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RESEARCH PAPER

Distribution Features of Microplastic Particles in the Bolshiye Koty Bay (Lake Baikal, Russia) in Winter

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ABSTRACT
The problem of pollution of aquatic ecosystems with microplastics has been actively studied by the world scientific community. Most of this research has been devoted to marine ecosystems, whereas scant research has been conducted on fresh water bodies. Lake Baikal (Russia) is a unique natural reservoir. Previous studies devoted to the amount of microplastics in the waters of Lake Baikal were carried out singularly and were not of a systemic character; therefore, previously obtained data does not reflect a complete picture of the state of the lake. Within the framework of this study, our goal was to study the composition and morphological structure of microplastic particles in the ice of Lake Baikal at different distances from the coastline. To do this, a number of ice samples were taken from the upper and lower sides at five different points in South Baikal opposite the village of Bolshiye Koty. Later these samples were analyzed for the types of microplastics and their amount. In the samples taken, two types of microplastics were found—fragments and fibers—with fibers being predominant. The median values of the number of microplastics particles are higher in samples taken at the interface between water and ice, compared to samples taken from the ice surface. Presumably, main part of microplastic fibers found opposite the village of Bolshiye Koty were brought in by a constant circular current from the opposite east coast. In turn, the low number of fragments in the samples may be due to the freezing of the coastline.
Keywords: Lake Baikal, microplastics, plastic pollution, microplastics in ice.

INTRODUCTION

Microplastics are plastic particles no larger than 5 mm (Courtene-Jones et al., 2017; Akdogan & Guven, 2019). Microplastic was first discovered about 50 years ago, just 20 years after the start of mass production of plastic products (Carpenter & Smith, 1972; Carpenter et al., 1972; Scherer et al., 2017). It can be of different origins: primary microplastics are produced in the form of granules or pellets for industrial use (periodically, fibers are also referred to them); secondary microplastics are formed as a result of the destruction of plastic products (Geilfus et al., 2019). Primary microplastics enter the aquatic environment through the discharge of domestic wastewater. Secondary microplastics are formed by the destruction of plastic products under the influence of sunlight, heat, wind and other abiotic factors, as well as in cold and anoxic conditions of the aquatic environment (Akdogan & Guven, 2019; Zhang, 2017). Microplastics have penetrated all continents and is found almost everywhere in water, air, and soil (Akdogan & Guven, 2019). It has been found in atmospheric precipitation, in which particles can be transported over long distances (up to 100 km) and fall over protected

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or sparsely populated areas (Brahney et al., 2020; Allen et al., 2019). The low density of plastic particles is good for its diffusion in the environment. Due to their small size, low density and high resistance to destruction, microplastics are classified as the most dangerous environmental pollutants. Therefore, all over the world, microplastic pollution has become a serious problem that is increasingly being studied.

Microplastics are divided into several types depending on their morphological structure: fibers, fragments, granules and films (Akdogan & Guven, 2019; Kane & Clare, 2019; Klein et al., 2015). Fibers and fragments are especially common types, and they also cause the greatest harm to living organisms (Karnaukhov et al., 2020; Akdogan & Guven, 2019). Microplastic negatively affects important physiological processes such as nutrition, growth, and reproduction and can affect all groups of organisms, from invertebrates to large mammals (Avio et al., 2017; Cedro & Cleary, 2015; Scherer et al., 2017). It contains harmful chemical compounds and is capable of adsorbing pollutants from the environment, making it even more dangerous (Geilfus et al., 2019; Avio et al., 2017; Ma et al., 2020; Akdogan & Guven, 2019).

