



Quantification and distribution of marine microdebris in the surface waters of Livingston Island (South Shetland Islands, Antarctica)

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ABSTRACT

Microdebris are ubiquitous and the Southern Ocean is no exception. Despite the recent increment in Antarctic studies assessing this threat, there is still scarce information available. Here, we quantified the microdebris in surface water, and their distribution within two bays of Livingston Island (South Shetlands, Antarctica). The two studied bays included one with human presence and one pristine, barely visited. Microdebris pollution was found in all samples with a mean concentration of 0.264 ± 0.185 items/m³. Fibres (82.19 %) were the main item, with polyester (61.67 %) as the main plastic polymer, followed by nylon (29.54 %). No differences in the distribution pattern were observed, with microdebris being homogeneously distributed along the two bays. Our results suggest that nearshore waters of Livingston Island are prone to the accumulation and retention of microdebris. The composition of the microdebris also points to Antarctic local activities as principal contamination contributors.

1. Introduction

Marine microdebris (MD, <5 mm), encompasses a wide range of synthetic, semi-synthetic and naturally-derived objects (Kroon et al., 2018). This type of debris is prevalent worldwide, and the Southern Ocean is not exempt from its presence (Tirelli et al., 2022; Caruso et al., 2022). Despite being one of the remotest regions on earth, with relatively little human presence, evidence of pollution in both abiotic and biotic matrices has been reported, particularly in the last decades (Barnes et al., 2009; Waller et al., 2017; Tirelli et al., 2022; Rota et al., 2022). Among marine debris, microplastics are getting the most attention, especially in Antarctic surface waters (Rota et al., 2022). Nevertheless, to contribute to a more realistic assessment of the potential ecological impacts of marine MD it is important to accurately characterize and describe all its components, and not just plastics. This is evidenced by recent reports indicating that non-plastic items may constitute a considerable proportion of the total amount of pollution (Barrows et al., 2018; Kroon et al., 2018; Suaria et al., 2020a).

Microdebris suppose a threat to the ecosystem and its wildlife. Ingestion may result in physical and chemical hazards, hampering feeding, reproduction, and survival rates (Li et al., 2016). So far, in

Antarctica, microplastics have been found in a wide range of organisms such as benthic invertebrate fauna (Sfriso et al., 2020; Unpublished data from the authors), planktonic species like Antarctic krill (*Euphausia superba*) and salps (*Salpa thompsoni*; Dawson et al., 2018; Wilkie Johnston et al., 2023), and predators like penguins (Bessa et al., 2019; Le Guen et al., 2020; Fragão et al., 2021). Local activities, such as tourism, fisheries, the presence of military forces, and research stations, are considered the main sources of contamination in Antarctic waters (Caruso et al., 2022). There is also evidence of northern-southern MD dispersal since the Antarctic Circumpolar Current (ACC) which limits the Southern Ocean does not act as a barrier as previously thought (Caruso et al., 2022; Rota et al., 2022). Furthermore, air masses and wind may contribute to long-range transport (Waller et al., 2017; Cunningham et al., 2020, 2022). Once MD are south of the ACC, they are probably trapped around the continent, especially in the Antarctic Peninsula, due to multiple transportation systems as well as sea ice retention (Lacerda et al., 2019; Cunningham et al., 2020, 2022).

Current MD reports in the Southern Ocean are scarce and patchy, resulting in the absence of a holistic view, particularly when it comes to fully understanding the extent of microplastic pollution in the surface waters of the Antarctic region (Tirelli et al., 2022; Rota et al., 2022).

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Despite surface water is one of the main studied debris compartments, most studies have focused on the West Antarctic Peninsula (Absher et al., 2019; Lacerda et al., 2019; Jones-Williams et al., 2020), the Ross Sea (Cincinelli et al., 2017; Zhang et al., 2022) and its circumpolar waters (Kuklinski et al., 2019; Suaria et al., 2020b). Besides, in the subantarctic islands, only King George Island has been partially studied in detail (Absher et al., 2019; González-Pleiter et al., 2021; Lozoya et al., 2022; Perfetti-Bolaño et al., 2022). Further studies in less investigated areas or compartments are needed to complete the picture of marine debris distribution, a necessary task as MD represents an increasing threat to the Antarctic ecosystem.

We surveyed the nearshore surface waters of the southern coast of Livingston Island. Previously, the only debris reports on Livingston Island are from a beach survey (Almela and Gonzalez, 2020) and in the freshwaters of Byers Peninsula (Almela and Gonzalez, 2020). To further understand the MD dynamics there, our study aimed to determine the concentration, characteristics, distribution, and origins of MD in surface waters around Livingston Island. We hypothesize a higher concentration of contamination in areas with larger human activity, and in the near-shore areas, due to the proximity of the possible pollutant sources and the transport dynamics and accumulation of pollution on the coast. Our aim is that the data presented here may serve as a baseline not only for future and more complex studies needed to increase our comprehension of the threat but also to inform policymakers for better management policies and for adopting strategies to preserve the Antarctic environment.

