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Special issue plastics in polar regions

Plastic contamination is a pervasive environmental issue impacting over the most remote regions of the planet, including scarcely inhabited mountains (Allen et al., 2019), offshore islands (Lavers and Bond, 2017) and deep ocean trenches (Jamieson et al., 2019).

Polar regions have long been considered unique and pristine environments, however anthropogenic pressure, which more recently includes plastic pollution, is increasingly posing new threats also to these remote ecosystems (Aronson et al., 2011; Stark et al., 2019). Although detected in limited amounts compared to other regions of the world, records of plastic litter in Arctic and Antarctic islands date back to the 1970–80s. Early reports documented microplastics occurrence in the Arctic sea ice (Obbard et al., 2014; Peeken et al., 2018), surface waters (Cózar et al., 2017) and deep-sea sediments (Bergmann et al., 2017). In the Southern Ocean, floating macroplastic (i.e. fishing buoys and packaging bands) were found along the shores of Antarctic and Sub-Antarctic islands (Convey et al., 2002) and down to 73° S in the Bellingshausen Sea (Barnes et al., 2010). Do Sul et al. (2011) defined as a "tip of an iceberg" the discontinuous observations of marine debris in the Southern Ocean which raised serious concerns by the scientific community on the actual ability of the Antarctic Circumpolar Current (ACC) to prevent the transboundary movement of plastics (Isobe et al., 2017).

Plastic pollution, as a further anthropogenic stressor for polar regions, may affect the capability of polar organisms to cope with other sources of disturbance which have already been documented both at global (e.g. climate change, ocean acidification) and regional scale (e.g. fisheries, tourism and contamination from research stations) (Stark et al., 2019). Plastics can exert extremely diversified impacts on polar wildlife, whose severity depends not only on the intrinsic properties of plastics (e.g. size, shape, surface charge and polymeric composition) but also on the polar environmental conditions (e.g. UV radiation, strong winds, low temperatures) which could significantly affect their behavior and fate. First studies on plastics in polar regions show substantial transformation in plastic size and behavior once taken up by living organisms with potential detrimental effects along food chains (Dawson et al., 2018) or highlight the role of plastics as potential vectors of the spread of antibiotic resistances when colonized by microbial communities (Laganà et al., 2019).

The aim of this special issue *Plastics in polar regions* is to collect the latest advances regarding plastic pollution in polar regions and boost the scientific research on this topic. The special issue arises from an idea shared among the Guest Editors from both the Italian Institute of Polar Sciences and the University of Siena (Italy), actively involved in the field and within the Action Group "Plastics in polar environments" of the Scientific Committee on Antarctic Research (SCAR) (https://www.scar.org/science/plastic/home/). Both SCAR and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) recently recognized microplastics in polar regions as a "serious and emerging threat" (CCAMLR Secretariat, 2019; SCAR, 2020).

This collection includes 10 high-impact papers which cover several research topics from plastic occurrence and distribution from sea-ice, along water column down to sediments and biota, methods of quantification of microplastics with challenges associated with samples coming from remote environments and their potential impacts in the Arctic and in the sub-Antarctic and Antarctic regions. Policy recommendations in terms of mitigation strategies to manage plastic waste and reduce the contamination in such remote regions are also included, with a contribution of the 5 Gyres Institute.

The issue of plastic contamination in polar regions is thus presented under different perspectives, through field-based and laboratory studies, and at different levels, from macro-sized debris down to meso-, micro- and nanoplastics, following the metrology proposed by Hartmann et al. (2019).

In the Arctic, von Friesen and co-workers demonstrate how in two fjords of the Svalbard archipelago the origin of anthropogenic microlitter (AMPs < 50 μm, ranging from 3 to 95n/L) from summer sea ice melting throughout the water column is concomitant with ice-edge bloom of sympagic and pelagic marine communities. An additional land-based point source of AMPs from local wastewaters is also hypothesised along the coast of Svalbard's fjords, where a large presence of synthetic and non-synthetic fibres of textile origin is found in surface waters.

