Review

Microplastics in Aquatic Environment: Insight from Research in Montenegro

Bošković Neda[1,*]

[1.] National Institute of Chemistry, Ljubljana, Slovenia *
Correspondence: Neda Bošković: nedaboskovic93@gmail.com

Citation: Bošković N. Microplastics in aquatic environment: insight from research in Montenegro. Proceedings of Socratic Lectures. **2026**, 14, 2-11. https://doi.org/10.55295/PSL.14.2026.IV1

Publisher's Note: UL ZF stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Abstract:
Microplastics have emerged as one of the most significant environmental pollutants of the 21st century due to their persistence, mobility, and potential ecological and human health impacts. Aquatic ecosystems are particularly vulnerable because rivers, lakes, and marine environments act both as sinks and transport pathways for plastic debris. This paper presents an overview of microplastics in aquatic ecosystems with a specific focus on Montenegro. Available investigations conducted during the last seven years indicate the presence of microplastics in freshwater systems, lake sediments, coastal sediments, fish, and shellfish. Elevated concentrations were reported in several rivers and coastal zones compared with regional literature data. The findings highlight the need for systematic monitoring, improved waste management, wastewater treatment, and stronger regulatory measures.

Keywords: Microplastics, Aquatic ecosystems, Montenegro, Sediments, Fish, Shellfish

1. Introduction

Plastic materials have become indispensable in modern society due to their durability, versatility, lightweight properties, and low production costs. Their widespread application includes packaging, construction, healthcare, agriculture, transportation, and consumer products. However, the continuous increase in plastic production, combined with inadequate waste management practices, has created a serious global environmental problem. Approximately 40% of plastic products are intended for single-use or short-term applications, particularly packaging materials, with an average lifespan of less than one month. Although recycling rates have improved in some regions, only a relatively small proportion of plastic waste is effectively recycled, while the majority accumulates in landfills or is released into the environment (Klein et al., 2015; Fischer et al., 2016).

Unlike natural materials, conventional plastics are highly resistant to biodegradation and do not readily decompose into harmless end products. Instead, they gradually fragment through physical, chemical, and biological weathering processes such as photodegradation, oxidation, hydrolysis, thermal stress, and mechanical abrasion. Over time, these processes generate progressively smaller particles known as microplastics and nanoplastics (Scherer et al., 2020).

Microplastics are commonly defined as synthetic solid polymer particles ranging from 1 μm to 5 mm in size. They exhibit substantial variability in morphology, color, density, and polymer composition. Due to their small size, persistence, and ease of transport, microplastics are now ubiquitous contaminants detected in terrestrial, freshwater, and marine environments, including remote polar regions, rivers, lakes, estuaries, coastal zones, and open oceans (Fischer et al., 2016; Hengstmann et al., 2021).

According to their origin, microplastics are generally divided into two main categories. Primary microplastics are intentionally manufactured microscopic particles used in cosmetics, personal care products, industrial abrasives, synthetic textiles, and resin pellets. Secondary microplastics arise from the fragmentation of larger plastic items such as bottles, bags, fishing gear, packaging waste, and other discarded materials. In addition to source-based classification, microplastics are frequently categorized by morphology (fibers, fragments, films, pellets, foams), particle size, color, and polymer type (Scopetani et al., 2019).

Aquatic ecosystems are among the most threatened environments with regard to plastic contamination. Rivers, lakes, transitional waters, and marine ecosystems receive continuous inputs of plastic debris from urban runoff, wastewater effluents, industrial discharges, tourism, fisheries, maritime transport, and improper waste disposal. Rivers are considered one of the principal pathways and major sources of microplastic transport from land-based environments toward lakes, estuaries, seas, and oceans (Rodrigues et al., 2018; Simon-Sánchez et al., 2019). It is estimated that nearly 80% of aquatic plastic pollution originates from terrestrial sources, while the remaining proportion is associated with marine-based activities such as shipping, aquaculture, and fisheries.

Marine environments are particularly vulnerable because floating and suspended plastic particles can be transported over long distances by currents and winds, leading to widespread contamination of coastal and offshore ecosystems. Sediments in rivers, lakes, and coastal zones act as important sinks for microplastics, where particles may accumulate over time and remain available for remobilization under changing hydrodynamic conditions (Atwood et al., 2019; Hengstmann et al., 2021).

Aquatic organisms are especially sensitive to microplastic exposure due to their constant interaction with contaminated water and sediments. Numerous studies have demonstrated the ingestion of microplastics by plankton, benthic invertebrates, mollusks, crustaceans, and fish. Once ingested, microplastics may cause physical damage, feeding disruption, reduced growth, oxidative stress, inflammation, and altered reproductive performance. Furthermore, microplastics may act as vectors for additives and adsorbed environmental contaminants, thereby increasing ecological risks and potential transfer through food webs (Digka et al., 2018; Avio et al., 2019; Gomiero et al., 2019).

