RESEARCH PAPER

BIODIVERSITY OF BRYOPHYTE OF PHOTIC ZONES OF CAVES IN THE KUTUK TRACT (SOUTHERN URAL, BASHKIRIA)

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ABSTRACT. This article presents results of a study of bryophytes in seven caves of the Kutuk tract of the National Park «Bashkiria» of the Republic of Bashkortostan, including the largest cave in Bashkiria – Kutuk-Sumgan.

Fifty-five bryophytes species were found in the studied caves. The dominant species in all caves was *Timmia bavarica*. The species composition of bryophytes of each cave is unique. Among identified bryophytes species 23, species were found only in one cave, and 11 species in 2 caves. During our survey, we found 31 species in Kutuk-Sumgan Cave, 21 species in Kutuk-2 and Kutuk-3 caves, 19 species in Kutuk-4 caves, 18 species in Vintovaya and Zigzag caves and 14 species in Kutuk-1 cave.

Using the Jaccard and Phi-squared similarity indices, we revealed the stability of the bryoflora of the caves in different years and show its changes. Changes in the composition and structure of mosses in the Kutuk tract may be caused by mechanical influences. Benchmark similarity analysis allowed us to determine the influence of entrance morphology and glaciation in the photic zone of the caves on the composition of bryophytes.

Using the Kutuk tract caves as an example, it is shown that in the primary analysis of the bryoflora, when selecting a characteristic cave, up to 40% of the total species composition of the caves can be identified in a single cave. The current study of Kutuk tract caves shows that identification of the primere analyses of bioflora permits identification of up to 40% of species composition of an individual cave.

Three criteria for selecting a characteristic cave were identified: size of the photic zone and morphology of the entrance, diversity of habitats, and the least degree of disturbance.

KEYWORDS: Cave, photic zone, mosses, Kutuk-Sumgan, bryophytes

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INTRODUCTION

Karst caves are the most vulnerable part of karst ecosystems due to various anthropogenic influences (Neill et al. 2004; Parise et al. 2009; Zhang and Zhu 2012; Simòes et al. 2014). In the recent years the number of studies of the biodiversity of karst caves is constantly increasing. However, in many regions caves remain poorly studied, for example, in the Republic of Bashkortostan (South Ural, Russia). Of particular interest is the biota of the habitats of the cave entrance zones, which have several unique features. Unusual climatic conditions and high humidity (Northup and Lavoie 2001; Williams 2008), the presence of environmental gradients (Mulec et al. 2008), habitat diversity (Mulec et al. 2008; Novak et al. 2012; Czerwik-Marcinkowska 2013), the proven microrefugial role of the cave entrances as ecotones (Monro et al. 2018), determine the high biodiversity of phototrophs realized in small volumes of subterranean cavity entrances. The most popular are studies of species adaptations to cave environments, relationships and competition within populations and communities, features of reproductive strategies, the habitat-forming potential of cave biota, biodiversity formation, and the conservation value of cave photic zones (Serena and Meluzzi 1997; Pentecost and Zhaohui 2001; Tao et al. 2015; Monro et al. 2018; Puglisi et al. 2019).

The discrete and distant location of different cave entrances determines the disjunct range of species in the entrance zones of the caves. In addition, the adaptability to certain specific conditions, low reproductive potential, and small population sizes increase the probability of extinction, including habitat loss (Bichuette and Trajano 2010).

The low diversity of mosses in karst caves, the relationship of species composition with the microhabitat and the possibility of using mosses as indicators of the plant diversity of caves were revealed (Ren et al. 2021).

Participation of bryophytes in communities is related to cave humidity and increases in the presence of water flows (Popkova and Mazina 2019; Mazina et al. 2020). Generally, bryophyte of cave habitats diversity decreases southwards and in dryer caves (Mazina and Popkova 2017; Kozlova et al. 2019; Popkova et al. 2019; Popkova and Mazina 2020). Evidence from the caves of Montenegro, located in a small area, shown the low similarity of species composition of bryophytes explained by the peculiarities of morphology of cave entrance zones, without analyzing their disturbance (Kozlova et al. 2019; Kozlova and Mazina, 2020). Ren et al. (2021) indicated that the diversity of bryophytes and the number of individuals decreased with various disturbances, liverworts disappeared with drought-tolerant species prevailed. At the same time, the authors highlight the heterogeneity of the habitat as a factor influencing the diversity of plants in caves.

There are several problems in assessing the floristic composition of cave entrance sites. Considering the diversity of biotopes in the photic zones of caves, the question arises of the influence of the morphological features of the entrance on the species composition. For specially protected nature conservation areas, a constant task is to monitor the state of ecosystems in order to determine the dynamics of their development and timely identify negative changes. Inventory of cave flora is complicated by their inaccessibility. Therefore, it is relevant to determine the required minimum of studied objects to obtain objective information about biodiversity of bryophytes in caves within a relatively small and quite homogeneous territory. Comparison of the similarity of bryophytes in the photic cave zones can provide an answer to the question of how many entrances need to be investigated for the initial assessment of bryophytes cave biodiversity; whether there are characteristic objects and what are the criteria for their selection; what percentage of the flora is found in each cave, and whether these data can be extrapolated to other caves.

The objectives of the study were defined as follows. First, to determine the species composition of bryophytes in the entrance photic zones of the Kutuk tract caves. Second, to compare the species composition and species structure depending on the morphology of the entrance zone. As a third point, the most significant (characteristic) cave types for biodiversity assessment were identified.

MATERIALS AND METHODS

Objects of study

The Kutuk tract is located in the watershed area of the Belaya and Nugush rivers between the Yamantau and Kibiz ridges, on the western slope of the Southern Urals. Administratively, the Kutuk tract is located in Meleuz District of the Republic of Bashkortostan on the territory of the «Bashkiria» National Park (Fig. 1).

The caves of the Kutuk tract are divided into two groups according to their position in relief and determining conditions of their development – riverine or interfluves. Caves of riverine environment are horizontal, slightly descending, dry or with insignificant often seasonal watercourses, confined to the sides of gorges or dry riverbeds. All surveyed caves belong to the caves of interfluves environment; are collectors of karst waters and participate in the formation of the modern underground flow; most of them begin with unwalled shafts of the area (Golubev et al. 1976).

The caves of the Kutuk tract are embedded in gray massive limestones of the Viseian Stage of the Lower Carboniferous (Abdrakhmanov et al. 2002; Kamalov and Chvanov 2014). In the period of floods and rains the entrance shafts of the caves are ponors.

