EXPECTED FLORISTIC CHANGES IN HYGRO-CRYOPHILIC AND SNOWBED PLANT COMMUNITIES CAUSED BY CLIMATE CHANGE AND HUMAN IMPACT IN THE ROMANIAN CARPATHIANS

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Abstract: In the Romanian Carpathians, there are only 6 massifs where glacial forms (valleys and cirques) occupy sufficiently large areas to support typical high altitude wetlands and snowbed vegetation. We have analyzed 424 relevés with this type of vegetation published in Romanian literature in the past century from these massifs. The cryophilic vegetation was grouped in 17 plant associations, 4 alliances and 3 Natura 2000 habitats. A total of 150 subalpine-alpine plant species (11 endemic) were registered in these communities (27% of the total 550 high mountain taxa found in the entire Romanian Carpathian range). Future scenarios for the glacial landforms of the Carpathians suggest a temperature increase of about 2.5°C in 2050 and 3°C in 2070. Species adapted to cool humid environments (*Soldanella rugosa*, *Soldanella pusilla*, *Lychnis nivalis*, *Carex lachenalis*, *Chrysosplenium alpinum*, *Carex nigra* subsp. *dacica*, *Carex pyrenaica*, *Carex bicolor*, *Juncus castaneus*, *Juncus triglumis*, *Plantago gentianoides*) are the most exposed to the threat of climate warming, as the disappearance of their typical habitat would mean extinction. Aside from the endemic flora, other cryophilic alpine taxa are also threatened. Natura 2000 habitats typical to these landforms (6150, 7240* and 3220) are being monitored in all 6 massifs, but there are no current administrative measures to monitor the presence of cryophilic species or plans to place glacial landforms under strict protection (IUCN category 1a), measures needed as human impact is more and more present at high altitudes.

Keywords: glacial landforms, high altitude wetlands, endemic species, alpine and boreal habitats, temperature projections, extinction risk, snow depth, plant diversity

Introduction

Cryophilic and snowbed plant communities occur in many ranges of the Romanian Carpathians, but are typical and occupy larger areas only in the 6 massifs with well-developed glacial land forms: Rodna, Făgăraș, Parâng, Retezat, Țarcu and Godeanu. They can be assigned to 3 Natura 2000 habitats (6150, 7240*, 3220), all characterized by a pronounced biogeographical fragmentation. All Natura 2000 habitats which have been identified and described in the Romanian Carpathians [16, 14] are fragmented to a certain degree, due to natural (climate and biotic interactions) or anthropic causes. Alpine and subalpine environments, which are naturally fragmented, are some of the most exposed to climate impact [18, 15].

While the main source for fragmentation of cryophilic and snowbed communities is natural (caused by the climate and biotic interactions such as competition, dispersal limitations, etc.), they have also suffered from human activities. The anthropic impact in the Carpathian

range has started with early human populations, which begun to transform forested areas in pastures [34]. The wood was used for housing and energy, while the pastures were used as food source for livestock during summer. As population reached modern day numbers, the range and intensity of impacts has increased, reaching the subalpine and alpine regions as well. The most destructive impact on high altitude vegetation has been the extensive deforestation of the subalpine shrub belts (characterized by *Pinus mugo* and *Juniperus communis* ssp. *alpina*). These habitats, which once occupied extensive areas, while not completely destroyed (by logging or by using fire), have been significantly reduced in order to expand the mountain pasture area. The secondary pasture communities installed in the deforested areas are dominated by a few species (e.g. *Nardus stricta*, *Deschampsia flexuosa*, *Festuca nigrescens*), and have a small floristic diversity index compared to natural subalpine pastures [11].

The deforestation of the subalpine belt has triggered large scale soil erosion processes of the upper mountain slopes and has reduced significantly the water retaining capacity of the soil in the subalpine belt. As the organic layer above the soil has been reduced and in some cases even completely destroyed [8], the general hydrology of these regions has changed. As a consequence, the cover of high altitude wet areas, usually found near springs and rivulets, has decreased in the last decades in the Romanian Carpathians, a decrease which is accompanied by a loss of rare plant species [35]. This process is intensified by the present day climate warming [26], as some subalpine and alpine springs go dry during the summer, threatening the future existence of cryophilic species, which are strongly related to this type of habitat. Changes in snow cover duration and snow depth are expected to progress in the coming decades toward higher altitudes, possibly even in glacial cirques or in other landforms which currently harbor such plant species.

The ecology and biogeography of these species in the Carpathians needs to be better understood. This is even more valid for plants which are endemic for such environments, and may significantly or completely go extinct with their habitat. Today, adding to the destructive actions on the wet and nival habitats, intensive grazing with sheep is practiced on large areas. This causes plant root damage, as well as soil compacting processes [3], and has the potential to aggravate the existing climate pressure on the habitat types in question.

Material and Methods

Study area

The Romanian Carpathians are a continuous mountain range, characterized by significant altitudinal variation, with large continuous portions of lower altitudes, especially in the Eastern part. Glaciation landforms have been confirmed in 11 mountain massifs [41], of which 6 are truly representative (Fig. 1). Thus, we have taken these 6 massifs into consideration for our analysis. From the Eastern Romanian Carpathians: Rodna Mts. [37, 27]. In the Southern Romanian Carpathians: Făgăraș Mts. [29, 32], Parâng Mts. [41, 17], Retezat Mts. [29, 39], Godeanu Mts. [38, 30], Țarcu Mts. [30].

Quaternary glaciation in the Romanian Carpathians has occurred in two distinct periods: Riss (cca. 300,000 to 130,000 years ago) – when valley glaciers have formed, and Würm cca. 115,000 to 10,000 years ago), when high altitude glaciers have formed [40, 37, 27, 24]. The general consensus of existing studies places the lower limit of perennial snow in the Carpathian range during Riss, at an elevation of 1550-1600 m.s.m.. The same studies consider the perennial

snow line during the Würm period at a higher altitude, of 1850-1900 m.s.m. We have digitized the glacial land forms found in the Romanian Carpathians, based on information found in the literature [38, 41, 37, 27, 32, 17, 39, 30], using satellite imagery and Romanian Topographic maps (1:25.000), in ArcGIS software [44]. This information was used to calculate average altitude of glacial landforms per massif, as well as the area occupied by each glacial landform (in hectares) (Tab. 1).