In the Southern Ocean, a first circumpolar baseline of the abundance of floating plastics across a broad size spectrum (from macro- to microplastics) is reported south of the Subtropical Front (STF) by Suaria and co-workers in the framework of the Antarctic Circumnavigation Expedition (ACE) in 2016/2017. The density of floating plastics south of the STF is very low, further supporting the barrier role of the fronts, winds and ACC in preventing the southward transport of drifting litter in the Southern Ocean. In a similar field survey but on a smaller scale, Jones-Williams and co-workers report the occurrence of plastic debris (down to 300 μm) in surface waters of the Scotia Sea, in the Atlantic sector of the Southern Ocean down to Adelaide Island, near the Antarctic Peninsula. Furthermore, they show that microplastics -even in low amounts - are consumed by zooplankton and "hot-spot" areas of large biomass should be targeted in future studies to understand biological interactions with plastics. In a survey conducted over three decades at Bird and Signy Islands in the Scotia Sea, Waluda and co-workers document a dominance of beached macro- and mesoplastic (>5 mm) (97.5% by number) among other anthropogenic waste materials. As suitable

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bioindicators of plastic input from vessels sailing across the southwest Atlantic Ocean, Phillips and Waluda propose seabirds such as albatrosses and petrels, due to their documented highest ingestion rates of plastics among marine vertebrates. Long time-series measurements (available since 1994) reveal a substantial variation in the amount, characteristics and origin of marine debris (mainly macro- and meso-plastics, excluding fishing gears) in seabirds at South Georgia Island and, for the two target species, long-term increase in incidence since 1994.

Current methods to extract and detect plastic from biota are quite diverse in terms of number and/or mass of recovered plastic debris and have limitations, such as for instance different size detection limits.

This special issue proposes suitable protocols to be applied for microplastic extraction from polar marine organisms, including zooplankton (see Jones-Williams et al.) and benthos (see Sfriso et al.) as well as a specific method developed for the isolation and detection of polymeric fibres from not destructive samples of seabirds (see Le Guen et al.). In the first survey of microplastic contamination in benthic fauna from the Ross Sea (Terra Nova Bay), Sfriso and co-workers document the presence of microplastics (0.01–3.29 items/mg, size ranging from 33 to 1000 μm) in 83% of the macrobenthic species analysed. The similarity in polymer composition (polyamide, polyethylene and polyester) with microplastics found in Arctic benthos (Fang et al., 2018) supports the hypothesis that plastic debris has a global diffusion in benthic habitats. A first indirect evidence of microfiber ingestion in the King penguin *Aptenodytes patagonicus* foraging at South Georgia Island is reported by Le Guen and co-workers, who show also how the majority of plastic contamination (88%) is related to natural cellulosic fibres, rather than those of synthetic origin (polyester, nylon or rayon). A higher fibre loads is found in the excreta of incubating penguins, potentially related to the distance of foraging, with a potential transfer to chicks. In terms of ecological risk assessment of plastic pollution in polar areas, two bench-scale studies investigate for the first time the impact of micro- and nano-scale polystyrene beads (PS) -as a proxy for micro- and nanoplastics - on sensitive species of primary producers and consumers. Hoffmann and co-workers clarify how the interaction between the ice diatom *Fragillariopsis cylindrus* and PS microbeads (0.5 μm) has an influence on plastic incorporation into sea ice, with possible implications for the sympagic food webs, strictly associated to sea ice.

Moving down to nanoplastics, Bergami and co-workers investigate the acute short-term toxicity of PS nano-spheres (50–60 nm) on juveniles of the Antarctic krill *Euphausia superba*, showing disruption in moulting and swimming behaviour but also egestion in faecal pellets with associated changes in microbial communities and their sinking properties. Antarctic krill is thus able to feed on nanoplastics and egest them as faecal pellets with consequences on their biodistribution by increasing their residence time in the epipelagic zone (down to 200 m depth). This could affect their remineralization by zooplankton and prokaryotes, which, in turn, could have an impact on C transfer and sequestration to the Southern Ocean sea floor.

A New Development article on plastic waste management in polar regions, with a focus on their socioeconomic and cultural impacts on Arctic remote communities is included. Eriksen and co-workers identify the best mitigation strategies to adopt from pole to pole, including monitoring programs for plastic contamination, advanced waste management in remote areas, the application of extended producer responsibility and "leave no trace" policies.

To conclude, this special issue *Plastics in polar regions* provides an extensive overview of plastic contamination in the Arctic and Antarctic environments, highlighting the importance of wide monitoring efforts to catalogue marine debris and long-term dataset to identify trends and impacts. The novel bench-scale studies address the interactions of plastic particles of different size including nanoplastics with two sensitive ecological levels: primary producers such as the sea ice diatom and primary consumers such as the Antarctic krill. Here, we would like to thank the Editors (Adrian Covaci and Da Chen) and the Journal Manager for encouraging and supporting this special issue, and their assistance throughout the editorial and review process. We also acknowledge the anonymous reviewers for their efforts and critical comments and the authors for their contributions regarding the theme of plastic pollution occurrence and effects in polar regions.

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.

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