The Adriatic Sea, including the Montenegrin coastal area, represents an environmentally and economically important marine region characterized by intense seasonal tourism, maritime traffic, fisheries, and coastal urbanization, all of which may contribute to plastic inputs. At the same time, Montenegro possesses diverse freshwater ecosystems, including rivers, lakes, and reservoirs, which may also serve as recipients and transport routes for microplastic pollution (Blašković et al., 2017; Palatinus et al., 2019).

The aim of this review is to summarize and critically evaluate studies on microplastic contamination conducted in aquatic ecosystems of Montenegro over the past seven years. Particular attention is given to reported concentrations and characteristics of microplastics in river sediments, lake sediments, coastal marine sediments, as well as in mussels, shellfish, and fish collected from the Montenegrin region. In addition, this review provides a comparative analysis of concentrations recorded in Montenegro with data reported from neighboring countries and the wider regional context. Such an overview is essential for assessing the current state of microplastic pollution in Montenegro and identifying priorities for future monitoring and management strategies. Studies from Montenegro consistently demonstrate the presence of microplastics across all investigated compartments, highlighting rivers as transport pathways, lakes as accumulation zones, and coastal sediments and biota as long-term sinks, emphasizing the integrated nature of pollution dynamics in the region (Bošković et al., 2021; 2022a; 2022b; 2023a; 2023b; 2025a; 2025b; 2026a; 2026b).

2. Microplastics in aquatic environment in Montenegro

The first investigations of microplastics in Montenegro began approximately seven years ago. Since then, studies have included seven rivers, three lakes, and the Montenegrin coastal zone (sediments, fish and shellfish).

Investigated rivers include Sitnica, Ribnica, Cijevna, Zeta, Morača, Bojana, and Tara. The occurrence and characteristics of microplastics in river sediments in Montenegro, in comparison with selected European rivers, are summarized in **Table 1**. As shown in **Table 1**, microplastic concentrations in Montenegrin rivers exhibit considerable variability, with mean values generally higher than those reported for rivers in Slovenia, such as the Ljubljanica and Kamniška Bistrica. This difference may reflect variations in waste management practices, population density, and local pollution sources. However, when compared with larger European rivers such as the Rhine and Elbe, the observed concentrations fall within a comparable range, indicating that microplastic contamination is a widespread issue across Europe rather than a localized phenomenon. The dominant polymers identified in Montenegrin rivers are polyethylene (PE) and polypropylene (PP), which is consistent with their extensive use in packaging materials and consumer products. In terms of morphology, both fragments and fibers are present, with fibers often associated with domestic wastewater and textile-related sources. The relatively narrow size range (predominantly 0.5–1.0 mm) suggests ongoing fragmentation processes and potential methodological consistency across studies. Importantly, no clear relationship between river length and microplastic concentration can be observed, indicating that local anthropogenic inputs and hydrological conditions play a more significant role than river size itself. The wide concentration ranges recorded in certain rivers further point to spatial heterogeneity and the influence of site-specific factors. With respect to lake ecosystems, research has focused on lakes located within national parks of Montenegro. The analyzed lakes include Black Lake and Devil Lake, which belong to Durmitor National Park and are of glacial origin, as well as Skadar Lake, located within Skadar Lake National Park.

Table 1. Comparison of the microplastics abundance, polymer type, shape, size and color of microplastics in rivers sediment from Montenegro compared to river sediments data from the Europe (MP/100g dry sediment)

