Testate amoebae analysis in the peat deposits of the swamp Dolgon’koye in the south of Western Siberia and peatland paleohydrology for last 3100 years

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Abstract. Our research is devoted to paleohydrological reconstruction in the swamp located in the river valley on the piedmont of the Altai Mountains in the south of Western Siberia. The reconstruction was carried out based on rhizopod analysis for the last 3100 cal yr. A large amount of different testate amoebae was found in the peat. Total 64 testate amoebae taxa were recorded in the peat core with the most abundant being: Trinema lineare, Centropyxis aculeata, C. aerophila, Euglypha rotunda, Cryptodifflugia sp. Decrease of surface wetness in the swamp are observed 2280, 2140, 1900–600 cal yr BP and increase – in 2700, 2500–1900, 230–215 cal yr BP. The results of our reconstruction of the swamp paleohydrology agrees well with the paleoclimatic data obtained earlier for the central area of the south of Western Siberia Plain. It indicates a high sensitivity of the swamp to climatic changes in the Holocene. The rhizopod analysis proved to be very effective when used for paleohydrology reconstruction in minerotrophic peat.

1. Introduction
Our study focuses on the reconstruction of surface wetness dynamics in minerotrophic swamp during its development based on rhizopod analysis data. Rhizopod analysis is a study of fossil testate amoebae remained in the peat. Testate amoebae (Rhizopoda, Testacea) are unicellular organisms, which are widespread in mire ecosystems and often used in paleoecological research as bioindicators for reconstruction of surface wetness dynamics. In most cases, this analysis is applied in researches of ombrotrophic mires, because their surface wetness depends directly on hydroclimatic fluctuations [1-3]. However, evaluating the possibility of using rhizopod analysis for the fens is of special interest. This will allow us to expand the borders of application of the paleoecological reconstructions based on rhizopod analysis for the areas where there are no ombrotrophic bogs. The south of Western Siberia Plain may be considered as one of such areas. According to [4] this area belongs to the eutrophic (phragmites) and brackish bog zone, where peatlands generally occur in valleys or in topographic depressions. For paleoclimatic reconstructions, such natural archives as lake sediments are of primarily use [5-7]. Although one of the works [3] reconstructed the amoeba-based paleohydrology of an ombrotrophic bog located at the border of the southern taiga and the birch-poplar forest steppe, it is important to note that the area under study belongs to the zone of insufficient moisture, so the hydrological conditions in the peatlands of this territory are strongly dependent on the climate
humidity [4]. Therefore, the peatland deposits are a very promising object for the paleohydrology reconstruction and paleoclimatic studies in this regard.

The purpose of the study is to reconstruct the surface wetness dynamics in the floodplain terrace minerotrophic swamp in the south of Western Siberia during the Holocene. We are posing the following specific questions: 1) What is the structure of the composition and species of the testate amoebae assemblages in the minerotrophic peat? 2) How many tests of amoebae are in minerotrophic peat and is it worth to use the rhizopod analysis for reconstruction of swamp paleohydrology? 3) Are there enough amoeba tests in the peat for quantitative reconstruction of the water table depth (WTD)? 4) What is the sensitivity of the minerotrophic deposits to the paleoenvironmental changes, which may be expressed in presence, frequency, amplitude of fluctuations of reconstructed WTD?

2. Study area

The study area belongs to the south of Western Siberia, Kosikhinsky district of the Altai region, to the territory of the third floodplain terrace on the right bank of the Ob’ River on a piedmont of Altai mountains [8] (figure 1). The investigated swamp Dolgon’koye lies in the valley of the shallow river Bobrovka in 4 km from the lake Krasilovo (53°12’45’’ N, 84°24’26’’ E, 198 m a.s.l.). Due to the pristine relief, the swamp shape is elongated from the southwest to the northeast. It is 1600 m long and its maximum width is about 300 m. At the present time, tall birch forest (tree height is 13–15 m) grows on the surface of the swamp with a rich shrub and herb cover. It includes a mixture of forest, meadow, marsh, marsh-swamp and weedy species of plants. The upper 10 cm layer of the peat is highly decomposed, well-structured humus horizon due to the activity of large number of earthworms. The overgrowth of the swamp by the high-stand forest clearly indicates its drainage in the last several decades. In the absence of direct anthropogenic impact on the swamp, this process is possibly caused by the influence of the climate. The peat core was collected in the thickest part of the swamp profile. The thickness of the peat deposit is 287 cm. It is underlaid by 135 cm of laminated organo-mineral deposits. For the peat deposit 10 radiocarbon dates were obtained by liquid–scintillation method in the laboratory of IMCES SB RAS (table 1). The peat deposit is formed by minerotrophic peat with clear layers of different color. Total 32 peat samples for rhizopod analysis were collected with step 1 cm selectively throughout the depth of 210 cm of the peat deposits (from the deeper part of the peat core only small samples were selected due to the very dense structure of the deposits. So they were not sufficient for the rhizopod analysis). The peat sample from the 209-208 cm depth is dated 3090 cal yr BP.

