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RESEARCH PAPER

Microplastics in Lake Sediments in Robert Island, Antarctica

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Abstract

Microplastic (MP) pollution was investigated in the sediment of lakes on Robert Island in the South Shetland Islands located in the northwest of the Antarctic Peninsula. Sediment samples were taken from a glacial lake (L1) and three coastal lakes (L2, L3 and L4) in March and April 2018 as part of the Turkish Antarctic Science Expedition-II (TAE-II). MPs were counted, and physically (shape, colour, size) and chemically characterized by stereomicroscope and Fourier-transform infrared spectroscopy (FT-IR) respecitvely. Fibers and fragments were found in the coastal lakes, while only fibers were found in the glacial lake sediment. The meanMP concentration was 28.3 mp. L^{-1}±37.9 mp. l^{-1} sediment in the glacial lake and 49.6 mp. l^{-1}±97.1 mp. l^{-1} sediment in coastal lakes. A total of six different colours of MPs were found with transparent and blue were dominant. The size of MPs varied between 0.08-2.12 mm (mean 0.96±0.55 mm). FT-IR analysis confirmed that MPs were composed of Ethylene Vinyl Acetate (EVA), Polyethylene terephthalate (PET), Polypropylene (PP), Polymethyl Methacrylate (PMMA), Polyethylene (PE), Polyurethane (PU), and Polyacrylonitrile (PAN). Presence of MPs in the lake's sediment highlights the vulnerability of Antarctica's environment to this unbounded and unpredictable pervasive pollutant and raises concerns about the potential effects of MPs on its unique ecosystems, which are critical to global climate regulation. More comprehensive research on distribution, characteristics, sources and transport of MPs in this remote region is recommended to fully understand the level of risk that MPs represents to ecosystem health.

Introduction

Antarctica, one of Earth's last pristine environments, is a unique and fragile region that plays a vital role in the planet's climate system and ecosystems. However, microplastic pollution in this remote area is an increasing concern with significant ecological and global implications. Microplastic pollution in Antarctica arises from both local and global sources, despite its remote location. Locally, research stations and tourist activities release microfibers and microplastics into the environment mainly through synthetic clothing, wastewater discharge, and poorly managed plastic waste. Fishing activities in the Southern Ocean, such as lost fishing gear and resin pellet spills from shipping, are also significant contributors of microplastic pollution.

Globally, microplastics are transported to Antarctica via ocean currents, particularly the Antarctic Circumpolar Current, and through long-range atmospheric transport, where they settle with precipitation (Cunningham et al., 2022, Aves et al., 2022). Additionally, larger plastic debris carried by currents or trapped in sea ice degrades into microplastics due to UV radiation and physical wear. These particles accumulate in ice, snow, and sediments, posing a serious threat to the region's fragile ecosystem.

Microplastics can be ingested by marine organisms like krill, a keystone species in the Antarctic food web. This ingestion can disrupt feeding behaviours, deplete energy reserves, and impair reproduction, creating a ripple effect through the food chain that impacts fish, seabirds, and marine mammals reliant on krill.

Moreover, microplastics can carry harmful chemicals and pathogens, introducing pollutants into this pristine environment and endangering native species.

Recent studies revealed that Antarctica is contaminated by microplastics despite limited human activity in the region. Microplastics have been found in snow, ice, sediment, and water samples from various Antarctic locations (Rota et al., 2022). Evidence of high concentration of MPs in deep sediment core compared to less remote ecosystems suggests that the Antarctic deep-sea accumulates higher numbers of microplastic pollution than previously expected (Cunningham et al., 2020). Their accumulation in ice, snow, and sediments may also alter the physical and chemical characteristics of these habitats can affect the organisms that depend on them. Given Antarctica's vital role in global climate regulation and biodiversity, the ecological impacts of microplastic pollution could extend far beyond the region, with potential consequences for global environmental and climatic systems (Bargagli, 2005; Fleming et al., 2009; Rota et al., 2022).

Growing number of research in Antarctica has been carrying out to understand the presence, sources, and impacts of microplastics in one of Earth's most remote ecosystems. However, there is no information on presence of microplastics in lakes sediments in Antarctic. The aim of this study was to assess the occurrence and characteristics of microplastics in lake sediments of Robert Island, Antarctica. The result of the present study contributes to the current knowledge on microplastic pollution in the Antarctica and provides the scientific evidence to the Committee for Environmental Protection (CEP) for policy development to protection of the Antarctic Treaty area.