Kutuk-Sumgan Cave (53°0′2″N 56°45′5″E) is 9860 m long, 134 m deep, 52260 m^2 area, 350000 m^3 volume, amplitude 134 m, the lower floors of the cave are flooded. The cave is located at the confluence of Uluklansky and Sumgansky arroyo, confined to faults and zone of intense tectonic fracturing, at a depth of 130 m from the surface the underground river runs along the bottom of the cavity. The entrance zone is a vertical shaft, 116 m deep and 10x20 m in diameter in the upper part, and its mouth is 9.0x4.5 m. At a depth of 60 meters there is a horizontal platform covered with firn. From this platform passages, lead to the labyrinth galleries of the middle tier, which are hypsometrically confined to the level of the ancient (Upper

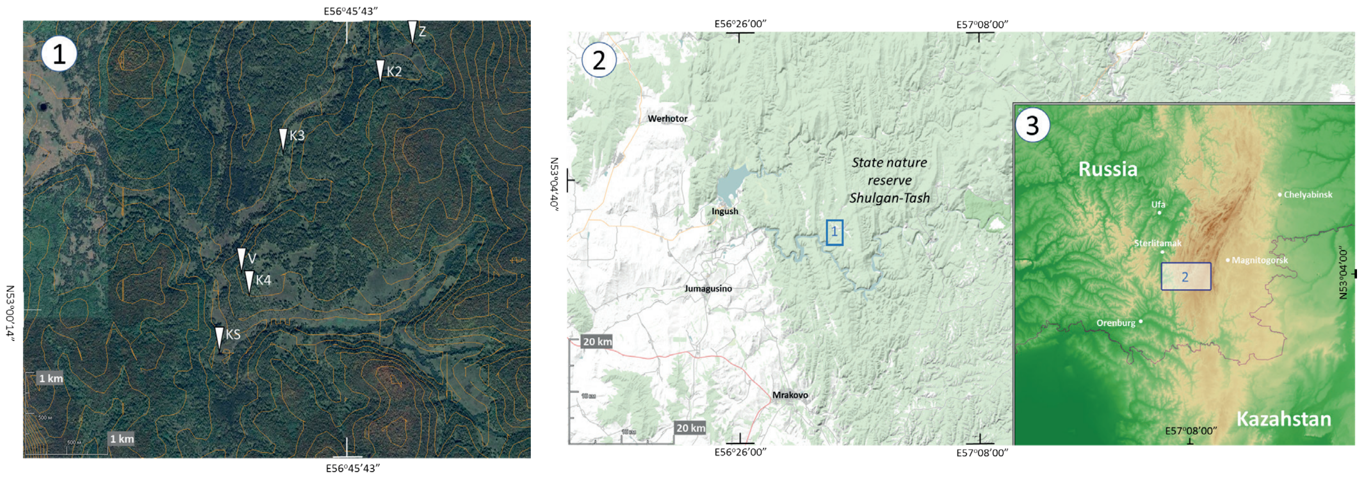


Fig. 1. Location of the explored caves in the Kutuk tract, Republic of Bashkortostan. KS – Kutuk-Sungan, K1 – Kutuk-1, K2 – Kutuk-2, K3 – Kutuk-3, K4 – Kutuk-4, V – Vintovaya, Z – Zigzag. Font: http://earth.google.com. 2022

Pliocene) terrace of the Belaya river valley above floodplain. The walls of the shaft are mostly flat, but in places they act as canopies[1] (Golubev et al. 1976; Kamalov and Chvanov 2014). The walls of the shaft contain ice and snow-ice masses, which provide constant drips and streams along the cave walls, the intensity of water flows varying in different seasons. Snow-ice masses and blocks of ice periodically fall, which leads to fragmentary destruction of the cavity vegetation cover, represented mainly by mosses. Kutuk-1 cave (Ice cave) is located 2.8 km to the north of the Kutuk-Sumgan cave at the base of the limestone wall of the right side of the dryland. The cave is horizontal, with a sloping cavity (main entrance angle 15-20º), consists of two halls-grottoes of 50x70 m and 20x30 m and side passages with the stream. The total length of the cave is 520 meters, it is iced during the whole year. The entrance area of the cave is an inclined icy descent with various sintered ice forms (Bogdanovich 1969). From the entrance to the central part of the largest grotto of the cave, there is a blanket of perennial ice. In the center of the grotto is a clay scree, frozen in some places, in the marginal part of the glacier clay, covers the ice with a layer up to 0.5 m (Kadebskaya and Stepanov 2016).

Kutuk-2 cave (Stalactite cave) is located 2.5 kilometers north of the Kutuk-Sumgan cave. The total length of the passages of Kutuk-2 is 2050 meters, with the amplitude of 110 meters. The length of the accessible part of the cave is 970 meters. The entrance zone is unwalled shafts of 12.5 meters in depth, at the bottom of which opens collapsing grotto, in the north-western part begins a gallery with dry and watered side tributaries. The gallery is blocked by two siphons and is going westward with the deepening of strata. It ends at a depth of 70-80 m with pebble siphons. In the southern part of the avalanche grotto another gallery with a stream goes to the southwest. This gallery is overlapped by a siphon at a depth of 110 m and has a narrow passage to the main part of the cave (Golubev et al. 1976). In winter seasonal glaciation forms in the entrance zone of the cave (Kadebskaya and Stepanov 2016).

Kutuk-3 is located in the Uluklansky log, two hundred meters south of the Kutuk-1 cave in the dry valley. The entrance part has the form of a rectangular sinkhole, at the bottom of which there is 8 meters long inclined (45°) ledge, leading to the descent into the 40 m deep mine. From the entrance to the bottom of the well there is an extended tongue-shaped glacier. At the end of the cave there is more than 50 m long inclined gallery, which is blocked up with blocks. The total depth of the cave is 65 m, at a depth of 61 m it impassably narrows. The walls of the entrance zone are covered with hydrogenous ice (Golubev et al. 1976).

Kutuk-4 cave is 1869 m long, 155 m deep, has 6728 m^2 area, 50500 m^3 volume, and 155 m amplitude. The cave is located on the left slope of Uluklansky log, 0.4 km north of Kutuk-Sumgan cave with an excess of 25 m above the entrance of the latter. The entrance to the cave is in the form of unwalled shafts, 10 m deep, which opens into a hall with ice. Flora is located on the walls of the shaft, on the shelves and at the bottom of the hall, mostly in areas that are not occupied by ice and snow-ice masses. At the bottom of the well, there are clastic and rubble deposits, which are the result of frost weathering. At the entrance part of the cave perennial ice is to be found. This ice field can reach a length of 300 m and a width of 6 m. The formation of the ice was caused by meltwater coming in the spring mainly through the entrance. The main part of the cave consists of the inclined (15°) meander gallery with a length of over 1800 m running along the dip of limestone beds, perpendicular to the extension of Uluklan valley. At a depth of 100-110 m from the entrance side tributaries flow into the main gallery. The cave is watered; the stream is fed by the glacier of the near-entrance part and by infiltration water[2] (Bogdanovich 1969; Kadebskaya and Stepanov 2016).

