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Morphology and biology of *Cyclops scutifer* Sars, 1863 in high mountain lakes of East Siberia (including Lake Amut)*

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Abstract Data on zooplankton from 13 high-mountain lakes of East Siberia have shown that the Holarctic copepod *Cyclops scutifer* Sars, 1863 dominates among crustaceans. In July, its abundance comprised 64%–98% of the total plankton fauna in the pelagial of these lakes, approximately 30% in the littoral zone and 10% in small northern thermokarst lakes. Biometric measurements and morphological descriptions based on scanning microscope images are supplemented by the data on its geographic distribution and phenology.

Keyword: high mountain lakes; *Cyclops scutifer*; morphology; biology; distribution

1 INTRODUCTION

The crustacean *Cyclops scutifer* Sars, 1863 is one of the most abundant zooplankton species in high-mountain water bodies of East Siberia, including lakes of the Baikal Rift Zone. Some researchers have identified *Cyclops scutifer wigrensis* as a subspecies living in these waters (Vasilyeva, 1967; Sheveleva et al., 2009). At present the *C. scutifer* complex includes 8 more species besides the nominal one, among which 4 new species were described by E.A. Streletskaya from the North East USSR (Streletskaya, 1990). Until recently, there were some difficulties in identification of the forms and subspecies of *C. scutifer* because descriptions and drawings of the *scutifer* group presented in identification keys (Rylov, 1948; Monchenko, 1974; Identification keys…, 1995; Identification keys…, 2010), lacked details. More thorough examination of the morphological features of this species by means of scanning microscopy enabled us to show that the *C. scutifer* in habitat in high-mountain water bodies of East Siberia was identical to the one from the identification guide of Einsle (1996). Our investigations have provided data on the morphology, biology, and distribution of this species.

Cyclops scutifer Sars, 1863 is an abundant zooplankton species in high mountain water bodies of East Siberia, including lakes within Bikal Rift Zone.

The genus *Cyclops* in the zooplankton of Lakes Amut and Ilchiris is represented by one species *Cyclops scutifer* Sars, 1863. Our investigations provided data on morphology, biology, and distribution of this species.

2 MATERIAL AND METHOD

Cyclops scutifer Sars, 1863, collected from 13 mountain lakes of East Siberia, mainly from the Baikal Rift Zone, was the subject of our analysis. The water bodies under study were oligotrophic, mainly fed by melting snow and ice. All these lakes are characterized by a long freeze-up period that starts in mid-late October. Ice disappears by the end of the second or third decade of June. Among the lakes under study are some of tectonic-glacial origin (Oron, Nichatka, and Leprindo), glacial-moraine (Amut) and karst and thermokarst medium and small lakes (Fig.1).

The elevation of the lakes above sea level varies

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Table 1 Geographic parameters of lakes

No.	Lake name	Latitude, longitude	Depth (max) (m)	Area (km^2)	Elevation above sea level (m)
1	Ilchir	51°97'N, 101°99'E	12	3.1	1 963
2	Istok Lena	53°95'N, 108°06'E	16	110.2	1 470
3	Oron	57°10'N, 116°52'E	150	51.3	600
4	Devochanda	56°80'N, 116°17'E	23	0.2	1 174
5	Polovinskoe	57°03'N, 116°51'E	21	0.4	1 400
6	Krestaki	56°84'N, 116°38'E	21	0.7	1 400
7	Amut	55°29'N, 111°77'E	70	10.7	1 453
8	Goltsovoe	56°61'N, 117°40'E	25	0.3	984
9	Nichatka	57°76'N, 117°65'E	117	44.0	554
10	Leprindo	56°62'N, 117°52'E	74	26.2	984
11	Leprindokan	56°55'N, 117°50'E	26	12.1	1 056
12	Big Nichangna	57°12'N, 118°81'E	4	0.8	674
13	Small Buldyazhik	57°09'N, 118°75'E	2	0.2	685

from 554 (Nichatka) to 1 963 m (Ilchir). Tectonic-glacial and glacial-moraine lakes are mostly large and deep compared to karst and thermokarst ones (Table 1).

Zooplankton was sampled in lakes of the Kuanda-Chara depression: Leprindo, S. Buldyazhik, and B. Nichangna, June–September 1988; Nichatka, July 1990; Amut, April, June–August 2008; Oron, Krestaki, Goltsovoe and Devochanda, June–September 2000; Istok Lena, June–September 1998–1999, 2002; Ilchir, January–December 1998.

