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Article

Testate amoebae of the natural monument bog “Klyukvennoye-2” (Usman pine forest, Voronezh Oblast, Russia)

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Abstract. This paper was the first to present the results of investigations of species composition of testate amoebae from different microbiotopes with regard to watering and a substrate type of the protected natural area “ bog Klyukvennoye-2” of Usman Pine Forest. A total of 72 species of testate amoebae were identified. Mesophilic communities of testate amoebae dwelling in the intermediate habitats between moss and aquatic microbiotopes were the richest in terms of species number and abundance. These indicators for the testate amoebae community inhabiting dry sphagnum tussocks turned out to be the least. *Arcella gibbosa* had the highest abundance among all identified species.

Keywords: Protista, sphagnobionts, protected natural areas

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*Научная статья***Раковинные амёбы памятника природы болота «Клюквенное–2» (Усманский бор, Воронежская область, Россия)**О.Н. Загумённая *Институт биологии внутренних вод им. И.Д. Папанина РАН, 152742, Россия, Ярославская обл., Некоузский р-н, п. Борок, 109**zagumelga@gmail.com*

Аннотация. В работе впервые рассматриваются результаты изучения видового состава сообществ раковинных амёб из разнотипных микробиотопов, отличающихся по степени обводнённости и составу субстрата переходного болота Клюквенное-2 (ООПТ) Усманского бора. Выявлено 72 вида раковинных амёб. Наиболее богатыми по числу видов и количественному обилию были мезофильные сообщества раковинных амёб, населяющие промежуточные местообитания между моховыми и водными микробиотопами. Сообщество раковинных амёб, населяющих сухие сфагновые кочки, отличалось самыми низкими показателями. Среди всех выявленных видов *Arcella gibbosa* имела максимальное количественное обилие.

Ключевые слова: Protista, сфагнобионты, ООПТ

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Introduction

Testate amoebae are a polyphyletic group of amoeboid protozoa with a protective shell, uniting the filose testate amoebae of the clades Rhizaria and Stramenopiles (supergroup TSAR, domain Diaphoretickes) and lobose testate amoebae referred to the Amoebozoa supergroup (domain Amorphea) (Adl et al., 2019; Kosakyan et al., 2016). These organisms are the primary destructors of plant litter. They decompose lignin and cellulose (Gilbert, 2003; Schönborn, 1965), accumulate mineral elements (calcium, magnesium, and silicon), play an important role in microbial food webs and represent a dominant group of eukaryotes in sphagnum bogs (Mieczan and Tarkowska-Kukuryk, 2013; Mitchell et al., 2003). Testate amoebae quickly respond to local changes in environmental conditions and are sensitive to the degree of moisture and acidity. Shells of testate amoebae are resistant to decomposition (Bobrov, 2002) that makes them a valuable bioindicator of a hydrological regime of swamps.

The present study was aimed at investigating the testate amoebae communities from different-type microbiotopes with various degree of watering and substrate composition of the transitional bog Klyukvennoye-2 (the Natural Monument of Usman Pine Forest in Voronezh Oblast, Russia).

Material and methods

Usman Pine Forest is a forest area located on the left-bank sandy terraces of the Voronezh River at the western boundary of the Oka-Don lowland plain (Fig. 1). The Klyukvennoye-2 sphagnum bog is the natural monument of regional significance with an area of ~ 0.02 km². The sphagnum cover is represented by cotton grass-sphagnum, willow-sphagnum, sphagnum-bog bean, and sphagnum-cranberry associations. The water is characterized by aerobic conditions with pH = 6.44 at the periphery and pH = 5.70 in the center (Zhivotova and Koroteeva, 2002).