The Vintovaya cave is located in the thalweg of the Uluklan valley, 0.6 km to the north of the Kutuk-Sumgan cave. Its entrance is located at the base of the rock outcrop in a small funnel. From this tunnel a low passage follows to a steeply dipping (30°) high meandergallery, which is about 1 m wide. This meander gallery is developing in the direction of the dipping layers. It impassably narrows at a depth of 60 m, 270 m from the entrance. A small stream flows in the cave (Golubev et al. 1976).

Zigzag cave is 150 m deep, 2500 m long, has volume of 37900 m^3, is located in the side of the sinkhole, 800 m to the northeast of Kutukskaya-2 cave. The cave forms zigzag meander galleries which are ending with siphons. The mentioned galleries contain an underground river with the flow rate of 50-25 l/sec flows. At a depth of 110 m, the cave cuts through the contact zone of limestones and dolomites. The entrance is represented by two holes about 1.5 m in diameter, which follows to the inclined gallery. In the entrance zone a watercourse can be formed periodically in the form of a stream (Golubev et al. 1976). The cave maps are shown in Fig. 2, the photic zone of the caves in Fig. 3.

Methods

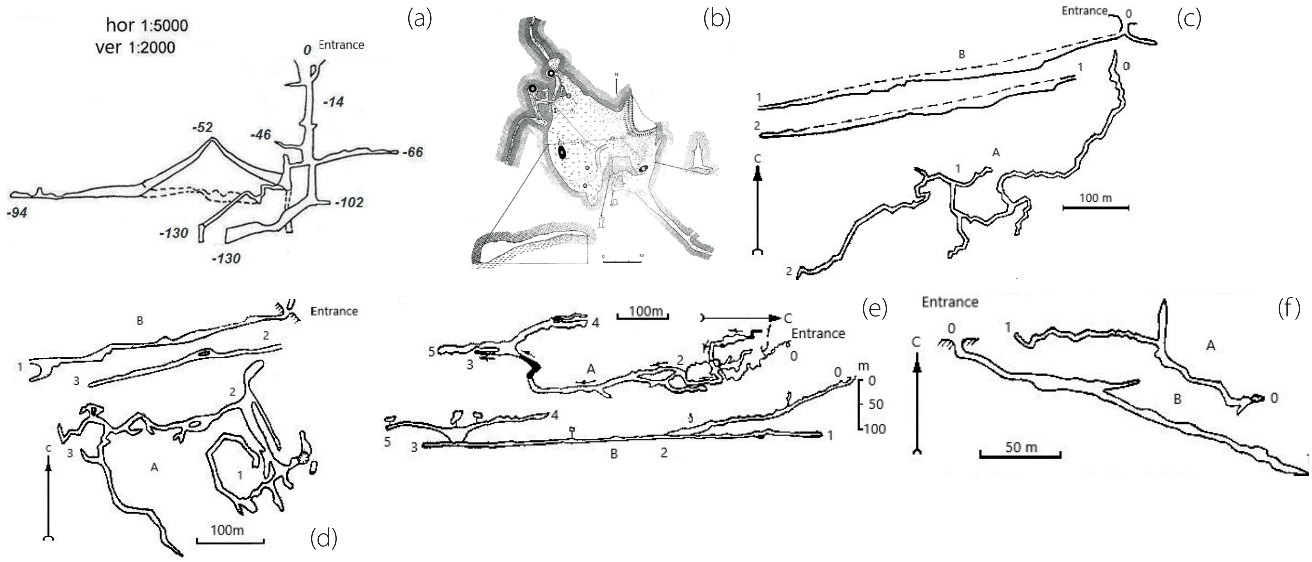
The bryophyte samples were collected in photic zones of caves-entrance sites illuminated by natural sunlight. For vertical shafts entrances, the beginning of the cave was marked out below the surface level. For inclined entrances, the beginning of the cave was determined by lowering the vertical line from the ceiling to the floor inside the cave. Most caves were processed in: May and November 2010; January, March and June 2012; August and November 2016. Samples from cave Zigzag were collected 5.2010, 11.2010, 6.2012, 11.2016. Samples from cave Vintovaya were collected 11.2010, 6.2012, 11.2016. At the sampling points, temperature and humidity were measured with electronic thermometers with an accuracy of 1ºC, 1%.

Samples in the caves were taken from each visually distinguishable tuft of mosses in sterile containers or paper envelopes and provided with a description of the habitat. Collected mosses were dried and soaked in water again before determining. The determination was carried out by observation of anatomical and morphological features using light microscopy. The following treatments were used for the identification: Ignatov and Ignatova (2003–2004), Abramov and Volkova (1998), Shlyakov (1981), Savich and Ladyzhenskaya (1936). Part of the specimens was brought to the herbarium of the Ufa Institute of Biology of the Russian Academy of Sciences. The rest are kept by Gainutdinov I.A. and in the collection of Mazina S.E. Several identifications were confirmed by E.Z. Baisheva (Ufa Branch of the Russian Academy of Sciences).

The nomenclature follows Ignatov et al. (2006) for mosses and Konstantinova et al. (2009) for liverworts.

The participation of species in the community was assessed by the proportion of the species in the sample. Only samples collected in 2016 were analyzed using the

[1] *https://speleoatlas.ru/caves/sumgan-13153*
[2] *https://speleoatlas.ru/caves/kutukskaya-4-17432*



