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Persistent Organic Chemicals in Antarctica: A horizon scan of priority challenges

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Information Paper submitted by SCAR

Summary

This information paper has been developed by the SCAR [ImPACT \(Input Pathways of Persistent Organic Pollutants in Antarctica\) Action Group](#) and presents a horizon scan of priority challenges in the field of persistent organic chemical research in Antarctica.

Persistent Organic Pollutants (POPs) are a subset of synthetic chemicals that share the four characteristics of: i) persistence, ii) mobility in the environment, iii) toxicity, and iv) tendency to bioaccumulate. The SCAR ImPACT Action Group was established in 2018 to facilitate coordinated investigation and monitoring of chemical input to the Antarctic region. In March 2021, all ImPACT members were invited to participate in a scoping meeting to identify key priorities for Antarctic persistent organic chemical research.

This paper presents a summary of identified priority research gaps and suggested actions arising from this meeting. It suggests potential approaches for coordinated research and monitoring efforts and highlights the importance of such activities for informed policy decision-making. It also outlines a number of actions needed to align Antarctic persistent organic chemical research with international efforts and existing global monitoring frameworks. The ImPACT Action Group aims to undertake further work towards specific recommendations, in consultation with other interested groups.

Background

Mitigating human influences in Antarctica has been identified as one of six priorities for Antarctic science^{1,2}. Global chemical production is increasing faster than chemical policy frameworks can respond³. In the Antarctic context, these challenges are compounded by considerable regional research gaps, serving to elevate the need for timely progress in the field of Antarctic chemical research via collaborative, policy-relevant research⁴.

Globally, a reliance on chemical innovation to meet industrial and societal challenges has grown exponentially over the past 70 years. Today, 1 million new chemicals are produced every year³. Managing the myriad of chemicals present in the natural environment represents one of the greatest Planetary Health challenges of our time^{5,6}.

Persistent Organic Pollutants (POPs) are a subset of synthetic chemicals that demonstrate the four shared characteristics of: i) persistence, ii) mobility in the environment, iii) toxicity, and iv) tendency to bioaccumulate. Concerns regarding the human and environmental impacts of POPs led to the promulgation of the Stockholm Convention in 2004, an international agreement that aims to restrict and eliminate the use and production of such chemicals.

The majority of listed POPs are semi-volatile compounds that achieve environmental mobility via atmospheric transport, moving along temperature gradients to progressively colder latitudes, thus making the polar regions of the Earth 'sink' environments for these compounds. An expanding diversity of chemical structures, and therefore chemical behaviours, flagged as 'of concern' has meant that increasingly hydrospheric, and even biological long-range environmental transport pathways must also be considered when trying to uncover Antarctica's chemosphere. Frequent incomplete knowledge surrounding each of the four POP risk criteria for individual chemicals, and associated time lags in regulation of chemicals, has led to a broadening of the research and monitoring scope beyond regulated POPs, to include other persistent organic chemicals, or "POP candidates". Polar regions are special interest areas for persistent organic chemical research, both from environmental management and chemical policy viewpoints.

POPs have been detected in Antarctica since the 1960s⁷, yet research on this topic is inherently slow. In 2009, the former SCAR Environmental Contaminants in Antarctica (ECA) Action Group carried out a review of Polycyclic Aromatic Hydrocarbon and POP research in Antarctica⁸, reporting just 35 publications between 2000 and 2008. This report, combined with several subsequent review articles (e.g.^{9,10}) contributed an overview of past organic chemical research in the Antarctic context. The slow output of the field is the result of common challenges associated with organic chemical research, such as the high cost of analysis. These are amplified in the Antarctic context where they are compounded by: the logistical challenges of Antarctic fieldwork, and limitations in infrastructure and service support; difficulties in detection/contamination risk; and sporadic and unpredictable access to Antarctica. Limited opportunity for successful research in turn carries the risk of portraying the erroneous impression that there is adequate understanding, and that current operational approaches are appropriate.

The purpose of this information paper is to highlight key areas of persistent organic chemical research in Antarctica that require traction in order to close limiting research gaps; and secondly provide a framework of suggested actions to address these gaps and inform decisions on related chemical and environmental policy.

This paper is produced by the SCAR ImPACT Action Group, which was established in 2018 to facilitate coordinated investigation and monitoring of chemical input to the Antarctic region. ImPACT has four objectives within the term of the Action Group, which are to:

- 1) Co-ordinate current and ongoing research efforts aligned with the Action Group terms of reference, ensuring data collected meets minimum quality assurance requirements for temporal trend collation, and that data is made publicly available via open source data repositories.
- 2) Pursue national and multi-national funding strategies for establishment of permanent atmospheric monitoring stations at multiple sites across the continent.
- 3) Publish collaborative synthesis works arising from coordinated monitoring efforts.
- 4) Identify ways in which the ImPACT Action Group can facilitate the establishment of an Antarctic Monitoring and Assessment (AnMAP) body (acknowledging that this requires progress and actions beyond the capacity and term of the Action Group)

In March 2021, all ImPACT members were invited to participate in a scoping meeting to identify key priorities for Antarctic persistent organic chemical research. This horizon scan is a summary of identified priority research gaps and suggested actions arising from this meeting.

