Roczniki Akademii Rolniczej w Poznaniu CCCXC

Botanika – Steciana

15, 2011, 105-121

www.up.poznan.pl/steciana

ISSN 1896-1908

BRYO-CHOROLOGICAL ANALYSIS OF THE CHANGES IN THE MOSS FLORA OF THE KARKONOSZE MTS GLACIAL CIRQUES DURING XX CENTURY

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(Received: July 16, 2010. Accepted: February 11, 2011)

ABSTRACT. Bryo-floristical data from the 19th century and first decade of the 21st century were compared to find whether species related to cold climate, reported in the objects studied in the past, have disappeared and those typical for warmer regions spread in higher altitudes what is expected as montane plants' response to warming. According to the meteorological data given by Głowicki (2009) an average annual air temperature on Śnieżka Mt (the highest summit in the Karkonosze Mts range) rose of about 1°C in a period of 1959-2008 while an average monthly temperature for January of 2.5°C. Attachment of the moss species to climatic zones follows Düll's concept of the bryophyte chorological elements (Düll 1984, 1986, 1994 a, b, Düll and Meinunger 1989). The analysis showed that during the 20th century a slight decrease of species richness (of nine taxa) and considerable exchange of species (51%) happened. Total number of the mountain species decreased but opposite to expectations the strongest impoverishment has affected a group of boreal-montane species which theoretically should be rather resistant to warming. This question is discussed in the paper. Additionally, complete list of species reported from the Karkonosze Mts glacial cirques, including both all available historical and contemporary data published, as well as unpublished so far records from the Kocioł Wielkiego Stawu glacial cirque, is provided.

KEY WORDS: changes of bryoflora, mountain mosses, mosses response to warming, glacial cirques, mosses of Kocioł Wielkiego Stawu glacial cirque, Karkonosze Mts, Sudetes

INTRODUCTION

The Karkonosze Mts seem to be a good model area for studies on the mountain bryophyte flora changes during 20th century as they belongs to one of the best bryologically explored in the past mountain ranges in Europe thanks to surveys done nearly continuously since the end of the 18th century what resulted in long list of moss species known from there at the end of 19th century (Milde 1869, Limpricht 1876, 1890, 1895). In spite of not very high elevation which seldom exceeds the altitude of 1450 m a.s.l. numerous (sub)arctic-(sub) alpine plant species were reported from there (Limpricht 1930). Some authors suggested that these species came and colonized the studied area together with arctic-alpine tundra during the Late Glacial (Starkel 1977). In the climatic optimum of the late-Atlantic period, when the woodlands expanded towards the topmost summits, the arctic-alpine ecosystems were either destroyed or reduced to sites where snowdrift and avalanche action hindered the forest development. Such places were the glacial cirques there. A specific topography and wind action within the glacial cirques create severe climatic conditions what was conducive to survive these elements of moss flora (Jeník 1997). The most historical data were collected just from the glacial cirques and slopes and summit of the Śnieżka Mt – the highest top in the range: 1609 m a.s.l. (Wilczyńska 1996).

According to the meteorological data given by Głowicki (2009) an average annual air temperature on the Śnieżka Mt (where a meteorological station is located) rose by about 1°C in the period of 1959-2008 while an average monthly temperature for January by 2.5°C. Bryophytes are thought to be plants which react rapidly to climatic fluctuations. Frahm and Klaus (2001) reported and documented range extensions of several hundred kilometers to the east or north-east of 34 bryophyte species with Atlantic or Mediterranean distributions in Europe. According to these authors there is a correlation between an increase in the mean temperatures of the winter months and a shift of the 3.5°C isotherm to the east and the moss species observed range extensions to the east.

Thus the following question arose: Did moss flora of the Karkonosze Mts glacial cirques change during the 20th century in such way which indicates an average temperature increase in January in the last 50 years? Looking for the answer the bryo-floristical data from 19th century and first decade of 21st century were compared to find whether species related to cold climate, occurring in Europe in arctic, subarctic, alpine or sub-alpine zones, disappeared and those typical ones for warmer zones spread in higher altitudes? The paper presents data of the glacial cirques' moss flora changes and their bryo-chorological analysis. For practical reasons only glacial cirques situated in the Polish part of the Karkonosze Mts were studied.

CHARACTERISTICS OF OBJECTS STUDIED

The range of the Karkonosze Mts, situated in the areas of Poland and the Czech Republic, belongs to the old middle European mountains, the so-called Hercynians. The altitudinal span reaches from 727 to 1602 m a.s.l. on the Polish area but the elevation of the main massif seldom exceeds 1450 m a.s.l. The climate of the Karkonosze Mts is severe, similar to that prevailing in the subarctic areas. The geology is various but granitoids prevailed (STAFFA 1993).

Post-glacial cirques in the Karkonosze Mts resulted from erosion activity of local mountain glacier which occurred in Pleistocene. Altogether, there are nine objects situated in summit region of the range: six in Polish (northern) and three in Czech (southern) part. The ones on the Polish side form two separate groups (Fig. 1):

