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Microplastic accumulation in benthic invertebrates in Terra Nova Bay (Ross Sea, Antarctica)

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ABSTRACT

Microplastic contamination of the benthic invertebrate fauna in Terra Nova Bay (Ross Sea, Antarctica) was determined. Twelve macrobenthic species, characterized by different feeding strategies, were selected at 3 sampling sites at increasing distance from the Italian Scientific Base (Mario Zucchelli, Camp Icarus, Adelie Cove). The 83% of the analyzed macrobenthic species contained microplastics (0.01–3.29 items mg^{-1}). The size of the particles, measured by Feret diameter, ranged from 33 to 1000 μm with the highest relative abundance between 50 and 100 μm. Filter-feeders and grazers displayed values of microplastic contamination from 3 to 5 times higher than omnivores and predators, leading to the hypothesis that there is no evident bioaccumulation through the food web. The prevalent polymers identified by micro-FTIR were nylon (86%) and polyethylene (5%); other polymers identified in Antarctic benthos were polytetrafluoroethylene, polyoxymethylene, phenolic resin, polypropylene, polystyrene resin and XT polymer.

1. Introduction

The world plastic production from the year 1950 has increased from 1.7 to 348 million tons in 2017, with a proportional increase in the production of plastic waste (PlasticsEurope, 2008, 2018). Part of this waste get discharged into the environment, a problem exacerbated by the common use of throw-away "user" plastic products, that when inappropriately managed and discarded, ultimately reach the sea producing damage to marine life (Cole et al., 2011; Thompson et al., 2009). Plastic waste has been subdivided into 5 dimensional classes (Andrady, 2017): macroplastics (> 200 mm), mesoplastics (200–5.01 mm); large microplastics (5–1.01 mm); small microplatics (1.00 mm-1 μm) and nanoplastics (< 1μm). The origin of microplastics can be due to direct input of particles already included in a dimensional range between 5 mm and 1 μm. These are reported as primary microplastics, and are introduced into the environment by discharge of many "open use" products such as glitter, face scrub, syntetic fibers from washed wears and many other goods (Napper and Thompson, 2016). Secondary microplastics are produced instead by the interaction of atmospheric agents, waves, ultraviolet rays and biological agents with macroscopic plastic pieces leading to their progressive fragmentation (Artham et al., 2009; Muthukumar et al., 2011). Eventually the action of fouling (Fazey and Ryan, 2016; Galloway et al., 2017) increase the density of these particles and favors their aggregation in marine snow that sink onto the seabed becoming potentially accessible for benthonic organisms (Porter et al., 2018).

One of the primary environmental risks associated with microplastics is their bioavailability for marine organisms, since they mimic the appearance of food, possibly obstructing and compromising the functionality of the digestive system (Gall and Thompson, 2015). Moreover microplastics can act as a source and vector of toxic plastic additives (Hermabessiere et al., 2017; Hahladakis et al., 2018). Microplastics can be ingested by marine invertebrates with different feeding methods, as the particles are in the size range of plankton: mussels (filter feeders), lugworms (deposit feeders) and sea cucumbers (detritivores) were found to ingest microplastics (Naji et al., 2018; Lusher et al., 2017; Bonanno and Orlando-bonaca, 2018; Browne et al., 2008; Graham and Thompson, 2009). There is growing evidence that microplastics can get transferred in the food chain (Farrell and Nelson, 2013; Nelms et al., 2018), rising concern about detrimental

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implications for bioaccumulation from one trophic level to the next.

Microplastics contamination has been reported for many remote and isolated areas of the globe, including Antarctica (Cincinelli et al., 2017; Isobe et al., 2017; Munari et al., 2017). The Antarctic continent has been affected by direct and indirect human activity for about two centuries (Stark et al., 2019). Moreover, the intense industrialization of the world brought new compounds and new hazards to ecosystems worldwide, and Antarctica was not an exception (Stark et al., 2019). In most parts of the continent the effects of the scientific activities and tourism resulted in different types of pollution, such as organic enrichment (Conlan et al., 2004), chemicals contamination, especially by hydrocarbons (Lenihan and Oliver, 1995), metals (Guerra et al., 2011), and microplastics (Cincinelli et al., 2017; Isobe et al., 2017; Munari et al., 2017), with mostly unknown ecological effects. Moreover, terrestrial and marine habitats adjacent to current or abandoned Antarctic scientific bases are affected by localized contamination (Bargagli, 2008).

