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Microplastic Presence in Antarctic Seawater and Surface Sediment Samples: Findings from the Turkish National Antarctic Scientific Expedition TAE-7

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Abstract

Increasing production and widespread use of plastics have led to an alarming increase in plastic waste, affecting remote regions such as Antarctica. Despite its isolation by currents, Antarctica experiences anthropogenic pollution transported by oceanic and atmospheric currents. This study focused on microplastic contamination in Lystad Bay, Antarctica. During the TAE-7 Antarctic Expedition, samples were collected from seawater, subsurface water and sediment sites at Lystad Bay. In seawater samples, an average microplastic concentration of 0.1055±0.0285 particles/m² (2.1102±0.5707 particles/m³) was found, predominantly fibres, and the dominant size ranges were found to be 500-999 (36.02% of all particles) µm and 1000-1499 (22.01% of all particles) µm. Polyethylene, polyamide and polyisoprene were the most commonly identified polymers. The mean particle concentration in the subsurface water samples was 11.2±5.5 particles/L, with fibers and fragments being the most common shapes. In the sediment samples, the average microplastic concentration was 0.895 particles/g DW, with fibers as the dominant shape. Six polymer types were identified, with polycarbonate and polyoxymethylene being the most common. The results highlight the pervasive impact of human activities and natural transport mechanisms on microplastic pollution in one of the most remote environments on Earth.

Introduction

Plastic pollution, recognized as a global problem, continues to pose a serious threat to ecosystems, particularly the world's oceans (Andrady, 2017). Global plastics production has grown steadily and reached 400 million tonnes in 2022 (PlasticsEurope, 2023). Plastics are widely used because of their many beneficial properties, particularly low cost and durability. As a result, it is estimated that the production of plastics will reach billions of units in the next 30 years (Kaza et al., 2018). The lack of effective implementation of waste management systems in some countries, coupled with the inadequate implementation of existing policies, has resulted in an increase in the amount of plastic waste generated following the utilization of plastics. By 2050, the amount of plastic waste is estimated to be around 12,000 million tonnes creating even more plastic wastes (Barnes et al., 2009). The current technology enables the manufacturing of plastics that are more durable and resistant to biodegradation. Consequently, these materials persist in the environment for extended periods of time (Shah et al., 2008). Plastic pollutants are therefore not only found in terrestrial and freshwater environments, but can also reach the oceans, uninhabited island coastlines, the deep seabed and even the polar regions (Bergmann, Lutz, et al., 2017).

Plastics found in various environments can break down into smaller plastic particles called microplastics (MPs) when exposed to various physical and biological

factors such as light, temperature, mechanical wear and waves. MPs can be formed in nature by the spontaneous degradation of plastics under the influence of various factors but can also be formed by the deliberate production of small plastic particles such as fragments, fibers, beads, films, foams for use in various industrial activities. The physical properties of MPs can vary considerably, including shape, colour and chemical composition (Duis & Coors, 2016). Despite this diversity, there is currently no consensus on a standardized classification system for MPs, and different approaches and classifications can be found in the literature. As ubiquitous contaminants, MPs pose potential threat to environmental ecology and human health and have naturally attracted considerable recent attention from biological and ecological research. MPs entering the aquatic environment can be ingested by organisms, from lower trophic level food chain organisms to predators at the top of the chain (Lusher et al., 2015). If MPs are ingested into the digestive tract, these particles can cause various physiological damage to organisms, such as digestive tract obstruction and injury (Rummel et al., 2016; Tanaka & Takada, 2016). Such effects can negatively affect both the health of individual organisms and the ecosystem balance along the food chain in marine ecosystems. The presence of MPs has been conclusively documented in a range of different environmental matrices, including seas (Cózar et al., 2014), freshwater systems (Wagner et al., 2014), the seabed (Woodall et al., 2014), wastewater treatment plants (Mason et al., 2016) , and sediments (Klein et al., 2015).

Plastics and MPs in the marine environment are very difficult to remove and are transported by various meteorological factors, especially currents, throughout the ocean and to distant regions such as the poles (Mishra et al., 2021). MP deposition in polar regions is caused by a number of different sources, including ocean currents, local shipping activities, sewage and effluent discharges, and landfills. In addition, the melting of glaciers as a result of climate change releases trapped MPs into the environment, increasing pollution. Despite being one of the world's most remote and generally isolated regions, the Arctic contains surprisingly high levels of MPs. Evidence of plastic and MP pollution in Arctic ecosystems has been highlighted by several studies. Research has shown that Arctic surface waters have the highest concentrations of MPs in global comparisons (Cózar et al., 2017). Several studies have confirmed that the amount of litter on the Arctic seabed has increased significantly over the past 20 years (Bergmann et al., 2019; Bergmann, Wirzberger, et al., 2017).

The study by Lusher et al. (2015) holds an important place as the first study on MP pollution in Arctic waters. The study analysed the effects of environmental variables such as temperature, salinity, wind speed and direction, and boat speed on MP density. The results showed that the particles were mostly in the form of fibers, and that they may have come from larger plastic materials in wastewater from local human activities or from coastal areas carried by ocean currents (Lusher et al., 2015). Cozar et al. (2017) reported the presence of high levels of floating plastics in northern and eastern Greenland and the Barents Sea. Bergmann et al. (2016, 2017a, 2017b) recorded floating plastics during observations in the Barents Sea, and found macro- and micro-sized plastics in the deep sediments of Fram Strait (Bergmann et al., 2016; Wirzberger, et al., 2017; Tekman et al., 2017). In addition, Kanhai et al. (2018) detected MP in the subsurface waters of the Arctic Central Basin. In the study, the abundance of MP was analyzed in different layers and depths, and it was reported that the concentration of MP was generally between 0-375 particles/L (La Daana et al., 2018). A study conducted at Columbia University has shown that MPs are transported by snowfall, reaching the most remote regions of the planet (Mishra et al., 2021). Although studies of MPs in Antarctica are limited compared to the studies conducted in the northern hemisphere, MPs were detected in tidal sediments of South Georgia Island (Barnes et al., 2009), deep sediments of the Weddell Sea (Van Cauwenberghe et al., 2013), and surface waters in the Pacific part of the Southern Ocean (Isobe et al., 2017). Isobe et al. (2017), who investigated MP contamination in Southern Ocean, found a total of 44 MPs in samples collected from five points defined as the study area, and reported that MPs could be trapped in the Antarctic polar current (Isobe et al., 2017). In addition, environmental science projects such as Adventure Science (2016) have also reported similar levels of MPs detected in the Southern Ocean as in dense regions of the world's oceans. It was reported that a mean MP concentration of 22 particles/L and a maximum of 117 particles/L in seawater samples from the West Antarctic Peninsula (AdventureScience, 2016). However, Munari et al. (2017) conducted the first study to investigate the presence of MP in sediment samples from different parts of Antarctica. In this study, a total of 1661 particles were detected in 31 sediment samples. Furthermore, while fibers were the dominant form of MP detected in the study, rubber and nylon-type MPs were found to accumulate in high concentrations in samples collected from shorelines (Munari et al., 2017). The average particle concentration was 29.4±4.7 particles/L in 0-2 cm deep snow samples from Ross Island, East Antarctica (up to 20 km from McMurdo and Scott Base). Analyses showed that fibrous MPs made up the majority of the particles in the samples, with the remainder in the form of fragments and films (Aves et al., 2022). Research and evidence show that plastic pollution reaches even the most remote ecosystems. There are still a limited number of studies on MP pollution in the Southern Ocean, and no standard and comparable methodology has been developed.

Antarctica, which is the southernmost part of the world and covers the South Pole, is the coldest continent

in the world. Horseshoe Island is located at the west coast of the Antarctic Peninsula and is an important center for scientific research on the Antarctic continent. Antarctica and other polar regions are areas that require special protection and conservation due to their unique and fragile ecosystems. Although they are geographically remote from human populations, the available scientific evidence points to the presence of MPs in these regions. With the expected environmental changes due to climate change and the opening of new transport routes, human activities in the region are expected to increase. This situation increases the potential for an increase in plastic and thus MP pollution in the region in the future. In this context, it is necessary and urgent to protect polar ecosystems and effectively control sources of pollution.

Horseshoe Island, Antarctica, is an understudied polar region where MPs have been observed but never systematically studied. The first objective of this paper is to describe the current status of MP contamination on Horseshoe Island in Lystad Bay, Antarctica. In this study, the distribution and concentration of MPs in sea surface water (SSW) and seafloor sediment (SED) collected during the Antarctic Expedition TAE-7 (February 2023) as a result of scientific research visits to the area were determined, as well as the classification of MPs in terms of shape, colour, size and polymer type.