Table 1: Characteristics of the glacial landforms in the Romanian Carpathians

No.	Massif	Avg. Altitude m.s.m.	Total area ha	Avg. Area ha
1	Făgăraș	2101.92	10186.09	59.91
2	Godeanu	1947.85	2571.82	65.94
3	Parâng	2049.19	2386.62	56.82
4	Retezat	2059.62	3776.51	94.41
5	Rodna	1821.91	2703.42	87.2
6	Țarcu	1923.05	2579.50	71.65

To complete the regional specificity of the glaciation phenomenon, we also emphasize that the size of glacial cirques in the Romanian Carpathians varies between the Eastern rim – 0.85-4 km² in the Rodna Mts. [27] and the Southern rim, 3.5-40 km² in the Retezat Mts. [40].

Fig. 1: Glacial landforms in the Romanian Carpathians, by massif

Phytocoenosis investigation

The floristic and phytocoenotic database with plant communities typical to glacial and pre-glacial landforms from the 6 mountain massifs has been compiled from literature data published by several geo-botanical experts in the past few decades [6, 4, 42, 9, 1, 33].

Table 2: The floristic structure of cryophilic and cryo-hygrophilic plant communities – plant species constancy expressed as classes from 1 to 5 (Alliances: **SH – *Salicion herbaceae*, **CM** – *Cardamino-Montion*, **CF** – *Caricion fuscae*, **CB** – *Caricion bicolori-atrofuscae*)**

ALLIANCE	SH								CM					CF			CB
Association no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
No. of relevés	15	31	19	27	10	24	39	16	17	91	40	25	24	13	20	8	5

Char. ass.

<i>Polytrichum sexangulare</i>	5	1	1	1	3	1	1	2	.	.	.	.	.	.	.	.	.
<i>Salix herbacea</i>	2	5	.	1	1	1	1	.	.	.	.	.	.	.	.	.	.
<i>Arenaria biflora</i>	.	.	5	1	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Soldanella pusilla</i>	2	2	2	5	.	1	2	2	.	.	.	.	.	.	.	.	.
<i>Soldanella rugosa</i>	2	2	.	.	5	1	1	2	.	.	.	.	.	.	.	.	.
<i>Poa granitica ssp. disparilis</i>	1	.	.	.	3	.	1	.	.	.	.	.	.	.	.	.	.
<i>Poa supina</i>	.	1	.	.	.	4	.	1	.	.	.	.	.	.	.	.	.
<i>Luzula alpino-pilosa ssp. obscura</i>	3	2	3	2	5	1	5	3	1	1	1	.	.	.	.	.	.
<i>Nardus stricta</i>	.	.	2	3	1	2	.	5	.	.	.	.	.	3	2	.	.
<i>Polytrichum alpinum</i>	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.

Salicion* et *Salicetalia herbaceae

<i>Gnaphalium supinum</i>	2	2	5	4	5	4	1	5	.	.	.	.	.	.	.	.	.
<i>Ranunculus crenatus</i>	4	2	2	4	5	.	2	2	.	.	.	.	.	.	.	.	.
<i>Kiaeria starkei</i>	3	1	.	.	3	1	1	1	.	.	.	.	.	.	.	.	.
<i>Carex pyrenaica</i>	2	.	.	2	.	1	1	.	.	.	.	.	.	.	.	.	.
<i>Crysanthemum alpinum</i>	.	1	.	2	.	1	1	.	.	.	.	.	.	.	.	.	.
<i>Kiaeria falcata</i>	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.

Salicetea herbaceae

<i>Cerastium cerastioides</i>	4	1	.	2	.	5	2	1	1	1	1	.	.	.	.	.	.
<i>Sedum alpestre</i>	1	1	2	1	2	4	3	3	.	.	.	.	.	.	.	.	.
<i>Veronica alpina</i>	1	1	2	.	.	1	1	1	.	.	.	.	.	.	.	.	.
<i>Oligotrichum hercinicum</i>	2	.	.	.	2	1	.	.	.	.	.	.	.	.	.	.	.
<i>Anthelia juratzkana</i>	3	.	.	.	3	.	.	2	.	.	.	.	.	.	.	.	.
<i>Lychnis nivalis</i>	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.
<i>Epilobium anagallidifolium</i>	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.

Char. ass.

<i>Cardamine opizii</i>	.	.	.	.	.	.	.	.	5	1	1	.	.	.	.	.	.
<i>Chrysosplenium alpinum</i>	.	.	.	1	1	1	.	.	2	3	.	.	1	.	.	.	.
<i>Philonotis seriata</i>	.	.	.	.	.	.	.	.	3	4	4	3	.	.	2	.	.
<i>Caltha laeta</i>	.	.	.	.	.	.	.	.	3	2	5	1	3	1	2	4	5
<i>Cratoneuron commutatum</i>	.	.	.	.	.	.	.	.	1	.	.	.	3	1	1	1	.