Samples were collected in June 2016 in different-type microbiotopes of the Klyukvennoye-2 bog with various degree of watering and substrate composition. Sphagnum moss from a birch-sphagnum

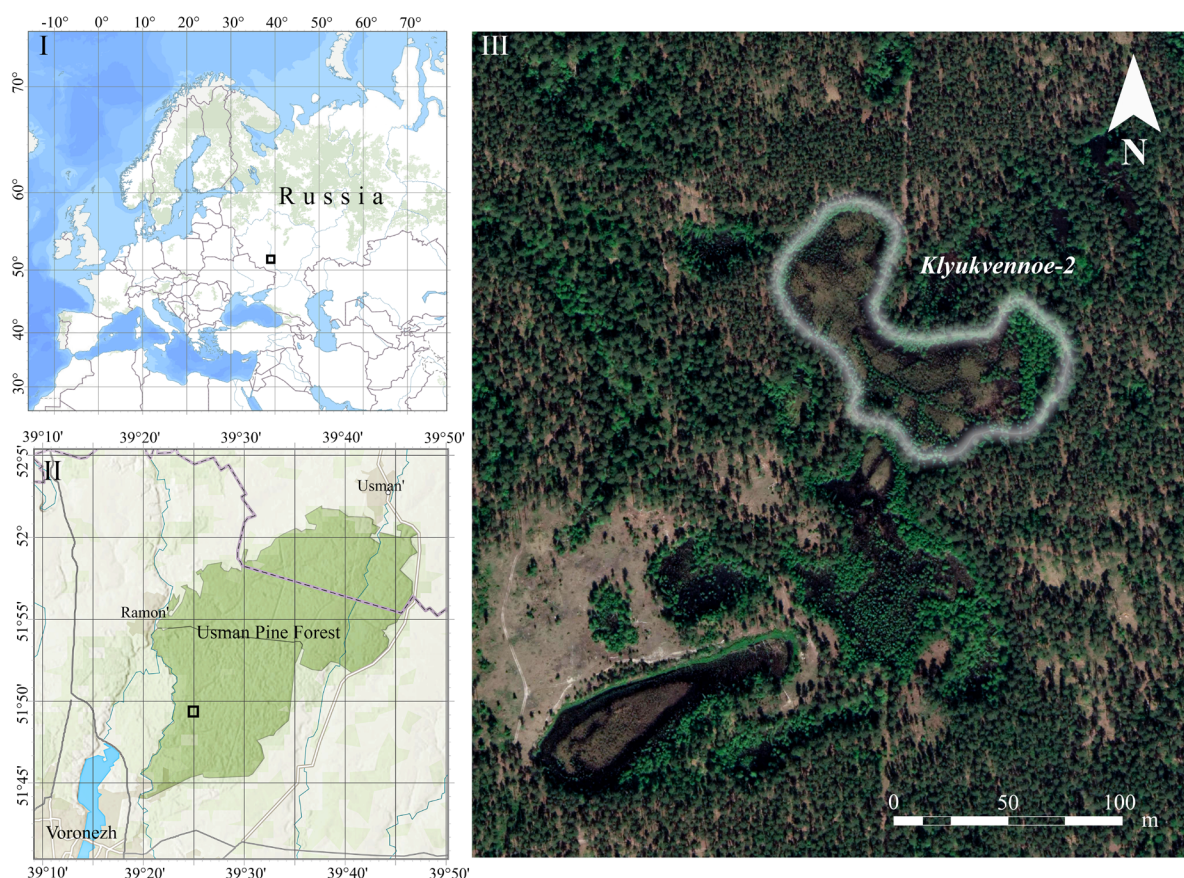


Fig. 1. . Bog Klyukvennoye-2. Usman Pine Forest. Voronezh oblast.