Materials and Methods

Study Area

Horseshoe Island, situated to the west of the Antarctic Peninsula, hosts the temporary Turkish Scientific Research Camp, established during the 3rd National Antarctic Science Expedition (TAE-3) in 2019. TÜBİTAK MAM Polar Research Institute continues to work on establishing a permanent base on the island in order to conduct more effective and long-term studies.

The Graham region is the part of the Antarctic continent closest to South America, with the Drake Passage serving as the connecting strait between the two continents. The Antarctic Peninsula is the main route for researchers to access the regions of the continent where scientific activities are conducted. The Graham region is also an important location for tourists from different parts of the world who want to visit Antarctica. Horseshoe Island, measuring 10.5 km in length and 4.8 km in width, is located at the entrance of Square Bay on the west coast of the Graham District in Antarctica. The island was named "Horseshoe" due to its distinctive horseshoe-like shape. SSW and SED samples were collected from Lystad Bay between 13-24 February 2023, during the TAE-7 expedition (Tables 1 and 2).

Sampling and MPs Isolation Procedure

Sea surface water and sediment samples were collected using Zodiac boats of the research vessel Betanzos. The sampling locations are shown in Figure 1. The bathymetric data presented on the Figure 1 were provided by the Hydrography and Oceanography Department of the Turkish Naval Forces. SSW samples were obtained using a manta trawl equipped with a 330 µm mesh size and a rectangular opening measuring 0.3 m by 0.13 m. The Van Veen grab (250 cm^2 gripping area, 20x25x60 cm dimensions and 5.5 kg weight) used to collect bottom sediments at the SED stations is manufactured by Hydrobios and was obtained from the temporary Turkish Science Base.

The manta net was towed for 15 minutes from the starting coordinates at 8 stations listed in Table 1, and the boat speed was maintained below 1 knot during this time. The manta net was towed from the starboard side of the Zodiak boat to avoid contamination by marine debris and waves from the boat. To prevent the manta from being affected by the rudder water and drifting under the boat, the manta was held away from the boat using a claw. After 15 minutes of filtering the surface water with the manta net, the manta net was rinsed with seawater from the outside and the collected sample was concentrated in the collector section. The samples collected in the manta collector were transferred to glass jars, filled with 70% ethyl alcohol solution, sealed with metal jar lids and stored on board at +4°C. The surface water samples collected during the project were taken to the research laboratory in the manta net collectors and the material collected in the collector was first transferred to a metal sieve having 100 µm pore size. The material on the sieve was then transferred to a 500 mL glass beaker and covered with aluminium foil. Meso-sized materials such as feathers in the beakers were separated from the samples by washing with distilled water filtered through glass fiber filter paper (0.7 µm). In order to remove the water contained in the samples transferred to the beakers, the samples were covered with aluminium foil and kept in an oven at 40°C. The drying process took about 5-6 days. The dried material in the beaker was subjected to wet oxidation with hydrogen peroxide. A 20 mL aliquot of a 0.05 M Fe(II) solution, prepared using $FeSO_4 \cdot 7H_2O$, was added to the beaker, followed by the addition of 20 mL of 30% hydrogen peroxide (H_2O_2) (Merck). The beaker was covered with aluminium foil and kept at a constant temperature of 40-45°C, stirred occasionally with a glass rod, and subjected to oxidation. At this stage, no magnetic stirrer was used to prevent further disintegration of the microplastics contained in the samples, and the temperature was prevented from rising above 45°C. If hydrogen gas bubbles were observed during digestion, the beakers were kept at 45°C for a while (about 30 min) and then removed from the heating to prevent bubbles and overflow that could occur during the reaction. If, after the first digestion, it was observed that there was still visible organic matter in the samples, 20 mL of 30% H_2O_2 was added, and the process was repeated until there was no visible organic matter. Once the oxidation process was complete, the

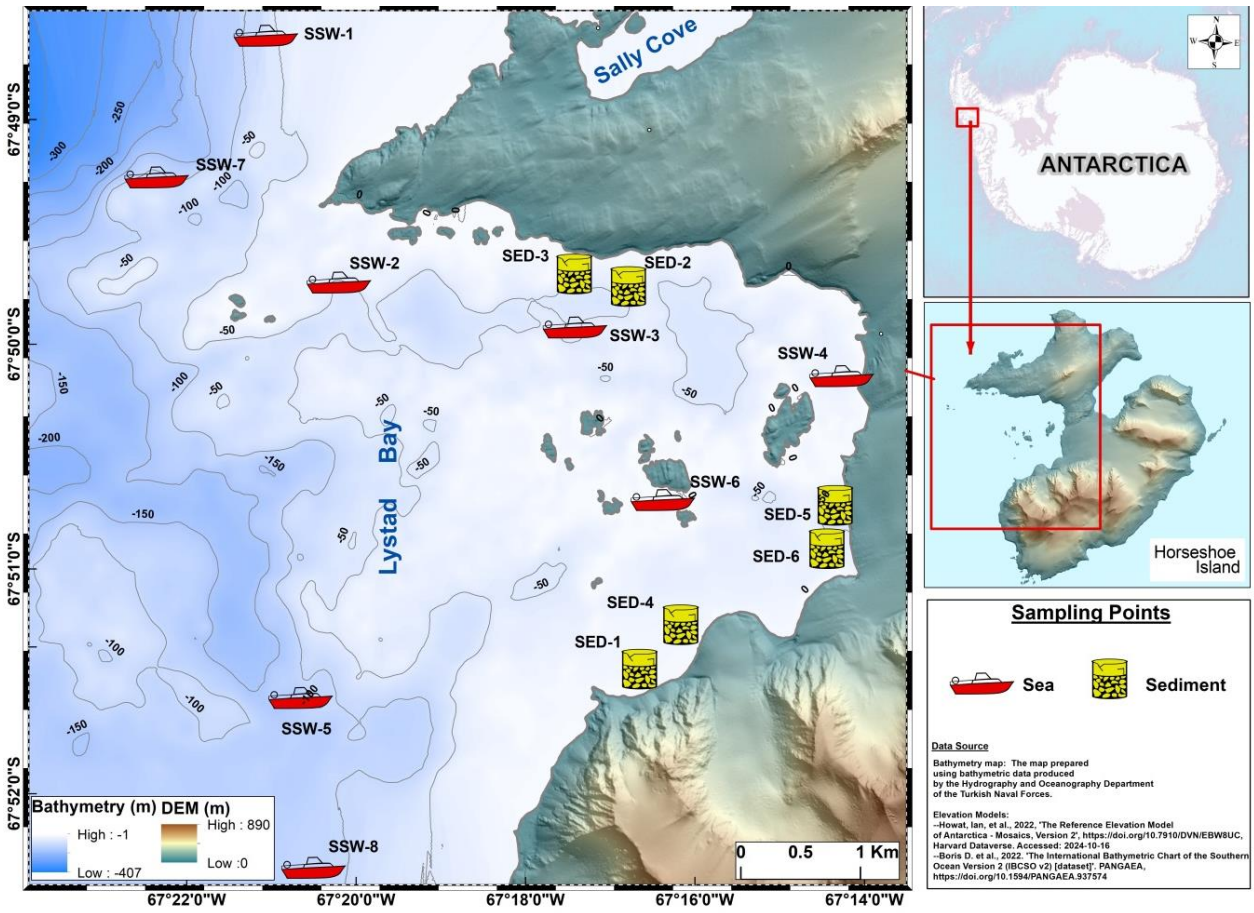


Figure 1. Stations for sampling MPs from surface waster and surface sediments created in ArcGIS 10.4.1.

Table 1. Locations and coordinates of the stations together with the conditions for sampling sea water at the surface (SSW stations)

Station	Sampling date	Start coordinate		End coordinate		Wind speed (m/sn)	Wind direction (°)	Sea water temperature (°C)
		Latitude S	Longitude W	Latitude S	Longitude W			
SSW-1	13.02.2023	67° 48.582′	67° 21.526′	67° 49.424′	67° 22.122′	5.3	68	0.5
SSW-2	13.02.2023	67° 49.665′	67° 20.531′	67° 49.893′	67° 19.474′	5.3	68	0.5
SSW-3	13.02.2023	67° 49.816′	67° 17.725′	67° 49.858′	67° 16.355′	5.3	68	0.3
SSW-4	14.02.2023	67° 49.976′	67° 14.556′	67° 49.729′	67° 14.961′	1.3	235	0.5
SSW-5	14.02.2023	67° 51.522′	67° 20.755′	67° 51.433′	67° 20.184′	1.3	235	0.5
SSW-6	14.02.2023	67° 50.565′	67° 16.594′	67° 50.467′	67° 16.152′	1.3	235	0.5
SSW-7	15.02.2023	67° 49.235′	67° 22.734′	67° 49.499′	67° 22.143′	1.5	179	0.3
SSW-8	15.02.2023	67° 52.275′	67° 20.509′	67° 51.746′	67° 19.846′	1.5	179	0.2

phase of separating microplastics by density difference was started. After wet peroxide oxidation, the residual peroxide in the samples was allowed to evaporate, and then the separation step by density difference was started. Zinc chloride ($ZnCl_2$, Carlo Erba) solution was used at this stage. The $ZnCl_2$ solution, prepared with filtered distilled water at a density of 1.6 g/cm^3, was filtered through glass fiber filter paper (0.7 µm). After adding $ZnCl_2$ to the beakers, the material in the beaker was transferred to separating funnels. After waiting for 24 hours, the solid material collected under the funnel was transferred to the beaker, the supernatant was filtered through 0.7 µm glass-fiber filter paper, and the filter paper was transferred to a glass petri dish and covered. The petri dishes were stored in a dark and cool place until microscopic examination.

