Act now – Legacy and Emerging Contaminants in Polar Regions

WORKSHOP REPORT

Online Expert Workshop
January 25th –26th 2022

Helmholtz-Zentrum Hereon, Geesthacht, Germany

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Glossary

ACAP – Arctic Contaminants Action Program. Focus: Reduction of Arctic pollution and environmental risks. →*Arctic Council*

AnMAP – Antarctic Monitoring and Assessment Programme

AMAP – Arctic Monitoring and Assessment Programme. Focus: Measuring and monitoring pollutants and climate change effects on ecosystems and human health in the Arctic. →*Arctic Council, AMAP Working Group*

Antarctic Treaty – Signed by 12 countries 1 December 1959 and entered into force 1961. The total number of Contracting Parties is 54 (2022). Antarctica shall be used for peaceful purposes only (Art. I). Freedom of scientific investigation in Antarctica (Art. II). Scientific observations and results from Antarctica shall be exchanged and made freely available (Art. III). No acts or activities taking place while the present Treaty is in force shall constitute a basis for asserting, supporting or denying a claim to territorial sovereignty in Antarctica or create any rights of sovereignty in Antarctica (Art IV). The provisions of the present Treaty shall apply to the area south of 60º South Latitude (Art. VI). Parties are obliged to inform each other of their activities in Antarctica and facilitate inspections by other Parties of their facilities (Art. VII). →*Madrid Protocol*

Arctic Council – Established 1996 by the Ottawa Declaration. Intergovernmental forum, cooperation, coordination and interaction among the Arctic States, Arctic Indigenous peoples and other Arctic inhabitants in particular on issues of sustainable development and environmental protection. Member States are Canada, Denmark (Greenland/Faroe Islands), Finland, Iceland, Norway, Russia, Sweden, United States. Working Groups →**ACAP** (Arctic Contaminants Action Program), →**AMAP** (Arctic Monitoring and Assessment Programme).

ATCM – Antarctic Treaty Consultative Meeting, →*Madrid Protocol*

CEACs – Chemicals of Emerging Arctic Concern

CECs – Contaminants of Emerging Concern

CEP – Committee for Environmental Protection →*Madrid Protocol*

Digital Sample Freezing – Digital archives of high-resolution mass spectral data from the analysis of environmental samples. ‘Digitally frozen’ samples can be retrospectively screened for previously not recognized contaminants. →*Non-Target Screening*

ESBs – Environmental Specimen Banks. Systematic long-time storage of environmental samples at low or ultra-low temperatures to support real-time and retrospective trend analysis and to provide samples for future generations.

FAIR data principles – Set of principles to enhance the reusability of data: Findability, Accessibility, Interoperability, and Reusability.

ImPACT – Input Pathways of persistent organic pollutants to AntarCTica. →SCAR working group to facilitate coordinated investigation and monitoring of chemical input to the Antarctic region. Policy-impact driven Action Group which aims to serve both the Global Monitoring Plan of the Stockholm Convention, as well as the Madrid Protocol which explicitly prohibits the importation of POPs to Antarctica. Targeted system chemical input pathways of investigation include; atmospheric transport; oceanic transport; in-situ usage, and migratory biota.

IPCHEM – Information Platform for Chemical Monitoring. EU platform for chemical monitoring data.

IPCP – International Panel on Chemical Pollution. An international network of researchers established in 2008.

Legacy contaminants – chemicals with substantial knowledge on their environmental fate and potential adverse effects, largely regulated, i.e. production and applications banned or only allowed for defined purposes.

LRET – Long-range environmental transport. →*POPs*

Madrid Protocol (Protocol on Environmental Protection to the Antarctic Treaty) – Signed in Madrid on October 4, 1991 and entered into force in 1998, shall supplement the Antarctic Treaty. It designates Antarctica as “a natural reserve, devoted to peace and science”. The Protocol is open to accession by Antarctic Treaty Parties only. Antarctic Treaty Consultative Meetings (**ATCM**) (Art. X) shall review the work of the Committee for Environmental Protection (CEP) and shall draw fully upon its advice and recommendations in carrying out the tasks …, as well as upon the advice of the Scientific Committee on Antarctic Research (**SCAR**). The Protocol established the **CEP** (Art. XI), which shall be to provide advice and formulate recommendations to the Parties in connection with the implementation of this Protocol, including the operation of its Annexes, for consideration at Antarctic Treaty Consultative Meetings.

Minamata Convention on Mercury – Entered into force 2017. International treaty designed to protect human health and the environment from anthropogenic emissions and adverse effects of mercury.

Non-Target Screening (NTS) – Non-targeted chemical analysis of unknown contaminants using high-resolution mass spectrometry complementing the →”Target Analysis” of contaminants. NTS includes Non-Target Analysis for unknown compounds, *Suspect Screening*, which utilizes lists with information on known chemicals which could be present in a sample, and target verification.

NORMAN Network – Enhances the exchange of information on emerging environmental substances, encourages the validation and harmonisation of common measurement methods and monitoring tools, and operates extensive data bases on CECs.

PANGAEA – Data Publisher for Earth & Environmental Science hosted at the Alfred Wegener Institute (AWI), Germany.

PFAS – Per- and polyfluoroalkyl substances

PIC – Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade. →*Rotterdam Convention (PIC)*

POPs – Persistent Organic Pollutants. Under the Stockholm Convention, POPs fulfil the criteria for persistence, bioaccumulation, toxicity and long-range environmental transport (LRET).

PPCPs – Pharmaceuticals and personal care products

Prioritisation of Chemicals – in view of more than 350,000 registered chemicals, efficient prioritisation criteria are needed to identify environmentally relevant substances. Main criteria are persistence, potential bioaccumulation, toxicity and long-range environmental transport (→LRET). Prioritisation of Chemicals is equally important for chemicals policy and regulation.