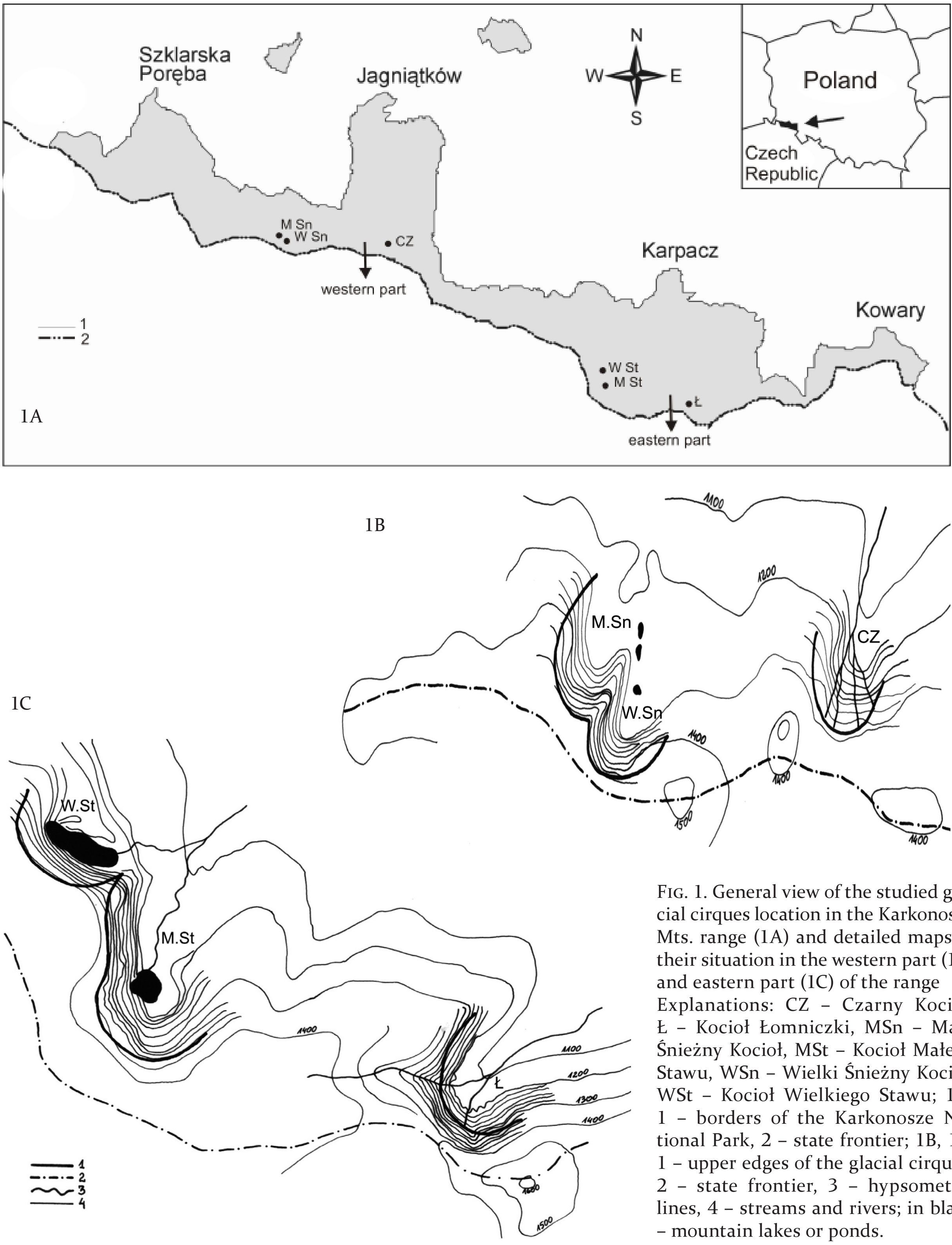

FIG. 1. General view of the studied glacial cirques location in the Karkonosze Mts. range (1A) and detailed maps of their situation in the western part (1B) and eastern part (1C) of the range
Explanations: CZ – Czarny Kocioł, Ł – Kocioł Łomniczki, MSn – Mały Śnieżny Kocioł, MSt – Kocioł Małego Stawu, WSn – Wielki Śnieżny Kocioł, WSt – Kocioł Wielkiego Stawu; 1A: 1 – borders of the Karkonosze National Park, 2 – state frontier; 1B, 1C: 1 – upper edges of the glacial cirques, 2 – state frontier, 3 – hypsometric lines, 4 – streams and rivers; in black – mountain lakes or ponds.

western (3 objects) and eastern (3 objects). Although general view of the cirques is similar: semi-circular or oval concave landform limited from three sides with steep often almost perpendicular rocky slopes (walls) and from the fourth side with moraines or rocky bar, they differ in altitudinal span, geological structure, geomorphologic forms and hydrological conditions what reflects on vegetation structure and its variety (Table 1). The specific local climate conditions in some cirques favour a long-term snow cover, what makes them similar to arctic or alpine objects. However, they lack perennial snow and permafrost (Jeník 1997).

MATERIALS AND METHODS

The list of historical data was compiled basing on all available papers published. Most information about mosses occurred in the Karkonosze Mts. They were collected during the all 19th century (i.e. Milde 1861) but the first Flora presenting bryophytes occurring in there was published in 1876 (Limpricht 1876). Many bryo-floristic notes from all the glacial cirques situated presently in Poland were gathered in general bryophyte floras of Silesia by Milde (1869) and Limpricht K.G. (1876, 1890, 1895). Later bryo-exploration of the Karkonosze Mts seems to be rather fragmentary. In the first half of 20th century Limpricht W. (1930) published the complete study of mountain plants, including mosses, occurred in three cirques situated in western part of the range. In the quoted publication he inserted mainly data reported by Milde (1869) and Limpricht (1876, 1890, 1895) with some later notes not published. In Herbarium of Lower Silesia (WRSL) have preserved only 77 specimens of mosses collected in glacial cirques in 19th century and in the first half of 20th (Wilczyńska 1996). A part of K.G. Limpricht's collection containing also specimens collected in the Karkonosze Mts is deposited in the herbarium BP (Hungary) but their revision was not possible within the frame of this project.

Additionally, some data were obtained from taxonomical works in which herbarial specimens collected in Karkonosze Mts were revised (Bednarek-Ochyra 1995, Kučera and Fudali 2004, Wojtuń 2006).

The list of mosses occurring in the glacial cirques in the beginning of the 21st century is based mainly