This paper presents preliminary results of the rhizopod analysis using only 32 separated samples from the peat core. In the future, we are planning to continue the research and obtain a continuous series of testate amoeba data for this peat core. To carry out the rhizopod analysis we selected 32 peat samples with the most contrasting results in regards of the obtained peat humification (authors unpublished data). The peat humification was determined by the spectrophotometric method [9].

3. Methods

Peat samples (approximate volume is 3 cm³) for testate amoeba analysis were prepared following a modified water-based sieving technique [10]. The samples were mixed with water and thoroughly shaken. The suspension passed through a sieve with mesh opening of 0.355 mm. Then the suspension was concentrated by sedimentation to the volume of 10 ml. The testate amoebae were indentified and counted in the wet mounts using a light microscope (Altami, Russia) with ×200-400 magnification. The quantitative reconstruction of the water table depth during the swamp development is carried out based on testate amoeba data. For these calculations we used the calibration model, which we developed in the other study on some minerotrophic mires in the southern taiga of Western Siberia. The model included 45 moss samples taken from the mire surface. The results of the canonical correspondence analysis confirmed that the relationships between the water table depth and the species structure of testate amoebae assemblages are statistically significant. Therefore, transfer functions could be developed for the water table depth. The transfer function WA (weighted averaging) was
applied for the reconstruction. The model performance was achieved with jackknifing (leave-one-out) method: RMSEP – 7.1; \( r^2 \) – 0.75; Max bias – 11.7; and bootstrapping (999 cycles): RMSEP – 6.8; \( r^2 \) – 0.79; Max bias – 12.7.

![Geographical location of the study site](image)

**Figure 1.** Geographical location of the study site (pointed star).

| Lab. No  | Dated material | Depth, cm | Age \(^{14}\text{C} \) yr BP | Age cal yr BP (1 \( \sigma \)) | Probability |
|----------|----------------|-----------|-----------------------------|-----------------------------|-------------|
| IMCES-14C921 | Peat          | 36–37     | 572 ± 83                    | 616 (584–648)               | 0.617       |
| IMCES-14C905 | Peat          | 49–50     | 706 ± 111                   | 677 (621–733)               | 0.675       |
| IMCES-14C547 | Peat          | 70–71     | 963 ± 72                    | 863 (793–932)               | 1.000       |
| IMCES-14C909 | Peat          | 80–81     | 1503 ± 68                   | 1368 (1319–1417)            | 0.745       |
| IMCES-14C926 | Peat          | 105–106   | 1929 ± 102                  | 1881 (1771–1990)            | 0.911       |
| IMCES-14C542 | Peat          | 124–125   | 2108 ± 74                   | 2073 (1989–2156)            | 0.891       |
| IMCES-14C903 | Peat          | 132–133   | 2173 ± 111                  | 2184 (2051–2317)            | 1.000       |
| IMCES-14C546 | Peat          | 168–169   | 2398 ± 72                   | 2422 (2346–2497)            | 0.749       |
| IMCES-14C907 | Peat          | 191–192   | 2758 ± 81                   | 2853 (2776–2929)            | 0.950       |
| IMCES-14C544 | Peat          | 208–209   | 2944 ± 63                   | 3090 (2999–3180)            | 0.980       |
4. Results and discussion
The total 64 testate amoebae taxa were recorded in the peat core with the most abundant being: 
Trinema lineare (average relative abundance 24%), Centropyxis aculeata (13%), C. aerophila (8%), 
Euglypha rotunda (8%), Cryptodifflugia sp. (7%) (figure 2). 36 species from the peat samples are used 
in the calibration model, so these species are included in the reconstruction of the water table depth 
dynamics. The other 28 testate amoebae species from peat samples do not participate in the calibration 
model. So their optima are not estimated and they are not included in the reconstruction. Although 
according to the literature [11-12] the most of these species are typical for minerotrophic mires. 