2. Materials & methods

2.1. Study site

Samples were collected during the BLUEBIO-1 cruise (December–February 2018–2019) at Livingston Island (South Shetland Islands, Antarctica). Two bays were sampled: False Bay and South Bay, in three different areas comprised of three transects each (Table S1). Areas were divided from an inner zone close to the coast and sheltered, to a further outer one more exposed to the currents of the open sea (Fig. 1). A total of

18 transects were conducted, with 9 transects performed in each bay. Due to the challenging weather conditions and the presence of ice, one of the replicated transects of False Bay was lost.

2.2. Sample collection

Collection in each transect was carried out, in calm seawater conditions, by using a Manta Trawl net with a rectangular opening of $0.6 \text{ m} \times 0.25 \text{ m}$ and a mesh size of $250 \mu\text{m}$. The net was towed from between the sides of two zodiacs, navigating in parallel, at a distance of a minimum of 30 m one from each other to prevent the disturbance of floating debris and contamination from the zodiac. The net was carefully rinsed with 70 % ethanol before each sampling to avoid contamination. Coordinates were recorded at the beginning and the end of each trawl. A flowmeter was attached to the net opening to measure the transect length, area, and volume of water sampled. We multiplied the transect distance, by the width (0.6 m) of the mouth of the manta, to estimate the total sampled area. Also, we multiplied the latter by the approximate height of the trawl that was submerged during sampling (0.20 m) to estimate the total volume of water in which our samples were collected. The net was towed at a speed of 2.0 to 3.4 kn for periods of 15 to 30 min in each transect (Table S2). After this period, the net was raised on board and rinsed with seawater to accumulate the entire sample in the cod end and transferred to clean bottles of 1 L on board. Then, in the laboratory, samples were carefully filtered through a $125 \mu\text{m}$ sieve to ensure microdebris retention and avoid contamination, and stored in glass vials of 20 mL with 70 % ethanol for further laboratory analyses.

2.3. Quantification and characterization of microdebris

Samples were poured through filter paper which retained solid residues. Residues were transferred to a glass petri dish for examination under the Olympus SZX10 dissection microscope. Marine debris items were visually identified and classified as fibres or fragments (Fig. S1) and transferred to another petri dish containing a wet filter paper to retain the items. Sequentially, all items were counted, measured and divided into 11 size categories at 0.5 mm intervals, and classified by

