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Brief communication: Atmospheric dry deposition of microplastics and mesoplastics in an Antarctic glacier: The case of the expanded polystyrene.

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Abstract

Plastics have been found in marine water and sediments, sea ice, marine invertebrates, and penguins in Antarctica. However, there is currently no evidence of their presence in Antarctic glaciers. Our pilot study investigated plastic occurrence on two ice surfaces that constitute part of the ablation zone of Collins Glacier (King George Island, Antarctica).

Our results showed concentrations of expanded polystyrene (EPS) in the 0.17-0.33 items m^{-2} range. We registered an atmospheric dry deposition between 0.08 and 0.17 items m^{-2} day^{-1} (February 2019). This is the first report of plastic pollution in an Antarctic glacier, to which it was probably transported by wind, possibly from local research activities.

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Introduction

The cryosphere is defined as the frozen hydrosphere of the Earth system that consists of areas in which the temperatures are below 0°C for at least part of the year (NOAA, 2019). The greatest proportion of the cryosphere in terms of volume is in Antarctica. Although its extent of ice has increased in the last decades (Rignot et al 2019), it is estimated that the Antarctic cryosphere holds around 90% of Earth's ice mass (Dirscherl et al 2020) covering its cap of ice up to 6% of the planet during the austral winter (Shepherd et al 2018). Furthermore, Antarctic cryosphere represents the majority of the world's freshwater (Shepherd et al 2018) being, probably, the largest freshwater ecosystem in the planet.

Plastics, especially microplastics (plastics items < 5 mm; MP), have been detected in several compartments of the cryosphere including alpine glaciers (Ambrosini et al., 2019; Cabrera et al., 2020; Materić et al., 2020), snow (Huntingdon et al. 2020; Bergmann et al., 2019; Österlund et al., 2019) and sea ice (Obbard et al., 2014; Peeken et al., 2018; Geilfus et al., 2019; Kelly et al., 2020; La Daana et al., 2020; Von Friesen et al., 2020). The concentration of MP in Arctic snow is generally lower (0 to 14.4 x 10^3 MP L^{-1} of melted snow) (Bergmann et al., 2019), than in sea ice (up to 12,000 MP L^{-1} of melted ice), although there are large differences between studies and sites even from the same region (Peeken et al., 2018; Von Friesen et al., 2020, Bergmann et al., 2019). The use of different units in reporting MPs concentration in alpine glaciers such as number of items per mass of sediment weight (78.3 ± 30.2 MPs kg^{-1} of sediments; Ambrosini et al., 2019) and mass of MPs per volume (0 to 23.6 ± 3.0 ng of MPs mL^{-1}; Materić et al., 2020), makes comparisons between studies difficult. Regarding the shape of the MP found in the cryosphere, fibers seem to be dominant in alpine glaciers (65 %) and sea ice (79 %) followed by fragments (Ambrosini et al., 2019; La Daana et al., 2020). Concerning the size of MP, La Daana et al. (2020) reported a broad size distribution in sea ice, with 67% of MP in the 500-5000 µm range. Other studies found lower sizes, however, with significant amounts (around 90%) of MPs smaller than 100 µm in snow and sea ice (Bergmann et al., 2019; Peeken et al., 2018; Ambrosini et al., 2019; Kelly et al., 2020) due to the analytical methods used, which can capture smaller-sized plastic. In general, the presence of plastics > 5mm are not reported in compartments of the cryosphere, probably due to the difficulty of large plastic items to reach the remote areas where these are located. MP identification using micro-Fourier transform-infrared spectroscopy (µ-FTIR) revealed that polyethylene terephthalate (PET), polyamide (PA), polyester (PE), varnish (acrylates/polyurethane), nitrile rubber, ethylene-propylene-diene monomer (EPDM) rubber, polypropylene (PP), varnish, rayon and polyurethane (PU) are the most common types of MPs found (Obbard et al., 2014; Peeken et al., 2018; Ambrosini et al., 2019; Bergmann et al., 2019; Kelly et al., 2020; La Daana et al., 2020; Materić et al., 2020) in cryogenic matrices. On the other hand, sources for these MP detected in the cryosphere remain poorly understood. It has been suggested that they could be transported by wind before being deposited by both wet and dry deposition in remote