Table 1. Brief characteristics of the glacial cirques studied

Name of the glacial cirque	Mały Śnieżny Kocioł	Wielki Śnieżny Kocioł	Czarny Kocioł	Kocioł Małego Stawu	Kocioł Wielkiego Stawu	Kocioł Łomniczki
Altitude span [m a.s.l.]	1175-1420	1240-1480	1095-1325	1145-1425	1225-1430	1150-1430
Geological composition	granitoids, basalt outcrop on western wall	granitoids	granitoids	granite-gneiss, schists	granite-gneiss, schists	granite-gneiss, schists
Dominating geomorphologic forms and presence of superficial water	rocky walls, rubble, erratic blocks; spring along the S wall	rocky walls, rubble, erratic blocks	erratic blocks, rubble, rocky outcrops (S wall); stream along the S wall and bottom	rubble, erratic blocks, rocky W wall, rocky outcrops in E wall; numerous springs along the S and W walls, in the bottom: mountain lake and river	rubble, rocky outcrops, the whole bottom filed with the mountain lake	rubble, erratic blocks, rocky S wall, spring along the SW wall and the bottom, numerous tracts with trickling water along the all walls
Main vegetation types on the walls	M, G, CN, F, V; excl. W wall: Xerophytic grassland on basalt outcrop, HM	M, G, CN, F	G, CN, F, M; excl. E, W walls: P; excl. S wall: MC, V	G, CN, F, V, M; excl. E, W walls: P, MC	M, CN, F, V; excl. S wall: HM, excl. W , N walls: Bg, D	M, CN, G, V, F; excl. E wall: P; excl. W wall: D; excl. S wall: HM, HT, Bg, MC
Main vegetation types in the bottom	M	G, F, M	MA, G, Bg, MC, HM	M, D, F, P, Bg, HM	aquatic vegetation	M, F, NC, G, V, P, D, Bg, HM, MC

Explanation of symbols: type of vegetation[1]: Bg – plots of subalpine swamps within subalpine grasslands, CN – short subalpine grasslands of *Carici rigidae-Nardetum* community, D – deciduous shrubs of *Pado-Sorbetum*, F – fern community *Athyrietum alpestris*, G – high subalpine grasslands of *Crepido-Calamagrostietum villosae* community, HM – tall herbs of *Adenostyletum aliariae* community, HT – tall herbs of *Aconitetum plicatae*, M – *Pinetum mughii sudeticum*, MA – tall grasslands *Molinio-Agrostietum*[2], MC – spring community of *Cardaminae-Montion* alliance, P – spruce forest of *Piceetum hercynicum*, V – blueberry aggregations, probably depauperated form of *Empetro-Vaccinietum*, excl. – exclusively.

[1] Plant communities were recognised according to Matuszkiewicz W. and Matuszkiewicz A. (1974).
[2] According to Kwiatkowski (2004).

on research of the author and co-workers (Fudali and Kučera 2002, 2003, Fudali et al. 2003, Fudali 2004, 2010 a, b and unpublished data collected in 2009 from the Kocioł Wielkiego Stawu glacial cirque). Collection of moss specimens gathered during the field research was deposited in the Mosses Herbarium of the Institute of Botany of Polish Academy of Sciences (KRAM-B). Some data, concerning contemporary stations of peat mosses (*Sphagnum* sp.) were included following Wojtuń (2006).

All the moss species reported from the glacial cirques were grouped according their chorological status defined by Düll's conception of bryophyte chorological elements (Düll 1984). This classification system was proposed to distinguish groups of European and Macaronesian bryophytes (mosses and liverworts) which show, in majority, limited ranges of occurrence due to climatic zones. The basic criterion for classifying taxa is their attachment to primary centers of distribution (Düll 1984, 1986, 1994 a, b, Düll and Meinunger 1989). As geographical distribution of bryophytes is still insufficiently known some Düll's proposals to the species bryo-chorological affiliation should be taken carefully as provisional assignation. This reservation refers among others to species which seem to have very wide world distributional range, e.g. *Ceratodon purpureus* or *Bryum argenteum* (Ochyra 1998) assigned by Düll and Meinunger (1989) to the temperate element. In the paper the species quoted were classified as Holarctic element.

Within each of the bryo-chorological group lists of historical and present-day stations were compared to know the number of species which disappeared and number of "new comers". Assessment of quantitative changes within these bryo-chorological groups allowed to answer the question arisen. In that comparison the objects studied were taken as a whole, it means that the information analysed was a fact of species occurrence at least in one of the glacial cirques studied. We should be aware that the method used (comparison with old historical data published) is burdened with a mis-conclusion possibility as methods of the 19th researchers differed from the ones used by the author. It is highly possible that they omitted species commonly occurring, an estimation of species frequency was arbitrary without quantitative data, stations were reported broadly. During the 20th century a taxonomical approach to many taxa changed but most of specimens damaged during both world wars and their revision is impossible. That is why conclusions resulting from such comparisons should be taken approximately. Nomenclature of mosses follows Ochyra et al. (2003).

RESULTS

Quantitative changes – a slight decrease of the species richness and considerable exchange of species

Historical papers and some herbarial specimens mentioned above concern 163 moss species (164 taxa, including two subspecies of *Buclandiella macounii*) occurring in the studied glacial cirques up to 1930 (Table 2). With addition of *Encalypta microstoma* collected in the Mały Śnieżny Kocioł glacial cirque by Ŝmarda in 1945 (see: Kučera and Fudali 2004) it makes 164 species (165 taxa). In a case of three species reported in the past a possibility of mis-identification can-not be neglected. It is striking that historical authors did not at all record subarctic-subalpine *Kiaeria blyttii* which presently occur frequently but they reported from the five cirques another species of the genus *Kiaeria* – subarctic--subalpine *K. falcata* not found presently. It is very probable that at least some records of *K. falcata* will rather belong to *K. blyttii*. However in the Czech side of the Karkonosze Mts *Kiaeria falcata* was re-found in 2002 at the altitude of 1405 m a.s.l. (Kučera et al. 2004 b). The second doubtful historical record is subarctic-subalpine *Rhizomnium pseudopunctatum*. According to Zmrhalovà (Kučera et al. 2004 a, b) who revised all available in the Czech Republic herbarial speciments of *R. pseudopunctatum* from the Karkonosze Mts the all of them were *R. magnifolium* which in the 19th was not recognized as separate species (Ochyra et al. 2003). Similarly, widespread presently boreal-montane *Rhytidiadelphus subpinnatus* was not identified in the 19th and treated as *R. squarrosus* (= *R. squarrosus* subsp. *calvescens* – ochyra et al. 2003). However, presently *R. squarrosus* s.s. was also found so we can not assumed that all historical data of *R. squarrosus* refer to *R. subpinnatus.* Considering the doubts mentioned above only *Rhizomnium pseudopunctatum* has been excluded from the further analysis and its historical records were credited to *R. magnifolium*.

