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Findings of *Phreatalona protzi* (Hartwig, 1900) (Cladocera: Anomopoda: Chydoridae) in Russia

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ABSTRACT: We discovered subfossil remains of *Phreatalona protzi* (Hartwig, 1900) (Cladocera: Anomopoda: Chydoridae) in a short sediment core taken from a small tundra lake Pe-03 located in the Pechora River delta, North-East of European part of Russia. This species had been described previously only from Central and Northern Europe. The occurrence of *P. protzi* in the Russian Arctic suggests that this chydorid species must be much more widely distributed than previously reported, and in the near future we expect findings of this species in other regions of Russia.
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Находки *Phreatalona protzi* (Hartwig, 1900) (Cladocera: Anomopoda: Chydoridae) в России

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РЕЗЮМЕ: Субфоссильные остатки *Phreatalona protzi* (Hartwig, 1900) (Cladocera: Anomopoda: Chydoridae) были обнаружены в колонке донных отложений небольшого тундрового озера Pe-03, расположенного в дельте р. Печоры на северо-востоке европейской части России. Ранее находки данного вида отмечены только в Центральной и северной Европе. Обнаружение *P. protzi* в арктической зоне России предполагает, что данные вид хидорид распространен значительно шире, чем ранее сообщалось и следует ожидать в ближайшее его находок в других частях России.

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КЛЮЧЕВЫЕ СЛОВА: *Phreatalona protzi*, Cladocera, Арктика, термокарстовые озера, дельта Печоры, палеолимнология

Introduction

Cladocerans are microscopic branchiopod crustaceans occurring in all kinds of freshwater habitats from large lakes to ponds, and can be found even in small ditches, puddles and water-filled tire ruts (Smirnov, 1971; Kotov *et al.*, 2010). Cladocerans are a major component of the micro-crustacean fauna in freshwater water-bodies playing multiple roles in aquatic ecosystems (Korhola, Rautio, 2001).

Although the indicative potential of Cladocera as a paleolimnological proxy is well recognized (Smirnov, 1971; Kotov *et al.*, 2019), cladoceran communities from Arctic regions of Russia received relatively little attention until now (Kienast *et al.*, 2011; Frolova *et al.*, 2014, 2017) because of their geographical remoteness and difficulties of access (Frolova *et al.*, 2018). Sediment archives integrate Cladocera remains from all habitats: from pelagic, benthic and hyporheic zones of the lakes over several hundreds or thousands of years. Previous studies have shown that a single surface sediment sample could provide a more complete list of chydorid species than multiple hydrobiological samples from the contemporary environment (Frey, 1960; Davidson *et al.*, 2007).

Surface sediments (0–2 cm) in each lake contain remains of the taxa deposited over the past few years, they are usually well preserved and can be identified (Solovieva *et al.*, 2015; Syrykh *et al.*, 2017). Paleolimnological methods of analysis improve our knowledge of the species biogeography by contributing to taxonomical resolution of the hardly accessible sites, where long-term hydrobiological studies are impossible (Nazarova *et al.*, 2017a). This is especially important for small-sized cladoceran taxa, like chydorids as they may easily be overlooked in routine hydrobiological studies due to high diurnal, seasonal, spatial patchiness and difficulties of morphological identification (Nevalainen, 2010; Sweetman, Sarmaja-Korjonen, 2017).

Investigation of the cladocera remains from bottom sediments helps to clarify and expand our knowledge about the distribution of certain species of the cladocera (Nykänen, Sarmaja-Korjonen, 2007; Sweetman, Sarmaja-Korjonen, 2017). E.g., in the Kharbei lakes system (Bolshezemelskaya Tundra, Russia), *Camptocercus rectrostris* Schödler, 1862 was first discovered in a short sediment core taken from the lake Bolshoi Kharbei and only recently this species was found in modern zooplankton communities of this lake as well (Nazarova *et al.*, 2014).