In the present study, we analyzed 12 invertebrate species from Terra Nova Bay (Ross Sea, Antarctica), with the aims (i) to determine whether the benthos of that remote area exhibit microplastic contamination, (ii) to evaluate differences of microplastic contamination among different species characterized by different feeding strategies, (iii) to characterize polymer type, and finally (iv) to determine whether microplastic presence can be attributed to trophic transfer. This is the first time that such a comprehensive study on microplastic contamination has been carried out on the Antarctic benthos.

2. Materials and methods

2.1. Study area and sampling

The Ross Sea (Southern Ocean) is located between Victoria Land and Marie Byrd Land and is the largest continental shelf ecosystem south of the Antarctic Polar Front. Terra Nova Bay (Ross Sea) is a coastal marine area encompassing 29.4 km^2 between Adélie Cove and Tethys Bay (Fig. 1). It is an important littoral area for well-established and long-term scientific investigations immediately to the south of the Mario Zucchelli Station, a scientific research centre and a strategic logistics node for other bases in Antarctica (Munari et al., 2017). The area has been subjected of extensive ecological investigations, and was proposed as an Antarctic Specially Protected Area (ASPA) by Italy, in 2003. No marine resource harvesting has been conducted within the Area, nor in the immediate surrounding vicinity. At the moment, human impacts within the Area are believed to be minimal and confined to those arising from the nearby Mario Zucchelli Station and scientific work conducted within the Area (Munari et al., 2017).

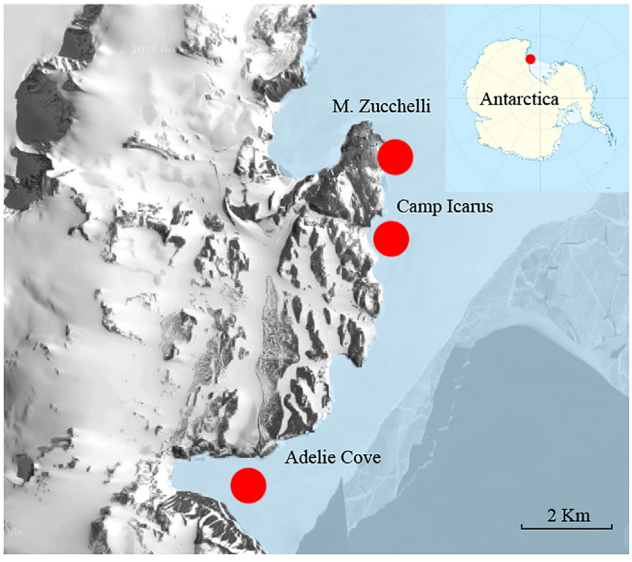

Fig. 1. Map of the sampling areas.

In the austral summer 2015, during the 30th Antarctic Expedition (PNRA, Italian Research Program in Antarctica), sediment samples were taken from Terra Nova Bay. The sampling program was carried out aboard the MS "Malippo" in January 2015, and sediment samples containing the animals were collected with a Van Veen grab (surface 0.18 m^2) from stations at increasing distance and depth (ranging 25–140 m) from the Mario Zucchelli Base (Fig. 1): in front of the base, at Camp Icarus (4 km south of the base) and at Adelie Cove (10 km south of the base). Benthic macroinvertebrates were extracted from the sediment by metal sieve and thoroughly rinsed with seawater in field, fixed in ethanol (absolute, for HPLC, ≥99.8%, Sigma Aldrich) and stored in glass vials until reaching the laboratory where they were identified and stored at 4 °C in ethanol.

Twelve invertebrate species, characterized by different feeding strategies, were selected for microplastic contamination analysis. They were: *Edwardsia meridionalis* (Williams, 1981)(Cnidaria, Anthozoa: predator), *Cyamiocardium denticulatum* (E.A. Smith, 1907)(Mollusca, Bivalvia: filter feeder), *Yoldiella antarctica* (Thiele, 1912)(Mollusca, Nuculanida: surface deposit feeder), *Aequiyoldia eightsii* (Jay, 1839) (Mollusca, Nuculida: suspension feeder), *Thyasira debilis* (Thiele, 1912) (Mollusca, Lucinida: suspension feeder), *Harpiniopsis similis* (Stephensen, 1925)(Arthropoda, Amphipoda: predator), *Orchomenella franklini* (Walker, 1903)(Arthropoda, Amphipoda: deposit feeder), *Eatoniella* sp. (Mollusca, Littorinimorpha: grazer), *Oweniidae* sp. (Annelida, Sabellida: surface deposit feeder), *Aglaophamus macroura* (Schmarda, 1861) (Annelida, Phyllodocida: omnivore), *Leitoscoloplos mawsoni* (Benham, 1921)(Annelida, Orbiniidae: subsurface deposit feeder), *Perkinsiana milae* (Giangrande and Gambi1997)(Annelida, Sabellida: filter feeder). Those taxa were selected because of their numerical dominance in the benthic community. Microplastic quantification in the organisms was carried out on all taxa and areas by the Nile red staining technique and the qualitative identification of the polymers was carried out by microFTIR on the most contaminated taxa. The digestion methods for Nile red count and microFTIR identification were optimized for the subsequent analytical determinations and the samples were processed separately and specifically for the two procedures.