The samples were collected by a Juday net with a filtering capron cone (sieve No. 55, mesh 125 μm) and a hydrobiological net for filtering 10–60 L of water. Qualitative samples were collected with a net. Mature females with egg sacs and males were selected to examine morphology of *Cyclops*. Before preparation, each specimen was measured following (Fig.2) the method of Kozminski (1936). Setae on caudal rami were designated according to Dussart (1969). During this investigation, we used a microscope (Olympus CX 41) and a scanning electron microscope (Philips 525 M).

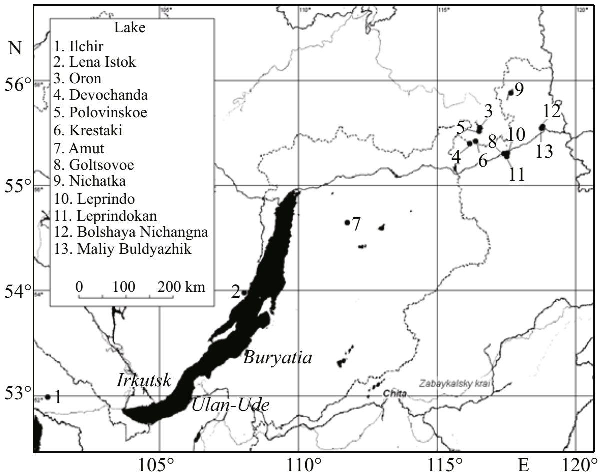

Fig.1 Schematic presentation of the lakes

3 RESULT

3.1 Morphology

Basic biometric measurements of a female and male, and the detailed description of morphology are presented in Table 2 and Figs.3–8.

Female body length excluding furcal setae 1 025–1 175 μm, body elongate, slender. Cephalothorax approximately 1.5 times longer than its width. Posterior angles of cephalothorax and thoracic segments of the same structure do not protrude backwards (Fig.3).

The fourth and fifth thoracic segments with well-defined, pointed lateral protrusions. Genital segment evenly constricted posteriorly (Fig.3c, d). Anal plate poorly defined (Fig.3e). Caudal rami relatively short, making 10%–11.7% of the body length, their width 4.6–5.2 times less than length (Table 2), slightly separating from each other, totally covered by hairs on the inner side (Fig.3f). Lateral seta attached on first 1/3 of the caudal rami length. Dorsal seta (Td) slightly more than 1.5 times longer than Te (Table 2).

Antennule long, 17-segmented, reaching middle of the fourth thoracic segment. The first article of antennule bears a row of fine spines (Fig.3h). Antenna 4-segmented with 7 setae at the end (Fig.4a). The whole inner margin of the third and fourth article bearing fine hairs at an angle to its surface (Fig.4d). The inner (or medial) margin of the third article is bearing setae, while the outer (lateral) margins of the third and fourth articles are bearing hair-like spinules.

Mandible with 2 stout, long setae and a short one (Fig.5a, b). Cutting edge of mandible armed with a plumose seta and short pointed bifurcated teeth (Fig.5c). Maxillulary palp and praecoxalarthrite

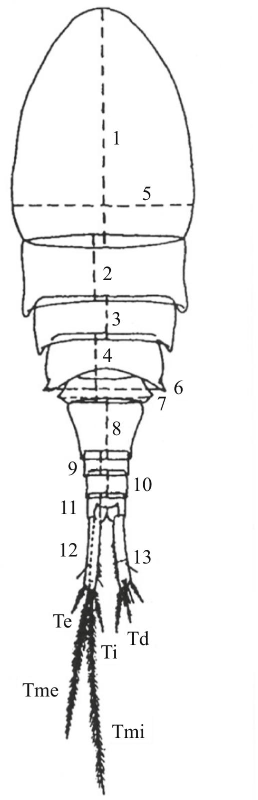

Fig.2 *Cyclops* measurement by Kozminski (1936)

1+2+3+4=long ceph.; 5=lat. Max. Ceph.; 6=lat. th. 4; 7=lat. th. 5; 8+9+10+11=long. abd; 12=long furca; 13=lat.furca. Ti: terminal internal seta; Te: terminal external seta; Tmi: terminal median seta; Tme: terminal medial external; Td: dorsal seta.