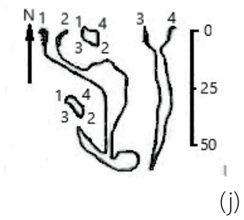
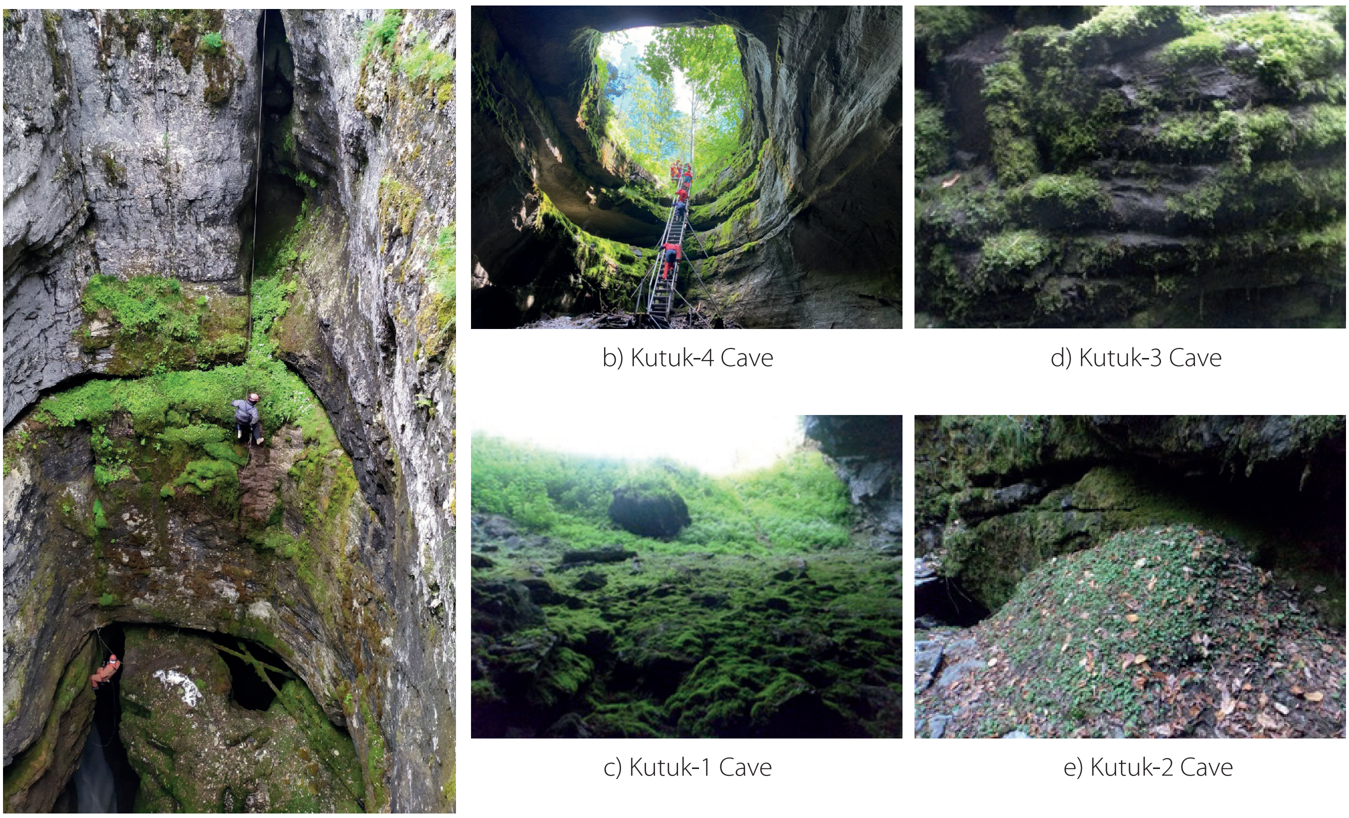


Fig. 2. The cave maps: a) Kutuk-Sumgan Cave, section; b) Kutuk-1 Cave, plan; c) Kutuk-4 Cave, a – plan, b – section (S. Truba); d) Kutuk-2 Cave, a – plan, b – section (L. Emelyanov, S. Truba, S. Golubev, Yu. Novikov); e) Zigzag Cave, a – plan, b – section (V. Apollonov, R. Murtazin, I. Khamidulin).; f) Vintovaya Cave, a – plan, b – section (V. Ageev); j) Kutuk -3 Cave, section (T. Novikova); (maps from Lobanov. 1979).



b) Kutuk-4 Cave
d) Kutuk-3 Cave
c) Kutuk-1 Cave
e) Kutuk-2 Cave
a) Kutuk-Sumgan Cave

Fig. 3. The photic zone of the Caves. Photo from Pozdnyakova L., Asylguzhin A., Dmitrieva S., Gainutdinov I.

projective coverage of species. A 5-point scale – analogue of the Brown-Blanquet scale (Braun-Blanquet 1964) was used. Were 1 – the number of organisms is small (up to single), organisms are sparse or with little coverage up to 5%; 2 – the number of organisms is large coverage is from 5 to 25%; 3 – with any number of organisms coverage is from 25 to 50%; 4 – with any number of organisms coverage is from 50 to 75%; 5 – with any number of organisms the coverage is more than 75%. Relative participation was defined as the ratio of the participation of a species to the total participation of all moss species in the photic zone of the cave (as a percentage), the species with the greatest participation were considered to be dominants. The relative occurrence of species was calculated as the ratio of the sum of samples in which the species was detected to the total occurrence of all species (as a percentage).

The Jaccard Index was used to assess the similarity of the species structure. It was calculated on the basis of the occurrence of species (Jaccard 1901, Schmidt 1980). The Phi-square coefficient, which was calculated based on species occurrence and used to estimate species structure (Byul and Cefel, 2005). The values determined for parallel samples were used as a similarity standard (Maksimov 1984). In accordance with the methodological approach described in the works of Maximov and Kuznetsova (2013) as well as Pichugina and Mazina (2020) the Jaccard index from 0.4 to 1 and the Phi-square index from 0 to 0.6 were chosen as reference values of similarity. The proximity of the cave flora was calculated using square Euclidean distance (Spencer 2013) and Ward method (Blashfield and Aldenderfer 1978). The contribution of each cave to the total composition of the flora was calculated as the ratio of the number of identified species in one cave to the total number of species as a percentage. Statistical processing of the data was carried out using MS Excel, IBM SPSS Statistics 26.

RESULTS AND DISCUSSION

In the studied caves, 55 species of bryophytes and 6 liverworts species were found. The list of species and the distribution of species by caves are presented in Appendix 1.

The number of bryophyte species varied from cave to cave (Appendix 1). In the largest Kutuk-Sumgan cave, 31 species were found; 21 species in Kutuk-2 and Kutuk-3; 19 species in Kutuk-4; 18 species in Vintovaya and Zigzag caves; 14 species in Kutuk-1. The entrances of Kutuk-Sumgan, Kutuk-2, Kutuk-4, Kutuk-3 caves are vertical shafts with snow-ice masses at the bottom and walls. Kutuk-1 has an entrance in the form of an inclined icy descent. The Vintovaya and Zigzag caves are small sloping entrances without glaciation, having clay deposits. The smallest number of species was found in a cave with a sloping ice entrance Kutuk-1. The shafts caves are the richest in terms of the abundance and diversity of bryophytes.