Gelöscht: water part

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Kommentiert [MB1]: Huntington, A., Corcoran, P.L., Jantunen, L., Thaysen, C., Bernstein, S., Stern, G.A., Rochman, C.M., 2020. A first assessment of microplastics and other anthropogenic particles in Hudson Bay and the surrounding eastern Canadian Arctic waters of Nunavut. FACETS 5, 432-454.

Gelöscht: 2017

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Gelöscht: 10^5

Gelöscht: near urban areas

Gelöscht: 2017

Kommentiert [MB2]: Should it not rather be ice weight? We are not really talking about sediments here?!

Gelöscht: Kg

Gelöscht: 2017

Kommentiert [MB3]: I do not think that this is assumption is likely. Why should larger plastic not make it to the same places in the ocean as microplastic? I think the reason why they have not been reported in the marine cryosphere is that their concentrations are lower compared with MP. The likelihood of catching them is smaller, especially when analysing small sample sizes.

Gelöscht: Bergmann et al.,¶
2017;

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areas such as polar regions (Bergmann et al., 2019; Halsband and Herzke, 2019). In fact, it has been reported that air masses can transport MPs through the atmosphere over distances of at least 100 km, and that they can be released from the marine environment into the atmosphere by sea-spray (Allen et al., 2019; Allen et al., 2020).

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So far, studies on plastics have been conducted on three compartments of the cryosphere (alpine glacier, snow and sea ice); however, there is no evidence to date about their presence in freshwater glaciers in Antarctica. In this sense, our hypothesis is that plastics have reached these glaciers and that dry deposition is crucial in this process. Therefore, we carried out a pilot study to investigate the presence of plastics on the surfaces of two freshwater glaciers that constitute part of the ablation zone of Collins Glacier in Maxwell Bay, King George Island (Antarctica), as well as the occurrence dynamics of the MPs in the absence of rainfall.

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Materials and Methods

2.1 Study area

Collins Glacier is located on the northeast of Fildes Peninsula (King George Island, Antarctica; Figure 1A) and has a total surface area of 15 km^2 (Simoes et al., 2015). Our study was carried out on the ice surface of the glacier ablation areas around two lakes (Uruguay or Profound, and Ionosferico) in Maxwell Bay (Figure 1B). Uruguay lake (-62.18515, -58.91173) is located in the proximity of the Artigas Antarctic Scientific Base and its access road (~300 m) is subjected to intense human transit (Figure 1B). The lake is used for drinking and domestic water supply. The glacier surface covers 1680 m^2. Ionosferico lake (-62.17987, -58.91070) is located ~600 m from Artigas Base and has minimal human transit. The glacier surface extends over an area of 537 m^2 (Figure 1B). It should be noted that there were no visible footpaths through or nearby the glacier surfaces of both lakes during the duration of our study.

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Gelöscht: studied in this lake
Gelöscht: covered
Gelöscht: studied in this lake covered

2.2 Sampling and identification of plastics

To evaluate the concentration of plastics, twelve squares were marked on the ice around Uruguay lake (Figure 1C) and six squares on Ionosferico lake (Figure 1D) on the 18 of February 2020. Squares of 1 m^2 were randomly distributed every ten meters covering the entire ice surface on the margin of Uruguay (Figure 1E) and Ionosferico lakes. All items visually resembling plastic (suspected plastic) inside the squares were collected (Figure 1F) and registered.

