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State of marine biota in the water area of the Muchke Bay's Coal Terminal of the Tatar Strait

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Abstract. An analysis of the species composition of phytoplankton and ichthyoplankton was carried out for the first time in the port water area of the Muchke Bay (Tatar Strait) in autumn. The species composition, distribution features and structure of macrozoobenthos were considered. Phytoplankton density is evenly distributed in the study area. The density of diatoms reached 97 % of the total phytoplankton density, and the biomass was 99 %. The microalgae *Sceletonema costatum* (Greville) Cleve, 1873 and *Cylindrotheca closterium* (Ehrenberg) Reimann & J.C.Lewin, 1964, species that live in polluted waters, were discovered. The development of phytoplankton in the autumn period was active, but the peak of flowering was not observed. Ichthyoplankton in October 2017 is represented by live eggs of *Limanda sakhalinensis* (Schmidt, 1904) (8 ind./m^3), in September 2018 - by the larvae of *Hexagrammos stelleri* Tilesius, 1810 (0.003-0.056 ind./m^3) and *H. octogrammus* (Pallas, 1814) (0.01-0.077 ind./m^3). Up to 85 representatives of macrozoobenthos were registered from the research area, including 40 species of Polychaeta, 19 ones of Crustacea, 16 species of Mollusca, 5 ones of Echinodermata and 5 species of other fauna groups. After dredging, a decrease in the species diversity of phytoplankton, ichthyoplankton and macrozoobenthos was found in the samples.

1 Introduction

In 2007, LLC Daltransugol carried out work on construction of the Vanino Bulk Terminal with design capacity of 12 million tons in the area of the Muchke Bay. Currently, this specialized coal transshipment complex is one of the youngest in Russia. The port in the Muchke Bay provides the shortest route from mining enterprises to end consumers in China, South Korea, Japan and Taiwan. Development of the coastal port infrastructure facilities will result in increased pressure on the ecosystem of the Muchke Bay and the Tatar Strait as a whole. The closed conveyor technology and rotary car dumper systems used at the Vanino Bulk Terminal do not exclude the formation of coal dust, and the storage of large amounts of coal at open sites causes particles to enter the sea water. The presence of large amounts of coal particles in the water changes the properties of the marine environment and can

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negatively affect marine organisms [1, 2], affect the density of microalgae, embryonic and larval development of benthos and nekton organisms [3-6].

Information on the current state of marine biota of the harbor waters in the western part of the Tatar Strait (including the Muchke Bay under conditions of coal terminal operation) is scarce in the relevant publications.

Comprehensive hydrobiological studies were not conducted during implementation of the Vanino bulk terminal construction project, and were started recently due to the expansion of coal transshipment complex activity, periodic dredging and reconstruction of berths in the Muchke Bay.

A contribution to the study of microalgae communities of the Far Eastern seas was made by G.N. Konovalova and coauthors [7-9]. A review of phytoplankton studies in the Sea of Okhotsk and the Tatar Strait is given in J.R. Tskhai [10]. The phytoplankton of the coastal area of the western part of the Tatar Strait has received little attention in the research papers.

The ichthyoplankton of the northern part of the Sea of Japan and the Tatar Strait in summer 2017 was studied in detail by V.A. Shelekhov et al. [11, 12]. The paper provides data on the concentration of eggs and larvae in the western part of the Tatar Strait, including Sovetskaya Gavan Bay. In the Tatar Strait, O.N. Mukhametova [13] investigated ichthyoplankton of only near-Sakhalin waters.

Analysis of macrobenthos surveys and data on group composition and quantitative distribution of bottom population in the northern part of the Sea of Japan and the northwestern part of the Tatar Strait in 1985 are given in the paper by V.A. Nadtochiy and Yu.A. Galysheva [14]. Diver surveys performed by the Khabarovsk Branch of the Pacific Ocean Fisheries Research Center and trawl surveys of the Sakhalin Branch of the All-Russian Research Institute of Fisheries and Oceanography obtained data on the composition, structure, and resources of macrobenthos in the Tatar Strait. The researches are mainly devoted to the study of large forms of epibenthos, valuable invertebrate species and conditions of formation of their commercial assemblages [15-17], as well as the distribution of macrophytobenthos [18-21]. In addition, diver surveys in the Sovetskaya Gavan Bay (the Tatar Strait) were conducted in 2010 [22], and the results of 2012-2014 highlighted three binomial types of benthos belt composition [23]. A dredge survey established the species composition and quantitative distribution of macroepibenthos in the northwestern part of the Tatar Strait in 2018 [24].

