

## The bryoflora of the Zacharovana Dolyna Reserve (the Ukrainian Carpathians): species diversity and taxonomic structure

Rostyslav Sadygov & Lyubov Felbaba-Klushyna

Department of Botany, Uzhhorod National University, 32 Voloshyn Str., Uzhhorod 88000, Ukraine;  
[rostyslav.izhyk@gmail.com](mailto:rostyslav.izhyk@gmail.com)

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**Abstract:** Zacharovana Dolyna is a Ukrainian national geological reserve that was established in 1978. In 2009, it formed the basis for establishing the National Nature Park Zacharovany Krai, and now it is the most interesting part of the park regarding its environmental diversity. Investigations of the biodiversity of this park remain at the initial stage, and data on bryophytes are not available so far. We identified 114 bryophyte species, including 45 species that were proven new to the Volcanic Carpathians. We performed a taxonomic analysis of the bryoflora and clarified that Mniaceae (10 species), Polytrichaceae (8 species), and Brachytheciaceae (8 species) were the species richest families; the last one mentioned belongs to the three species richest families of the Ukrainian Carpathians. Most species of the families Mniaceae, Polytrichaceae and Brachytheciaceae prefer overmoistened ecotopes prevailing in the studied area, including wet rocks and stones along streams. A special feature of the Reserve is that a significant percentage of the species were found on stony substrates. The bryophyte flora documented here also includes the species of conservation concern. *Pseudohygrohypnum fertile* is considered vulnerable, endangered, or rare in many European countries, while *Dicranum viride* is the Bern Convention species. *Neckera pennata* is especially rare for Zakarpattia and is a vulnerable species listed in the Ukrainian Red List of Bryophytes. We registered a high species diversity of bryophytes in a relatively small area of the Zacharovana Dolyna Reserve due to the high diversity of potential bryophyte substrates and microhabitats.

**Keywords:** Volcanic Carpathians, National Nature Park Zacharovany Krai, mosses, liverworts, substrates, *Pseudohygrohypnum fertile*, *Dicranum viride*, *Neckera pennata*.

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## Introduction

The Zacharovany Krai National Nature Park is located in the Volcanic Carpathians in the western part of Ukraine (Zakarpattia, Fig. 1). The Volcanic Carpathians stretch from the northwest to the southeast about 100 km from Slovakia through the Transcarpathian region of Ukraine and ends in Romania. The ridge is a barrier separating the Transcarpathian lowland from the high flysch mountains in the north. The altitudes of 700 - 800 m above sea level prevail within the Transcarpathian region (Herenchuk 1981). This mountain massif consists of volcanic rocks - andesites, andesite-basalts, basalts, and their tuffs. The ridge climate is influenced by a mild Mediterranean and humid Atlantic climate. The sum of positive temperatures reaches 1800-2200°C. Annual precipitation in the territory of the Volcanic Carpathians ranges from 800 to 1200 mm (Tsis 1966; Andrianov 1968; Herenchuk 1981).

The main protected objects are old forests dominated by *Quercus petraea* L. and beech (*Fagus sylvatica* L.) forests. The first nature sanctuary established in this area long before the national park was founded was the Zacharovana Dolyna National Geological Reserve. The area of the Reserve reaches 150 hectares, and altitudes range from 400 to 800 m a.s.l. It was established to protect the old forests and the peculiar stone formations derived from secondary quartzites that had taken fancy shapes we can find in the forests, meadows, caves, and rocks. Within its boundaries, one may come across forest, shrub, rock, meadow phytocoenoses, and swampy banks of brooks. Therefore, we expected that a substantial part of the species diversity of the National Nature Park's bryoflora may be present in the study area. Owing to the influence of the warm climate that penetrates the Volcanic Range through the Great Hungarian Plain, many warm-loving plants grow here. These plants have migrated from the Balkan Peninsula and the Mediterranean, and they continue to play an important role in the modern dynamics of the florogenesis of Zakarpattia. This mountain range is characterised by various stony forms that are the habitat for numerous lithophilic bryophyte species. At the same time, the bryoflora of the Volcanic Ridge is poorly documented.