Table 2 Measurements of *Cyclops scutifer* (females and male) from Lake Amut (A) and by Einsle, 1996 (B)

INDEX	A	A	B
	Female (*n*=15)	Male (*n*=15)	Female
Body length (mm)	1.0–1.2 (min–max)	0.920–1.03 (min–max)	1.1–1.6 (min–max)
Furcal rami; L/W	4.6–5.2 (min–max)	4.8–5.5 (min–max)	4.1–5.5 (min–max)
Furcal rami/body length (%)	10–11.7	10.4–12.5	10–11
Ti/furcal rami	1.05–1.2 (min–max)	0.98–1.16 (min–max)	1.1–1 (min–max)
Ti/body length (%)	12.1–14.7	10.2–13.3	12–13
Tmi/furcal rami	3.1	2.94	3
Tmi/body length (%)	34–40	32–38	28–36
Tme/furcal rami	1.6	1.67	2
Te/Ti	0.47	0.5	0.5
Td/Te	1.56	2.11	<2

armed with stout setae (Fig.5d). Maxilla without any specific features compared to most of cyclopids (Fig.5e). Long hair-like spinules present on distal third of syncoxopodite and medial (inner) half of basipodite on frontal surface of maxilliped (Fig.5f).

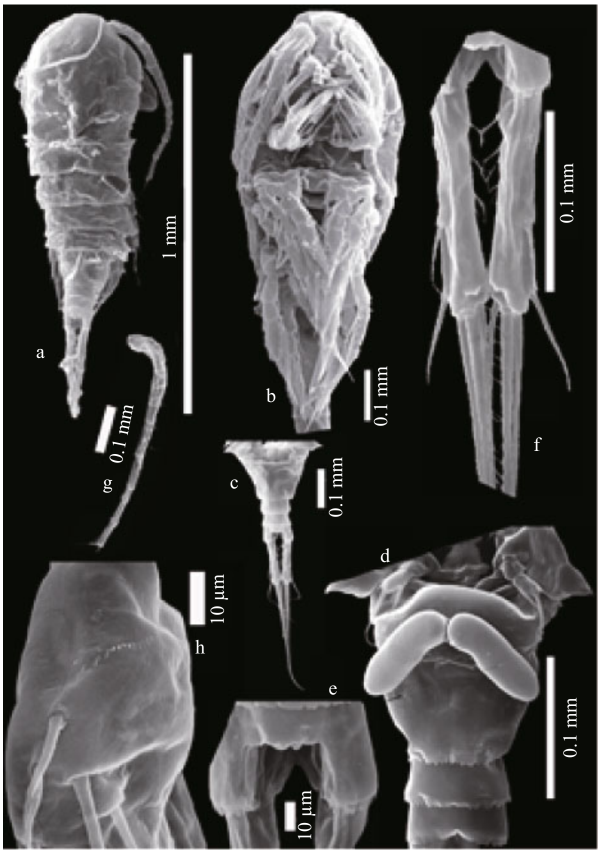

Fig.3 *Cyclops scutifer* (1)

a. female, dorsal view; b. female, ventral view; c. genital segment, dorsal view; d. genital segment with spermatophores; e. anal somite; f. caudal rami; g. antennule; h. fist segment of antennule.

P1–P4 rami three-segmented, spine formula 3/4/3/3 and seta formula 5/5/5/5. Endopodite and exopodite articles of rectangular shape (Figs.6, 7). Medial seta of P1 basipodite long, reaching distal edge of the third article. P2 and P3 coxae with 5–7 spinules (Fig.6b, c). P4 coupler naked, with small humps on distal margin. Coxal seta swollen and bearing thick setules (Fig.7c, d). P4 coxopodite adorned with spinules groups “A”, “B”, “C”, “D” and “F” to the corresponding group of spinules in Fig.7c. P4end3 almost three times as long as wide (Fig.7e). First endopodal segment of P4 with a cuticular outgrowth (Fig.7a, b). P5 has 2-segments, distal article three times longer than wide (Fig.6d). Basal part of seta and spine on the distal article armed with a row of spinules. Spine long extending beyond the article rim (Fig.6d).