The study of plankton and benthic communities as an integral part of marine ecosystem monitoring allows to assess the condition of the marine environment and to take possible measures for its protection and improvement, especially under conditions of increasing anthropogenic load. The necessity of monitoring is also conditioned by the important fishery significance of the Muchke Bay.

The purpose of this study in the Muchke Bay is to determine the characteristics of plankton communities and the condition of macrozoobenthos in the area of the coal-loading complex, where periodic dredging and reconstruction of berths are carried out.

2 Material and methods

2.1 Study area

The Mucheke Bay is located in the Tatar Strait to the north of the Vanino Bay, embedded into the shore between the unnamed cape located to the north-west of the Muchukey-Dua Cape and the Aimianku Cape. The shores of the bay are low, precipitous and fringed with reefs and shoals. The depths start from 12-13 m at the inlet promontory of the bay and gradually decrease towards its shores. The bottom is sand [22]. The current system is complex and during windy or calm weather the surface currents are mainly influenced by tides. The

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ichthyofauna of the bay is represented by valuable commercial species: pink salmon, cherry salmon, taimen, herring, char, saffron cod, smelt, flounder, lost ling, pilengas. The bay belongs to the highest category in terms of its fishery value [17].

Samples were collected in the Muchke Bay in the fall of 2017 and 2018, after dredging to ensure safe approach and mooring of large-displacement vessels. In September 2020, samples were collected prior to the next dredging event.

2.2 Sampling methods and procedure

2.2.1 Phytoplankton

Marine biota was sampled for species composition and quantification in the Muchke Bay at 10 stations in October 2017, September 2018, and September 2020 (Figure 1, Table 1).

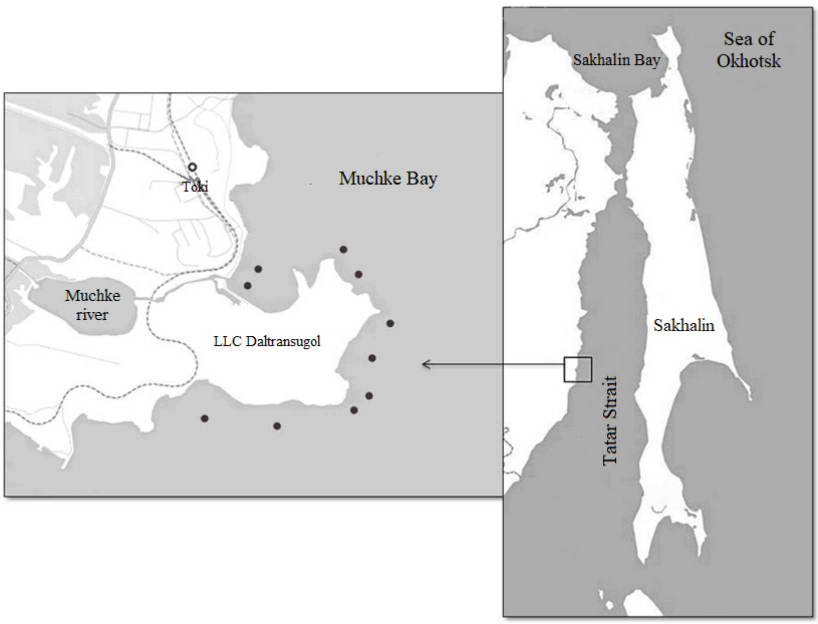

Fig. 1. Map-scheme of sampling in the area of the Muchke Bay and the coal terminal.

Phytoplankton was sampled in the surface layer using a Niskin bottle. Samples were fixed with 5% iodine solution and stored in a darkened place at a relatively low temperature. Cell numbers were counted in counting chambers of 0.05 and 1 ml, taking into account the minimum representative sample of the counted number of cells [25-27]. Sixty samples were collected and processed during all periods of the study. Algae biomass was estimated by volumetric method [26, 28, 29], with subsequent conversion to weight units: mg/m3. The density was taken as the number of cells in 1 L of water. Dominant and subdominant species were considered to be those with the densities of at least 10% and at least 20%, respectively, of the total density of other species in the community.

