Phototrophic communities of Ahshtyrskaya Cave in the condition of artificial light

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Abstract
Investigation presents the multiyear assessment of biodiversity and development features of phototrophic communities from hypogean habitats. Caves exploitation as a tourist sites leads to anthropogenic transformation of subterranean ecosystems and formation of new communities named lampenflora. An example is given by the Ahshtyrskaya Cave (Sochi, Russia), which was equipped in 2000. The air temperature in the cave was 9-18 °C, humidity average 60-80%, the content of 222Rn 250-550 Bk/m³. Species identification was performed using standard approaches and cultivation methods. Cluster analysis was used to estimate similarity of communities in different cave zones. Biodiversity of phototrophs was revealed in entrance zone and zone of artificial light in 2017 - 2019. Species Microcystis pulverea, Scytonema drilosiphon, Chlorella vulgaris, Eucladium verticillatum predominated in communities of abovementioned zones. Considering the entrance zone communities as climax ones, comparison them with lampenflora can help to determine the speed and direction of succession. As a result of cluster analysis, it was established that species composition of lampenflora is most close to the entrance zone in case of maximum illuminated area. Thus, the succession of lampenflora depends on the intensity of illumination and tends to the species composition of the entrance zone communities.

Key words: lampenflora, hypogean habitats, cyanobacteria, algae, mosses.

Introduction
Caves represent a high interest for human because of unique subterranean landscape and presence of fascinating historical artifacts, for example, Paleolithic paintings, remains of ancient animals and shelters of prehistoric man. As a consequence, more caves become touristic ones. Caves museumification is associated with the development of infrastructure and installation of artificial lighting equipment (Gillieson, 2011). These actions lead to anthropogenic transformation of cave ecosystems, firstly by appearance of new sources of matter and energy. Under such conditions changes in organic input and modification of food chains are realised in originally oligotrophic cave environments (Saiz-Jimenez, 2012). Moreover, formation of new nonspecific phototrophic communities named lampenflora is observed in areas around artificial lighting (Smith & Olson, 2007).
The most common photosynthetic organisms isolated from lampenflora are ferns, mosses, cyanobacteria, green algae and diatoms (Aley, 2004). Generally, these communities are strongly adhered to cave substratum and can form biofilms (Roldán & Hernández-Maríné, 2009). According to Mulec & Kosi (2009) prokaryotic cyanobacteria and eukaryotic algae predominate on the early phase of colonization and succession, while mosses and ferns appear later in the succession.

As a result of detailed research taxonomic structure of lampenflora from many world regions was revealed (Smith & Olson, 2007; Mulec et al., 2008; Mazina & Maximov, 2011; Lamprinou et al., 2014; Pfendler et al., 2018). However, impact of illumination, temperature, relative humidity, substratum quality, presence of water flows on lampenflora development remains disputable (Mulec et al., 2008; Martinez & Asencio, 2010; Lamprinou et al., 2014, Borderie et al., 2014). In addition, variants of propagules input and succession of lampenflora communities are still discussed (Abdullin, 2014; Mazina, 2016).

An example of constantly visited cave with relative absence of lampenflora clearance is given by Ahshtyrskaya Cave. It has only one main entrance therefore it is possible to track main path of propagules into cavity: one with air flow, humans and animals, another with periodic waters in the far part of the cave. First records dedicated to biodiversity of lampenflora from Ahshtyrskaya Cave are given in article of Mazina & Maximov (2011).

The aim of the present study was the assessment of biodiversity of phototropic communities of Ahshtyrskaya Cave developing in the condition of essential and artificial light.

Material and Methods

Akhshyrskaya cave is located in the Adler district of the Sochi city (Krasnodar region, Russia) on the territory of the Sochi national park. The cave entrance is located at an altitude of 185 m above sea level.

The cave has following dimensions: length – 270 m, the projective length – 160 m, the area – 480 m² and the volume – 1340 m³. Akhshtyrskaya cave is laid in the limestone of the Upper Cretaceous. The content of the clay fraction increases with distance from the entrance. Calcite incrustations are rarely recorded in the distant part of the cave.