Females transparent, rarely bluish. Egg sacs rounded, tightly stuck to the genital segment, 16–19

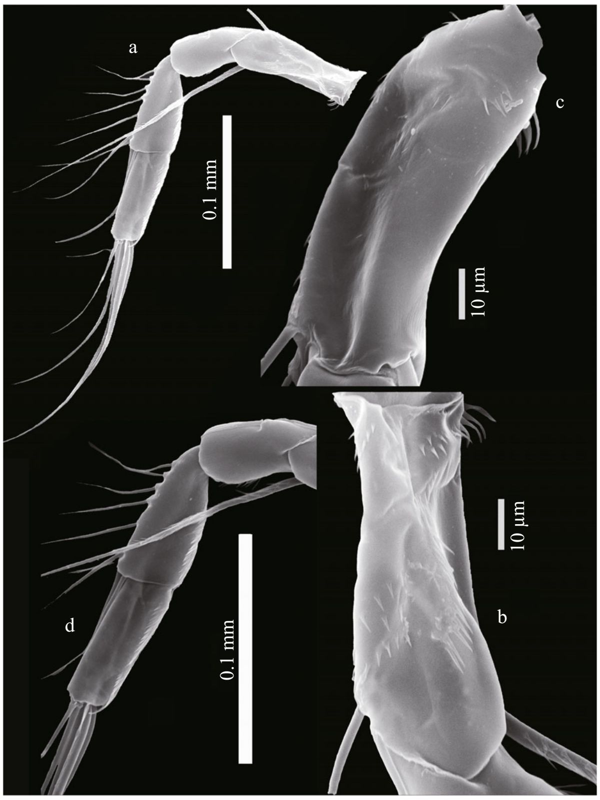

Fig.4 *Cyclops scutifer* (2)

a. antenna; b. antennary basipodite, caudal; c. antennary basipodite, frontal; d. 2-4 segment of antenna.

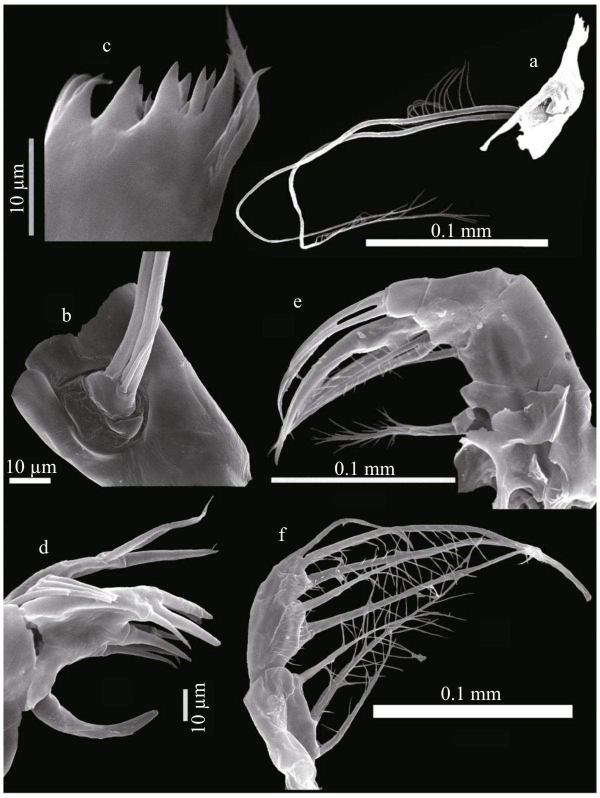

Fig.5 *Cyclops scutifer* (3)

a. mandible; b. rudiment of endopodial of mandible; c. pars incisive of mandible; d. maxillula; e. maxilla; f. maxilliped.

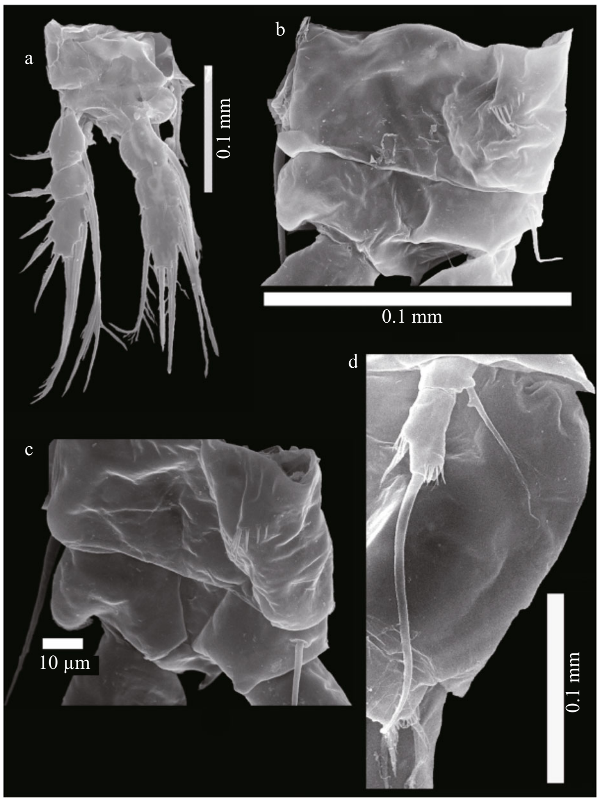

Fig.6 *Cyclops scutifer* (4)

a. Leg 1; b. coxa P2; c. coxa P3; d. Leg P5.