### History of bryological research in the Ukrainian Carpathians

It was in the late 19<sup>th</sup> century that the bryophytes of the Ukrainian Carpathians began to be studied. The earliest records belong to the Polish researchers who studied the bryophytes of Galicia (the territory of modern Ternopil, Lviv, and Ivano-Frankivsk oblasts of Ukraine) (Lobazewski 1847; Lilienfeldówna 1911; Wisniewski 1923; Reiment-Grochowska 1958). The works of the first half and middle of the last century were devoted to the inventory of certain parts of the Carpathians. Thus, by the end of the 60s there was published information on the bryophytes of the Chornohora Massif (Wilczek 1931), the Borzhava Massif (Maloch 1932), the valley of the Vyzhenka River in the Chyvchyn-Hryniav Mountains (Stefureac 1936), the Pokuttia-Bukovyna Mountains (Szafran 1936, 1964), the Svydovets Massif

(Slobodyan 1950). Šmarda (1936, 1948) and Boros (1941, 1944) made the first attempts to generalize information about the bryoflora of Zakarpattia. Ulychna (1956) published a list of leafy mosses of Chernivtsi oblast, for the first time, touched upon the issue of the history of the distribution of bryophytes in the Chornohora Ridge (Ulychna 1966), and published a list of bryophytes of the Chyvchyn Mountains (Ulychna & Partyka 1970).

The most comprehensive generalized information of that period on the bryoflora of Zakarpattia belongs to Boros & Vajda (1969). Their research covered the regions of the Eastern Beskids, the Gorgany, the Maramures Alps, the Chornohora, and some swamps, including the Bahno Swamp on the Volcanic Ridge. In total, they found 536 species of bryophytes in the Ukrainian Carpathians.

In the second half of the 20<sup>th</sup> century and the early 21<sup>st</sup> century, the main national floristic summaries were published (Lazarenko 1955; Zerov 1964; Zerov & Partyka 1975; Bachurina & Melnychuk 1987, 1988, 1989, 2003). Zerov & Partyka (1975) provided information on the distribution of bryophyte species in specific floristic areas, gave a brief description of the ecological conditions of growth, and also carried out a geographical analysis of the bryoflora and characterized the main stages of its development in the Ukrainian Carpathians. They listed 653 bryophyte species for the Ukrainian Carpathians; among them, only 135 were referred to the Volcanic Carpathians. The geography of collecting mosses on the Volcanic Ridge was very narrow, and the majority of the listed species are indicated for three locations:

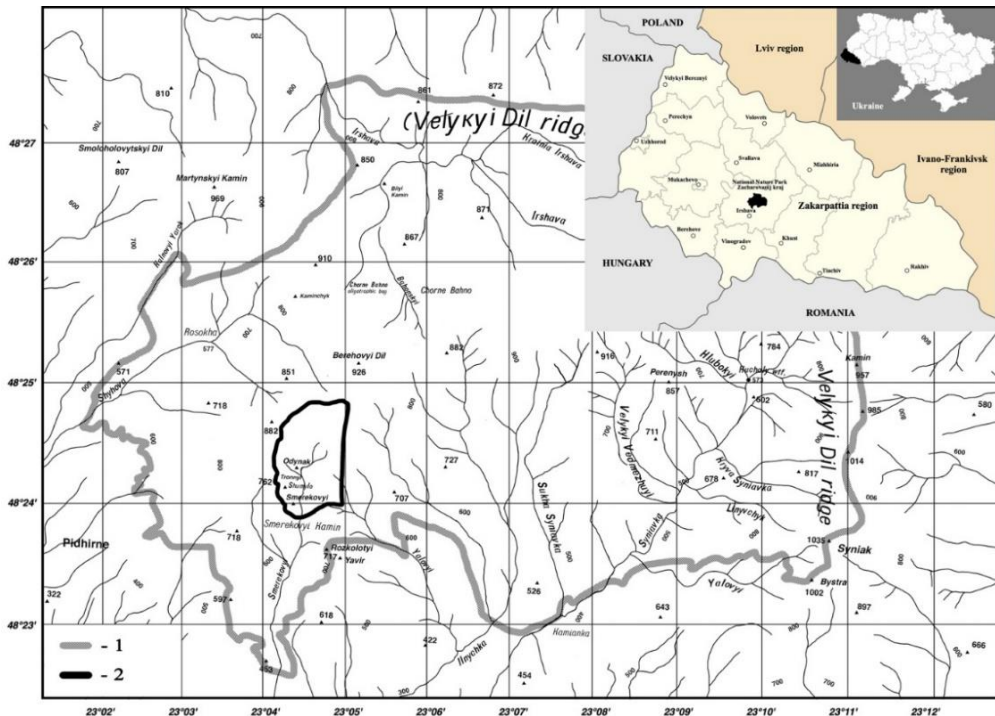


Fig. 1 Map of Zacharovskyi Krai National Nature Park (1) and Zacharovana Dolyna Reserve (2) and its position in the western Ukraine.