It was discovered that Akhshtyrskaya cave was used by the Paleolithic man (the era of Moustier) as a dwelling sites. In 1978, the cave site was recognized as a unique monument of primitive archeology of world importance (Klimenko et al., 1991). As a consequence, the cave became open for tourists and was equipped with artificial illumination in 2000 (fig. 1-3).

The investigation was conducted in 2017 - 2019. The assessment of habitat parameters (air temperature, relative humidity, pH of substrates) was performed using electronic devices Elin Complex iBDLR-L-U (thermochron) with an error of 0.1 °C and 1%, pH meters PH200 (accuracy ± 0.02 pH) and PH-013 (accuracy ± 0.01pH). The airborne alpha radiation from radon was measured using Radon Scout and RADEX MR-107. Track REI with LR115 film was used for the integral measurements of radon. Detectors were kept outside during the same exposure period for background correction. Measurements were taken from March 2017 to March 2019. The results were processed at the State Research Center of the Federal Medical Biological Agency, Russia.

Sample sites were located at the entrance zone and zone of artificial illumination. Specimens for investigation were taken from visible colonized substratum using sterile scalpel. In addition, pieces of substratum were collected in order to preserve the natural form of the community. Scraped material was directly observed under light microscopes Leica DMLS (Germany) and Biolam MBS-9 (Russia). To clarify species composition specimens was inoculated on solid agar medium enriched with Bristol’s medium. Cultures were maintained at a temperature of 11 and 25 °C and light intensity of 30-40 μm × m² × s⁻¹. To identify the propagules of phototrophs introduced into the caves by streams, soil samples and water were cultivated in Bristol’s medium. Water was pre-filtered through nuclear filters, and then the filtrate was placed on the culture medium for 11 months (Netrusov, 2005). Phototrophs were identified using classic literature (Andreeva, 1998; Komarek & Anagnostidis, 2005; Whitton, 2011; Ignatov & Ignatova, 2004; Mayevsky, 2014; Andreev, 2008). Systematics of cyanobacteria and algae is given by Guiry & Guiry (2019), mosses by Ignatov & Ignatova (2004), ferns by Cherepanov’s report (1995). The lichen systematics is present according to the database available at mycobank.org (date of appeal 28.06.2019). The abundance of phototrophs was estimated applying analogue of 5-point Brown-Blank scale.
Figure 1. Lampenflora.
Figure 2. One of the illuminated distant halls.
Cluster analyses based on the species composition was used for to estimate similarity of communities in different cave zones. Jacquard index and phi coefficient was applied to assess similarity of species composition. Statistical processing of data was performed using Excel, SPSS v10.0.5, Statistica 10.

Results

Habitat parameters. The monitoring of microclimatic parameters is of particular importance for touristic caves. Significant changes were not found in the Akhshtyrskaya cave during the period of measurements from 2008 to 2019. Temperature fluctuations were observed in the entrance zone and were caused by changes in surface temperature. The air temperature could decrease to 0 °C during winter period and increase to 28 °C in summer. In the distant parts of the cave, the temperature was more stable and ranged from 9 to 18 °C during the summer period and from 9 to 12 °C in winter. Humidity varies from 40 to 100%.

Numerous measurements of the radon concentration in the cave’s air demonstrated the frequency of its emanation. Most of the measurements were within acceptable limits, but a number of measurements showed an increase of $^{222}$Rn concentration to 1200 Bq/m$^3$ in distant parts of the cave during the winter period. During the summer months, the radon concentration ranged from 170 to 620 Bq/m$^3$, and in the winter from 350 to 580 with a sharp increase to 1200 Bq/m$^3$. Probably these increases are associated with floods in the caves of the karst mountain range. Equivalent equilibrium radon volumetric activity was $280 ± 84$ Bq/m$^3$. 

