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ORIGINAL ARTICLE

Role of *Gmelinoides fasciatus* (Crustacea: Amphipoda) in Macrozoobenthos on the Littoral of Lake Onego During the Subglacial Period

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Macrozoobenthos of the littoral of Lake Onego is represented by 22 units of different taxonomic rank. The invasive species *Gmelinoides fasciatus* (Stebbing 1899) (CRUSTACEA: AMPHIPODA) plays a dominant role by biomass in the littoral macrozoobenthos community during the subglacial period. The peculiarities of the size and sex composition of the *G. fasciatus* population are studied. It was shown for the first time that in the subglacial period on the littoral of Lake Onego the population of amphipods contains young individuals from 2.1 mm, in contrast to the size composition of this species in Lake Ladoga. Apparently, these are crustaceans that appeared in the summer of the previous year, as we did not discover any breeding females. The sexual structure of the *G. fasciatus* population in Lake Onego is stable, with the ratio of females to males being 1:1.

Key words: taxonomic composition, invasive species, size structure, Lake Onego, Gmelinoides fasciatus

Lake Onego is located in the zone of the European North of Russia and it is the second largest freshwater lake in Europe. In its natural state the mirror area was 9,720 km², of which 250 km² is occupied by 1,500 islands. Lake Onego belongs to large cold-water reservoirs of the temperate zone. The lake is covered with ice - from December (sometimes January) to mid-May - within 120-164 days (Lake Onego.., 2010).

Up to date, the state of deep-water macrozoobenthos communities in the growing season of Lake Onego has been studied in detail. The composition and distribution of bottom communities, their quantitative development, bioproductive processes, regularities of reactions of bottom complexes to eutrophication have been considered, the bioresource potential has been estimated, and an easy-to-use biotic index reflecting the degree of disturbance of bottom communities in deep-water areas of the lake has been developed. The research results are summarized in a large number of publications (Hydrobiology of Petrozavodsk Bay, 1980; Petrozavodskoye Onego..., 1984; Ecosystem of Lake Onego..., 1990; Bolshaya Guba..., 1992; Lake Onego..., 1999, 2010; State..., 2007; Bioresources..., 2008; Largest..., 2015). The information database "Macrozoobenthos of Lake Onego" containing data on more than two thousand samples since 1964 has been created, protected and is being updated (Polyakova, 2012).

Special studies were also carried out in the littoral zone of the lake – the contact zone of terrestrial and aquatic natural complexes, where the main transformation of allochthonous components of different origin takes place. The first data on the benthic fauna of the littoral zone of Lake Onego were published by S. V. Gerd (1954), B. M. Alexandrov (1962) and V. A. Sokolova (1969). In the collective monograph "The Littoral Zone of Lake Onego" (1975), T. D. Slepukhina was the first who gave a systematic review and taxonomic list of the fauna of benthic invertebrates during the growing season and gave qualitative and quantitative characterization of the population of the main biotopes of the littoral zone.

During the growing seasons of 1978 and 1979, the distribution, composition and functioning of benthic fauna on the littoral was studied in the Gorskaya Guba of Bolshoye Onego Bay (Limnological..., 1982). In addition, studies of the macrozoobenthos of the littoral of Lake Onego were carried out in the Bolshaya Guba of Povenets Bay in 1967 (Sokolova, 1969), when the coastal areas most exposed to pollution were covered.