ALLIANCE	SH								CM					CF			CB
Association no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
<i>Doronicum carpaticum</i>	.	.	.	.	.	1	.	.	1	.	.	.	3	.	.	.	.
<i>Saxifraga aizoides</i>	.	.	.	.	.	1	.	.	.	1	.	1	5	.	.	.	4
<i>Silene pusilla</i>	.	.	.	.	.	.	.	.	2	1	1	1	5	.	.	.	4
<i>Cratoneuron filicinum</i>	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	5
Cardamino-Montion et Montio-Cardaminetalia																	
<i>Saxifraga stellaris</i>	1	.	2	.	.	.	.	.	4	5	2	5	1	1	2	4	1
<i>Viola biflora</i>	.	1	.	.	.	1	1	.	1	1	1	1	4	.	.	.	2
<i>Epilobium nutans</i>	.	.	.	.	.	.	.	.	2	2	1	3	2	.	1	3	1
<i>Epilobium alsinifolium</i>	.	.	.	.	.	.	.	.	2	1	2	1	2	.	.	.	1
<i>Chrysosplenium alternifolium</i>	.	.	.	.	.	.	.	.	1	1	1	1	1	.	.	.	.
<i>Bryum pseudotriquetrum</i>	.	.	.	.	.	.	.	.	.	1	1	.	1	1	1	.	.
<i>Stellaria nemorum</i>	.	.	.	.	.	.	.	.	2	1	1	.	1	.	.	.	.
<i>Saxifraga heucherifolia</i>	.	.	.	.	.	.	.	.	1	1	.	1	1	.	.	.	.
<i>Cardamine amara</i>	.	.	.	.	.	.	.	.	.	2	2	3	2	.	.	.	.
<i>Philonotis fontana</i>	.	.	.	.	.	.	.	.	.	.	1	.	.	1	1	2	.
<i>Philonotis caespitosa</i>	.	.	.	.	.	.	.	.	.	.	.	.	1	1	1	2	.
<i>Veronica beccabunga</i>	.	.	.	.	.	.	.	.	1	.	1	1	.	.	.	.	.
<i>Brachytecium rivulare</i>	.	.	.	.	.	.	.	.	2	1	.	.	.	.	.	.	.
<i>Scapania undulata</i>	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.
<i>Stellaria uliginosa</i>	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
<i>Pinguicula vulgaris</i>	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
Char. ass.																	
<i>Carex n.* dacica</i>	.	.	.	.	.	.	.	.	.	1	2	1	.	5	5	2	2
<i>Plantago gentianoides</i>	.	.	.	.	.	.	.	.	.	1	1	1	.	4	2	.	.
<i>Drepanocladus fluitans</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.
<i>Drepanocladus exannulatus</i>	.	.	.	.	.	.	.	.	1	1	.	.	.	.	3	5	.
<i>Eriophorum scheuchzeri</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	5	.
<i>Carex lachenali</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
Caricion et Caricetalia fuscae																	
<i>Carex canescens</i>	.	.	.	.	.	.	.	.	.	.	.	1	.	1	3	5	4
<i>Juncus filiformis</i>	.	.	.	.	.	.	.	.	.	1	1	1	.	3	2	.	.
<i>Agrostis canina</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
<i>Carex echinata</i>	.	.	.	.	.	.	.	.	1	1	1	1	.	.	1	.	.
<i>Aulacomnium palustre</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
<i>Sphagnum subsecundum</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
<i>Carex rostrata</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Char. ass.																	
<i>Carex bicolor</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5
<i>Swertia perennis</i>	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	5

ALLIANCE	SH								CM					CF			CB
Association no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Caricion bicolori-atrofuscae et Tofieldietalia																	
<i>Juncus castaneus</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	4
<i>Juncus alpinus</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
<i>Trifolium badium</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
<i>Bartsia alpina</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
<i>Selaginella selaginoides</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
Scheuchzerio-Caricetea nigrae																	
<i>Cardamine p. * rivularis</i>	.	.	.	.	.	1	.	.	1	.	2	.	2	1	2	4	3
<i>Juncus triglumis</i>	.	.	.	.	.	.	.	.	.	1	.	.	1	1	1	1	5
<i>Parnassia palustris</i>	.	.	.	.	.	.	.	.	.	.	1	.	2	1	1	.	2
<i>Dactylorhiza cordigera</i>	.	.	.	.	.	.	.	.	.	.	.	1	.	2	1	.	2
<i>Luzula sudetica</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	2	1	.	1
<i>Sphagnum recurvum</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.
<i>Sphagnum teres</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.
<i>Comarum palustre</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
<i>Menyanthes trifoliata</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
<i>Calliargon stramineum</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
<i>Dactylorhiza maculata</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
<i>Carex dioica</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
<i>Campylium stellatum</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
Sphagnetalia																	
<i>Eriophorum vaginatum</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	3	2	.	4
<i>Polytrichum commune</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.
<i>Polytrichum strictum</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2	.	.
<i>Carex pauciflora</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Compagnes																	
<i>Deschampsia caespitosa</i>	2	.	.	1	2	1	1	3	1	2	3	2	3	2	2	5	4
<i>Ligusticum mutellina</i>	2	1	2	4	4	.	3	4	.	1	1	.	.	3	2	4	2
<i>Poa alpina</i>	1	.	3	3	.	.	2	3	1	.	1	1	2	.	.	.	.
<i>Taraxacum alpinum</i>	.	.	.	.	.	2	1	1	.	.	.	.	.	2	1	2	2
<i>Primula minima</i>	2	3	.	2	4	.	3	1	.	.	.	.	.	.	.	.	.
<i>Taraxacum nigricans</i>	1	1	.	1	.	.	1	1	.	.	.	.	2	.	.	.	.
<i>Geum montanum</i>	1	.	1	4	3	.	3	3	.	.	.	.	.	.	.	.	.
<i>Agrostis rupestris</i>	.	1	1	1	1	.	1	1	.	.	.	.	.	.	.	.	.
<i>Festuca airoides</i>	.	1	1	1	.	1	2	2	.	.	.	.	.	.	.	.	.
<i>Homogyne alpina</i>	.	1	.	1	.	.	2	1	.	.	.	.	.	2	1	.	.
<i>Veratrum album</i>	.	.	.	1	1	.	1	1	.	1	1	.	.	.	.	.	.
<i>Anthoxanthum alpinum</i>	.	.	.	1	.	1	1	1	.	.	.	.	.	1	1	.	.
<i>Carex curvula</i>	1	1	.	1	2	.	1	.	.	.	.	.	.	.	.	.	.