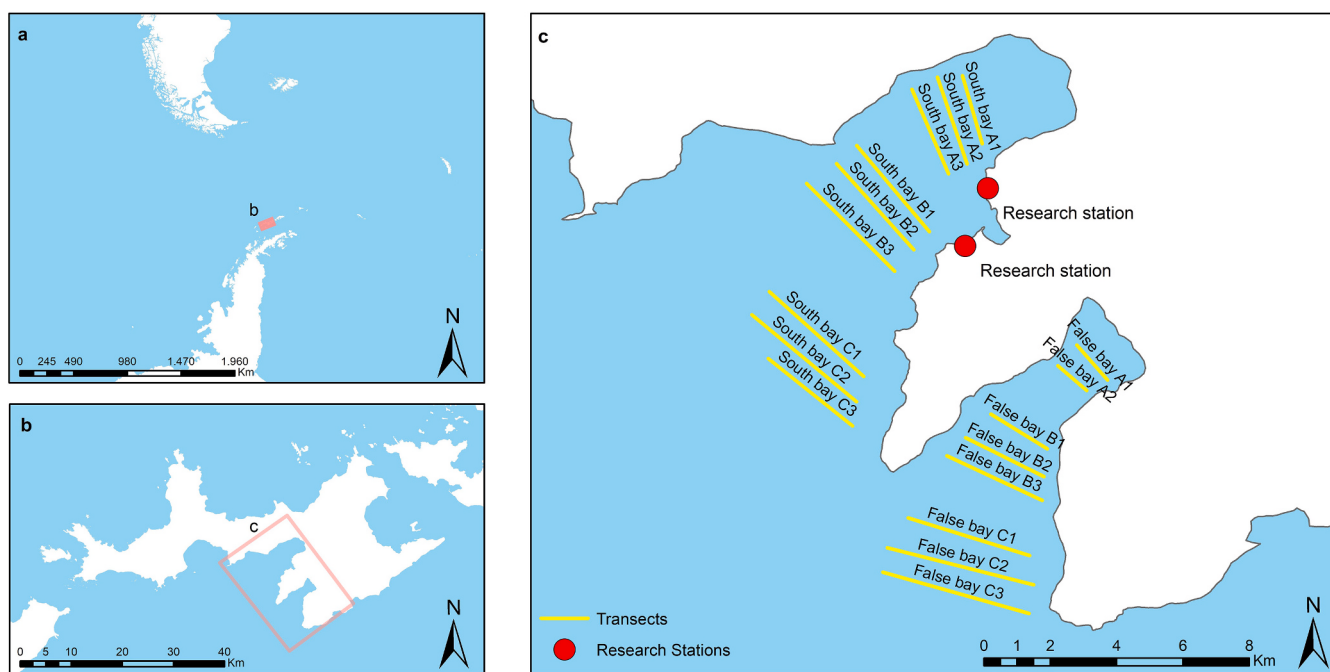


Fig. 1. Map of the sampling areas. a, West Antarctic Peninsula with the relative location of the sampled area (red square); b, Livingston Island with the relative location of the sampled area; c, Schematic distribution of the transects. Map constructed with ArcGIS software (v 10.8). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

colour using a dissection microscope Olympus cell Sens Standard 1.6 Software and kept for further analyses. Items smaller than 0.25 mm were excluded as we used a mesh size of 250 μm . Consequently, their representation was certainly underestimated.

2.4. Composition of the microdebris

Analysis of the microdebris was conducted by using imaging-Fourier Transform Infrared (FTIR) at the CCiT-UB Services at the University of Barcelona. Items were handpicked from the filter paper using ultrafine laboratory tweezers and placed between two CaF_2 slides. We randomly selected the maximum number of fibres and fragments according to their availability and fit within the limits of the CaF_2 slides capacity for analysis. Thermo SCIENTIFIC NICOLET iN10 MX for transmission in two CaF_2 slides with an MCT detector of 50 μm of overture, 4 cm^{-1} spectral resolution and 4000 to 800 cm^{-1} spectral range was used. Polymer composition was determined by comparing the obtained profiles to the CCiT-UB OMNIC polymer spectral database.

2.5. Contamination protocol and quality control

To prevent contamination along the process, we manipulated the samples in a contamination-restricted fume hood. Samples were handled always by the same person, wearing a 100 % cotton white lab coat and thoroughly washed hands before each analysis. The work surface was cleaned before and after each sampling procedure. The material used was mostly glass and metal, as far as possible. It was cleansed using a 1 % HNO_3 solution and rinsed several times with distilled water. For the unavoidable plastic material, 70 % ethanol was used.

A petri dish with moistened filter paper was exposed under the hood during sample handling and also next to the dissection microscope during sorting as a control to check for contamination of suspended air items during the lab work. All control samples were examined following the same procedure used for seawater samples. To compensate for external contamination each sample was conservatively reduced by the number of items found in the respective controls, if needed, according to its shape, colour, and composition. Data from the controls are reported in the Supporting Information (Table S3).

2.6. Statistical analyses

Statistical analyses were performed in R version 4.1.2 (Rstudio). To assess the distribution pattern of the items, the number of possible MD items was standardized according to the filtered water volume (m^3) of each transect calculated by the flow meter. Data were analysed using a two-way ANOVA (fixed-effects and interaction) with bay and area as factors to estimate a significant number of MD differences between bays and areas. Shapiro-Wilk normality test and Levene's test of homogeneity were performed in order to check normality and variance homogeneity.

3. Results

3.1. Abundance and characteristics of marine debris

A total of 702 items were retrieved from all samples analysed, averaging 41.29 ± 28.92 items per transect, out of 14,040.25 m^2 sampled and 2826.77 m^3 of seawater filtered. All samples presented putative marine debris items. Concentrations ranged from 0.067 to 0.656 items/ m^3 per transect with an average of 0.264 ± 0.185 items/ m^3 . In general, fibres were the most abundant debris representing 82.19 % with an average of 0.221 ± 0.165 fibres/ m^3 followed by fragments which represented 17.81 % of the found items, with an average of 0.043 ± 0.038 fragments/ m^3 (Table 1).

Most of the items had a range size of 0.5 to 0.99 mm (29.05 %) followed by 1 to 1.49 mm (14.83 %) class range, and the rest of the size ranges. Fibres followed the same pattern of 0.5 to 0.99 mm (25.75 %)

Table 1

Total concentrations of putative marine debris. In addition, the fibres and fragments average concentrations are presented. Concentrations are expressed as the number of items per sampling volume (m^3).

Marine debris (min. to max.)	0.067 to 0.655
Marine debris (mean $\pm$ sd)	0.264 ± 0.185
Fibres (mean $\pm$ sd)	0.221 ± 0.165
Fragments (mean $\pm$ sd)	0.043 ± 0.038

followed by 1 to 1.49 mm (15.04 %) class range, whereas fragments were mainly of 0.5 to 0.99 mm (43.44 %) followed by 0.25 to 0.49 mm (31.15 %) class range (Fig. 2). We successfully measured 91.88 % ($n = 645$) of the samples, while the remaining ones could not be measured due to technical difficulties encountered during the visual sorting process. Out of the total measured items, we excluded a 4.66 % ($n = 32$), which comprised items smaller than 0.25 mm. Items presented diverse colours with black (62.77 %) and blue (21.07 %) as the most predominant ones. Fibres and fragments presented the same colour patterns. All items were characterized by their colour. Here we show the colours that were represented by >10 items, accounting for 98.72 % ($n = 693$) of the total (Fig. 3).