River / country	Length of the river (km)	Concentration (min-max /mean)	Polymer	Shape	Size (mm)	Color	Reference
Sitnica, Montenegro	19	7-48.7 / 28.3 ± 12.2	PP, PE	fragment, fiber	0.5-1.0	blue, red, clear	Bošković et al. 2026a
Ribnica, Montenegro	10	14.7-38.7 / 24.9 ± 8.1	PE	fragment	0.5-1.0	blue, red, clear	
Cijevna, Montenegro	56	13.7-59 / 27.3 ± 14.1	PE, PP	fragment	0.5-1.0	blue, red, clear	
Zeta, Montenegro	89	5-43 / 14.5 ± 11	PP, PE	fragment, fiber	0.5-1.0	blue, red, clear	Bošković et al. 2023b
Morača, Montenegro	113.4	2-44 / 16.9 ± 11.3	PE, PET	fiber	0.5-1.0	blue, red, clear	
Bojana, Montenegro	41	11-25 / 18 ± 5.3	PP, PE	fiber	0.5-1.0	blue, red, clear	
Tara, Montenegro	157	1-61 / 11.9 ± 11.1	PE, PP	fiber	0.1-5.0	blue, red, clear	Bošković et al. 2025a
Ljubljanica, Slovenia	41	0.5-4 / 2.3 ± 2.5	PE, PP	fragment	0-0.99	colored	Matjašič et al. 2022
Kamniška Bistrica, Slovenia	33	1-3.3 / 2.2 ± 2	PE, PP	fragment	0-0.99	colored	
Ticino, Italy	248	/ 1.1 ± 0.8	EVA	/	/	/	Winkler et al. 2022
Po, Italy	652	0.05-7. /9	PE, PP	/	/	/	Atwood et al. 2019
Osa, Italy	20	/ 28.6 ± 3.7	/	fiber	/	colored	Cannas et al. 2017
Albegna, Italy	70	/ 45.3 ± 42.4	/	fiber	/	colored	
Ombrone, Italy	161	4.5-106.9 /	/	fiber	/	black, white, clear	Guerranti et al. 2017
Cecina, Italy	78	7.2-19.1 /	PVC	fragment, fiber	0.630-1.462	colored	Blašković et al. 2018
Tisza, Central Europe	1419	/ 317.7 ± 197	/	fiber	/	/	Kiss et al. 2021
Rhine, Germany	123	22.8-376.3 /	PE, PP, PS	fragment	0.630-5.0	colored	Klein et al. 2015
Main, Germany	524.9	78.6-136.8 /	PE, PP, PS	fragment	0.630-5.0	/	
Elba, Germany	1165	0.9-1596.2 / 208 ± 467	PE, PP	granule, fragment	0.126-5.0	clear	Scherer et al. 2020
Tet, France	115.8	0.7-102.9 / 25.8 ± 25.9	PE, PP	fragment, fiber	/	/	Constant et al. 2020
Ebro, Spain	930	/ 42.2 ± 11.9 / 205.2 ± 74.6	PA, PE	fiber	0.200-0.500	clear, orange	Simon-Sanchez et al. 2019
Kelvin, Great Britany	35	16.1-43.2 /	/	fiber	/	colored	Blair et al. 2019
Antuã, Portugal	38	1.8-62.9 /	PE, PP	fragment	0.055-5.0	colored	Rodrigues et al. 2018

A comparison of microplastics abundance and characteristics in lake sediments from Montenegro and other European regions is presented in **Table 2**. The data presented in **Table 2** reveal notable differences in microplastics concentrations among Montenegrin lakes, largely reflecting the degree of anthropogenic influence. Lower concentrations are observed in glacial lakes such as Black Lake and Devil Lake, which are relatively remote and less exposed to direct human activities. In contrast, Skadar Lake shows higher levels of contamination, likely due to its connection with river inflows, surrounding settlements, and agricultural activities. When compared with European data, microplastics concentrations in Montenegrin lakes fall within the lower to moderate range. They are generally lower than heavily impacted systems such as Bizerte Lagoon in Tunisia, but comparable to values reported for lakes in Italy and Switzerland. This suggests that, while contamination is present, it is still influenced by regional environmental pressures rather than extreme pollution sources. Similar to river sediments, fibers and fragments dominate, and common polymers include PE, PP, and PET. These findings confirm that lakes act as accumulation zones, or sinks, for microplastics transported from surrounding catchments. The observed patterns highlight the importance of watershed characteristics and human activity in determining contamination levels.

Table 2. Comparison of the microplastics abundance, polymer type, shape, size and color of microplastics in lake sediment from Montenegro compared to lake sediments data from the Europe (MPs/100g dry sediment)

Lake / country	Concentration (min-max /mean)	Polymer	Shape	Size (mm)	Color	Reference
Black Lake, Montenegro	0-16 5.1 ± 1.4	PE	fragment, fiber	0.5-3	blue, red	Bošković et al. 2026b
Devil Lake, Montenegro	1-12 3.8 ± 0.5	PE, PET, PP	fragment, fiber	1-5	blue, red	
Skadar Lake, Montenegro	9-22 15.4 ± 4.3	PE, PP	fiber, fragments	1-3	blue, red, clear	Bošković et al. 2025b
Upper Balma, Italy	/ 1.75 ± 0.62	PE, PP	fiber, fragment	0.1	blue, white, black	Pastorino et al. 2023
Lower Balma, Italy	/ 1.33 ± 0.67	PE, PP	fiber, fragment	0.1	blue, white, black	
Bolosena Lake, Italy	/ 11.2 ± 3.2	/	fragment, fiber	0.3-0.5	/	Fischer et al. 2016
Chiusi Lake, Italy	/ 23.4 ± 8.5	/	fiber, fragment	0.3-0.5	/	
Lake Sassolo, Switzerland	/ 33	PE, PP	fiber	/	/	Negrete Velasco et al. 2020
Multiple lakes, Türkiye	13-121 /	PET, PP, PE	fragment, fiber,	1	/	Akdemir et al. 2025
Bizerte Lagoon, Tunisia	300-1800 796 ± 687	/	fiber, fragment	0.3-5.0	clear, white, blue	Abidli et al. 2017
Hampstead Pond no. 1, London	/ 53.9	PS, PA	fiber	0.5-1.0	blue, white, red	Turner et al. 2019
Lake Tollene, Germany	/ 141 ± 82.2	PE, PET	fragment	0.063-2 mm	/	Hengstmann et al. 2021
Vesijarvi Lake, Finland	/ 39.58 ± 9.07	PA, PS, PET	fiber, fragment	/	/	Scopetani et al. 2019