The temperature in the inlet zones of the cave shafts during the sampling period in winter in the upper parts was close to the surface temperature, and in the bottom parts it was from -3 to +2˚C. In summer, the temperature in the shafts was 7-12˚C and in Kutuk-Sumgan cave in the upper part was 4-14˚C. In the caves with horizontal entrances, the temperature was -4 to +7˚C in winter and 7-14˚C in summer. In Kutuk-1 cave, winter temperature was -12 to -5˚C, and in summer from -2 to 4˚C. Humidity in all caves was close to 100%.

In all caves with shafts entrances, the moss layer was well pronounced and constituted 60 to 90% of the surface on clay sediments or soil-like bodies. On limestone blocks, the projective cover was lower, about 20 to 40%. In caves with inclined entrances, areas with moss cover were located within the well-lit zone at the very beginning of the cave, mostly on clay deposits, discretely, occupying 20-30% of the area.

The calculated relative participation indexes showed that *Timmia bavarica* dominated in the photic zones of all caves. In Kutuk-Sumgan Cave the subdominants were *Distichium capillaceum, Brachythecium rotaeanum, Brachytheciastrum velutinum;* in Kutuk-2 *Distichium capillaceum, Plagiomnium medium;* in Kutuk-3 *Distichium capillaceum, Plagiomnium medium, Brachythecium rotaeanum, Hylocomium splendens;* Kutuk-4 *Cratoneuron filicinum, Brachytheciastrum velutinum, Brachythecium rivulare;* in Kutuk-1 *Brachythecium salebrosum, Distichium capillaceum, Brachytheciastrum velutinum, Pohlia cruda;* in Spiral *Campylidium sommerfeltii, Hylocomium splendens, Plagiomnium medium, Orthothecium strictum;* in Zigzag *Distichium capillaceum, Brachythecium glareosum, Sciuro-hypnum curtum, Plagiomnium medium.*

Among the dominant and subdominant species *Timmia bavarica, Distichium capillaceum, Brachythecium glareosum, Pohlia cruda,* and *Orthothecium strictum* belonged to species growing on carbonate rocks and limestone. Among all the species found in the caves, only one, *Rhynchostegium arcticum*, is included in the Red Data Book of the Republic of Bashkortostan (Mirkin 2011).

Only two species of *Brachytheciastrum velutinum* and *Timmia bavarica* were found in all studied caves, and species of *Distichium capillaceum* and *Marchantia polymorpha* were found in six caves. Twenty-three species were found in only one cave and 11 species in two caves. That is, 41% of the cave flora of bryophyte of the Kutuk tract's bryophyte flora are species found only in one cave, with the highest number of such species (6) in the Kutuk-Sumgan Cave. The contribution to the total cave flora of the tract differed between caves (Appendix 2), and ranged from 23 to 41%. The highest contribution to the cave bryophyte species composition was in the cave with the largest entrance zone Kutuk-Sumgan.

Information on the bryoflora of Bashkiria National Park is given in (Flora… 2010), but we did not find any information on cave species in it. In addition to the species listed in the current paper, cave surveys have also revealed species: *Serpoleskea confervoides, Rhynchostegium murale, Rhizomnium punctatum, Plagiothecium denticulatum, Orthothecium strictum, Loeskypnum badium, Pohlia wahlenbergii, Dichodontium pellucidum.*

The reference similarity of bryophytes of the entrance zones during the study period (2010-2016 years) was revealed only in Zigzag and Vintovaya caves, and the similarity of the structure only in Zigzag cave. These caves have small, inclined entrances without glaciation. The most frequent deviations from the reference similarity are noted in caves with large, failed entrances with large amounts of glaciation, such as Kutuk-4 and Kutuk-Sumgan. In most caves composition of bryophytes was similar. In assessing similarity, it is noticeable that the species structure varies more than the species composition (Table 1).

Most of the studied caves have an entrance in the form of a shaft, at the bottom of which accumulations of ice are formed and persist all year round. In winter, snow and ice fall into the well. In spring and summer, ice formations melt on the walls of the well and water flows down. Open entrances collect streams of water during precipitation and the snowmelt season. In addition to water and ice, trees and biota can also fall into cave wells.

Opened shaft cave entrances are more accessible to new species. The mechanical effect of water and ice leads to the removal of part of the fouling from the walls and the flat of the well. Tree trunks overgrown with mosses and soil collapses enter the cave, so the biota may include species that are not characteristic of growing on the host rock (limestone).

There are extremely few data in the literature on the stability of entrance zone communities. For algal biofilms, seasonal changes in species composition in caves in eastern Serbia were determined (Popović et al. 2019), whereas other caves are characterized by stability of entrance zone communities within the cave (Popkova et al. 2019; Kozlova et al. 2019). Apparently, changes in the bryoflora in the caves of the Kutuk tract are related to the morphology of the entrances and reflect disturbances associated with the impact of snow-ice masses.

We analyzed similarity indexes (Jaccard and Phi-square) between the caves and calculated the percentage of occurrence of reference similarity during the studied period (Appendix 2). The species structure of bryophytes in Kutuk-2 and Zigzag caves is most similar, and the species composition is similar in Kutuk-2 and Zigzag, Kutuk-Sumgan and Zigzag, and Kutuk-3 and Kutuk-Sumgan caves. Benchmark similarity is most often revealed for bryophytes within the same cave. Caves with shaft entrances during the study period showed reference similarity to each other. The Zigzag and Vintovaya caves stand out, the latter having bryoflora significantly different from other caves. Both of these caves have small entrance areas without permanent glaciation. The bryoflora of the Kutuk-1 cave, which also has an inclined entrance, but with permanent glaciation, is not so different from caves with shaft entrances. In other words, the presence of permanent snow-ice masses or glaciation in the entrance zone affects the composition of bryophytes. Consequently, while selecting objects for the inventory of bryoflora of caves, we can recommend investigating caves with different types of entrances and taking into account the presence of ice or snow-ice masses in the entrance zone of the cave.

For comparison of species composition of studied caves a cluster analysis was carried out, which showed similar results for cave proximity. The Ward method provided meaningful clasterisation. Moreover, it is possible to apply statistical criteria to the clustering results. According to the dendric diagram (Fig. 4) from the 7th clasterisation level (9 clusters) the correlation between cluster and sampling place (cave) is revealed.

Pearson coefficient 0.025 (α < 0.05). If at the first six levels of clustering there was no separation which correlates with the sampling site, then there are some other factors that affect the species structure of communities. There is an error of experiment, selection or determination. However, if a correlation is found at the seventh and subsequent levels, then it can be assumed that there are at least 9 significant parameters or combinations of parameters that are directly related to the characteristics of the cave. The exact number of parameters is a controversial thesis, due to a high variability of natural ecosystems.

