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RESEARCH ARTICLE

Adsorption of different types of microplastic particles by macrophytes of Lake Baikal

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Abstract

Submerged macrophytes are capable of adsorbing microplastic particles on their surface. This can affect the vital activity of plants and associated aquatic communities. At present, no studies have been conducted on the distribution and concentration of microplastics on the macrophytes of Lake Baikal. In this study, the possibility of adsorption of different types of microplastic particles by representatives of different groups of macrophytes from Lake Baikal was investigated under experimental conditions. The study showed that all three studied macrophyte species (*Myriophyllum spicatum*, *Draparnaldioides baicalensis* and *Stuckenia* sp.) are able to adsorb microplastic particles on their surface. From 2.9 to 50.7% of fibers and from 42.8 to 95.1% of fragments from the prepared sample were adsorbed on macrophytes. Part of the adsorbed plastic (not exceeding 10% of the total amount) remains on the sample even after interaction with the hypersaline solution. At the same time, for *D. baicalensis*, a higher percentage of plastic particles remaining on the sample is noted, which is associated with the presence of a mucous sheath on the surface of the plant. The methodology used in this study can be effectively applied to assess the possibility of microplastic particle adsorption by macrophytes both in laboratory studies and for studies of the level of contamination of macrophytes with microplastic particles in natural conditions.

Keywords
Microplastics, Lake Baikal, macrophytes, adsorption, freshwater ecosystems

Introduction

Lake Baikal is a unique and species-rich ecosystem (Galaziy 1987). Macrophytes are a significant component of the lake. They create the necessary habitat and act as food sources for many aquatic organisms (Rusinek et al. 2012). As anthropogenic influence on the lake increases, so do the anticipated risks to aquatic plants and associated aquatic organisms. One of the issues that requires detailed study in the 21st century (both in relation to Lake Baikal and other ecosystems of the world) is the spread of microplastics (Frank et al. 2022). Microplastics are plastic particles smaller than 5 mm in size. The minimum values for these particles are defined differently, but recently they have been set at 1 μm. The study of the problem of pollution of Lake Baikal with plastic particles has begun recently (Karnaukhov et al. 2020) and at the moment there are some data on the content and distribution of microplastic particles in the lake waters, ice and some organisms (Il'ina et al. 2021; Karnaukhov et al. 2020; Karnaukhov et al. 2022; Moore et al. 2022; Yang et al. 2025). There have been no studies on the adsorption of microplastic particles by macrophytes in natural conditions for Lake Baikal to date.

At the moment, it has already been proven that microplastics have a negative impact on plants, for example, they can interfere with the growth and development of some plant organs and reduce the intensity of photosynthesis (Bosker et al. 2019; Weert et al. 2019; Polechonska et al. 2023; Liu et al. 2025). Plastic particles can also have a negative impact on plant-associated aquatic organisms. Plastic adsorbed on the surface of a plant can be mistaken for a food source. When ingested, such plastic can cause damage to internal organs (especially the gastrointestinal tract) through physical impact due to its shape, or have a toxic effect due to the polymer itself (or dyes and other substances included in its composition) (Mateos-Cardenas et al. 2021; Tang et al. 2022). In addition, all of this can affect the growth and development of animals, and can also be transmitted through trophic levels, up to higher-order consumers (Dong et al. 2023; Huang et al. 2023; Kalcikova 2023; Kim et al. 2024).

Studies devoted to the study of the process of adsorption of microplastic particles by macrophytes have noted that leaf morphology and the presence of a sticky layer on the plant surface have a significant impact on the amount of adsorbed particles (Kalcikova 2020; Mateos-Cardenas et al. 2021; Tan et al. 2023). Due to these characteristics, macrophytes effectively adsorb microplastic particles from the aquatic environment, which can later be used for phytoremediation of water bodies. For example, during an experiment with *Lemna minor* L., it was found that 15 cycles of phytoremediation can remove up to 79% of microplastic particles from the aquatic environment under laboratory conditions, and complete removal of particles can be achieved in 53 cycles (Rozman et al. 2023).