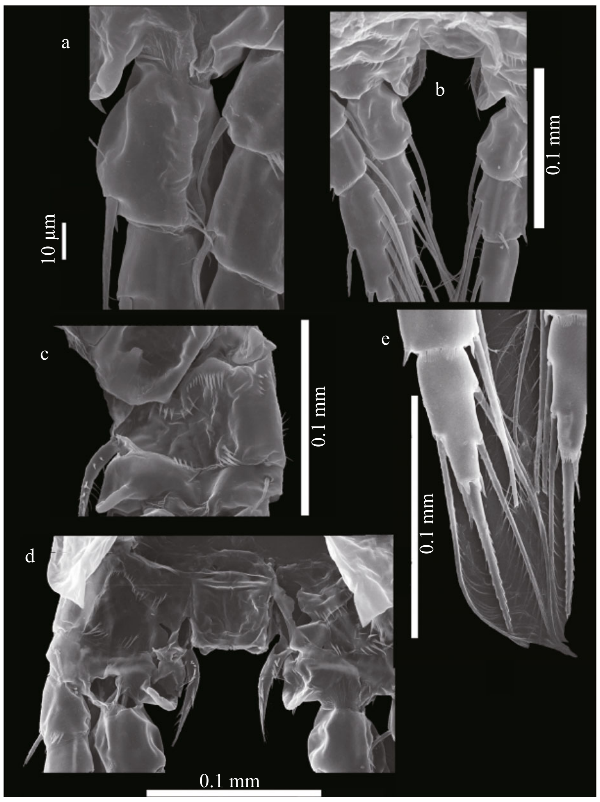

Fig.7 *Cyclops scutifer* (5)

a. End1P4; b. Leg P4; c. coxa P4; d. coupler of P4; e. End 3 P4.

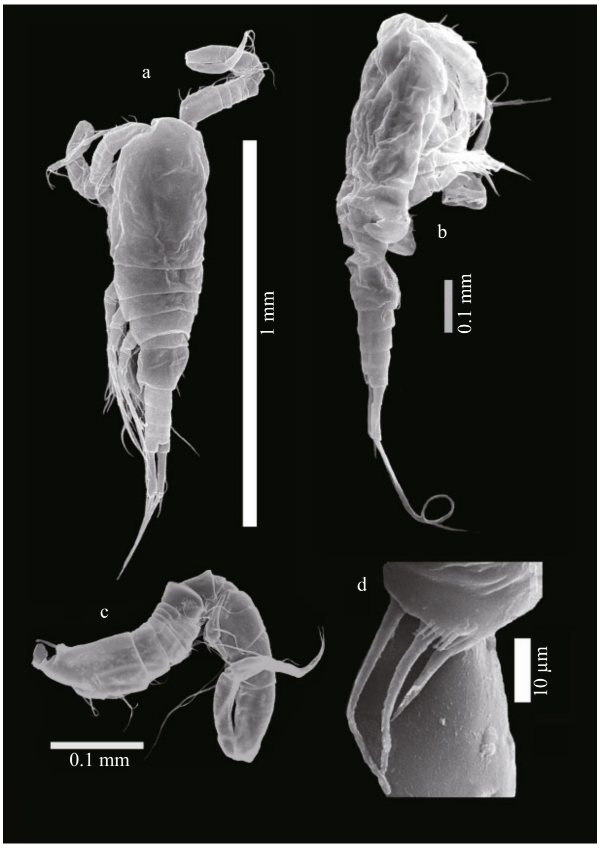

Fig.8 *Cyclops scutifer* (6)

a. male, dorsal view; b. male, right lateral; c. antennule; d. P6.

eggs in each sac.