Material and Methods

Study Area

The South Shetland Archipelago spans approximately 300 km in a northeast direction, running parallel to the northern Antarctic Peninsula and comprises 11 major islands. Between 80 and 90% of the land area of the islands is permanently glaciated. It is segregated from the Antarctic Peninsula by the Bransfield back-arc marginal basin to the east. Robert Island (~18 × 18 km) is in the central part of the archipelago and is mostly covered by a single ice cap. (Figure 1b). All investigated lakes are developed on this complex geological formation. Özyurt et al. (2023) investigate the geochemistry of the lake sediments on Robert Island revealing insights into local weathering processes and sedimentary contributions. The lake sediments predominantly composed of fine-grained sand, clay, and silt particles (Özyurt et al., 2023). Geomorphology and location of the basins, which are mostly situated along the coast where foehn winds have a limited influence over ice-free areas, it is likely that locally resuspended materials have had a significant impact (Özyurt et al., 2023).

Sampling

The study was conducted in March-April 2018 as a part of the Turkish Antarctic Expedition-II (TAE-II). Samples were collected from littoral zones of the lakes in the glacier-free land area on the Robert Island, South Shetland Islands Archipelago (Figure 1). The studied lakes included a glacier inland lake (L1) and three coastal lakes (L2, L3, and L4), that were mostly located along the coastal rocky shores (Figure 2). L1 glacier lake was the largest among them. Its depth was 1.5 m and covered an area of 11,961 m^{-2}. The coastal lakes' depth was between 0.3 and 1.1 m (Table 1). The lakes were sampled using the snapshot sampling protocol (Jeppesen et al., 2017) and detailed information on these lake's coordinates, altitudes and physicochemical characteristics were reported in Özkan (2023). Vertebrate mammal activity was observed especially around coastal lakes. Some waterbird activity was also observed in the glacial lake. Littoral sediment samples were taken from four points at L1 and three points in L2, L3 and L4. The sediments primarily consist of fine-grained sand, clay, and silt-sized particles with diverse petrographic compositions.

Microplastic Analysis

Sediment samples were homogenized, and their volume (ml) and weight (g) recorded. Microplastics (MPs) were extracted using the density flotation method (Frias et al., 2018). Saturated NaCl solution (1.2 g/cm^3) was prepared with ultrapure water, filtered (0.2 µm), and added to sediment in glass beakers. Samples were stirred, settled for 1 hour, and the supernatant was filtered through a 10 µm sieve, and retained particles were rinsed into beakers with 30% H_2O_2 solution. This process was repeated three times to ensure complete MP recovery. Covered beakers were heated at 45°C for up to 48 hours. The resulting solution was filtered onto glass microfiber filters (Whatman GF/C, 1.2 µm, Ø47 mm) and dried in petri dishes. Potential MPs were identified using a Leica SAPO stereomicroscope with MIC 170 HD camera and LAS software, classified by shape and color, and measured for largest dimensions. Filters with suspected MPs were stored for further FT-IR analysis.

FT-IR analysis

Fourier transform infrared spectroscopy (FTIR) confirmed the polymer origin of particles found in the sediment. Analyses utilized a Perkin Elmer Spectrum 100 spectrophotometer equipped with an Attenuated Total Reflection (ATR) apparatus. Spectra were recorded within a range of 4000-650 cm^{-1} at a resolution of 1.0 cm^{-1} with 32 scans per measurement. Results were compared against the instrument library, and polymers were identified for matches exceeding 70% similarity.

Quality Assurance and Quality Control

Cotton lab coats and nitrile gloves were worn throughout the procedures. All laboratory analyses were conducted in a laminar flow cabinet, and microscopic identification was performed in a cabinet. All glassware and equipment were thoroughly cleaned with ultrapure water and pre-rinsed with ethanol to minimize contamination. All filters were inspected under a microscope prior to use. To mitigate airborne contamination, dampened filters in petri dishes were placed at every stage of laboratory work. Procedural blanks were processed alongside the samples and any identified MPs were subtracted from the final results. Possible contamination from clothing during sampling was also confirmed.

Results

A total of 32 microplastic particles were found within the sediment samples. The primary shape was fibers in sediment of all lakes analyzed, fragments were only found in two coastal lakes no films, beads, pellets, foam or paint were found (Figure 3). Mean microplastic concentrations in the sediment of lakes ranged between 11-98 mp. l^{-1} (mean 44±38 mp.l^{-1}) (Figure 4).

A total of 6 different colours of microplastics were found in the sediment. Blue was the most common colour (38 %), followed by transparent (34 %), black (13 %), red (6%), orange (6%), and pink (3%) (Figure 5). The size of microplastics ranged between 0.081 to 2.128 mm (mean 0.96±0.55 µm). The most common size of microplastics in sediment 200 µm-1mm (50 %), followed by 1-2 mm, 2-5 mm (6 %) and < 200 µm (6 %). FT-IR