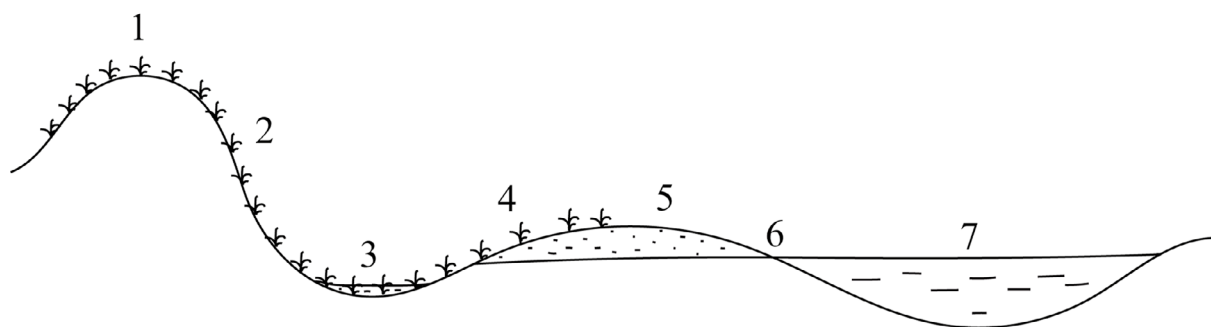


Fig. 2. Schematic representation of microbiotopes. 1 –birch-sphagnum hummock, 2 – space between hummock and mosshole, 3 – mosshole, 4 – sphagnum-covered waterlogged edge of lake, 5 – unvegetated waterlogged edge of small lake, 6 – boundary of small lake, 7 – small lake, suspension of the bottom detritus.

hummock, a hollow, a vegetation-free waterlogged edge of a small lake, suspension of bottom detritus of the lake and intermediate spaces between the listed biotopes were collected with a sampling step of 25–30 cm (Fig. 2).

In different microbiotopes of the bog, samples were taken in duplicate in 50 ml plastic tubes in accordance with a previously described method (Mazei et al., 2009). Sphagnum samples consisted of a bunch of moss stems up to 10 cm high, separated from the lower more decomposed part. Samples from waterlogged areas and rotted remains were taken by scooping substrate and water with bottom sediment, filling the sampling tube three-quarters full. The obtained samples were transported to the laboratory for further study at 4 °C.

Species identification was made using monographs (Mazei and Tsyganov, 2006; Todorov and Bankov, 2019) and the electronic database Microworld¹. Quantitative counts of testate amoebae in one gram of substrate were carried out based on the sedimentation and concentration method (Rakhleeva and Korganova, 2005) with photo documentation using an inverted microscope. Testate amoebae were counted in total and separately for each species. The number of specimens of testate amoebae in 1 gram of substrate was calculated. Species were considered dominant if their relative abundance in 1 gram of sample was more than 10% of the total number of testate amoebae in 1 g of the microbiotope under study (Mazei and Tsyganov, 2007.).

An inverted light microscope CKX41 (Olympus, Tokyo, Japan) with phase contrast (20× and 40× magnification) and an EOS 650D digital camera (Canon, Tokyo, Japan) were used to observe testate amoebae.

To identify the differences between local communities from different microbiotopes, species ordination was made using the principal component analysis. The PAST 4.03 software package was employed in statistical processing (Hammer et al., 2001).

A fine structure of testate amoebae shells was studied with scanning electron microscopy. Shells were transferred onto coverslips using a glass micropipette. After drying the slides in air at room temperature, they were washed three times with distilled water for 5 minutes each and dried again. The coverslips were glued to aluminum electron microscope stages using a conductive carbon tape (Nisshin EM Co., Ltd., Tokyo, Japan). The preparations were studied with a JSM-6510 LV scanning electron microscope (Jeol, Tokyo, Japan) at an accelerating voltage of 15 kV.

Results

As a result of the study, 72 species and infraspecific taxa of testate amoebae were identified in different types of microbiotopes of the Klyukvennoye-2 bog (Fig. 3). The abundance of each species of testate amoebae in 1 g of substrate was calculated for each type of microbiotope, and the dominant species were determined (Table 1).

¹ Siemensma, F.J., 2022. Microworld, world of amoeboid organisms. Web page. URL: <https://arcella.nl> (accessed 22.04.2022).