Our observations are consistent with data on the caves in Montenegro, where the morphology of the entrance zone affects the species composition of phototrophs (Kozlova et al. 2019). It can be assumed that large cave entrances, as in Kutuk-Sumgan Cave, have more diverse habitats, which affects biodiversity. This fact can be confirmed by the studies of Monro et al. (2018) and Ren et al. (2021) in caves in China.

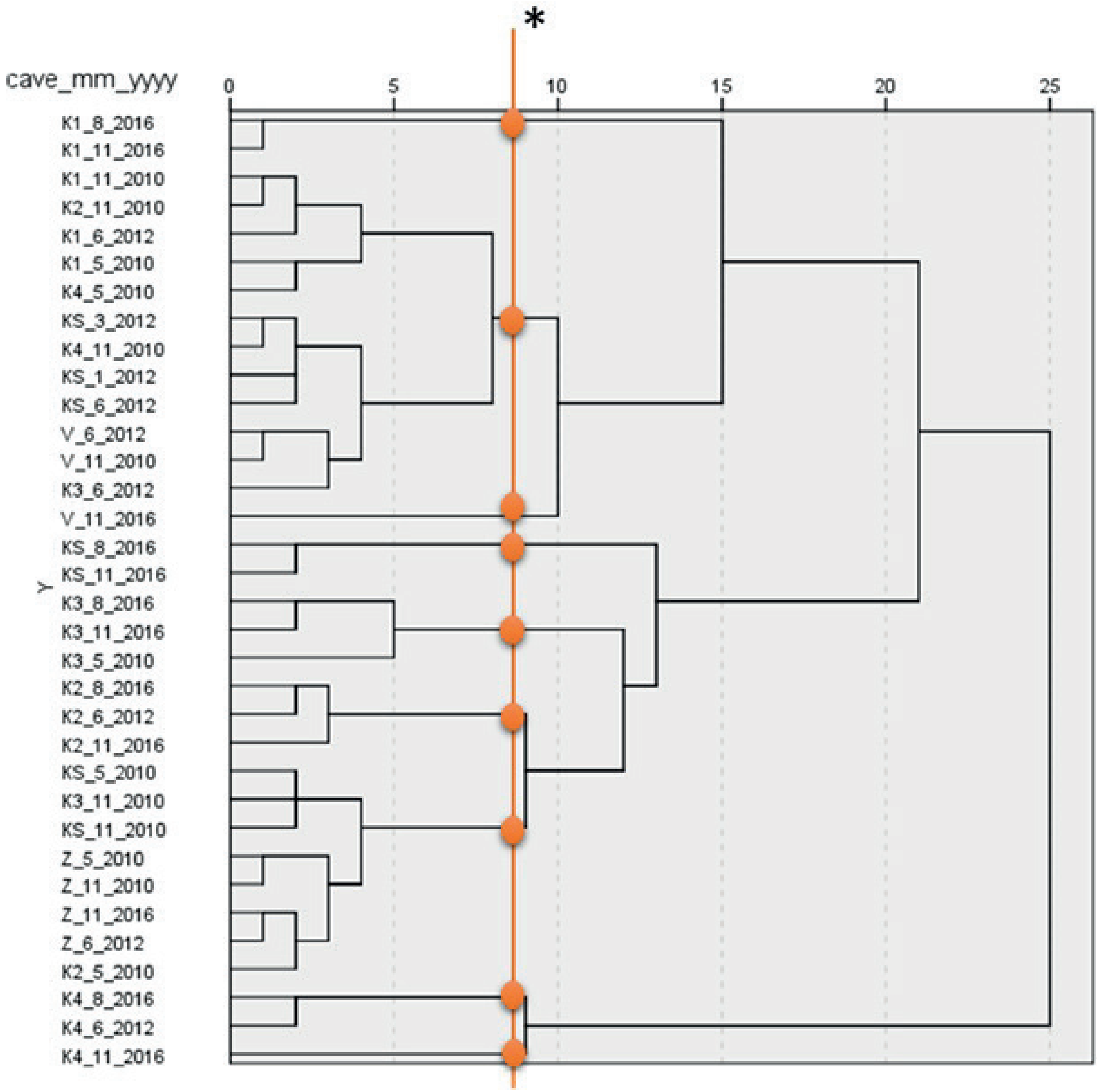


Fig. 4. Hierarchy cluster analyses of the cave bryophyte species structure. Ward method and the square of Euclidian distance were applied. KS – Kutuk-Sungan, K1 – Kutuk-1, K2 – Kutuk-2, K3 – Kutuk-3, K4 – Kutuk-4, V – Vintovaya, Z – Zigzag. The date of sampling was also taken into account. * – from the 7th clasterisation level (9 clusters) the correlation between cluster number and sampling place is reveled. Pearson coefficient 0.025 (α < 0.05)

CONCLUSIONS

A study of biodiversity of bryophytes in the caves of the Kutuk tract was carried out for the first time.

The study revealed the stability of the species composition and species structure of moss caves in different years. At the same time, the species composition differed less. The caves with small inclined entrances were the most stable.

Changes in the bryoflora of the photic zones of caves can be related to disturbances, in this case mechanical, due to falling snow and ice, water flows, human actions when passing through the wells with climbing equipment, and the number of species is related to the size of the photic zone, glaciation and habitat diversity. When selecting caves for biodiversity assessment, caves with different morphological entrances should be included in the study, their degree of disturbance should be assessed, selecting among the caves with similar entrance sites the least disturbed ones.

Analysis of bryophytes of the photic zone of the single characteristic cave can reveal up to 40% of the bryoflora of caves situated around.

Instability of cave bryoflora can be an indicator of disturbance, which is convenient to use to assess negative influences or natural processes.

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Table 1. Similarity of the species structure and species composition of bryophytes in the caves in different years