Unapertura latens was first described from the cores of some Scandinavian lakes (Sarmaja-Korjonen *et al.*, 2000) and only recently an intact specimen was found. The species was placed in the genus *Rhynchotalona* (Van Damme, Nevalainen, 2019). Apparently, a chance of finding of rare species remains in sediments is sometimes higher than a chance of collecting living specimens by standard hydrobiological sampling methods.

The rare cladoceran *Phreatalona protzi* (Hartwig, 1900) (Anomopoda: Chydoridae) is among such species. Three specimens (2 females and 1 male) were collected in the coast zone of Lake Hellsee, near Biesenthal (Brandenburg, Germany) by Dr. A. Protz, a curator of Konigsberg's Museum in 1889 (Hartwig, 1900). W. Hartwig named this new species in honour of Dr. A. Protz (Van Damme *et al.*, 2009). Van Damme *et al.* (2009) relocated the species to the genus *Phreatalona*, as the species has some primitive features along with specialization to the rheic life mode.

After initial description, *P. protzi* was reported from Germany (Keilhack, 1911), England (1921), Slovakia (Vranovsky, 1971), Danube Delta in Romania (Negrea, 1966), Turkey (Dumont, Negrea, 1996), Poland and Lithuania (Flössner, 1972), France (Dumont, 1987), Ohrid Lake, Macedonia (Brancelj, Sket, 1990) and Belgium (Van Damme *et al.*, 2009). Further to the East, it was found in the Voronezh Area of Russia (Smirnov, 1971) and in lakes of the Pripyat region of Belarus (Rassashko *et al.*, 2013). The species was never found to the south of the Pyrenees, in the Alps, in the Taurus Mountains or east of the Ural Mountains (Bjerring *et al.*, 2008; Kotov *et al.*, 2010).

In sediment samples *P. protzi* was found for the first time in northern Denmark (Whiteside, 1970). In Finland the species was found both in zooplankton and in subfossil remains (Nykänen, Sarmaja-Korjonen, 2007). In this manuscript we report on the first finding of subfossil remains of *Phreatalona protzi* in Russia and provide environmental characteristics of the site where the species was found.

Regional setting

The Pechora River Basin is situated in Russia at the eastern border of Europe, west of the Ural Mountains, in the Komi Republic and Nenets Autonomous District of the Arkhangelsk Area. The study area is located beyond the Polar Circle, on the southern border of tundra landscape (Nelson, Anisimov, 1993). It belongs to the Malozemelskaya-Bolshezemelskaya province of the tundra and forest-tundra zones of the Russian Plain. In the delta there are lakes and duct fragments, as well as wetlands. Lakes of the region are mostly small in size (0.5–3.0 ha), are located in drainless depressions and have moraine or thermokarst origin. The lakes are mainly low-mineralized, oligotrophic and do not experience any anthropogenic impact (Solovieva *et al.*, 2008; Nazarova *et al.*, 2017b).

The climatic conditions of the study area are determined by the proximity of the sea, by the plain landscape and the fact that it is situated entirely north of the Polar Circle. Prevailing winds have south and southwest direction. The subarctic climate of the region is characterized by short and mild summers with a mean July temperature around +13.5 °C and severe winters with a mean January temperature –17.2 °C. Annual precipitation is around 500 mm. Snow cover lasts 219 days and snow has depth up to 93 cm (climate station, established in Naryan-Mar town in 1926, http://www.pogodaiklimat.ru/climate/23205.htm). The territory is characterized by the presence of mainly discontinuous or patchy permafrost (Nikonova, 2015).

We analyzed surface sediment samples from 17 lakes, located in the delta of the Pechora River and a short sediment core taken from one of these lakes (Fig. 1). The short core was drilled in a study site located at N 68°11′31″ and E 53°47′50″; 1 m a.s.l. This small lake did not have an official name and during the field campaign received a technical name Pe-03 that we use further through the text. It has a northeast-southwest oriented elongated shape with a surface area of *ca* 4.3 ha and maximal size of 350x250 m (Fig. 1). Its maximum depth is 2.0 m. Our vegetation survey within the catchment area revealed that the southern shrub tundra here is dominated by *Carex aquatilis*, *Arctophila fulva*, *Eriophorum scheuchzeri*, *Salix phylicifolia* (>2 m), *Salix* sp. grows predominantly along the lake and river shoreline.