Figure 2. Testate amoeba relative abundance diagram showing all species with relative abundance of 
more than 10% in the peat core from the swamp Dolgon’koye.

The amoebae tests are well preserved in the studied peat core. The average number of species per 
sample is high (20 ± 5 SD). In the most part of the peat samples (21) more than 300 specimens of 
testate amoebae were counted, in 9 peat samples – more than 150 specimens and only in 2 peat 
samples (from the depth 170–169, 183–182 cm) less than 150 specimens were counted. It is important 
to note that Euglyphid species: Trinema lineare, Euglypha rotunda, Corythion pulchellum, – reached a 
high abundance throughout the depth of the peat deposits. Although according to research [13-14] the 
Euglyphid species are very rarely found in peat bogs and are characterized by low preservation of tests 
compared to other species. As our results showed, Euglyphid species seem to be well preserved in the 
minerotrophic peat. This fact further emphasizes the prospects of using rhizopod analysis in 
paleoecological studies of minerotrophic mires.

Twelve stages of the swamp development and its WTD dynamics are distinguished by the 
stratigraphically constrained clustering of testate amoebae assemblages in the peat core.

Stage 1. 210–208 cm (3105–3075 cal yr BP) – testate amoebae assemblages are dominated by 
Trinema lineare and Corythion pulchellum (dry condition indicators). They represent the low level of 
the swamp surface wetness (WTD is 10.0 cm).

Stage 2. 208–201 cm (3075–2980 cal yr BP) – this stage is characterized by increases in 
Cryptodifflugia sp.1. This species is accompanied by Cyclopyxis eurystoma, C. eurystoma v. parvula, 
C. kahli, Plagiopyxis minuta v. oblonga. A combination of these species indicates the low level of the 
swamp surface wetness (WTD is 6.8 cm).
Stage 3. 201–191 cm (2980–2835 cal yr BP) – species Centropyxis aculeata and C. aerophila dominate the testate amoebae assemblages. In addition, the assemblage contains dry indicators: Plagiopyxis minuta v. oblonga and Cyclopyxis eurystoma. It represents the period with slightly wetter conditions (WTD is 5.8 ± 1.8 cm).

Stage 4. 191–188 cm (2835–2780 cal yr BP) – Cryptodifflugia sp.1 dominates as well. With this species Centropyxis aerophila, C. constricta v. minima, C. aculeata are present in the assemblage. WTD is slightly increases up to 6.5 cm. Surface wetness seems to be a little less.

Stage 5. 188–172 cm (2780–2480 cal yr BP) – this stage is characterized by dominating of Centropyxis aculeata and C. aerophila. These species are accompanied with C. cassis, Arcella discoides v. difficilis, A. jurassica, Schoenbornia humicola and Cyclopyxis eurystoma. It indicates a tendency towards wetter conditions on the swamp surface (WTD is 3.1 ± 2.4 cm).

Stage 6. 172–170 cm (2480–2440 cal yr BP) – testate amoebae assemblages are dominated by Cryptodifflugia sp.1. There are also hydrophilic species: Centropyxis aculeata, Arcella jurassica, Schoenbornia humicola, and dry indicator: Plagiopyxis minuta v. oblonga. WTD is 1 cm.

Stage 7. 170–148 cm (2440–2280 cal yr BP) – species Centropyxis aculeata dominates. It represents wet conditions in the swamp surface (WTD is 2.2 ± 1.5 cm).

Stage 8. 148–142 cm (2280–2245 cal yr BP) – this stage is characterized by absolute dominance of the species Trinema lineare. It indicates dry period (WTD is 13.4 cm).

Stage 9. 142–130 cm (2245–2140 cal yr BP) – species Paraquadrula irregularis reached a high abundance. This species was not found in our study in modern conditions, but in accordance with another research [12] it is most typical for bryophyte tufts in calcareous fens. So it represents the period with the wettest conditions in the swamp surface (WTD is 0 cm).