A total of 354 items were analysed by FTIR techniques. We were only able to analyse 50.43 % of the items found due to the limitations imposed by technical constraints. We picked an average subset of 24 items, varying from 12 to 47 items per sample. The average proportion of analysed items per sample was 69.97 %. Characterization was possible for 320 of the analysed items (90.39 %), 265 fibres (45.93 % of the total) and 55 fragments (44 % of the total). FTIR revealed most items were microplastics ($n = 241$; 75.31 %) for both fibres (73.21 %) and fragments (85.45 %). Regarding fibres, we also found cellulosic fibres (26.79 %) (Fig. 4). As for fragments, others were cellulosic fragments (3.63 %), which also showed a mineral fraction (10.90 %). These latter fragments were eliminated from the final count as they could not be regarded as marine debris. Items from the controls ($n = 24$) were all cellulosic fibres.

Among the items identified as microplastics, the main plastic polymers for fibres ($n = 194$) were polyester (PEST; 61.67 %) and nylon (29.54 %), followed by acrylics (7.73 %), acrylates (0.53 %), and polypropylene (PP; 0.53 %). For fragments ($n = 47$), the main polymers were polyethylene (PE; 46.81 %) and nylon (17.02 %) followed by polypropylene (PP; 12.76 %). Additionally, in the case of fragments, polyesters (PEST; 6.38 %), polyvinyl chlorides (PVC; 6.38 %), acrylics (4.26 %), polystyrene (PS; 2.13 %), alkyd resin (2.13 %), and silicone (2.13 %), were also identified.

3.2. Marine debris spatial distribution

Microdebris items were evenly distributed throughout the two bays and different sampled areas. Shapiro-Wilk normality test and Levene's test of homogeneity showed normality and variance homogeneity but the analysis of variance did not show any significant difference between the number of items per bay (p -value = 0.7099; $F = 0.1458$), per area (p -value = 0.0858; $F = 3.0959$) nor their interaction (p -value = 0.65303; $F = 0.4431$).

4. Discussion

The Southern Ocean, previously considered a pristine region, is not exempt from marine pollution, in this case, microdebris. Although recently there has been an increment of studies assessing this issue (Tirelli et al., 2022; Caruso et al., 2022; Rota et al., 2022), there is still a strong need for information. In this context, the present study provides novel data for MD pollution in the surface waters of Livingston Island, comparing two bays with different levels of human presence. The pollution was homogeneously distributed throughout the two bays and