Materials and methods

Subfossil valves, head shields and postabdomens of *P. protzi* were extracted from the sediment core from the lake Pe-03 (Fig. 1). For coring a UWITEC gravity corer (Mondsee, Austria), equipped with 6 cm inner diameter and 60 cm length core liners, was used. A 48-cm sediment core was obtained from the water depth of 2.0 m in the deepest part of the lake in August 2017. The core was sectioned at 1–2-cm intervals, which resulted in 26 sediment subsamples.

The lowermost sample of bulk sediments was AMS dated in the AMS Laboratory of

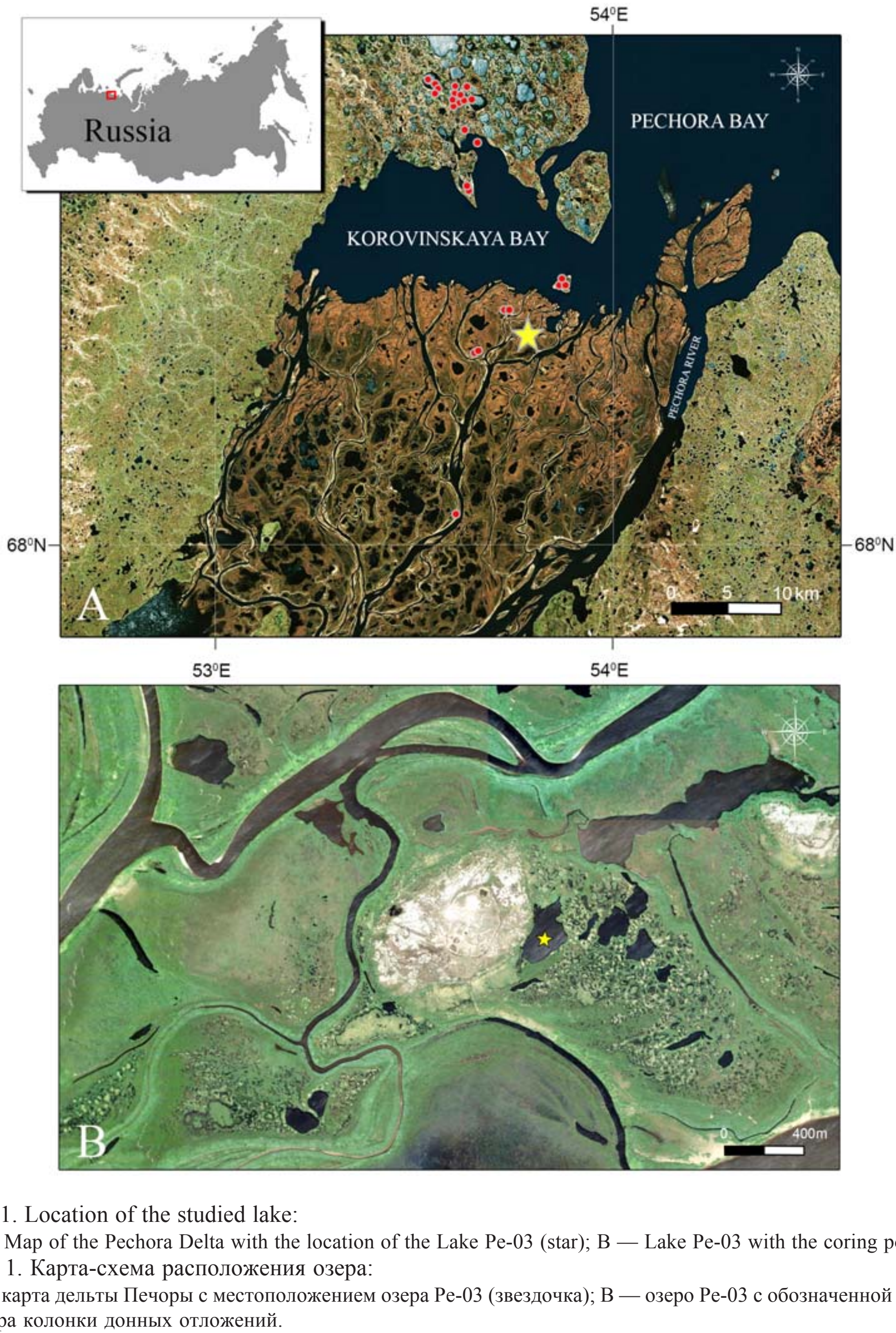

Fig. 1. Location of the studied lake:
A — Map of the Pechora Delta with the location of the Lake Pe-03 (star); B — Lake Pe-03 with the coring position.
Рис. 1. Карта-схема расположения озера:
А — карта дельты Печоры с местоположением озера Pe-03 (звездочка); В — озеро Pe-03 с обозначенной точкой отбора колонки донных отложений.

Taiwan University. The uppermost sediment sample of core were analysed for ^{210}Pb activity at the Geochronology Laboratory of St. Petersburg State University in order to obtain an additional timescale and to control the radiocarbon chronology. ^{210}Pb found in the upper sediment samples, gave evidence for the modern age of the upper part of the core.

Sediment samples were prepared for Cladocera analysis using the methods described by Frey (1986) and Korhola & Rautio (2001). The samples (0.5 gr in the upper part of the core and up to 7.8 gr of dry sediments in the bottom part of the core) were heated for approximately 30 minutes at 75°C in 10% KOH. The KOH-sediment mixture was then poured onto a 50-µm mesh sieve. A few drops of ethanol and safranin-glycerin solution were added to prevent fungal growth and to stain the cladoceran remains. The samples were then mounted on microscopic slides and analyzed for their cladoceran species composition under a light microscope Axiostar plus (Carl Zeiss) with magnifications of 100x/200x/400x. The chitinous remains of cladoceran (headshields, shells, postabdomens, postabdomenal claws and ephippia) were identified with reference to subfossil (Frey, 1982, 1986; Szeroczyńska, Sarmaja-Korjonen, 2007) and modern (Flössner, 1972, 2000; Smirnov, 1971, 1996; Kotov *et al.