Microplastics concentrations and characteristics in marine sediments from the Montenegrin coast, in comparison with other European marine environments, are summarized in **Table 3**. As indicated in **Table 3**, the Montenegrin coastal sediments exhibit relatively high levels of microplastics contamination compared to several locations in the Adriatic Sea, particularly along the Croatian coast. However, the reported values remain lower than those observed in highly polluted regions such as parts of the Mediterranean Sea, including Tunisia. Marine sediments represent a major sink for microplastics, where particles accumulate due to hydrodynamic processes and sedimentation. The dominance of fibers and fragments in Montenegrin samples suggests a combination of sources, including wastewater discharges, textile fibers, and the degradation of larger plastic debris. The prevalence of PE and PP further supports the role of land-based plastic waste as a primary source. The semi-enclosed nature of the Adriatic Sea likely contributes to the retention and accumulation of microplastics, limiting their dispersion and enhancing local contamination. Additionally, seasonal tourism, maritime activities, and coastal urbanization represent significant pressures that may further increase microplastic inputs into the marine environment.

Table 3. Comparison of the microplastics abundance, polymer type, shape, size and color of microplastics in marine sediment from Montenegro compared to marine sediments data from the Europe (MP/kg dry sediment)

Country / Sea	Concentration (min-max /mean)	Polymer	Shape	Size (mm)	Color	Reference
Montenegro, Adriatic Sea	410.5 ± 44.7	PP, PE	fiber, fragment	1-3	blue, clear, red	Bošković et al. 2021, 2022a, 2022b
Croatia, Adriatic Sea	177.6 ± 112.6	/	fiber	1-5	clear, white, black	Blašković et al. 2017
Croatia, Adriatic Sea	310 ± 109	/	fiber, fragment	1-5	black, blue	Renzi et al. 2019
Croatia, Adriatic Sea	360 ± 169.1	PE, PP	fiber, fragment	2.5-5	clear, white, black	Palatinus et al. 2019
Croatia, Adriatic Sea	263.6 ± 64.8	PVC, PP, PA	fiber	0.5-2.5	/	Renzi & Blašković, 2020
Italy, Adriatic Sea	1445.2 ± 458.4	PE, PP	fragment	1-5	/	Vianello et al. 2013
Italy, Adriatic Sea	254.6 ± 200.4	/	fiber	2-5	clear, white, black	Renzi et al. 2018
Italy, Mediterranean Sea	272.8 ± 44	PP	fragment	0.5-1	blue, black	Piazzolla et al. 2020
Tunisia, Mediterranean Sea	7960 ± 6840	/	fiber, fragment	0.3-5	clear, white, blue	Abidli et al. 2017
Spain, Mediterranean Sea	499.1	/	fiber	0.5-2	black, blue	Alomar et al. 2016
Belgium, North Sea	166.7 ± 92.1	PS, PP, PA	fiber, granule	/	/	Claessens et al. 2011
Belgium, North Sea	585.3	/	fiber	1-3	black, clear, white	Maes et al. 2017
Holland, North Sea	224.5	/	fiber	1-3	black, clear, white	Maes et al. 2017
English, North Sea	306	/	sphere	1-3	Black, clear, white	Maes et al. 2017
France, North Sea	481.2	/	fiber	1-3	black, clear, white	Maes et al. 2017

In addition to abiotic samples, studies have also investigated the presence of microplastics in biotic components of the marine ecosystem, specifically in fish and shellfish from the Montenegrin coast. The occurrence and characteristics of microplastics in selected marine organisms from Montenegro, compared to similar species from other European regions, are presented in **Table 4**. The results summarized in **Table 4** indicate that microplastics are widely present in marine organisms from the Montenegrin coast, with relatively high average particle counts per individual and a high frequency of occurrence. In many cases, these values exceed those reported for the same species in other parts of the Adriatic and Mediterranean Seas, suggesting elevated exposure levels in the study area. Fibers are the dominant form of microplastics detected in both fish and shellfish, which is consistent with their prevalence in the surrounding environment and their origin from wastewater and textile sources. A variety of polymers, including PE, PP, PET, and others, have been identified, indicating multiple contamination pathways. The presence of microplastics in commercially important species highlights the potential for transfer through the food web and raises concerns regarding ecological and human health impacts. However, differences among studies should be interpreted with caution, as they may also reflect variations in sampling methodologies, analytical techniques, and species-specific feeding behaviors.

3. Current Challenges

Despite increasing awareness of plastic pollution and microplastics contamination, Montenegro still faces several important challenges in environmental management and pollution control. Limited institutional capacity, insufficient infrastructure, and strong seasonal pressure caused by tourism significantly complicate the implementation of effective mitigation measures.