ALLIANCE	SH								CM					CF			CB
Association no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
<i>Potentilla a.*</i>																	
<i>chrysocraspeda</i>	.	1	1	2	.	.	1	5	.	.	.	.	.	.	.	.	.
<i>Chaerophyllum hirsutum</i>	.	.	.	.	.	.	.	.	2	1	1	1	2	.	.	.	.
<i>Myosotis laxa</i>	.	.	.	.	.	.	.	.	1	2	1	1	.	.	.	.	1
<i>Campanula alpina</i>	.	2	.	1	.	.	2	2	.	.	.	.	.	.	.	.	.
<i>Juncus trifidus</i>	.	1	.	1	.	.	1	1	.	.	.	.	.	.	.	.	.
<i>Polygonum viviparum</i>	.	2	.	.	.	1	.	.	.	.	.	.	2	.	.	.	1
<i>Achillea schuri</i>	.	.	1	.	.	.	1	.	.	1	.	.	2	.	.	.	.
<i>Lychnis flos-cuculi</i>	.	.	.	.	.	.	.	.	1	1	1	1	.	.	.	.	.
<i>Veronica baumgarteni</i>	.	1	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.
<i>Hieracium alpinum</i>	.	1	.	1	.	.	1	.	.	.	.	.	.	.	.	.	.
<i>Phyteuma confusum</i>	.	1	.	1	.	.	1	.	.	.	.	.	.	.	.	.	.
<i>Rhododendron myrtifolium</i>	.	.	.	.	2	.	1	2	.	.	.	.	.	.	.	.	.
<i>Arabis alpina</i>	.	.	.	.	.	1	.	1	.	.	.	.	2	.	.	.	.
<i>Soldanella major</i>	.	.	.	.	.	.	2	.	.	.	.	.	.	.	2	1	.
<i>Aconitum tauricum</i>	.	.	.	.	.	.	.	.	2	1	1	.	.	.	.	.	.
<i>Senecio subalpinus</i>	.	.	.	.	.	.	.	.	.	1	1	.	1	.	.	.	.
<i>Crepis paludosa</i>	.	.	.	.	.	.	.	.	.	.	1	.	1	.	1	.	.
<i>Bryum bimum</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	1	.
<i>Drepanocladus uncinatus</i>	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.
<i>Phleum alpinum</i>	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	.
<i>Pulsatilla alba</i>	.	.	.	1	.	.	1	.	.	.	.	.	.	.	.	.	.
<i>Poa media</i>	.	.	.	1	.	.	1	.	.	.	.	.	.	.	.	.	.
<i>Mnium punctatum</i>	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	.	.
<i>Galium uliginosum</i>	.	.	.	.	.	.	.	.	1	.	.	1	.	.	.	.	.
<i>Doronicum columnae</i>	.	.	.	.	.	.	.	.	1	.	.	.	1	.	.	.	.
<i>Alchemilla glabra</i>	.	.	.	.	.	.	.	.	1	.	.	.	2	.	.	.	.
<i>Myosotis scorpioides</i>	.	.	.	.	.	.	.	.	.	2	2	.	.	.	.	.	.
<i>Ranunculus repens</i>	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.
<i>Carex flava</i>	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1	.	.
<i>Eriophorum latifolium</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.
<i>Dicranella heteromalla</i>	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Diplophyllum taxifolium</i>	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Oreochloa disticha</i>	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
<i>Pleuroclada islandica</i>	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.
<i>Gentiana punctata</i>	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
<i>Saxifraga androsacea</i>	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
<i>Campanula polymorpha</i>	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
<i>Alchemilla fissa</i>	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
<i>Saxifraga hieracifolia</i>	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
<i>Ranunculus montanus</i>	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
<i>Doronicum stiriaceum</i>	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
<i>Valeriana simplicifolia</i>	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
<i>Juncus effusus</i>	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.

ALLIANCE	SH								CM					CF			CB
Association no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
<i>Equisetum palustre</i>	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
<i>Carex pallescens</i>	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
<i>Rumex alpinus</i>	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
<i>Poa trivialis</i>	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
<i>Cardamine mathiolii</i>	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
<i>Alchemilla vulgaris</i>	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
<i>Viola dacica</i>	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
<i>Polygonum bistorta</i>	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
<i>Geum rivale</i>	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
<i>Sphagnum girgensohnii</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.