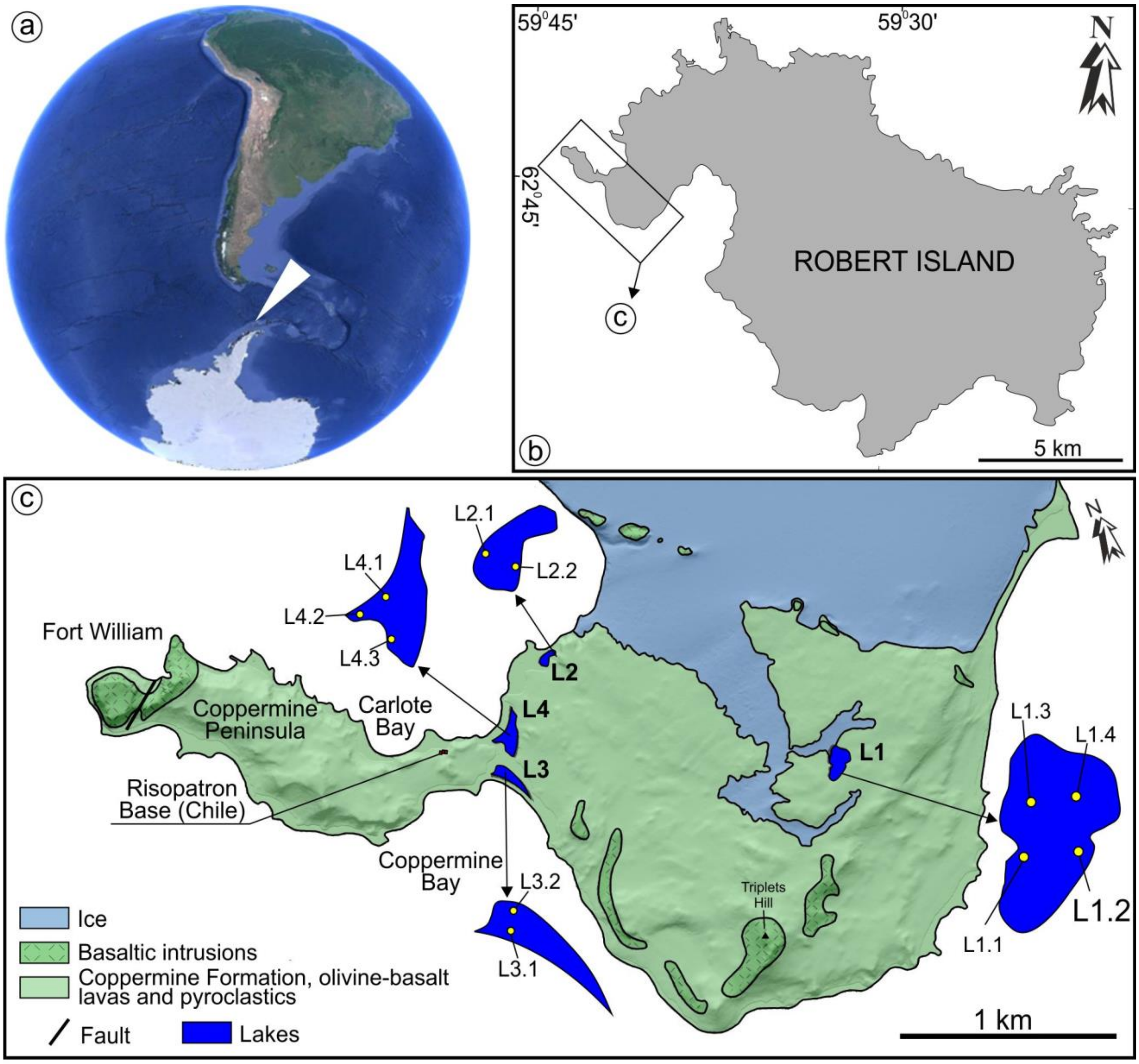

Figure 1. a- Geographic location of the South Shetland Islands (white arrow), b- Studied area on the Robert Island c- Geological map of Coppermine Peninsula (modified from Smellie et al., 1984 and Machado et al., 2005) and geographic location of studied lakes (Özyurt et al., 2023).