REACH – Registration, Evaluation, Authorisation and Restriction of Chemicals. EU Chemicals Regulation.

Rotterdam Convention (PIC) – Adopted in 1998. Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade. Promotes cooperative efforts in the international trade of certain hazardous chemicals in order to protect human health and the environment and contributes to the environmentally sound use of those hazardous chemicals.

SAICM – Adopted 2006. Strategic Approach to International Chemicals Management. Global multi-sectoral and multi-stakeholder policy framework, whose secretariat is hosted by the UN Environment Programme.

SCAR – Scientific Committee on Antarctic Research. Interdisciplinary body of the International Science Council (ISC). It coordinates international scientific research efforts in Antarctica, including the Southern Ocean. →*Madrid Protocol*

Stockholm Convention – Stockholm Convention on Persistent Organic Pollutants (→**POPs**). Entered into force 2004.

Target Analysis – Identification and quantification of contaminants in samples by chemical analytical methods using the respective pure chemicals as reference. →*Non-Target Screening*

Executive Summary

Both the Arctic and Antarctic, once pristine habitats, are threatened by pollution from new, local emissions as well as long-range transport from the production and use of chemicals in industrial regions. The German Environment Agency (UBA) and the Helmholtz-Zentrum Hereon co-hosted the workshop „Act now – Legacy and Emerging Contaminants in Polar Regions“. For the first time, international experts from contaminant research in polar regions, representatives from regulatory chemical assessment and monitoring, environmental specimen banks, and information and data platforms jointly discussed pressing chemical pollution issues in the two polar regions and opportunities for collaboration.

The goal of the workshop was to provide recommendations for improving screening, monitoring, assessment, cooperation, and data sharing to provide environmental policy and chemicals management with effective and reliable pollution data to protect the polar environment. (Fig.1). Members of the European Commission, the Stockholm Convention, the Arctic Council, the Antarctic Treaty Consultative Meeting, Environmental Specimen Banks and Data Centres discussed together with the research community two questions which were a common thread throughout the workshop: What are the common goals and scientific bases for chemical research and monitoring in the polar regions - and how do the respective approaches differ for the Arctic and Antarctic?

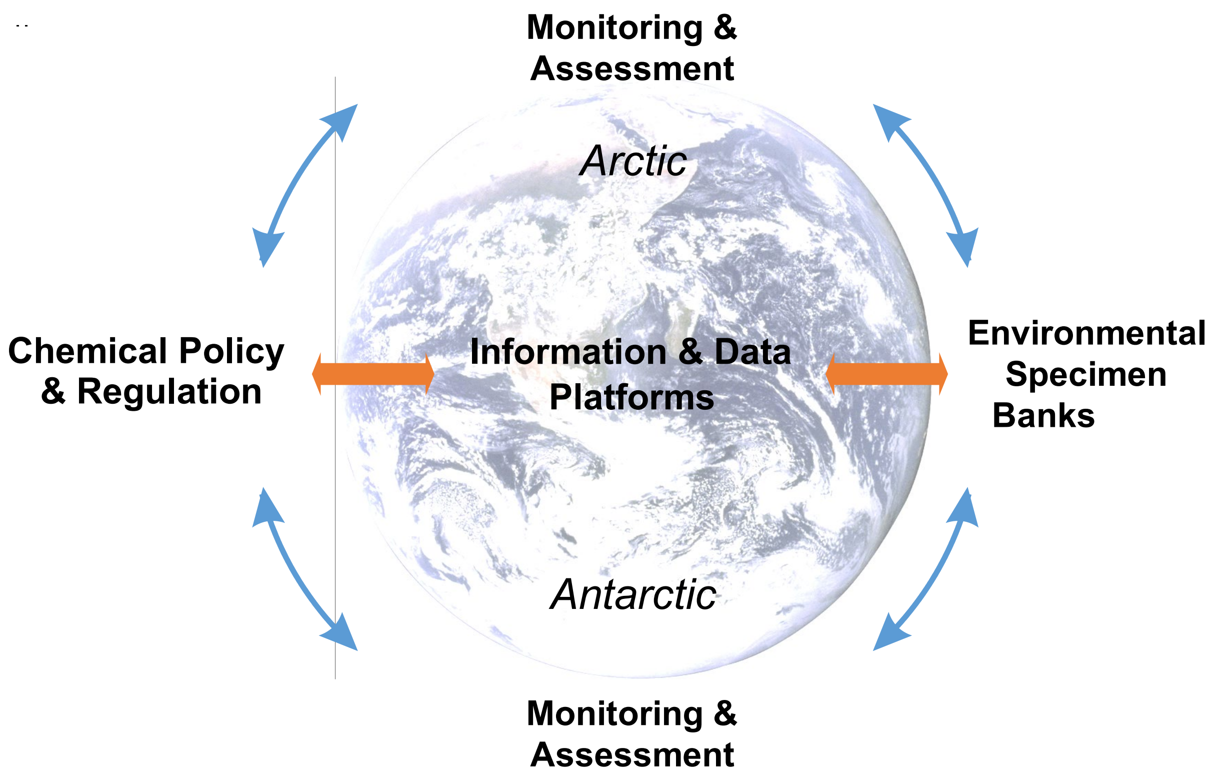

Figure 1: Key actors in networking to protect the polar environments from chemical pollution.