Studies of marine ecosystems indicate that 73% of marine debris is plastic (Avio et al., 2017; Scherer et al., 2017; Geilfus et al., 2019). There are very few studies on ice contamination by microplastics, and almost all of them are devoted to the ice of Antarctica (Obbard et al., 2014; Obbard, 2018; Peeken et al., 2018; Kelly et al., 2020; Friesen et al., 2020). Scientists have detected microplastic particles even where the presence of people is minimal, such as remote research stations and the areas surrounding them. Therefore, scientists have concluded that microplastics can be transported by ocean currents over long distances, as well as accumulate in the ice of Antarctica. A study was also conducted on the pollution of the Baltic Sea ice. Scientists have investigated the question of how microplastic particles can affect the properties of sea ice and how they are distributed in its thickness and determined that the particles are unevenly distributed throughout the ice (Geilfus et al., 2019). Perhaps this is due to the relatively inhomogeneous distribution of particles in the water column, as well as to the slow freezing of ice. Microplastic was found at all sampling points and was small in size and low in concentration, suggesting that it does not affect the properties of sea ice. However, if the concentration of microplastics increases, it can affect salinity, permeability, and the melting of sea ice (Geilfus et al., 2019).

Microplastic pollution of fresh water ecosystems has been under-explored (Sarah et al., 2015; Scherer et al., 2017). As a result, only a few studies have been devoted to the pollution of Lake Baikal (included in the UNESCO World Heritage List) (Karnaukhov et al., 2020; Biritskaya et al., 2020; Il’ina et al., 2021), and even less attention has been paid to other objects of the lake's drainage basin (Karnaukhov et al., 2020; Free et al., 2014). In two studies carried out on Lake Hovsgol (Mongolia), it was found that microplastic particles were found there several times less than on Lake Baikal, but their concentration still reaches high levels, given the sparsely populated shores of Lake Hovsgol (Karnaukhov et al., 2020; Free et al., 2014). Studies carried out in the Selenga River delta near the village of Novy Enkhaluk indicate that, despite the small number of residents (about 170 people), the amount of microplastic in the waters opposite the village is quite high - 18 thousand particles/km^2 (Il’ina et al., 2021). Thus, the Selenga River can be a major source of microplastic pollution, as its basin covers a vast territory, which includes large cities such as Ulan-Ude, as well as Ulan Bator (Mongolia) and many other settlements. Large cities in Mongolia have a high population density and well-developed industrial activity, but there is little or no waste recycling. Most of the waste (about 90%) is taken to landfills for disposal, while the remaining 10% remains in the environment (Battulga et al., 2019). Previously, it was proven that the absence of a sewerage system and treatment of domestic wastewater is one of the main sources of river pollution (Itoh et al., 2011). River runoff, in turn, is one of the main ways plastic pollution travels from settlements into the open water environment (Battulga et al., 2019). For the waters of Lake Baikal, which are distinguished not only by their purity but also by a large amount of endemic life, pollution of such a large source of fresh water significantly threatens living organisms.

The ice of Lake Baikal was previously examined by freezing aquatic organisms into it and studying their development in winter. It has been proven that pelagic and benthic organisms are able to freeze into ice while they are in a state of "hibernation" and remain viable until the warmer seasons. Means of getting the organisms into the ice differ. This is accomplished either by an independent ascent or transporting them together with ice floes and other objects from the bottom or movement with an underwater current (Mechanikova et al., 2009). For some organisms, ice becomes an additional habitat in which they not only hibernate, but also grow and feed. Research on microplastic contamination of ice on Lake Baikal has not been previously conducted. However, considering the above facts, such a study seems necessary for a complete understanding of the lake pollution and the effect of microplastics on its ecosystem. In this case, it was interesting for us to study whether the distance from the settlement affected the composition of microplastics and its quantitative values. Based on this, the aim of this study was to study the differences in the number of microplastic particles of different morphological structures in ice at different distances from the coastline and settlement.

MATERIALS AND METHODS

The study was carried out from Feb. 20,2021 to Feb. 27,2021 in South Baikal, Bolshiye Koty Bay. For the study, ice samples were taken from areas differing in the following characteristics (Table 1): 1. location over the sublittoral zone; 2. location above the pelagic zone; 3. location above the littoral zone near the pier; 4. location over the littoral zone near the river mouth; and 5. location above the littoral zone away from the settlement (distance from the settlement 1540 m) (Fig. 1).