Among the seven types of studied microbiotopes with different watering and substrate composition, the highest species richness and abundance were revealed in mesophilic communities of testate amoebae inhabiting the intermediate habitats between moss and aquatic microbiotopes, such as the sphagnum-covered waterlogged edge of the small lake (25 species, 1620 ind./g) and the unvegetated waterlogged edge of the lake (24 species, 1600 ind./g).

The lowest number of species (11) and abundance of testate amoebae (280 ind./g) were noted for the sphagnobiont xerophilic community on dry sphagnum hummocks. Three species of testate amoebae (*Assulina quadratum*, *Assulina colaris*, and *Euglypha strigosa glabra*) were found only here.

Various species of testate amoebae differed in abundance. This indicator was the highest for the detritophilic species *Arcella gibbosa* (180 ind./g), while the least – for the eurytopic sphagnophilic species *Assulina quadratum* (10 ind./g).

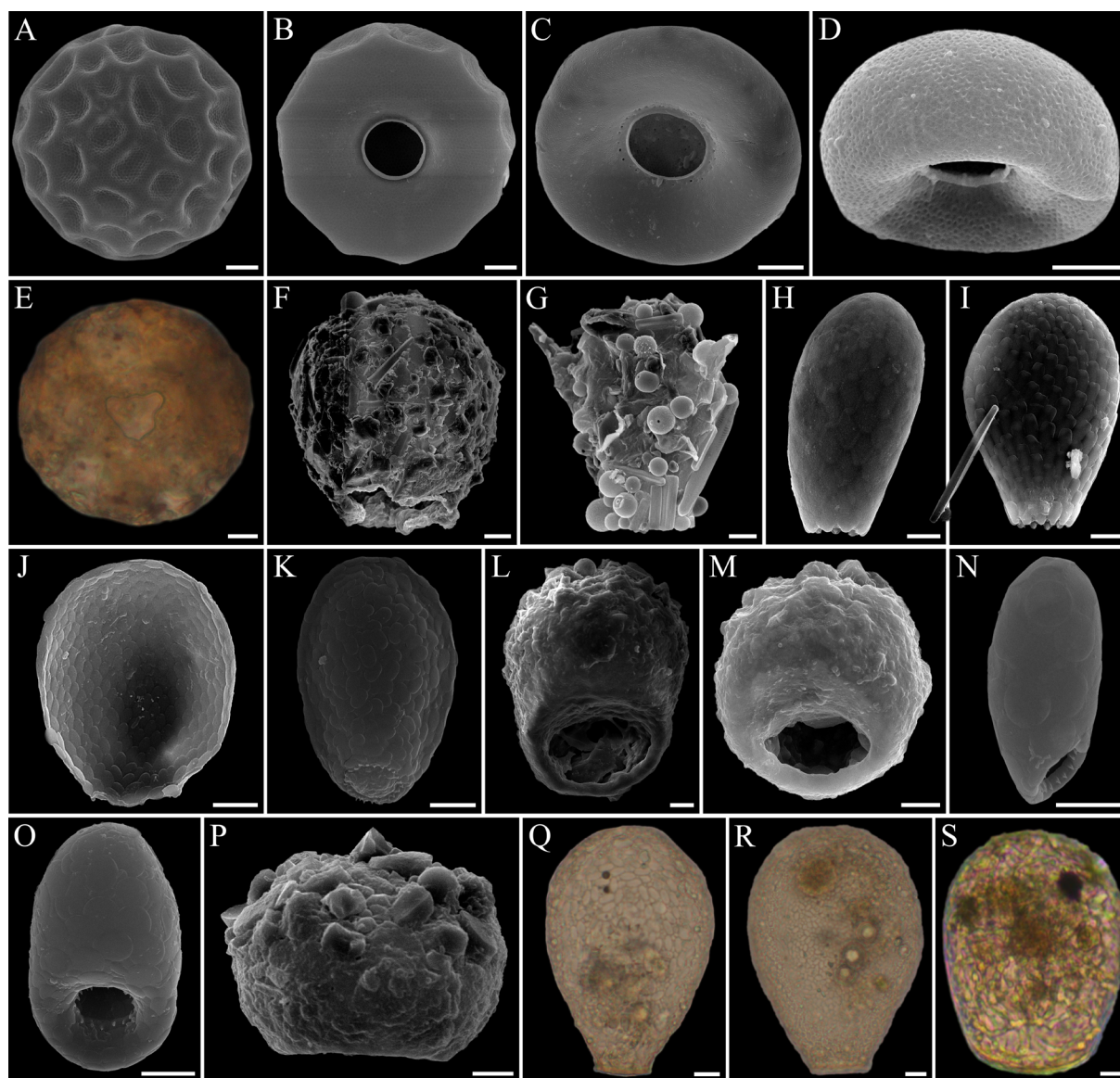


Fig. 3. The representatives of testate amoebae of the bog Klyukvennoe-2, light (E, Q–S) and scanning electron microscopy (A–D, F–P). A–B – *Arcella gibbosa*; C – *A. artocrea*; D – *A. rotundata*; E – *Trigonopyxis arcula*; F – *Diffugia gramen*; G – *D. leidy*; H – *Euglypha laevis*; I – *E. strigosa glabra*; J – *Assulina muscorum*; K – *Corythion dubium*; L – *Centropyxis constricta*; M – *C. aerophila*; N – *Trinema lineare*; O – *T. complanatum*; P – *Cyclopyxis eurystoma*; Q – *Nebela tincta*; R – *N. collaris*; S – *Heleopera rosea*. Scale bar: A–G, I, J, L, M, P–S – 10 µm; H, K, N, O – 5 µm.