2.2. Contamination control

All necessary precautions were implemented to minimize microplastic contamination while handling and processing the samples: cotton lab coats and clothes were worn in the laboratory at all times, and three procedural blanks were included in each digestion round; all solutions (tap water included) were filtered by GF-F fiberglass filters (0.7 μm), all the glassware was accurately rinsed at least two times (inside and outside) with filtered tap water and the samples were capped with aluminum foil and glass caps during the identification and analysis to minimize airborne contamination.

2.3. Nile red count

For each area individuals of each species were counted under the stereomicroscope, pooled together and weighted to reach an ethanol wet biomass of approx. 200 mg. In supplementary material a table was provided (Table S1) with number of pooled organisms per sample. For *A. eightsii* (a species with an average larger size in comparison with all the other organisms) a wet biomass of 1.5 g was used, treated with a proportional volume of digesting solution. The organisms were dried in the oven at 80 °C for 1 h on pre-weighted aluminum capsules and their dry biomass was recorded. The organisms were very gently homogenized in a mortar with 10 mL of an NaOH 1% solution (0.25 M) and transferred by Pasteur pipette into a test tube, the digestion was completed at 40 °C for 24 h after a final vortexing. The evaluation of the

digestion method efficiency was performed in triplicate on dried samples of *Ruditapes philippinarum* (Adams and Reeve, 1950) soft tissue and *Gammarus pulex* (Linnaeus, 1758), two representative organisms for soft animals and chitinous ones. The digestion efficiency was evaluated as percentage of dissolved organism and was obtained as dry weight difference after filtration of the digest on pre-weighted oven dried (105 °C × 1 h) GF-F fiberglass filters (0.7 μm).

The microplastics were collected from the digests by density-floating method. An addition of 3.6 g of NaCl (calcinated at 700 °C for 3 h to remove any trace of microplastics) was dissolved by vortexing for 30 s, the test tube was quickly degassed by sonication for three seconds and let to settle for 1 h. The test tube was put into 100 mL cylinders and a saturate filtered NaCl solution (1.22 g cm^{-3}) was slowly poured to overflow and collect the low density microplastics into the cylinder, this operation was repeated three times waiting 1 min between each overflow. The microplastics were filtered on GF-F fiberglass filters (0.7 μm) and the filters were rinsed with 5 mL of milli-Ro water and 5 mL of hexane. The microplastics were stained by 1 mL of Nile red solution (10 μg mL^{-1} in hexane) in 5 cm closed Petri plates for 30 min as in Maes et al. (2017) and the excess dye was removed filtering 5 mL of hexane to remove background staining. The microplastics were counted per optical field under a stereomicroscope (equipped with a 10 W blue LED and an orange photo filter). The images were recorded with a digital camera and processed by ImageJ to identify size (Feret diameter) in the range 30 μm–5 mm and particle circularity. The number of microplastics was normalized both on the dry biomass digested and on the number of organisms pooled and digested together. The values were expressed as number of microplastics per dry weight (items mg^{-1}) for station comparison and as number of microplastics per individual (items $individual^{-1}$) for species comparison. The coefficient of variation was estimated on a composite sample in which *R. philippinarum* was ground and sprinkled with polystyrene microplastics produced by a mincer, followed by repartition in three replicates and analysis. A spike recovery test was performed by addition of 100 polystyrene microplastics (with approximate diameter size 500 μm) to samples of *R. philippinarum* and *G. pulex* to estimate the microplastic yield of the method for low density microplastics.