Workshop recommendations for contaminant research and monitoring in polar regions

Strategic recommendations

- Raise awareness among policymakers and the public about the need to take better action against chemical pollution in the Arctic and Antarctic,
- setup a network of all relevant actors and stakeholders, including policy makers, regulators, the research community, non-governmental organisations, indigenous communities and the public,
- promote polar environments as sentinels of the Earth's condition and forcefully present their importance to the concepts of planetary boundaries and the EU's goal of zero pollution ambition,
- define stakeholder needs and make systematic use of polar pollution data in regional and international chemicals management,
- develop long-term perspectives for standardized monitoring: establish chemical monitoring capacities and expertise in the Antarctic and strengthen existing infrastructure in the Arctic,
- support systematic environmental specimen banking to help monitor temporal trends, support environmental research and provide samples for future generations,
- foster data repositories according to the FAIR data principles so that all polar contaminant data are findable, accessible, interoperable and reusable, and link to other data bases, e.g. EU IPCHEM, the Norman network.

Technical recommendations

- Establish harmonised workflows for collecting, shipping, processing, and archiving of environmental samples, and their chemical analysis,
- connect monitoring approaches for long-range transport of pollutants and the local chemical footprint from tourism, research, and settlements,
- integrate state-of-the-art chemical analysis methods, including mass spectrometry and effects directed analysis to monitor contaminants of emerging concern together with legacy pollutants,
- link to innovative prioritisation and screening approaches and explore advanced modelling approaches for chemicals in the environment,
- explore the use of innovative monitoring tools, such as passive samplers, in extreme environments like the Antarctic where operations and logistics are challenging,
- generate data for POPs and CECs in the Russian part of the Arctic to enable a more comprehensive circumpolar view and to investigate large-scale spatial and temporal trends.

Political and public awareness: Policymakers, researchers, and society must recognize that chemical pollution of the polar regions is their responsibility and take patronage of their future - even if the problems take place far from their own doorsteps. Chemical stressors are as pressing a problem for the Arctic and Antarctic as the impacts of climate change and biodiversity loss, and they interact directly with them. It is now important to build a network that reaches out to all relevant environmental actors and stakeholders in the two polar regions and builds pressure for more sustainable management of our resources. In this context, the media, the Internet and educational projects play an important role in risk awareness and environmental education.

The ***precautionary approach*** is a fundamental part of both, the Arctic Council and the Antarctic Treaty system. Based on the compiled knowledge – including scientific findings as well as traditional knowledge in the Arctic – scientific reports are developed, which serve as the starting point for a set of policy recommendations and best practices within the Arctic Council. The Madrid Protocol and the work of the Committee for Environmental Protection (CEP) of the Antarctic Treaty Consultative Meeting (ATCM) together with a better understanding of the current state of the Antarctic environment and the long-term effects of persistent contaminants on the organisms and food chains, would enable the Antarctic Treaty Parties to allow necessary decisions or to take measures for the protection of the Antarctic environment, wherever needed and distinguish local from global sources.

For ***chemicals policy and regulation***, data on chemical substances in the Arctic and Antarctic, jointly generated by research and monitoring programs, and accessible through databases, are essential. The Strategic Approach to International Chemicals Management (SAICM), the Rotterdam Convention (PIC) the Stockholm Convention (POP), the Minamata Convention on Mercury and the International Panel on Chemical Pollution (IPCP) are of special importance here. Specifically, identification of POPs and verification of the effectiveness of their use restrictions depend on monitoring data from polar regions and assessment of long-range transport of the substances. It is equally important to identify local pollutant emissions from human activities in polar regions, such as research and tourism in Antarctica and, beyond that, settlements in the Arctic. This data can be used to better understand the current state of the Antarctic environment and inform policymakers about reliable plans for protecting its future.

Innovative contaminant research and monitoring is needed to prioritize the assessment and monitoring of existing and emerging chemicals in view of more than 350,000 registered chemicals. This is even more true for polar regions, and especially the Antarctic, where only little contaminant research takes place and systematic and regulatory monitoring activities are largely absent. While arctic-wide assessments were already prepared through the Arctic Monitoring and Assessment Programme (AMAP) within the Arctic Council such assessments are still missing in the Antarctic. The ATCM together with the Scientific Committee of Antarctic Research (SCAR (e.g. ImPACT group)), the National Antarctic Programmes (NAPs) and Environmental Agencies could use proven frameworks and structures by AMAP to strengthen their efforts to initiate a more structured sample and data collection of environmental contamination in the Antarctic.

When selecting substances for ***screening programs in polar regions***, the potential for long-range transport in the environment must be considered in addition to fate and effects data. Modelling the long range transport potential is often hampered by the lack of emission inventories, as information on production sites and production volumes is generally still considered confidential. However, *in silico* modelling and prioritization based on physico-chemical properties are constantly improving and will be an important cornerstone for chemical risk assessment in polar regions. Novel analytical Non-Target Screening, including suspect screening approaches in polar sample extracts are a powerful tool for identifying previously unknown chemicals in the environment. So far confirming structures with high confidence remains labour intensive despite many advances in data science. Regulatory monitoring of contaminants will therefore continue to require targeted analyses of known contaminants, but these will need to be systematically combined with broad screening approaches to continuously prioritize new candidates for monitoring.

Environmental specimen banks (ESBs) are maintained by countries and scientific institutions as a promise to the future. By archiving the state of the environment, they enable future generations to establish historical references for known and new environmental problems. ESBs also support today's chemical management and provide samples for the analysis of contaminants. Mostly based in industrialized regions, they are used to provide temporal and spatial trends for pollutants that were previously not analytically detectable, not known to be hazardous, or not considered environmentally relevant. In the Arctic, contaminant programs are already supported by ESBs in North America and Scandinavia. A broader initiative to establish ESBs for Antarctica is needed to complement the current single Antarctic ESB at University Genova, Italy. Rapidly establishing more ESB activities can help us gain ground and shape contaminant research in the changing Antarctic environment into the future.