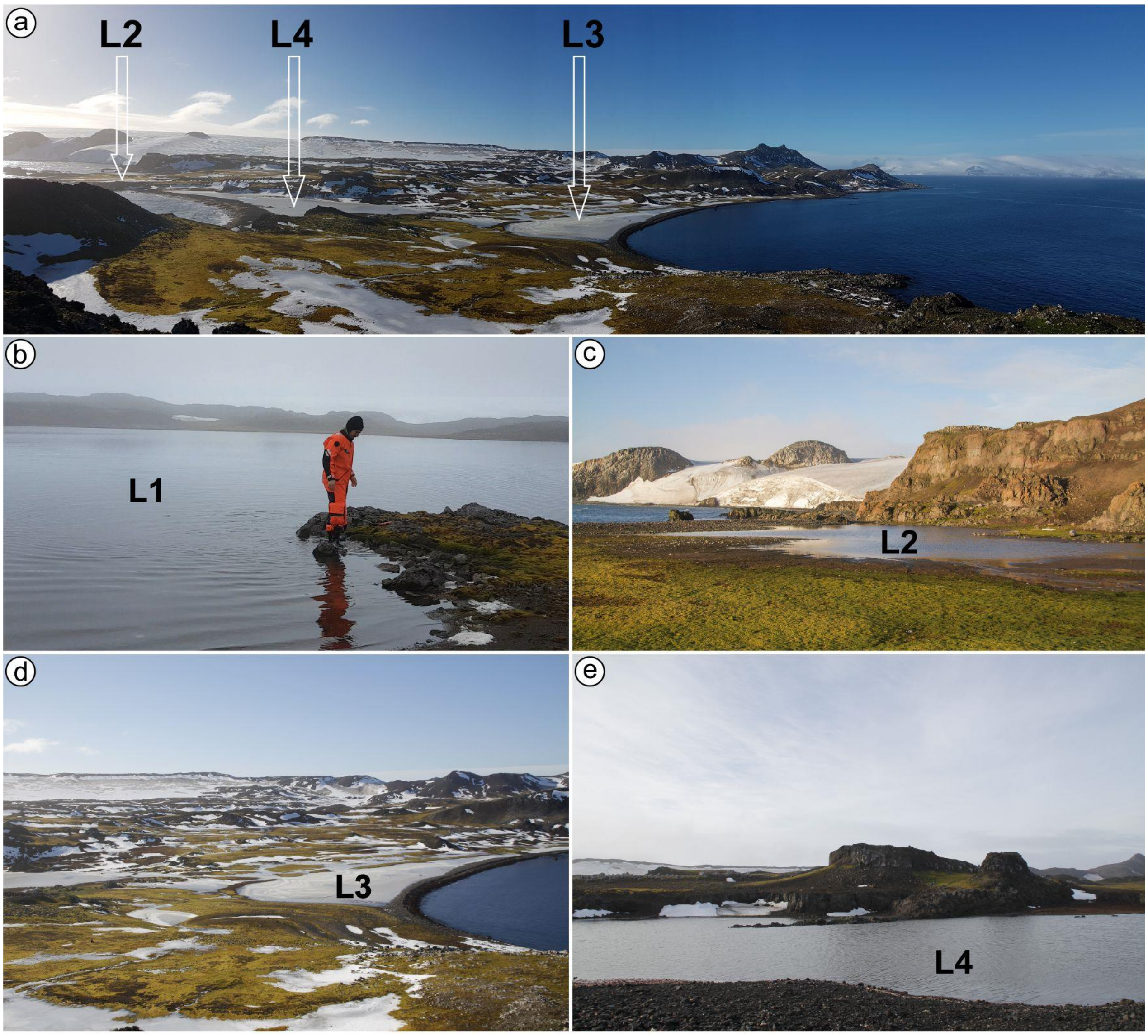

Figure 2. Sampled lakes in Robert Island.

Table 1. Locations and morphological characteristics of sampled lakes (Özkan, 2023)

Sampling Site	Latitude	Longitude	Altitude (m)	Max depth (m)	Area (m^2)	Circumference (m)	Distance to sea (m)
L1, Robert Island	62°23'05.6"	59°40'04.4"	38	1.5	11,961	481	638
L2, Robert Island	62°22'38.6"	59°41'12.8"	3	0.3	8,431	434	70
L3, Robert Island	62°22'49.5"	59°41'40.5"	1	0.8	6,379	489	10
L4, Robert Island	62°22'43.5"	59°41'35.3"	2	1.1	11,578	624	26

analysis confirmed that microplastics in sediment samples were composed of Ethylene Vinyl Acetate (EVA), Polyethylene terephthalate (PET), Polypropylene (PP), Polymethyl Methacrylate (PMMA), Polyethylene (PE), Polyurethane (PU), and Polyacrylonitrile (PAN) (Figure 5).

Discussion

Present study shows the ubiquitous presence of microplastics mainly fibers in lake sediments in Antarctica, for the first time. Many recent studies reported evidence of MPs in intertidal or deep-sea sediment (Table 2). Microplastic concentrations have been reported using various units (e.g., m^{-2}, g^{-1}), which complicates direct comparison with certain previous studies (Table 2). Therefore, only studies reporting MP concentrations in units of particles per milliliter (par.ml^{-1}) from sediment samples were used for comparison (Table 2). Microplastics concentration reported here lower than those reported from near shore stations in the Rothera Station, Adelaide Island (Reed et al., 2018) and intertidal sediments in Fildes Bay, King George Island (Perfetti-Bolaño et al., 2022). The variability in microplastic concentrations reported across studies can be attributed to several factors, including the proximity of sampling sites to research stations in coastal areas, the intensity of ship traffic,