Chorna hora (Black Mount) in the vicinity of Vynohradiv town, the vicinity of Nevyske village of Uzhhorod district and the vicinity of Mukachevo town.

Since the 90s of the 20<sup>th</sup> century, the period of compiling bryophyte checklists has begun. Thus, in 1993, *The Consolidated List of Anthocerotopsida and Liverworts of Ukraine* (Vania & Virchenko 1993), *The Consolidated List of Mosses of Ukraine* (Danylkyiv et al. 1995), as well as three *Lists* of individual groups of bryophytes of Ukraine (Virchenko 2000a, b, 2001). Each of these works contains information about the location of bryophytes within the Ukrainian Carpathians and the Volcanic Carpathians, including.

Lobachevska (2003) generalized the bryological information concerning the Ukrainian Carpathians at that time, analyzed the modern flora composition, and carried out its taxonomic analysis, which differed significantly from the accepted classification of Zerov & Partyka (1975). Therefore, her list included 653 bryophyte species (Anthocerotopsida – 2; Hepaticopsida – 163; Bryopsida – 605), while the list of Zerov & Partyka (1975) included 653 species (Anthocerotopsida – 2; Hepaticopsida – 163; Bryopsida – 488). Lobachevska (2003) also conducted a geographical, chorological, and ecological analysis of the bryoflora, presented her view on the main stages of its formation in the studied territory, and provided the information on rare species of the Carpathians.

Inventory work was also carried out in separate protected areas of the Ukrainian Carpathians. Currently, there is information on the bryological diversity of the Carpathian Biosphere Reserve (over 440 species; Danylkyiv et al. 1997), the Gorgany Nature Reserve (231 species; Nyporko 2005), such National Nature Parks as Hutsulshchyna (235 species; Virchenko & Nyporko 2011), Synevyr (208 species; Solomakha et al. 2016) and Uzhan (179 species; Coppins et al. 1998; Danylkyiv 1998). Some new publications are devoted to the inventory of bryophytes of the highlands of the Ukrainian Carpathians or new findings (Mamchur et al. 2018a, b; Felbaba-Klushyna 2010).

A new stage of summarisation of the bryophytes of Ukraine at the national level was initiated by Boiko (2008, 2014). In the latest summary for Ukraine, Boiko (2014) listed 849 species of bryophytes, of which 752 species were recorded in the Ukrainian Carpathians; species records are identified by administrative regions or names of mountain massifs without specifying their affiliation to floristic regions.

It should be admitted that the inventory of biodiversity of objects belonging to a lower-ranking nature reserve fund (sanctuaries, protected tracts, natural monuments, etc.) is scarcely conducted. Our survey represents the first bryological study in the Zacharovany Krai National Nature Park.

## **Material and Methods**

The survey was conducted from 2018 to 2022 at the Zacharovany Krai National Nature Park, located within the Zacharovana Dolyna reserve. The material was collected during several expeditions, and 371 samples were collected in total.

The determination of bryophyte species was carried out by the authors in the Bryology Laboratories of the Kholodny Institute of Botany (Kyiv), the Institute of Ecology of the Carpathians (Lviv), and the Department of Botany, Uzhhorod National University. The methods of light microscopy, using microscopes MBS-9, MBS-10 and Olympus BX-53, and several identification keys (Zerov 1964; Lazarenko 1955; Bachurina & Melnychuk 1987, 1988, 1989, 2003; Ignatov & Ignatova 2003, 2004; Smith 2004) were used. The scientific names of bryophyte species and their taxonomic status are presented according to Hodgetts et al. (2020).