Bottom sediment samples were collected with a Van Veen grab from the coordinates listed in Table 2. The bottom sediment samples were placed in glass sample containers and stored in the deep freezer (-20°C) on board until they were taken to the laboratory. Although it was planned to collect bottom sediments from the stations where surface water samples were collected as specified in the project proposal, it was not possible to collect at the specified locations either because the seabed was rocky or too deep. Sediment

Table 2. Locations and coordinates of seafloor sediment sampling stations and depths (SED station)

Station	Sampling date	Coordinate		Total sample weight	Depth (m)
		Latitude S	Longitude W		
SED 1	19.02.2023	67° 51.322′	67° 16.775′	400 g	22
SED 2	19.02.2023	67° 49.622′	67° 17.119′	300 g	27
SED 3	19.02.2023	67° 49.578′	67° 17.764′	50 g	35
SED 4	20.02.2023	67° 51.519′	67° 16.421′	300 g	26
SED 5	20.02.2023	67° 50.552′	67° 14.561′	300 g	38
SED 6	20.02.2023	67° 50.699′	67° 14.232′	300 g	17

samples, stored at -20 °C until analysis, were first thawed at room temperature, then weighed in their wet state, dried at 40-45 °C, and subsequently processed for density separation. In the density difference separation step, $ZnCl_2$ (1.6 g/cm^3) was used as was with the surface water samples, and this step was carried out in 3 stages in the sediment-microplastic separation unit. The isolated microplastics were transferred to glass-fiber filter paper (0.7 µm) and stored in a dark place until microscopic examination.

Microscopic Detection of MPs and Determination of Shape, Size and Colour

MP particles were analyzed using an optical microscope (Olympus CX23 with a ToupTech XP 1050HP digital camera) and a stereomicroscope (Zeiss Stemi 508 with an Axiocam 208 color digital camera) at magnifications ranging from 5x to 10x. The size, color, and shape of the extracted MPs were recorded to characterize their physical properties. The isolated MPs were categorized into two size groups: 0.3–1 mm and 1–5 mm. Based on their type, MPs were classified into five categories: fragments, fibers, films, foams, and granules/pellets. Additionally, their color was categorized as black, white/transparent, red, blue, green, or other.

Sample Preparation for µ-FT-IR Analysis

Samples filtered on GF/C paper were transferred to 250 ml beakers. Distilled water was added to the beakers and kept on the shaker for 30 min to allow the samples to pass into the distilled water. The GF/C papers were removed from the beakers and the samples were prepared for filtration using a filtration device. All possible MP particles were filtered on anodiscs with a diameter of 13 mm and a mesh size of 0.1 µm and then transferred to glass Petri dishes. The samples were kept in an oven at 60°C for 2 hours and prepared for measurement by µ-FT-IR. The dried filters were stored in a dust-free environment until analysis.

The filters were scanned in the imaging mode of the Perkin Elmer FT-IR Spotlight 400 using the Spectrum Image application (optical imaging) and reflectance measurements (chemical imaging) were made over the entire filter surface. The IR spectrum of the 200 µm×200 µm surface in the range 690-4000 cm^{-1} in the 10 mm×10 mm area was scanned with the Spectrum 3 application. The spectra were compiled by applying atmospheric correction, and data processing (microplastic mapping) was performed with the siMPle application (a freeware software developed at Aalborg University (Denmark) and Alfred Wegener Institute (Germany)). Microplastic distribution graphs were generated with the results compiled with the siMPle application.

Quality Assurance and Quality Control (QA/QC)

During the study, all laboratory equipment, apparatus, and surfaces were carefully cleaned with ultrapure distilled water or ethanol to minimize contamination risks. To further mitigate contamination, glass and stainless-steel materials were predominantly used for microplastic isolation and subsequent procedures. Samples were covered with aluminium foil during isolation to prevent exposure to airborne particles. All solutions ($ZnCl_2$, ethanol, H_2O_2 and iron solution) and distilled water used for microplastic isolation were filtered through glass fiber filter paper prior to use. To limit contamination, natural or cotton fiber lab coats and nitrile gloves were worn when necessary. Airborne particles were routinely monitored using Petri dishes containing ultrapure water. The contents of these dishes were filtered, and the particles were counted to evaluate contamination levels, which were subsequently factored into the microplastic results to account for fibrous contaminants from the laboratory environment. Fiberglass filter papers used for particle isolation were examined under a stereomicroscope before use to confirm they were free of contamination, ensuring that only uncontaminated filters were employed for sample isolation.

Results and Discussion

MP Abundance in Sea Surface Water Samples

The abundance of MPs in sea surface water was investigated and is shown in Figure 2. As can be seen from Figure 2a, the particle concentrations were evaluated as particle/m^2 and particle/m^3 and higher particle concentrations were found at stations SSW-5 (0.138 particle/m^2; 2.771 particle/m^3), SSW-6 (0.139 particle/m^2; 2.781 particle/m^3) and SSW-7 (0.135 particle/m^2; 2.697 particle/m^3). The lowest MP

concentrations at SSW stations were recorded at SSW-1 (0.074 particle/m^2; 1.482 particle/m^3 and SSW-3 (0.076 particle/m^2; 1.520 particle/m^3). Mean particle concentrations were calculated as 0.105±0.028 particles/m^2 and 2.110±0.571 particles/m^3 at all SSW stations.

Figure 2b shows the shape distributions of the particles detected at all SSW stations. A total of 203 particles were detected at SSW stations, of which 112 were fiber type (55.44%), 43 were film type (21.29%) and 47 were fragment type (23.28%). While 66.7% of the 36 microplastic particles detected at SSW-1 were fibers, 19.4% were films and 13.9% were fragments (Figure 3a). While 57.1% of the 28 particles detected at SSW-2 were fibers, 35.7% were films and 7.1% were fragments. The distributions at SSW-3 showed a parallel change to SSW-2. The stations with the highest number of fragments were SSW-4, SSW-8 and SSW-5 (42.9%, 39.3% and 38.9%, respectively). At the other stations, fiber-type particles dominated, followed by fragments and film-type particles.

The size distribution of microplastics detected at the SSW stations is shown in Figure 2c. Evaluations were made in 7 different size categories (300-499 µm, 500-999 µm, 1000-1499 µm, 1500-1999 µm, 2000-2499 µm, 2500-4999 µm and >5000 µm), including the pore size of 300 µm and >5000 µm of the horizontal manta net. In these surface water stations, where fiber-type particles dominate, it is noticeable that particles between 500-900 µm are dense (36.02±5.37% on average in all stations). The other most common size range was 1000-1499 µm and the proportion of particles with a size between 1000-1499 µm was 22.01±9.44% in all stations. Although fiber spheres >5000 µm were observed in the SSW samples, the ratio of these particles to all particles was 3.60±1.97%, and no particles of this size were found at SSW-5.