So far, a centralised ***access to data for legacy and emerging contaminants*** in polar regions is missing. Instead, some data can be retrieved from selected data platforms or are published in scientific reports or articles. It is also true for the data situation that activities for the Arctic are much more developed than for the Antarctic. Set up data repositories according to the FAIR data principles so that all polar contaminant data are findable, accessible, interoperable and reusable, and link to other data bases, e.g. EU IPCHEM, the NORMAN network. This of great importance for science-based networking of all key players including chemical policies and regulation.

"***Digital Sample Freezing Platforms***" or "virtual ESBs" are a promising approach for a better overview on contaminants in polar environments, as they digitally store large datasets from non-target screening (NTS) in such a way that they are always available for analysis using the classic non-target analysis and suspect screening mode. This approach has already been established in the NORMAN network, for example, with an open access Digital Sample Freezing Platform supported with NTS data from different NORMAN activities. Because generic NTS cannot yet cover all organic compounds, ESBs are essential as a backup for optimized methods or other innovations in contaminant monitoring.

New approaches to ***regulatory risk assessment*** are needed as more compounds are constantly being detected in the polar environment and evidence is growing that many of them are finding their way into the Arctic and Antarctic simply because they are very persistent. It should also be the goal to avoid "regrettable substitution" and to prevent, through grouping approaches, that a compound that is regulated because of its hazardous properties is substituted by another substance with very similar substance properties. A prominent example are per- and polyfluorinated alkyl substances (PFAS), a group of several thousand chemicals, where extensive use restrictions are being discussed by regulatory authorities in the EU and other regions in combination with the concept of essential use.

The overarching outcome of this workshop is that all key stakeholders including policy makers and the public, need to join forces to achieve better networking of actions to protect ecosystem and human health in our polar regions.

1 Abstracts of presentations

The EU Chemicals Strategy for Sustainability and the polar regions: opportunities for a higher level of protection from contaminants

Cristina de Avila

Head of Unit, Safe and Sustainable Chemicals, DG Environment, European Commission

Slide 1 – title slide

Slide 2

The EU Chemicals Strategy for sustainability is an important part of the European Green Deal, where it fits under its "zero pollution ambition, for a toxic-free environment".

The EU has sophisticated chemicals legislation, which generated the most advanced knowledge base on chemicals.

However, **science keeps on alerting us on areas where we urgently need to act**. People and the environment, including the polar regions, are still exposed to very harmful chemicals, in particular through consumer products[1].

Chemical pollution is recognized by scientists as one of the key drivers putting the Earth at risk – and the polar regions were even called the "chemical sink of the globe" by WWF (in 2005).

Today I would like to present those elements in the EU Chemicals Strategy for Sustainability that will also open opportunities for better protection of the polar regions.

Slide 3

Our strategy presents a clear **vision, and includes objectives plus a concrete action plan to address today's and tomorrow's challenges**.

VISION

The overall vision it to ensure that by 2030, we achieve a **toxic-free environment** where chemicals are produced and used in a way that **maximises their contribution to society while avoiding harm to the planet and to current and future generations**. Production and use of **safe and sustainable chemicals** becomes the EU market norm and a **global standard**.

Slide 4

How do we do this?

In the strategy, we have two overarching and mutually supportive objectives:

1. boosting innovation for safe and sustainable chemicals

[1] The chemicals found in the arctic include brominated flame retardants, chlorinated parafins, PFAS…

2. increasing protection of health and the environment

And **3 Key Enablers** as

1. Simplification & coherence
2. Knowledge and science
3. The international dimension

Slide 5

Safe and sustainable chemicals must become the EU market norm, and this would be a win-win for the protection of people and the environment and for the competitiveness of EU industry, which needs to regain global market.

So this year, we will be developing **criteria for safe and sustainable by design chemicals**.

We will also establish an EU**-wide support network** to promote cooperation and sharing of information and provide technical expertise on alternatives.

There is **financial support** for the commercialisation and uptake of safe and sustainable by design chemicals, materials and products, via EU funding.

The strategy supports the **green transition of the chemical sector and its value chain**, including by promoting EU's **open strategic autonomy** for those critical chemicals that are needed to build the technologies that we need to achieve climate neutrality.

In addition, we need make sure that we

- **achieve safe products and non-toxic material cycles in the Circular Economy**. This should happen by minimising the presence of substances of concern in products.
- Finally, we will be establishing and updating a **research and innovation agenda** for chemicals.

Slide 6

We are improving our protection measures by strengthening legislation. This can be summarized in three objectives:

1. Firstly, to ensure that **all chemicals** on the market are used safely and sustainably.
2. Secondly, to promote and reward substitution for those chemicals causing long-term effects on humans and the environment – the **substances of concern**.
3. Thirdly, to avoid that the **most harmful chemicals** are present in consumer products or affect vulnerable groups.

Slide 7

We will apply the **concept of essential uses** to ensure that those most harmful substances are only allowed if their use is necessary for health, safety or is critical for the functioning of society and if there are no acceptable alternatives.

The criteria for essential uses are being defined this year, and we will be inspired by the criteria that were used successfully under the Montreal Protocol.

Slide 8

Now I would like to turn to some of our legal instruments because to achieve what I just said, we need to revise our legislation.

First, we need to make sure that some substances that are very hazardous can be identified as such. Therefore we will revise the regulation of Classification, Labelling and Packaging of chemicals, and we will include endocrine disruption as a new hazard class.

In the same revision exercise, we will also include substances that are persistent, bioaccumulative and toxic (PBT) and persistent, mobile and toxic (PMT) as new hazard classes. This is a step that is highly relevant for the polar regions.

When will these changes be proposed? This year already, 2022.

Slide 9

The second legal instrument that we have is the REACH regulation.