Table 1. Characteristics of sampling points

№	Location name	Point No.	Distance from the coast, m	Depth, m	Geographical coordinates
1	Location over the sublittoral zone	1	110	44	51°54'07.9"N 105°04'23.4"E
		2	134	51	51°54'07.1"N 105°04'22.8"E
		3	113	45	51°54'07.8"N 105°04'22.6"E
2	Location above the pelagic zone	1	856	470	51°53'44.0"N 105°04'30.0"E
		2	864	479	51°53'43.1"N 105°04'30.4"E
		3	863	479	51°53'42.7"N 105°04'29.7"E
3	Location above the littoral zone near the pier	1	26	2.5	51°54'10.8"N 105°04'09.7"E
		2	22	2	51°54'10.9"N 105°04'09.6"E
		3	19	1.7	51°54'11.0"N 105°04'09.4"E
4	Location over the littoral zone near the river mouth	1	26	3	51°54'10.6"N 105°04'26.8"E
		2	23	2.5	51°54'10.7"N 105°04'26.7"E
		3	26	3	51°54'10.6"N 105°04'26.6"E
5	Location above the littoral zone away from the settlement	1	30	4	51°54'03.5"N 105°06'23.8"E
		2	29	4	51°54'03.8"N 105°06'23.3"E
		3	32	4.3	51°54'03.5"N 105°06'23.3"E