2.4. FTIR identification

The two most contaminated benthic species (both per weight and per individual) identified by Nile red staining at the stations Mario Zucchelli and Adelie Cove were processed for a microFTIR qualitative identification of the particles. The organisms were digested in glass bottles with 5 mL of hydrogen peroxide (30% w/w in H_2O, contains stabilizer, Sigma Aldrich, purchased from Merck Darmstadt, Germany) as performed by Nuelle et al. (2015) on biogenic materials and were shaken on a orbital shaker for at least 72 h at room temperature. Digested samples were then filtered on ANODISCs (Anopore Inorganic Membrane, 0.2 μ, 47 mm, Whatman™, purchased from Merck, Darmstadt, Germany). Filters were rinsed before and soon after the filtration with ethanol and stored in glass Petri dishes previously decontaminated and dried for at least 72 h, before analysis. All these operations were performed in a plastic free clean room ISO 7. In order to qualitatively identify polymers, plastic particles were analyzed by micro-FTIR. A Nicolet iN10 infrared microscope (Thermo Fisher Scientific, Madison, WI, USA) with a liquid nitrogen-cooled MCT detector and motorized stage was employed; filters were analyzed in transmission mode with the WIZARD section of the OmnicTM PictaTM software and the collected spectra from 5 optical fields were then compared with specific reference library databases.

2.5. Statistical analysis

Data analysis was performed on microplastic contents and dry organisms using R, program version 3.5.1. The model that best fits the experimental data was obtained after removing existing outliers and examining the kernel density of all samples. As a result a linear regression was firstly applied to all data (Crawley, 2012) by mean of package “stats” in R (Hothorn and Everitt, 2009). Afterwards, due the lack of fit of linear model (O’Brien et al., 2009), we applied a one step non linear regression to samples by means of package “nlstools” in R (Baty et al., 2015). The goodness of fit was then assessed through the examination of the regression analysis of residuals (Box et al., 2005) by plotting the distribution of fitted values versus residuals (Montgomery et al., 2012). The model, which distribution of residuals showed no visual tendency (so randomly distributed around zero), was selected as the most adequate one (Tsai et al., 1998). The parameters were then estimated by Maximum Likelihood Estimation (MLE) method (Taboga, 2012).

3. Results

3.1. Method validation

The coefficient of variation of the analysis estimated from a composite sample was within 9%. The blank values were performed before and after the analysis and were considered acceptable within 3 items per filter. The microplastic spike recovery test yielded from 91 to 97% of the low density microplastics added to the samples on both soft and chitinous animals. The digestion efficiency was almost complete reaching 96% for soft tissues from *R. philippinarum,* but lower digestion efficiencies were found for *G. pulex* (73–86%) due to the abundance of insoluble chitin, though the NaOH solution alters the chitin preventing a subsequent staining with the Nile red dye that would otherwise interfere creating false positives. Additional information on the results of the tests were provided in supplementary material (Tables S2 and S3). The NaOH is known to produce the deacetylation of chitin and the conversion to chitosan (Elieh-Ali-Komi and Hamblin, 2016). This led us to assume that Nile red could interact with the acetylated groups that are cleaved during the NaOH digestion or the reaction could favor hydration and swelling of the chitin reducing the subsequent interaction with the non-polar staining solution. The microFTIR digestion method by H_2O_2 proved to be poorly compatible with the Nile red count method in this form and viceversa. The H_2O_2 digestion of the samples if used for Nile red count in epifluorescence do not remove the interference of chitin that is stained by Nile red, after the digestion, and became strongly fluorescent creating false positives in chitinous samples. Conversely, NaOH digestion prevents misidentification of chitin by epifluorescence but tends to dissolve and clog the ANODISC filters used for microFTIR identification (these filters had the lowest background signal in comparison with GF-F fiberglass filters), moreover NaOH digestion produce a dirty background that compromise the effectiveness of the microFTIR identification. This led the choice of the use of two different extraction methods for the two analysis.

3.2. Microplastic abundance

The 12 most abundant benthic taxa were considered in the 3 investigated areas (a total of 35 samples, due to the absence of *Eatoniella* sp. at Adelie cove). The 83% of the biological samples contained microplastics ranging from 0.01 to 3.29 items mg^{-1}. The size of the particles recovered from the environmental samples, measured by Feret diameter, ranged from 33 to 1000 μm with the 95% of the particles within 500 μm, the 70% within 200 μm and the highest relative abundance between 50 and 100 μm. The circularity (0/elongated shape particles − 1/circular shape particles) for the 80% of the particles was higher than 0.8 approximating the majority of the microplastics to a circular shape and only 2% displayed circularity values lower than 0.5 with elongated shapes similar to fibers (Fig. 2).