In the REACH **registration process**, we will update the mandatory information that chemical companies need to provide, in particular for endocrine disruptors, but companies will also need to provide more information about the **use and exposure to chemicals and about their environmental footprint**.

In addition, we will include endocrine disruptors, and also the **new persistent mobile and toxic substances** as categories of chemicals that can be listed as "substances of very high concern". This means that stricter measures will apply to these substances, for example they can be restricted or banned.

<u>This is therefore also a measure that can have an impact on the polar regions.</u>

Finally, we already have a ban on the use of carcinogens in consumer products via the "**generic risk approach**", but we will include other very harmful substances under this approach. (These can include substances that are harmful to human health but also to the health of wildlife, including in the polar regions.)

Slide 10

The impact assessment on the benefits and the costs is currently ongoing. We have just opened the public consultation on the revision of REACH.

Slide 11

REACH and PFAS – Some members of the PFAS group of substances are found in the polar regions.

The EU is preparing a general ban on the whole group under REACH. A group of 5 countries, the Netherlands, Germany, Denmark, Sweden, and Norway are preparing this restriction and are planning to submit the dossier in July 2022.

In the meantime a restriction on PFAS in fire-fighting foam is already in a most advanced stage (ECHA dossier: 14 January 2022).

Slide 12

To close the list of legal instruments: in the EU the "POP regulation" implements the Stockholm convention. Persistent organic pollutants (POPs) are organic substances that persist in the environment, accumulate in living organisms and pose a risk to our health and the environment. The Stockholm convention has 184 parties and was founded in 2004.

POPs can be transported by air, water or migratory species across international borders, and so reach regions where they have never been produced or used, such as the polar regions.

The Regulation bans the production and use of POPs (with exemptions), it manages the unintentional production of POPs and the presence of POPs in waste.

Slide 13

The European Commission, together with Member States, play an active role in proposing new POPs to be listed. The Commission also makes sure that the POP regulation is implemented in the EU and coordinates with Member States and expert groups. The European Chemicals Agency supports this work.

Slide 14 – Knowledge base

I said in my introduction that the EU has a sophisticated chemicals management framework. But we need to recognise that it is still quite limited. Thanks to REACH, we now have information on more than 20,000 substances that are used at above one tonne per year – but hazard characterisation and exposure details are limited.

Only about 500 substances are very well characterised for their hazards and exposure.

Slide 15 - A comprehensive knowledge base

We need to improve this. We need to start acquiring some knowledge on polymers (the building blocks of plastics), we need to be able to identify the most harmful substances at any production volume (it is useless to say we do not want them in consumer products, if we do not know which are these substances), and amongst these we need to absolutely identify all substances that cause cancer, as a necessary step in our fight against this disease.

We also need to start having information on the environmental footprint as well as improve our knowledge on the use of chemicals amongst others by tracking substances on concerns in products/materials.

Therefore, what we will do is:

- establish a EU research & innovation agenda for chemicals (in 2022)
- Promote innovative testing and risk assessment methods and their regulatory uptake
- Finance via the Research and Innovation programmes Human and Environmental (Bio)-monitoring
- Create an EU early warning and action system for chemicals
- And we will establish a framework of indicators to better assess our policies.

Slide 16 – IPCHEM

I just said that the Chemicals Strategy also includes an action to finance human and environmental (bio) monitoring – via Research and innovation programmes.

Not only do we finance monitoring, I would also like to highlight that the European Commission set up an information platform for chemical monitoring in 2015. This is a very useful tool for researchers and scientists as well as for policy makers, and we continue to seek data providers as well as data users.

My colleague Antonio Franco will give a complete presentation on what IPCHEM is, what it can do for you, and what you can do for IPCHEM.

So please make sure you go to Antonio's talk this afternoon!

Slide 17 – EU and global action

Indeed, as you know very well, chemicals are global business. Therefore the European Commission proposes a number of objectives and actions to step up **international standards** on the sound management of chemicals, and for the **EU to lead** on safe and sustainable chemicals. As I mentioned, the EU often leads the listings of POPs, we will be introducing new hazard categories to identify persistent, mobile and toxic chemicals, and endocrine disruptors.

One important spearhead in our action plan: chemicals that are no longer allowed on the EU internal market, should also no longer be allowed for production for export. At the moment we are assessing what the best legal instrument is.

Slide 18 – wrap up

To sum up: The EU has a comprehensive system in place to manage risks from chemicals, but the alerts that we continue to receive from the scientists have prompted us to go further. The chemicals strategy for sustainability aims to protect people and the environment by prevention. The strategy provides an action plan and a timeline to make stricter legislation, to promote innovation and safe and sustainable by design, to fund research including monitoring of chemicals in the environment, and finally to be a global leader.

Our goal is a toxic-free environment, including toxic-free polar regions, and it is all hands on deck for policy makers like us, industry, scientists and civil society to make it happen.

Thank you for your attention.

Activities of Russian Stockholm Convention Regional Centre including in the Arctic region

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The Stockholm Convention Regional Centre for Capacity Building and the Transfer of Technology in the Russian Federation was nominated by the decision SC-4/23 by the eighth meeting of the Conference of the Parties to the Stockholm Convention on Persistent Organic Pollutants (COP8) in 2017.

The Stockholm Convention Regional Centre in the Russian Federation (SCRC NIOCH) is hosted by N.N. Vorozhtsov Novosibirsk Institute of Organic Chemistry Siberian Branch of Russian Academy of Science (NIOCH SB RAS) in Novosibirsk city. Regional Centre in Russian Federation (SCRC NIOCH) is a part of 16 Regional Centers network in the world.