One of the major issues is the insufficient development of systems for waste separation, recycling, and final treatment of plastic waste. Although progress has been made in municipal waste management, plastic recycling rates remain relatively low, while considerable quantities of waste are still disposed of in landfills or released into the environment. Inadequate waste collection in rural areas and along the coast further increases the probability of plastic leakage into rivers, lakes, and marine ecosystems.

Another important limitation is the restricted capacity of wastewater treatment facilities. Microplastics originating from domestic wastewater, laundry effluents, industrial discharges, urban runoff, and personal care products may enter aquatic environments through sewage systems. In the absence of advanced filtration and tertiary treatment technologies, a substantial proportion of these particles can pass through treatment plants and be discharged into rivers or coastal waters.

High consumption of single-use plastic products, including plastic bags, beverage containers, food packaging, and tourism-related disposable items, remains an additional concern. During the summer season, the population in coastal municipalities increases considerably, leading to a temporary but significant rise in waste generation and pressure on local waste management systems.

Table 4. Comparison of the microplastics abundance, frequency of microplastics occurrence, shape, and polymer type of microplastics in studied species from Montenegro compared to same species data from Europe

Species	Area	Average MP items/ individual	Frequency of MP occurrence (%)	Shape	Polymer	Reference
M. barbatus	Montenegro, Adriatic Sea	2.9 ± 0.5	58.6	fiber, fragment	PE, PP, PET, PA	Bošković et.al. 2022b
	Italy, Adriatic Sea	1.5 ± 0.7	19.2	fiber	PE, PP	Avio et.al. 2019
	Italy, Adriatic Sea	1.0	29	fiber	/	Giani et.al. 2019
	Italy, Mediterranean Sea	1.1 ± 0.2	16.1	fiber	/	
	Greece, Mediterranean Sea	1.5 ± 0.3	32	fragment	PE, PP, PET	Digka et.al. 2018
	Turkey, Mediterranean Sea	2.1 ± 1.4	66	fiber	Nylon	Güven et.al. 2017
	Spain, Mediterranean Sea	1.9 ± 1.3	18.8	fiber	/	Bellas et.al. 2016
M. merluccius	Montenegro, Adriatic Sea	3.2 ± 1	54	fiber, film	PP, PE, PET, PA	Bošković et al. 2022b
	Italy, Adriatic Sea	1.6 ± 0.1	35	fiber, film	PE, PP	Avio et.al. 2019
	Italy, Adriatic Sea	1.1 ± 0.3	30.6	fiber	/	Giani et.al. 2019
	Italy, Mediterranean Sea	1.4 ± 0.5	28.2	fiber	/	
	Italy, Mediterranean Sea	/	46.3	/	/	Mancuso et.al. 2019
	Spain, Atlantic Ocean	1.0	6.7	fiber	/	Bellas et.al. 2016
M. galoprovincialis	Montenegro, Adriatic Sea	2.53 ± 1.1	3.3	fiber	PP, PE, PET, PA, PS, PVC, PVS	Bošković et al. 2023a
	Italy, Adriatic Sea	/		fiber, fragment	PE, PP, PET PS, PVC	Gomiero et al., 2019
	Italy, Mediterranean Sea	3.95 ± 2.54	1.1	fiber	PE, PP, PET, PVC	Nalbone et al. 2021
	Italy, Adriatic, Ligurian and Tyrrhenian Sea	3.0 - 12.4		fiber	/	Renzi et al. 2018
	Greece, Ionian Sea	1.9 ± 0.2	6.3	fiber, fragment	PE, PP, PTFE	Digka et al. 2018
	Tunisia, Mediterranean Sea	7.7 ± 3.8	7	fiber, fragment	PE, PP, celophane	Wakkaf et al. 2020
	Spain, Mediterranean Sea	4.54 - 18.2		/	/	Capo et al. 2021
	Spain, Cantabrian Sea	2.65 ± 1.46	00	fiber	rayon, PET, PS, PE	Masia et al. 2022

A further challenge is the absence of legislation that explicitly recognizes microplastics as a specific pollutant category. While general regulations concerning waste, water protection, and marine management exist, more detailed legal frameworks are needed to regulate monitoring obligations, emission sources, industrial responsibility, and prevention strategies in line with current European environmental policies.

The lack of long-term national monitoring programs also represents a significant scientific and management gap. Most studies conducted in Montenegro have been site-specific or project-based, without continuous monitoring of trends in water, sediments, and aquatic organisms. Without harmonized methodologies and regular data collection, it remains difficult to assess temporal changes, identify hotspots, or evaluate the effectiveness of mitigation measures.

The need for coordinated regional action is particularly important because the Adriatic Sea is considered one of the more vulnerable semi-enclosed European seas regarding plastic accumulation. Its limited water exchange, intense maritime traffic, coastal urbanization, fisheries, and seasonal tourism all contribute to pollutant retention and transboundary transport. For this reason, regional cooperation among Adriatic countries is essential for effective long-term management.