Figure 3. Scheme of Akhshtyrskaya Cave with the location of the lamps, scheme is given by Isaev & Starikh (2002).
Table 1. Taxonomical structure of phototrophic communities from Akhshtyrskaya cave

| Phylum          | Class                | Order            | Family            | Genus      | Species number |
|-----------------|----------------------|------------------|-------------------|------------|----------------|
| Cyanobacteria   | Cyanophyceae         | Nostocales       | Microcystaceae    | Microcystis| 1              |
|                 |                      |                  | Aphanotheceae     | Aphanothece| 1              |
|                 |                      |                  | Nostocae          | Nostoc     | 2              |
|                 |                      |                  | Synechococcaceae  | Synechocystis| 1             |
|                 |                      |                  | Trichormus        | Trichormus| 1              |
|                 |                      |                  | Chlorococcaceae   | Chlorococcum| 2             |
|                 |                      |                  | Mychonastaceae    | Mychonastes| 1              |
|                 |                      |                  | Prasiolaceae      | Stichococcus| 1            |
|                 | Chlorophyta          | Trebouxiphycaeae| Coccomyxa         | Coccomyxa| 1              |
|                 |                      |                  | Chlorella         | Chlorella| 1              |
|                 |                      | Prasiolae        | Muriella          | Muriella| 1              |
|                 |                      | Aspleniaceae     | Chlorella         | Chlorella| 1              |
|                 |                      |                  | Hedera            | Hedera| 1              |
|                 |                      |                  | Carex             | Carex| 1              |
|                 |                      |                  | Poa               | Poa| 1              |
|                 |                      |                  | Geraniaceae       | Geranium| 1              |
|                 |                      |                  | Caryophyllaceae   | Stellaria| 1             |
|                 |                      |                  | Campanulaceae     | Campanula| 1              |
|                 |                      |                  | Cystopteridaceae  | Asplenium| 3              |
|                 |                      |                  | Woodsiaceae       | Gymnocarpium| 1            |
|                 |                      |                  | Pteridaceae       | Woodsia| 1              |
|                 |                      |                  |                  | Pteris| 1              |
|                 |                      |                  |                  | Adiantum| 1             |
|                 |                      |                  |                  | Metzgeria| 1             |

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TABLE 1.

| Order                     | Family           | Genera   | Species |
|---------------------------|------------------|----------|---------|
| Bryophyta                 | Hypnales         |          |         |
|                           | Brachytheciaceae |          |         |
|                           | Neckeraeae       |          |         |
|                           | Leskeaceae       |          |         |
|                           | Plagiotheciaceae |          |         |
|                           | Rhabdoweisiaceae |          |         |
| Bryophyta                 | Dicranales       |          |         |
|                           | Fissidentaceae   |          |         |
|                           | Grimmiaeae       |          |         |
|                           | Seligeriaceae    |          |         |
| Bryophyta                 | Pottiales        |          |         |
|                           | Bryaceae         |          |         |
| Bryophyta                 | Bryales          |          |         |
|                           | Orthotrichaceae  |          |         |
|                           | Bartramiaee      |          |         |
| Ascomycota                | Lecanoromycetes  |          |         |
| Lecanorales               | Stereocaulaceae  |          |         |

**Phototrophic communities.** A seventy-four species of phototrophic organisms were identified in communities of the entrance zone and zone of artificial light in Akshtyrskaya cave. Phylum Bryophyta was the dominant group, represented by 22 species (29.73% of the reported species). Phylum Cyanobacteria included 20 species (27.03%), in time when phylum Chlorophyta was represented by 10 species (13.51%), phylum Bacillariophyta by 7 species (9.46%), phylum Polypodiophyta by 7 species (9.46%), phylum Magnoliophyta by 6 species (8.11%) and phylum Marchantiophyta by 1 species (1.35%). Only one species of lichen was reported in cave. A total number of orders, classes, families and genera are present in Table 1.

The most frequently encountered mosses were members of the order Hyplanes (6 Families, 9 Genera, 11 species). Among Cyanobacteria Nostocales was the most common order with 7 species in 5 genera: *Anabaena, Nostoc, Trichormus, Scytonema* and *Tolypothrix*.

According to relative abundance green algae *Chlorella vulgaris*, cyanobacteria *Microcystis pulvorea, Gloeocapsa punctata, Synechocystis aquatilis* and mosses *Eucladium verticillatum, Fissidens gracilifolius* were dominants in the entrance zone of the cave. The maximum relative abundance in the communities of lampenflora had ferns’ prothallia, cyanobacteria *Scytonema drilosiphon*, *Microcystis pulvorea* and moss *Eucladium verticillatum*.