It has been documented that the South Polar Sea surrounding the Antarctic continent is exposed to anthropogenic pollution through ocean and atmospheric currents and circulation, despite being the most remote point of our planet (Bargagli, 2008;

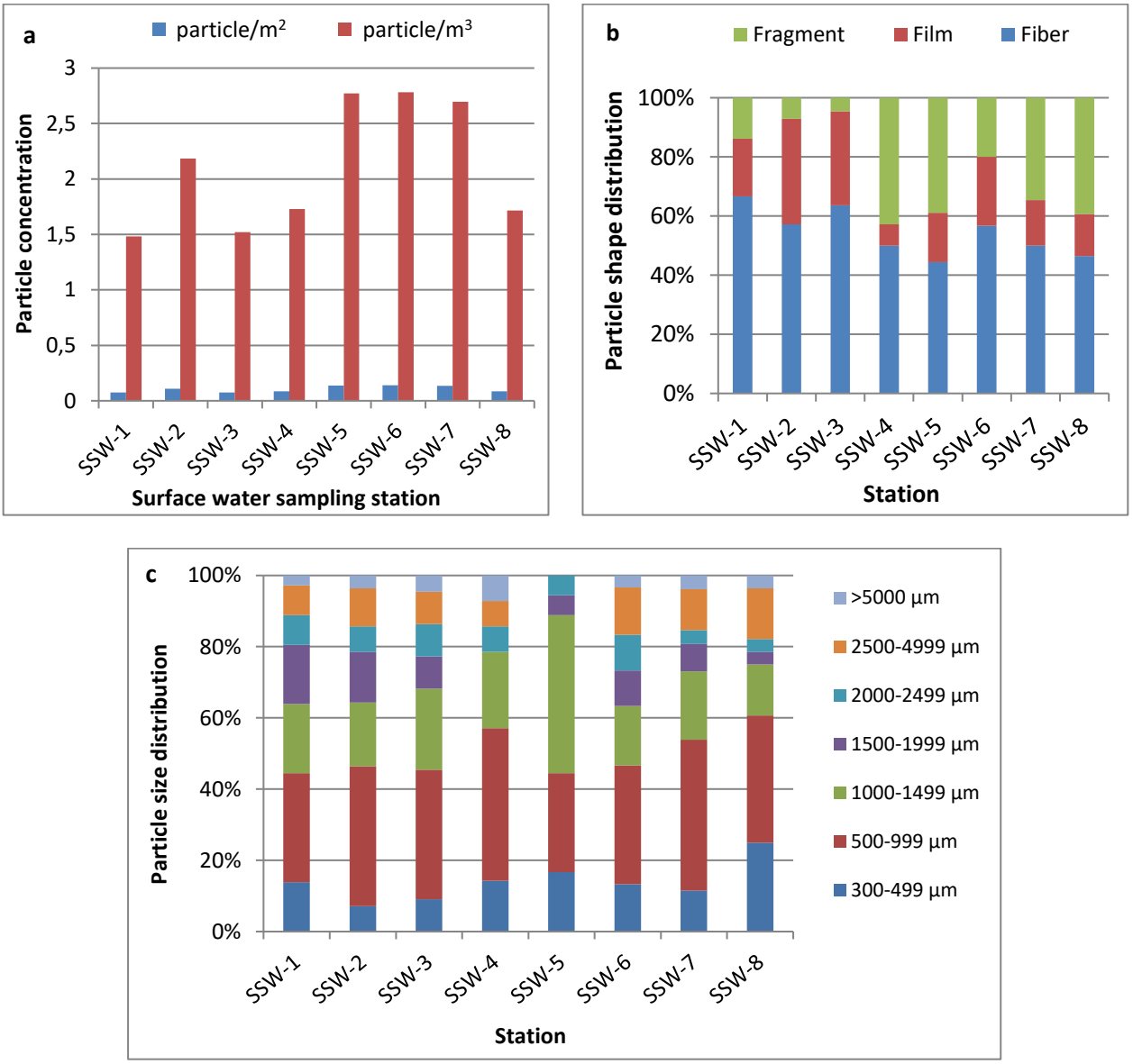


Figure 2. Particle concentration, shape and size distributions in SSW samples.

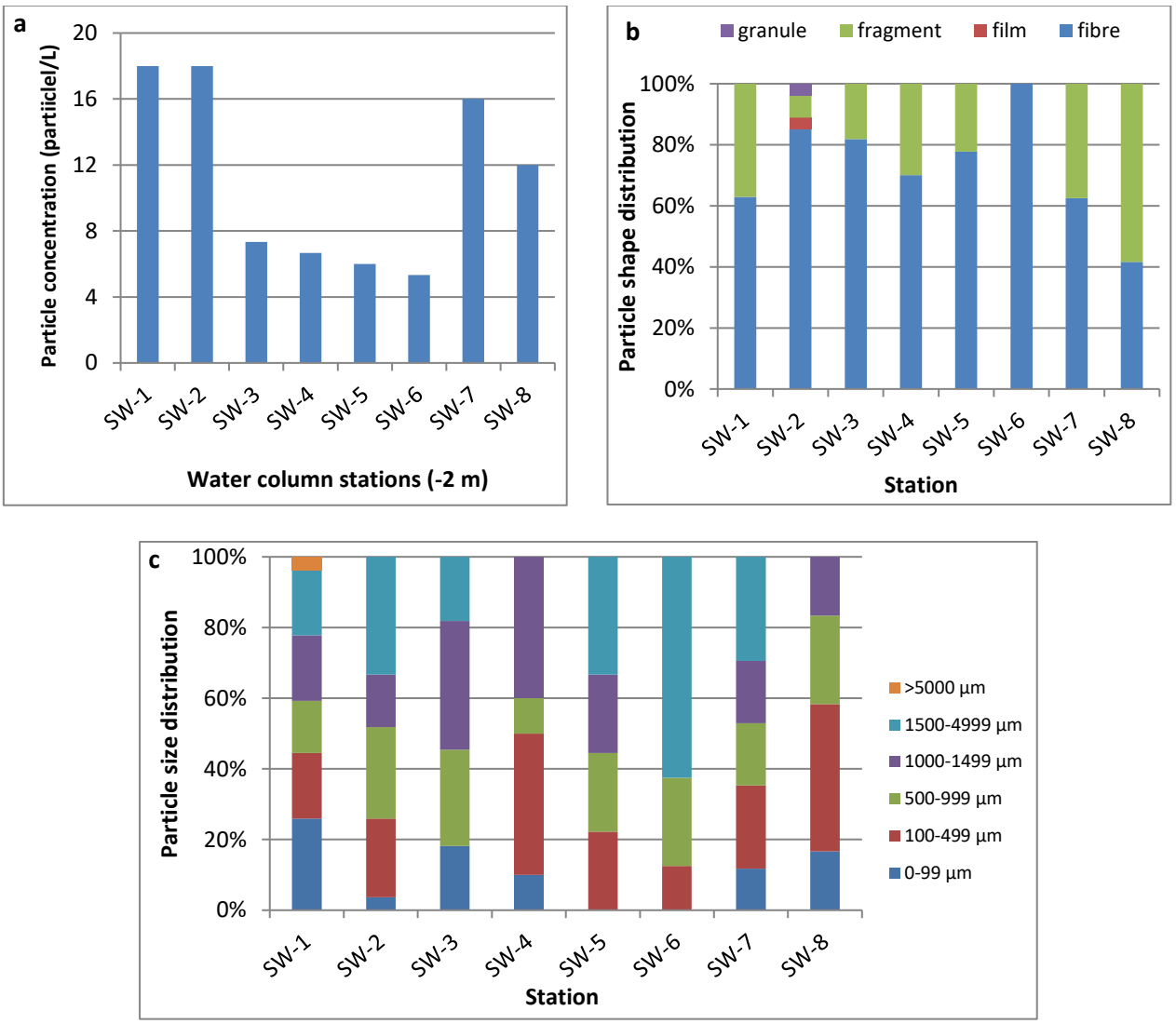


Figure 3. Particle concentration and shape and size distributions in SW samples below in 2 m from surface.

Szopińska et al., 2017). The detection of plastic waste in Antarctica was reported in scientific papers in the 1980s, and several studies highlighted the migration of Antarctic fur seals with discarded plastic waste and the consumption of plastic waste as food by birds native to the Antarctic continent (Bonner & McCann, 1982; van Franeker & Bell, 1988). More than 6000 pieces of plastic waste were found on the coast of Antarctica for six months in 2000-2001, and it has recently been estimated that an average of 1794 pieces/km^2 of plastic waste float around the Antarctic Peninsula (Eriksson et al., 2013; Lacerda et al., 2019a).

Isobe et al. (2017) investigated microplastic pollution in the Southern Ocean. In the study, surface water samples were collected with a Neuston net from 5 selected stations between Antarctica and Australia. During the study, wind speed and wave height were measured and recorded hourly. Sampling time was 20-40 minutes at each station by towing the Neuston net at a speed of 2-3 knots. It was reported that 44 pieces of microplastics were collected at all stations and 38 microplastics were detected at the stations closest to Antarctica. The microplastics detected at these two stations closest to Antarctica were estimated to be at the level of 100,000 pieces/km^2 (Isobe et al., 2017). It has also been reported that microplastics can be trapped in the Antarctic polar current south of the polar front in the Southern Ocean (Isobe et al., 2017). The concentrations of microplastics found in sea surface water samples from other studies conducted in the region are presented in Table 3.