The ecological requirements of determined species and their distribution data for Ukraine are provided based on published sources (Virchenko 2000a, b, 2001; Virchenko & Nyporko 2022, Boiko 2014; Dierßen 2001; Bachurina & Melnichuk 1987, 1988, 1989, 2003; Zerov 1964; Zerov & Partyka 1975) and supplemented by our observations.

## Results

We have recorded 114 species of bryophytes in total. There were determined 17 species of liverworts belonging to 14 families, and 97 mosses species referred to 33 families (Tab. 1). Following the results of our study, 45 species were identified for the first time in the Volcanic Carpathians.

## Discussion

High species richness demonstrate families Mniaceae (10 species) Brachytheciaceae (8 species) and Polytrichaceae (8 species), which in the Ukrainian Carpathians also have 18 to 35 species (Zerov & Partyka 1975). The presence of a large number of forest streams and swampy banks creates favorable conditions for the occurrence of hygrophytes that belong to these families. The richest orders are Hypnales (17 families, 35 genera and 38 species) and Dicranales (6 families, 12 genera and 20 species). We recorded an exceptionally high number of bryophyte species on stony substrates. Some species were found exclusively on stones and rocks (*Chiloscyphus polyanthos*, *Fissidens bryoides* and *F. dubius*).



Fig. 2 Localities with *Pseudohygrohypnum fertile* and *Neckera pennata* (left) and *Pellia epiphylla* (right) on the rock near stream (photographed by R. Sadygov 2020).

**Tab. 1 Species list, substrates differentiation of the Zacharovana dolyna Reserve and bryophytes, new species to Volcanic Carpathians.** Abbreviations: br – bark of trees and shrubs; dw – dead wood and stumps; sl – soil; rck – rocks, st – stones; VC - new species for the Volcanic Carpathians (✓).

№	NAMES OF TAXA	Substrates					VC
		br	dw	sl	Stone substrates		
					rck	st	
<b>MARCHANTIOPHYTA</b>							
<b>JUNGERMANNIOPSIDA - JUNGERMANNIALES</b>							
<b>Anastrophyllaceae</b> L. Söderstr., De Roo & Hedde.							
1	<i>Barbilophozia barbata</i> (Schmidel ex Schreb.) Loeske				x		
<b>Calypogeiaceae</b> Arnell							
2	<i>Calypogeia azurea</i> Stotler & Crotz			x	x	✓	
<b>Lepidoziaceae</b> Limpr.							
3	<i>Bazzania trilobata</i> (L.) Gray		x	x	x	✓	
<b>Lophocoleaceae</b> Vanden Berghen							
4	<i>Chiloscyphus polyanthos</i> (L.) Corda					x	
5	<i>Lophocolea bidentata</i> (L.) Dumort.			x	x		
6	<i>Lophocolea heterophylla</i> (Schrad.) Dumort.	x	x	x	x	✓	
<b>Plagiochilaceae</b> Müll. Frib.							
7	<i>Plagiochila porelloides</i> (Torr. ex Nees) Lindenb.	x	x	x		x	
<b>PORELLALES</b>							
<b>Frullaniaceae</b> Lorch							
8	<i>Frullania dilatata</i> (L.) Dumort.	x	x		x	✓	
<b>Lejeuneaceae</b> Cavers							
9	<i>Lejeunea cavifolia</i> (Ehrh.) Lindb.	x	x	x	x	✓	
<b>Porellaceae</b> Cavers							
10	<i>Porella platyphylla</i> (L.) Pfeiff.	x			x	✓	
<b>Radulaceae</b> Müll. Frib.							
11	<i>Radula complanata</i> (L.) Dumort.	x			x	✓	
<b>PTILIDIALES</b>							
<b>Ptilidiaceae</b> H. Klinggr.							
12	<i>Ptilidium pulcherrimum</i> (Weber) Vain.		x		x		
<b>METZGERIALES</b>							
<b>Metzgeriaceae</b> H. Klinggr.							
13	<i>Metzgeria furcata</i> (L.) Dumort.	x		x	x	✓	
<b>PELLIALES</b>							
<b>Pelliaceae</b> H. Klinggr.							
14	<i>Apopellia endiviifolia</i> (Dicks.) Nebel & D. Quandt		x	x			
15	<i>Pellia epiphylla</i> (L.) Corda			x		✓	
<b>MARCHANTIOPSIDA - MARCHANTIALES</b>							
<b>Conocephalaceae</b> Mull. Frib. ex Grolle							
16	<i>Conocephalum salebrosum</i> Szweyk., Buczk. & Odrzyk.			x	x	✓	
<b>Marchantiaceae</b> Lindl.							
17	<i>Marchantia polymorpha</i> L.			x	x	x	
<b>BRYOPHYTA</b>							
<b>SPHAGNOPSIDA - SPHAGNALES</b>							
<b>Sphagnaceae</b> Dumort.							