1. *Polytrichetum sexangularis* Frey 1922: 10 rel. from Coldea 1990 (Rodna Mountains), 5 rel. from Puşcaru-Soroceanu 1981 (Făgăraş Mountains). 2. *Salicetum herbaceae* Rübel 1911: 5 rel. from Puşcaru et al. 1956 (Bucegi Mountains), 5 rel. from Boşcaiu 1971 (Țarcu-Godeanu Mountains), 12 rel. from Puşcaru-Soroceanu 1981 (Făgăraş Mountains), 9 rel. from Coldea (Rodna Mountains). 3. *Arenarietum biflorae* Voik 1976: 10 rel. from Voik 1976 (Făgăraş Mountains), 4 rel. from Drăgulescu 1995 (Sadu Valley). 4. *Soldanello pusillae-Ranunculetum crenati* (Borza 1931) Boşcaiu 1971: 14 rel. from Boşcaiu 1971 (Țarcu-Godeanu Mountains), 8 rel. from Resmeriță 1976 (Retezat Mountains), 5 rel. from Voik 1976 (Făgăraş Mountains). 5. *Soldanello rugosae-Ranunculetum crenati* Coldea (1985) 2017: 10 rel. from Coldea 1985 (Rodna Mountains). 6. *Poa supinae-Cerastietum cerastioidis* (Söyr. 1954) Oberd. 1957: 8 rel. from Resmeriță 1976 (Retezat Mountains), 11 rel. from Boşcaiu 1971 (Țarcu-Godeanu Mountains), 5 rel. from Coldea 1985 (Rodna Mountains), 10 rel. from Alexiu 1998 (Iezer-Păpuşa Mountains). 7. *Luzuletum obscurae* (Szafer et al. 1927) Dúbravcová 2000: 8 rel. from Coldea 1985 (Rodna Mountains), 7 rel. from Boşcaiu 1971 (Țarcu-Godeanu Mountains), 8 rel. from Resmeriță 1976 (Retezat Mountains), 14 rel. from Borza 1934 (Retezat Mountains), 2 rel. from Drăgulescu 1995 (Sadu Valley). 8. *Nardo-Gnaphalietum supini* Bartsch 1940: 8 rel. from Coldea 1985 (Rodna Mountains), 8 rel. from Resmeriță 1976 (Retezat Mountains). 9. *Cardaminetum opicii* Szafer et al. 1923: 10 rel. from Coldea 1990 (Rodna Mountains), 6 rel. from Boşcaiu 1971 (Țarcu-Godeanu Mountains), 1 rel. from Voik 1976 (Făgăraş Mountains). 10. *Chrysosplenio alpini-Saxifragetum stellaris* Pawl. et Wal. 1949: 8 rel. from Coldea 1990 (Rodna Mountains), 18 rel. from Voik 1976 (Făgăraş Mountains), 5 rel. from Puşcaru-Soroceanu et al. 1981 (Făgăraş Mountains), 25 rel. from Boşcaiu 1971 (Țarcu-Godeanu Mountains), 7 rel. from Boşcaiu et al. 1972 (Retezat Mountains), 13 rel. from Plămadă 1974 (Retezat Mountains), 10 rel. from Huml. et al. 1979 (Făgăraş Mountains). 11. *Philonotido-Calthetum lactae* (Krajina 1933) Coldea 1991: 7 rel. from Coldea 1990 (Rodna Mountains), 7 rel. from Sanda et al. 1997 (Piatra Craiului Mountains), 6 rel. from Puşcaru-Soroceanu et al. 1981 (Făgăraş Mountains), 10 rel. from Boşcaiu 1971 (Țarcu-Godeanu Mountains), 5 rel. from Boşcaiu et al. 1972 (Retezat Mountains), 5 rel. from Resmeriță 1970 (Vlădeasa Mountains), 5 rel. from Mihăilescu 2001 (Piatra Craiului Mountains). 12. *Philonotido-Saxifragetum stellaris* Horv. 1949: 25 rel. from Boşcaiu 1971 (Țarcu-Godeanu Mountains). 13. *Doronicum carpatice-Saxifragetum aizoidis* Coldea 1990: 11 rel. from Coldea 1990 (Rodna Mountains), 5 rel. from Olos 1982 (Piatra Rea), 5 rel. from Boşcaiu 1971 (Țarcu-Godeanu Mountains), 3 rel. from Coldea 1991 (Retezat Mountains), 5 rel. from Stancu 2005 (Făgăraş Mountains), 5 rel. from Neblea 2006 (Leaota Mountains). 14. *Carici dacicae-Plantaginetum gentianoides* Boşcaiu et al. 1972: 8 rel. from Boşcaiu et al. 1972 (Retezat Mountains), 1 rel. from Borza 1934 (Retezat Mountains), 4 rel. from Coldea et Plămadă 1980 (Făgăraş, Rodna Mountains). 15. *Carici dacicae-Drepanocladetum exannulati* Boşcaiu et al. 1972: 8 rel. from Boşcaiu et al. 1972 (Retezat Mountains), 6 rel. from Borza 1934 (Retezat Mountains), 10 rel. from Coldea 1990 (Rodna Mountains), 2 rel. from Resmeriță 1973 (Rodna Mountains), 5 rel. from Alexiu 1998 (Iezer-Păpuşa Mountains). 16. *Eriophoretum scheuchzeri* Rübel 1912: 8 rel. from Coldea 1990 (Rodna Mountains). 17. *Swertio perennis-Caricetum bicoloris* Coldea et al. 2008: 5 rel. from Coldea et al. 2008 (Rodna Mountains).

Cryophilic and hygro-cryophilic phytocoenosis were investigated using the method developed by Braun Blanquet (1964) [5]. The standard phytocoenotic relevée area in our study is 25 m². In the phytocoenotic synthetic table (Tab. 2), the species constancy of occurrence (sensu Cristea et al. 2004 [13]) is expressed in arabic numbers (1-5). The phytocoenosis have been

grouped into plant associations (communities) based on characteristic and dominant plant species, typical to the habitats under investigation. Aside from the characteristic species, several other plant taxa occurred more frequently in certain communities, allowing us to draw similarities between the different coenosis, and to group them into plant associations.

The floristic structure of the relevées was then used to group the associations into several syntaxonomic units. These units are distinct, and define the alpine and subalpine habitats which are the focus of this study, in a manner which is relevant to their structure and functioning [35]. For the accuracy of assigning the associations into alliances, we have used the Jaccard similarity index to observe the natural grouping of the communities (*vegan* package, R software) [31].

In order to assess the diversity of the communities, we have used the Shannon diversity index, for the constancy values of each plant association (using the *renyi* function, sensu Jost 2006 [22]).

The scientific name of all cormophyte taxa was considered after Ciocârlan 2009 [7].

Climate data

We have extracted temperature and precipitation data from yearly meteorological reports for the last 50 years at 2 weather stations, one in the eastern rim (Iezeru Pietrosului, 1785 m.s.m.), and one in the southern rim (Omului peak, 2500 m.s.m.). Snow cover trend for the two weather stations extracted from Carpatclim [36] were analyzed for trend (linear models) in R software, and used to predict the first years when snow cover will be possibly missing.

Using monthly climate data, we have calculated a yearly average for temperature and precipitation. Decadal means were also calculated, for each 10 years starting with the year 1961, until 2010. The results of these calculations are presented in two separate graphs. Data concerning snow depth and snow cover duration, referred to further in the material, are taken from the work of Micu D. M. et al. 2015 [26], and from existing databases (Carpatclim) [36].

Finally, future climate projections from 10 Global Circulation Models (GCMs) were taken into consideration (Tab. 3), in order to determine the most likely future scenario for the glacial landforms found in the Romanian Carpathians. Namely, we have used the *bioclim 1* (Annual Mean Temperature), *bioclim 11* (Mean Temperature of Coldest Quarter), *bioclim 12* (Annual Precipitation) and *bioclim 19* (Precipitation of Coldest Quarter) variables from the Worldclim dataset [20] produced by the GCMs, downscaled at 30 seconds (aprox. 1km), for all available scenarios (Representative Concentration Pathways [45], or RCPs – 2.6, 4.5, 6.0, 8.5). Climate information for the glacial landforms from the Romanian Carpathians was extracted in R software [46], using the *raster* package [19]. The *dplyr* package [43] was also used in handling the output data.