Horizon scan – limiting research gaps

1. Regulated versus ‘suspect’ POPs in Antarctica

Environmental monitoring in Antarctica has to date focused on chemicals of regulatory relevance, via targeted methods. Targeted analytical approaches using mass spectrometry, present benefits in terms of sensitivity, selectivity and reliability. These approaches, however, require that the operator defines the chemicals of interest *a priori* and, in doing so, only these selected chemicals can be detected. Targeted approaches will as such always miss “unknowns” regardless of how elevated or toxic the levels of unknowns are.¹¹

Detection of new chemicals in Antarctica is largely fortuitous, yet these discoveries underscore the fact that current analytical repertoires capture only a fraction of chemicals making their way to Antarctica. New and advanced technology developments are allowing a broader, non-targeted analytical approach^{12,13} to identify contaminants without prior knowledge of their presence, effectively moving the research question from “Is this chemical here?” further towards, “What chemicals are here?” Such approaches must be implemented on specially-collected Antarctic environmental media to provide a truer picture of present-day persistent organic chemical contamination in Antarctica. This information will fit the needs of international chemical policy (e.g. Stockholm Convention) by uncovering chemicals that meet the chemical risk criteria of persistence and environmental mobility, as demonstrated by their presence in the most remote region of the planet.

2. Remote vs. local sources

Distinguishing long range sources from *in-situ* human usage (e.g. stations and maritime activities)^{14, 15, 16} must serve as a quality assurance component. Information regarding local emissions will in turn inform policy, such as the Madrid Protocol, which explicitly prohibits emissions of harmful chemicals in Antarctica.

3. How will climate change impact persistent organic chemical contamination in Antarctica?

All major drivers of organic chemical behaviour and fate stand to be impacted in a warming climate¹⁷. These include air and sea temperature, cryosphere dynamics, organic carbon cycling, ocean pH, and food web connections. Atmospherically delivered organic chemicals may, for example, be trapped in the cryosphere until ice-melt releases these, often hydrophobic, compounds into the marine environment¹⁸. Here they will preferentially associate with organic carbon-rich particulates, providing an efficient vector for transfer to higher trophic levels, or the ocean floor. Reduced glacial ice may initially result in enhanced release of historically deposited persistent organic chemicals to the atmosphere¹⁹, whilst warmer temperatures and expanded ice-free land areas may facilitate greater terrestrial primary production and generate new terrestrial sinks for persistent organic chemicals.

In the marine realm, ice-dependent species are expected to be impacted most severely in a warming Antarctic²⁰. These include Antarctic krill (*Euphausia superba*), a keystone species of the Antarctic sea-ice ecosystem. Altered food-web connections, driven by reduced prey biomass, is expected to, in turn, impact chemical exposure. Similarly, changed foraging ranges, particularly for highly mobile and migratory species, may result in higher latitude feeding with associated higher persistent organic chemical uptake. Investigating, and temporally tracking, chemical dynamics in response to shifts in bio-physical change in Antarctica, is fundamental for accurate interpretation of observations and trends.

4. What is the role of hydrospheric and biological transport, compared to atmospheric transport pathways of persistent organic chemicals to Antarctica?

With a growing list of POP candidate compounds that will come from a widened analytical scope, it is also anticipated that the range of chemicals with properties that satisfy the risk criteria of mobility and persistence will also grow. A historical example is provided by perfluoralkyl substances (PFAS). In contrast to chlorinated and brominated POPs that achieve environmental mobility largely through atmospheric transport, these chemicals are hydrophilic and their environmental transport is expected to be governed by ocean currents.²¹ This has implications for how we monitor for the presence of persistent organic chemicals in the Antarctic region. Transport of chemicals to Antarctica via the hydrosphere, compared to the atmosphere, will take decades, if not centuries.²² It is ~70 years since widespread commercial manufacture of POPs commenced. We are therefore currently in a position to capture initial input from which to monitor temporal trends²². Routine observation systems that capture these trends remain an operational limitation, preventing an information response targeted at this research gap.

5. What is the toxicological sensitivity of Antarctic biota on account of unique metabolism, extended life spans and often, capital breeding life histories?