Tab. 1 - cont.

18	<i>Sphagnum fallax</i> (H. Klinggr.) H. Klinggr.		X		
<b>POLYTRICHOPSIDA - POLYTRICHALES</b>					
<b>Polytrichaceae</b> Schwägr.					
19	<i>Atrichum undulatum</i> (Hedw.) P. Beauv.		X	X	X
20	<i>Pogonatum aloides</i> (Hedw.) P. Beauv.			X	
21	<i>Pogonatum urnigerum</i> (Hedw.) P. Beauv.		X	X	
22	<i>Polytrichum commune</i> Hedw.		X	X	✓
23	<i>Polytrichum formosum</i> Hedw.		X		
24	<i>Polytrichum juniperinum</i> Hedw.		X		X
25	<i>Polytrichum longisetum</i> Sw. ex Brid.		X		X
26	<i>Polytrichum piliferum</i> Hedw.		X		
<b>BRYOPSIDA - FUNARIALES</b>					
<b>Funariaceae</b> Schwägr.					
27	<i>Funaria hygrometrica</i> Hedw.		X		X
<b>DICRANALES</b>					
<b>Leucobryaceae</b> Schimp.					
28	<i>Leucobryum glaucum</i> (Hedw.) Ångstr.		X		
29	<i>Leucobryum juniperoideum</i> (Brid.) Müll. Hal.		X		X
<b>Dicranellaceae</b> M. Stech					
30	<i>Dicranella heteromalla</i> (Hedw.) Schimp.		X	X	
<b>Fissidentaceae</b> Schimp.					
31	<i>Fissidens dubius</i> P. Beauv.				X
32	<i>Fissidens bryoides</i> Hedw.				X
<b>Dicranaceae</b> Schimp.					
33	<i>Dicranum majus</i> Sm.			X	✓
34	<i>Dicranum scoparium</i> Hedw.			X	✓
35	<i>Dicranum viride</i> (Sull. & Lesq.) Lindb.	X			X
36	<i>Dicranum flagellare</i> Hedw.		X		✓
37	<i>Dicranum montanum</i> Hedw.			X	X
38	<i>Paraleucobryum longifolium</i> (Hedw.) Loeske			X	X
39	<i>Dicranoweisia cirrata</i> (Hedw.) Lindb.	X			✓
<b>Ditrichaceae</b> Limpr.					
40	<i>Ceratodon purpureus</i> (Hedw.) Brid.			X	X
<b>Pottiaceae</b> Schimp.					
41	<i>Bryoerythrophyllum recurvirostrum</i> (Hedw.) P.C.Chen			X	
42	<i>Syntrichia papillosa</i> (Wilson) Jur.	X			✓
43	<i>Syntrichia ruralis</i> (Hedw.) F. Weber & D. Mohr			X	✓
44	<i>Tortula muralis</i> Hedw.			X	
45	<i>Tortula subulata</i> Hedw.			X	
46	<i>Tortella tortuosa</i> (Hedw.) Limpr.				X
47	<i>Weisia controversa</i> Hedw.			X	
<b>GRIMMIALES</b>					
<b>Grimmiaceae</b> Arn.					
48	<i>Racomitrium canescens</i> (Hedw.) Brid.		X		X
49	<i>Grimmia ovalis</i> (Hedw.) Lindb.				X
50	<i>Grimmia pulvinata</i> (Hedw.) Sm.				X
51	<i>Schistidium apocarpum</i> (Hedw.) Bruch & Schimp.				X

Tab. 1 - cont.