The Regional Centre SCRC NIOCH provides support to the Stockholm Convention contracting Parties (countries) in its geographical region to fulfil their obligations under the Stockholm Convention. The region of responsibility combining the North Asia, partly Central Asia and East Europe. Main part of the region is occupied by the Russian Federation including the large area in the Arctic zone. Area of responsibility of SCRC NIOCH also includes the following countries: Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Mongolia, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan.

SCRC NIOCH as based in research institute fulfils several roles: an academic institution providing university education and practical researches in the field of ecology including expert and analytical activities at emergency situations; a research institution working on revealing of contamination with Persistent Organic Pollutants (POPs) of the environment and effects on living organisms; and supporting implementation of and capacity building under the Stockholm

Convention and other global environmental agreements and initiatives with Stockholm Convention parties.

According to working plan Regional Centre SCRC NIOCH activities will focus on the next goals directed toward the implementation of Stockholm Convention in the region: find sources for permanent financial support, update list of laboratories and their instrumentation across the region, support implementation of the Global Monitoring Plan to the Stockholm Convention, organize the trainings of laboratory experts in performing analytical measurements of POPs in accordance with modern requirements, identifying the status of exposure to POPs among the population of Russia and countries in the Central and Eastern Europe. Provide technical assistance to all countries in the region.

In addition, SCRC NIOCH supports decision making by communicating with local authority and government concerning POP contamination and necessity of environment control, presentation of environmental and human data in relation to toxic chemicals through electronic tools and by enlarging capacities in the management of PCBs, new POPs, and a greater understanding of linkages between environment and health.

The Regional Centre works as a project partner with UNEP, UNIDO and the Arctic Council to build environmental capacities in developing countries and organizes conferences and workshops. Recent conference organized by SCRC NIOCH was the conference "Management of persistent organic pollutants in Russia and abroad" on October 2021 (online format). The main objectives of the conference were as following: existing threats to the state of ecosystems and public health, as well as future generations caused by the production, distribution and bioaccumulation of persistent organic pollutants; exchange of experience in the development of environmental programs and strategies on the management of persistent organic pollutants (POPs) and the implementation of the Stockholm Convention on POPs; informing about existing developments in the field of identification, monitoring and destruction of persistent organic pollutant etc. More then 50 experts and specialists on POPs management and analysis from 8 countries took part at the conference.

SCRC NIOCH also provides expertise and long-term experience in finding practical solutions for environmental challenges to all interested stakeholders including national and local authorities, other Stockholm Convention Regional Centres, secretariat of the Stockholm Convention and research organizations. Recent activities of the Regional Centre SCRC NIOCH concern risk estimation and discussion on new chemical substances compounds considered as candidates for inclusion the list of Stockholm Convention, in particular methoxychlor, dechloran plus, UV-328, decabromodiphenyl ether, chlorinated short chain paraffins.

SCRC NIOCH includes certified analytical laboratory for a wide range of studies, including: identification of compounds and organic substances of synthetic and natural origin, identification and quantification of a wide range of persistent organic pollutants, including polycyclic aromatic hydrocarbons, petroleum products, polychlorinated dioxins and furans, polychlorinated biphenyls, chlorine-containing pesticides, and other chemical compounds. Modern equipment (gas chromatography, mass-spectroscopy of low and high resolution, liquid chomatograohy) is used to measure the POPs and other organic contaminants content in environmental objects.

Recent activities of the analytical laboratory concern analysis of the content of certain groups of persistent organic pollutants including POPs (polychlorinated biphenyls, polycyclic aromatic hydrocarbons etc.) in environmental objects from various sites of industrial enterprises, energy companies in Siberian and Arctic region; identification of organic substances, including production waste, to determine the composition and possible subsequent disposal; identification of substances in the atmospheric emissions of industrial enterprises; chemical and analytical studies of the composition of atmospheric air on the territory of the cities of the region in order to identify marker substances of odors and pollutants; analysis of the content of organic pollutants within the framework of the expedition in polar region.

Recent SCRC NIOCH activity in accumulation of the data of POPs content in environmental objects includes preparation of the review “The State (Inventory) Overview of Persistent Organic Pollutants in Environmental Objects of the Murmansk Region” [Tkacheva N.I., Morozov S.V., Tretyakov E.V., Tkachev A.V., Environment protection and nature reserve management (in Russian), 2021, No.3-4(4). The review provides information about the current state of environmental pollution in the Murmansk region. The main sources of potential formation and emissions of POPs, objects of accumulated environmental damage and "hot spots" of the Murmansk region are considered. Review includes the data from scientific publications, public reports of Russian and international organizations about state pollution monitoring and data of Russian and international studies conducted in the period 2000-2019 on the content of POPs in various environmental objects, including food.

AMAP work on POPs/CEACs in the context of regional to global perspectives

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The Arctic Council (AC) is an intergovernmental forum for collaboration on environment, sustainable development and climate change in the Arctic (https://arctic-council.org/) and the Arctic Monitoring and Assessment Programme (AMAP) (https://www.amap.no/) is one of its six working groups. AMAP is responsible for monitoring and assessing a range of pollution- and climate-related issues to "*provide reliable and sufficient information on the status of, and threats to, the Arctic environment, and scientific advice on actions to be taken in order to support Arctic governments in their efforts to take remedial and preventive actions relating to contaminants and adverse effects of climate change*" (AMAP, 2010a). The AMAP Working Group (WG) consists of delegations from the eight Arctic countries represented in the Arctic Council (Canada, Denmark, Finland, Iceland, Norway, Sweden, Russian, USA), as well as from Permanent Participants (representatives of indigenous peoples groups) and observer countries and organizations. The AMAP WG has several expert groups at its disposal covering climate, litter and microplastics, mercury, radioactivity, short-lived climate forcers, human health, and persistent organic pollutants (POPs). The AMAP POPs expert group has produced several scientific assessments that address the occurrence of environmental contaminants characterized as POPs, as well as chemicals and groups of substances that are Chemicals of Emerging Arctic Concern (CEACs). Data for these assessment reports comes from the harmonized AMAP programme for monitoring of contaminants, which is based on national monitoring programmes in the eight Arctic countries. The monitoring programme includes subprogrammes for air sampling and sampling of biotic and abiotic matrices from terrestrial, marine and freshwater environments in the Arctic. It also includes extensive analytical quality assurance and quality control in order to ensure comparability of the data used and activities that support data reporting, management and analysis. The Human Health expert group covers monitoring of contaminants in Arctic human populations. Other data used in assessments come from published research studies.

