Particularly characteristic is the change of correlation from the negative one to the positive one along the altitude of the gully. The species positively correlated in both gullies, *Festuca picta, Luzula alpino-pilosa* and *Geum montanum*, are joined upward with *Juncus trifidus*, *Soldanella carpatica, Agrostis rupestris, Hieracium alpinum* and *Potentilla aurea*.

The gully on Beskid Mt. (study area B), in opposition to the study area A, is characterised by the occurrence of few species positively correlated with the snow patch (Table 5). These are the species already indicated on the basis of the PCA, namely *Luzula alpino-pilosa*, *Festuca picta*, *Cerastium cerastoides*, as well as *Mutellina purpurea* and *Geum montanum*. A number of species displays a variable correlation with snow thickness, depending upon the location on the profile. These include *Juncus trifidus*, *Anthoxanthum alpinum, Kiaeria starkei* and *Soldanella carpatica*. The remaining large group is constituted by the species negatively correlated with snow thickness. They are especially abundant in the middle parts of the gully. The highest values of the coefficient are observed particularly for *Agrostis rupestris, Vaccinium myrtillus* and *Deschampsia flexuosa*.

Thus, the relation between snow thickness and vegetation has a local character, i. e. it is different not only for the two gullies considered, but also within their boundaries. It is also supplied by the relations between the variability of the snow patch duration, maximum thickness of the snow patches and the average number of the plant species, as well as the relation between snow patch thickness and the number of species (Fig. 9). The variability of the Spearman rank correlation coefficients between the transects, calculated for the dependence between the thickness of the snow patch and the coverage by the selected plant species illustrates the varying character of this dependence (Fig. 10).

The parameters of the snow follow as a rule the Gaussian curve (Fig. 9), and in the case of maximum thickness of the snow patch on Beskid Mt. gully the respective curve is approximated by the quadratic equation. This indicates the existence of the distinct places in the centres of the gullies, where accumulated snow persists for a long period. On the other hand the dependence of the average number of species on the altitude (a.s.l.) (Fig. 9) has a linear character, with the line slightly pointing upwards with the increase of the altitude, up to the locations, where both gullies flatten out in the higher parts. Then, the variability of the Spearman rank correlation coefficients for the dependence of the plant species number upon the maximum thickness of the snow patch (Fig. 9) has a different character for the two gullies studied. On the study area A, this dependence is conform to a linear function, with the straight line pointing more steeply upwards than in the case of the diagram of average number of species. On the study area B this dependence is approximated by the quadratic curve, which attains the lowest values in the middle of the gully.

The curves approximating the dependence of the selected plant species, *Luzula alpino-pilosa, Festuca picta, Deschampsia flexuosa, Vaccinium myrtillus* (Fig. 10), upon the snow cover have in both gullies the course defined by the same type of equations i. e. the quadratic equations in the majority of cases. Only for *Festuca picta* it is the linear equation. The course of the curves is also similar for *Luzula alpino-pilosa*, *Festuca picta* and *Deschampsia flexuosa*, reflecting the positive or negative character of relation of these species to snow thickness. Only *Vaccinium myrtillus* displays a different reaction with respect to snow thickness in both gullies, negative in the gully on Beskid Mt., and weakly positive in the gully on Uhrocie Kasprowe Mt.

5. DISCUSSION

The study results illustrate the importance of different spatial scale for high-mountain vegetation patterns. There is the spatial differentiation of vegetation between the gullies, resulting from abiotic conditions for given altitude belt (subalpine and alpine) on one hand and the differentiation along the vertical profile inside the gully (distance above 100 m) and micro-scale differentiation in the transversal profile between the middle part and the edge of the gully (distance 10–30 m) on the other hand.