A significant difference between phototrophic communities of Akshtyrskaya cave identified in 2008 and in 2017 - 2019 was revealed (Jacquard index 0.39).

Cluster analysis was used to generate distances among the communities developed in entrance zone and zones around artificial light. Lamps 9, 10 and 19 were excluded from analysis because of absence of phototropic communities around them. As a result differences between lampenflora and entrance zone communities were shown. It should be noted that this difference was observed both at the level of cyanobacterial / algal flora and at the level of higher plants. The composition of algal flora is closest to entrance zone ones in the communities developed around lamps with greatest intensity of illumination (for example, lamp 6 located in the grotto, where a high intensity of illumination and low ventilation was observed). The proximity of lamp 8 also located near the grotto and lamps located deep in the cave (14, 17 and 20) were noted.
Table 2. Species composition and abundance of prototrophs from Akhshtyrskaya cave

| Species Composition | Lamp 1 | Lamp 2 | Lamp 3 | Lamp 4 | Lamp 5 | Lamp 6 | Lamp 7 | Lamp 8 | Lamp 9 | Lamp 10 | Lamp 11 | Lamp 12 | Lamp 13 | Lamp 14 | Lamp 15 | Lamp 16 | Lamp 17 | Lamp 18 | Lamp 19 |
|---------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| **EMPIRE PROKARYOTA** |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Phylum Cyanobacteria |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Microcystis palvea (Wood) Forti emend. Elenk. | 3 | 2 | 3 | 4 | 2 | 5 | 3 | 3 | 4 | 3 | 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| Gloeocapsa atrata Kützing | 2 | 3 | 4 | 5 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 |
| Gloeocapsa rupestris Kutz | 4 | 2 | 2 | 2 | 1 | 5 | 4 |
| Gloeocapsa punctata Nägeli | 1 | 3 | 2 | 3 | 1 |
| Aphanothece sp. | 2 | 3 | 1 |
| Anabaena minima Chernov [Tschernov] | 1 | 3 |
| Nostoc microscopicum Carmichel ex Bornet et Flahault | 2 | 1 | 2 | 5 | 5 | 3 |
| Nostoc punctiforme Hariot | 2 | 2 | 2 |
| Trichormus variabilis (Kützing ex Bornet et Flahault) Komárek et Anagnostidis | 1 | 4 | 2 | 2 | 2 | 2 | 4 |
| Scytonema drilosphon (Kutz.) Elenk. et Poljansk. | 3 | 2 | 5 | 3 | 4 | 3 | 3 | 2 | 3 | 3 | 4 | 5 | 2 | 3 | 3 |
| Tolypothrix calcarata Schmide | 1 | 1 | 2 | 1 | 5 | 1 |
| Tolypothrix sp. | 2 |
| Synechocystis aquatilis Sauvageau | 4 | 2 |
| Jaagineda subtilissimum (G.Schmid) Anagnostidis et Komárek | 2 | 2 | 2 | 3 | 4 | 2 | 3 |
| Jaagineda woronichinii (Anissim.) Anagnostidis et Komárek | 1 | 1 | 3 | 1 |
| Anagnostidis et Komárek | 2 | 4 | 4 | 5 | 3 | 4 | 4 | 3 |
| Leptolyngbya foveolarum (Montagne ex Gomont) Anagnostidis et Komárek | 4 | 3 |
| Leptolyngbya boryana (Gomont) Anagnostidis et Komárek | 2 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 3 |
| Anagnostidis et Komárek | 1 | 1 | 2 | 1 | 2 | 1 |
| Lepraria sp. | 2 | 1 | 3 | 3 | 1 | 3 | 1 | 4 |
| **EMPIRE EUKARYOTA** |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Phylum Ascomycota | 3 | 4 | 4 |
| Phylum Marchantiophyta | 3 | 4 | 4 |
| Phylum Bryophyta | 3 | 4 | 4 |