Present-day research has documented 155 moss species occurrence in the beginning of 21st century (Table 2). So a slight decrease of the species number (of 8 species but 9 taxa) has happened (Table 3). The comparison of bryo-floristic lists from both periods shows that among 213 moss species (214 taxa) reported altogether from the glacial cirques studied only 105 species (49%) occurred both in 19th and 21st. 50 species were noted for the first time in the beginning of 21st while 58 species (59 taxa) were not re-found. It suggests that during 20th century a species composition of moss flora occurring in the glacial cirques changed considerably (in 51%). Unfortunately, historical works do not provide any information of the species' occurrence frequency in the glacial cirques so we do not know whether the species not re-found presently were abundant in 19th or scattered just then? The author's research showed that nowadays most of the moss species occur very rarely or sporadically, often only in one of the glacial cirques studied, in one or a few places (Table 2). Most of the "newcomers" in the glacial cirques occurred in the range of the Karkonosze Mts just in the past but some of the newly found species were not reported in 19th from the Polish side of the range (Wilczyńska 1996); these are: *Andraeaea nivalis*, *Aulacomnium androgynum*, *Sciuro--hypnum populeum*, *Dicranoweisia cirrata*, *Plagiothecium platyphyllum* and *P. succulentum*.

Qualitative changes – decrease in percentage incidence of mountains species

Among bryo-chorological groups distinguished by Düll (1984, 1986) 11 can be defined as mountain species group (Table 3). The total number of species representing them decreased during 20th from 117 (71% of the historical data) to 89 (57% of the contemporary data).

TABLE 2. Comparison of historical and present-day stations within bryo-chorological groups (sensu DÜLL 1984, 1986)

Name of species	Species occurrence in the particular glacial cirques in the past and number of notes in the 21st century											
	MSn		WSn		CZ		MSt		WSt		Ł	
	1869-1930	2000-2001	1869-1930	2001	1869-1930	2004	1869	2003-2009	1867-1869	2009	1869	2003-2008
1	2	3	4	5	6	7	8	9	10	11	12	13
Arctic-alpine element												
Andreaea nivalis **!**	.	**1**	.	.	.	.	.	.	.	.	.	.
Arctoa fulvella	.	1	■	0	.	.	.	.	.	.	.	.
Pohlia ludwigii	■	10	.	3	.	.	.	.	.	.	.	.
Pohlia obtusifolia	.	.	.	.	.	.	1930■	1-cfr.F*	.	.	■	0
Subarctic-alpine element												
Bryum muehlenbeckii	■	0	.	.	.	.	.	.	.	.	.	.
Dicranum elongatum	■	0	■	0	.	.	.	.	.	.	.	***
Plagiomnium medium	.	2	.	1	.	2	■	6	.	4	■	11
Subarctic-subalpine element												
Amphidium lapponicum	■	0	.	.	.	.	■	0	.	.	.	.
Bryum schleicheri var. *latifolium*	.	.	■	0	.	.	.	.	.	.	.	.
Buclandiella microcarpa	1882■BO*	0	■	0	.	.	1981■BO*	0	.	.	.	1
Buclandiella macounii ssp. alpinum	1882■BO*	3	■	1	.	.	1953■BO*	.	.	.	1970■BO*	.
Buclandiella sudetica	■	30	■	30	■	30	■	19	■	13	■	18
Desmatodon latifolius	■	2	.	.	.	.	.	.	.	.	.	.
Ditrichum zonatum	.	**1**	.	.	.	.	.	.	.	.	.	.
Encalypta microstoma	1945■	0	.	.	.	.	.	.	.	.	.	.
Fissidens osmundoides	■	1	.	.	.	.	.	.	.	.	.	.
Grimmia funalis	■	2	■	3	.	.	■	0	.	.	.	.

TABLE 2 – cont.

1	2	3	4	5	6	7	8	9	10	11	12	13
Grimmia incurva	■	0	■	4	.	.	.	.	.	.	.	***
Herzogiella striatella	■	1	■	2	■	0	■	8	■	0	■	8
Hygrohypnum smithii	.	.	.	.	.	.	■	2	.	.	■	0
Hylocomiastrum pyrenaicum	■	2	■	0	.	.	■	0	.	.	■	0
Hypnum callichroum	■	1	■	0	■	0	■	4	.	.	■	1
Kiaeria blyttii	.	**30**	.	**20**	.	**10**	.	**3**	.	**3**	.	**1**
Kiaeria falcata	■	0	■	0	.	.	■	0	■	0	■	0
Kiaeria starkei	■	25	■	10	■	3	■	16	■	4	■	16
Lescuraea saxicola	■	0			.	.			.	.	.	.
Oligotrichum hercynicum	■	20	■	20	■	20	.	12	.	5	■	12
Oncophorus virens	.	.	.	.	.	.	.	**1**	.	.	.	.
Palustriella decipiens	.	.	.	.	.	.	■	0	.	.	■	0
Pohlia wahlenbergii var. *glacialis*	■	3	.	3	.	5	.	.	.	2	■	3
Polytrichastrum alpinum	■	30	■	30	■	20	■	35	■	14	■	31
Polytrichastrum sexangulare	■	1	.	.	.	.	.	.	.	.	.	.
Pseudobryum cinclidioides	.	.	.	.	■	0	1961■	0	.	.	.	.
Ptychodium plicatum	■	2	■	0	.	.	.	.	.	.	.	.
Sphagnum lindbergii	■	0	■	0	.	.	■	1	.	W1999*	■	2-EF2009
Tayloria serrata	■	0	.	.	■	0	■	1	.	.	■	0
Tayloria splachnoides	.	.	.	.	.	.	.	.	.	.	■	0
Tetraplodon angustatus	■	0	■	0	.	.	.	.	.	.	.	.
Tetrodontium repandum	.	.	.	.	.	.	■	1	.	.	.	.
Warnstorfia sarmentosa	■	1	■	2	.	.	■	1	■	1	■	2

TABLE 2 – cont.