Male slender and smaller than female, 920–1 025 μm long (Table 2). Antennules 17-segmented (Fig.8c). Pediger 4 and 5 without "wings", similar in shape to preceding somites (Fig.8a). Furcal index varies from 4.8 to 5.5, average 5.1 (Table 2). Longitudinal ridge on caudal rami missing. Tmi of caudal rami long and, as a rule, curved inwards (Fig.8b). Spermatophores large, bean-shaped, attached at right angle to genital double-somite of female, extending beyond the segment margins (Fig.3d). Male P6 armed with 2 setae and a spine. Spine 1.3 times shorter than medial seta and slightly more than twice as short as the dorsal one (Fig.8d).

3.2 Biology

Because of the remoteness of Lakes Amut and Ilchir, we could perform our investigations only sporadically. The life cycle of *C. scutifer* was studied in Lake Amut in April, June, July, and August, and in Lake Ilchir in January, February, March, April, August, and December. The area of Lake Amut is three times that of Lake Ilchir and its depth is 6 times

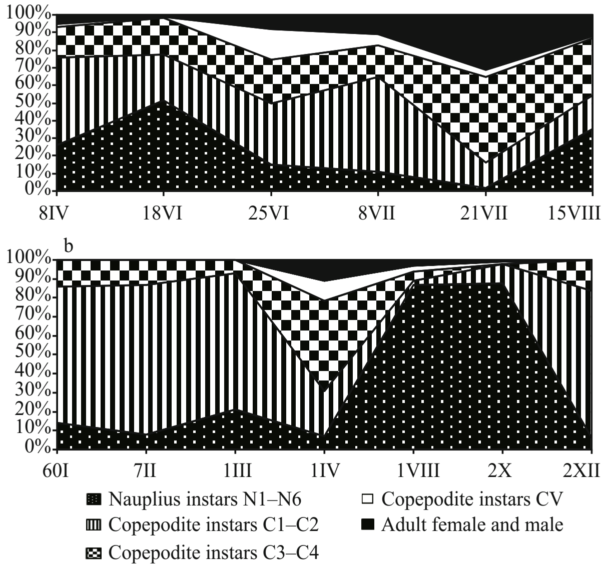

Fig.9 Structure of population (%) of *Cyclops scutifer* in Lake Amut (a) and Lake Ilchir (b)

that of Lake Ilchir. However, Lake Ilchir is 500 m higher above sea level than Lake Amut (Table 1).

In early April, the *Cyclops* population in Lake Amut was dominated by junior (I–II) copepodites (50%) and nauplii (26%), whereas mature individuals amounted to only 5% (Fig.8a). Most of them were males and females without egg sacs. In June after ice breakup in the lake (water temperature 6°C), the *Cyclops* population included all age groups (Fig.8a) with the dominance of nauplii (50%). Junior (I–II) copepodites were the second densest group. By the end of June, the abundance of nauplii decreased in plankton, whereas the density of copepodites increased. At that period, a peak abundance of the V copepodite instar was observed. Matured individuals were dominated by males. In early July (Fig.8a), the abundance of the juvenile (I–II) copepodite instar reached its maximum, and by the end of July, the age composition of the population changed into the III–IV stage. The abundance of mature individuals was also maximal. Mature specimens were represented mainly by females. In mid-August, we observed abundant reproduction of *Cyclops* and a peak of nauplii. According to our observations in lakes of Kuanda-Chara Valley and to those by Klishko (1998), relatively high abundance of *Cyclops* nauplii was recorded in mid-late August. It is likely that *Cyclops* reproduction starts in autumn like in other deep-water lakes of North Russia (Ivanova, 1975; Korobtsova, 1975; Sheveleva and Shishkin, 1986; Rivier, 2012), and their growth continues in autumn-winter, mainly under the ice.

We also studied the growth of *C. scutifer* in small high-mountain Lake Ilchir (area 3.1 km^2 and maximal depth 12 m) (Fig.8b). From January to March, the abundance of the I–II copepodite instar made up 80%; no matured individuals or copepodites of the V stage were recorded (Fig.8b). By early April, the abundance of the senior (III–IV) copepodite instars increased, and mature crustaceans also emerged. It is more likely that nauplii had hatched in April, and the second cycle of their development continued in late summer-early autumn (data for July and October) because nauplii made up the majority of *Cyclops* density (88%): the population at this age stage descended under the ice. By early December (Fig.8b), the population structure changed: the majority of nauplii had transformed into copepodites. Consequently, the reproduction of *C. scutifer* in Lake Ilchir took place in April. In late summer-early autumn, the crustaceans at the nauplii stage began overwintering. During the ice-cover period (January–March), crustaceans grew slowly. The population was dominated mainly by the junior (I–II) copepodite instars. Hence, *C. scutifer* from Lake Ilchir has two evolution cycles.