Table 1. Sampling stations in the Muchke Bay (the Tatar Strait).

Station	Coordinates		Depth of location	Water temperature, °C			Sediment's characteristic
	Latitude	Longitude		October, 2017	September, 2018	September, 2020	
1.	N49°06.377'	E140°19.921'	1.8	13.0	15.4	15.8	Sand
2.	N49°06.499'	E140°20.190'	9.5	12.5	15.0	15.5	Sandy mud
3.	N49°06.635'	E140°20.576'	13.1	12.5	15.1	15.0	Sandy mud
4.	N49°06.370'	E140°21.003'	13.1	13.5	14.5	15.1	Sand with broken shells and empty clam shells
5.	N49°06.177'	E140°21.230'	18.9	12.0	14.3	14.9	Sand with broken shells
6.	N49°05.897'	E140°20.931'	18.3	12.8	14.3	14.9	Silt deposit
7.	N49°05.693'	E140°20.868'	19.2	12.4	15.0	15.4	Sand with broken shells
8.	N49°05.577'	E140°20.703'	20.9	13.4	15.2	15.5	Sand with broken shells and empty clam shells
9.	N49°05.525'	E140°20.277'	17.4	12.6	15.3	15.1	Silt deposit
10.	N49°05.560'	E140°19.435'	10.2	12.5	14.7	15.1	Silt deposit

2.2.2 Ichthyoplankton

Collection of ichthyoplankton was performed by horizontal fishing with a caviar net IKS-80 (inlet opening diameter 80 cm, mesh 0.35-0.55 mm) according to the standard methodology [30]. Thirty samples of ichthyoplankton were processed. Samples were fixed with 4% formaldehyde solution. Total amount of ichthyoplankton in the sample was counted using a stereomicroscope and its concentration in 1 m^3 of water was estimated.

2.2.3 Macrozoobenthos

Three replicates of sediment samples were taken for analysis of macrobenthic fauna at each of 10 stations in September 2018 and 2020, using a 0.1 m^2 Van Veen grab.

Macrobenthos was washed through a system of hydrobiological sieves with the smallest mesh of 0.5 mm and then fixed with 4 % formaldehyde solution. At the laboratory, macrobenthos was sorted and identified to the lowest possible taxonomic level, and the density and crude biomass of bottom hydrobionts in the sample were also determined.

3 Results

3.1 Phytoplankton

In October 2017, there was a lot of suspended matter in the phytoplankton samples, while in September 2018 there was a small amount of suspended matter.

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During the entire period of study the composition of phytoplankton was formed by 40 species and intraspecific taxa belonging to two phylums: diatoms (Bacillariophyta) and dinophytes (Dinophyta). Diatoms were rich in species - 33 species and intraspecific taxa, dinophytes included 7 species (*Alexandrium tamarense* Halim, 1960, *Gymnodinium agiliforme* Schiller, 1928, *G. japonicum* Hada, 1974, *G. wulffii* J.Schiller, 1933, Gymnodinium sp., *Karlodinium vitiligo* (D. Ballantine) J. Larsen, 2000, *Protodinium simplex* Lohmann, 1908).

In all periods of research the basis of flora was formed by neritic species (*Asterionella glacialis* Castracane, 1886, *Chaetoceros affinis* Lauder, 1864, *Ch. compressus* Lauder, 1864, *Stauroneis granii* E.Jorgensen, 1905, *Sceletonema costatum* and others) which reached 66 % of total number of species with known ecological characteristic. The species with the cosmopolitan type of areal prevailed (46 %): *Cylindrotheca closterium*, *Coscinodiscus oculus-iridis* (Ehrenberg) Ehrenberg, 1840, *Leptocylindrus danicus* Cleve, 1889, *Thalassionema nitzschioides* (Grunow) Mereschkowsky, 1902, *Chaetoceros constrictus* Gran, 1897, etc.

Marine species (28 species or 87.5%: *Asterionellopsis glacialis*, *Chaetoceros affinis*, *Chaetoceros compressus*, *Coscinodiscus centralis* A. Schulze, 1879, etc.) during the autumn. Brackish-water species (*Cylindrotheca closterium*), brackish-water-marine species (Cyclotella sp.) and freshwater-saline species (*Stephanodiscus bramaputrae* Ehrenberg, 1854) were found in one species (3.12%).