4. Conclusions

Available scientific evidence clearly demonstrates that microplastics are already present in multiple aquatic ecosystems of Montenegro, including rivers, lakes, coastal sediments, as well as in fish and shellfish species of ecological and commercial importance. These findings confirm that microplastic contamination is no longer an isolated or emerging issue, but an established environmental concern affecting both freshwater and marine environments of the country. Freshwater systems, particularly rivers flowing through urbanized and industrialized areas, appear especially vulnerable because they function as major transport pathways for land-based plastic waste toward downstream lakes and the Adriatic Sea. At the same time, Montenegro's coastal zone is exposed to combined pressures from local waste sources, tourism activities, fisheries, maritime transport, and transboundary inputs carried by marine currents. Sediments in rivers, lakes, and coastal areas are of particular importance because they act as long-term sinks for microplastics and may serve as secondary contamination sources through resuspension processes. Comparisons with studies from neighboring countries indicate that several Montenegrin sites show elevated concentrations of microplastics, highlighting the need for more detailed spatial investigations and source identification. However, differences in analytical methods and sampling strategies among studies emphasize the necessity for methodological standardization in future research. Future priorities should therefore include the establishment of a harmonized national monitoring network covering water, sediments, and biota; improvement of laboratory methodologies; reduction of single-use plastics; modernization of waste collection and recycling systems; expansion of wastewater treatment capacity; stronger environmental legislation; and increased public awareness. Regional cooperation within the Adriatic basin will also be essential for addressing the transboundary nature of plastic pollution. As a country with high biodiversity, valuable freshwater resources, and an internationally recognized ecological identity, Montenegro has the opportunity to become a regional example of proactive microplastic management. By integrating scientific evidence into environmental policy, prevention strategies, and sustainable resource management, it is possible to substantially reduce future plastic contamination and protect aquatic ecosystems for the long term.

Conflicts of Interest: The author declare no conflict of interest.

References

1. Abidli S, Toumi H, Lahbib Y, Trigui El Menif N. The first evaluation of microplastics in sediments from the complex lagoon-channel of Bizerte (Northern Tunisia). Water Air Soil Pollut. 2017; 228:262. DOI:10.1007/s11270-017-3390-3
2. Akdemir T, Terzi Y, Gündoğdu S, et al. Microplastic contamination in high-altitude glacier lakes in Northern Anatolia. Environ Sci Eur. 2025; 37:92. DOI:10.1186/s12302-025-01139-0
3. Alomar C, Estarellas F, Deudero S. Microplastics in Mediterranean sediments. Mar Environ Res. 2016; 115:1–10. DOI:10.1016/j.marenvres.2016.01.005