An assessment process of the AMAP WG concerning organic environmental contaminants begins with a decision on the need to fill a particular knowledge gap or follow-up on previous assessments of POPs/CEACs. The POPs expert group is then tasked with carrying out the assessment by formulating policy-relevant questions, searching the published literature, compiling recent data, writing the assessment as a peer-reviewed, technical report and later helping to develop the short summary for policy-makers (SPM), as well as other communication and outreach initiatives. The assessment SPM summarizes the findings of the assessment with conclusions (key findings) and recommendations provided to inform science-based policy- and decision-making. The POPs expert group takes part in outreach including presentations at scientific conferences and side-events at policy-meetings, and in many cases, the assessment report is also reformulated into review articles published in peer review journals.

Results presented on POPs in the first AMAP assessment report (AMAP 1998) showed that organochlorine contaminants such as PCBs were found to be widespread in the Arctic, at high concentrations in top predators such as polar bears, and also in humans populations, at some of the highest concentrations globally in Inuit from Canada and Greenland. This was found to be due to a combination of long range atmospheric transport from source regions at the lower latitudes delivering POPs to the Arctic via air and ocean currents and the fat-rich and long food web, which leads to higher biomagnification in top predators. The recognition that the Arctic was connected to the rest of the globe stimulated the development of the regional POPs Protocol of the Convention on Long Range Transport of Atmospheric Pollutants (CLRTAP) (https://unece.org/environment-policy/air/protocol-persistent-organic-pollutants-pops) and the global UN Stockholm Convention on POPs (http://www.pops.int/). The Stockholm Convention entered into force in 2004 and banned or restricted 12 organochlorine POPs (PCBs, DDTs, chlordanes, hexachlorocyclohexanes (HCH), dieldin, endrin, chlorinated benzenes, toxaphene, mirex and polychlorinated dibenzodioxins and furans). Under the Stockholm Convention, one of the criterion for establishing that chemicals are 'persistent' in the environment is their presence in the environment at locations "distant from sources" or "where monitoring data show that long-range environmental transport of the chemical…may have occurred" (UNEP, 2009 (Annex D)). Thus the Arctic has become an important indicator region for assessing persistence and bioaccumulation of chemicals as well as long-range transport.

The Stockholm Convention's POPs Global Monitoring Plan (GMP) tracks the effectiveness of bans and restrictions on listed chemicals. Of particular relevance in this connection are temporal trend data primarily from human tissues and air, but monitoring data for other media are accepted as well. Arctic monitoring data, and especially air and biota temporal trend data sets, have been influential in supporting the implementation and further development of the Stockholm Convention, including the GMP via the Western Europe and Other Group (WEOG) (UNEP, 2013). Arctic monitoring data and POPs/CEACs assessments have also been important in the evaluation of new chemicals proposed and later added for listing under the Stockholm Convention (AMAP 2010b; AMAP 2016, AMAP 2017). On a regional level, AMAP's marine monitoring programme is coordinated with monitoring programmes of the Oslo-Paris Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) and the Helsinki Convention on Protection of the Marine Environment of the Baltic Sea (HELCOM). For air monitoring, AMAP air monitoring is coordinated with the European Monitoring and Evaluation Programme (EMEP) of the Air Monitoring Convention (CLRTAP). AMAP's continuing work on POPs and CEACs aims to strengthen its work, in particular in relation to CEACs, to support policy-making to reduce global and regional threats from environmental chemicals. This includes consideration of the impacts of Climate Change on POPs and CEACs (AMAP, 2021) and a new assessment underway of local vs long-range transport sources of POPs/CEACs.

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The Antarctic Monitoring and Assessment Programme; Modelling Antarctic Progress on Arctic Success

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Introduction

The Arctic Monitoring and Assessment Programme (AMAP) has served as a science-policy boundary organisation with disproportionate impact over the past thirty-one years. Recognizing the success of AMAP, the goal of The Antarctic Monitoring and Assessment Programme (AnMAP) is to transfer proven frameworks and structures to the Antarctic region. The Antarctic region, however, is unique from the Arctic in a number of notable ways. Aside from clear geographical, ecological and meteorological differences between the two regions, the Antarctic lacks any permanent human inhabitants. This distinction, combined with the lack of sovereignty of the Antarctic continent, has and continues to influence chemical pollution research activity in the region. Key research and monitoring gaps and challenges related to chemical transfer, fate, and impact in Antarctica, have shaped the AnMAP strategic goals and workplan.

AnMAP Overview

AnMAP offers an opportunity for the incorporation of best-practice methodologies for robust temporal and spatial assessment of chemical pollution in Antarctica. AnMAP seeks to:

- Model the demonstrated efficacy and impact of AMAP by transferring proven frameworks and structures to the Antarctic region.
- Address limiting research gaps with respect to pollution and climate change issues in Antarctica and the Southern Ocean through circum-polar, collaborative, research. Research products will form the basis of expert-led assessments for evidence-based policy.
- Facilitate implementation of sustained surveillance programs.
- Meet international obligations in the Antarctic region with respect to chemical pollution.