MP Abundance in Seawater 2 m Below the Surface

The particle abundance at the SW stations at 2 m below the sea surface is shown in Figure 3a. A total of 120 particles predicted to be plastic were detected at these stations, of which 86 were fibers, 32 fragments, 1 film and 1 granule. The highest number of particles was found at stations SSW-1 and SSW-2 with 27 pieces, while the lowest number of particles was found at station SW-6 with 8 pieces. The mean particle concentration at SW stations was 11.2±5.5 particles/L, the highest particle concentration was 18 particles/L at SW-1 and SW-2

stations, while the lowest particle concentration was 5.33 particles/L at SW-6 station.

The distribution of particle shapes at the SW stations is shown in Figure 3b. As shown, the most common particle shapes were fibers (72.73±17.64%), fragments (26.33±18.56%), films (3.70%) and granules (3.70%). At station SW-6, all the particles detected were of the fiber type. In contrast, at station SW-8, fibers accounted for 41.67% and fragments for 58.34%, making SW-8 the only station where fragments were dominant. Film and granular particles were found only at the SW-2 station.

Size distributions at SW stations were analysed in 6 size categories as 0-99 µm, 100-499 µm, 500-999 µm, 1000-1499 µm, 1500-4999 µm and >5000 µm (Figure 3c). The mean particle size distribution for all stations was 24.41±20.35% for particles with a size of 1500-4999 µm and 22.58±13.61% for particles with a size of 100- 499 µm. The percentages of 500-999 µm and 1000-1499 µm particles were 20.98±6.18% and 20.78±12.61%, respectively. While no particles between 0 and 99 µm were detected at stations SW-5 and SW-6, fibrous particles >5000 µm were detected only at station SW-1. As shown in Figure 3c, fragment type particles were generally detected in the size ranges 0-99 µm, 100-499 µm, 500-999 µm.

Cincinelli et al. (2017) conducted a microplastic survey in the waters of the Ross Sea, Antarctica. Microplastics ranging from 0.0032 to 1.18 pieces/m^3 were detected in samples collected with a pump 5 m below the surface at 15 selected stations along the Ross Sea coast and offshore. The study found that the average concentration of microplastics was 0.17±0.34 pieces/m3 and emphasised that this result was low compared to the microplastics found in the oceans worldwide (Cincinelli et al., 2017). In the study conducted by Grover-Johnson (2018), a concentration of 0.001-0.154 particles/m^3 was determined by visual analysis in seawater collected 10 m below the surface in the Ross Sea and East Antarctic region (Grover-Johnson, 2018). In the study conducted by Zhang et al. (2022) in subsurface water, the mean microplastic abundance in subsurface water was found to be 1.66±1.20 substances/m^3, with the highest abundance observed in the Dumont d'Urville Sea (Zhang et al., 2022).

Abundance of MPs in Surface Sediment Samples

In the study, surface sediment samples were collected at 6 different stations and the particle concentrations detected after the oxidation and density separation step are presented in Table 4 and Figure 4.

Table 3. Particle concentrations detected in Antarctic surface waters at different locations

Study area	Average particle concentration	Dominant Shape	Dominant Colour	Dominant Size	Dominant polymer type	Reference
West Antarctic Peninsula	246500±175000 particle/km^2	-	-	0.33-4.75 mm	-	(Eriksen et al., 2014)
Antarctic Peninsula	1.794 item/km^2 (max-3524, min-755) items/km^2	Fragment (%51,3)	White, black	<5 mm (%54), >5-20 mm (%46)	Polyurethane, polyamide and polyethylene PU, PA, PE, PS and PP	(Lacerda et al., 2019b)
Ross Sea	0,10±0,14 particle/m^3	Fiber (%98,9)	-	2.0-2.5 mm (2.50±1.11 mm)	Polyester (PET) (%87,3)	(Zhang et al., 2022)
Ross Sea, Antarctica 2010	MP ranged 0.0032 to 1.18 particle/m^3 of seawater (mean 0.17±0.34 particle/m^3)	Fragment (71.9%)	Red and blue	300 to 1000 µm	PE and PP were the dominant, followed by PES, PTFE, Polymethyl Methacrylate and PA	(Cincinelli et al., 2017)
East Antarctica	0.17±0.34 particle/m^3	Fragment (%72)	-	>60 µm	-	(Leistenschneider et al., 2021)
South Georgia and West Antarctic Peninsula	15.4±8 particle/L	-	-	0.1-9.6 mm	-	(Barrows et al., 2018)
Southern Ocean (at five stations), 2016	Station 1: 9.9×10^{-2}; Station 2: 4.6×10^{-2} (nearest Antarctica); Mean 3.2×10^{-2} (pieces/m^3)	Fragment	-	<5 mm	PE, PP	(Isobe et al., 2017)
Antarctic continent 2016–2017	5.7 items/L (mean value all around the Antarctic continent)	Fragment (90%)	White	3.03±2.81 mm	PE, PP, PS, PVC, nylon and PMMA	(Suaria et al., 2020)
Admiralty Bay, King George Island, XXIX Brazilian Antarctic Expedition (2010−2011)	2.40 (±4.57) microfibers/100 m^3 (603 microfibers in 60 samples)	Fiber	Transparent black, red, and blue	2 to 5 mm	Polyethyleneglycols, PU, PET and PA	(Absher et al., 2019)
Horseshoe Island in Marquerite Bay, Antarctica	0.1055±0.0285 particle/m^2 2.1102±0.5707 particle/m^3	Fiber (55.44%)	Black, blue	500-999 µm and 1000-1499 µm	PE (31.8%), PA (20.8%), Polyisopyrene (11.4%), PE (5.2%)	This study

As shown in Figure 4a, the highest particle concentration in sediment samples was 22.91±10.75 particles/g-DW at station SED-3, while the lowest particle concentration was 0.49±0.10 particles/g-DW at station SED-4. High particle concentrations can be attributed to the relatively limited sample quantity that could be collected at station SED-3. The mean particle concentration at all other stations except station SED-3 was 0.98±0.30 particles/g-DW. In terms of particle shape, 100% fiber-type particles were detected in samples SED-1, SED-3, SED-5 and SED-6, while 94.44±7.86% fibre and 5.56±7.86% film-type particles were observed in station SED-2 (Figure 4b). In station SED-4, these percentages were found to be 86.61±1.26%, 6.25±8.84% and 7.14±10.10%, respectively. The predominance of fibrous particles in all stations parallel to the sea surface water of Lystad Bay shows that the polar region is also polluted with fibrous particles.

Figure 4c shows the size distribution of the particles detected in the sediment samples. The analysis revealed that no particles with a diameter of < 99 µm were present in any of the samples. The ranges of size distributions obtained from the results of the isolation and particle observations performed in duplicate vary, and this is reflected in the standard deviations of the mean data. It is observed that the most dominant particle size range in sediment samples is 1500-4999 µm in all stations except station SED-6, while the most dominant size range in station SED-6 is 500-999 µm. Considering that fiber-type particles are dominant in the sediment stations, it can be said that long fibers are effective in the size distributions.

The particle concentrations identified in polar and Antarctic sediments from studies reported in the literature are summarized in Table 5. Munari et al. (2017) analyzed 31 sediment samples collected from 11 stations in Terra Nova Bay (Ross Sea, Antarctica), and plastics were detected in all samples. A total of 1661 pieces of debris (weighing 3.14 g) were recorded. The plastic concentrations ranged from 5 to 1705 fragments/m². Plastic particle sizes varied between 0.3 and 22 mm, with microplastics classified as particles smaller than 5 mm. The most prevalent particle size was 2–3 mm (Munari et al., 2017). The samples contained fibers, films, and fragments of various colors, suggesting that the particles originated from multiple sources, including the breakdown of larger plastic objects.

The highest abundance of plastics, both in terms of number and weight, was observed in sample RB25, with values of 676.5±536.4 debris/m² and 3.03±2.85 g/m², respectively. Conversely, the lowest mean values were recorded in sample AC25, with 12.83±12.04 debris/m² and 0.004±0.006 g/m². Numerically, fibers were the most common shape (42.8%), followed by films (35%) and fragments (22.2%). Microplastics were significantly more prevalent than mesoplastics and macro debris. The frequency distribution indicated that microplastics constituted 78.4% of the total debris, mesoplastics accounted for 19.9%, and macro debris for 1.7%.

FT-IR spectroscopy identified nine polymer types within the samples: polyethylene (PE), polypropylene (PP), nylon 6,6 (nylon), polystyrene butadiene styrene (SBS), polyvinyl chloride (PVC), polystyrene (PS), thermoplastic polyurethane (TPU), polyvinyl alcohol (PVA), and ethylene propylene rubber (EPR). The predominant polymer type varied with location. For instance, SBS was most abundant near Mario Zucchelli Base (e.g., SMZ25, RB25), whereas remote areas, such as Adelie Bay, exhibited different polymer compositions (Munari et al., 2017).