*, 2010) cladoceran identification keys. Between 92 and 509 (mean 253) cladoceran remains per sample were counted from each sample. The most abundant body part was chosen for each species to represent the number of individuals, and 42–209 individuals were counted per sample. In subfossil Cladocera analyses, a minimum of 100 individuals has been proposed to be sufficient for describing the assemblages, although in low-richness lakes and lakes with low abundances of chydorids, a minimum count of 30 to 80 individuals likely reveals most of the occurring taxa (Kurek *et al.*, 2010). The percentages for cladoceran species were calculated from this sum of individuals. A stratigraphic diagram was built in the program TILIA version 2.0.b.4 (Grimm, 1993).

Results

The analysis of the surface sediments from 17 lakes and of the short sediment core from the Pechora Delta (Fig. 1) lead to identification of 10695 cladoceran remains (headshields, valves, postabdomens, postabdomenal claws and ephippiua) that belonged to 35 taxa. Only in the small shallow lake Pe-03 we found remains of *P. protzi.* The lake has thermokarst origin, is shallow, has soft silty bottom with peat accumulation and dense underlying sandy layer. The near-shore area is covered by well-developed macrophyte belt. The oxygen saturation of the water during the study period was high (10.09 mg/l), pH was close to neutral (7.23) (Table). The lake water had a low mineralization and an extremely low conductivity. Bicarbonates and sodium ions prevailed (Table).

The 47.5 cm-long sediment core covers *ca.* 2300 years of sedimentation. The relative abundances of cladocerans in the core are presented in Fig. 2. In the whole core a total of 6578 cladoceran remains (2943 individuals) of Cladocera were counted and identified. They represented 30 cladoceran taxa (24 Chydoridae). *Bosmina* (*Eubosmina*) *longispina* and *Chydorus* cf. *sphaericus*-type occurred in all samples. The cladoceran communities were dominated by *Bosmina* (*E.*) *longispina* (up to 67.50%) and *Chydorus* cf. *sphaericus* (up to 47.67%). *Alonella nana* (mean relatively abundance 5.83%), *Alona guttata/Coronatella rectangula* (4.63%), *Alona quadrangularis* (4.43%), *Disparalona rostrata* (3.36 %) were quite common throughout the core. Other cladocerans were present at lower abundances.