Gelöscht: /2/

Immediately after this evaluation of visible large plastics, we started the study of the dry atmospheric deposition of plastics on ice. For this purpose, we monitored six squares on the ice around each lake. For that, we used the squares where suspected plastics had already been observed (squares 1U and 5U in Uruguay lake, and squares 1I and 5I in Ionosferico lake; see details in Table 1) and we marked other new squares up to a total of six squares in each lake around where, at least, one suspected plastics were observed. All squares were visually monitored every 12 hours for 2 days (18 - 20/02/2020). Every item visually resembling plastic detected in the squares at the end of the experiment was collected with stainless steel tweezers, placed into 100 mL ISO reagent bottles, and stored at 4°C until analysis. No rainfall occurred during the duration of the experiment.

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All collected items were photographed, measured and their composition was identified by FTIR using an Agilent Cary 630 FTIR spectrometer or by µFTIR using a Perkin-Elmer Spotlight 200 Spectrum Two apparatus equipped with a MCT detector (depending on the size of the item). Their spectra were taken using the following parameters in micro-transmission mode: spot 50 µm, 32 scans and spectral range 550-4000 cm^{-1} with 8 cm^{-1} resolution. The spectra were analysed by Omnic software (Thermo Fisher). Items with matching values > 60% were considered plastic materials. The results of concentration and atmospheric dry deposition of plastics reported in this study are only of those items positively identified as plastics, per total area of the sampled squares.

Results and discussion

Assessment of glacial plastic pollution

In total, 45 items visually resembling plastics were collected from surface snow in squares, of which 29 items were spectroscopically confirmed as plastic. The size of plastics found ranged in length from 2,292 - 12,628 µm and in width from 3 - 11,334 µm (Figure 2A). According to their size, 13 mesoplastic items (plastic items between 5-25 mm long; MeP) and 3 MP items were obtained on the ice around Uruguay lake and 12 MeP items and 1 MP item on the ice around Ionosferico lake (Figure 2B). Meso and microplastics (hereinafter referred to as plastics) of expanded polystyrene (EPS) were found on the ice around both lakes: 8 plastic items on the ice around Uruguay lake and 13 plastic items on the ice around Ionosferico lake (Figure 2 B, C and D). Polyester (n = 7 items; Figure 2B, E and F) and polyetherurethane (n = 1 item; Figure 2B, G and H) items were present only on the ice around Uruguay lake. It should be noted that spectra of the polyester (Figure 2F) showed a high similarity with alkyd resin (polyester modified by the addition of other components), which are widely used in many synthetic paints.

Expanded polystyrene items were ubiquitous on the ice with concentrations ranging from 0.17 items m^{-2} on the ice around Uruguay lake to 0.33 items m^{-2} on the ice around Ionosferico lake. The concentration of polyester, which was found only on the ice around Uruguay lake, was 0.25 items m^{-2}. No polyetherurethane items were observed at Ionosferico lake.

Experimental assessment of atmospheric plastic deposition

A dry deposition of 0.08 EPS items m^{-2} day^{-1} and 0.17 EPS items m^{-2} day^{-1} was observed on the ice around Uruguay and Ionosferico lakes, respectively (Table 1). Polyester showed a deposition rate of 0.08 items m^{-2} day^{-1} on the ice around Uruguay lake (Table 1), probably due to its proximity to Artigas Base. Items deposited on the ice in Ionosférico lake during the experiment were exclusively EPS (Table 1).

The presence of plastics has been reported in different places in Antarctica such as sea ice (Kelly et al. 2020), sea surface (Suaria et al. 2020; Lacerda et al. 2019; Isobe et al. 2017; Cincinelli et