Table 1. Species composition and abundance (ind./g) of testate amoebae of bog Klyukvennoe-2. BSH – birch-sphagnum hummock; SHM – space between hummock and mosshole; M – mosshole; SW – sphagnum-covered waterlogged edge of lake; W – waterlogged edge of small lake; BL – boundary of small lake; L – small lake, suspension of bottom detritus.

Species	Microbiotope						
	BSH	SHM	M	SW	W	BL	L
<i>Arcella catinus</i> Penard, 1890	–	–	–	60	80	60	–
<i>A. costata</i> Ehrenberg, 1847	–	–	–	–	–	–	80
<i>A. formosa</i> Nicholls, 2005	–	–	–	–	–	–	120
<i>A. gibbosa</i> Penard, 1890	–	–	–	–	40	160	180
<i>A. mitrata</i> Leidy, 1876	–	–	–	40	–	–	–
<i>A. ovaliformis</i> Chardez et Beyens, 1987	–	–	–	90	60	–	–
<i>A. rotundata</i> Playfair, 1918	–	–	–	–	–	–	40
<i>A. vulgaris</i> Ehrenberg, 1830	–	–	–	–	–	40	–
<i>Argynnia crenulata</i> (Deflandre, 1936)	–	–	–	40	–	–	–
<i>A. dentistoma</i> (Penard, 1890)	–	–	–	–	–	60	–
<i>Assulina colaris</i> Kufferath, 1932	–	40	–	–	–	–	–
<i>A. muscorum</i> Creeff, 1888	30	60	–	–	80	80	–
<i>A. quadratum</i> van Oye, 1958	10	–	–	–	–	–	–
<i>A. seminulum</i> (Ehrenberg, 1848) Leidy, 1879	–	40	–	40	–	–	–
<i>Centropyxis aerophila aerophila</i> Deflandre, 1929	20	40	120	140	120	–	–
<i>C. aerophila sphagnicola</i> Deflandre, 1929	–	40	80	–	–	–	–
<i>C. constricta</i> (Ehrenberg, 1841) Penard, 1890	–	–	–	140	–	–	–
<i>C. delicatula</i> Penard, 1902	–	–	–	–	40	100	–
<i>C. orbicularis</i> Deflandre, 1929	–	40	120	–	100	120	100
<i>C. pontigulasiformis</i> Beyens, Chardez et De Bock, 1986	–	–	–	40	–	–	–
<i>C. sylvatica</i> (Deflander, 1929) Bonnet et Thomas, 1955	20	–	–	60	–	–	–
<i>Clypeolina marginata</i> Penard, 1902	–	–	–	–	–	–	60
<i>Corythion constricta</i> (Certes, 1889) Jung, 1942	–	–	80	–	–	–	–
<i>C. dubium</i> Taranek, 1871	30	80	80	100	60	–	80
<i>Cryptodiffugia crenulata</i> (Playfair, 1917)	–	–	–	60	40	–	–
<i>C. minuta</i> Playfair, 1917	–	–	–	–	60	20	–
<i>C. oviformis</i> Penard, 1902	30	–	–	40	80	–	–