Cunningham et al. (2020) sampled 30 deep-sea sediments from the Antarctic and Southern Ocean regions with sediment cores and analyzed microplastics. Microplastic contamination was identified in 93% (28 out of 30) of the sediment cores analyzed. The average (± standard error) microplastic concentrations per gram of sediment were 1.30±0.51 MP/g for the Antarctic Peninsula, 1.09±0.22 MP/g for the South Sandwich Islands, and 1.04±0.39 MP/g for South Georgia (Cunningham et al., 2020). The accumulation of microplastic fragments is significantly correlated with the percentage of clay in the cores, suggesting that microplastics have similar dispersal behavior to low-density sediments. Although there were no differences in microplastic abundance between regions, levels were much higher than in less remote ecosystems, suggesting that the Antarctic and Southern Ocean deep sea accumulates more microplastic debris than previously thought. Fragments were the most common particle found, accounting for 56 percent (82/147) of the total microplastics. Fibers and films made up the rest of the particles found, with 39% (57/147) and 5% (8/147), respectively. The µ-FT-IR analysis identified seven different polymer types: polyester (PEst, including alkyd), polypropylene (PP), polystyrene (PS), polyurethane (PU), polyvinyl chloride (PVC), rubber (TPE), and acrylic polymers. Polyester, particularly in the form of colored fibers such as blue fragments, was the predominant microplastic detected in this study. Blue polyester fragments were present in 35% (32 out of 90) of the total sediment subsamples, with polyester overall constituting 59% (17 out of 29) of the microplastic subsamples identified across three sites (Cunningham et al., 2020). Perfetti-Bolaño et al. (2022) investigated the occurrence of MPs in surface soils and tidal sediments along the coast of Fildes Bay (ASPA No. 125; King George Island), which hosts six permanent Antarctic stations and an airport that is the main logistic center for the Antarctic Peninsula. The highest abundance of MPs was found in soil (mostly fragments 20-500 µm long, with an average sample concentration of 0.272 items/mL), while tidal sediments were dominated by fibers (500-2000 µm long; 0.03 items mL-1 sample). A plastic fiber was also detected in a sediment sample from Ardley Island, an ASPA with no permanent human settlements and only two occasional shelters (Perfetti-Bolaño et al., 2022).

Table 4. The concentration of particles in the sediment samples in terms of wet weight and dry weight.

Station	Repetitions	Wet weight (g)	Dry weight (g)	Particle (item)	Particle/g-wet weight (WW)	Particle/g-dry weight (DW)	Fiber (%)	Film (%)	Fragment (%)	100-499 µm	500-999 µm	1000-1499 µm	1500-4999 µm	>5000 µm
SED-1	1	15.3371	11.8242	12	0.78	1.01	100	0	0	0.00	33.33	25.00	33.33	8.33
	2	15.5454	12.3282	12	0.77	0.97	100	0	0	0.00	33.33	33.33	33.33	0.00
SED-2	1	15.8977	9.7841	9	0.57	0.92	88.9	11.1	0	11.11	0.00	22.22	55.56	11.11
	2	16.1564	10.1432	11	0.68	1.08	100	0	0	0.00	18.18	45.45	36.36	0.00
SED-3	1	0.8286	0.4915	1	1.21	2.03	100	0	0	0.00	20.00	13.33	60.00	6.67
	2	1.3503	0.8492	1	0.74	4.07	100	0	0	7.69	30.77	23.08	38.46	0.00
SED-4	1	20.1134	16.7425	7	0.35	0.42	85.7	0	14.3	14.29	28.57	14.29	42.86	0.00
	2	19.7748	14.3385	8	0.40	0.56	87.5	0	12.5	12.50	0.00	50.00	37.50	0.00
SED-5	1	21.9713	7.721	11	0.50	1.42	100	0	0	18.18	9.09	36.36	36.36	0.00
	2	26.5734	17.0887	10	0.38	0.59	100	0	0	10.00	10.00	40.00	40.00	0.00
SED-6	1	25.0973	18.6447	12	0.48	0.64	100	0	0	8.33	58.33	25.00	8.33	0.00
	2	27.7555	21.0015	10	0.36	0.48	100	0	0	10.00	30.00	10.00	50.00	0.00

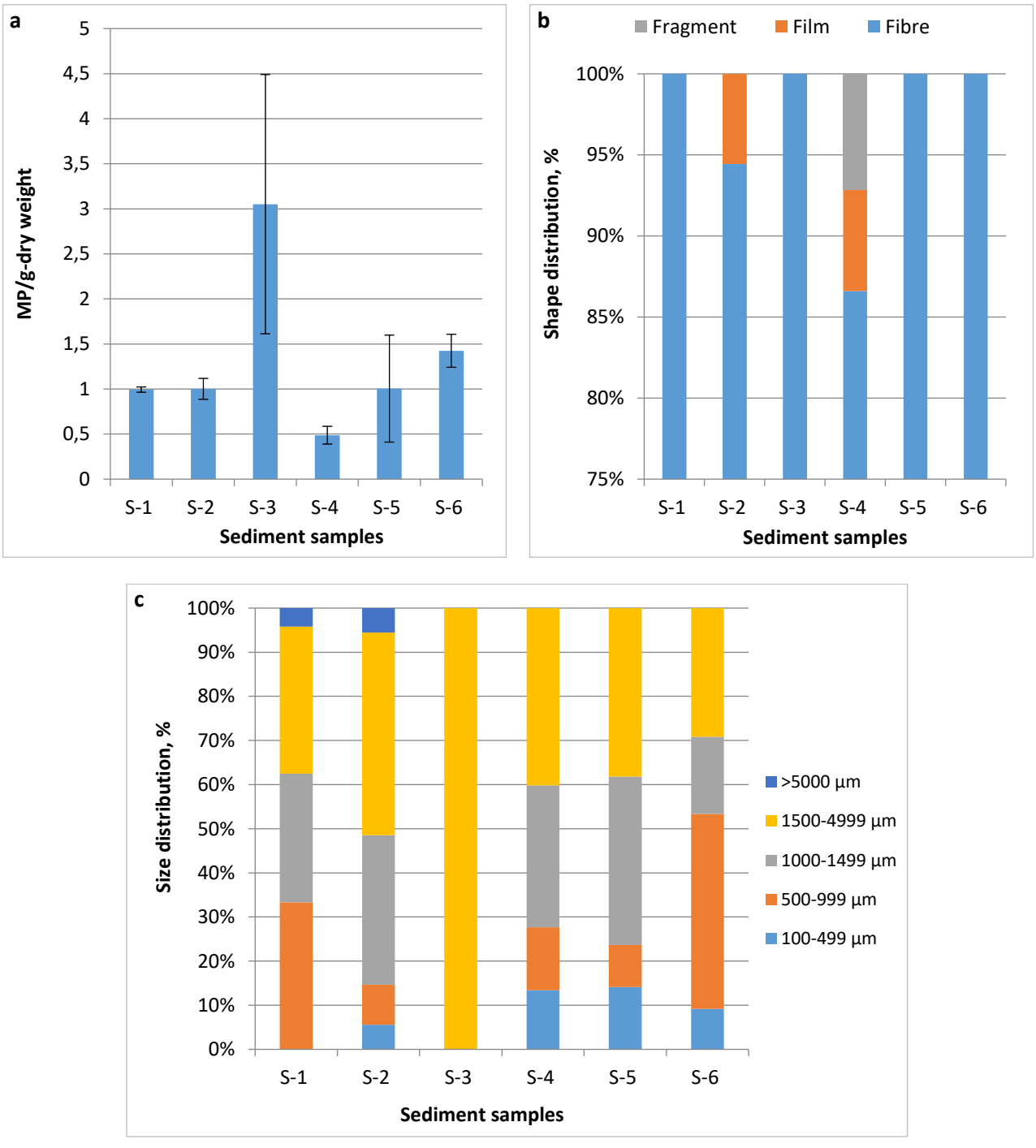


Figure 4. Particle concentration and shape and size distributions in SED samples.

