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Plastic Pollution in the Southern Ocean

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Summary

Plastic pollution has been reported in the Southern Ocean for at least the past four decades. It is important to understand the origins of plastics, their transport routes and their distribution in the Southern Ocean, sub-Antarctic islands and continental Antarctica. There is an urgent need to assess the impact of macro-, micro-, and nanoplastics on the environment and biota, and how these interact with other anthropogenic stressors, such as toxic chemicals, fisheries, ocean acidification, and climate change. We highlight the benefits of introducing standardised monitoring and impact assessment methodologies and tools, as well as the importance of increased global cooperation in addressing the issues of plastic pollution in the Southern Ocean and Antarctica.

Introduction

The Southern Ocean provides fundamental ecosystem services for our planet, playing a major role in global oceanic circulation, being responsible for 40% of the global anthropogenic carbon uptake, and supporting fisheries for Antarctic krill and toothfish (Kennicutt et al. 2015).

Antarctica is often considered to be a "pristine" environment, but despite significant measures in place for environmental protection, plastic pollution has been reported from open ocean, marine and coastal environments around the Antarctic continent and many sub-Antarctic Islands (e.g. Waller et al. 2017; Jones-Williams et al. 2020; Caruso et al. 2022). Being well adapted to extreme but stable environmental conditions, with unique phenotypic traits, Antarctic species can be highly vulnerable to environmental perturbations and chemical pollution, with plastic pollution posing a potentially serious threat to finely balanced Southern Ocean ecosystems.

Plastic found in the Southern Ocean is likely to have originated from both local and global sources, with new evidence that some items may have entered the ocean at lower latitudes, crossing perceived oceanographic barriers to reach Antarctic coasts (Rota et al. 2022). Therefore, it is critically important that the impact of plastic pollution on Southern Ocean ecosystems should not be considered in isolation but set in a global context. It is widely accepted that scientific research needs to address this issue in a transdisciplinary manner, encompassing knowledge and competencies from both global and regional experts. Understanding the interconnection between the various anthropogenic impacts (including climate change) affecting the Antarctic must be considered a priority in order to properly assess the impact of plastic pollution.

The SCAR Plastic in Polar Environments Action Group

The SCAR Plastic in Polar Environments Action Group (Plastic-AG) was established in June 2018 in order to connect researchers from around the globe with an interest in plastic pollution in Polar regions. The key aims of the Plastic-AG are to collate information, establish baselines, understand the impacts of plastic pollution, establish standardised procedures for sampling and monitoring, and propose new measures to reduce and/or limit any potential negative impacts on Polar Environments.

Key milestones to date include:

i) launch of the PLASTIC-AG at a side meeting at SCAR POLAR 2018 in Davos, Switzerland;

ii) collation of open access data for all plastic pollution records in the Southern Ocean, from published literature (up to 2016) hosted by the Southern Ocean Observing System (SOOS) http://www.soosmap.aq/;

iii) an International workshop on "Plastic in the Polar Environment: sources, impacts and solutions" in 2019 at the University of Hull, UK;

iv) the publication of a special issue of the journal *Environment International* (Elsevier) in 2020 entitled: "Plastics in Polar Regions";

v) a session on "Plastic in the Southern Ocean" during the XXXI SETAC Europe Annual Meeting in 2021;

vi) a Satellite Activity under the umbrella of the UN Ocean Decade on "Plastic pollution in the Southern Ocean: a global outlook" in 2022;

vii) the establishment of a Plastic-AG Early Career researcher network to share upcoming events and opportunities;

viii) the establishment of the first open access polar plastics repository summarising national and international projects dealing with plastic pollution in the Antarctic and sub-Antarctic regions (https://www.scar.org/scar-news/plastic-news/project-repository/).

Types of plastic pollution in the Southern Ocean

Macroplastics (defined as > 5 mm) were first observed in the Southern Ocean in the 1970s with reports of seals entangled in marine debris (Bonner and McCann 1982) and the ingestion of plastics by seabirds (Van Franeker and Bell 1988). Microplastics (1 µm-5 mm) were first reported by Thompson et al. (2004), but not recorded in the Southern Ocean until 2009, when particles were identified in intertidal sediments from South Georgia Island (Barnes et al. 2009). Since then, microplastics have been reported in shallow waters (<50 m depth) at a number of locations around the Antarctic Peninsula and South Georgia; in deep sea sediments of the Weddell Sea; in East Antarctic sea ice and in circumpolar surface waters (Van Cauwenberghe et al. 2013; Waller et al. 2017; Kelly et al. 2020; Suaria et al. 2020).

Nanoplastics (< 1 µm) are the most recently reported type of plastic in Antarctica, with a single record from a sea ice core from Cape Evans, Ross Island (Materić et al. 2022). As such, nanoplastics may originate from sources such as emissions from atmospheric and marine transport, (re)emission, deposition and ice incorporation, however both their environmental occurrence and distribution are still in the very early stages of evaluation.

Impact of plastic pollution on Southern Ocean ecosystems

The presence of macroplastics on shorelines and in association with seabirds (Waluda et al. 2020; Phillips and Waluda 2020), and their impacts on marine species including entanglement (Waluda and Staniland 2013) have been monitored by the Commission for the Conservation of Marine Living Resources (CCAMLR) since 1989 (https://www.ccamlr.org/en/science/marine-debris). In addition, CCAMLR has implemented measures to reduce the amount of debris entering the marine system and to mitigate its impact in Antarctica. While microplastic pollution is recognised by CCAMLR as an emerging threat, it is not currently part of its routine monitoring programme.