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### TABLE 2

| Species                                                      | Count 1 | Count 2 | Count 3 | Count 4 | Count 5 | Count 6 | Count 7 | Count 8 | Count 9 | Count 10 |
|--------------------------------------------------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|----------|
| Oxyrrhynchium hians (Hedw.) Loeske                          | 2       | 3       | 3       | 1       | 3       |         |         |         |         |          |
| Sciuro-hypnum plumosum (Hedw.) Ignatov & Huttunen            | 2       | 3       | 1       | 2       | 1       |         |         |         |         |          |
| Sciuro-hypnum populeum (Hedw.) Ignatov & Huttunen            | 2       | 4       | 2       |         |         |         |         |         |         |          |
| Thamnobryum alopecurum (Hedw.) Nieuwl. ex Gangulee           | 3       | 1       | 3       | 2       | 3       | 3       |         |         |         | 1        |
| Lescurea saxicola (Schimp.) Milde                           | 2       | 1       |         |         | 3       |         |         |         |         |          |
| Isoterygiospis pulchella (Hedw.) Iwats.                     | 1       |         |         |         |         |         |         |         |         |          |
| Amphidium mougeotii (Bruch & Schimp.)                       |         | 3       | 5       | 3       | 2       | 1       | 3       |         |         | 1        |
| Sciurohypnum plumosum (Hedw.) Ignatov & Huttunen            | 2       | 3       | 2       | 4       | 4       | 5       |         |         |         |          |
| Sciurohypnum populeum (Hedw.) Ignatov & Huttunen            | 3       | 4       | 3       |         |         |         |         |         |         | 2        |
| Niphophyllum canescens (Hedwig)                             | 3       | 2       |         |         | 3       |         |         |         |         |          |
| Fissidens gracilifolius Brugg.-Nann. Et Nyh. In Nyh.        | 2       | 1       | 2       | 3       | 3       | 3       | 2       | 4       | 4       | 5       |
| Fissidens taxifolius Hedw.                                  | 3       | 2       |         |         | 3       |         |         |         |         |          |
| Fissidens bryoidea Hedw.                                    | 1       |         |         |         |         |         |         |         |         |          |
| Niphophyllum canescens (Hedwig)                             | 3       | 4       | 3       |         |         |         |         |         |         |          |
| Niphophyllum canescens (Hedwig)                             | 1       |         |         |         |         |         |         |         |         |          |
| Seligeria pusilla (Hedw.) B. S. G.                          | 2       |         |         |         |         |         |         |         |         |          |
| Eucladium verticillatum (Brid.) Bruch & Schimp. in B.S.G.   | 4       | 2       | 3       | 3       | 3       | 3       | 2       | 3       | 2       | 2       |
| Tortula euryphylla Zander                                    | 4       | 2       |         |         |         |         |         |         |         |          |
| Eucladium verticillatum (Brid.) Bruch & Schimp. in B.S.G.   | 1       |         |         |         |         |         |         |         |         |          |
| Orthotrichum sp.                                            | 1       |         |         |         |         |         |         |         |         |          |
| Orthotrichum sp.                                            | 2       | 1       |         |         |         |         |         |         |         |          |
| Plagiopus oederianus (Sw.) Crum et Anderson                 | 2       | 1       | 1       | 2       | 2       |         |         |         |         |          |
| Hedera helix L.                                              | 3       |         |         |         |         |         |         |         |         |          |
| Carex sp.                                                    | 2       |         |         |         |         |         |         |         |         |          |
| Poa sp.                                                     | 2       |         |         |         |         |         |         |         |         |          |
| Geranium robertianum L. s.l.                                | 3       |         |         |         |         |         |         |         |         |          |
| Stellaria media (L.) Vill. S.l.                             | 3       |         |         |         |         |         |         |         |         |          |
| Campanula sp.                                               | 1       |         |         |         |         |         |         |         |         | 1        |
| Campanula sp.                                               | 2       |         |         |         |         |         |         |         |         |          |
| Asplenium ruta-muraria L.                                   | 2       | 3       | 2       | 2       | 3       | 2       |         |         |         | 1        |
| Asplenium trichomanes L.                                    | 2       | 3       | 2       | 1       | 2       | 4       |         |         |         | 2        |
| Asplenium scolopendrium (L.) Newman                         | 3       | 2       | 2       | 2       | 1       | 2       | 2       | 2       | 2       | 3       |
| Woodsia fragilis (Trev.) Moore                              | 1       |         |         |         |         |         |         | 3       | 2       | 2       |
| Gymnocarpium dryopteris (L.) Newman                         | 2       | 2       | 1       | 2       | 2       |         |         |         |         |          |
| Pteris cretica L.                                           | 2       |         |         |         |         |         |         |         |         |          |
| Adiantum capillus-veneris L.                                | 3       | 2       | 2       | 2       | 1       | 1       | 2       | 2       | 3       | 2       |
| Phylum Magnoliophyta                                        | 2       | 3       | 2       | 3       |         |         |         |         |         |          |
| Phylum Polypodiophyta                                       | 3       |         |         |         |         |         |         |         |         |          |
| Phylum Chlorophyta                                          | 2       | 3       | 2       | 3       |         |         |         |         |         |          |