Results

Glacial landforms have developed in the Romanian Carpathians during the previous tens of thousands of years. They are more or less typical as a function of the altitude of each massif and of the altitudinal variability of these massifs (Tab. 1).

The 424 phytocoenotic relevées, published from glacial and periglacial landforms from the 6 massifs of the Romanian Carpathians, have been classified as belonging to 17 plant communities (associations) – using dominant and characteristic species. Further on, using species with similar ecological requirements, these 17 communities have been classified in 4

alliances (Tab. 2, Tab. 4): *Salicion herbaceae*, *Cardamino-Montion*, *Caricion fuscae*, *Caricion bicolori-atrofuscae* [35, 10, 23].

Table 3: Global Circulation Models (GCMs) used from the Worldclim database [20]

No.	Name	Country	Code
1	Beijing Climate Center Climate System Model	China	BCC-CSM1-1
2	Community Earth System Model	USA	CCSM4
3	Goddard Institute for Space Studies	USA	GISS-E2-R
4	Met Office Hadley Center Atmosphere Model	UK	HadGEM2-AO
5	Met Office Hadley Center Earth System Model	UK	HadGEM2-ES
6	Japan Agency for Marine-Earth Science and Technology – Model for Interdisciplinary Research on Climate - Earth System Model – Atmospheric Chemistry	Japan	MIROC-ESM-CHEM
7	Japan Agency for Marine-Earth Science and Technology - Model for Interdisciplinary Research on Climate	Japan	MIROC-ESM
8	Japan Agency for Marine-Earth Science and Technology - Model for Interdisciplinary Research on Climate	Japan	MIROC5
9	Japan Meteorological Research Institute	Japan	MRI-CGCM3
10	Norwegian Earth System Model	Norway	NorESM1-M

Fig. 2: Jaccard similarity of high altitude wetlands and snowbed plant communities in the Romanian Carpathians (number of association identical to Tab.4)

Table 4: Plant communities with cryophilic vegetation, typically found in the glacial and peri-glacial landforms of the Romanian Carpathians.

No.	Plant communities (associations)	Altitude (min-max)	Species number (Endemic)	Shannon diversity (Jost 2006)
1. <i>Salicion herbaceae</i> (Hab. 6150)				
1	<i>Polytrichetum sexangularis</i>	1800-2340	23 (3)	3.01
2	<i>Salicetum herbaceae</i>	2000-2450	27 (2)	3.20
3	<i>Arenarietum biflorae</i>	1700-2500	18 (2)	2.74
4	<i>Soldanello pusillae-Ranunculetum crenati</i>	1850-2250	36 (2)	3.41
5	<i>Soldanello rugosae-Ranunculetum crenati</i>	1800-2150	26 (5)	3.11
6	<i>Poo supinae-Cerastietum cerastioides</i>	1830-2050	33 (6)	3.27
7	<i>Luzuletum obscurae</i>	1900-2270	45 (4)	3.63
8	<i>Nardo-Gnaphalietum supinae</i>	1700-2100	31 (3)	3.27
2. <i>Cardamino-Montion</i> (Hab. 3220)				
9	<i>Cardaminetum opicii</i>	1500-1900	31 (4)	3.29
10	<i>Chrysosplenio alpine-Saxifragetum stellaris</i>	1500-2200	36 (5)	3.44
11	<i>Philonotido-Calthetum laetae</i>	1550-1900	41 (3)	3.52
12	<i>Philonotido-Saxifragetum stellaris</i>	1550-1900	35 (1)	3.38
13	<i>Doronico carpatici-Saxifragetum aizoidis</i>	1500-1900	33 (3)	3.36
3. <i>Caricion fuscae</i> (Hab. 3220)				
14	<i>Carici dacicae - Plantaginetum gentianoidis</i>	1800-2200	33 (1)	3.33
15	<i>Carici dacicae-Drepanocladetum exannulati</i>	1850-2150	44 (1)	3.67
16	<i>Eriophoretum scheuchzeri</i>	1900-2100	19 (1)	2.79
4. <i>Caricion bicolori-atrofuscae</i> (Hab. 7240*)				
17	<i>Swertio perennis-Caricetum bicoloris</i>	1665-1685	28(1)	3.20

In the floristic structure of these plant associations, we could find a total of 150 plant species, most of which are characterized by a preference for subalpine-alpine habitats [12]. The dominant phyto-geographical elements in the structure of these communities are arctic-circumpolar species and alpine-central-european species, followed by eurasiatic species, Carpathian species and dacic-balkan species.

The Jaccard similarity reveals 2 large clusters (Fig. 2), one corresponding to the alliance *Salicion herbaceae*, and the other to the remaining 3 alliances, of which *Cardamino-Montion* and *Caricion fuscae* form two different sub-clusters. The alliance *Caricion bicolori-atrofuscae* is

included in the *Caricion fuscae* cluster, based on the higher proportion of shared species.

Fig. 3: Observed average decade temperature and precipitation trends in the past 50 years at 2 high mountain weather stations

Fig. 4: Observed yearly snow depth trend in the past 50 years from the locations of the 2 weather stations (Carpacim data).

While associations from the alliance *Cardamino-Montion* have the highest average number of species (on average 35.2 species), the highest species richness of individual associations is found in the alliances *Salicion herbaceae* (*Luzuletum obscurae* – 45 species) and *Caricion fuscae* (*Carici dacicae-Drepanocladetum exannulati* – 44 species) (Tab. 4). Shannon diversity varies between 2.74 (*Arenarietum biflorae*) and 3.67 (*Carici dacicae-Drepanocladetum exannulati*), and is in general correlated with species richness values.