The aim of the study is to determine the possibility of adsorption of microplastic particles of various morphologies by representatives of different groups of macrophytes of Lake Baikal under experimental conditions. An additional objective of the study was to test a method for studying the adsorption of microplastic particles by macrophytes and evaluate its effectiveness.

Materials and methods

Macrophytes of three taxa were selected for the experiment (*Myriophyllum spicatum* L., *Stuckenia* sp. and *Draparnaldioides baicalensis* (Meyer) Vishnyakov). A total of 6 samples of each of the three species were collected near the village of Bol'shiye Koty in October 2024.

Fluorescent microplastic particles (varying in morphological structure) were prepared in advance (Biritskaya et al. 2024). Polyester fibers and polystyrene fragments (Table 1) were used for the experiments. The first were made from fluorescent needlework threads, the second from a stationery line (the names of the polymers were determined according to the manufacturers' data). The upper limit of the fibers was 2000 μm, and the fragments 160 μm (Fig. 1). At the same time, we understand that smaller particles have a higher adsorption capacity, which is associated with a larger specific surface area (Mateos-Cardenas et al. 2021). These particles fluoresced under blue and ultraviolet light, making them easy to count and minimizing the likelihood of confusing these particles with particles from the natural environment. All work was carried out under a fume hood with all precautions taken to prevent microplastic particles from entering from outside (Wesch et al. 2017; Jones et al. 2024). The laboratory glassware used was washed with distilled water. All internal surfaces of the fume hood were wiped with lint-free cloths moistened with distilled water. To control contamination, filters soaked in distilled water were placed in Petri dishes inside the fume hood.

Table 1. The number of microplastic particles in the sample

No	Morphological structure	Weight	Mean value ± standard error	Coefficient of variation (CV)
1	Fibers	5 mg	2540±36	2%
2	Fragments	5 mg	20366±3984	27.6%

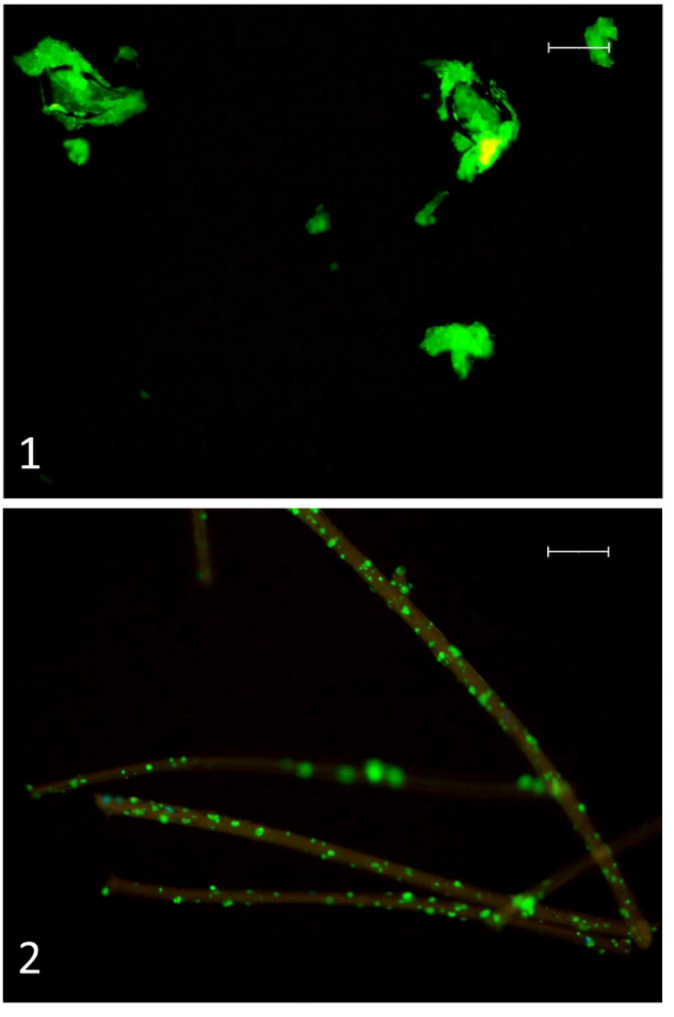

Figure 1. Fragments (**1**) and fibers (**2**) of microplastic used in the experiments (segment – 100 μm).