The density of diatoms reached 97% of the total phytoplankton density, and the biomass reached 99% of the total microalgae biomass. The distribution of microalgae density in the studied area was uniform. High values were observed in September 2020 (Figure 2), when samples were collected before dredging.

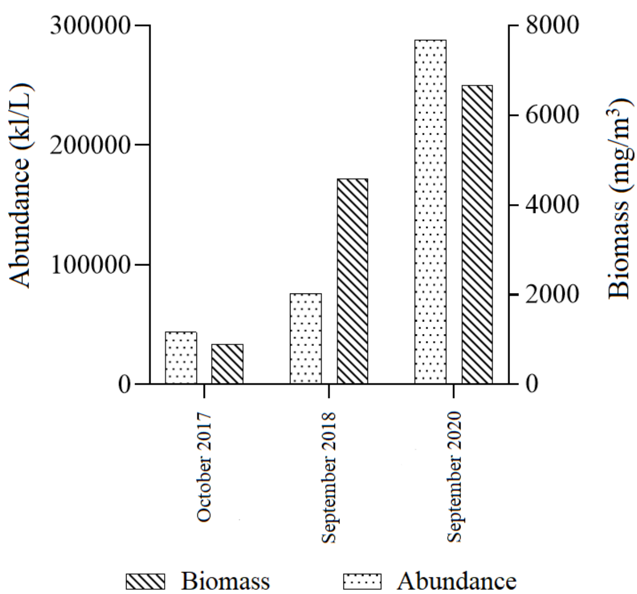

Fig. 2. Comparative characterization of phytoplankton biomass (mg/m^3) and abundance (cells/L) in the study area during the fall period: October 2017 and September 2018 - after dredging; September 2020 - before dredging.

3.2 Ichthyoplankton

In October 2017, ichthyoplankton was represented by one species from the flounder family. Live spawn of *Glyptocephalus stelleri* (5 ind./fishing) at the stage IV of development was observed at one station at the depth of 13 m in the Muchka Bay, 200 m from the pier of the coal-loading complex. The egg diameter was 1.35-1.50 mm. In September 2018, the ichthyoplankton was represented by 2 fish species of Hexagrammidae family. Unformed larvae of *Hexagrammos stelleri* (16 ind./fishing, length 10.0-11.0 mm) and *H. octogrammus* (10 ind./fishing, length 6.0-7.5 mm) were at the yolk sac stage. Peak spawning was recorded for these two species. Spawning is typical for terpug in this area in the fall [31], however, these two species were not observed in October 2017. In September 2020, eggs and larvae of 9 fish species were found in the samples: eggs of *G. stelleri* (3 ind./fishing), *Limanda punctatissima* Steindachner, 1897 (18 ind./fishing), *Limanda sakhalinensis* Hubbs, 1915 (3 ind./fishing), *Limanda sakhalinensis*, 1915 (3 ind./fishing), and *Limanda punctatissima* Steindachner, 1897 (18 ind./fishing). /The larvae of *Hemilepidotus gilberti* (ind./fishing), *H. stelleri* (16 ind./fishing), *H. octogrammus* (10 ind./fishing), *Mallotus villosus* (1 ind./fishing, length 9.5 mm), *Sebastes minor* (4 ind./fishing, size 5.0-7.0 mm). Fish eggs were alive, at stages III-IV of development, with no signs of pathology.

3.3 Macrobenthos

85 representatives of benthic invertebrates of 8 types (Cnidaria, Nemertea, Annelida, Sipuncula, Arthropoda, Mollusca, Brachiopoda, Echinodermata) and 1 species of ascidians (Chordata type) were found in the bottom dredging macrobenthos of the coal terminal water area. 53 species and 57 species were found in September 2018 and 2020, respectively. The polychaetes where found dominated (46 % of the total species composition) everywhere. *Scoloplos armiger* (Müller, 1776) was recorded at all stations in autumn 2020, and in 2018 it was absent only at the site with sandy-shelly soil of Stations 4, 7, 8. The predators *Goniada maculata* Örsted, 1843, *Glycinde armigera* Moore, 1911, *Kuwaita heteropoda* (Marenzeller, 1879), and collecting detritophages and sestonophages of the Family Spionidae were also frequently found among polychaetes. The Amphipoda and Bivalvia groups included 17 and 12 species, respectively. A frequently encountered species among amphipods was *Ampelisca macrocephala* Liljeborg, 1852. It was found at almost all stations in 2020. It should be noted that in 2018 the occurrence of *A. macrocephala* was lower, the species was registered only at the stations in the open part of the studied water area to the south of the coal-loading complex. Probably, it could be due to dredging in 2018 near the berths of the terminal. In 2020, there was a repopulation with benthic organisms in the damaged areas of the bottom.