Climate warming trends are registered for the entire Carpathian chain, with values ranging from +1 to +6.2°C in the years 2050 and 2070. Precipitation may also increase overall and in the coldest quarter for the years 2050 and 2070, but there is higher variability observed for this type of data, as there are also models which predict a decrease (Fig. 5).

Snow depth is decreasing at both investigated stations, with an estimated 0.08 cm/year at Iezeru, and 0.054 cm/year at Omul (Fig. 4).

Discussions

The alliance *Salicion herbaceae* Br.-Bl. et Jenny 1926, is typical for glacial cirques (landforms with a pronounced concave aspect), where snow lasts until the end of spring (April).

We have delimited 8 plant associations in this alliance (Tab. 4). In the structure of these

Fig. 5: Predicted climate change in the glacial cirques of the Romanian Carpathians

communities 69 plant species have been registered, of which 60 cormophytes, most of them characteristic for subalpine-alpine environments, and an additional 9 cryophyte alpine bryophyte species. Of the 60 cormophytes, 9 species are endemic to the Carpathian range, of which 5 are endemic in the Romanian Carpathians (*Lychnis nivalis*, *Soldanella rugosa*, *Achillea schurii*, *Poa granitica* subsp. *disparilis* and *Chrysosplenium alpinum*). These species are strongly endangered by the warming climate, as their typical habitat (Natura 2000 Habitat 6150) is expected to reduce its cover in the Romanian Carpathians during the coming decades. Of the 8 plant associations specific for this habitat, the association *Luzuletum obscurae* (Szafer et al. 1927) Dúbravcová 2000 is the richest in species, with a high Shannon diversity index (3.63). It is also the most wide spread association of those analyzed within the alpine region of the Romanian Carpathians. The other 7 associations, although frequent in the alpine belt, occupy small areas, rarely over 30-40 m² [10].

In the alliances *Cardamino-Montion* Br.-Bl. 1926 and *Caricion fuscae* W. Koch 1926 em. Klika 1934, we have grouped hygro-cryophilic plant communities typical to high altitude springs and subalpine moors (*Quelle more*). 8 plant associations have been included here, similar from a floristic point of view. There are 102 plant species present in their structure, of which 20 are bryophytes and 82 cormophytes. Plant communities in these 2 alliances are grouped together in Natura 2000 habitat 3220 [16]. Of the 82 cormophyte species, only 5 are considered to be endemic for the Romanian Carpathians [21]. Given that the plant communities grouped in these 8 associations live in the subalpine zone, in areas with no shrub cover, exposed to the solar insolation, both during summer and winter, it is expected that a warming climate may produce radical changes in the structure of this habitat. In the past 3 decades, several springs and subalpine bogs in the Rodna and Retezat National Park have been found completely dry during the summer season [10]. This is the main reason for which these communities continuously lose species, and in the near future they may even disappear from several mountain massifs.

The alliance *Caricion bicolori-atrofuscae* is in the same situation. *Carex bicolor* communities are found only in the Rodna Mountains, and the warming climate is expected to have drastic effects on these phytocoenosis.

The structural degradation of these wet-cryophilic communities is also caused by sheep grazing in the subalpine-alpine belts. In the summer period, subalpine springs and rivulets are frequently visited by sheep. The animals compact the soil with their hoofs and destroy many rare plant species found near these springs and high altitude bogs, such as: *Juncus castaneus*, *Juncus triglumis*, *Carex dioica*, *Carex lachenali*, *Carex nigra* ssp. *dacica*, *Pinguicula vulgaris*, *Carex pauciflora* [9].

The “in situ” persistence of these cryophyte and hygro-cryophyte plant communities depends on the values of the most important ecological factors which generate them, namely temperature and precipitation [28]. The analysis of historically observed climate trends for the past 50 years from the 2 high-altitude weather stations (Iezeru (1785 m.s.m.) and Omul (2500 m.s.m.)) revealed a clear climate warming process for both locations (Fig. 3). An analysis with data from all Romanian weather stations for the time period 1961-2010 [26] observed a warming trend of 0.5°C per decade in the last two decades. The same study made a projection for temperature change in the year 2050, estimating an increase in temperatures of 2.5-3°C. Our analysis of 10 Global Circulation Models for the glacial landforms of the Carpathians predicts also an average increase of 2.5°C for the year 2050, and 3°C for the year 2070 (Fig. 5).

While the trend is clear for temperature, there is more of a debate regarding precipitations. First of all, precipitations generally have a varied spatial pattern compared to temperature. In Romania, there are several factors influencing the precipitation pattern [26]. The most important precipitation gradient is from the North West towards South East. Oceanic airflows travel from the North Atlantic towards Europe, and are characterized by high moisture. The western slopes of all the mountain ranges in the Romanian Carpathians (and the northern slope of the Southern Romanian Carpathians) usually receive more precipitation compared to the eastern / southern slopes. It is also worth noting that this airflow causes persistent cloud cover particularly in high-elevation areas during warm periods, as well as foehn effects on leeward slopes. A second important influence is from the South and South-West (from the Mediterranean Sea), with currents which brings warmer weather and high atmospheric instability. This influence is most evident on the southern slopes of the southern rim of the Carpathians. The third important influence is from north-eastern continental airflows, which are usually cold and dry, and affect the eastern slopes of the eastern rim of the Carpathians, being responsible for prolonged dry spells and for colder winters.

Analyzing the observed weather station record (Fig. 3), we can notice long precipitation cycles, spreading over decades. The Iezer station data shows a cyclic pattern, with precipitation currently returning to the higher values of the 1960s and 1970s. These values are representative for the mountains of northern Romania, where precipitation levels are usually higher, under the influence of the aforementioned oceanic airflow travel (North West to South East airflows). The Omul weather station is located in the eastern part of the southern rim of the Romanian Carpathians, at the “end” of the North West to South East rainfall gradient. This weather station registered also a cyclic precipitation behavior, but with an overall downward trend, as current day precipitations did not come back to the previous levels of the 1960s and 1970s. An overall downward trend in precipitation has been observed also by other climatic analysis of Romanian climate [28, 25].