4. Atwood EC, Falcieri FM, Piehl S, Bochow M, Matthies M, et al. Coastal accumulation of microplastic particles emitted from the Po River, Northern Italy. Mar Pollut Bull. 2019; 138:561–574. DOI: 10.1016/j.marpolbul.2018.11.040
5. Avio CG, Pittura L, Abel S, Amorello S, Marino G, Gorbi S, et al. Microplastics in Adriatic food webs. Environ Pollut. 2019; 258:113766. DOI: 10.1016/j.envpol.2019.113766
6. Bellas J, Martínez-Armental J, Martínez-Cámara A, Besada V, Martínez-Gómez C. Ingestion of microplastics by fish. Mar Pollut Bull. 2016; 109:55–60. DO:10.1016/j.marpolbul.2016.06.026
7. Blair RM, Waldron S, Phoenix VR, Gauchotte-Lindsay C. Microplastics in freshwater river sediments (Scotland). Environ Sci Pollut Res. 2019; 26:12491–12504. DOI:10.1007/s11356-019-04648-w
8. Blašković A, Fastelli P, Čižmek H, Guerranti C, Renzi M. Plastic litter in Telaščica bay sediments. Mar Pollut Bull. 2017; 114:583–586. DOI:10.1016/j.marpolbul.2016.10.072
9. Blašković A, Guerranti C, Fastelli P, Anselmi S, Renzi M. Plastic levels in sediments close to Cecina river estuary (Tuscany, Italy). Mar Pollut Bull. 2018; 135:105–109. DOI:10.1016/j.marpolbul.2018.07.025
10. Bošković N, Joksimović D, Peković M, Perošević-Bajčeta A, Bajt O. Microplastics in surface sediments along the Montenegrin coast, Adriatic Sea: Types, occurrence, and distribution. J Mar Sci Eng. 2021; 9:841. DOI:10.3390/jmse9080841
11. Bošković N, Joksimović D, Bajt O. Microplastics in fish and sediments from the Montenegrin coast (Adriatic Sea): similarities in accumulation. Sci Total Environ. 2022a; 850:158074. DOI:10.1016/j.scitotenv.2022.158074
12. Bošković N, Joksimović D, Perošević-Bajčeta A, Peković M, Bajt O. Distribution and characterization of microplastics in marine sediments from the Montenegrin coast. J Soils Sediments. 2022b; 22:2958–2967. DOI:10.1007/s11368-022-03166-3
13. Bošković N, Jaćimović Ž, Bajt O. Microplastic pollution in rivers which belong to the Adriatic Sea basin in Montenegro: Impact on pollution of the Montenegrin coastline. Sci Total Environ. 2023a; 905:167206. DOI:10.1016/j.scitotenv.2023.167206
14. Bošković N, Joksimović D, Bajt O. Microplastics in mussels from the Boka Kotorska Bay (Adriatic Sea) and impact on human health. Food Chem Toxicol. 2023b; 173:113641. DOI:10.1016/j.fct.2023.113641
15. Bošković N, Jaćimović Ž, Bajt O. Distribution of microplastic pollution in Skadar Lake within the National Park of Montenegro. Water Air Soil Pollut. 2025a; 236:489. DOI:10.1007/s11270-025-08138-0
16. Bošković N, Jaćimović Ž, Bajt O. Protected natural areas are not protected from plastic pollution and its ecological risks: The case of Tara River in Montenegro, protected by UNESCO. J Environ Chem Eng. 2025b; 13:117726. DOI:10.1016/j.jece.2025.117726
17. Bošković N, Race A, Jaćimović Ž, Bajt O, Trebše P, Jerman I. Tributaries as reservoirs and vectors of microplastic pollution within a fluvial network: ecological implications for the Morača river basin. Environ Geochem Health. 2026a; 48:198. DOI:10.1007/s10653-026-03097-9
18. Bošković N, Jaćimović Ž, Jerman I, Race A, Trebše P, Bajt O. Microplastic pollution and ecotoxicological risk in high-altitude glacial lakes of Durmitor, Montenegro. Sci Rep. 2026b . DOI:10.1038/s41598-026-51455-5
19. Cannas S, Fastelli P, Guerranti C, Renzi M. Plastic litter in sediments from the coasts of south Tuscany (Tyrrhenian Sea). Mar Pollut Bull. 2017; 119:372–375. DOI:10.1016/j.marpolbul.2017.04.008
20. Capo X, Rubio M, Solomando A, Alomar C, Compa M, Sureda A, Deudero S. Microplastic intake and enzymatic responses in mussels. Chemosphere. 2021; 280:130575. DOI:10.1016/j.chemosphere.2021.130575
21. Claessens M, De Meester S, Van Landuyt L, De Clerck K, Janssen C. Microplastics in marine sediments along the Belgian coast. Mar Pollut Bull. 2011; 62:2199–2204. DOI:10.1016/j.marpolbul.2011.06.030
22. Constant M, Ludwig W, Kerhervé P, Sola J, Charrière B, et al. Microplastic fluxes in Mediterranean rivers. Sci Total Environ. 2020; 716:136984. DOI: 10.1016/j.scitotenv.2020.136984
23. Digka N, Tsangaris C, Torre M, Anastasopoulou A, Zeri C. Microplastics in mussels and fish from the northern Ionian Sea. Mar Pollut Bull. 2018; 135:30–40. DOI:10.1016/j.marpolbul.2018.06.063
24. Fischer EK, Paglialonga L, Czech E, Tamminga M. Microplastic pollution in lakes and lake shoreline sediments. Environ Pollut. 2016; 213:648–657. DOI:10.1016/j.envpol.2016.03.012
25. Giani D, Baini M, Galli M, Casini S, Fossi MC. Microplastics in edible fish species. Mar Pollut Bull. 2019; 140:129–137. DOI:10.1016/j.marpolbul.2019.01.035
26. Gomiero A, Strafella P, Øysæd KB, Fabi G. Microplastics in native mussels from the Adriatic Sea. Environ Sci Pollut Res. 2019; 26:24407–24416. DOI:10.1007/s11356-019-05698-0
27. Guerranti C, Cannas S, Scopetani C, Fastelli P, Cincinelli A, et al. Plastic litter in Maremma regional park. Mar Pollut Bull. 2017; 117:366–370. DOI:10.1016/j.marpolbul.2017.01.020
28. Güven O, Gökdağ K, Jovanović B, Kıdeyş AE. Microplastics in Turkish Mediterranean waters and fish. Environ Pollut. 2017; 223:286–294. DOI:10.1016/j.envpol.2017.01.025