Bottom communities of the littoral zone of the lake are currently undergoing significant structural transformations under the influence of invasion of the amphipod of Baikal origin *Gmelinoides fasciatus* (Stebbing). Amphipoda *G. fasciatus* is a Baikal subendemic, the only species of the genus of Baikal origin. Until the early 1960s, the range of this species was limited to the basins of Siberian rivers: Angara, Barguzin, Irtysh, Lena, Pyasina, Tunguska, Selenga, and Yenisey (Berezina *et al.*, 2012). In the 1960-1970s, aquatic invertebrates were introduced to increase the fish food base (Ioffe, 1960; Beckman, 1962; Ioffe, 1968). According to published data, the amphipod first appeared in the southern part of Lake Onego in the early 2000s (Berezina and Panov, 2003). Since 2005, the current state of macrobenthic communities of coastal shallow waters has been studied (Bioresources..., 2008), but only during the growing season. In Lake Onego, *G. fasciatus* inhabited almost all littoral biotopes, becoming a dominant component of the benthos (Sidorova and Belicheva, 2017). However, there are no literature data on a detailed consideration of the population structure and dynamics during the subglacial period for the conditions of Lake Onego. In the available studies on the life cycle of *G. fasciatus* in the Gulf of Finland of the Baltic Sea (Berezina, Panov 2004; Berezina, 2005), in Lake Otradnoye (Nilova, 1976), and in Lake Baikal (Beckman, 1962), studies are conducted from May to October. There are rare works on Lake Arakhley (Matafonova *et al.*, 2005), and on Lake Ladoga (Barkov, 2006; Barkov and Kurashov, 2011), where studies of the life cycle and size composition of the *G. fasciatus* population were conducted throughout the year. Such studies have not been carried out for the conditions of Lake Onego, which determines the relevance of the topic.

The aim of the work is to study the interannual dynamics of the littoral macrozoobenthos community and to consider the role of the invasive amphipod *G. fasciatus* in the community, to analyze for the first time the size and sex composition of the population in the subglacial period of Lake Onego.

MATERIAL AND METHODS

Hydrobiological sampling was conducted during the subglacial period on April 4, 2015, on January 18, 2022, and on February 3, 2023 at monitoring stations 1, 2, and 3 near Suysar village (Figure 1).

Collections were made at depths ranging from 0.45 to 1 m. Sampling at monitoring stations 1, 2 and 3 in the vicinity of Suisar village was carried out at the same three stations located at a distance of approximately 100 meters from each other in five repetitions in a sandy biotope in the area of *Phragmites australis* (Cav.) reed thickets. A total of 45 macrozoobenthos samples were collected in the Suysar village area. Additionally, researches were started on the littoral of Kizhi Island on March 4, 2023 (station 4), 5 samples were taken in a sandy biotope with macrophyte overgrowth.

Samples were processed in accordance with guidelines for collecting freshwater benthos (Vinberg and Lavrentyeva, 1984; Methodological Recommendations..., 2005). A modified Panov-Pavlov tube sampler with a capture area of 0,0013 m² and a height of 1,20 m (Panov and Pavlov, 1986) was used for benthos sampling. The sampler was lowered to the bottom and rotationally buried 5-10 cm into the soft soil. Then all hard substrates were manually transferred from the sampler to the tank. The sample was washed through mill sieve No. 24 (mesh size 250-275 μm) and fixed in 4% formalin solution. Macrozoobenthos organisms were identified using a Mikmed-6 microscope (LOMO, Russia), according to the identifier (Alekseev and Tsalolikhin, 2016).

In the laboratory, each amphipod was measured under a stereomicroscope MSP-2(2) (LOMO, Russia) with an ocular micrometer with an accuracy of 0,1 mm, and it was weighed on analytical scales VL-124V (GOSMETR, Russia) with an accuracy of 0,1 mg. The distance from the rostrum to the base of the telson was taken as the length, 320 specimens were measured. According to the works of D.V. Matafonov (2003), E.A. Kurashov and D.V. Barkov (2011), when studying the size composition of the *G. fasciatus* population in Lake Onego, individuals were grouped into the following size groups (sz.grp.): a) with length less than 1,5 mm - Group I; b) from 1,6 to 3,0 mm - Group II; c) from 3,1 to 5,0 mm - Group III; d) from 5,1 to 7,0 mm - Group IV; e) from 7,1 to 9,0 - Group V, and f) over 9,1 - Group VI.

Statistical processing of data was performed according to the published methodology (Ivanter and Korosov, 2010) in the licensed Microsoft Office Excel 2007 and PAST 4.03 package.