Table 5. Particle concentrations detected in Antarctic seafloor sediments at different locations

Study area	Equipment and depth	Average particle concentration	Dominant Shape	Dominant size	Polymer type	Reference
Antarctic Peninsula	OKTOPUS multicores, 499-1246 m	1.30±0.51 particle/g	Fragment, 56%, fiber 39%, film 5%	30.52 ± 3.53 µm	7 different polymer types (polyesters PP, PS, polyurethane (PU), PVC, rubber (TPE), and acrylic polymers (AP)	(Cunningham et al., 2020)
South Georgia	OKTOPUS multicores, 201-3633 m	1.04±0.39 particle/g	Fragment, 56%, fiber 39%, film 5%	24.82 ± 1.61 µm	7 different polymer types (polyesters PP, PS, polyurethane (PU), PVC, rubber (TPE), and acrylic polymers (AP)	(Cunningham et al., 2020)
South Sanwich Islands	OKTOPUS multicores, 1619- 3342 m	1.09±0.22 particle/g	Fragment 56%, fiber 39%, film 5%	30.71 ± 1.44 µm	7 different polymer types (polyesters PP, PS, polyurethane (PU), PVC, rubber (TPE), and acrylic polymers (AP)	(Cunningham et al., 2020)
King George Island (South Shetlands)	Van Veen grab and SCUBA sampling, 6-60 m	16-766 particle/m^2	Fragment and fiber	1-23 mm, most common size 1-2 mm	-	(Waller et al., 2017)
Terra Nova Bay (Ross Sea)	Van Veen grab, 25-140 m	5-1705 particle/m^2	Fiber (42.8%), film (35%) and fragment (22.2%)	0,3-22 mm (78.4%'i 5 mm altı), the most common size being 2–3 mm	9 different polymers, most common styrene-butadiene-styrene copolymer (SBS) nylon and polyethylene	(Munari et al., 2017)
Terra Nova Bay (Ross Sea), 30th Antarctic Expedition (PNRA, Italian Research Program in Antarctica)	Sediment samples (12 sp. Benthic macro-invertebrates were extracted)	0.7 items/mg (for all species and areas)	Circular	33 to 1000 µm	13 categories of polymers; dominant polymers were polyphthalamide, PA	(Sfriso et al., 2020)
Rothera Point included North Cove, Cheshire Island (c. 200 m from the station wharf) and South Cove	Boxcore, Divers used new sterile 500 ml bottles to take arc-shaped samples of the upper ~3 cm of marine sediment.	0-9 particles/10 mL (widespread <5 particle/10 mL)	fiber	2–5 mm in maximal length and <0.1 mm in diameter	-	(Reed et al., 2018)
United Kingdom's Rothera Research Station, Rothera Point, Adelaide Island	Marine sediment samples	31 MP particles	Fiber	2 to 5 mm	Rayon, most common (comprised 42% of all)	(Reed et al., 2018)
Fildes Bay, King George Island	In soil intertidal sediments	fragments average of 13.6 particles/50 mL in soil, no fragments, fiber abundance of 1.5 particles/50 mL in sediments	fibers (length: 500–2,000 µm), fragments (length: 20–500 µm)	-	the fibers had different colors and were composed of polyethylene terephthalate (PET)	(Perfetti-Bolaño et al., 2022)
Six sites: Atlantic Ocean (3) 3 others	Sediments (depth from 1176 to 4844m)	An average 0.5 microplastics per 25 cm^2 (top sediment); five microplastics from the deep-sea sediment	İrregular shapes	5 to 161 µm	-	(Van Cauwenberghe et al., 2013)
Horseshoe Island in Marquerite Bay, Antarctica	Van Veen grab 250 cm^2 gripping area, 20x25x60 cm dimensions and 5.5 kg weight (17-38 m)	1.328± 0.895particle/g-DW	Fibers	1000-1499 (39.3%), 500-999 (28.2%), 100-499 (22.6%)	6 different polymers, most PC (52.3%), POM (21.5%)	This study

Polymer Characterization of Detected MPs

The chemical characterization of the particles detected in sea surface water, 2 m below the surface and in surface sediment samples was performed by µ-FT-IR analysis. The polymer distributions and spectra obtained are shown in Figures 5, 6 and 7. µ-FT-IR analysis showed that PP (29.92%), PA (20.27%), polyisopyrene (10.82%), PE (4.33%), PVC (3.93%) and PEBA (0.19%) were found in SSW stations, corresponding to 70.27% microplastics in all particles analyzed. The percentage of Mater-Bi was found to be 2.75, and the rest of the particles contained stearate (7.68%), stearate+glyceride (1.81%), $CaCO_3$ (0.20%), resin (2.75%), protein (0.20%), unknown-1 particles (2.36%) and unknown-2 particles (12.60%) respectively in surface water samples collected from SSW stations. In addition, PP was found to be the dominant particle type at all SSW stations except SSW-7 and SSW-8 (Figure 5a). At stations SSW-7 and SSW-8, PA was found to be dominant (40.82% and 56%).

In the sediment samples, 41.88% PS, 28.52% polycarbonate (PC), 15.52% polyoximethilene (POM), 6.32% PE, 3.79% PNEU and 0.54% PU were found in all particles analysed by µ-FT-IR (Figure 5b). Although a higher percentage of PS was found for all the particles analysed, it was only at the SED-2 station that PS particles were found. On the other hand, PC was the dominant particle at all stations except SED-2, where none of this type of particle was detected. Another dominant particle type was POM (15.52%) found in all 554 particles analysed at all sediment stations except SED-2. As can be seen in Figure 5b station-based analysis, only PC (53.49%), POM (30.23%) and PNEU (16.28%) types were found, while in SED-2 station PS (86.24%), PE (13.01%) and protein (0.74%) were determined.

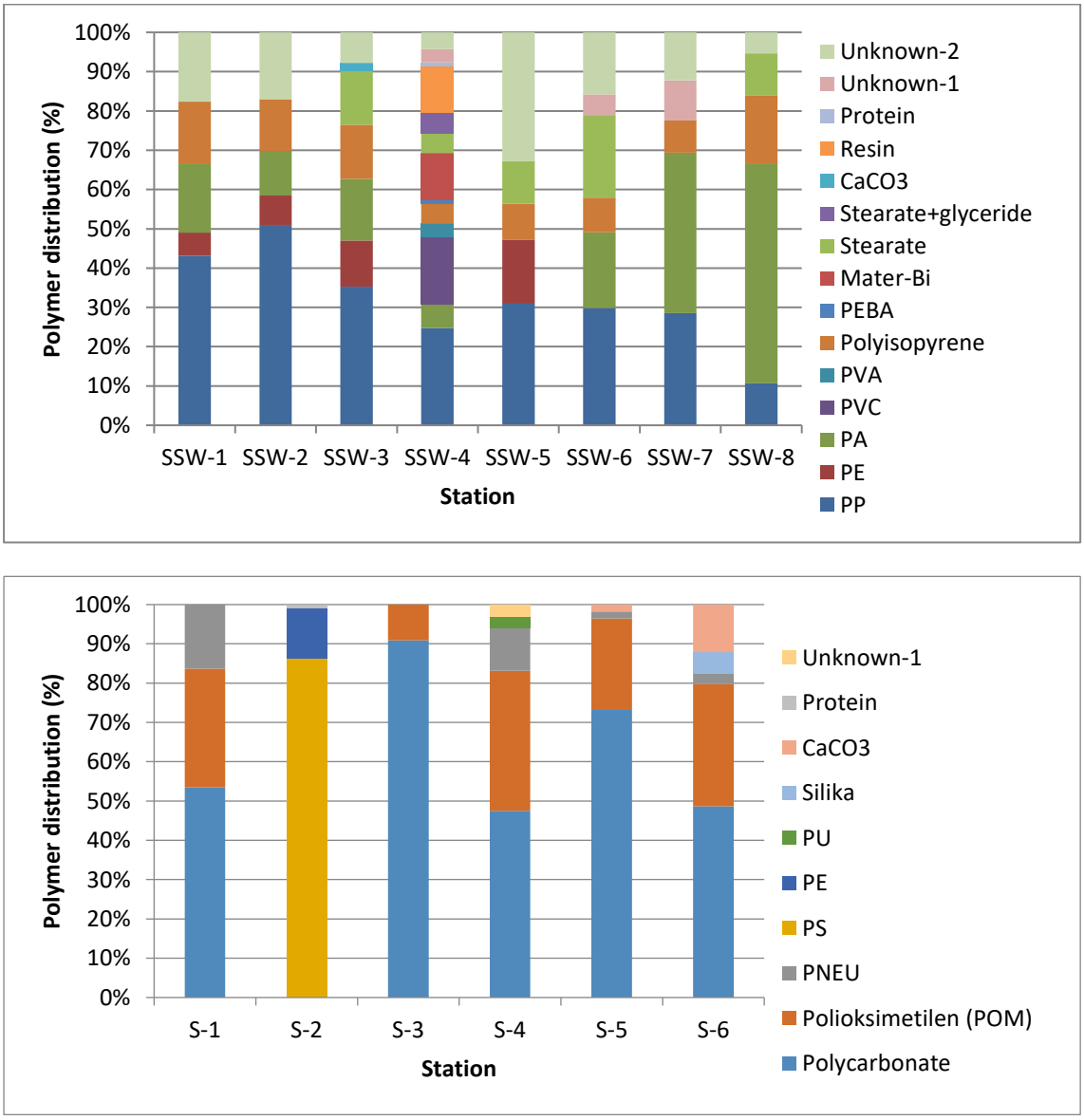
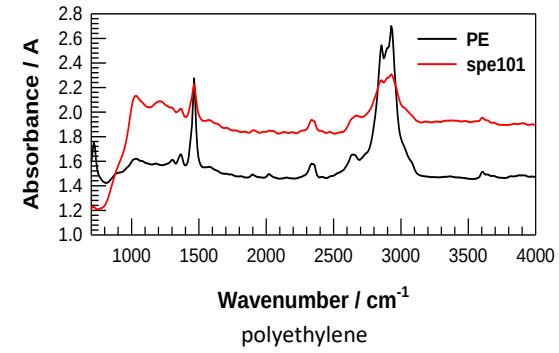
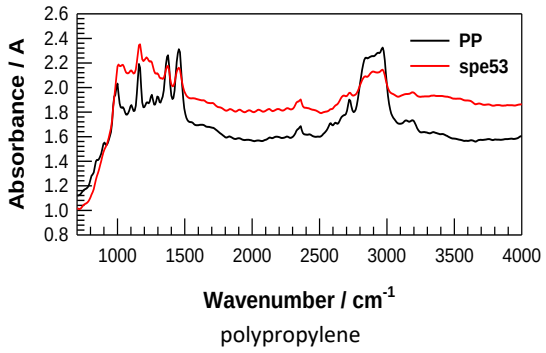