Each species of macrophytes was divided into two groups and placed in beakers with distilled water. A 5 mg sample of microplastic particles (of different morphological structures) was added to each glass separately for each group and 200 ml of water. Thus, 6 cups were prepared to work with each species of macrophyte: three with fibers and three with fragments. The contents of the beakers were then mixed on an orbital shaker at 130 rpm for two hours to simulate natural wave activity. The macrophyte samples were then transferred to beakers containing 200 ml of a hypersaline 5 M NaCl solution. Next, the glasses with macrophytes were mixed again on an orbital shaker under the same conditions. All this was done in order to separate particles from the surface using both the flotation principle and additional physical action (Miller et al. 2017; Constant et al. 2021; Miller et al. 2021). After this, the solution with the samples was filtered. When 50 ml of solution remained in the beaker, the macrophytes were removed and washed in distilled water, placed on filters and dried in a drying oven at 55°C to count the microplastics adsorbed on them and then determine the dry weight (by weighing the plant (excluding adsorbed plastic) using an OHAUS Adventurer analytical balance). The remaining saline solution and distilled water were also filtered. The resulting filters and dried plants were examined under a fluorescence microscope (Leica DMLB).

The Past 3.x and RStudio software packages were used for data processing and visualization. Data comparison was performed using the nonparametric Kruskal-Wallis test and Dunn's post hoc test with Bonferroni correction.

Results and discussion

As a result of the experiment, the following data were obtained. For *M. spicatum*, the average amount of fibers was 104.1±78.9 particles/g dry weight on the plant itself and 3431.9±1915.0 particles/g dry weight on filters. The average number of fragments on the plant is 10707.5±2157.1 particles/g dry weight (Fig. 2) and on the filter – 145764.2±30971.7 particles/g dry weight (Table 2).

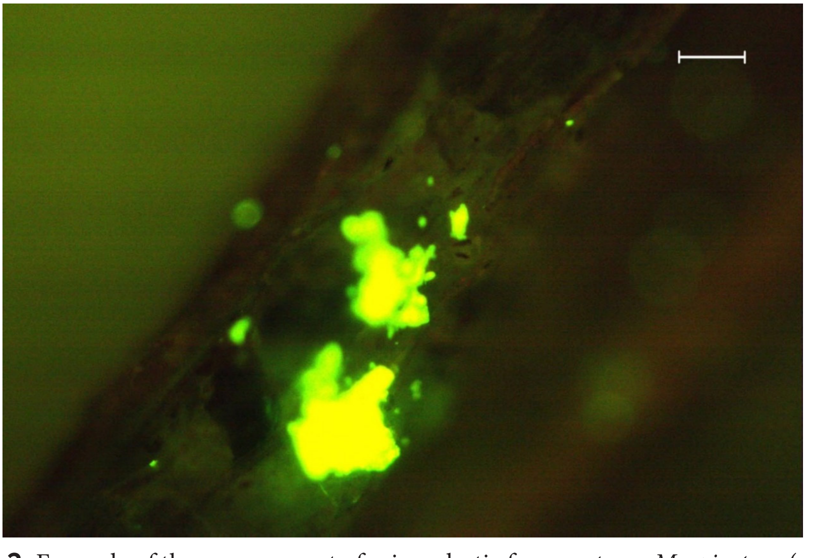

Figure 2. Example of the arrangement of microplastic fragments on *M. spicatum* (segment – 100 μm).

For *Stuckenia* sp. the average amount of fibers was 186.9±76.7 particles/g dry weight on the plant and 5477.5±3332.6 particles/g dry weight on the filters. The average number of fragments on the plant is 15323.5±5067.4 particles/g dry weight and on the filter – 318470.1±118553.3 particles/g dry weight (Table 3).