RESULTS

Quantitative indicators of macrozoobenthos groups on the littoral of Lake Onego

The average abundance of littoral macrozoobenthos at the monitoring stations (1-3) in the Suysar area varied from 4 to 56,5 thousand ind/m², the average biomass varied from 4,9 to 133,7 g/m² (Table 1). In the coastal zone of Kizhi Island, the mean number of benthic organisms was 19,6 ind/m², with an average biomass of 12,4 g/m².

Bottom biocenoses are represented by 9 taxonomic groups: Amphipoda, Oligohaeta, Chironomidae larvae, Ptychopteridae larvae, Ceratopogonidae larvae, Stratiomyiidae larvae, Mollusca, Trichoptera and Hydracarina larvae.

In terms of numbers, the proportion of Amphipoda varied from 3 to 89% in the macrozoobenthos communities on the littoral during the study period (Fig.2). The contribution of Chironomidae larvae by numbers was 7-75%. The abundance of Trichoptera larvae ranged from 0 to 50%. The share of other macrozoobenthos groups was insignificant.

In most of the studied habitats (at stations 2, 3 and 4) Amphipoda dominated in biomass in different years (Fig.3). Only at station 1 in 2015 and 2022, the share of Amphipoda was 8-18% by biomass.

Taxonomic composition of littoral macrozoobenthos community

The taxonomic composition of the macrozoobenthos community is represented by 22 units of different taxonomic rank (Table 2).

According to T.D. Slepukhina (1975), oligochaetes on the littoral of the reservoir are represented by 33 species, we found 5 common species *Limnodrilus hoffmeisteri, Lumbriculus variegatus, Sperosperma ferox, Stylodrilus heringianus and Tubifex tubifex*. The frequently occurring species *S. heringianus* was recorded in 70% of the samples, the other species were recorded from 10 to 40% (See Table 2). Amphipods were recorded in all hydrobiological samples (100%). Chironomidae larvae of the species *Limnophyes karelicus (60%) and Stempellina almi (70%)* were frequently found.

Peculiarities of the size composition of the amphipod G. fasciatus population

The group of amphipods is represented by a single species, the insect *G. fasciatus*. In all samples during the study period only *G. fasciatus* of different size groups were found, the native species *Gammarus lacustris*, which previously inhabited the littoral of Lake Onego, was not discovered.

During the subglacial period, the population of *G. fasciatus* from 2015 to 2023 in Lake Onego is represented by a fairly wide range of sizes - II-VI size groups (sz.grp.). It was shown for the first time that individuals with body lengths from 2.1 mm in 2022 and 2023 were observed in the population during the subglacial period; their proportion ranged from 15% to 82% of the total number (Fig. 4). Size group IV was the second most abundant during the study period.

In addition to these main groups, individuals of size group V from 0% to 50% (3rd station, April 2015) and size group VI (up to 3% in numbers at 1 station in March 2023) were recorded during the subglacial period. In all probability, these are individuals of the summer generation of the previous breeding year, which have already reached their maximum size.

In general, the amphipod population is represented by individuals with an average body length of 4,7±0,2 mm/ m² and an average biomass of 4,3±0,4 mg/ m². Young crustaceans with body length of 2,1 mm and biomass of 0,4 mg were observed. Apparently, these amphipods appeared in late summer of the previous year, as no females with eggs were found during the subglacial period. The body length of the largest crustaceans is 9,5 mm, with a biomass of 18,8 mg.

Peculiarities of the sexual structure of the amphipod G. fasciatus population

Analysis of the sex structure of the population in the Suysar Island area during the entire study period showed that the ratio of females to males remained relatively stable and did not differ significantly from the 1:1 ratio according to the χ2 criterion (Fig. 5).

Figure 1. Location map of monitoring stations (1-3) on the littoral in the Suysar village area (2015-2023) and station 4 on Kizhi Island of Lake Onego (2023).