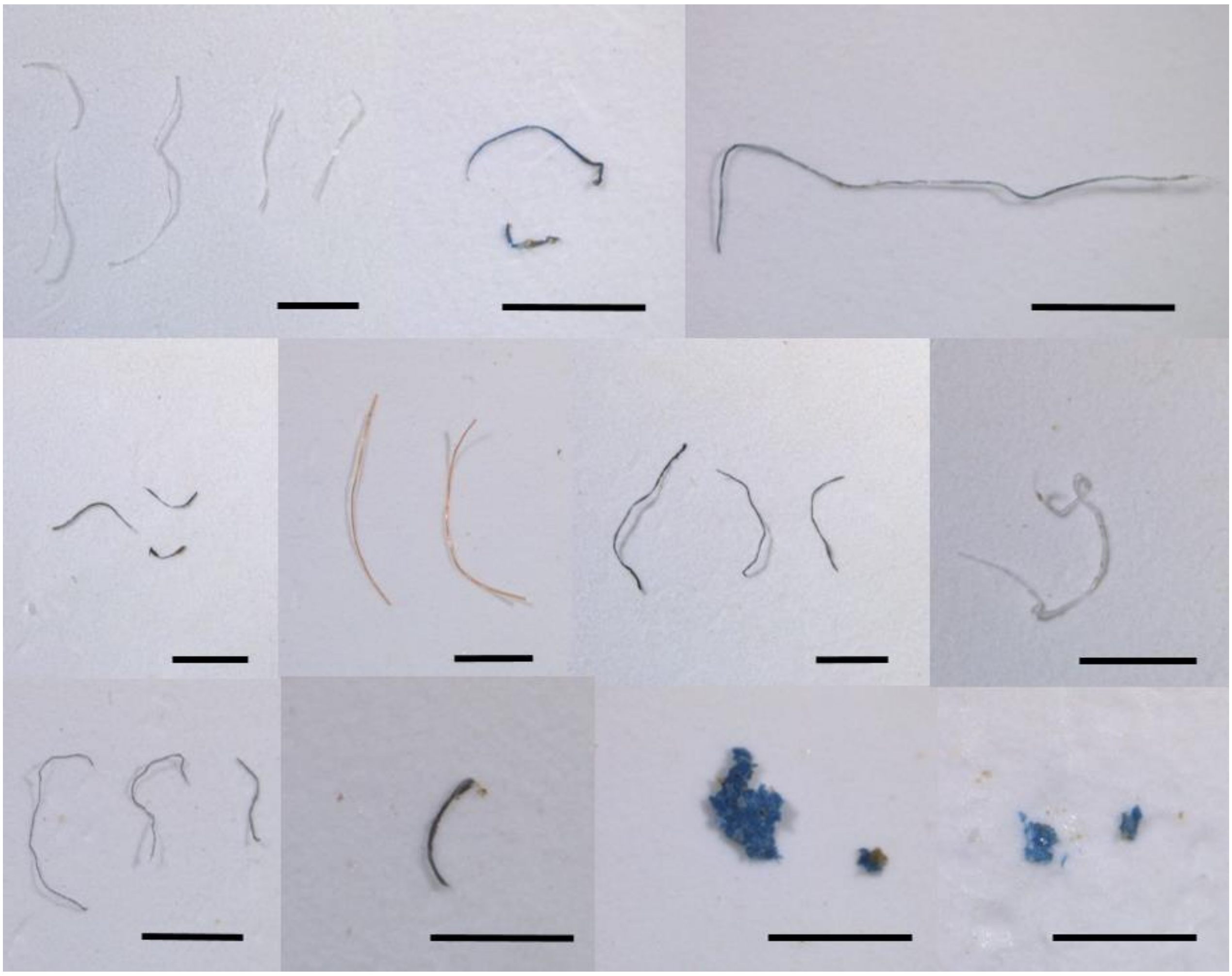

Figure 3. Examples of microplastics found in lake sediments in Robert Island (South Shetland Island, Antarctica) (scale: 500 µm).