<b>HEDWIGIALES</b>				
<b>Hedwigiaceae</b> Schimp.				
52	<i>Hedwigia ciliata</i> (Hedw.) P. Beauv.			X
<b>BARTRAMIALES</b>				
<b>Bartramiaceae</b> Schwägr.				
53	<i>Bartramia pomiformis</i> Hedw.			X
54	<i>Philonotis fontana</i> (Hedw.) Brid.		X	
<b>BRYALES</b>				
<b>Bryaceae</b> Schwägr.				
55	<i>Bryum argenteum</i> Hedw.		X	
56	<i>Ptychostomum pallescens</i> (Schleich. ex Schwägr.) J. R. Spence			X ✓
57	<i>Ptychostomum pseudotriquetrum</i> (Hedw.) J. R. Spence & H. P. Ramsay ex Holyoak & N. Pedersen			X
<b>Mniaceae</b> Schwägr.				
58	<i>Pohlia nutans</i> (Hedw.) Lindb.	X	X	X
59	<i>Mnium hornum</i> Hedw.	X		✓
60	<i>Mnium marginatum</i> (Dicks.) P. Beauv.			X ✓
61	<i>Mnium stellare</i> Hedw.		X	
62	<i>Plagiomnium affine</i> (Blandow ex Funck) T. J. Kop.	X		
63	<i>Plagiomnium cuspidatum</i> (Hedw.) T. J. Kop.		X	X
64	<i>Plagiomnium ellipticum</i> (Brid.) T. J. Kop.		X	✓
65	<i>Plagiomnium medium</i> (Bruch & Schimp.) T. J. Kop.	X	X	✓
66	<i>Plagiomnium undulatum</i> (Hedw.) T. J. Kop.		X	
67	<i>Rhizomnium punctatum</i> (Hedw.) T. J. Kop.	X	X	
<b>ORTHOTRICHALES</b>				
<b>Orthotrichaceae</b> Arn.				
68	<i>Lewinskya speciosa</i> (Nees) F. Lara, Garilleti & Goffinet	X		X ✓
69	<i>Nyholmiella obtusifolia</i> (Brid.) Holmen & E. Warncke	X		X
70	<i>Orthotrichum anomalum</i> Hedw.		X	X
71	<i>Orthotrichum pallens</i> Bruch ex Brid.	X		✓
72	<i>Orthotrichum pumilum</i> Sw. ex anon.	X		✓
73	<i>Pulviger a lyellii</i> (Hook. & Taylor) Plášek, Sawicki & Ochyra	X		✓
74	<i>Ulota crispa</i> (Hedw.) Brid.	X	X	
<b>AULACOMNIALES</b>				
<b>Aulacomnaceae</b> Schimp.				
75	<i>Aulacomnium palustre</i> (Hedw.) Schwägr.		X	
<b>HYPNALES</b>				
<b>Plagiotheciaceae</b> M.Fleisch.				
76	<i>Herzogiella seligeri</i> (Brid.) Z.Iwats.	X		✓
77	<i>Plagiothecium cavifolium</i> (Brid.) Z.Iwats.	X	X	
78	<i>Plagiothecium nemorale</i> (Mitt.)		X	✓
<b>Pterigynandraceae</b> Schimp.				
79	<i>Pterigynandrum filiforme</i> Hedw.	X		✓
<b>Climaciaceae</b> Kindb.				
80	<i>Climacium dendroides</i> (Hedw.) F. Weber. & D. Mohr.		X	
<b>Amblystegiaceae</b> G.Roth				
81	<i>Cratoneuron filicinum</i> (Hedw.) Spruce		X	✓