The average microplastic content for all species and areas was 0.7 items mg^{-1}, with relevant differences between different species. *H.*

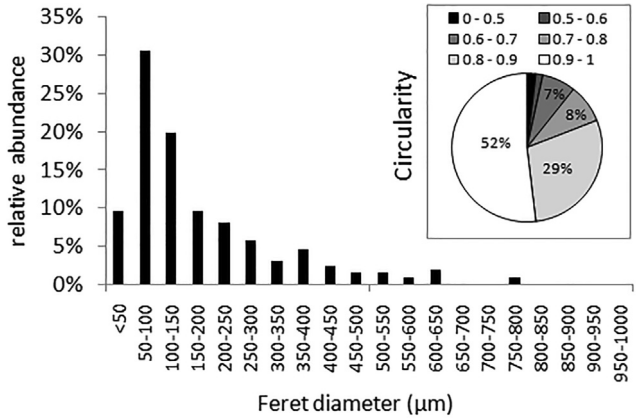

Fig. 2. Histograms of the relative abundance of microplastic for size range measured by Feret diameter – inset – Pie chart with the relative abundance of particles for circularity range (0/elongated shape-1/circular shape).

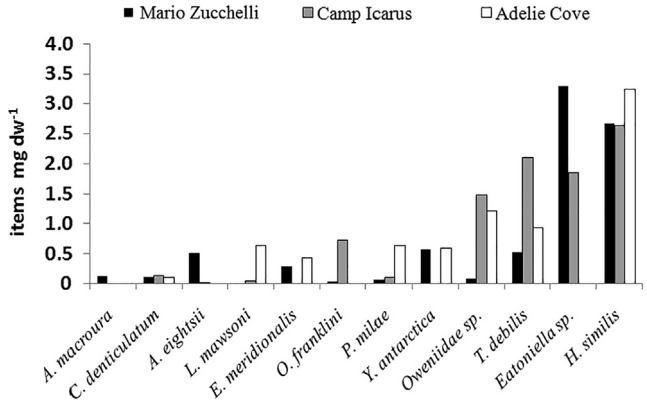

Fig. 3. Histogram of microplastic content per weight in different taxa.

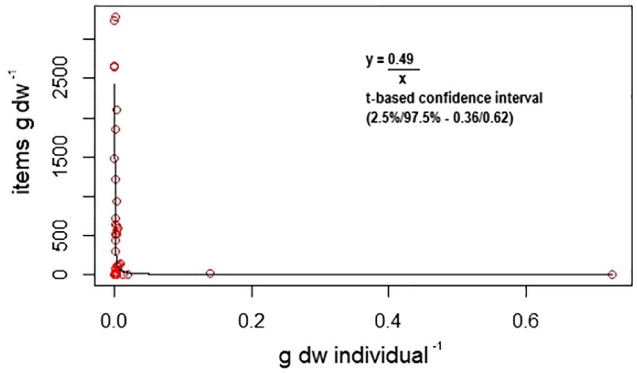

Fig. 4a. Plot of individual weights and relative microplastic contents with best fitting curve.

similis, Eatoniella sp., *Oweniidae* sp., and *T. debilis* displayed microplastic contents higher than 1.0 items mg^{-1} but for the first two organisms values as high as 3.2 items mg^{-1} were recorded at Adelie Cove and Mario Zucchelli, respectively (Fig. 3). Given the widespread presence of microplastics in all stations and species, if we assess the degree of contamination in different stations by the number of samples which were microplastic free (a minority of 17%) then no microplastic-free samples were found at Mario Zucchelli, which appears to contain a more widespread contamination between all the species. Microplastic-free samples were found for *Y. antarctica*, *O. franklini*, *A. macroura* and *E. meridionalis* in the other two sites. Eventually Camp Icarus was the station where the highest number of microplastic free samples was found and probably the least contaminated station. A global statistical analysis of average individual weights and relative microplastic contents showed a non linear model as the best fit (Fig. 4a), particularly the equilateral hyperbole function, as confirmed by fitted values vs residuals plot (Fig. 4b). Additional information on the test results were provided in supplementary material. This hyperbolic relation can be summarized by the smaller the organism (as organism weight), the higher the microplastic content. These microplastics should be considered as sum of both ingested and associated particles because the organisms were digested whole during the analysis and the washing step is not enough to ensure the complete removal of adsorbed particles.

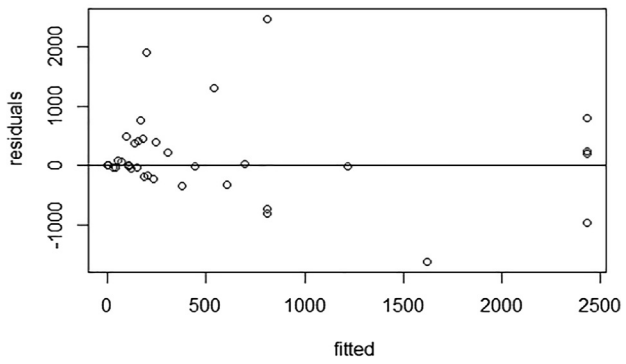

Fig. 4b. Fitted values vs residuals plot.