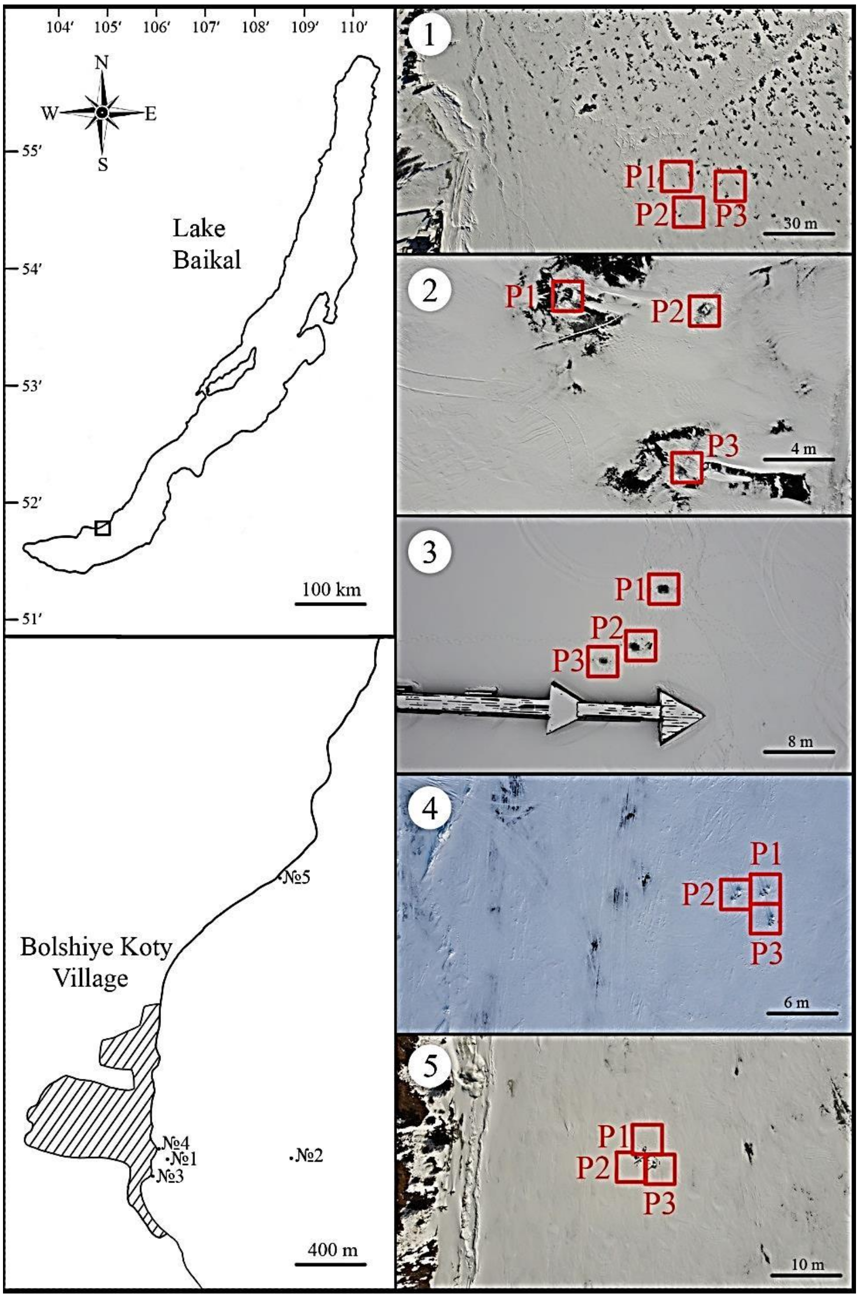

Fig. 1. Location of sampling points

The samples taken were blocks of ice cut with a chainsaw. For the study, two layers of ice cover were used: the upper layer (0-20 cm) and the lower layer (60-80 cm) in contact with water. This approach was applied based on the methodology used in Arctic research (Kelly et al., 2020). Cut samples using latex gloves (to prevent the ingress of microplastic particles from the outside) were transferred to pre-cleaned containers and melted at room temperature. Each sample was filtered using a 23 µm sieve, after which the volume of each ice sample was measured (in liters). A total of 30 samples were obtained, 15 samples of the upper ice layer and 15 samples of the lower ice layer.

The counting of microplastic particles in each taken ice sample was carried out in the laboratory. Microplastic particles were counted using a stereomicroscope at 98x magnification. The types of microplastics were divided into the following groups: fibers, fragments, granules, and films. Fragments belonging to microplastics were determined using the "hot needle" method (Masura et al., 2015). After counting microplastic particles, the data were converted to 1 liter of sample volume.

Statistical processing and visualization of the data obtained during the work was carried out using the Past 3x software packages (Shapiro-Wilk test, Dunn's test) and MS Excel (correlation analysis).

RESULTS AND DISCUSSION

Microplastic particles were found in all collected ice samples. Microplastic types such as fibers and fragments were observed in the samples. At the same time, most of the particles of microplastics were fibers, while fragments were observed singly, and in some samples were absent. Other types of microplastics were not detected in the samples.

The average number of microplastic fibers was 55.5 particles / L for samples taken from the upper side of the ice, and 65 particles / L for samples that were collected from the lower side of the ice. The average number of microplastic fragments in the upper samples was 0.3 particles / L, and for the lower samples, it was 1 particle / L (Fig. 2). Other studies on microplastics in ice show concentrations such as 8-41 particles / L for Baltic Sea (Geilfus et al., 2019), or 1145-4270 particles / L for Fram Strait (Peeken et al., 2018). Studies of microplastics in the ice of freshwater reservoirs have not previously been carried out.