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Kommentiert [MB8]: Kelly, A., Lannuzel, D., Rodemann, T., Meiners, K.M., Auman, H.J., 2020. Microplastic contamination in east Antarctic sea ice. Marine Pollution Bulletin 154, 111130.
Kommentiert [MB9]: Suaria, G., Perold, V., Lee, J.R., Lebouard, F., Aliani, S., Ryan, P.G., 2020. Floating macro- and microplastics around the Southern Ocean: Results from the Antarctic Circumnavigation Expedition. Environment International 136, 105494.
Kommentiert [MB10]: Lacerda, A.L.d.F., Rodrigues, L.d.S., van Sebille, E., Rodrigues, F.L., Ribeiro, L., Secchi, E.R., Kessler, F., Proietti, M.C., 2019. Plastics in sea surface waters around the Antarctic Peninsula. Scientific Reports 9, 3977.
Kommentiert [MB11]: Isobe, A., Uchiyama-Matsumo ...
Gelöscht: marine
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al. 2017; Barnes et al. 2010), beaches (Sander et al. 2009; Convey et al. 2002) , marine zooplankton (Absher et al., 2019), seafloor (Cunningham et al. 2020; Munari et al., 2017; Reed et al., 2018; Lenihan et al. 1990; Dayton & Robillard 1971), marine benthic invertebrates (Sfriso et al., 2020), fish (Cannon et al. 2016) and penguins (Le Chen et al. 2020; Laganà et al. 2019; Bessa et al., 2019) as well as other sea birds (Ibanez et al., 2020; Fijn et al., 2012; Creet et al., 1994; van Franeker & Bell, 1988). However, there was only one study about the presence of plastics in the Antarctic cryosphere that

Kommentiert [MB12]: Barnes, D.K.A., Walters, A., Goncalves, L., 2010. Macroplastics at sea around Antarctica. Marine Environmental Research 70, 250-252.

Kommentiert [MB13]: Sander, M., Costa, E.S., Balbao, T.C., Carneiro, A.P.B., Santos, C.R., 2009. Debris recorded in ice free areas of an Antarctic Specially Managed Area (ASMA): Admiralty Bay, King Georgia Island, Antarctic Peninsula. Neotropical Biology and Conservation 4, 36-39.
Convey, P., Barnes, D., Morton, A., 2002. Debris accumulation on oceanic island shores of the Scotia Arc, Antarctica. Polar Biology 25, 612-617.

Gelöscht: samples of ocean water

Gelöscht: marine sediments

Kommentiert [MB14]: Cunningham, E.M., Ehlers, S.M., Dick, J.T.A., Sigwart, J.D., Linse, K., Dick, J.J., Kiriakoulakis, K., 2020. High Abundances of Microplastic Pollution in Deep-Sea Sediments: Evidence from Antarctica and the Southern Ocean. Environmental Science & Technology.
Lenihan, H.S., Oliver, J.S., Oakden, J.M., Stephenson, M.D., 1990. Intense and localized benthic marine pollution around McMurdo Station, Antarctica. Marine Pollution Bulletin 21, 422-430.
Dayton, P.K., Robilliard, G.A., 1971. Implications of pollution to the McMurdo Sound benthos. Antarctic Journal, 53-56.

Kommentiert [MB15]: Cannon, S.M.E., Lavers, J.L., Figueiredo, B., 2016. Plastic ingestion by fish in the Southern Hemisphere: A baseline study and review of methods. Marine Pollution Bulletin 107, 286-291.

Kommentiert [MB16]: Le Guen, C., Suaria, G., Sherley, R.B., Ryan, P.G., Aliani, S., Boehme, L., Brierley, A.S., 2020. Microplastic study reveals the presence of natural and synthetic fibres in the diet of King Penguins (Aptenodytes patagonicus) foraging from South Georgia. Environment International 134, 105303. ...

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Kommentiert [MB18]: Ibañez, A.E., Morales, L.M., Torres, D.S., Borghello, P., Haidr, N.S., Montalti, D., 2020. Plastic ingestion risk is related to the anthropogenic activity and breeding stage in an Antarctic top predator seabird species. Marine Pollution Bulletin 157, 111351 ...

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was carried out in Antarctic sea ice (Kelly et al. 2020). Here, we provide the first report of plastics in the freshwater cryosphere of Antarctica, namely in Antarctic glaciers.