In order to compare organisms that are taxonomically different and with very different average sizes per taxon, we have chosen to unbind the number of plastics from biomass by normalizing the microplastics on the number of individuals analyzed per pool; in such a way the taxa become comparable without influences related to the size of the organism. This operation highlights that the microplastic content per individual is on average the highest in the bivalves (1.9 items $individual^{-1}$), follows with a decreasing trend the gastropod *Eatoniella* sp. (1.2 items $individual^{-1}$) then polychaetes, amphipods and cnidarians (Fig. 5). Globally, the mean microplastic content for all species was 1.0 items $individual^{-1}$. Filter feeders and grazers displayed on average values from 3 to 5 times higher than omnivore and predators, such as *A. macroura*, *E. meridionalis* and *H. similis* (average value of 0.4 items $individual^{-1}$) and this seems to exclude a trophic chain accumulation of particles toward predators among the identified organisms of the benthic communities.

Eventually in Fig. 6 data were plotted for all species and all areas about individual microplastic content and number of individuals counted per grab. The graph highlights a trend in which the numbers of microplastics per individual decrease at increasing numbers of

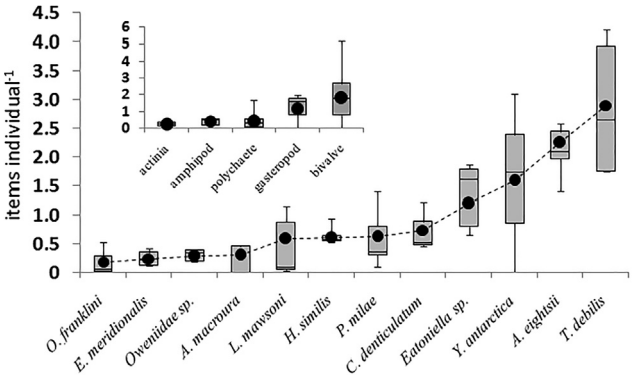

Fig. 5. Box-plot of microplastic content per individual in different taxa (combined data from all stations) with mean values (black dots). - inset- Box-plot of microplastic content per individual grouped at higher taxonomical orders.

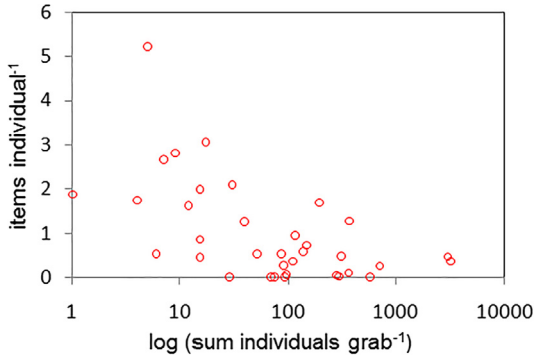

Fig. 6. Plot of microplastic content per individual at increasing numbers of individuals per grab.

individuals counted per unit of area (grab area is 31 cm × 58 cm). This represent a repartition of a space limited stock of microplastics among organisms of the community. The more they are, the less microplastics they have each.

3.3. Microplastic identification

The most contaminated species per individual and biomass were *H. similis, T. debilis*, *A. eightsii* and *Eatoniella sp*. No samples of *Eatoniella sp*. were available after Nile red count for further FTIR identification of the polymers. The microplastics were identified in *H. similis* (20 individuals from Mario Zucchelli and Adelie Cove), in *T. debilis* (4 individuals) and *A. eightsii* (3 individuals) from Mario Zucchelli and Adelie Cove, respectively. The identified microplastics from all samples were grouped in 13 categories of polymers (Table 1). Overall, the dominant polymers were those of the nylon family, especially aromatic polyphthalamide, polyarylamide (a partially aromatic polyamide) and generic polyphthalamide and polyamide for a global 86% of the microplastics composition. Nylon contamination was high for both stations but the relative abundance at Adelie Cove reached 93% in comparison with the 73% reported at Mario Zucchelli. On the other hand the second most abundant polymer family was that of polyethylene with an average 5% percentage and similar abundances in both stations. Eventually polytetrafluoroethylene particles were identified only at Mario Zucchelli with percentages of 14% and other compounds with percentages lower than 3% were: polyoxymethylene, phenolic resin, polypropylene, polystyrene resin and XT polymer.