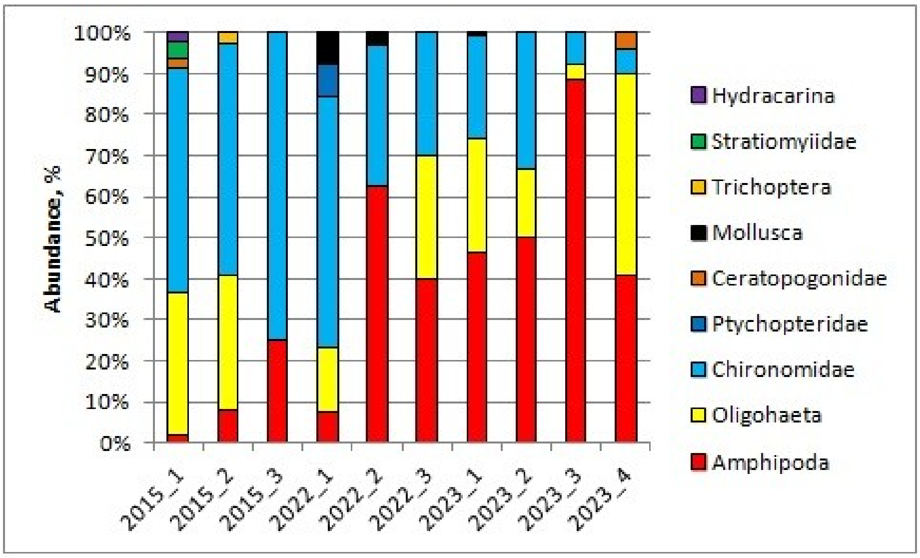

Figure 2. Ratio by numbers (%) of taxonomic groups on the littoral of Lake Onego in 2015-2023.

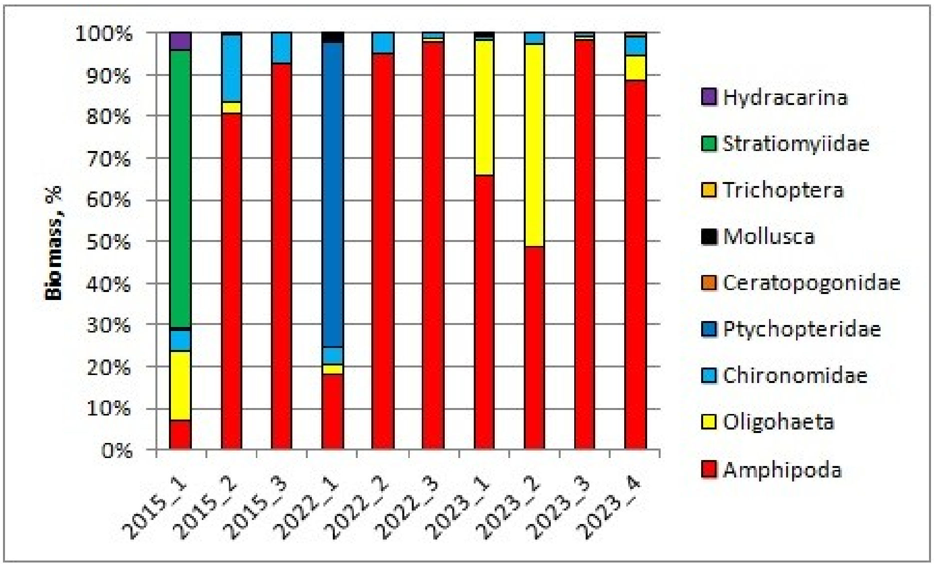

Figure 3 Biomass ratio (%) of taxonomic groups on the littoral of Lake Onego in 2015-2023.