The habitat differences between the gulliess, associated with the location in the climatic-vegetation belt are of primary importance. The indicators of these climatic differences are constituted by the different contributions of the characteristic species and characteristic communities for the alpine and subalpine belts in both gullies considered. The thermal conditions typical for a given vegetation belt influence the rates of snow melting on the two slopes and the duration of snow patches in both gullies. Slope exposure and the associated solar radiation play an important role, as well. Thus, warmer and drier habitats exist in Uhrocie Kasprowe Mt. (study area A), with east orientation, as compared to the northern slopes of Beskid Mt. (study area B), situated at the similar altitudes a.s.l.

There is one more specific feature of the gully on Uhrocie Kasprowe Mt. The share of the plots poorly overgrown by vascular plants is rather high (in %) due to the outcrop of rocks (the quartzites), in the place where the gully passes from the less inclined to the very steep part. The threshold is exposed to the action of erosion and hence its coverage with vascular plants is low.

The persistent snow patches, although with different periods of duration, play also different roles in the two gullies studied. This is reflected by the dependence between snow thickness and the number of species. On the cold and wet area of Beskid Mt. (study area B) in its central part the snow distinctly limits the number of species. On the dry and warm area of Uhrocie Kasprowe Mt. (study area A) snow is not the factor limiting the species diversity of plants, and may rather be treated as the source of water supply at the beginning of the growing season.

The distribution of the majority of plant species in the gullies does not depend upon the thickness of snow patches. Only two species, *Luzula alpino-pilosa* and *Festuca picta*, can be accepted as indicators of occurrence of the snow patches in both gullies. The distinctly snow-bed character of the vegetation in the gully on Beskid Mt. is additionally emphasised by the occurrence of such species as *Polytrichum sexangulare* and *Cerastium cerastioides*, positively correlated with the places, where snow persists for the longest periods.

At the beginning of the vegetation season the snow-bed species are found along the long axis of the nival gullies in the places protected from the ground frost in this period. After the snow cover had been melted the temperature amplitude under the snow patch and in its vicinity is small in contrast to the places not covered with snow. The results of microclimatic studies (Rączkowska 1993) provide evidence for that.

The results obtained allow to consider of the role of snow with respect *to Luzuletum alpino-pilosae* association. Field studies indicate that *Luzuletum alpino-pilosae* is rather an indicator of moist habitats protected against frost, than of places with shorted growing season. In early spring, in the studied part of the Tatra Mts., the places are observed where young sprouts of *Luzula alpino-pilosa* "pierce" through the already thin snow patches. These sprouts are frequently taller than those, which would have grown in the places that have been earlier not covered with snow. Thus, snow does not hinder the growth of this plant, but just the opposite, it protects the plant against ground frost. Similarly Coker and Coker (1973) found that *Phyllodoce caerulea* (L.) Bab can produce fresh sprouts under a shallow snow layer, but they are frost damaged very quickly if exposed above the snow surface.

The indicator species, positively associated with the snow patches, are common for the two gullies, although it turned out impossible to establish the list of species negatively correlated with snow which are common for the both gullies. Such species, identified in the gully on Beskid Mt. (especially *Vaccinium myrtillus*) are not dependent upon snow on Uhrocie Kasprowe Mt., since snow persists there for a shorter period and is not a limiting factor. Such an ambiguous reaction of *Vaccinium myrtillus* to snow is known from the Nordic mountains, where the communities with dominance of this species have been classified as the *Vaccinium myrtillus-Phyllodoce* *caerulea*-type, belonging to the heath vegetation, which requires snow protection, with, however, an early thaw. This may be associated with the life form of the plant (dwarf shrub) and the protective function of the snow cover which persists in short period.

The studies carried out allowed for establishment of an ample list of species, whose distribution in both gullies is not directly dependent upon snow cover. This is expressed as the oscillations of the correlation coefficient between the positive and negative values, which implies the relative character of these estimates, depending upon the study site. The conditions important for the spatial distribution of the species within the gullies requires further studies. A significant influence may be exerted by the biotic factors, especially the inter-species competition, the grazing by herbivores, etc.

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(Received after revising November 2005)