Sampling date		Kutuk-1						Kutuk-2				
		5. 2010	11. 2010	6. 2012	8. 2016	11. 2016		5. 2010	11. 2010	6. 2012	8. 2016	11. 2016
			Jaccard						Jaccard			
5.2010			**0,60**	0,30	0,25	0,23			**0,36**	**0,44**	**0,69**	**0,61**
11.2010	PHI	**0,46**		**0,50**	**0,42**	**0,38**	PHI	0,64		0,27	0,33	0,29
6.2012		0,62	**0,44**		**0,69**	**0,64**		0,58	0,62		**0,59**	**0,53**
8.2016		0,62	**0,53**	**0,42**		**0,92**		**0,47**	**0,53**	**0,41**		**0,88**
11.2016		0,62	**0,54**	**0,43**	**0,14**			**0,50**	0,59	**0,47**	**0,28**	
Sampling date		Kutuk-3						Kutuk-4				
		5. 2010	11. 2010	6. 2012	8. 2016	11. 2016		5. 2010	11. 2010	6. 2012	8. 2016	11. 2016
			Jaccard						Jaccard			
5.2010			**0,45**	**0,36**	**0,50**	**0,37**			**0,67**	0,30	**0,40**	0,27
11.2010	PHI	0,63		**0,42**	**0,46**	**0,41**	PHI	**0,51**		0,18	0,27	0,19
6.2012		0,69	**0,50**		**0,47**	**0,42**		0,57	0,72		**0,42**	0,29
8.2016		**0,53**	0,55	0,55		**0,71**		0,57	0,68	**0,48**		**0,64**
11.2016		0,57	**0,48**	**0,52**	**0,31**			0,65	0,72	0,61	**0,46**	
Sampling date		Zigzag						Vintovaya				
		5.2010	11.2010	6.2012	11.2016			11.2010		6.2012	11.2016	
			Jaccard							**Jaccard**		
5.2010			**0,91**	**0,64**	**0,60**			-		-	-	
11.2010		**0,26**		**0,60**	**0,56**					**0,62**	**0,35**	
6.2012	PHI	**0,46**	**0,45**		**0,69**		PHI	**0,38**			**0,53**	
11.2016		**0,46**	**0,49**	**0,40**				0,62		**0,48**		

Sampling date		Kutuk-Sumgan						
		5.2010	11.2010	1.2012	3.2012	6.2012	8.2016	11.2016
			Jaccard					
5.2010	PHI		**0,50**	**0,42**	0,23	**0,38**	0,32	0,25
11.2010		**0,42**		0,31	0,18	**0,37**	**0,38**	0,31
1.2012		0,69	0,69		**0,36**	**0,56**	**0,47**	**0,38**
3.2012		0,77	0,77	0,61		**0,41**	0,29	0,23
6.2012		0,62	0,65	**0,46**	**0,55**		**0,50**	**0,41**
8.2016		0,60	**0,56**	**0,49**	0,65	**0,50**		**0,78**
11.2016		0,64	0,63	0,57	0,69	0,58	**0,34**	

Appendix 1. List of bryophytes cave species of the Kutuk tract

	Relative occurrence								Relative participation (abundance)							
	Total	V	Z	K1	K2	K3	K4	KS	Total	V	Z	K1	K2	K3	K4	KS
Abietinella abietina (Hedw.) M.Fleisch.	0,80	-	-	-	-	-	-	3,23	0,39	-	-	-	-	-	-	1,74
Barbilophozia barbata (Schmidel ex Schreb.) Loeske	0,53	-	-	-	1,61	-	-	1,08	0,05	-	-	-	0,16	-	-	0,12
Barbula convoluta Hedw.	1,33	2,86	-	6,98	-	-	-	1,08	1,12	0,74	-	6,02	-	-	-	1,16
Brachytheciastrum velutinum (Hedw.) Ignatov & Huttunen	5,84	5,71	2,08	11,63	3,23	3,64	12,20	5,38	6,17	4,46	1,22	9,83	2,45	1,74	15,61	7,08
Brachythecium glareosum (Bruch ex Spruce) Bruch et al.	3,71	-	8,33	-	6,45	3,64	-	4,30	4,15	-	10,95	-	7,35	2,61	-	6,15
Brachythecium mildeanum (Schimp.) Schimp.	2,65	-	2,08	-	1,61	7,27	2,44	3,23	2,52	-	1,22	-	2,45	6,97	2,93	2,44
Brachythecium rivulare Bruch et al.	0,80	-	-	-	-	-	7,32	-	1,08	-	-	-	-	-	8,00	-
Brachythecium rotaeanum De Not.	5,31	8,57	8,33	-	-	9,09	2,44	7,53	4,77	7,44	6,20	-	-	9,32	1,95	7,83
Brachythecium salebrosum (F.Weber & D.Mohr) Bruch et al	3,18	5,71	-	11,63	6,45	-	-	1,08	3,51	4,91	-	15,45	5,72	-	-	0,58
Brachythecium sp.1	0,53	-	-	-	-	-	-	2,15	0,26	-	-	-	-	-	-	1,16
Brachythecium sp.2	0,80	-	-	4,65	-	-	2,44	-	0,92	-	-	6,02	-	-	0,98	-
Brachythecium albicans (Hedw.) Bruch et al.	0,53	-	-	-	3,23	-	-	-	0,26	-	-	-	1,63	-	-	-
Brachythecium rutabulum (Hedw.) Bruch et al.	2,12	-	-	2,33	6,45	1,82	-	2,15	1,01	-	-	1,20	3,27	0,87	-	0,87
Bryoerythrophyllum recurvirostrum (Hedw.) P.C.Chen	2,65	5,71	4,17	-	6,45	-	-	2,15	1,45	2,98	3,65	-	3,27	-	-	1,16
Calliergonella lindbergii (Mitt.) Hedenäs	0,27	2,86	-	-	-	-	-	-	0,26	2,98	-	-	-	-	-	-
Campylidium sommerfeltii (Myrin) Ochyra	0,80	8,57	-	-	-	-	-	-	0,91	10,27	-	-	-	-	-	-
Chilocyphus sp.	0,27	-	-	-	-	1,82	-	-	0,03	-	-	-	-	0,17	-	-
Conocephalum conicum (L.) Underw.	0,80	5,71	-	-	-	1,82	-	-	0,53	4,46	-	-	-	0,87	-	-
Cratoneuron filicinum (Hedw.) Spruce	2,12	-	-	-	-	-	9,76	4,30	3,13	-	-	-	-	-	15,90	4,35
Cyrtomnium hymenophylloides (Hueb.) Nyh. Ex T. Kop.	0,27	-	-	-	-	1,82	-	-	0,26	-	-	-	-	1,74	-	-
Dichodontium pellucidum (Hedw.) Schimp.	0,27	2,86	-	-	-	-	-	-	0,13	1,49	-	-	-	-	-	-
Distichium capillaceum (Hedw.) Bruch et al.	7,16	-	8,33	11,63	8,06	9,09	4,88	6,45	8,84	-	12,41	12,14	11,44	10,45	3,22	9,11
Encalypta sp.	0,80	-	2,08	4,65	-	-	-	-	0,66	-	1,22	4,01	-	-	-	-