4. Discussion

Recently, attention has been paid to the phenomenon of microplastic occurrence in samples from the most remote regions of the planet confirming the ubiquity of this class of contaminants in all the environmental spheres: terrestrial lands, freshwaters, deep ocean, remote lakes and air (Free et al., 2014; Gasperi et al., 2015; Horton et al., 2017; Van Cauwenberghe et al., 2013). Additionally, many researchers face considerable technical difficulties to avoid the contamination of the samples during sampling, transport and analysis phases and this is indicative of the ubiquity and dispersion of these contaminants. To date, there is little information on the presence of microplastics in Antarctica which has been reported as an emerging study area in this research field (Waller et al., 2017). In this framework we convey the first report on microplastic contamination in Antarctica benthic organisms. The results confirm an important presence of microplastics in the benthic communities from Terra Nova Bay (Ross Sea) and no substantial differences were recorded in the average microplastic content between the investigated sites (Mario Zucchelli, Camp Icarus, Adelie Cove). Nevertheless, if we consider the number of microplastic free samples, Mario Zucchelli result as the most contaminated station. This assumption find support in data provided for microplastic contamination in water and sediments from the bay, which highlighted the highest microplastic contamination in proximity of the Mario Zucchelli base station (Cincinelli et al., 2017; Munari et al., 2017).

Dominant polymer types found in the benthic fauna reflected the abundance of polymer types found in sediments of the same area (Munari et al., 2017), with nylon and polyethylene being the most common types. However, we found differences for other polymers (polystyrene-butadiene-styrene, polyvinyl chloride, polyester and polymethylmethacrylate), which were found in waters and sediments of Terra Nova Bay (Cincinelli et al., 2017; Munari et al., 2017), but not in its benthic fauna. Moreover, the fiber content identified in the benthic organisms was lower in comparison with the fiber content reported for surface water and sediment in those previous studies. This could be related to the fact that fibers are reported as the dominant shape in large microplastics (particles larger than 300 μm; as the ones measured in Munari et al. (2017), conversely the fragments should be the expected dominant shape in small microplastics (< 300 μm; Wang et al., 2018a,b). The difference in the small microplastic fraction could also be related to the averagely higher polyester percentages (28.6%) previously reported for surface waters of the same area (Cincinelli et al., 2017) and polyester represent the main polymer in the production of synthetic fibers for clothing in the world (Narayanaswamy et al., 2014). However, the micro-FTIR identification of microplastics in the benthic organisms (for which no floating steps of particles in high density solutions were carried out) excluded a significant presence of polyester and polyvinyl chloride associated with the benthic organisms. Moreover the absence of these polymers in the organisms examined with micro-FTIR seems to exclude the presence of particles non identifiable with the Nile red staining method in the range 30–1000 μm (Shim et al., 2016; Tamminga, 2017), except for high density polytetrafluoroethylene (14% – density 2.2 g cm^{-2}) that was recovered from both *A. eightsii* and *H. similis* in proximity of Mario Zucchelli Base.

Table 1
List of identified polymers and relative abundances at Mario Zucchelli, Adelie Cove and global contamination.

POLYMER		Mario Zucchelli		Adelie cove		Global	
Polyphthalamide-Aromatic (PAA)	(Nylon)	45%	73%	84%	93%	72%	86%
Polyarylamide (PARA)		22%		3%		9%	
Polyphthalamide		6%		4%		4%	
Polyamide (PA)		0%		2%		1%	
Polyethylene KR 16		4%	6%	2%	5%	3%	5%
Polyethylene type F	(Polyethylene-PE)	2%		2%		2%	
Ethene homopolimer		0%		1%		1%	
Polytetrafluoroethylene (PTFE)		14%		0%		4%	
Polyoxymethylene		0%		3%		2%	
Phenolic resin		2%		0%		1%	
Polypropylene (PP)		2%		0%		1%	
Polystyrene resin (PS)		2%		0%		1%	
XT Polymer (375-000-301)		2%		0%		1%	

Following the conceptual model of the "boomerang effect" proposed by Liubartseva et al. (2018) the microplastic source may be local for about 50% of the polymers, probably finding in Mario Zucchelli its main source, however we must emphasize that a polymer composition similar to ours was reported by Fang et al. (2018) for the Arctic and sub-Arctic benthic organisms on the opposite side of the globe, in which the three dominant polymers were: polyamide (nylon − 46%), polyethylene (23%) and polyester (18%). The main polymers reported for the Arctic sediments in Peng et al. (2018) were polyethylene, polyamide and polypropylene that were reported to account for 76% of the plastic polymers. Therefore especially nylon and polyethylene microplastics could have a global diffusion in benthic habitats.