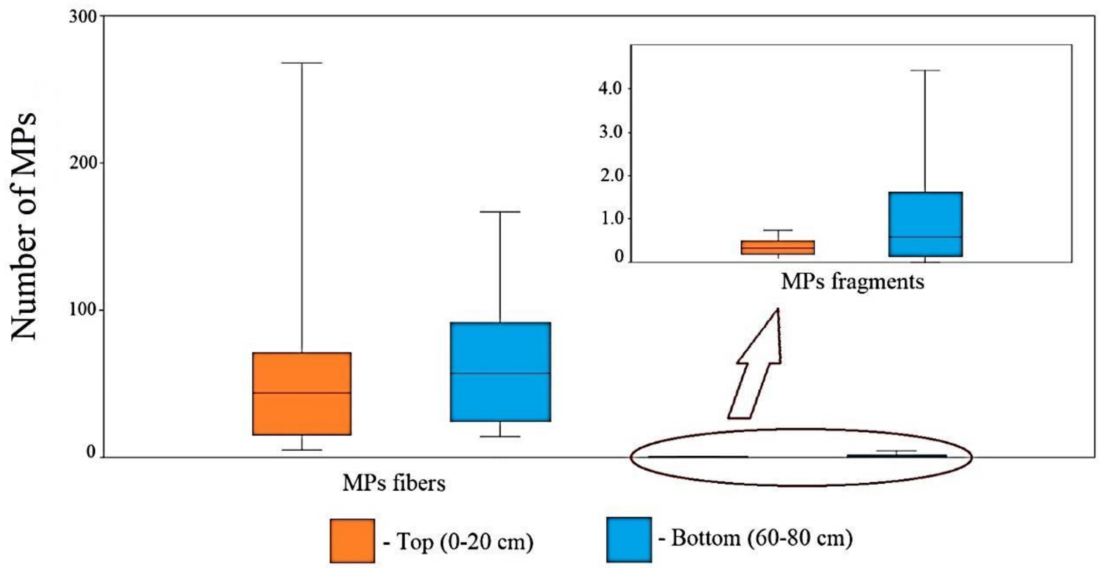

Fig. 2. The number of microplastic particles in samples

The use of Dunn's multiple comparison test showed statistically significant differences between the fibers and fragments of microplastics; however, there were no differences between the upper samples and the lower ones (Table 2). The observed slight correlation between the number of particles and the distance from the coast was not statistically significant.

Table 2. Levels of statistical significance (p) of pair wise comparisons calculated

	Top (fibers)	Bottom (fibers)	Top (fragments)	Bottom (fragments)
Top (fibers)	-	0,4707	2,96E-06	5,95E-05
Bottom (fibers)	0,4707	-	6,86E-08	2,18E-06

Based on the median values, most of the microplastics were concentrated on the lower side of the ice, which is in contact with water (Fig. 2). This was typical for both fibers and fragments, as well as for all sampling points, except for point No. 4 (Fig. 3).