Species	Microbiotope						
	BSH	SHM	M	SW	W	BL	L
<i>C. pusilla</i> Playfair, 1917	–	–	40	–	–	–	–
<i>C. sacculus</i> Penard, 1902	–	–	–	–	–	60	40
<i>Cucurbitella mespiliformis</i> Penard, 1902	–	–	–	–	–	20	–
<i>Cyclopyxis eurystoma</i> Deflandre, 1929	20	40	–	10	120	180	120
<i>C. intermedia</i> Kufferath, 1932	–	40	60	–	–	–	–
<i>C. kahli</i> Deflandre, 1929	–	–	–	–	–	–	100
<i>Diffugia brevicolla</i> Cash et Hopkinson, 1909	–	–	–	–	40	80	–
<i>D. compressa</i> (Leidi, 1879) Gauthier-Lievre et Thomas, 1958	–	–	–	60	–	–	–
<i>D. geosphaira</i> Ogden, 1991	–	–	–	–	–	–	40
<i>D. globulosa</i> (Dujardin, 1837) Penard, 1902	–	–	–	–	–	80	–
<i>D. gramen</i> Penard, 1902	–	–	–	–	–	–	60
<i>D. lebes</i> Penard, 1899	–	–	80	–	–	–	–
<i>D. leidy</i> Wailes, 1913	–	–	–	–	–	40	–
<i>D. mammillaris</i> Penard, 1893	–	–	–	–	–	–	40
<i>D. oblonga</i> Ehrenberg, 1838	–	–	–	60	–	–	–
<i>D. pulex</i> Penard, 1890	–	–	80	80	60	–	80
<i>D. rubescens</i> Penard, 1891	–	–	–	–	–	40	–
<i>Euglypha ciliata</i> (Ehrenberg, 1848) Leidy, 1878	–	–	–	60	40	–	–
<i>E. compressa glabra</i> Wailes, 1915	20	–	–	60	80	–	–
<i>E. laevis</i> (Ehrenberg, 1845) Perty, 1849	20	80	–	80	80	60	40
<i>E. penardi</i> Meisterfeld, 1979	–	–	–	–	–	60	–
<i>E. rotunda</i> Wailes, 1915	–	80	–	–	80	–	60
<i>E. strigosa strigosa</i> (Ehrenberg, 1848) Leidy, 1878	20	–	–	40	100	80	–
<i>E. strigosa glabra</i> Wailes, 1898	20	–	–	–	–	–	–
<i>Frenzelina minima</i> Hoogenraad, 1910	–	–	–	–	–	80	60
<i>Galeripora arenaria</i> (Greeff, 1866) González-Miguéns et al., 2021	–	–	–	–	–	–	40
<i>G. artocrea</i> (Leidy, 1876) González-Miguéns et al., 2021	–	–	80	–	–	–	–
<i>Heleopera rosea</i> Penard, 1890	–	–	–	–	–	40	–
<i>Lesquereusia pseudonebeloides</i> Golemansky, 1966	–	–	–	40	–	–	–