P. protzi occurs in the core sporadically. We found remains of 23 individuals in 12 of 26 studied samples. In all samples this taxon was present at very low relative abundances, that varied between 0.7 and 4.0 % (mean 0.35%). In toto in the entire core we found 21 headshields, 5 valves and 3 postabdomens of *P. protzi*. Remains of *P. protzi* were found in the uppermost part of core in the top centimeter of sediments. This allows us to assume that this species not only inhabited the lake in the past, but presumably can be found there nowadays as well.

We did not notice any morphological differences between the remains of *P. protzi* from the Pe-03 and the populations from Northern and Western Europe (Bjerring *et al.*, 2008; Van Damme *et al.*, 2009). All found head shields had a peculiar shape with a notched posterior margin and a short, broadly rounded rostrum (Bjerring *et al.*, 2008) (Fig. 3). Valves of *P. protzi* can

Table. Physical and limnological features of the lake Pe-03.
Таблица. Физико-географические, лимнологические и геохимические параметры озера Pe-03.

Location	68°11′31″ N 53°47′50″ E
Altitude, m a.s.l.	6.0
Surface area, ha	4.3
Fish status	No fishes
T_{water}, °C	15.4
$Depth_{max}$, m	2.0
Conductivity, μS /cm	54.10
TDS, mg/l	54.00
pH	7.23
O_2, mg/l	10.09
O_2, %	100.50
K^+, mg/l	0.98
Na^+, mg/l	12.90
Mg^{2+}, mg/l	1.83
Ca^{2+}, mg/l	4.75
Cl^-, mg/l	1.56
SO_4^{2-}, mg/l	5.45
HCO_3^-, mg/l	13.46

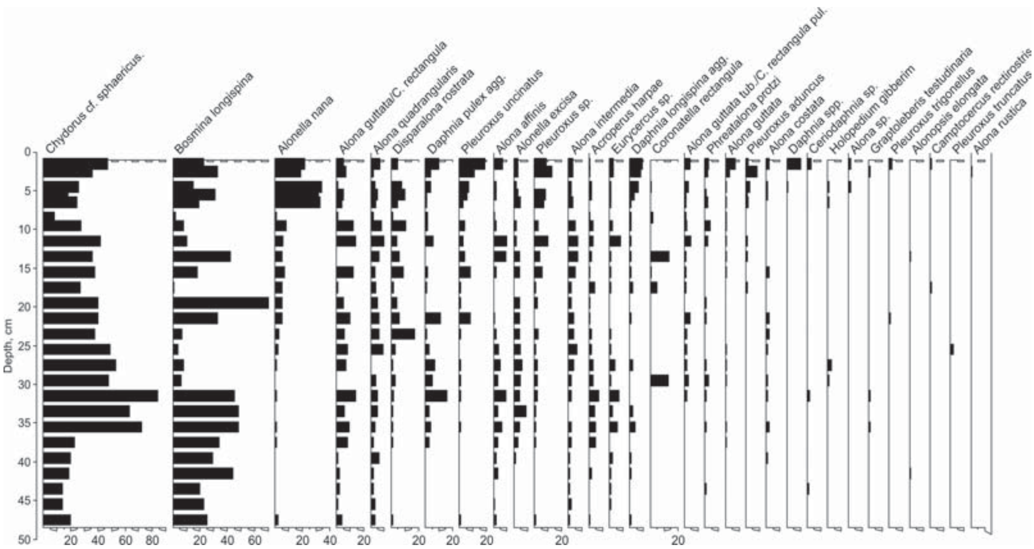

Fig.2. Relative abundance of Cladocera in the Pe-03 core.
Рис. 2. Относительная численность Cladocera в колонке донных отложений озера Pe-03.