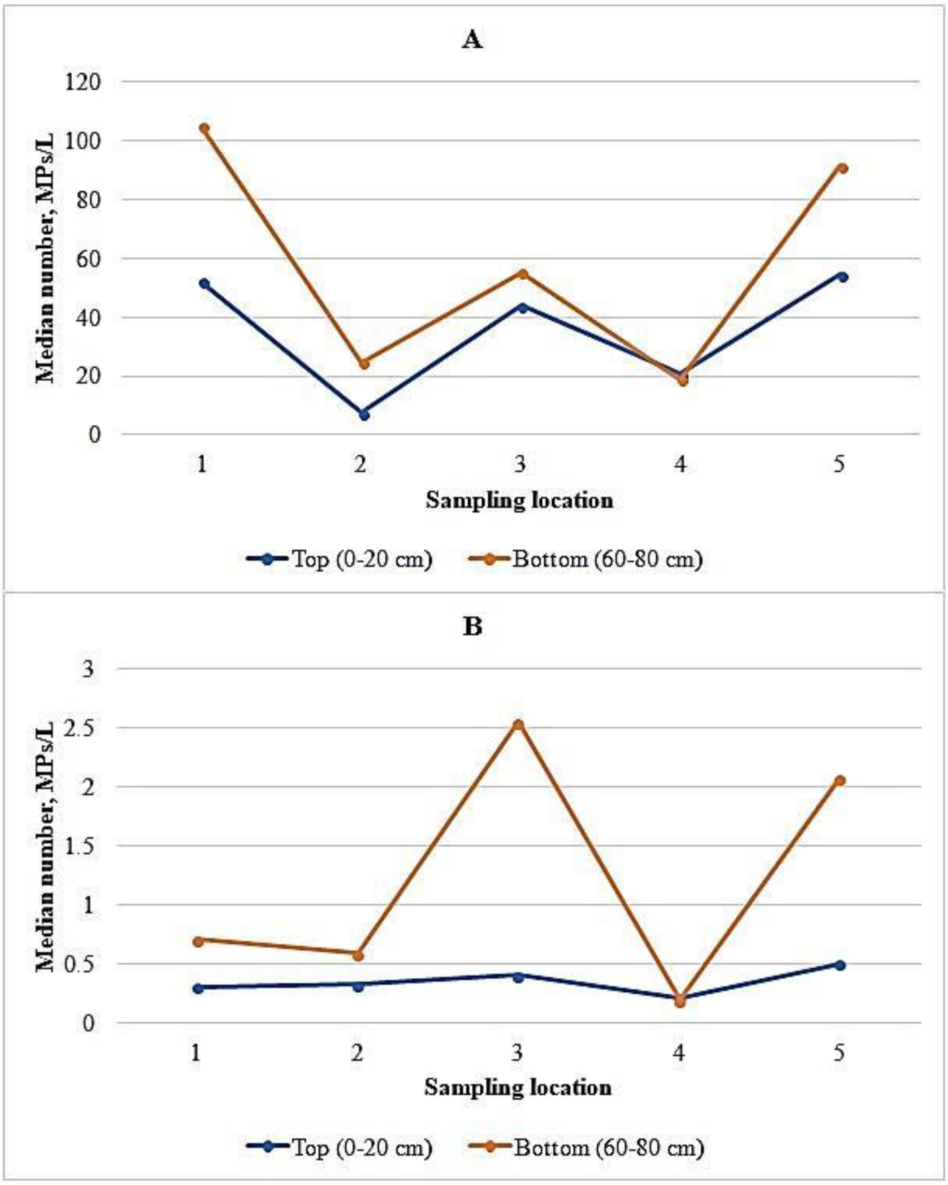

Fig. 3. Distribution of microplastics in layers of ice (A - fibers, B - fragments)

Fibers turned out to be the predominant type of microplastics in the samples; they were found in each sample in large quantities, regardless of the location of the sampling. The size of the fibers varied from 0.2 mm to 5 mm (Fig. 4). Microplastic fibers 0.7 mm in size were the greatest in frequency, accounting for 9%. In second place were fibers with a size of 1 mm (8.6%), and third were fibers that were 0.8 mm and 1.1 mm (6.7%).

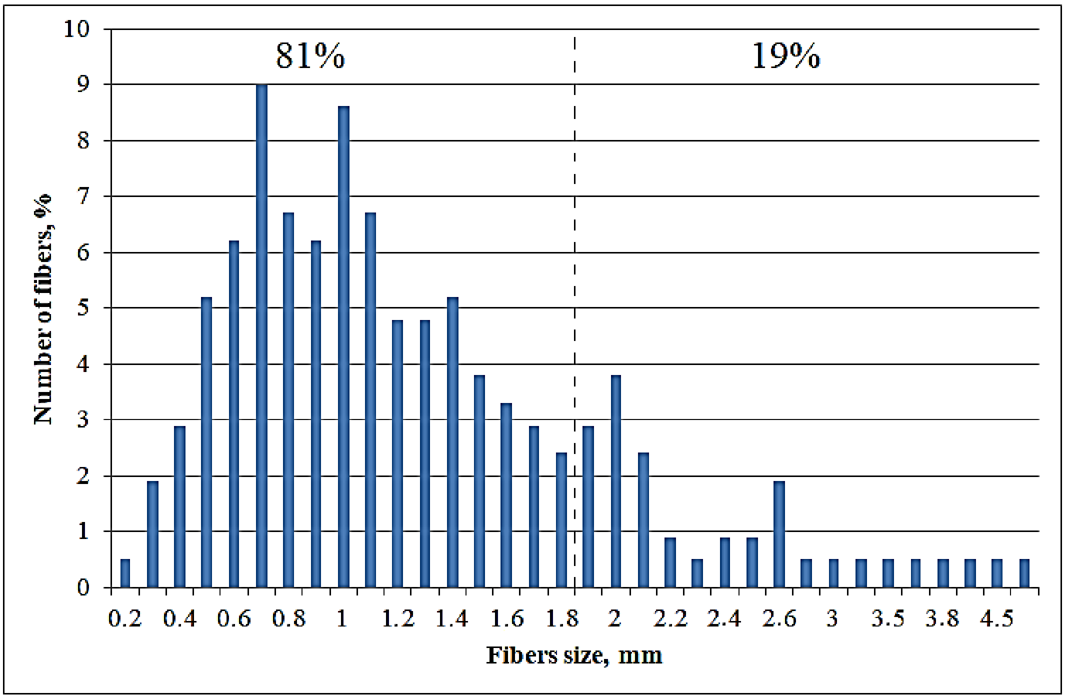

Fig. 4. Frequency of occurrence of different sizes of microplastic fibers (%) (the dashed line marks the median value of the detected sizes of microplastic fibers)

The observed absolute dominance of microplastic fibers over other types of particles in the samples can be associated with human household activities and settlements on the shores of the lake with no wastewater treatment systems. As a rule, wastewater from villages and large cities goes directly into rivers, and from there into open water bodies. However, even in the presence of a system of treatment facilities, they cannot cope with microplastic particles, because most often they are simply not captured by the cleaning systems due to their small size (Battulga et al., 2019).