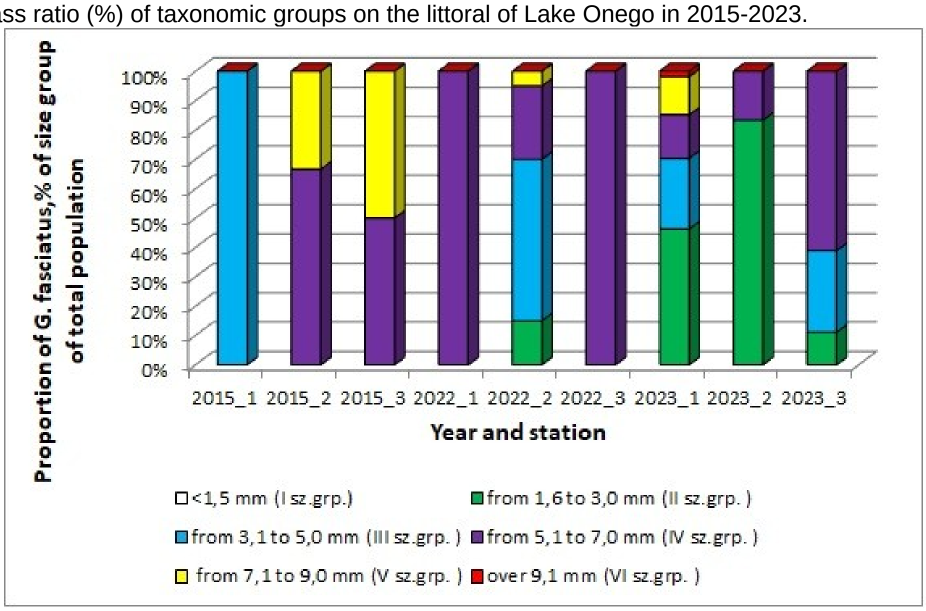

Figure 4 Population size structure (proportion of different size groups from the total number (N, %)) of *G. fasciatus* at stations 1, 2 and 3 in the Suysar area in 2015-2023.

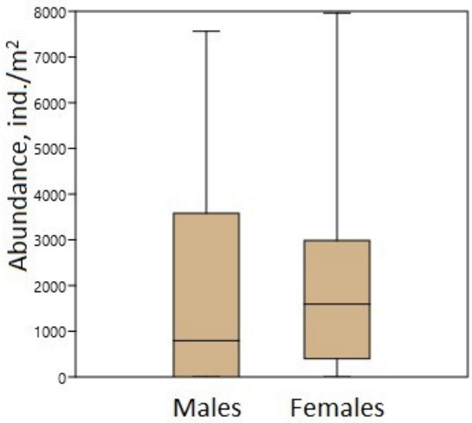

Figure 5. Numbers of males and females in the area of Suysar Island (stations 1-3) in 2015-2023.

Table 1. Mean number (thousand ind/m²) and average biomass (g/m²) of macrozoobenthos groups on the littoral of Lake Onego.

Taxon	N	Year _№ of station									
	B	2015_1	2015_2	2015_3	2022_1	2022_2	2022_3	2023_1	2023_2	2023_3	2023_4
Amphipoda	N	0,8	2,4	1,6	0,4	8	1,6	26,3	2,4	9,2	8
	B	1,8	19,8	19,2	0,9	11,2	48,2	87,8	3,8	19,7	11
Oligohaeta	N	12,7	9,6	0	0,8	0	1,2	15,5	0,8	0,4	9,6
	B	4,2	0,7	0	0,1	0	0,4	43,5	3,8	0,1	0,7
Chironomidae	N	19,9	16,7	4,8	3,2	4,4	1,2	14,3	1,6	0,8	1,2
	B	1,4	3,9	1,5	0,2	0,6	0,6	1,6	0,2	0,2	0,6
Ptychopteridae	N	0	0	0	0,4	0	0	0	0	0	0
	B	0	0	0	3,6	0	0	0	0	0	0
Ceratopogonidae	N	0,8	0	0	0	0	0	0	0	0	0,8
	B	0,1	0	0	0	0	0	0	0	0	0,1
Mollusca	N	0	0	0	0,4	0,4	0	0,4	0	0	0
	B	0	0	0	0,1	0	0	0,8	0	0	0
Trichoptera	N	0	0,8	0	0	0	0	0	0	0	0
	B	0	0,1	0	0	0	0	0	0	0	0
Stratiomyiidae	N	1,6	0	0	0	0	0	0	0	0	0
	B	17	0	0	0	0	0	0	0	0	0
Hydracarina	N	0,8	0	0	0	0	0	0	0	0	0
	B	1	0	0	0	0	0	0	0	0	0
N total		36,6	29,5	6,4	5,2	12,7	4	56,5	4,8	10,4	19,6
B total		25,4	24,5	20,7	4,9	11,8	49,1	133,7	7,8	19,9	12,4

Notes – N total – total number, thousand ind/m²; B total – total biomass, g/m²; N – number, thousand ind/m²; B – biomass, g/m²; № of station – station number.