1	2	3	4	5	6	7	8	9	10	11	12	13
Northoceanic-subalpine												
Dicranodontium uncinatum	■	0	■	0	.	6	.	2	.	.	.	4
Hygrohypnum molle	.	.	■	0	.	.	.	.	.	.	■	0
Boreal-montane												
Andrea rupestris	■	20	■	20	.	10	.	10	.	6	.	9
Bartramia halleriana	.	.	■	0	.	.	.	.	.	.	.	.
Bartramia ityphylla	■	3	■	0	.	2	■	0	.	2	.	.
Blindia acuta	■	1	■	1	.	.	■	1	■	0	■	0
Bryum elegans	■	0	.	.	.	.	■	0	.	.	.	.
Buclandiella affinis	.	.	.	.	.	.			1929■BO*	0	.	1
Buclandiella macounii ssp. *macounii*	.	.	.	.	1913■BO*	0	.	.	.	.	.	.
Buxbaumia viridis	.	.		.	.	.			.	.	■	0
Campylophyllum halleri	.	.	.	.	.	.			.	.	■	0
Codriophorus aquaticus	■	5	■	5	.	1	■	5	■	0	.	4
Codriophorus fascicularis	■	20	■	10	■	20	■	18	1930■BO*	6	1873■BO*	19
Cynodontium polycarpon	■	10		2	.	10	■	8	.	2	■	4
Cynodontium strumiferum	.	.	.	.	.	.	■	2	.	.	■	0
Dichodontium pellucidum	.	1	.	.	.	.	■	0	.	.	■	0
Dicranella subulata	■	1	.	.	■	0	■	0	.	.	■	0
Dicranodontium denudatum	■	10	■	10	.	20	■	14	■	2	■	19
Dicranum flexicaule	■	20	■	20	■	10	.	1	.	1	.	4
Dicranum fuscescens	.	.	.	.	.	.	■	5	.	5	.	10
Diobelonella palustris	.	1			.	4	■	5	■	1	■	6
Ditrichum heteromallum	**.**	**.**	**.**	**1**	**.**	**.**	**.**	**4**	**.**	**.**	**.**	**4**

TABLE 2 – cont.

1	2	3	4	5	6	7	8	9	10	11	12	13
Dryptodon patens	■	0	■	0	.	.	■	0	.	.	.	.
Encalypta ciliata	■	0	.	.	.	.	.	.	.	.	.	.
Gymnostomum aeruginosum	■	0	■	0	.	.	.	.	.	.	.	.
Heterocladium dimorphum	■	0	.	.	.	.	.	.	.	.	.	.
Hygrohypnum duriusculum	.	.	.	.	■	0	.	.	.	.	.	.
Hygrohypnum ochraceum	■	3	■	2	■	2	■	4	.	.	■	3
Hylocomiastrum umbratum	.	1	.	.	.	.	.	7	.	2	■	11
Hymenoloma crispulum	■	10	■	10	.	10	.	4	.	1	■	4
Hypnum lindbergii	■	3	.	.	.	.	.	.	.	.	.	.
Isopterygiopsis pulchella	.	.	.	.	.	.	.	.	.	.	■	0
Leskella nervosa EPIPH.	■	0	■	0	■	0	.	.	.	.	■	0
Mnium spinosum	.	4	.	1	.	.	.	2	.	.	■	3
Niphotrichum canescens	■	4	.	1	.	.	.	.	.	.	.	.
Orthothecium intricatum	■	0	.	.	.	.	.	.	.	.	.	.
Paraleucobrym longifolium	.	5	■	10	.	1	.	10	.	3	■	8
Philonotis seriata	■	5	■	2	.	5	.	12	.	1	.	15
Plagiothecium cavifolium	.	10	.	5	.	8	■	8	.	3	■	12
Pogonatum urnigerum	.	20	.	20	.	.	■	3	.	6	.	11
Pohlia drummondi	■	5	.	4	.	.	■	0	.	.	■	0
Pohlia elongata	■	0	.	.	.	.			■	0	.	.
Pseudoleskea incurvata	■	10	■	10	.	.	■	3	.	.	■	1
Ptilium crista-castrensis	.	.	.	.	.	.			.	.	■	0
Racomitrium lanuginosum	■	2	■	4	■	1	■	1	■	0	.	6
Rhabdoweisia fugax	■	2	■	0	.	.	■	0	.	.	.	.

TABLE 2 – cont.

1	2	3	4	5	6	7	8	9	10	11	12	13
Rhizomnium magnifolium	*R. pseud.*■	1	*R. pseud.*■	.	.	.	.	13	.	3	.	11
Rhodobryum roseum	.	3	■	1	.	.	.	3	.	1	.	.
Rhytidiadelphus subpinnatus	.	**5**	.	**10**	.	**6**	.	**30**	.	**11**	.	**25**
Saelania glaucescens	■	0	.	.	.	.	.	.	.	.	.	.
Sanionia uncinata	■	20	■	10	.	3	.	8	.	9	■	18
Sciuro-hypnum reflexum	■	30	■	20	.	10	■	26	■	8	■	25
Sciuro-hypnum starkei	.	5	■	10	.	4	.	14	.	5	■	15
Sphagnum fuscum	.	.	.	.	.	.	.	.	.	**W2000***	.	.
Sphagnum girgensohnii	■	20	■	20	■	20	.	23	.	8	■	26
Sphagnum russowii	.	.	.	.	.	.	.	**16**	.	**8**	.	**17**
Sphagnum teres	■	0	■	0	■	0	■	0	■	W1999*	.	.
Sphagnum warnstorfii	.	.	.	.	.	.	.	.	1912■W*	W1999*	.	.
Splachnum sphaericum	■	0	■	0	.	.	■	0	.	.	■	1
Tetraplodon mnioides	■	0	■	0	.	.			.	.	■	0
Tortella tortuosa	■	2	■	0	.	.	■	0	.	.	.	.
Warnstorfia exannulata	■	1	■	0	.	.	■	7	.	.	.	.
Subboreal-montane element												
Grimmia hartmanii	.	.	.	.	.	.	.	.	.	.	.	**1**
Orthotrichum pallens EPIPH.	■	0	■	0	■	0	.	.	.	.	.	.
Temperate-montane element												
Ctenidium molluscum	.	.	.	.	.	.	■	0	.	.	■	0
Fissidens cristatus	■	0	.	.	.	.			.	.	.	.
Grimmia muehlenbeckii	.	**1**	.	.	.	.			.	.	.	.
Pohlia cruda	■	1	.	.	.	.	■	0	.	.	.	.

TABLE 2 – cont.