The concentration of plastics found on the surfaces of two freshwater glaciers that constitute part of the ablation zone of Collins Glacier in Maxwell Bay (## - ## items m-2) are similar to those found in nearby Antarctic marine environments (e.g. ## -## microplastics m-2) (Cincinelli et al., 2017; Munari et al., 2017; Reed et al., 2018) supporting the notion that freshwaters could play a role in the life cycle of plastics in this region. In our study, wind was probably the transportation mode of plastics to the ice from the anthropogenic activities that occur around these lakes, and differences in the concentration of plastics (higher in Uruguay lake) a consequence of its proximity to these anthropogenic activities. Notably, EPS is widely used as insulation material of old buildings in the area, and alkyd resins find use as external coatings. Besides, a growing number of tourists exerts increasing pressure on the area. The long-range transport of plastic by wind would be supported by studies evidencing the transport of soil and propagules of terrestrial and marine invertebrates and grasses, mosses and algae (Nkem et al., 2006).

Our research indicates that our research in sensitive remote areas such as Antarctica leaves a footprint, namely plastic pollution. While reports of research-based litter pollution on the seafloor and beaches date back as early as the 1970's (Dayton & Robillard 1971; Lenihan et al., 1990; Sander et al. 2009) the handling of waste has improved through the Antarctic Treaty System, Annex III 'Waste Disposal and Waste Management'. It requires treaty states to remove all plastic from Antarctica, with the only exception being those plastics that can be incinerated without producing harmful emissions (Antarctic Treaty Secretariat, 1998). However, once plastics are broken down into small fractions and dispersed throughout the continent and nearby waters, management measures become very difficult to address, as indicated by our data. Sander et al. (2009) also report ongoing pollution from research debris, which had not been removed. A more rigorous management of macro- and microplastics is therefore essential for preserving the integrity of sensitive polar environments.

Conclusion

This is the first report of the presence of both MeP and MP in an Antarctic glacier, which was probably transported to the sites by wind. In total, three types of plastics were found on two glacier surfaces that constitute part of the ablation zone of Collins Glacier (King George Island, Antarctica) being EPS ubiquitous on the ice. Our study shows that the management of plastic contamination in Antarctica should focus strongly on the waste and microplastic generated by anthropogenic activities that occur in this place, including scientific research.

Author contribution

Miguel González-Pleiter: identified the research question, formulated the hypothesis,

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Kommentiert [MB20]: You can only make this statement if you have tested this. Because by looking at Fig. 2 B I could not be sure if there is actually a significant difference. But it would be interesting if you could, so I suggest, you do some t-testing or similar.

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Kommentiert [MB22]: Dayton, P.K., Robilliard, G.A., 1971. Implications of pollution to the McMurdo Sound benthos. Antarctic Journal, 53-56.

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Gelöscht: is the agreed mechanism for governance within the
Antarctic Treaty area. In fact

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developed the experimental design, planned the experiments, performed the experiments in the field, performed the experiments in the laboratory, compiled the data sets, analyzed the data, discussed the results, prepared graphical material, wrote the paper (original draft) and provided financial support. **Gissell Lacerot**: identified the research question, formulated the hypothesis, developed the experimental design, planned the experiments, checked the field data, discussed the results, wrote the paper (final version). **Carlos Edo**: performed the experiments in the laboratory, compiled the

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data sets, analyzed the data, discussed the results, prepared graphical material and review final manuscript. **Juan Pablo Lozoya**: developed the experimental design, checked the field data, discussed the results, review final manuscript and provided financial support. **Francisco Leganés:** discussed the results, review final manuscript and provided financial support. **Francisca Fernández-Piñas**: checked the field data, checked the laboratory data, discussed the results, review final manuscript and provided financial support. **Roberto Rosal**: checked the field data, checked the laboratory data, discussed the results, review final manuscript and provided financial support. **Franco Teixeira de Mello**: identified the research question, formulated the hypothesis, developed the experimental design, planned the experiments, performed the experiments in the field, checked the field data, prepared graphical material and provided financial support.