29. Hengstmann E, Weil E, Wallbott PC, Tamminga M, Fischer EK. Microplastics in lakeshore and lakebed sediments. Environ Res. 2021; 197:111141. DOI:10.1016/j.envres.2021.111141
30. Kiss T, Fórián S, Szatmári G, Sipos G. Microplastics in Tisza River sediments. Sci Total Environ. 2021; 785:147306. DOI:10.1016/j.scitotenv.2021.147306
31. Klein S, Worch E, Knepper TP. Occurrence and spatial distribution of microplastics in river shore sediments of the Rhine-Main area in Germany. Environ Sci Technol. 2015; 49:6070–6076. DOI:10.1021/acs.est.5b00492
32. Maes T, Van Der Meulen MD, Devriese LI, Leslie HA, Huvet A, Frère L, et al. Microplastics baseline surveys. Front Mar Sci. 2017; 4:135. DOI:10.3389/fmars.2017.00135
33. Mancuso M, Savoca S, Bottari T. Microplastics ingestion by European hake. J Fish Biol. 2019; 94:517–519. DOI:10.1111/jfb.13908
34. Masia P, Ardura A, Garcia-Vazquez E. Microplastics in seafood: input via mussels and salt. Int J Food Res. 2022; 153:110973. DOI:10.1016/j.foodres.2021.110973
35. Matjašič T, Mori N, Hostnik I, Bajt O, Kovač Viršek M. Microplastic pollution in small rivers along rural–urban gradients: variations across catchments and between water column and sediments. Sci Total Environ. 2022; 858:160043. DOI:10.1016/j.scitotenv.2022.160043
36. Nalbone L, Cincotta F, Giarratana F, Ziino G, Panebianco A. Microplastics in mussels from retail chains in Italy. Food Control. 2021; 125:108003. DOI:10.1016/j.foodcont.2021.108003
37. Negrete Velasco AdJ, Rard L, Blois W, et al. Microplastic and fibre contamination in a remote mountain lake in Switzerland. Water. 2020; 12:2410. DOI:10.3390/w12092410
38. Palatinus A, Viršek MK, Robič U, Grego M, Bajt O, Šiljić J, et al. Marine litter in the middle Adriatic Sea. Mar Pollut Bull. 2019; 139:427–439. DOI:10.1016/j.marpolbul.2018.12.051
39. Pastorino P, Anselmi S, Esposito G, et al. Microplastics in high-mountain lakes from Alps. Ecol Indic. 2023; 150:110215. DOI:10.1016/j.ecolind.2023.110215
40. Piazzolla D, Cafaro V, de Lucia GA, Mancini E, Scanu S, Bonamano S, et al. Microlitter in Tyrrhenian sediments. Estuar Coast Shelf Sci. 2020; 241:106819. DOI:10.1016/j.ecss.2020.106819
41. Renzi M, Guerranti C, Blašković A. Microplastic contents from maricultured and natural mussels. Mar Pollut Bull. 2018; 131:248–251. DOI:10.1016/j.marpolbul.2018.04.023
42. Renzi M, Čižmek H, Blašković A. Marine litter in Croatian sediments. Mar Pollut Bull. 2019; 138:25–29. DOI:10.1016/j.marpolbul.2018.11.033
43. Renzi M, Blašković A. Chemical fingerprint of plastic litter in Croatia. Mar Pollut Bull. 2020; 153:110994. DOI:10.1016/j.marpolbul.2020.110994
44. Rodrigues MO, Abrantes N, Gonçalves FJM, Nogueira H, Marques JC, et al. Microplastics in Antuã River (Portugal). Sci Total Environ. 2018; 633:1549–1559. DOI:10.1016/j.scitotenv.2018.03.233
45. Scherer C, Weber A, Stock F, Vurusic S, Egerci H, et al. Comparative assessment of microplastics in water and sediment of a large European river. Sci Total Environ. 2020; 738:139866. DOI:10.1016/j.scitotenv.2020.139866
46. Scopetani C, Chelazzi D, Cincinelli A, Esterhuizen-Londt M. Assessment of microplastic pollution in Finnish lakes. Environ Monit Assess. 2019; 191. DOI: https://doi.org/10.1007/s10661-019-7843-z
47. Simon-Sánchez L, Grelaud M, Garcia-Orellana J, Ziveri P. River deltas as hotspots of microplastic accumulation: the case study of the Ebro River. Sci Total Environ. 2019; 687:1186–1196. DOI:10.1016/j.scitotenv.2019.06.168
48. Turner S, Horton AA, Rose NL, Hall C. A temporal sediment record of microplastics in an urban lake, London, UK. J Paleolimnol. 2019; 61:449–462. DOI:10.1007/s10933-019-00071-7
49. Vianello A, Boldrin A, Guerriero P, Moschino V, Rella R, Sturaro A, Da Ros L. Microplastics in Venice lagoon sediments. Estuar Coast Shelf Sci. 2013; 130:54–61. DOI:10.1016/j.ecss.2013.03.022
50. Wakkaf T, El Zrelli R, Kedzierski M, Balti R, Shaiek M, Mansour L, et al. Microplastics in edible mussels from a Mediterranean lagoon. Mar Pollut Bull. 2020; 158:111355. DOI:10.1016/j.marpolbul.2020.111355
51. Winkler A, Antonioli D, Masseroni A, Chiarcos R, Laus M, et al. Fate of microplastics along the Ticino River. Sci Total Environ. 2022; 823:153638. DOI:10.1016/j.scitotenv.2022.153638