1	2	3	4	5	6	7	8	9	10	11	12	13
North oceanic-montane element												
Buckiella undulata	■	1	■	0	.	.	.	8	■	2	.	9
Suboceanic-montane element												
Brachydontium trichodes	.	.	■	0	.	.	.	1	.	.	■	0
Buclandiella heterosticha	.	.	.	.	.	.	.	.	.	.	.	**3**
Codriophorus acicularis	■	5	■	10	■	2	1841■BO*	10	■	1	■	8
Diphyscium foliosum	.	.	.	.	.	.	■	0	.	.	■	0
Oxystegus tenuirostris	.	**4**	.	**1**	.	.	.	.	.	.	.	.
***Plagiothecium platyphyllum* !**	.	**1**	.	.	.	.	.	.	.	**1**	.	**1**
North suboceanic-montane element												
Amphidium mougeotii	■	2	.	1	.	.	■	0	.	.	.	.
Andreae rothii ssp. *falcata*	.	.	■	2	.	.	■	0	.	.	.	.
Grimmia donniana	.	2	■	5	.	.	.	2	.	.	.	1
Heterocladium heteropterum	■	4	■	0	■	.	.	1	.	.	■	2
Hookeria lucens	.	.	.	.	.	.	.	.	.	.	■	0
Orthotrichum rupestre	.	.	.	.	.	.	.	.	.	.	■	0
Rhytidiadelphus loreus	.	4	■	5	.	1	.	1	.	.	.	5
Ulota drummondii EPIPH.	■	0	■	0	.	.	■	0	.	.	.	.
Subcontinental-montane element												
Anomodon rugelii EPIPH.	■	0	.	.	.	.	.	.	.	.	.	.
Brachyhecium geheebii	■	1	.	.	.	.	.	.	.	.	.	.
Hypnum pallescens EPIPH.	■	0	■	0	■	0	.	.	.	.	■	0
Lescuraea mutabilis EPIPH.	■	0	■	0	.	.	■	0	■	0	■	0
Mnium spinulosum	■	0	.	.	.	.	■	0	.	.	■	0

TABLE 2 – cont.

1	2	3	4	5	6	7	8	9	10	11	12	13
Orthotrichum speciosum EPIPH.	■	0	■	0	■	0	.	.	.	.	■	0
Platydictya subtile EPIPH.	.	.	.	.	.	.	.	.	.	.	■	0
Boreal element												
Aulacomnium palustre	.	.	.	.	.	.	.	**1**	.	.	.	.
Bryum pallens	.	.	.	.	.	.	■	0	.	.	■	0
Bryum weigeli	.	.	.	.	.	.	■	0	.	.	.	.
Campyliadelphus stellatus	■	0	.	.	.	.	.	.	.	.	.	.
Dichelyma falcatum	.	.	.	.	.	.	■	0	.	.	.	.
**Dicranella cerviculata*	■	4	■	5	.	6	.	3	.	4	.	10
***Dicranum majus*	.	3	.	1	.	.	■	5	.	.	.	7
Hygrohypnum luridum	.	.	.	.	.	.	■	0	.	.	.	.
Plagiothecium laetum	.	**4**	.	**1**	.	**1**	.	**6**	.	.	.	**4**
Polytrichastrum longisetum	.	**2**	.	.	.	**3**	.	.	.	.	.	.
Polytrichum strictum	.	**1**	.	.	.	.	.	.	.	**2**	.	**4**
Pylaisiella polyantha EPIPH.	.	.	.	.	.	.	.	.	.	.	■	0
Sphagnum centrale	.	.	.	.	.	.	.	.	1912■W*	W1999*	.	.
Sphagnum compactum	.	.	.	.	.	.	■	3	■	0	■	2
Sphagnum cuspidatum	.	.	.	.	.	.	.	**1**	.	.	.	**1**
Sphagnum inundatum	.	.	.	.	.	.	.	**1**	.	**1**	.	**1**
Sphagnum magellanicum	.	.	.	.	.	.	.	2	■	W1999*	.	1
Sphagnum palustre	.	.	.	.	.	.	.	.	.	**1**	.	**2**
Sphagnum riparium	.	.	.	.	.	.	.	**2**	.	**1**	.	**1**
Sphagnum subsecundum	.	.	.	.	.	.	.	.	.	**W1999***	.	.
Straminergon stramineum	.	10	.	10	.	4	■	12	■	1	■	5

TABLE 2 – cont.

1	2	3	4	5	6	7	8	9	10	11	12	13
Subboreal element												
Brachythecium albicans	.	.	.	.	.	.	.	**1**	.	**2**	.	**1**
Brachythecium rivulare	.	**2**	.	**1**	.	.	.	**1**	.	**1**	.	**1**
Brachythecium salebrosum	.	**5**	.	**1**	.	**1**	.	**6**	.	**5**	.	**4**
Cirriphyllum piliferum	.	**2**	.	.	.	.	**1961■**	**5**	.	.	.	**3**
Dicranum scoparium	.	**50**	.	**40**	.	**40**	.	**25**	.	**15**	.	**31**
Fontinalis antipyretica	.	.	.	.	.	.	■	2	.	.	.	.
Herzogiella seligeri	.	.	.	.	.	.	.	**4**	.	**2**	.	.
Hylocomium splendens	■	20	■	10	■	0	.	18	.	7	.	19
Orthodicranum montanum EPIPH.	.	2	.	4	.	1	■	9	■	6	.	14
Plagiothecium curvifolium	.	**2**	.	**5**	.	**10**	.	**25**	.	**7**	.	**24**
Plagiothecium denticulatum	.	20	.	10	.	20	■	5	.	4	■	11
Plagiothecium ruthei	.	.	.	.	■	0	.	.	.	.	.	.
Pleurozium scheberi	.	**40**	.	**30**	.	**10**	.	**22**	.	**11**	.	**25**
Polytrichum commune	■	10	■	10	■	30	.	19	.	10	.	16
Pohlia nutans	.	**10**	.	**20**	.	**10**	.	**17**	.	**10**	.	**20**
Rhytidiadelphus triquetrus	■	1	■	0	.	.	.	.	.	.	.	2
Rhytidiadelphus squarrosus	■	3	■	2	.	6	■	1	■	1	.	.
Rhytidium rugosum	■	1	.	.	.	.	■	0	■	0	.	.
Schistidium confertum	■	0	.	.	.	.	.	.	.	.	.	.
Sphagnum angustifolium	.	.	.	.	.	.	.	.	.	**W1999***	.	.
Sphagnum fallax	.	.	.	.	.	**6**	.	**8**	.	**1**	.	**3**
Sphagnum flexuosum	.	.	.	.	.	.	.	.	.	**W1999***	.	.
Thuidium tamariscinum	.	.	.	.	.	.	.	.	.	.	.	**2**

TABLE 2 – cont.