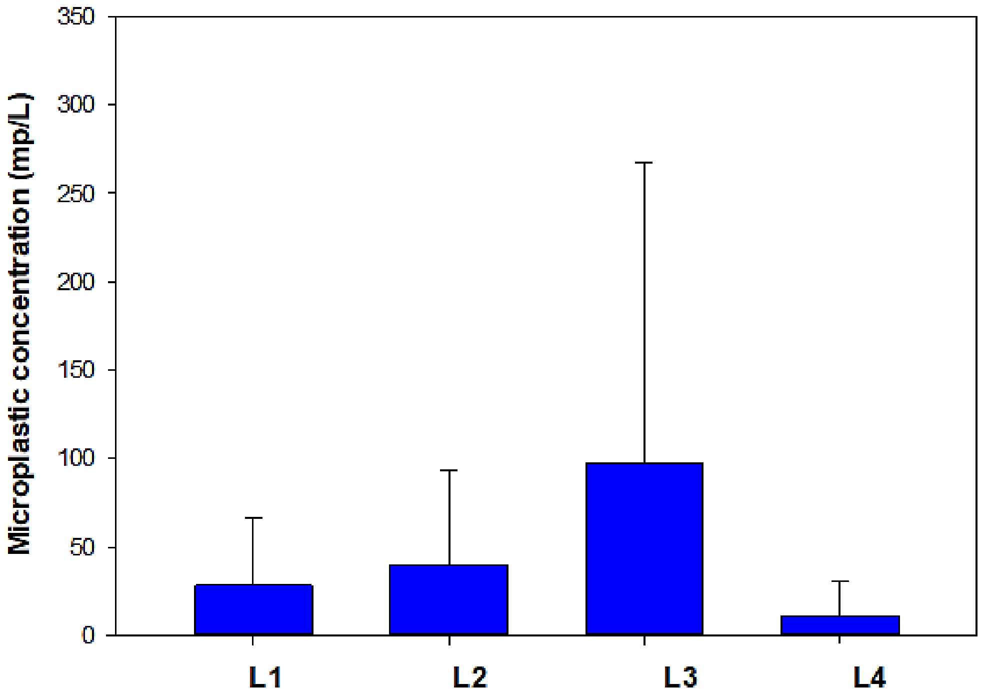

Figure 4. Concentration of microplastics in sampled lakes.

transport via ocean currents, and other environmental and human-related influences. Perfetti-Bolaño et al. (2022) examined the presence of microplastics (MPs) in intertidal sediments which were dominated by fibers with minimum concentration of 0.03 mp.ml^{-1}. They also found fibre in sediment from a protected area with no permanent human settlements, highlighting the reach of plastic pollution even in minimally impacted areas.

Fibers were found predominantly in the sediment in agreement with previous studies carried out in Terra Nova Bay (Munari et al., 2017), in Admiralty Bay in King George Island (Waller et al., 2017), in Rothera Station in Adelaide Island (Reed et al., 2018), in South Georgia Island (Cunningham et al., 2020) and in Fildes Bay in King George Island (Perfetti-Bolaño et al., 2022). Microplastics have become a widespread airborne pollutant, reaching even the most remote and untouched environments on Earth, including Antarctica (Aves et al., 2022). Microplastics, including fibers, are known to be carried by air masses and dust clouds from land to sea (Allen et al., 2019; Bergmann et al., 2019; Liu et al., 2019) and can ravel vast distances from urban and industrialized regions to the polar regions (Obbard, 2018). Fibres were also reported to be the most abundant microplastics in Antarctic snow (Aves et al., 2022). Their presence in Antarctica illustrates the extensive influence of human activities and the truly global scale of microplastic pollution. Once deposited through atmospheric processes, such as precipitation or settling from the air, microplastics can accumulate in Antarctic snow (Aves et al., 2022), ice (González-Pleiter, et al., 2021; Kelly et al., 2021; Matrec et al., 2022) and other ecosystem matrices (Table 2).

Research stations and tourism activities (more than 70,000 visitors in the 2019–2020 season) are also important local sources of microplastics. In Antarctica, 37% of the research stations are year-round permanent stations and 69% of the stations used only during the austral summer and 52% of the all-research stations have no wastewater treatment systems (Gröndahl et al., 2009). Fibers and other microplastics can be released into the environment through synthetic clothing, wastewater discharge, and poorly managed plastic waste. Fishing activities such as lost fishing gear and resin pellet spills from shipping, are sea-based sources and can make a significant contribution to microplastics pollution in the Southern Ocean. In Arctic Sea, researchers found higher plastic pollution in the deep waters where numbers of fishing boats increased in the region (Tekman et al., 2017).

Microplastics can also be transported to Antarctica via ocean currents, particularly the Antarctic Circumpolar Current. Additionally, larger plastic debris carried by currents or trapped in sea ice degrades into microplastics due to UV radiation and physical wear. These particles accumulate in ice, snow, and sediments, posing a serious threat to the region's fragile ecosystem.