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TABLE 2.

| Species | Frequency |
|---------|-----------|
| Klebsormidium flaccidum (Kützing) P.C.Silva, K.R.Mattox & W.H.Blackwell | 2 3 |
| Klebsormidium nitens (Meneghini) Lokhorst | 2 2 |
| Ulothrix sp. Kützing | 1 2 3 |
| **Phylum Bacillariophyta** | |
| Humidophila contenta (Grunow) Lowe, Kociolek, J.R.Johansen, Van de Vijver, Lange-Bertalot & Kopalová | 3 2 2 3 3 3 2 3 |
| Humidophila gallica (W.Smith) Lowe, Kociolek, Q.You, Q.Wang & Stepanek | 3 2 2 2 |
| Navicula sp. | 2 2 |
| Navicula cryptocephala Kütz. | 1 2 |
| Pinnularia borealis Ehr. | 1 1 2 1 1 |
| Hantzschia amphioxys (Ehrenberg) Grunow in Cleve & Grunow | 2 2 2 1 1 |
| Aulacoseira sp. | 2 1 |

**Figure 4.** Scatter plots of 18 sites based on: a) total species composition, b) higher plants species composition, c) algae and cyanobacteria species composition; d) cluster analysis for 18 sites based on total species composition of communities in different cave zones.
It was established that species composition of lampenflora is most close to the entrance zone in case of communities’ development under the lamps, which are located in more or less closed and less ventilated grotto parts of the cave with temporary water flows and a variety of substrates.

Discussion

Relative to the aerophytic phototrophs from the cave entrances, lampenflora is completely independent of essential light and other external climatic factors (Mulec et al., 2008). However biodiversity of lampenflora communities is not stable in time. As a result of multiyear analysis dedicated to phototropic communities from Akshhtyrskaya cave the difference in species composition and structure was revealed in 2008-2019. Results of present study show increase in species composition by 42 species compared with data of Mazina & Maximov (2011) representing biodiversity of abovementioned communities on the earlier stages of succession. This fact indicates communities’ development in the direction of increasing biodiversity, which is associated with the lack of significant cleaning of the lampenflora and the continuous exploitation of the cave in different seasons, as well as with the constant location of most lamps.

Generally Cyanobacteria predominates in phototropic cave communities of show caves (Mulec et al., 2008; Smith, Olson, 2007; Czerwik-Marcinkowska, Mrozińska, 2011; Lamprinou et al., 2014; Popović et al., 2015). However, in Ahshtyrskaya cave species of Bryophyta and Cyanobacteria prevailed.

It should be noted that both the phototrophic communities of the entrance zone and the communities of light spots around lamps was discrete, which is probably associated with the presence of different substrates in the illuminated zones: clay deposits of different thickness, limestone and calcite. Colonization is complicated by the presence of cracks in the rock, filled with clay material and the influence of meso-landscapes and water flows. Cave's geomorphology, water circulation and air fluxes as well as human presence and illumination time play a significant role in lampenflora development (Borderie et al., 2014).

For the first time, an analysis of the similarity of the communities from different cave zones was carried out in a stationary and long-equipped cave. Analogous comparing at the initial stage of lampenflora development showed a low similarity of species composition (Mazina & Kozlova, 2018). The tendency of lampenflora communities to species composition of entrance zone ones were revealed in Ahshtyrskaya cave.

Thus, communities of the entrance zone, especially for horizontal caves with one large entrance, as Ahshtyrskaya cave can be considered as a model for lampenflora communities.

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