1	2	3	4	5	6	7	8	9	10	11	12	13
Ulota coarctata EPIPH.	■	0	■	0	.	.	.	.	.	.	■	0
Warnstorfia fluitans	.	1	.	.	.	.	■	0	.	.	.	.
Suboceanic element												
Antitrichia curtipendula EPIPH.	.	.	.	.	.	.	.	.	.	.	■	0
Campylopus flexuosus	.	.	.	.	.	.	.	.	.	.	■	0
***Dicranoweisia cirrata* ! EPIPH.**	.	.	.	.	.	.	.	.	.	.	.	**1**
Orthotrichum stramineum EPIPH.	■	0	■	0	■	.	.	.	.	.	■	0
Pseudotaxiphyllum elegans	.	6	.	2	■	6	.	3	.	.	■	10
North-suboceanic element												
Mnium hornum	.	.	.	.	.	.	.	**5**	.	**1**	.	**3**
***Plagiothecium succulentum* !**	.	**5**	.	**2**	.	**1**	.	**4**	.	.	.	**5**
Rhizomnium punctatum	■	10	■	3	■	3	.	4	.	2	.	6
Sciuro-hypnum plumosum	.	4	.	.	.	.	■	0	■	0	■	0
Sphagnum denticulatum	.	.	.	.	.	6	.	10	■	2	.	4
Sphagnum papillosum	.	.	.	.	.	.	.	.	1912■W*	1	.	.
Ulota bruchii EPIPH.	■	0	■	0	.	.	.	.	.	.	■	0
Temperate element												
***Aulacomnium androgynum* !**	.	.	.	.	.	**1**	.	.	.	.	.	.
Brachytheciastrum velutinum EPIPH.	.	.	■	0	.	.	.	2	.	1	■	1
Brachythecium rutabulum	.	.	.	.	.	.	.	.	.	.	.	**1**
Bryum capillare	.	**2**	.	.	.	.	.	.	.	.	.	.
Bryum pallescens	.	.	.	.	.	.	.	.	.	**2**	.	**2**
Bryum pseudotriquetrum	.	**2**	.	**1**	.	.	.	**2**	.	**1**	.	**2**
Bryum turbinatum	.	.	■	0	.	.	.	.	.	.	.	.

TABLE 2 – cont.

1	2	3	4	5	6	7	8	9	10	11	12	13
Dicranella heteromalla	.	10	■	10	.	6	.	11	.	1	.	.
Ditrichum pusillum	.	.	.	.	.	.	.	.	.	.	■	0
Hypnum cupressiforme	.	.	.	.	.	.	.	.	.	.	.	1
Isothecium alopecuroides EPIPH.	.	.	.	.	.	.	■	0	.	.	■	0
Philonotis fontana	■	0	■	0	■	PK1999	1956■	0	.	.	■	0
Plagiomnium affine	.	2	.	2			.	1	.	.	.	.
Plagiothecium nemorale	.	.	■	0	.	2	.	2	.	4	■	4
Platyhypnidium riparioides	.	.	.	.	.	.	■	0	.	.	.	2
Polytrichastrum formosum	.	1	.	5	.	2	.	1	.	.	.	3
Polytrichum juniperinum	■	30	■	30	■	10	.	9	.	4	.	8
Polytrichum piliferum	.	40	.	40	.	4	.	11	.	3	.	8
Schistidium apocarpum	■	0	.	.	.	.	.	.	.	.	.	.
Sciuro-hypnum populeum ! EPIPH.	.	.	.	.	.	.	.	.	.	.	.	1
Sphagnum capillifolium	■	2	■	0	■	2	.	3	.	.	.	.
Sphagnum squarrosum	■	4	■	0	■	5	.	14	1961■	3	.	11
Ulota crispa EPIPH.	■	0	■	0	■	0	.	.	.	.	■	0
Holarctic-species widely distributed in Europe												
Bryum argenteum	.	1	.	.	.	.	.	.	.	.	.	.
Ceratodon purpureus	.	.	.	1	.	1	.	2	.	2	.	3
Tetraphis pelucida	.	.	.	1	.	3	.	3	■	0	.	9

Explanation of symbols and abbreviations: ■ – species reported in the years given in the table's head or in the year given next to this symbol, 1882■BO* – specimen dated on the year given and revised by BEDNAREK-OCHYRA (1995), 1912■W* – specimen dated on the year given and revised by WOJTUŃ (2006), cfr. – identification not certain, EPIPH. – epiphytic species, F* – species reported in FUDALI et AL. (2003), PK – species found by KWIATKOWSKI (2004) and revised by FUDALI (2004), *R. pseud.* – given as *Rhizomnium pseudopunctatum* (see chapter Results), W1999* – species found by Wojtuń in the year given and reported in WOJTUŃ (2006), *** – species collected presently above the upper range of the glacial cirque; ! – species reported in the Polish part of the Karkonosze Mts for the first time in the 21st century; species' name in bold – species reported from the glacial cirques for the first time in the 21st century; grey shadow – species occurring during the whole period studied.