Research on microplastics in Antarctica has revealed a range of polymer types, reflecting pollution from both local and distant sources. The most prevalent

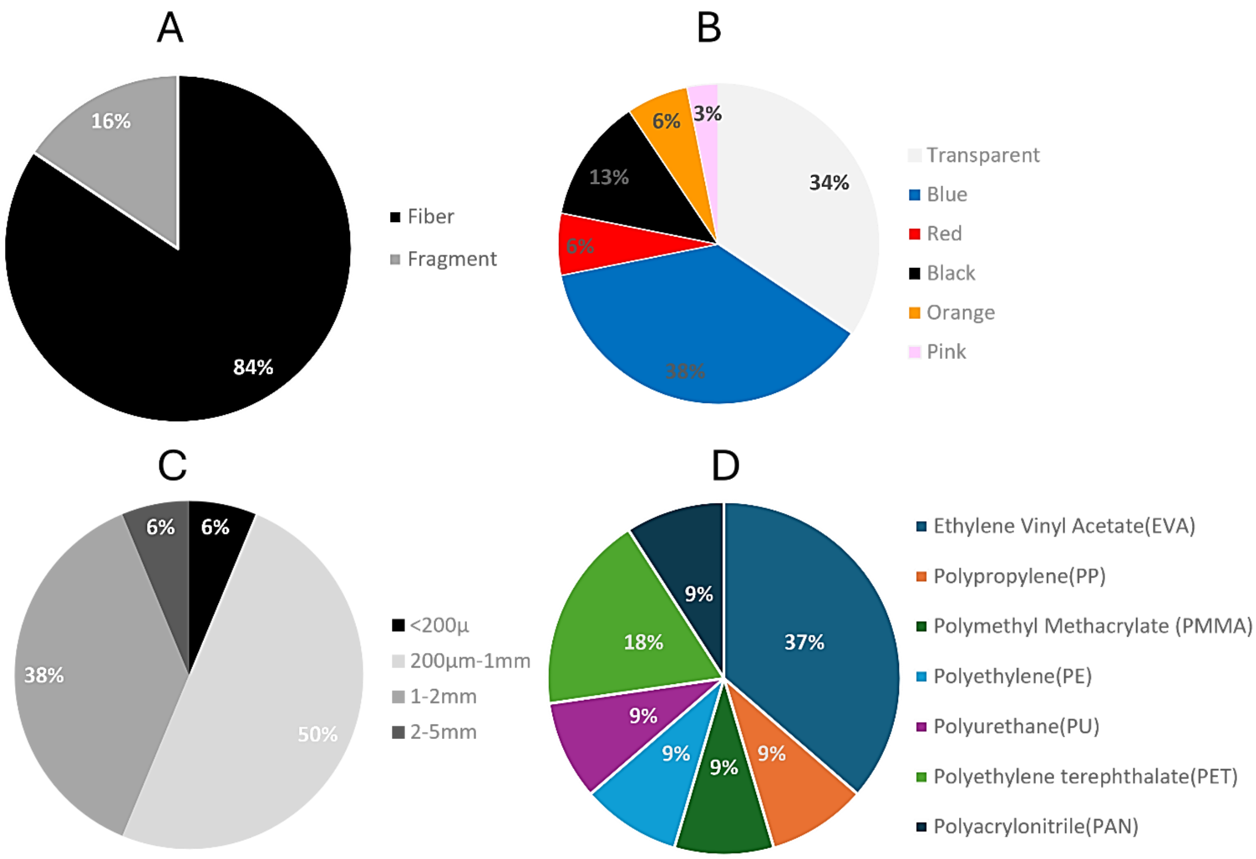

Figure 5. Shape (A), colour (B), size (C) and polymer composition (D) of microplastics in sediment.

polymers include polyethylene (PE) and polypropylene (PP), commonly used in packaging and fishing gear, and polyethylene terephthalate (PET), associated with clothing and beverage containers. In the present study EVA and PET were the most common polymers found in sediment. PET was reported from Air samples collected over the West Pacific Ocean (Liu et al., 2019) and Antarctic snow samples (Aves et al., 2022). These findings point to diverse origins, from local activities such as research operations and shipping, to long-range atmospheric and oceanic transport of plastic waste. This highlights the urgent need for more research and tailored strategies to mitigate microplastic pollution in Antarctica's vulnerable ecosystem.

Conclusion

Our study confirmed that the sediments of glacial lake and coastal lakes are contaminated by microplastics mainly synthetic fibers. Ubiquitous presence of microplastics highlights the vulnerability of Antarctica's environment and raises concerns about the potential effects of microplastics on its unique ecosystems, which are critical to global climate regulation. There is an urgent need to implement enhanced regulations and adopt integrated monitoring and management strategies to address microplastics and their specific impacts. These measures should consider local environmental conditions and the broader context of