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Declaration of competing interest

The authors declare no conflict of interest.

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Formatiert: Durchgestrichen

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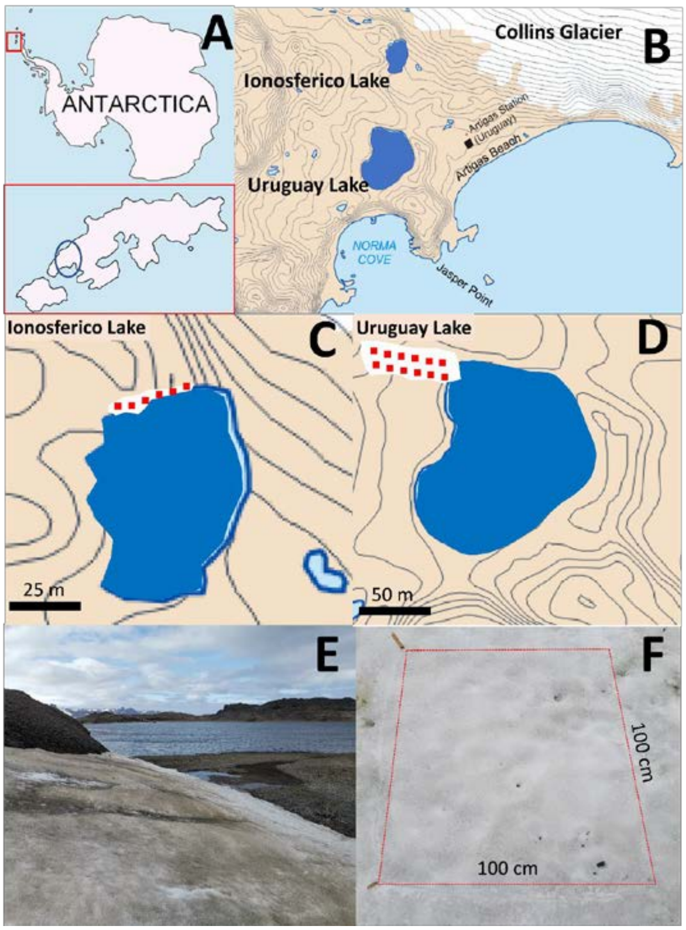

Figure 1. (A) General view of Antarctica and location of King George Island. The blue circle indicates the Fildes Peninsula. Collins Glacier is located on the northeast of Fildes Peninsula. (B) A detailed view of Ionosferico lake, Uruguay lake, Artigas Research Station and Collins Glaciers in the Fildes Peninsula. (C) and (D) ablation zone of Collins Glacier around Ionosferico lake and Uruguay lake, respectively. (E) Photograph of the glacier surface around Uruguay lake that constitute part of the ablation zone of Collins Glacier taken on 18/02/2020. (F) A representative square on the glacier surface used in this study.