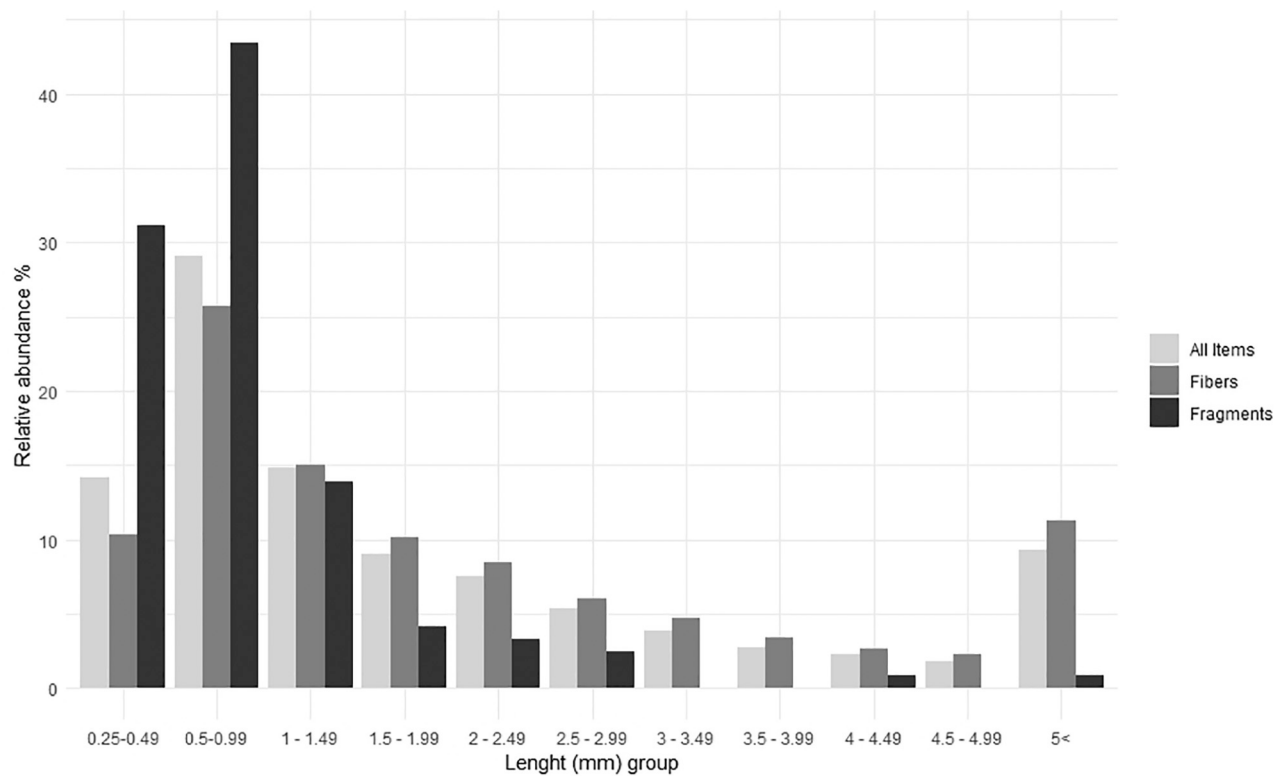


Fig. 2. Histogram of total microdebris items in surface water ($n = 654$), fibres ($n = 532$), and fragments ($n = 122$), maximum size. Represented in % by each size group.

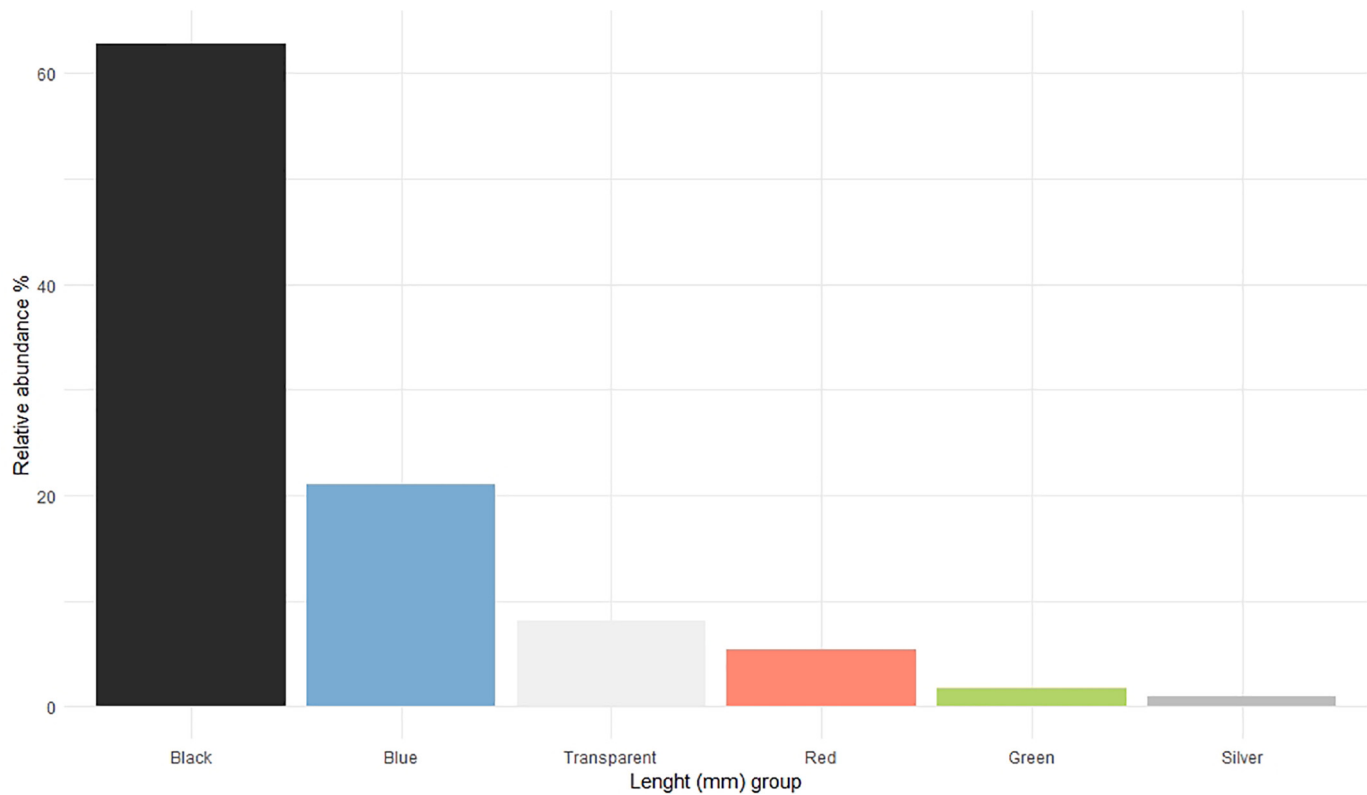


Fig. 3. Histogram of surface water relative microdebris ($n = 693$) colour represented in %. Only colours with >10 fibres are represented.