Encalypta rhaptocarpa Schwägr.	0,53	-	-	-	-	3,64	-	-	0,26	-	-	-	-	1,74	-	-
Eurhynchiastrum pulchellum (Hedw.) Ignatov & Huttunen	0,53	-	-	-	-	-	-	2,15	0,26	-	-	-	-	-	-	1,16
Hygroamblystegium humile (P. Beauv.) Vanderpoorten	0,53	-	-	-	-	-	2,44	1,08	0,26	-	-	-	-	-	0,98	0,58
Hygrohypnum luridum (Hedw.) Jenn.	1,06	-	-	-	-	3,64	4,88	-	0,78	-	-	-	-	3,48	1,95	-
Hylocomium splendens (Hedw.) Bruch et al.	2,12	8,57	-	-	-	5,45	-	2,15	2,60	9,52	-	-	-	9,06	-	1,74
Leiocolea heterocolpos (Thed. ex C.Hartm.) H.Buch	0,27	2,86	-	-	-	-	-	-	0,39	4,46	-	-	-	-	-	-
Loeskypnum badium (Hartm.) H.K.G.Paul	0,80	-	-	-	1,61	-	4,88	-	0,66	-	-	-	0,82	-	3,90	-
Marchantia polymorpha L.	7,16	-	8,33	9,30	6,45	7,27	9,76	7,53	4,94	-	6,08	4,01	4,90	5,23	5,85	6,15
Mnium marginatum (Dicks.) P.Beauv.	4,51	-	4,17	6,98	6,45	5,45	-	5,38	4,47	-	3,65	3,01	6,54	6,97	-	6,96
Orthothecium strictum Lorentz	2,65	8,57	4,17	-	-	-	7,32	2,15	2,31	8,33	3,65	-	-	-	4,88	2,32
Plagiochila porelloides (Torr. ex Nees) Lindenb.	0,27	-	-	-	-	-	-	1,08	0,01	-	-	-	-	-	-	0,06
Plagiomnium ellipticum (Brid.) T. Kop.	0,27	-	-	-	-	-	-	1,08	0,39	-	-	-	-	-	-	1,74
Plagiomnium medium (Bruch et al.) T.J.Kop.	5,31	8,57	8,33	-	8,06	9,09	-	3,23	5,60	9,38	8,52	-	10,46	10,02	-	2,90
Plagiomnium rostratum (Schrad.) T.J.Kop.	2,65	2,86	-	6,98	-	1,82	-	5,38	2,57	2,68	-	7,02	-	0,87	-	5,68
Plagiothecium cavifolium (Brid.) Iwats.	0,27	-	-	-	-	-	-	1,08	0,13	-	-	-	-	-	-	0,58
Plagiothecium denticulatum (Hedw.) Bruch et al.	1,06	-	-	-	4,84	-	-	1,08	0,92	-	-	-	3,27	-	-	1,74
Plagiothecium sp.	0,27	-	-	-	-	-	2,44	-	0,53	-	-	-	-	-	3,90	-
Pohlia cruda (Hedw.) Lindb.	3,18	-	8,33	6,98	4,84	1,82	-	1,08	2,88	-	4,87	8,22	6,29	0,87	-	0,58
Pohlia wahlenbergii (Web. Et Mohr)	0,27	-	2,08	-	-	-	-	-	0,13	-	1,22	-	-	-	-	-
Ptilium crista-castrensis (Hedw.) De Not.	0,27	-	-	-	-	-	-	1,08	0,13	-	-	-	-	-	-	0,58
Rhizomnium punctatum (Hedw.) T.J.Kop.	0,80	5,71	-	-	-	-	2,44	-	0,53	4,46	-	-	-	-	0,98	-
Rhynchostegium arcticum (I.Hagen) Ignatov & Huttunen	1,06	-	2,08	-	-	-	-	3,23	0,53	-	1,22	-	-	-	-	1,74
Rhynchostegium murale (Hedw.) Bruch et al.	0,27	2,86	-	-	-	-	-	-	0,13	1,49	-	-	-	-	-	-
Rhytidiadelphus triquetrus (Hedw.) Warnst.	0,27	-	-	-	-	-	2,44	-	0,26	-	-	-	-	-	1,95	-
Sanionia uncinata (Hedw.) Loeske	1,59	-	-	2,33	-	7,27	2,44	-	1,73	-	-	1,00	-	7,14	3,90	-

Sciuro-hypnum curtum (Lindb.) Ignatov	2,65	-	8,33	-	1,61	-	-	5,38	2,19	-	9,98	-	0,82	-	-	4,35
Sciuro-hypnum populeum (Hedw.) Ignatov et Huttunen	0,53	-	-	-	1,61	1,82	-	-	0,39	-	-	-	0,82	1,74	-	-
Sciuro-hypnum reflexum (Starke) Ignatov & Huttunen	2,39	-	8,33	-	6,45	-	2,44	-	2,22	-	7,54	-	4,90	-	4,59	-
Serpoleskea confervoides (Brid.) Loeske	3,18	-	2,08	4,65	4,84	-	4,88	4,30	2,25	-	1,22	4,01	4,25	-	1,95	2,84
Stereodon vaucheri (Lesq.) Lindb. ex Broth.	0,53	2,86	-	-	1,61	-	-	-	0,39	1,49	-	-	1,63	-	-	-
Taxiphyllum wissgrillii (Garov.) Wijk & Margad.	0,53	-	-	-	-	3,64	-	-	0,53	-	-	-	-	3,48	-	-
Timmia bavarica Hessl.	8,75	8,57	8,33	9,30	8,06	9,09	12,20	7,53	16,20	18,45	15,21	18,05	17,57	14,63	16,59	14,56

V – Vintovaya, Z – Zigzag, K1 – Kutuk-1, K2 – Kutuk-2, K3 – Kutuk-3, K4 – Kutuk-4, KS – Kutuk-Sungan

Appendix 2. Percentage of reference similarity in the analyzed samples

Entrance morphology		Small sloping				Inclined icy descent		Shafts							
		Vintovaya		Zigzag		Kutuk-1		Kutuk-2		Kutuk-3		Kutuk-4		Kutuk-Sumgan	
				Jaccard											
		%	n**	%	n	%	n	%	n	%	n	%	n	%	n
Vintovaya		100\66*	3	0	12	0	15	0	15	13	15	0	15	0	21
Zigzag	PHI	0	12	100\100	6	0	20	80	20	45	20	10	20	54	28
Kutuk-1		0	15	0	20	70\70	10	36	25	12	25	16	25	20	35
Kutuk-2		0	15	65	20	24	25	70\80	10	12	25	8	25	34	35
Kutuk-3		0	15	25	20	0	25	16	25	100\80	10	12	25	43	35
Kutuk-4		7	15	5	20	8	25	8	25	12	25	40\50	10	11	35
Kutuk-Sumgan		0	21	32	28	0	35	17	35	17	35	29	35	62\48	21

*Jakkard/PHI-square, **n- number of combinations.