At stations confined to the sandy plain with seagrass *Zostera asiatica* in the coastal part of the Muchke Bay and at depths of 1.5-10.5 m the macrobenthos included 45 representatives of benthic invertebrates, the average biomass was 46.9±22.3 g/m^2, the number was 455±253 specimens/m^2. *Z. asiatica* formed thickets at depths of 1.5-3.0 m. The polychaete *S. armiger* (up to 40%) formed the basis of settlement density among polychaetes. *S. armiger* is a selective detritivore, widespread mainly in shallow waters, often forming mass aggregations in sandy soil. According to T.A. Belan [32], the settlement density of this species decreases in the direction of increasing pollution of bottom sediments, the polychaete is not found in the most polluted water areas of the Peter-the-Great Bay (Zolotoy Rog Bay, Nakhodka Bay) of the Sea of Japan.

Macrobenthos species composition of sandy-silty grounds between stony-boulder placers at the depth of 11-13.5 m included 38 representatives. *Agarum clathratum* Dumortier 1822 was quite abundant on the surface of boulders. The found algae species were: *Corallina pilulifera* Postels& Ruprecht 1840, *Stephanocystis crassipes* Draismaet. al. 2010, and

Saccharina cichorioides Laneet. al., 2006. Dredge benthos biomass at the site reached 66.08±21.81 g/m^2, with an abundance of 255±134 specimens/m^2. Along the boulder slopes of the study area there were settlements of bivalve mollusks, including the coastal scallop [22].

Sites with sandy and sandy-silty substrate at depths from 1.5 to 15-17 m had 14 common macrobenthic animal species. Changes in the composition and structure of the benthic population occurred with increasing depth.

At greater depths (18-21 m), sandy soil with varying degrees of siltation was covered with empty bivalve shells or broken shells. There were 36 representatives of benthic invertebrates at the site. The species composition was dominated by polychaetes (32%). Macrobenthos biomass reached 110.22±72.5 g/m^2 and abundance made 250±177 specimens/m^2. The sea anemone *Metridium farcimen* (37.3 g/m2) and the sea urchin *Scaphechinus griseus* (34.65 g/m^2) accounted for the maximum biomass. Amphipod *A. macrocephala* was the most abundant (83 specimens/m^2).

In the open part of the water area at a depth of 17-19 m the bottom was covered with a layer of silty-sandy deposits 0.15-0.2 m thick. Irregular holes of about 0.5-10 cm in diameter were found in the ground, some of which were filled with tubes of polychaetes of Sabellidae Family. Rare fragments of seagrass *Z. asiatica* were observed. There were 40 representatives in the macrobenthos. The biomass reached 93.01±28.17 g/m^2, abundance was 2262±1239 specimens/m^2, mainly due to the presence of amphipods *A. macrocephala* (22.89 g/m^2 and 1593 specimens/m^2).

4 Discussion

4.1 Phytoplankton

The autumn phytoplankton of the Tatar Strait is transient in composition and most diverse compared to other seasons. Biological autumn in the Tatar Strait off the southwestern Sakhalin lasts from late September to November. Warm-loving and relatively warm-loving species predominate. In September, the role of diatoms increases significantly again after the summer break [33]. *Bacteriastrum delicatulum*, *Hemiaulus hauckrii*, *Rhizosolenia stoiterforthii*, *Ceratiumma croceros*, and *Goniaulax lurbynei* are found among the mass diatoms at this time. This is the period of maximum heat supply and the highest productivity of waters. In the second half of September, the autotrophic phase ends and the second autumn-winter heterotrophic phase begins. It continues until spring. During this very long phase, destruction of organic matter and regeneration of biogens take place, while preparing the basis for phytoplankton development during the autotrophic phase in the next spring [34].