Polar biota has adapted to the seasonal productivity of high latitude environments. Common adaptations include slower metabolism, extended lifespans, and behavioural life-history adaptations such as fasting and/or migration. Seasonal productivity has also driven a dependence of polar biota on lipid-rich prey sources²³. In combination, a lipid-rich diet and adaptations that markedly impact lipid dynamics may influence sensitivity to, and expression of, the toxicological impacts of lipophilic organic chemicals. Advancing understanding of the comparative toxicological sensitivity of Antarctic biota, relative to temperate or tropical counterparts, remains a key ecotoxicological research gap²⁴. Often, ecotoxicological assessment of Antarctic biota has generated surprise findings of disproportionate relevance or impact outside of the field. Examples include the discovery of families of organic pollutant degrading bacteria²⁵, which could lead to commercial biotechnology applications, as well as the discovery of the ability of Antarctic krill to crush microplastics to form nanoplastics, the first species on the planet observed to do so²⁶.

Next steps

In order to align Antarctic persistent organic chemical research with international efforts and existing global monitoring frameworks, a number of actions are needed. These are outlined below, and the ImpACT Action Group aims to undertake further work towards specific recommendations, in consultation with other interested groups.

Antarctica as part of the Global Monitoring Plan of the Stockholm Convention

The Global Monitoring Plan (GMP) forms one component of the effectiveness evaluation of the Stockholm Convention. It seeks to provide a harmonized organizational framework for the collection of comparable monitoring data on the presence of POPs from all regions and recommends longitudinal monitoring of 'core media,' including ambient air and seawater. Most consultative parties to the Antarctic Treaty are also signatories of the Stockholm Convention. However, routine, large-scale monitoring is lacking in Antarctica, except for the continuous monitoring of atmospheric POPs at the Norwegian Troll observatory since 2009. Consequently, temporal assessment can only be made from Troll from 2009 onwards, while spatial assessment cannot be made. This is in stark contrast to Arctic nations where coordinated monitoring frameworks have been in place for the past 40 years, and which now represent major contributions via the Arctic Monitoring and Assessment Programme (AMAP) towards evaluation and guidance of global chemical policy.

Globally standardized, systematic monitoring to contribute to the requirements of the GMP could include:

- Continuous air sampling. High volume air sampling will entail installation of permanent, semi-automated, high volume sampling equipment, as well as service agreements for the collection and transport of samples to an approved laboratory for analysis and/or archiving.
- Seasonal collection of surface seawater in north-south transect across the Antarctic circumpolar current. Such sampling would be undertaken via research and re-supply voyages. Low effort sampling may be conducted via service level agreements, with support for subsequent transport of samples to an approved laboratory for analysis and/or archiving.

Additional monitoring for the Antarctic region could include:

- Non-targeted and suspect screening of specially-collected environmental media to provide a truer picture of present-day persistent organic chemical contamination in Antarctica. Findings will guide policy and ongoing priority analyte lists for harmonized monitoring across the region.
- A network of summer-time, air and seawater passive sampling stations could be integrated into the Global Atmospheric Passive Sampling (GAPS) network²⁷, and the recently launched AQUA-GAPS monitoring program for POPs in the Waters of the World²⁸.
- In the absence of human media, it is proposed that one or more model species, with a circum-polar distribution be selected for long-term persistent organic chemical biomonitoring. Two options are proposed to fulfill distinct purposes, 1) a coastal benthic invertebrate for routine sampling around stations via service level agreements, which could be used for the identification of local source contamination. 2) Secondly, a higher trophic level species could be targeted to provide integrated ecosystem information, and information regarding bioaccumulation potential of specific compounds. Such routine sampling could take place in conjunction with the Convention for the Conservation of Antarctic Marine Living Resources Ecosystem Monitoring Program (CEMP)²⁹, or the Humpback Whale Sentinel Program (HWSP)³⁰, two long-term Antarctic sea-ice ecosystem observation programs. The HWSP protocols encompass routine POP monitoring for this purpose.
- Systematic collection of environmental samples for archiving and retrospective analysis of persistent organic chemicals, as and when either new priority chemicals are identified, or new methodologies become available, is a robust strategy that has generated many valuable contribution to global chemical policy. Coordination between national Antarctic Programs and national Environmental Specimen Banks for the inclusion of systematic collection and archiving of Antarctic environmental samples is one proposed approach.

Achievement of the above actions requires comparable, quality assured, chemical analysis, and it is suggested that selected laboratories could be nominated for analysis. Nominated laboratories would need to be approved for delivery of data to the GMP and as such, regularly participate in inter-laboratory calibration exercises.

Finally, the ImPACT Action Group advocates a Planetary Health approach to persistent organic chemical research in Antarctica. Planetary Health acknowledges that the health of human civilisation is dependent upon, and inextricably linked to, the state of natural systems⁶. Investigations of human impacts must therefore be viewed at a systems scale. Notably, the expression of toxic effects in humans and wildlife alike, are typically exacerbated by environmental factors. As such persistent organic chemical risk must be considered through the lens of multiple stressors and ecosystem health.

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