Table 3. Quantitative changes within the bryo-chorological elements (sensu Düll 1984, 1986) in the moss flora reported in 19th and 21st

Bryo-chorological groups	Noted in 19th	Not re-found in 21st	Persistent during 20th	New in 21st	Noted in 21st in total
	Number of taxa				
In total	164	59	105	50	155
Groups of mountain species	**117**	**41**	**76**	**13**	**89**
Arctic-alpine	3	0	3	1	4
Subarctic-alpine	3	2	1	0	1
Subarctic-subalpine	30	9	21	3	24
North oceanic-subalpine	2	1	1	0	1
Boreal-montane	56	16	40	4	44
Subboreal-montane	1	1	0	1	1
North oceanic-montane	1	0	1	0	1
Suboceanic-montane	3	1	2	3	5
North suboceanic-montane	8	3	5	0	5
Temperate-montane	3	2	1	1	2
Subcontinental-montane	7	6	1	0	1
Other groups	**46**	**18**	**28**	**35**	**63**
Boreal	12	6	6	9	15
Subboreal	12	3	9	13	22
Temperate	13	5	8	10	18
Suboceanic	4	3	1	1	2
North suboceanic	5	1	4	2	6
Holarctic	**1**	**0**	**1**	**2**	**3**

Among them the majority of changes happened within three bryo-chorological groups: subarctic-subalpine, in which the species loss concerns nine species (30% of the previously reported) and three species were reported for the first time in 21st; boreal-montane, with the total species loss of 12 (from 56 to 44) including 16 not re-found and four new; and subarctic-alpine, in which among three species reported in the past only one was re-found and none new was reported. At the same time a percentage incidence of other bryo-chorological groups (boreal, subboreal, temperate, suboceanic, north suboceanic, north oceanic) increased, from 46 to 63. Among them the highest increase concerns two groups: sub-boreal and temperate, respectively: from 12 to 22 and from 13 to 20.

DISCUSSION

During the 20th century in the glacial cirques' moss flora appeared visible changes in the species composition manifested in a decrease of the mountain species' total number. In opposite to theoretical expectations that species representing arctic, subarctic or alpine geographical elements should be more sensible to warming than other mountain species (Good 1974 in Kornaś and Medwecka-Kornaś 2003) the strongest impoverishment affected boreal-montane bryo-chorological group: ratio of the species loss amounts 20% (12 taxa) and species composition exchanged in 33%. Similar changes affected a group of subarctic-subalpine species: 18% (6 taxa) of the species were not re-found and a species composition exchanged in 36%. These results have arisen some questions: the first – may be the warming observed in the summit of the Śnieżka Mt (1609 m a.s.l.) could not have a real impact upon the vegetation situated of 200 to 500 m below? The second – may be the classification of chorological elements applied for analysis is not adequate to the real species occurrence in the mountains? Stebel (2006) quoted an opinion that in the ranges of low mountains mosses appeared a tendency to descend in lower altitudes and occur much lower than in high mountains. The third, may be another environmental factors have affected mosses flora stronger than the supposed warming? It is striking that almost all epiphytes reported in 19th were not re-found in 21st in the whole range of Karkonosze Mts, both on Polish (Table 2) and Czech side (Kučera and Buryova 1999, Kučera et al. 2004 a, b). Epiphytes are known to be the most sensible to sulphur dioxide effect ecological group among the mosses (Rao 1982) and in the years 1970-1980 the Karkonosze Mts suffered huge atmospheric pollutions from power-stations situated nearby (Kmieć et al. 1994). Epiphytes could vanish in result of sulphur dioxide effect not of warming. They represented various bryo-chorological groups what seems to confirm that opinion.

Analysis of species representing bryo-chorological groups other than "montane" also has brought some questions. Among them there are 37 species (24% of the present-day flora) reported for the first time from the glacial cirques, but only four of them were not reported from the Karkonosze Mts in 19th: temperate – *Aulacomnium androgynum* and *Sciuro-hypnum populeum*, north-suboceanic *Plagiothecium succulentum* and suboceanic *Dicranoweisia cirrata* (Wilczyńska 1996). The rest were observed in the range in the past and could be neglected by collectors in the glacial cirques as species common for the whole region. These opinions seem to be confirmed by the notice there are numerous taxa among them which occur both in mountains and in lowlands with a similar frequency. These are: acidophytic species occurring in the coniferous forests as *Dicranum scoparium*, *Pleurozium schreberi* and *Plagiothecium curvifolium*, humicolous forest ubiquist as *Pohlia nutans* as well as numerous higrophytes building moss carpet of peatbogs, as: *Aulacomnium palustre*, *Sphagnum cuspidatum*, *S. inundatum*, *S. fallax*, *S. palustre*, *S. riparium*.

Among "newcomers" in the glacial cirques representing the bryo-chorological groups not "montane" there are some species noted in the past only below the altitude of 1000 m a.s.l. (Wilczyńska 1996) while presently occur higher, at least on the altitude of 1110 m a.s.l. Such a reaction caused appearance of sub-oceanic species *Mnium hornum* (1230-1265 m a.s.l.), representatives of temperate bryo-chorological element *Brachythecium rutabulum* (1130 m a.s.l.), *Bryum pseudotriquetrum* (1130-1340 m a.s.l.), *Plagiomnium affine* (1195 m a.s.l.), *Polytrichastrum formosum* (1310 m a.s.l.) as well as subboreal species *Cirriphyllum piliferum* (1130-1235 m a.s.l.) *Herzogiella seligeri* (1145-1220 m a.s.l.) and *Thuidium tamariscinum* (1130-1170 m a.s.l.). All of them occurred very rarely or sporadically, on singular stations (Table 2). The question is: were they omitted by the 19th researchers or did they appear in 20th spreading at higher altitudes? Then they would indicate supposed but weak response to warming but this is only a speculation without scientific value.

CONCLUSIONS

1. Moss flora of the Karkonosze Mts glacial cirques visibly changed during 20th century and a decrease of the species number representing some of the bryo-chorological groups with distribution centers in mountains occurred. However, these changes seem to have much more complex character than being only a supposed response to warming documented in the summits of the Karkonosze Mts in the last 50 years. Almost all epiphytes noted in the past representing various bryo-chorological groups disappeared during the 20th century what indicates rather the air pollution impact effect.

2. A comparison of the species composition showed a high increase of species representing other bryo-chorological groups than "montane", from 47 to 65, but it is highly probable that most of these species occurred in the glacial cirques just in the past and their presence was neglected then by the researches as not important for a description of the glacial cirques moss flora peculiarity.

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For citation: Fudali E. (2011): Bryo-chorological analysis of the changes in the moss flora of the Karkonosze Mts glacial cirques during XX century. Rocz. AR Pozn. 390, Bot. Stec. 15: 105-121.