In the Muchke Bay during the whole research period, the species composition of phytoplankton was mainly represented by diatom algae, which accounted for about 97 % of the total number of cells. *Sceletonema costatum*, *Cylindrotheca closterium*, *Chaetoceros affinis*, *Rhizosolenia setigera*, *Thalassiosira bramaputrae* and *Rhizosolenia setigera* were the dominant species in the autumn period (Figure 3).

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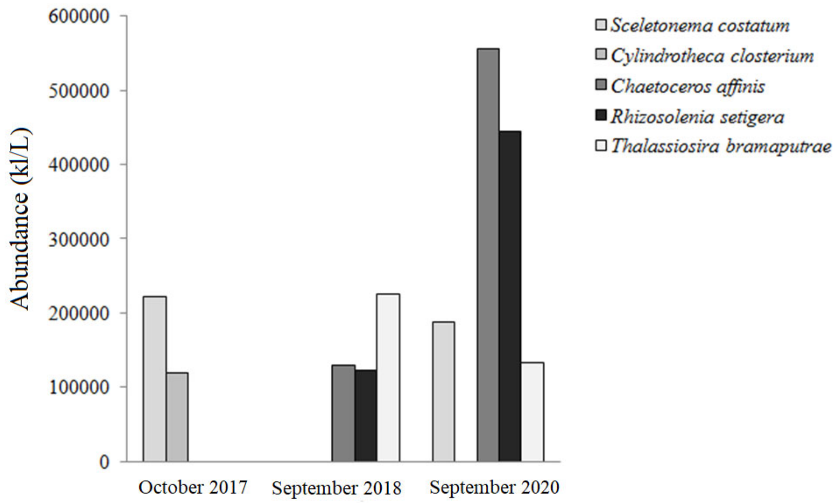

Fig. 3. Dominant species of diatom algae during the fall in the Muchke Bay.

The species *Coscinodiscus oculus-iridis* (about 1418.20 mg/m^3, i.e. about 45 % of all phytoplankton) and other representatives of Coscinodiscus spp. dominated in autumn biomass in all years.

The presence of the diatom algae *Sceletonema costatum*, an indicator of eutrophic waters, in the samples shows to a high content of biogenic organic matter in the water area [35]. In the Muchke Bay, the microalgae *Sceletonema costatum* abundance in September 2018 was 128500 cells/L and a maximum of 188500 cells/L was recorded in September 2020.

In spring and fall, *Cylindrotheca closterium*, a neritic euryhaline species (cosmopolitan), is particularly abundant in polluted and eutrophic bays [35]. In the Muchke Bay, average abundance of this species reached 12000 cells/L in October 2017 and in September 2020 – 5000 cells/L.

The toxic algae *Alexandrium tamarense* was also found in all samples in the Muchke Bay at a concentration of 250-500 cells/L (Figure 4). This algae content is not dangerous for shellfish and fish [36].

Fig. 4. The toxic alga *Alexandrium tamarense* from the Muchke Bay.

Species of the Alexandrium genus are widely known as producers of paralytic toxin (in particular saxitoxin and its analogues), which is transmitted through food chains, causing poisoning of humans as well as mass death of warm-blooded animals [36, 37]. About ten representatives of this genus are capable of producing toxins that affect the neuromuscular, sensory, digestive, and cardiovascular systems of humans. This poisoning is called Paralytic Shellfish Poisoning (PSP). Tens of thousands of human cases of paralytic toxin poisoning are reported worldwide each year from eating fish, shellfish and other seafood. The most common toxic "blooms" are caused by the species *Alexandrium tamarense*. Cases of human poisoning by eating shellfish during red tides caused by *A. tamarense* "blooms" have been reported off Kamchatka and in the Bering Sea [38].

According to Mogilnikov et al. [39], in samples from the Tatar Strait (west coast of Sakhalin Island), algae from five Phylums developed in the September phytoplankton. The major part of the abundance was the diatoms *Phaeodactylum tricornutum* (31.8 %), benthic dinoflagellates *Ostreopsis aff. siamensis* (21.5 %) and green Chlamydomonas sp. In October phytoplankton algae development was active, diatoms and dinophytes were found. Mass species were mainly diatoms: *Chaetoceros socialis* and other representatives of this genus, *Dactylosolen fragilissimus* and *Thalassionema nitzschioides*. Out of the group of potentially toxic algae, species of the genus *Pseudo-nitzschia* (September-October), *Prorocentrum micans* (October) and mass vegetation of epiphytic species from dinoflagellates *Ostreopsis aff. siamensis* (N = 33.803×103 cells/L, September) were registered in low numbers.