In Lake Amut, there was no reproduction of nauplii as females were immature, whereas nauplii in Lake Ilchir grew in spring as, despite the altitude above sea level, the water temperature in this small lake was higher than that in Lake Amut.

3.3 Distribution

C. scutifer inhabit mainly water bodies of the Northern Hemisphere. In North America, they were registered in the areas from 42° to 69°N (Elgmork and Halvorsen, 1998; Elgmork, 2004). In the European part of Russia, their distribution is limited to 60°N (Rylov, 1948), which was confirmed by Rivier (2012). In the northeastern part of Russia, *C. scutifer* and their closely related species are represented by 9 species (Streletskaya, 1990). Our research on *C. scutifer* carried out in lakes of East Siberia, mainly in the Baikal Rift Zone (51° to 57°N), recorded only one species.

A stenothermal, psychrophilic *C. scutifer* was registered in these high-mountain lakes all the year round being one of the main components in the zooplankton community. In July, their abundance was 64%–98% of the total number of planktonic animals in the pelagic zone of lakes M. and B. Leprindo, Nichatka, Amut, and Ilchir, whereas in the littoral zone their abundance made up from 7% to 30% (Itigilova and Klishko, 1995; Itigilova and Sheveleva, 2009; Sheveleva et al., 2009). The age composition of pelagic and littoral communities of *Cyclops* exhibited temporal variations in Lake B. Leprindo. The abundance of *Cyclops* never exceeded 10% of the total number of zooplankton in shallow thermokarst lakes (such as Nichangna and Buldyazhik).

4 DISCUSSION

The life cycle of *C. scutifer* is different in various lakes, and may or may not show diapause. In two high-mountain lakes of Norway, 1–3-year life cycles of this crustacean were recorded (Elgmork, 1985; Elgmork and Eie, 1989). Some growth stages lasted for almost a year in the lakes. This is likely dependent on the depth of lakes, water temperature, food resources, etc. The duration of life cycles increased with latitude and was inversely proportional to temperature (Elgmork, 2004). It is known that *C. scutifer* prefer cold water (=10°N) and inhabit well-oxygenated hypolimnia of the lakes (Elgmork, 1967; Halvorsen and Elgmork, 1976). While studying vertical distribution of *Cyclops* in the Arctic Lake Toolik in Alaska, Cody et al. (2007) revealed that these species were not restricted to cold waters. The optimal temperature for their growth and reproduction, as a rule, appeared to be much higher than the temperature in the hypolimnion (Elgmork, 1967; Halvorsen and Elgmork, 1976). Various cohorts of the *C. scutifer* population with different reproduction times were recorded in deep lakes of Kamchatka (Lake Dalneye up to 50 m deep and Lake Azabachye up to 30 m deep) (Wetsler, 2009). Senior copepodites fell into a diapause period in Lake Azabachye during the ice-cover period (Bazarkina, 1993). In Lake Siverskoe (the Volga River basin), *Cyclops* were not found in the water column in winter (Rivier, 2012).

5 CONCLUSION

Our studies performed in high-mountain lakes of East Siberia show that *Cyclops scutifer* dominates in the zooplankton of deep lakes. Diapause was not recorded in this species. In Lake Amut, like in other deep-water bodies of Russia (Korobtsova, 1975; Ivanova, 1975; Sheveleva and Shishkin, 1986; Rivier, 2012), the development of *C. scutifer* lasts throughout a year, i.e., it has one life cycle. Reproduction of *Cyclops* takes place in August–September. The nauplius stage is observed mostly under the ice. Later, during the short ice-free period, nauplii transform into copepodite and adult stages. Two life cycles of *C. scutifer* were recorded in high-mountain shallow

Lake Ilchir. During the ice-cover period *Cyclops* go through all growth stages due to intense development of cryptophytes and chrysophytes in winter and early spring with their abundance up to 1×10^6 cells/L (Bondarenko et al., 2002).

In Lake Amut, there was no reproduction of nauplii in spring as females were immature, whereas in Lake Ilchir nauplii developed in spring as, despite the altitude above sea level, the water temperature is higher in this small lake and the ice-free period is longer (140 days) than in Lake Amut (120 days).

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