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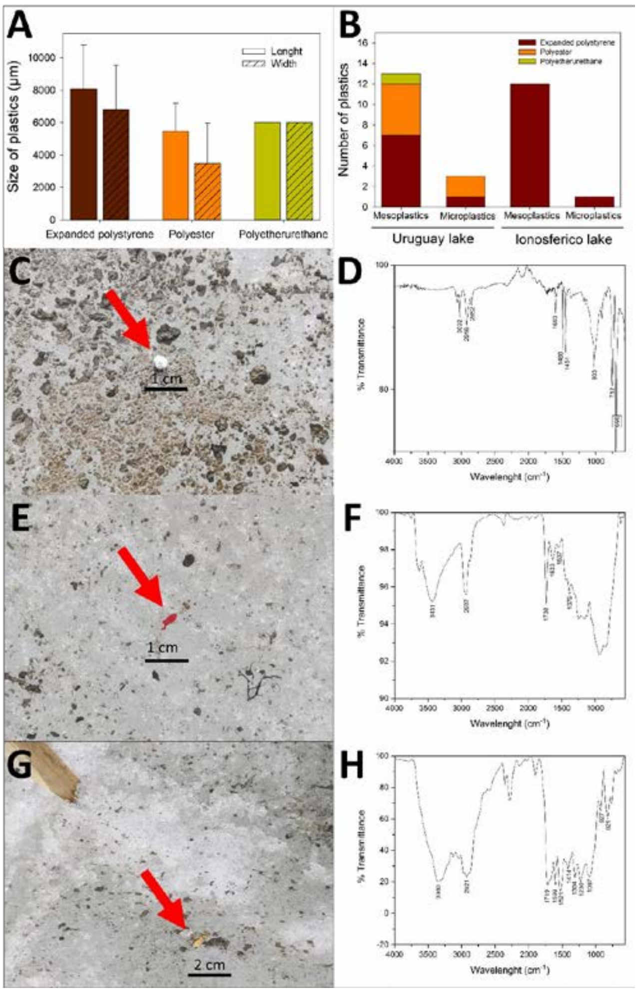

Figure 2. (A) Size of the plastics collected on the glacier surface. (B) Total number of the mesoplastics and microplastics found on the glacier surface around Uruguay lake and Ionosferico. Representative photographs of expanded polystyrene (B), polyester (D) and polyetherurethane (F) found on the glacier surface. The red arrows indicate the plastics. FTIR representative spectra of expanded polystyrene (C), polyester (E) and polyetherurethane (G) found on the glacier surface.

Table 1. Concentration of plastics found in each square on 18/02/2020 and dry atmospheric deposition of plastics monitored every 12 hours for 2 days (18/2/2020 and 20/2/2020). The asterisks indicate squares where suspected plastics had already been observed when we evaluated their concentration.

Concentration of plastics

Uruguay lake														
Squares	1U	2U	3U	4U	5U	6U	7U	8U	9U	10U	11U	12U	Plastics m^{-2}	Total plastics confirmed by FTIR
EPS	1	0	0	0	1	0	0	0	0	0	0	0	0.17	2
Polyester	1	1	0	0	0	0	0	0	0	0	0	1	0.25	3
Polyetherurethane	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Plastic	2	1	0	0	1	0	0	0	0	0	0	1	###	###
Ionosferico lake														
Squares	1I	2 I	3 I	4 I	5 I	6 I							Plastics m^{-2}	Total plastics confirmed by FTIR
EPS	1	0	0	0	1	0							0.33	2
Polyester	0	0	0	0	0	0							0	0
Polyetherurethane	0	0	0	0	0	0							0	0
Total Plastic	1	0	0	0	1	0								

Atmospheric dry deposition experiment

Uruguay lake																																
Squares	1U					2U*					3U*					4U*					5U					6U*					Total plastics confirmed by FTIR	Plastics m^{-2} day^{-1}
Time (h)	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48		
EPS	1										1					1		-1			1					4		1			8	0.08
Polyester	1	-1		+1												4															5	0.08
Polyetherurethane						1																									1	0
Total Plastic	2	1	0	1	0	1	0	0	0	0	1	0	0	0	0	5	0	1	0	0	1	0	0	0	0	4	0	1	0	0	14	
Ionosferico lake																																
Squares	1 I					2 I *w					3 I *					4 I *					5 I *					6 I *					Total plastics confirmed by FTIR	Plastics m^{-2} day^{-1}
Time (h)	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48	0	12	24	36	48		
EPS	1					3		1			2		1			3					1					1					13	0.17
Polyester																															0	0
Polyetherurethane																															0	0
Total Plastic	1	0	0	0	0	3	0	1	0	0	2	0	1	0	0	3	0	0	0	0	1	0	0	0	0	1	0	0	0	0	13	

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