Table 2. Number of microplastic particles adsorbed by *M. spicatum*

Type of microplastic	Sample No.	Particles on plant, particles/g dry weight	Particles on filter, particles/g dry weight	Total particles, particles/g dry weight
Fibers	1	48.2	2624.5	2672.7
	2	4.2	593.2	597.4
	3	259.8	7077.9	7337.7
Average value, particles/g dry weight ± standard error		104.1±78.9	3431.9±1915.0	3535.9±1993.1
Fragments	1	11927.9	116135.4	128063.3
	2	6513.8	113468.9	119982.7
	3	13680.9	207688.4	221369.3
Average value, particles/g dry weight ± standard error		10707.5±2157.1	145764.2±30971.7	156471.8±32532.5

Table 3. Number of microplastic particles adsorbed by *Stuckenia* sp.

Type of microplastic	Sample No.	Particles on plant, particles/g dry weight	Particles on filter, particles/g dry weight	Total particles, particles/g dry weight
Fibers	1	256.8	4287.2	4544.0
	2	337	393.1	426.8
	3	270.3	11752.1	12022.4
Average value, particles/g dry weight ± standard error		186.9±76.7	5477.5±3332.6	5664.4±3393.9
Fragments	1	17306.3	510947.1	528253.4
	2	5724.7	102318.8	108043.5
	3	22939.5	342144.4	365083.9
Average value, particles/g dry weight ± standard error		15323.5±5067.4	318470.1±118553.3	333793.6±122308.9

Unfortunately, fewer *D. baicalensis* samples were analyzed, but the results obtained are consistent with the general distribution pattern of microplastic particles. The amount of microplastic fibers for one of the samples was 754.7 particles/g dry weight on the plant and 9830.2 particles/g dry weight on the filter. The average number of fragments on the plant is 72560.0±8937.6 particles/g dry weight, and on the filter – 801747.0±134191.4 particles/g dry weight (Table 4).

Table 4. Number of microplastic particles adsorbed by *D. baicalensis*

Type of microplastic	Sample No.	Particles on plant, particles/g dry weight	Particles on filter, particles/g dry weight	Total particles, particles/g dry weight
Fibers	1	754.7	9830.2	10584.9
Fragments	1	69338.8	828181.8	897520.6
	2	58943.7	555493	614436.7
	3	89397.6	1021566.3	1110963.9
Average value, particles/g dry weight ± standard error		72560.0±8937.6	801747.0±134191.4	874307.1±143804.2

According to the data obtained, despite the large number of particles on the filters, there is a slight predominance of microplastic fragments over fibers directly on the plant (Fig. 3). This is especially evident for *M. spicatum*.

The applied method showed that the adsorption of microplastic particles with different morphological structures by macrophytes occurred in all cases (from 2.9 to 50.7% of fibers and from 42.8 to 95.1% of fragments from the sample were adsorbed on plants). Moreover, the results show that some microplastics remain on the plants even after interaction with the hypersaline solution. Analysis of the 16 cases revealed that plant retention of adsorbed microplastics was typically between 5% and 10% (observed in 11 cases). The remaining five cases exhibited minimal retention, with less than 5% of particles remaining (Fig. 3).