In our case, we observed the absence of statistically significant differences between the number of microplastic particles at different sampling points that differ from each other, including different distances from the village. Considering that the village of Bolshiye Koty is a small settlement with a permanent resident population of about 50 people, we assume that this lack of differences is due to the fact that the discovered microplastic was carried by currents from another place. It has long been known that Lake Baikal is characterized by the presence of constant circular currents and temporary flows of water masses caused by strong winds. The streams of water on the west coast move to the south, and on the east coast to the north. One of the permanent circular currents is called the Selenginskoe. It is formed as a result of the river flow of one of the largest rivers in the Baikal basin, the Selenga River. The Selenginskoe current forms two branches: the main, southwestern branch is directed to the western shore of the lake, to the area of the village of Bolshiye Koty; and the source to the Angara River (Fig. 5) (Sokolnikov, 1964). The noted wide distribution of plastic waste in the delta of the Selenga River may be one of the main reasons for the pollution of Lake Baikal waters with microplastics (Battulga et al., 2019), including the village of Bolshiye Koty, largely due to the activity of constant currents. It should be noted that the total runoff of the Selenga River is almost 29 km^3 per year (Ilyicheva et al., 2014), which is about 50% of the total annual river runoff entering Lake Baikal. It is also noteworthy that on the Selenga River there are a number of settlements (more than ten), including the capital of the Republic of Buryatia, the city of Ulan-Ude (population over 400,000 people).

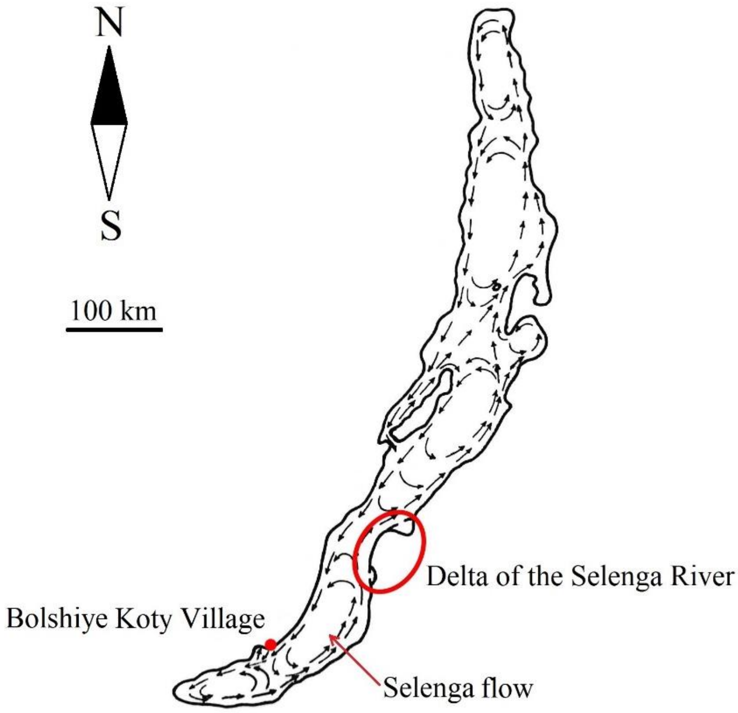

Fig. 5. Scheme of circular currents in Lake Baikal

Microplastics that enter open waters through drains in main concentrate on the surface (Chubarenko et al., 2018), but if the surface of the reservoir is covered with ice, the microplastic will concentrate at the interface between the ice and water, which can lead to adhesion of microplastic particles to the ice from the bottom side. Perhaps this explains the fact that the median value of fibers and microplastic fragments in our samples is higher from the lower side. This circumstance can create an additional risk factor for organisms that use the underside of the ice as a habitat. The exception in our samples is the fourth sampling site; however, it is located in the immediate vicinity (on average 25 m) of the mouth of a small local river, the flow from which, apparently, can minimize the adhesion of microplastic particles from the underside of the ice or simply wash them away.