Table 2. Taxonomic composition and occurrence (P,%) of macrozoobenthos at stations 1, 2 and 3 in the Suysar village area and station 4 on Kizhi Island in 2015-2023.

Taxon	2015_1	2015_2	2015_3	2022_1	2022_2	2022_3	2023_1	2023_2	2023_3	2023_4	P, %
Annelida type Class Oligochaeta											
Limnodrilus hoffmeisteri Claparede, 1862	+	-	-	-	-	-	-	-	-	+	20
Lumbriculus variegatus (Müller, 1774)	-	-	-	-	-	-	+	-	-	-	10
Sperosperma ferox Eisen, 1879	-	+	-	-	-	-	-	-	-	-	10
Stylodrilus heringianus Claparede, 1862	+	+	-	+	-	+	+	+	+	-	70
Tubifex tubifex (Müller, 1774)	+	+	-	+	-	-	-	-	-	+	40
Type Mollusca											
Bivalvia	-	-	-	+	+	-	+	-	-	-	30
Type Arthropoda Class Crustacea Amphipoda species											
Gmelinoides fasiatus	+	+	+	+	+	+	+	+	+	+	100
Class Arachnoidea Acarina species Hydracarina sub-order											
Hydracarina	+	-	-	-	-	-	-	-	-	+	20
Class Insecta (larvae) Trichoptera species											
Trichpotera	-	+	-	-	-	-	-	-	-	+	20
Diptera species Family Chironomidae											
Chironomus sp. Meigen, 1803	+	-	-	-	-	-	-	-	-	+	20
Cricotopus gr. *silvestris* Fabricius, 1794	-	-	-	-	-	+	-	-	-	-	10
Cryptocladopelma viridula (Linne, 1767)	-	+	-	+	+	-	+	-	-	-	40
Limnophyes karelicus (Tshernovskij, 1949)	-	+	+	-	+	+	+	-	+	-	60
Orthocladius sp. Goetghebuer, 1914	-	-	-	-	-	-	+	-	-	-	10
Paracladopelma camptolabis (Kieffer, 1913)	-	+	-	-	-	-	+	-	-	-	20
Polypedilum scalaenum (Schrank, 1803)	-	+	+	-	-	-	+	-	-	-	30
Procladius sp. Skuse, 1889	-	+	-	-	-	-	-	-	-	+	20
Stempellina almi Brundin, 1947	-	+	+	+	+	-	+	+	+	-	70
Tanytarsus gr. *gregarius* Kieffer, 1905	-	-	-	-	-	-	-	+	-	-	11
Family Ceratopogonidae											
Ceratopogonidae	+	-	-	-	-	-	-	-	-	-	10
Family Ptychopteridae											
Ptychoptera	-	-	-	+	-	-	-	-	-	-	10
Family Stratiomyiidae											
Odontomyia	+	-	-	-	-	-	-	-	-	-	10

Note – P, % – frequency of occurrence, %.

DISCUSSION

Taxonomic composition of littoral macrozoobenthos community

According to literature data in Lake Onego, bottom biotopes are inhabited by over 500 species and forms of benthic invertebrates, most of which are concentrated in the coastal areas of the reservoir. During the growing season the macrozoobenthos of the littoral zone is quite diverse and includes more than 20 groups of benthic invertebrates of different taxonomic rank. The most widespread and numerous are low bristle worms, crustaceans and larvae of amphibiotic insects such as mayflies, caddisflies, stoneflies and two-winged bugs. The average abundance of macrozoobenthos in the coastal zone is 11,8±1,7 thousand ind/m², and biomass is 11,8±1,5 g/ m² (Lake Onego..., 2010). In our studies, the benthic fauna is represented by only 22 units of different taxonomic ranks; probably, low taxonomic diversity indicators are related to the subglacial period of the study, when, as shown in small lakes of Karelia, organisms may migrate from shallow waters that are frozen to the bottom at a distance of 100 m from the shore. And in April, when the ice becomes thinner and the temperature slightly increases, partial migration of benthofauna to the littoral zone is observed. Enrichment of the littoral fauna takes place from April, and biomass continues to remain high here until ice-freezing (Sokolova, 1956).