The results of the phytoplankton study in the Muchke Bay coincide with the geographical analysis data obtained earlier for some areas of the northwestern Japan Sea [7, 9, 40, 41]. Phytoplankton development was active in the Muchke Bay in 2017-2020, but no peak blooms were observed. The species composition, biomass, and abundance were typical for the Tatar Strait in the fall season. However, it should be noted that only 18 diatom species and 1 dinophyte species were observed in phytoplankton samples in fall 2017 and 2018 after dredging. Whereas in September 2020, a maximum of 40 species were recorded in the phytoplankton composition before the next dredging.

It has previously been shown that planktonic organism complexes can be negatively impacted when suspended matter concentrations increase in the water accompanying the processes of remedial scooping and extraction of soils from the aquatic environment [42-44]. Suspended matter can contribute to changes in phytoplankton density.

4.2 Ichthyoplankton

According to Shelekhov et al. [11, 12], 16 fish species from 10 families were encountered in the Tatar Strait in July-August 2017. The Pleuronectidae (*Glyptocephalus stelleri*, *Cleisthenes herzensteini*, *Limanda aspera*, *L. punctatissima*, and *Acanthopsetta nadeshnyi*) appeared to prevail in the number of species. The summer hydrological season in the Tatar Strait ends in September. In October-November, the diversity of ichthyoplankton species and forms, as well as the total number of eggs and larvae decrease [11, 12]. It is known that for Pleuronectidae, spawning peak is in the spring-summer period, with spawning rates decreasing by September (Pertseva-Ostroumova, 1961). No larvae of the Hexagrammidae Family were observed in the Tatar Strait in summer 2017 [11, 12]. Spawning is typical for Hexagrammidae in autumn [31].

During the period of this study, ichthyoplankton contained 4 species from the Pleuronectidae Family, 2 species from the Hexagrammidae Family and 1 species each from the families of Cottidae, Osmeridae, Scorpaenidae. In 2020, prior to dredging, ichthyoplankton samples were more diverse compared to 2017 and 2018.

4.3 Macrobenthos

The studied water area can be divided into 4 main areas according to the nature of substrates: sandy substrates of the coastal shallow water part of the Muchke Bay; sandy-silty areas between stony-boulder placers; sandy substrate with an admixture of broken and whole bivalve shells and silted plains in the open part of the study area. Collecting detritophages, mobile sestonophages, and predatory polychaetes were the most common animals, while nonselective detritophages were present to a lesser extent. On sandy plains with seagrass beds and on sandy-silty soil between large boulders, polychaetes dominated in terms of biomass and abundance. On mud flats in the open part of the water area, polychaetes and amphipods formed the biomass almost equally (33-34%), and *A. macrocephala* was the most abundant. On sandy-silty ground with an admixture of shells, sea anemones and sea urchins formed the basis of the biomass.

5 Conclusion

All representatives of phytoplankton, ichthyoplankton, and macrobenthos collected in the fall period in the harbor waters of the Muchke Bay were typical of the northwestern part of the Sea of Japan and the Tatar Strait.

Neritic species formed the basis of the flora, and the distribution of microalgae density was uniform. High values of phytoplankton quantitative characteristics were observed in September 2020 before dredging, and the minimum values – in October 2017 after dredging. Diatoms were the dominant group (97% of total density and 99% of total phytoplankton biomass).

Dredging also affected the species composition of ichthyoplankton and macrobenthos. Before dredging, ichthyoplankton was represented by eggs and larvae - 9 fish species, macrobenthos - 57 species. After dredging, ichthyoplankton was represented by eggs and larvae of 1-2 fish species only, macrobenthos - by 53 species.

According to the authors data, no traces of coal dumping and coal dust emissions were found during the investigated period. Phytoplankton bloom was not observed. However, periodic dredging can negatively influence the state of marine biota and decrease biodiversity, which requires further regular ecological monitoring of the near-port water area.

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