Species	Microbiotope						
	BSH	SHM	M	SW	W	BL	L
<i>L. spiralis</i> (Ehrenberg, 1840) Bütchli, 1888	–	20	40	60	–	60	–
<i>Meisterfeldia chibisovi</i> Bobrov, 2016	–	–	–	–	–	40	–
<i>Nebela collaris</i> (Ehrenberg, 1848) sensu Kosakyan et Gomaa, 2013	–	–	40	–	–	–	–
<i>N. fiabellulum</i> Leidy, 1974	–	–	–	–	20	–	–
<i>N. tincta</i> (Leidy, 1879) sensu Kosakyan et Lara, 2012	–	–	140	–	–	–	–
<i>Oopyxis cyclostoma</i> Thomas, 1958	–	–	–	–	–	20	–
<i>Phryganella acropodia</i> (Hertwig et Lesser, 1874) Hopkinson, 1909	–	–	–	–	–	–	40
<i>P. dissimulatrix</i> Chardez, 1969	20	40	–	–	–	–	–
<i>Pseudodifflugia archeri</i> Penard, 1899	–	–	–	–	40	–	40
<i>P. klarae</i> Kiss et Török, 2009	–	–	–	–	40	–	–
<i>Pyxidicula operculata</i> (Agardh, 1827) Ehrenberg, 1838	–	40	–	60	80	–	–
<i>P. patens</i> Claparède et Lachman, 1858	–	–	–	–	–	–	40
<i>Trigonopyxis arcula</i> Penard, 1912	–	40	–	–	–	–	–
<i>Trinema complanatum</i> Penard, 1890	–	60	40	100	–	–	–
<i>T. enchelys</i> Ehrenberg, 1838	–	20	–	–	60	–	–
<i>T. lineare</i> Penard, 1890	20	80	40	60	–	–	60
Total abundance, ind./g	280	880	1120	1620	1600	1580	1520
Number of species	13	18	15	25	24	23	22
Shannon index, bit/ind.	2.533	2.815	2.621	3.117	3.1	2.982	2.976

The total number of species found in each microbiotope ranged from 13 to 25. The number of dominant species in each biotope of the Klyukvennoye-2 bog was small (3–5 species).

By species structure, the communities of dominants were clearly divided into three types (Fig. 4). The first type included xerophilic species of testate amoebas (*Cryptodifflugia oviformis*, *Corythion dubium*, *Assulina muscorum*, *Euglypha rotunda*) and eurybiont species (*Trinema lineare*, *Euglypha laevis*) formed in the driest biotopes. The second one was composed of hydrophilic *Arcella gibbosa* and *Cyclopyxis euryostoma* formed in the most moistened microbiotopes. The third intermediate type (mesophilic) formed in microbiotopes with average moisture and included hydrophilic species (*Centropyxis constricta*, *Centropyxis aerophila*, *Centropyxis orbicularis*) and a xerophilic species of testate amoebae (*Nebela tincta*).

Discussion

The species composition of testate amoebae inhabiting different types of microbiotopes of the sphagnum bog of Usman Pine Forest largely coincides with that of the swamp ecosystems of the forest-steppe and southern forest zones of the East European Plain (Babeshko et al., 2015), as well as with the composition of sphagnobiont testate amoebae in wetlands of the European part of Russia (Tsyganov and Mazei, 2007).