Figure 5. Polymer type distributions of particles detected in SSW and SED samples.



polyethylene



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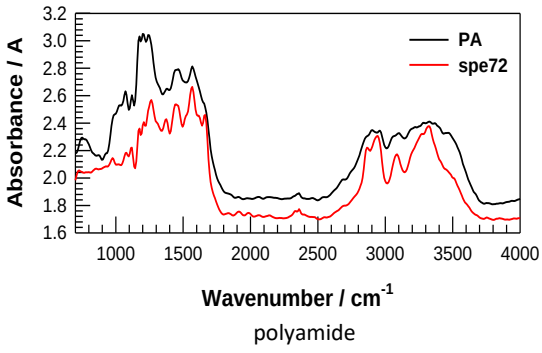
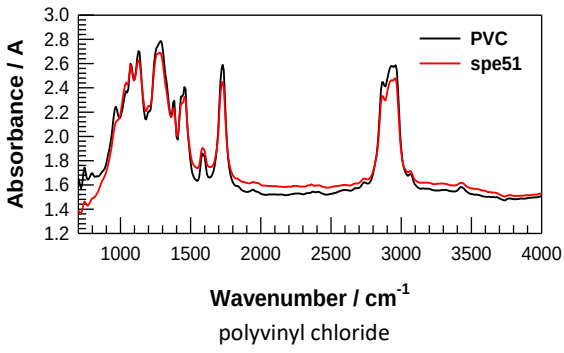
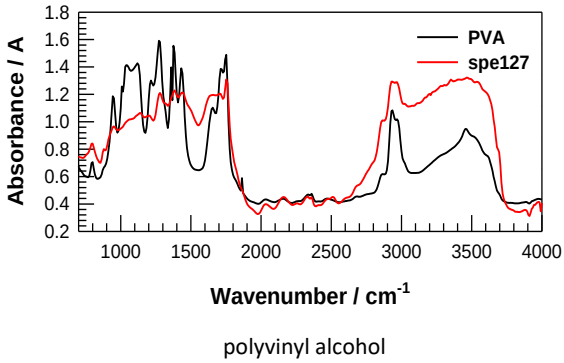


polyamide



polyvinyl chloride



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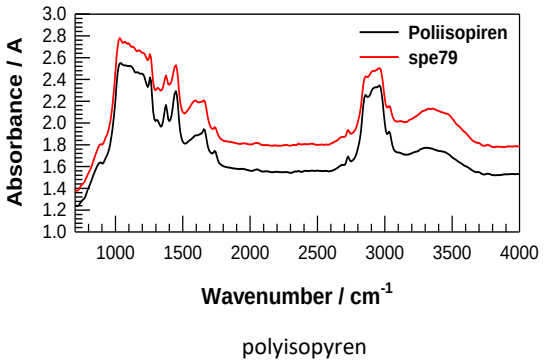
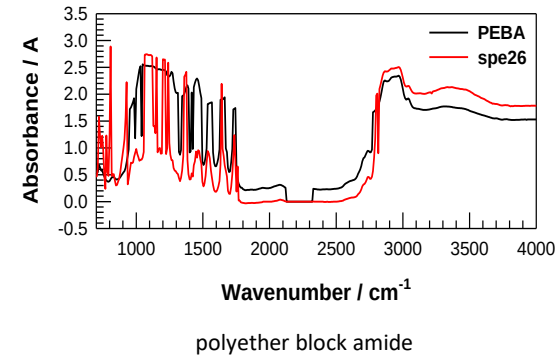
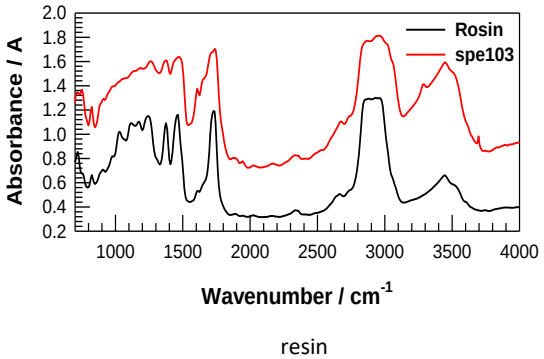


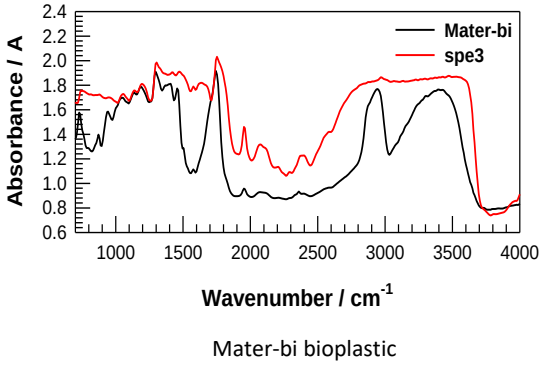
polyisopyren



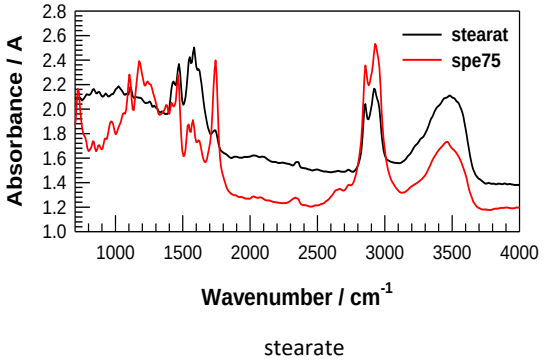
polyether block amide



resin



Mater-bi bioplastic



stearate

Figure 6. Comparing reference and sample spectra in SSW samples used in Spectrum 3 application and sample.

Figure 7. Comparing reference and sample spectra in SED samples used in Spectrum 3 application and sample.

Conclusions

This study provides valuable insights into microplastic pollution around Horseshoe Island in Lystad Bay, Antarctica, one of the most remote and isolated regions on Earth. Analysis of SSW, SW and SED samples clearly shows that Horseshoe Island is exposed to microplastic pollution. Fibres (54.4% for SSW samples and 96.84% for SED samples) were the predominant forms, with PP (31.77%), PA (20.84%) at SSW stations, PC (52.30%) and POM (21.54%) at SED stations being the most commonly detected polymers. These findings highlight that even pristine regions such as Antarctica are not immune to anthropogenic pollution and emphasize the role of oceanic and atmospheric transport in spreading pollutants far beyond urban areas and into remote zones. To gain a better understanding of microplastic pollution in Antarctica, it is imperative to implement comprehensive and sustained monitoring initiatives. These efforts should include not only surface waters and sediments, but also deeper water layers and ice formations. International cooperation is essential to prevent microplastic pollution in remote regions such as Antarctica. Stricter regulations can be implemented to reduce the contribution of microplastics from tourism and research expeditions.

Ethical Statement

The research carried out did not involve human or animal subjects and did not raise any ethical concerns requiring approval.

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Author Contribution

First Author: Data Curation, Formal Analysis, Methodology, Visualization and Writing-original draft: Second Author: Conceptualization, Methodology, Writing- original draft and editing; Third Author: Methodology and Visualization; and Fourth Author: Conceptualization, Fund provider, Supervision, Writing-review and editing.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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