Stage 10. 130–121 cm (2140–2030 cal yr BP) – this short stage is characterized by dominating of Euglypha rotunda. This species is accompanied with Cryptodifflugia sp.1, Cryptodifflugia sp.2, Centropyxis aculeata, Trinema lineare and Corythion pulchellum. Therefore, a combination of these species indicates the middle level of the swamp surface wetness (WTD is 5.9 cm).

Stage 11. 121–70 cm (2030–855 cal yr BP) – this stage is heterogeneous with different dominant species of testate amoebae. High percentages of species Centropyxis aculeata, Trinema lineare, Plagiopyxis minuta v. oblonga, Cryptodifflugia sp.3 are recorded in this stage. Overall, a combination of dry and wet indicators represents the middle level of swamp surface wetness with a high degree of dispersion (WTD is 7.4 ± 5.5 cm).

Stage 12. 70–15 cm (855–215 cal yr BP) – the stage is characterized by high abundance of Trinema lineare and represents dry conditions in the swamp surface (WTD is 11.1 ± 1.9 cm). The last period of the stage (230–215 cal yr BP) is characterized by increases in Trinema enchelys. It indicates the tendency towards slightly wetter conditions on the swamp surface (WTD is 6.3 cm).

Our result of the reconstructed swamp surface wetness is in good agreement with the paleoclimatic data having been obtained by other researchers for the south of West Siberia region (figure 3). The wet conditions in the swamp coincide with the increase of climate humidity 2700 cal yr BP, revealed, on the one hand, in the research of Zakh with co-authors [7], who studied lake sediments of several lakes located about 1000 km in the north-west using multi-proxy approach (archeological, geological and pollen data). On the other hand, this event is supported by the results from the paleohydrological reconstruction using rhizopod analysis of the peat on the ombrotrophic bog located 550 km in the north-west [3]. Besides, in accordance with the other researches [3, 6-7] the climate between 2500 and 1900 cal yr BP was humid. Two of these researches [3, 7] were mentioned above, and the third [6] was carried out using pollen and diatom records from the sediments of the lake situated 400 km in the west. This corresponds to wet conditions in the studied swamp during this period of the Holocene. Than in one of the works [7] a short decrease in the climate humidity was revealed between 2300 and 2100 cal yr BP, and in the other work [3] dry conditions on the bog were detected between 2300 and 2200 cal yr BP and in 2000 cal yr BP. In our study, there are coincident brief decreases of the swamp surface wetness in 2280 and 2140 cal yr BP. The period of a drier climate between 1900 and 600 cal yr BP, revealed in other research [6], corresponds with dry conditions in the swamp surface at this
time. This event also coincides with dry period revealed in the study [5] of the sediments from four lakes located about 400 km in the west, where paleoclimate was reconstructed based on the ostracod analysis. It also corresponds well to the some short dryings (1750, 1600, 1500, 1300–1200, 1100–1000 cal yr BP) on the bog surface in the study [3]. Although according to Zakh and co-author’s data [7] the climate was humid, nevertheless in the period later than 1000–700 cal yr BP drier climatic conditions were shown as well. In the study [7], the increase of climate humidity was shown for the last 300 years, in the other [3] - between 550 and 350 years and in the third study [6] it was shown for the period 750-500 cal yr BP. Slightly wetter conditions in the swamp surface are observed between 230 and 215 cal yr BP in accordance with our research. On the whole, a high degree of consistency of the swamp surface wetness with the paleoclimatic data indicates a high sensitivity of the peat deposits in the studied swamp to climatic changes that occurred in the Holocene.

Figure 3. Testate amoeba based paleohydrology of the swamp Dolgon’koye.

5. Conclusion
Rhizopod analysis in the peat deposits of the swamp revealed well preserved testate amoebae assemblages with high numbers of tests and of species. Therefore, this provided a quantitative reconstruction of the water table depth during the swamp development. The observed changes in species composition of testate amoebae assemblages throughout the depth of peat deposits and oscillations of reconstructed water table depth are clearly the result of paleoenvironmental fluctuations in the process of the swamp development in the Holocene. Our study demonstrated applicability of rhizopod analysis in paleoecological studies of minerotrophic mires.

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