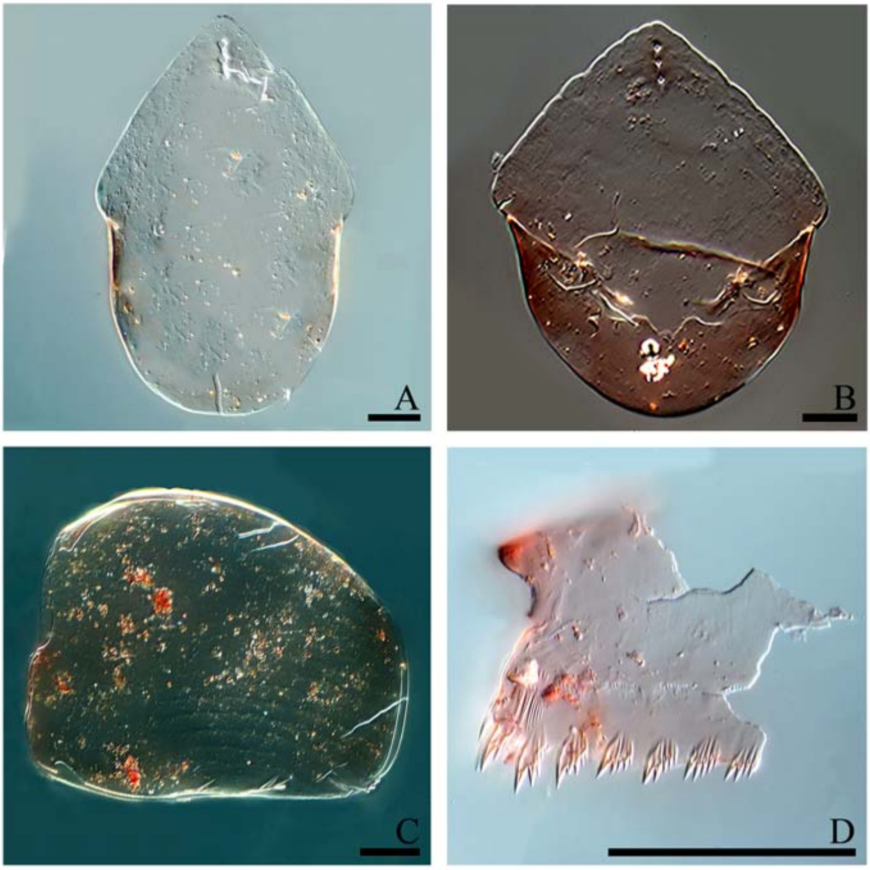

Fig. 3. *Phreatalona protzi* (Hartwig, 1900), from the lake Pe-03, Pechora Delta, Russia, female:
A–B — subfossil head shields; C — carapace; D — postabdomen. Scale bars: 0.1 mm for A–D.
Рис. 3. *Phreatalona protzi* (Hartwig, 1900) из озера Pe-03, дельта Печоры, Россия, самка:
A–B — субфоссильные головные щиты; C — карапакс; D — постабдомен. Масштабные линейки: 0,1 мм для A–D.

be recognized easily as this is the only small-sized European *Alona*-like species with 2–3 denticles on postero-ventral angle of the shell of the carapace (Van Damme, 2010). The only other *Alona* species with denticles is *A. affinis* (Leydig, 1860) var. *dentata*, but it is much larger than *P. protzi*, the length of adult specimen of which exceeds 0.7 mm (Smirnov, 1971; Bjerring *et al*., 2008).

Discussion

P. protzi remains were found in the sediments of Russia lakes for the first time. Previous studies of sediments of numerous lakes in northern and central Russia, conducted by the authors (Frolova *et al.*, 2014, 2016, 2017; Ibragimova *et al.*, 2018, 2019), did not revealed any subfossil remains of *P. protzi*. Evidently, the rarity of the species findings is caused by a peculiar ecology and specific requirements to habitats of the species.