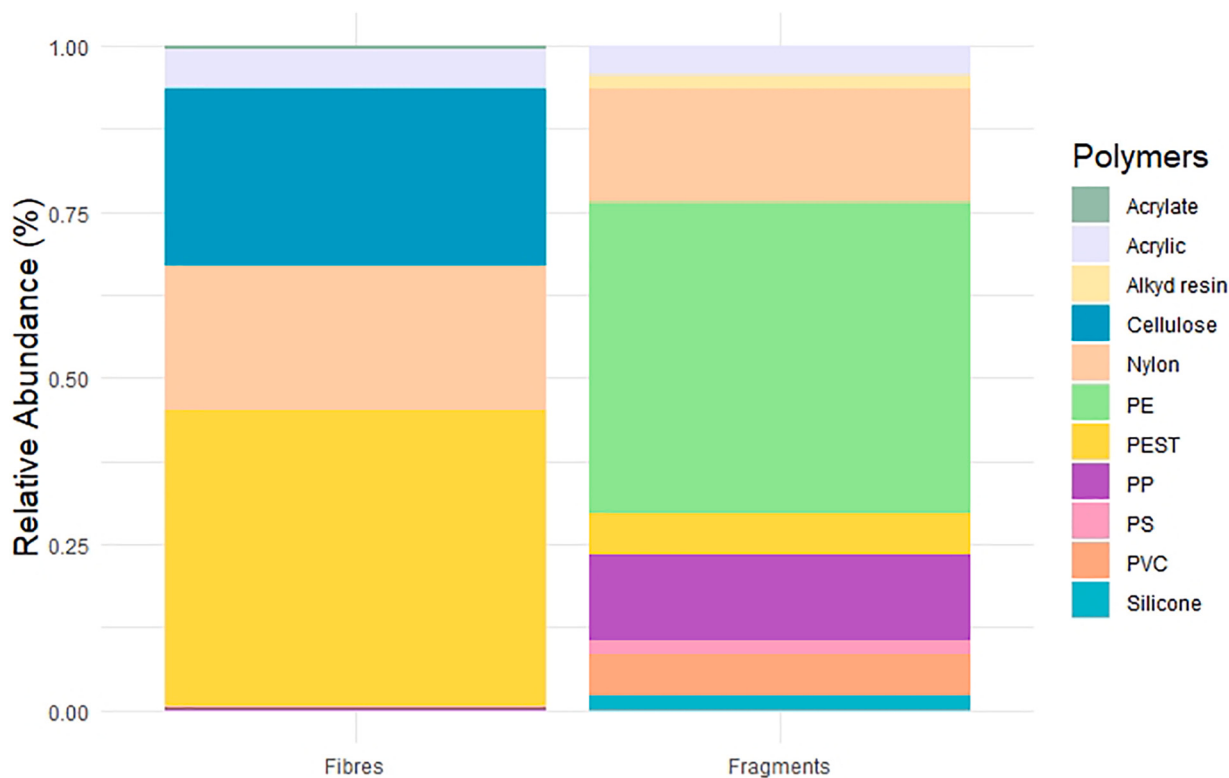


Fig. 4. Relative abundance of microdebris composition ($n = 312$) identified by FTIR, for fibres ($n = 265$) and fragments ($n = 47$). Acrylate, Acrylic, Alkyd resin, Cellulose, Nylon, PE: polyethylene, PEST: polyesters, PP: polypropylene, PS: polystyrene, PVC: polyvinyl chlorides.

their areas, reaching remote and pristine locations. We suggest that the MD found may be accumulated and retained there, and that Antarctic local activities probably are the principal pollutants. It is not yet clear whether we can exclude the nearby research stations as the main source of contamination, although we believe so (see below).

Livingston Island is part of the South Shetlands Islands archipelago, in the West Antarctic Peninsula. Our samples were taken in its southern coastal waters, finding MD in each of the transects. Similar studies along the Antarctic Peninsula, the Ross Sea, Dumont d'Urville Sea, Davis Sea, and Prydz Bay also found pollution in each of their samples (Cincinelli et al., 2017; Absher et al., 2019; Lacerda et al., 2019; Zhang et al., 2022), whereas in the Weddell sea microplastics were found in 65 % of surface water samples (Leistenschneider et al., 2021). Conversely, Antarctic circumnavigation studies found just 12 % of samples containing plastic (Suaria et al., 2020b) or none (Kuklinski et al., 2019). To further determine the level of pollution, we compared our findings with previous Southern Ocean reports (Table 2). To facilitate a fair comparison to other studies that did not take into account fibres (Jones-Williams et al., 2020; Leistenschneider et al., 2021), we considered only the fragments concentration (0.043 ± 0.038 items/ m^3). Overall, our results show larger concentrations of pollution in comparison to previous reports (Table 2) on Antarctic surface water microdebris. Although the pattern may indicate an increase in pollution over time until the present day, other reasons may have influenced these results. Perhaps differences can be attributed to our sampling approach, which focused on the nearshore, differing from the sampling strategy employed in the other studies with samples far from the coast. To date, no significant pattern of MD distribution in Antarctic waters has been described, although there is a trend towards a higher concentration of pollution the closer to the Antarctic coast (Cincinelli et al., 2017; Jones-Williams et al., 2020; Leistenschneider et al., 2021; Zhang et al., 2022). Ocean current systems may play a pivotal role in this phenomenon. Particularly, the South Shetlands Islands are surrounded by a partial recirculation of the upper ocean flow, primarily driven by the Antarctic Peninsula Coastal Current