Table 2. Comparison with previous studies carried in Antarctica

Location	Habitat	Type	Size	Density	Reference
East Antarctica, Ross Island	Snow	Fibers (61%), Fragments, Films	Mean: 606 µm Range: 50–3510 µm	Mean: 29.4±4.7 L^{-1} Range: 4–82 L^{-1}	Aves et al., 2022
King George Island	Ice	Fragments	Range: 2.3–12.6 mm	Mean: 9.5×10−4 m^{-3} Range: 0.17–0.33 m	González-Pleiter, et al., 2021
East Antarctica (North Casey Station)	Coastal landfast sea ice	-	Mean: 56.7 µm Range: 20–325 µm	Mean: 20.4 L^{-1} Range: 6–33 L^{-1}	Kelly et al., 2021
East Antarctica Ross Sea, Cape Evans	Coastal landfast sea ice	-	>200nm	Top of the core: 67 ng mL^{-1} Bottom: 37.7 ng mL^{-1}	Matrec et al., 2022
King George Island (Admiralty Bay)	Seawater	Fibers	Range: ca. 2–5 mm	Mean: 0.024±0.0457 m^{-3}	Absher at al., 2019
East Antarctica, Ross Sea (near-shore and offshore)	Seawater	Fragments (72%), Fibers (13%)	>60 µm	Mean: 0.17±0.34 m^{-3} Range: 0.0032^{-1}.18 m^{-3}	Cincinelli et al., 2017
Central Scottish Sea and Adelaide Island	Sea Surface water	Fragment %93, Film %7	%90<300µm	Mean:0.013±0.005m^{-3} (5056 ±2158km^{-2}) Max: 0.054 m^{-3}	Jones-Williams et al., 2020
Weddell Sea	Sea Surface water	Fragment %90.2, Fiber %8.8,	%74<900µm %64<700µm	Mean: 0.01±0.01m^{-3} Range 0–0.04 m^{-3} Mean: 0.04 ± 0.1 m^{-3} Range 0–0.47 m^{-3}	Leistenschneider et al.,2021
Antarctica Peninsula	Sea Surface water	Fragment %51.3, Fiber%42.3, Bead %6.4	%54 <5mm %46>5–200mm	Mean 1794 km^{-2} (0.008 $items^{-3}$) Range 755–3524km^{-2}	Lacerda et al., 2019
Southern Ocean	Sea Surface water	Fragment	<5 mm	Range 0.03–0.09 m^{-3}	Isobe et al., 2017
Southern Ocean	Sea Surface water	Fragment	Mean: 3.03±2.81 mm Range 0.68–21.5mm	Mean 188km^{-2}	Suaria et al.,2020a
Southern Ocean	Sea Surface water	Fiber %79.5 cellulose	Mean 0.9mm	Mean: 1.7L^{-1}	Suaria et al.,2020b
ASPA 126 Livingston Byers Peninsula	Sea Surface water	Fiber, Film	Fiber, Mean 1118 µm, Range 400–3546 µm Film, Mean 199 µm Range 10-1026 µm,	Range 0.47–1.43 items/1000 m^3	González-Pleiter, et al., 2020
East Antarctica, Ross Sea (Terra Nova Bay)	Sediment	Fibers (42.8%), Film (35%), Fragments (22.2%)	78.4% < 5 mm	Range: 5–1705 m^{-2}	Munari et al., 2017
King George Island (Admiralty Bay)	Sediment	Fibers and Fragments	<5mm	Range: 16–766 m^{-2}	Waller et al., 2017
Antarctic Peninsula Adelaide Island (Rothera Station)	Sediment	Fibers (nearly all)	<5mm	Range: 0–3 ml^{-1}	Reed et al., 2018
Antarctic Peninsula, South Sandwich Islands, South Georgia Island	Sediment (cores)	Fragments (56%), Fibers (39%)	<2mm	Mean: Antarctic Pen. 1.30±0.51 g^{-1} , S Sandwich Is. 1.09±0.22 g^{-1} , S Georgia Is. 1.04±0.39 g^{-1}	Cunningham et al., 2020
King George Island, Fildes Bay	surface soils and intertidal sediments	Fibers Fragments	fibers 500–2,000 µm, fragments 20–500 µm	1.5-3.6 particles/50 ml	Perfetti-Bolaño et al., 2022
Robert Island	Sediment	Fibers (84%), Fragments (16%)	mean 0.96±0.55 mm	Glacial lake, 28.3 mp.l^{-1}±37.9 mp.l^{-1} Coastal lakes, 49.6 mp.l^{-1}±97.1 mp.l^{-}	**This study**

climate change to ensure effective mitigation and protection of vulnerable ecosystems. Scientific stations and vessels in Antarctica should be equipped with appropriate sewage treatment systems wherever feasible to minimize environmental contamination. Additionally, national research programs and tour operators must actively raise awareness among personnel and visitors about the risks associated with plastics including alien species and other persistent pollutants, ensuring efforts to protect the region's unique and fragile ecosystems. There is a need for more comprehensive data to evaluate effects of microplastics.

Ethical Statement

Not applicable.

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Author Contribution

Ülgen AYTAN: Conceptualization, Investigation, Data Curation, Visualization, Writing – original draft. Yasemen ŞENTÜRK: Investigation, Visualization, Writing – original draft. Korhan ÖZKAN: Sampling, Data Curation, Methodology. Raif KANDEMİR: Sampling, Data Curation, Methodology, Visualization and Writing - original draft

Conflict of Interest

The authors declare that they have no conflict of interest.

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