Thus, we assume that microplastic fibers entered Bolshiye Koty Bay with currents that swept them from the opposite (east) bank, where they got into the water as a result of poor or no treatment facilities. In turn, fragments of microplastics could have been formed directly in the investigated bay as a result of mechanical degradation of plastic waste located in the littoral zone of the lake. As a result of the physical effects of the sun, wind, and waves, microplastic breaks down into small fragments in the littoral zone, from where it is washed out and carried by waves and winds. Based on this, it can be assumed that microplastic fibers are able to spread over Lake Baikal both in summer and in winter, together with constant circular currents, and fragments of microplastics, because their source is most likely the lake coast. The fragments actively move from the littoral zone into the depths of the reservoir only in summer, when there is active wave and wind activity, especially regular breezes. This assumption was indirectly confirmed by our data from 2019 and 2020, where in the summer period in Bolshiye Koty Bay the distribution of microplastics by type was on average as follows: 54% of fibers and 30% of fragments (Karnaukhov et al., 2020; Biritskaya et al., 2020), as well as data on Lake Baikal as a whole, where the amount of fibers ranged from 7%

to 62%, and fragments from 17% to 27% (Il'ina et al., 2021). Thus, in summer, a large number of microplastic fragments were observed in the near-surface layer, while in winter their number was only about 1%.

According to our data, more than 80% of the fibers were less than 2 mm in size. Microplastic fibers are potentially dangerous for living organisms as they can be perceived as edible particles. For example, being on the lower side of the ice, the fibers can resemble particles of filamentous algae. Moreover, the dominance of small fibers poses an even greater danger, since potentially more organisms will perceive them as food. Due to their structure, fibers can penetrate and accumulate in tissues, which, in turn, can disrupt the processes of nutrition, growth, and reproduction in living organisms (Cedro & Cleary, 2015). Due to the ability to accumulate in the body, microplastics can be transmitted along food chains, passing from prey to predator, which can potentially lead to the accumulation of large amounts of microplastics in the final links of the food chain.

Lake Baikal is a large, unique water body, which differs from others, including the purity of its waters and its rare endemic organisms; therefore, the study of the processes of ingress and spread of microplastics in the lake is extremely relevant today. With regard to the routes of entry, most likely, the problem of wastewater treatment comes to the fore, which has been confirmed by other studies (Il'ina et al., 2021). This problem can be explained by the almost complete absence or non-compliance of existing treatment facilities that meet modern requirements and standards. However, it should be noted that treatment facilities are planned in the near future in the Republic of Buryatia, and these should have a positive effect on reducing the spread of microplastic particles in the Baikal basin. Nevertheless, currently it is necessary to conduct regular monitoring of the amount of microplastic particles in different points of the lake, including organization of such monitoring at existing stationary observation points for the state of Lake Baikal.

CONCLUSION

Microplastic particles were found at all sampling points in the bay, regardless of their distance from the coastline. Among the microplastics found in the ice of Lake Baikal, fibers are the predominant type. Their number at almost all sampling points is many times greater than the number of microplastic fragments. More than 80% are fibers up to 1.8 mm which are often not captured by wastewater treatment systems and can be mistaken by living organisms for food.

Presumably, all discovered microplastic fibers were brought by the current from the opposite east coast (Selenga River delta area). Fragments of microplastics constituted a small amount of the total, because they are primarily formed directly in the bay on coastline, and in winter their distribution is inhibited by ice. To betterunderstand how to control the plastic pollution it is necessary to conduct annual monitoring of the surface waters of Lake Baikal, both in winter and in summer. In order to prevent serious pollution of the waters of the lake and its tributaries, it is also essential to build treatment facilities that meet environmental requirements.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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