Our data confirm the occurrence of *P. protzi* in Russia, where reports of this species are relatively rare. Due to inaccurate translation of the original species description (Hartwig, 1900) from German, some authors mistakenly presumed the first finding of this species in Koenigsberg (now Kaliningrad, Russia) (Van Damme *et al.*, 2009, 2010), although the Koenigsberg was mentioned in the text only as the working place of Dr. A. Protz but not as the typical location of the species. Bening (1941) reported *P. protzi* from Caucasus, but this record is doubtful and was never confirmed by later investigations. Smirnov (1971) recorded *P. protzi* in a small stream Olkhovets, Voronezh Area, Central European part of Russia. Lazareva *et al.* (2018) reported *P. protzi* in the list of pelagic zooplankton from Saratov reservoir (lower part of the river Volga). Both last references do not provide an exact position of the sampling sites where *P. protzi* was found.

Flössner (1972) defines the distribution of *P. protzi* as Palaearctic, Dumont and Negrea (1996) as West Palearctic, and according to Van Damme *et al*. (2009, 2010) it is restricted to "Danubian Europe". According to Sinev (2017) *P. protzi* is an endemic of the Western Palearctic, not widespread in the Mediterranean region.

Even within Europe, *P. protzi* is rare, and its ecology is not fully studied (Nykänen, Sarmaja-Korjonen, 2007). The species inhabits predominantly hyporheic zone of rivers, so only few specimens are usually found during the sampling taken by standard methods (Van Damme *et al*., 2009). The species was found in abundance only during specialized sampling of the hyporheic zone, conducted by Van Damme *et al.* (2009), who found it in relatively high numbers (>50) in two quarry locations near the River Maas (Maaseik, border Belgium-Germany) and in small branch of La Lanterne, an oligotrophic stream in Eastern France. Other occurrences of *P. protzi* belong to a variety of biotopes (Bjerring *et al.*, 2008; Van Damme *et al.*, 2009). In England a few living animals were found between *Cordylophora* in the running water of the river Ant (Gurney, 1921). Dumont (1983) found a small population of *P. protzi* in Turkey in a canal with stony walls and deep, wide cracks. In Slovakia some specimens were collected during zooplankton sampling in channels for filling rice bay, mostly in the littoral zone between *Schoenoplectus* (Vranovsky, 1971). In the Ohrid Lake *P. protzi* inhabits the algal mats on stones (Brancelj, Sket, 1990). In Denmark the species was found mostly in small clear lakes (Bjerring *et al*., 2008). Sporadically this species was found in lake littorals among dense submerged macrophytes (Nykänen, Sarmaja-Korjonen, 2007). Subfossil remains of *P. protzi* were found in rather variable habitats, from relatively nutrient poor, clear-water lakes to highly eutrophic lakes with neutral to alkaline pH and relatively low abundance of submerged macrophytes (Bjerring *et al.*, 2008). Van Damme *et al.* (2009) suggests that findings of *P. protzi* remains in macrophyte rich lake littorals can occur if the lakes have inflowing springs or small streams, or have groundwater feed.

Nykänen & Sarmaja-Korjonen (2007) presumed that presence of *P. protzi* remains has low value for paleolimnological reconstructions because of their rarity. In our opinion, presence of the species can have an important indicative value in paleolimnological research, as its occurence suggests a water inflow from river or stream and respectively existing of lotic conditions. Studied lake Pe-03 has no in- or outflow during the sampling time (August 2017), but it became connected with the river during spring floods. We suggest that findings of *P. protzi* remains can be seen as a signal of existing water flow or some connection between the lake and the river or stream. However, interpretation of the findings of *P. protzi* should be done with caution as it can be transported with water flow to an atypical environment.

The occurrence of *P. protzi* in the Pechora Delta in the Russian Arctic suggests that this species has a greater area of distribution than presumed previously; the species clearly is not restricted to "Danubian Europe". Systematic studies of subfossil Cladocera in Russian waterbodies in the future are very promising in terms of further records of *P. protzi* and other rare Chydoridae in other locations across Russia.

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