**Tab. 1 - cont.**

82	<i>Amblystegium serpens</i> (Hedw.) Schimp.	X	X	X		X	
83	<i>Pseudoamblystegium subtile</i> (Hedw.) Vanderp. & Hedenäs	X				X	
84	<i>Tomentypnum nitens</i> (Hedw.) Loeske				X		✓
	<b>Leskeaceae</b> Schimp.						
85	<i>Leskea polycarpa</i> Hedw.	X				X	X
86	<i>Pseudoleskeella nervosa</i> (Brid.) Nyholm	X					
	<b>Thuidiaceae</b> Schimp.						
87	<i>Abietinella abietina</i> (Hedw.) M.Fleisch.				X	X	
88	<i>Thuidium delicatulum</i> (Hedw.) Schimp.		X			X	
	<b>Brachytheciaceae</b> Schimp.						
89	<i>Eurhynchium angustirete</i> (Broth.) T. J. Kop.				X		
90	<i>Pseudoscleropodium purum</i> (Hedw.) Fleisch.				X		
91	<i>Oxyrrhynchium hians</i> (Hedw.) Loeske		X	X			
92	<i>Brachytheciastrum velutinum</i> (Hedw.) Ignatov & Huttunen		X			X	
93	<i>Brachythecium rutabulum</i> (Hedw.) Schimp.		X	X		X	
94	<i>Brachythecium salebrosum</i> (Hoffm. ex F.Weber & D. Mohr) Schimp.		X			X	✓
95	<i>Homalothecium sericeum</i> (Hedw.) Schimp.	X				X	
96	<i>Sciuro-hypnum populeum</i> (Hedw.) Ignatov & Huttunen					X	
	<b>Hypnaceae</b> Schimp.						
97	<i>Hypnum cupressiforme</i> Hedw.	X	X			X	
	<b>Callicladiaceae</b> Jan Kučera & Ignatov						
98	<i>Callicladium haldanianum</i> (Grev.) H. A. Crum	X	X			X	
	<b>Pylaisiadelphaceae</b> Goffinet & W.R.Buck						
99	<i>Platygyrium repens</i> (Brid.) Schimp.					X	
	<b>Pylaisiaceae</b> Schimp.						
100	<i>Pseudohygrohypnum fertile</i> (Sendtn.) Jan Kučera & Ignatov		X				✓
101	<i>Pylaisia polyantha</i> (Hedw.) Schimp.	X	X			X	
	<b>Hylocomiaceae</b> M. Fleisch.						
102	<i>Hylocomiadelphus triquetrus</i> (Hedw.) Ochyra & Stebel		X	X			
103	<i>Hylocomium splendens</i> (Hedw.) Schimp.		X			X	✓
104	<i>Pleurozium schreberi</i> (Willd. ex Brid.) Mitt.		X	X			✓
	<b>Leucodontaceae</b> Schimp.						
105	<i>Leucodon sciuroides</i> (Hedw.) Schwägr.	X				X	
	<b>Neckeraceae</b> Schimp						
106	<i>Alleniella besseri</i> (Lobarz.) S. Olsson, Enroth & D. Quandt					X	✓
107	<i>Alleniella complanata</i> (Hedw.) S. Olsson, Enroth & D. Quandt	X					
108	<i>Homalia trichomanoides</i> (Hedw.) Brid	X					
109	<i>Neckera pennata</i> Hedw.					X	X
110	<i>Pseudanomodon attenuatus</i> (Hedw.) Ignatov & Fedosov	X				X	
111	<i>Thamnobryum alopecurum</i> (Hedw.) Gangulee					X	
	<b>Heterocladiellaceae</b> Ignatov & Fedosov						
112	<i>Heterocladiella dimorpha</i> (Brid.) Ignatov & Fedosov					X	✓
	<b>Lembophyllaceae</b> Broth.						
113	<i>Isothecium alopecuroides</i> Lam. ex Dubois) Isov.	X				X	✓
	<b>Anodontaceae</b> Kindb.						
114	<i>Anomodon viticulosus</i> (Hedw.) Hook. & Taylor	X				X	X

These were representatives of the families Grimmiaceae and Pottiaceae and the genera *Racomitrium*, *Schistidium*, and other predominantly obligate lithophyte genera. According to Lobachevska (2003), the most diverse species group of bryophytes refers to rocky-stony substrates in the Ukrainian Carpathians.

Over 50 species were found on the soil in beech and beech-oak forests and along the swampy banks of the brooks. These were representatives of *Polytrichum*, *Leucobryum*, *Plagiomnium*, *Plagiothecium*, *Dicranum*, and other genera. On the soil in the forests but more often in the old stumps, *Pseudohygrohypnum fertile* was found. The primary substrates for this species within its habitat are the soil of moist old-growth mountain forests and rotten wood. It is a rare species in Europe and Ukraine. For instance, the only known locality for the species is the Giant Mountains in the Czech Republic (Kučera et al. 2019). Ancient forests in the Zacharovana Dolyna Reserve are predominant. Similar habitats are typical for *Neckera pennata* (Fig. 2). Such species as *Dicranum majus*, *D. scoparium* and *Leucobryum juniperoideum*, also growing on the soil, were identified for the first time for the Volcanic Carpathians. *Tomenthypnum nitens* is a relatively rare species in the Ukrainian Carpathians. It was found in the swamps and has not been identified for the Volcanic Carpathians so far (Sadygov & Felbaba-Klushyna 2022).