Table 2
Marine floating microdebris mean concentrations in the Southern Ocean.

Location	Mean concentration (items/ m^3)	Debris items	Study
King George Island (Admiralty Bay)	0.024 ± 0.0457	Microfibres	Absher et al., 2019
Ross Sea	0.17 ± 0.34	Microplastics (Including fibres)	Cincinelli et al., 2017
Mid Scotia Sea and Antarctic Peninsula	0.013 ± 0.005	Microplastics	Jones-Williams et al., 2020
Antarctic circumnavigation	0	Microplastics (Including fibres)	Kuklinski et al., 2019
Antarctic Peninsula	0.008 (1794 km^{-2})	Microplastics (Including fibres)	Lacerda et al., 2019
Weddell Sea	0.01 ± 0.01	Microplastics	Leistenschneider et al., 2021
Ross Sea, Dumont d'Urville Sea, Davis Sea, and Prydz Bay	0.1 ± 0.14	Microplastics (Including fibres)	Zhang et al., 2022
Livingston Island	0.264 ± 0.185	Microdebris	Present study
	0.221 ± 0.165	Fibres	
	0.043 ± 0.038	Fragments	

(Moffat and Meredith, 2018). This circulation pattern may confine pollutants within the region. Additionally, the sampling area is directly influenced by the Bransfield Front Current, which may transport or concentrate pollution to the studied waters (Sangrà et al., 2011). Furthermore, coastlines and coastal waters have been pointed to as important reservoirs of MD worldwide, with limited transport of buoyant debris between the coastal zone and the open ocean (Onink et al., 2021). Moreover, in the Antarctic coasts sea ice incorporates and accumulates MD and acts as a seasonal sink (Kelly et al., 2020;

Mountford and Morales Maqueda, 2021). In this context, and as previously proposed (Isobe et al., 2017; Lacerda et al., 2019), our results may indicate that the studied area is prone to retention and accumulation of MD.

Fibres are the most frequent type of anthropogenic particles, widely distributed and easily accumulated in the ocean, including the Southern Ocean (Gago et al., 2018; Absher et al., 2019; Suaria et al., 2020a; Zhang et al., 2022). In this study, fibres were the largest proportion of MD (82.19 %), similar to the study conducted in the Ross Sea, Dumont d'Urville Sea, Davis Sea, and Prydz Bay (Zhang et al., 2022). Although in some areas of the Southern Ocean fragments have shown larger relative abundances than fibres, when samples were taken near research stations fibres showed higher concentrations (Cincinelli et al., 2017; Lacerda et al., 2019). Regarding size, a redundant majority of the items found belonged to the smallest size group (29.05 %; 0.5 mm–0.99 mm; 14.22 % 0.25–0.49 mm), pointing not only to a high degree of secondary microdebris originating from larger pieces, as seen in similar works (Li et al., 2016; Isobe et al., 2017; Jones-Williams et al., 2020; Suaria et al., 2020b; Leistenschneider et al., 2021) but also to its ease to be widely distributed. Smaller particles are prone to long-range marine and aerial transport, meaning that they may be far from their source and also have the potential to be accumulated (Suaria et al., 2020a). For colours, black was the dominant (62.77 %), due to small black polyester fibres being the most abundant type of debris found. This finding suggests a substantial influence of textiles and clothing as a pollution source (Li et al., 2016; Napper and Thompson, 2016). Although little information can be obtained by colours due to high variability among studies, it is important to highlight that during our visual sorting, almost no weathering and colour fading was observed, suggesting fresh enough debris. Altogether, the characteristics of the recovered items suggest their susceptibility to movement and accumulation. Moreover, our findings may imply that Antarctic local activities are most probably involved in their origin.