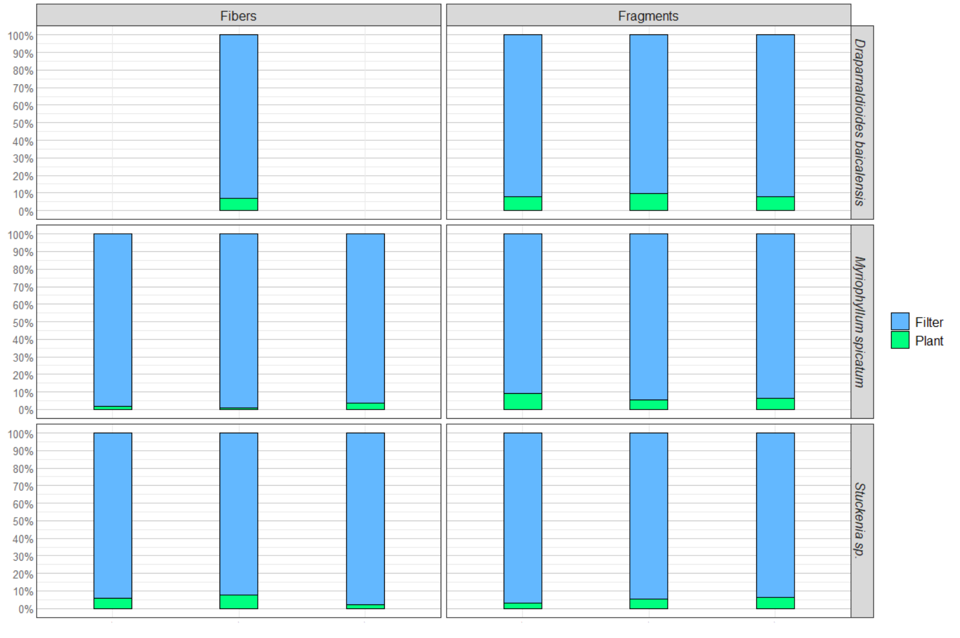

Figure 3. Percentage distribution of microplastic particles.

Statistical processing of the results using a group of tests showed that no significant differences were observed in pairwise comparisons of plant species and types of microplastic particles. However, statistically significant differences were found in the percentage of particles remaining on the plant and particles ending up in the hypersaline solution (separated from the plant surface). The above differences were noted for *D. baicalensis* and *M. spicatum* (p=0.02), and borderline values were also noted between the species *D. baicalensis* and *Stuckenia* sp. (p=0.054). Based on the results of statistical processing and average values, it can be assumed that *D. baicalensis* adsorbs particles to a greater extent. It is also worth considering that plastic particles are fixed more reliably on *D. baicalensis* plants. This is likely due to the presence of a mucous sheath, which performs protective and adhesive functions (Izhboldina 2007).

The presence of this feature (mucous sheath) is also characteristic of a number of macrophyte species in Lake Baikal. For example, for the mass species in the watershed zone – *Ulothrix zonata* (Weber et Mohr) Kütz. This species forms the first vegetation belt in the lake and provides food and shelter for many littoral organisms.

Macrophytes are often used as pollution indicators due to their high resistance to high concentrations of various types of toxicants. It is currently known that microplastic particles can have minor effects on growth and photosynthetic processes in plants, although the data obtained are limited (Liu et al. 2025). This suggests that direct exposure of plants to microplastics does not currently pose a risk. However, adsorbed plastic can be taken up by plant-associated aquatic organisms, making the likelihood of microplastics entering food chains much higher (Kalcikova 2020; Mateos-Cardenas et al. 2021). Particularly vulnerable are species that live directly on macrophytes or species that use plants as a food source. Given the high degree of potential adsorption of microplastic particles by some macrophyte species and the wide diversity of taxa associated with them, further research is needed to better understand the processes of microplastic particle transport along food chains within the ecosystem.

Conclusions

This study confirmed the possibility of adsorption of microplastic particles in laboratory conditions by some species of macrophytes of Lake Baikal. This applies to both widespread taxa and the endemic alga *D. baicalensis*. However, as in previous studies, we note species-specificity in the ability to adsorption of microplastic particles. The observed higher degree of adsorption of microplastic fragments, compared to fibers, may be due to their smaller size. This is due to the fact that small particles are more capable of adsorption than large particles.

The significant predominance of fragments over fibers should be recognized as the most significant drawback of our experiment. Another drawback of the experiment should be recognized as the fact that the recalculation of the number of particles was carried out only on the dry weight of the plant (without taking into account the surface area of individual species). In the case of using this method of processing samples to determine the level of adsorption of microplastic particles by macrophytes in natural conditions, it is worth considering that the indicators may be underestimated. The study requires further work to study the possibility and degree of adsorption of microparticles of artificial polymers by other taxa.

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