As for the content of microplastics in the organisms, taxa specific accumulations are revealed when we consider the content of microplastic fragments per individual, untying it from the average size of the organisms. Both the gastropod *Eatoniella* sp. and the bivalves displayed values averagely higher than 1.0 item individual^{-1} and bivalves displayed on average the highest number of microplastics per individual in accordance with previous reports on bivalves and filter feeders from laboratory experiments and a survey work (Kaposi et al., 2014; Setälä et al., 2016; Waller et al., 2017). Filter feeders, by their feeding mode concentrate food from large volumes of water and usually display the highest amount of microplastics. The average values found for bivalves correspond to half of the lowest microplastic content per individual reported by Li et al. (2015) in bivalves from the Shanghai market (4.3 items individual^{-1}) and the values are within the range found by Su et al. (2018) of 0.4–5 items individual^{-1} from the estuarine areas of the Yangtze River. Moreover, the mean abundance of microplastics in all the Antarctica benthic organisms, corresponding to 1.0 items individual^{-1}, was slightly higher than the 0.8 items individual^{-1} reported for benthic organisms from Arctic and sub-Arctic regions. This highlights a similar sparse microplastic contamination reaching two poorly populated extremes of the earth further confirming the wide diffusion of this contaminant.

The role that microplastics play in the environment, in many cases mimicking food, is closely linked to the feeding mode and size of the investigated organisms (Wright et al., 2013) and an inverse relationship has been found between microplastic abundance in the organisms by weight and the individual specific weights. This inverse relationship describes higher scores of microplastics associated with smaller organisms. This fact could be explained by the higher specific surface of interaction of small organisms with the surrounding habitat and surface sediments. The debate on the effects of microplastics at different levels of the ecosystem complexity and their role as pollutants or carriers is still open. Concerns has been raised in regard to the transfer toward the sediments and the benthic communities of hydrophobic persistent organic pollutants such as polychlorinated biphenyls (PCB) and polycyclic aromatic hydrocarbons (Batel et al., 2016; Derraik, 2002; Mato et al., 2001; Wang et al., 2018a,b). However the evidences on the contribution of microplastics to the trophic transfer of persistent organic pollutants are still scarce and the microplastics do not seem to clearly meet all the criteria (especially bioaccumulation and adverse effects) for being themselves defined as persistent organic pollutants (Koelmans et al., 2016; Ziccardi et al., 2016; Lohmann, 2017). No phenomena of accumulation of microplastics towards predators in the benthic trophic chain was noted among the investigated organisms (all invertebrates) as previously stated by Bour et al. (2018), conversely the lowest levels in the trophic chain, filter feeders and grazers, have shown the highest numbers of particles per individual. However this does not exclude accumulation phenomena toward bigger predators, for which a severe lack of evidence was reported (Au et al., 2017). The microplastic contamination seems to be shared among the organisms of the benthic community highlighting that the structure of the community affect as much as the environmental contamination the repartition of microplastics between benthic organisms. Even if microplastics did not have any direct effects on the organisms by simply being continuously ingested and expelled (Dawson et al., 2018) this could progressively ease the release of organic and inorganic plastic additives for which very few data are currently available (Lohmann, 2017) and that could represent an ecotoxicological risk especially for benthic marine organisms (Hermabessiere et al., 2017).

5. Conclusions

The benthic communities of Terra Nova Bay showed diffuse microplastic contamination in all the areas investigated and at all the levels of the benthic trophic chain. The most abundant polymers identified in the benthic organisms were part of the nylon and polyethylene family. Bivalves and gastropods displayed the highest microplastic contamination among the Antarctica benthic invertebrates, comparable to the values reported for other, less remote areas. No evident accumulation through the food web was detected. It is still not clear if the role of microplastics is that of pollutants or only of contaminants, however, it is necessary to deepen the knowledge on distribution and effects of microplastic and additives at all the levels of the food web to evaluate from a wider viewpoint the effects on marine organisms and ecosystems.

CRediT authorship contribution statement

Andrea Augusto Sfriso: Methodology. **Yari Tomio:** Investigation. **Beatrice Rosso:** Investigation. **Andrea Gambaro:** Investigation. **Adriano Sfriso:** Resources. **Fabiana Corami:** Investigation. **Eugenio Rastelli:** Investigation. **Cinzia Corinaldesi:** Resources. **Michele Mistri:** Conceptualization. **Cristina Munari:** Project administration, Investigation.

Declaration of Competing Interest

This manuscript has not been published previously, that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2020.105587.

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