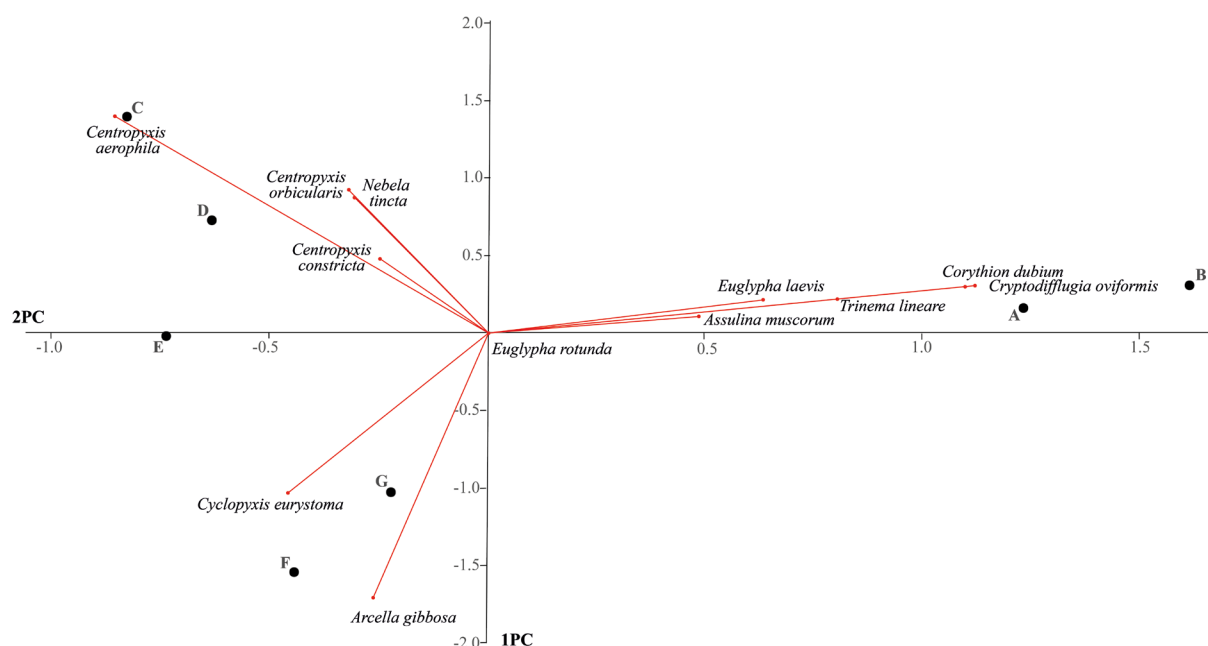


Fig. 4. Result of community ordination by principal component analysis: 1 PC – 41.6%; 2 PC – 24.5%; **A** – birch-sphagnum hummock, **B** – space between hummock and mosshole, **C** – mosshole, **D** – sphagnum-covered waterlogged edge of lake, **E** – unvegetated waterlogged edge of small lake, **F** – boundary of small lake, **G** – small lake (suspension of bottom detritus).

The studied communities of testate amoebae were dominated by four families, i.e. Diffugiidae, Euglyphidae, Arcellidae, and Centropxyidae, characteristic of lowland swamps (Malysheva et al., 2014). In general, these families are dominant in many boggy biotopes in the European part of Russia (Mazei and Tsyganov, 2007).

The low abundance of testate amoebae in the studied biotopes (250–1620 ind./g) in comparison with other related studies (Jassey et al., 2011; Mazei and Embulaeva, 2015; Mazei et al., 2007; Tsyganov and Mazei, 2007) may indicate extreme habitat conditions for testate amoebas due to frequent periods of drying out and watering of the Klyukvennoye-2 bog (Philippov and Prokin, 2017).

Conclusion

In various types of microbiotopes of the Klyukvennoye-2 bog, 72 species of testate amoebae were found, including intraspecific taxa. Among seven studied types of microbiotopes with different watering and substrate composition, mesophilic communities of testate amoebae, inhabiting intermediate habitats between moss and aquatic microbiotopes, were the richest in species number and most abundant. On the contrary, these indicators were the least for the community of testate amoebae inhabiting dry sphagnum hummocks. Abundance of various testate amoebae species in the communities differed: for *Arcella gibbosa* it was the highest, while for *Assulina quadratum* the lowest. A clear change in the species composition, dominant species structure and abundance of testate amoebae was observed along the studied transect with alternating different-type microbiotopes of the Klyukvennoye-2 bog.

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