We found a remarkable majority of plastics (75.31 %). For fibres, the vast majority were polyester (61.67 %) and nylon (29.54 %), whereas for fragments an outstanding plastic diversity was found, with polyethylene (46.81 %) and nylon (17.02 %) as principal polymers. This could indicate that fragments have more potential sources than fibres. Overall, the main polymers found are among the most usual plastic polymers in marine pollution (Andrady, 2017; Erni-Cassola et al., 2019). Even though there is a remarkable composition variability among Antarctic surface water studies, it seems that PEST fibres and PE fragments have an outstanding presence (Jones-Williams et al., 2020; Leistenschneider et al., 2021; Zhang et al., 2022). These polymer groups are prevalent in surface waters, in the case of PE mainly due to its specific gravity, whereas PEST and nylons might be retained on the water surface layer by the water surface tension or by vertical mixing and upwelling (Song et al., 2014; Leistenschneider et al., 2021). Polyester and nylon fibres are principally related to fishing gear and textile industry products (Li et al., 2016; Andrady, 2017). This is significant as previous investigations remarked on the impact of wastewater treatment stations as a marine debris point source, especially of synthetic fibres from clothes washing (Browne et al., 2011; Napper and Thompson, 2016; Sun et al., 2019; Kalnina et al., 2022). Moreover, the latest scientific evidence suggest that atmospheric deposition of fibres generated during the wear of textiles is likely the primary contributor of fibres to the environment (De Falco et al., 2020; Napper et al., 2023). In particular, the same kind of fibres found here were identified near Antarctic research stations (Cincinelli et al., 2017; Zhang et al., 2022), and furthermore, PEST fibres matching with the personnel of the Italian “Mario Zucchelli” station were found in a study conducted with wild Antarctic whelk *Neobuccinum eatoni* (Bergami et al., 2023). In our study, most nylon fibres were long and transparent, like those used for fishing lines. Moreover, a blue nylon rope with clear fragmentation was also found (Fig. S2). All these facts point to local activities like research stations, ships, and fisheries, as the most probable origin. This has been observed

in most investigations since the start of the Antarctic marine debris surveys and in this study in particular (Convey et al., 2002; Almela and Gonzalez, 2020; Rota et al., 2022; Caruso et al., 2022). PE is used for a wide range of products and is one of the most commonly abundant marine debris polymers worldwide (Li et al., 2016; Andrady, 2017). PE has been reported in most Antarctic studies also suggesting local activities among the main pollution sources (Waller et al., 2017; Lacerda et al., 2019; Jones-Williams et al., 2020; Leistenschneider et al., 2021). Nevertheless, due to its notable presence in subsurface waters, it may have a global origin through currents (Zhang et al., 2022). In this sense, our results are in agreement with the recent bibliography, showing the high impact of pollution that local Antarctic activities may have. However, we cannot omit the probable MD contribution of higher latitudes atmospheric and oceanic currents (Caruso et al., 2022; Cunningham et al., 2022).

Overall, we present here data on marine MD concentrations, including cellulose and other putative anthropogenic items identified during visual sorting. Although procedural blanks during each step of the methodology in the laboratory were taken, it is important to note that no field procedural blanks were collected and this could result in a certain degree of overestimation. Moreover, we suggest that further studies should make the most comprehensive characterization of items to obtain the maximum information possible to fill the remaining knowledge gaps. This is essential for a better understanding of this particular topic, and therefore to provide more accurate information to protect the Antarctic environment from pollution.

Marine microdebris, especially microplastics, clearly have an impact on the marine environment. Key species living and feeding in surface waters, like krill (*Euphausia superba*) and salps (*Salpa thompsoni*), are directly and indirectly affected at organismal and populations scales (Dawson et al., 2018; Le Guen et al., 2020; Wilkie Johnston et al., 2023). Hence, we stress here the need for more data to fully understand the extent of this problem and to be able to assess the MD impact on the Antarctic coastline, which is home to a significant portion of wildlife. Studying MD in this region is paramount to developing proper management policies and regulations implying all parties involved: tourism, fisheries, and research, which should increase awareness and promote responsible behaviours.

5. Conclusions

Microdebris are worldwide distributed, reaching remote sites such as the Southern Ocean. In this study we found microdebris in the surface waters of southern Livingston Island, finding contamination in each one of the samples along two different bays. The distribution of pollution did not show any differences among bays and areas, indicating that it is uniformly spread across the two bays, one pristine and one with research stations. We found a majority of microplastic debris. Based in our findings, we suggest that there is likely an accumulation and a retention of microdebris in the southern coastal waters of Livingston Island. Additionally, the composition of the microdebris points to Antarctic local activities as the primary sources of contamination, even though the nearby research stations cannot be regarded as the main pollution source. This study highlights the need for more investigation regarding microdebris in the Southern Ocean to develop proper management policies and regulations to better protect the Antarctic environment.

CRedit authorship contribution statement

CAP, CA conceived and designed the study. They also collected the samples. PMR performed the laboratory analysis, the Fourier-transform infrared spectroscopy (FT-IR) analysis, and the statistical analysis. The original draft was written by PMR. Reviewed and supervised by CAP, CA. Edited by CAP, CA, PMR. Resources and project administration, CA.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.marpolbul.2023.115516>.

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