More than 30 species were found on the bark of living trees. Only nine species were found exclusively on the bark of trees, of which seven were identified in the Volcanic Carpathians for the first time (e.g., *Dicranoweisia cirrata*, *Herzogiella seligeri*, *Orthotrichum pallens*, *O. pumilum*, *Pulvigerella lyellii*, *Pseudoleskeella nervosa* and *Pterigynandrum filiforme*). *Alleniella complanata* and *Homalia trichomanoides*, the species already recorded for the Volcanic Carpathians, also grew only on bark. In Ukraine, they can be found mainly in the old forests of the Ukrainian Carpathians, while the latter species are currently expanding throughout the country.

Twenty-nine species were found on dead wood, and only four were found exclusively on this substrate (*Dicranum flagellare*, *Mnium hornum*, *Plagiomnium affine* and *Pseudohygrohypnum fertile*) (Sadygov 2021). The former three species were recorded in the Volcanic Carpathians for the first time. Deadwood is the primary substrate for *Ptilidium pulcherrimum*, though we also found it on rocks. *Callicladium haldanianum* is relatively rare in Europe, but in Ukraine, it is widespread in all natural zones. It is a common species in the Ukrainian Carpathians. In the studied area, the species was found mainly on the bark of living and dead trees most often, and less often on rocks.

For instance, *Pseudohygrohypnum fertile* is listed in the European Red List of Bryophytes as a critically endangered species (Hodgetts et al. 2019). *Dicranum viride* is listed in the list of species of The Bern Convention, and it is considered a rare species (R) in the Red List of Bryophytes of Ukraine (Boiko 2010). *Neckera pennata* as a vulnerable species (V) in the Ukrainian Red List of Bryophytes, is extremely rare for Zakarpattia Oblast (Boiko 2010, 2012).

Some of the identified species are relatively rare in Ukraine and the Ukrainian Carpathians, which is why their findings are important for further observation of the

dynamics of their habitats. For instance, *Bazzania trilobata*, *Heteroclaadiella dimorpha* and *Leucobryum juniperoideum* are known in Ukraine exclusively from the Carpathian (mountainous) parts of two to four regions (Zakarpattia, Ivano-Frankivsk, Lviv and Chernivtsi oblasts) (Zerov & Partyka 1975; Boiko 2014).

Thus, 114 bryophyte species were found within the boundaries of the 150-hectare Zacharovana Dolyna Reserve, of which 45 species were recorded for the first time in the Volcanic Carpathians. This result can unconditionally be considered high species diversity compared with the bryophyte species diversity recorded in other, much larger nature reserves of the Ukrainian Carpathians. For example, there were recorded about 400 species of bryophytes (Danylkiv et al. 1997) in the Carpathian Biosphere Reserve (58,035.8 ha), and 150 species of bryophytes were registered in the forests of the Uzhanskyi National Park (39,159 ha) (Danylkiv 1998; Coppins et al. 1998). In the Tepla Yama Reserve (the Ukrainian Carpathians; 93 ha) sixty species of bryophytes were identified (Felbaba-Klushyna et al. 2022).

## Conclusions

1. A critical review of the literature shows that the territory of the Volcanic Carpathians is not sufficiently covered with bryological studies. Only scattered sources were available from the Zacharovany Krai National Park, and no bryological literature was available from the Zacharovana Dolyna Reserve.
2. In the Zacharovana Dolyna, 114 bryophyte species were identified, of which 45 species were found in the Volcanic Carpathians for the first time.
3. The species preferring stony substrates prevailed significantly in the area under consideration.
4. The bryoflora of the Zacharovana Dolyna Reserve includes three rare species: *Neckera pennata* (vulnerable), included in the Red List of Bryophytes of Ukraine; *Dicranum viride* (vulnerable), included in the List of species of the Bern Convention and *Pseudohygrohypnum fertile* is vulnerable in the Ukrainian Carpathians and included in the European Red List of Bryophytes (critically endangered).
5. The Zacharovana Dolyna Reserve is characterised by high bryological diversity due to the occurrence of primary forests and a significant diversity of biotopes.

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