Microplastics have been shown to be present in terrestrial collembola, marine invertebrates, fish and air-breathing predators such as penguins and seals (Caruso et al. 2022), however neither sources nor transfer mechanisms through the Antarctic food webs have yet been clearly described. It is likely that the unique and extreme environment of the Southern Ocean (high levels of ultraviolet irradiance in summer, wave action, ice scour and low temperatures) may contribute to the rapid breakdown of macroplastics into micro- and nanoplastics, increasing their bioavailability and potential risk to Antarctic species and ecosystems.

Recent findings show how sea-ice-associated species, such as Antarctic krill could play a role in the fragmentation of microplastics down to nanoscale dimensions, increasing the probability of exposure through marine food webs (Dawson et al. 2018). Due to their size and high surface

reactivity, nanoplastics can easily cross biological barriers with resulting adverse toxicological effects. Cellular uptake and disruption to the immune response of some Antarctic benthic grazers (sea urchins) and changes in swimming and moulting of Antarctic krill have only recently been reported (Bergami et al. 2019; Bergami et al. 2020).

Plastic pollution and multiple stressors on Southern Ocean ecosystems

Addressing the potential impact of plastic pollution in isolation does not allow us to fully predict consequences in years to come. It is critical to account for potential cumulative effects with other stressors, and efforts should be made to implement a holistic and interdisciplinary approach to studying plastic pollution in the Southern Ocean.

The interactions between climate change and micro- and nanoplastics are likely to magnify the potential for interactions with other toxicants, as well as lead to an enhanced susceptibility of Antarctic species to these stressors. A particular focus on keystone species, such as Antarctic krill, which support Southern Ocean ecosystems, is required in order to understand realistic plastic toxicity thresholds and potential trophic cascade impacts through the pelagic food web. Some impacts of multiple stressors have already been shown, with the development of Antarctic krill embryos being lowest under a scenario where nanoplastic exposure is coupled with ocean acidification (Rowlands et al. 2021). Nevertheless, expanding the scope of studies from single to multiple stressors is challenging, requiring a combination of empirical, experimental, and modelling approaches.

Improving understanding of plastic pollution in the Southern Ocean

The challenge of understanding the impact of plastic pollution in Antarctica is compounded by the difficulty in collecting samples and data, due to the remote location and inaccessibility of many study areas and species. For this reason, it is crucial to develop a common set of actions and strategies for consistent and replicable data collection and to establish standard procedures for monitoring the Southern Ocean and Antarctica. This will also enable scientists to increase spatial and temporal data coverage in order to improve our understanding of the fate and behaviour of plastics and their effects. This will require a joint effort from all stakeholders operating in the Southern Ocean and in adjacent regions, as well as knowledge and information exchange between scientists, industry, environmental agencies and conservation and management bodies.

ATCM Resolution 5 (2019) on *Reducing Plastic Pollution in Antarctica and the Southern Ocean* noted that there is a current lack of plastics monitoring data to inform decision-making and recommended the support of greater monitoring of plastic pollution in Antarctica using developing standards and comparative methodologies, particularly near areas of human activity. The Resolution further invited SCAR to report as new information emerges that quantifies plastic pollution and details the risks to Antarctic species and communities.

The CEP has also identified specific science needs regarding plastic pollution, including:

- Assess the impact of plastic pollution on natural systems under “multiple stressors” scenarios.
- Determine sources and transport routes of plastic pollution in Antarctic marine and terrestrial environments.

To support these aims and science needs, SCAR recommends that further research should be focussed on the following priorities:

1) Evaluating the extent of plastic pollution in the Southern Ocean. This includes assessing the distribution and concentration of plastics generated from both within and outside the Southern Ocean, and defining their behaviour across food webs as well as their response to specific environmental conditions. The PLASTIC-AG will continue its mission to increase awareness of the importance of studying plastic pollution in the Southern Ocean, and encourages the

participation of additional nations and scientific research institutes operating in Antarctica in future meetings and scientific publications.

2) Improving our understanding of current and future effects of plastic pollution on Southern Ocean biota and ecosystems. This can be achieved by identifying critical hotspots of cumulative impact of plastic with other toxic chemicals, determining individual and additive toxicity thresholds, and identifying biological and genetic adaptation strategies that may provide resilience to the impact. Furthermore, it is important to set plastic pollution in the context of climate change by taking into account the interaction between plastic pollution and multiple stressors. The PLASTIC-AG has also established an ongoing collaboration with the SCAR Input Pathways of Persistent Organic Pollutants to Antarctica (IMPACT-AG), with the aim of progressing common objectives.
3) Providing the research evidence needed to underpin effective global co-operation to build a common framework for developing an Antarctic "plastic footprint" action plan. The PLASTIC-AG has already instigated a number of activities including the Plastics at the Poles workshop and Ocean Decade satellite event, with more to come in the next 2 years.
4) Consolidating information on plastic-related activities and initiatives from different nations operating in Antarctica. The PLASTIC-AG has made published locations of plastic pollution available via SOOSmap (http://www.soosmap.aq/) and is leading the generation of an Antarctic plastics repository along with a user-friendly map displaying current project locations. This will be made freely available at: https://www.scar.org/science/plastic/home/.

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