In the 1970s, a study was carried out in the zone of anthropogenic influence in winter on the littoral of the Povenets Bay of Lake Onego. At this time all dynamic processes of water masses were decayed, thermal differences between coastal and deep-water zones were minimal, effluent conditions stood out clearly and created peculiar microconditions in a small area, which negatively affected the development of bottom population. During the subglacial period, oligochaetes were observed on the littoral of Povenets Bay, the number of which reached 2,819 ind/m², while on clean soils without allochthonous organic matter, the number of oligochaetes decreased significantly, and insect larvae appeared (Sokolova, 1969). In the 1970s, the invasive amphipod *G. fasciatus* was not observed.

For other water bodies, there are not so many publications on studying macrozoobenthos of the littoral zone in the subglacial period. For example, studies of the zoobenthos of the Novosibirsk Reservoir allowed us to establish the survival of benthic organisms during the winter drawdown of the reservoir in the wet soils of the temporary dewatering zone, with the biomass of zoobenthos in the dewatered biotopes being higher than in the zone of permanent flooding (Vizer, 2011).

Peculiarities of the size and sex composition of the amphipod G. fasciatus population

According to D.V. Matafonov and co-authors (2005), the particularities of the life cycle of *G. fasciatus* were studied in Lake Arakhley in 1997-1998. The authors showed that significant abundance of the species was also observed in the subglacial period. At this time, *G. fasciatus* accumulations on the remains of dying vegetation are possible - up to 19582 ind/m², with biomass up to 100 g/ m². The population of this species is represented by a rather wide range of sizes - III-VI size groups (sz.grp.). No individuals with a length of less than 3.1 mm were found. The fourth (IV) sz.grp. accounted for 42,4-75% of the total abundance of *G. fasciatus* during this period. The second highest abundance was in the fifth (V) sz.grp. - from 15 (March 1997) to 45% (December 1997). In general, individuals of size group V dominated in terms of biomass. In addition to these main groups, individuals of size group VI (up to 8% in abundance and 16% in biomass in March 1998) were recorded during the subglacial period. Apparently, these were individuals of the first breeding round, which had already reached their maximum size. In general, the abundance of size groups VI as well as III does not exceed 20% of the total abundance. We did not find breeding females in winter (January 2022, February 2023) and early spring (April 2015).

In Lake Ladoga during the 2004-2005 subglacial period, the size structure of the *G. fasciatus* population remained stable and was represented by size groups III-VI. Individuals with length less than 3.1 mm were not found. In terms of abundance, individuals of size group IV (45-53%) were dominant, and in terms of biomass - of size group V (22-42%). The total abundance and biomass of size groups III and VI were ≤30% (Barkov and Kurashov, 2011).

The sex structure in Lake Ladoga was relatively stable throughout the subglacial period 2004-2005 and in spring 2005, and the proportion of females remained 55-65% (Barkov and Kurashov, 2011).

CONCLUSION

Macrozoobenthos of the littoral in the subglacial period is represented by 22 units of different taxonomic rank, probably, low indicators of taxonomic diversity are related to the time of the study, when, as shown on small lakes of Karelia, there are possible migrations of bottom organisms from shallow waters that freeze to the bottom at a distance of 100 m from the shore.

In conclusion, it should be noted that in most of the studied habitats (at stations 2, 3 and 4) in different years the invasive species *G. fasciatus* dominated in biomass. We have shown for the first time that during the subglacial period on the littoral of Lake Onego the population of *G. fasciatus* contains young individuals from 2,1 mm, in contrast to the size composition in Lake Ladoga. Apparently, these are crustaceans that appeared in the summer of the previous year, as we did not find breeding females. The sex structure of the population in Lake Onego is stable, with a 1:1 ratio of females to males.

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CONFLICT OF INTERESTS

The author declares that she have no potential conflicts of interest.

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