In future projections for the year 2050 in the Romanian Carpathians [26], precipitations were considered as varying around $\pm 10\%$ of current values. This is consistent with the output of our analysis, as the 10 Global Circulation Models show a limited increase in precipitation for the glacial regions of the Romanian Carpathians, but some results indicate a decrease. Most of these models suggest a slightly more humid future in the coldest quarter of the year (relevant for snow cover). The average increase of precipitations predicted in the coldest quarter for all GCMs and all RCPs is marginal (about 10 mm in 2050, and 15 mm in 2070). As the climate is warming, more and more of the forecasted increased precipitation may fall as rain, impacting existing snow.

There is also proof of lower incidence of snow cover which affects to a large extent mountain areas located below 1600-1700 m.s.m. [25]. In the eastern and southern rim of the Romanian Carpathians, above 1700 m.s.m., the maximum snow depth (39-71 cm) occurs currently in March while snow cover duration in the subalpine and alpine belts has been reduced to 4-4 ½ months [26]. Starting with April, snow melts completely, and in June it can be found only on very small areas on the northern, shaded slopes. Our analysis (linear models) on the snow depth from the past 50 years at the 2 weather stations (Fig. 4) also indicated that it is possible to have years with no snow on the mountain tops by the end of the century (year 2100).

There is also an expectation of an increase in frequency of severe climatic events, such as

droughts, which impact high altitude flora [26].

Conclusions

For most of the 17 plant communities which occur currently in glacial landforms across the Romanian Carpathians, even the most optimistic changes of climate conditions which have been forecasted are expected to be associated with changes in the floristic structure. While today these communities are characterized by a mixture of arctic alpine species and endemics for the Carpathian range, the warming climate is expected to bring increased competition from other plant species, which are more adjusted to the expected warmer temperatures. We consider that only in the most optimistic scenario (26 RCP, Representative Concentration Pathway), changes in these communities may be limited. This is the optimistic scenario for gas emissions, in which CO₂ emissions would reach a maximum of 421 ppm in the period 2010-2020, and would decline after this decade [2, 45]. In all other scenarios, important changes are inevitable, as cryophilic and hygro-cryophilic plant species are usually narrowly specialized for cooler climate conditions, with snow persistence, and are poorly adapted for competing against other species.

The list of plant species threatened by these new conditions includes endemic species, such as *Soldanella rugosa*, *Lychnis nivalis*, *Aconitum tauricum*, *Poa granitica* ssp. *disparilis*, *Chrysosplenium alpinum*, *Carex lachenali*, *Carex nigra* ssp. *dacica*, and can be extended to cryophilic alpine taxa such as: *Soldanella pusilla*, *Carex pyrenaica*, *Saxifraga hieraciifolia*, *Plantago gentianoides*, *Juncus castaneus*, *Juncus triglumis* and *Carex bicolor*.

Additional threats for these species are an expected increase in the fragmentation of the habitats where they occur, and the existing pressure of grazing with sheep at high altitudes. Most of these glacial landforms are included in existing National Parks and Natura 2000 sites, but there has been no effort so far to monitor the presence of any of the species mentioned. In order to protect the habitats from grazing and excessive fragmentation, additional measures need to be taken into consideration, such as forbidding grazing inside the north facing glacial landforms. Moreover, in the two National Parks (Rodna and Retezat), the glacial landforms should be included in IUCN 1a category (Strict Nature Reserve). In the remaining four massifs (Parâng, Făgăraș, Țarcu, Godeanu), these landforms should be included in Botanical Reservations (IUCN category 3). The protection of the shrub belt should also be taken into consideration, at least in some areas, given its importance in retaining water in the subalpine belt and creating the proper habitat for many of the species requiring a humid cold environment.

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MODIFICĂRI ANTICIPATE ÎN STRUCTURA FLORISTICĂ A COMUNITĂȚILOR VEGETALE HIGRO-MICROTERME ȘI DE ZĂCĂTORI DE ZĂPADĂ DIN CARPAȚII ROMÂNIEI, CAUZATE DE SCHIMBĂRILE CLIMATICE ȘI DE IMPACTUL ANTROPIC

(Rezumat)

Doar 6 masive din Carpații României au forme glaciare (văi și circuri) pe suprafețe suficient de extinse pentru a adăposti vegetație crioofilă tipică pentru zăcători de zăpadă și zone umede de altitudine. Analiza noastră a cuprins 424 de relevée cu astfel de vegetație publicate în literatura din România din ultimul secol (pentru aceste masive). Acest tip de vegetație crioofilă a fost grupată în 17 asociații, 4 alianțe și 3 habitate Natura 2000. Un număr total de 150 de specii de plante alpine și subalpine (dintre care 11 endemice) au fost înregistrate în aceste comunități (27% din totalul celor 550 de taxoni de altitudine găsiți în întregul lanț Carpatic din România). Scenariile viitoare pentru formele geografice glaciare din Carpați sugerează o creștere a temperaturii de circa 2.5°C în 2050 și 3°C în 2070. Speciile de plante adaptate la climatul rece și umed (*Soldanella rugosa*, *Soldanella pusilla*, *Lychnis nivalis*, *Carex lachenalis*, *Chrysosplenium alpinum*, *Carex nigra* subsp. *dacica*, *Carex pyrenaica*, *Carex bicolor*, *Juncus castaneus*, *Juncus triglumis*, *Plantago gentianoides*) sunt cele mai expuse la amenințarea unui climat în încălzire, dispariția habitatelor lor fiind echivalentul dispariției lor complete din Carpați. Pe lângă flora endemică, și alte specii criofile alpine sunt de asemenea amenințate. Habitatele Natura 2000 tipice acestor forme de teren (6150, 7240*, 3220) sunt monitorizate în cele 6 masive, dar nu există măsuri administrative de monitorizare a prezenței speciilor de plante criofile, precum nu există nici planuri de a proteja strict formele geografice glaciare (categorie I IUCN), măsuri necesare mai ales ca urmare a impactului antropic din ce în ce mai pronunțat la altitudini ridicate.

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