Recently, the Scientific Committee for Antarctic Research (SCAR) Action Group, Input Pathways of persistent organic pollutants to AntarCTica (ImPACT), produced a horizon scan of priority challenges for persistent organic pollutant (POP) research in Antarctica [1]. Recommendations of the ImPACT group are closely aligned with the four foundation Research Pathways (RPs) of AnMAP:

1. *Input pathways of chemicals to Antarctica*

This policy-impact driven RP will serve both the Stockholm Convention on POPs, as well as the Protocol on Environmental Protection to the Antarctic Treaty (the Madrid Protocol) which explicitly prohibits the importation of chemicals of known risks to Antarctica. Environmental chemistry has a major role to play in strengthening efforts under existing chemical regulatory frameworks, both in the generation of policy-relevant chemical risk data, and in timely dissemination of relevant information to national, regional and international regulatory bodies. Polar regions present a unique environment for the detection of new chemicals of emerging concern due to the remoteness, sparse population, and low number of local contamination sources in these regions [2]. There is nowhere more remote than Antarctica, and therefore no stronger evidence for chemical persistence and mobility than detection in Antarctic environmental media. This RP will focus on suspect screening of Antarctic media for Chemicals of Arctic/Antarctic Concern (CEACs) for expedited regulation.

2. *Biogeochemical cycling of organic chemicals in a warming climate*

Biogeochemistry plays an important role in the transport of organic pollutants and control the water column concentrations, and thus exposure of Antarctic biota [3]. Polar Regions present a unique suite of biogeochemical processes and the manner in which these influence organic pollutant behaviour remains a critical research gap [4]. As rising temperature shifts chemical equilibria and alters both the physical and biological Polar landscape, it has become imperative to close this knowledge gap. This RP seeks to generate an understanding of the biogeochemical cycling of POPs in the Polar landscape in support of appropriate managerial action and Polar environmental protection through a time of accelerated environmental change.

3. *Ecotoxicological impact of organic chemicals to endemic biota*

RP3 seeks to fill major research gaps surrounding the toxicological sensitivity of Antarctic biota. Very little is known about the tolerance thresholds and detoxification mechanisms of Antarctic organisms to organic pollutant [5]. It has been posed that as these animals have evolved in the absence of xenobiotics, they have not developed the detoxification mechanisms of temperate and tropical counterparts [6]. Further, traditional ecotoxicological bioassays applied to Antarctic species are unlikely to capture true effects due to the characteristically slow metabolism of Polar biota [7]. This RP seeks to further knowledge in this area through application of novel, species-specific, approaches.

4. *Long-term, circum-polar surveillance of climate change and chemical pollution*

Temporal changes in environmental pollution levels may reflect: changes in primary emissions; changes in re-emissions from environmental media such as ice and surface waters; changes in environmental transport pathways, and processes, both in abiotic (e.g. ocean currents) and biological (food web connections) systems; and, in wildlife, changes to the nutritional state and body condition of animals [8]. Harmonized, long-term and circum-polar monitoring programs are therefore imperative for robust interpretation of spatial and temporal trends. This RP seeks to meet the Global Monitoring Plan of the Stockholm Convention requirements in the Antarctic region, with respect to atmospheric monitoring. Similarly, it incorporates the recommendations of the International Whaling Commission for the incorporation of cetaceans as sentinels of pollution and climate change in polar regions through sustained, long-term and circum-polar monitoring of southern hemisphere humpback whales (*Megaptera novaeangliae*).

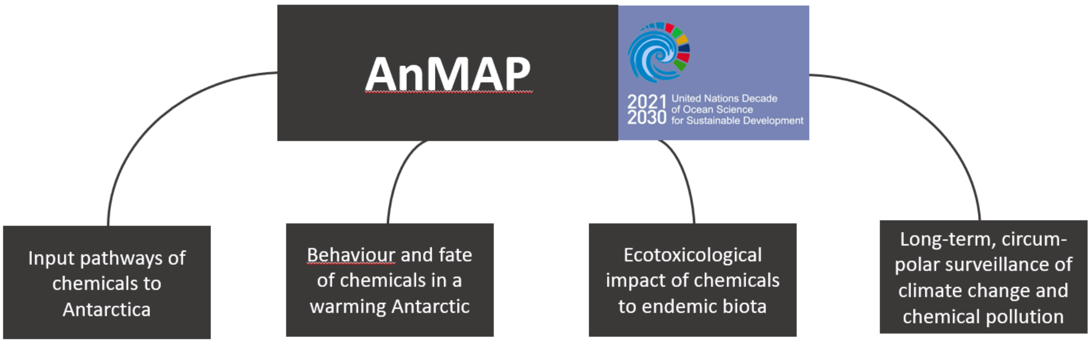

Figure 1: AnMAP Foundation Research Pathways

Conclusion

AnMAP is the product of the sustained efforts of the Antarctic chemical research community over the past 16 years, in bringing recognition and awareness to the critical need for a sustained research and surveillance networks to uncover the changing pollution footprint in Antarctica. Today, AnMAP is endorsed by the United Nations as an Ocean Decade activity and fulfills the Action Group goals of ImPACT. It has attracted research funding in support of RP1 and continues co-development with AMAP and other stakeholders.

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Contaminants in the Arctic – Screening, monitoring and assessment

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International cooperation on environmental pollution in the Arctic was initiated in the late 1980s, leading to the adaption of the Arctic Environmental Protection Strategy in 1991. Several programmes were instituted for its implementation, including the Arctic Monitoring and Assessment Programme, now a Working Group under the Arctic Council (AMAP, 1998). As part of this process and in response to documentation and awareness of pollution issues in the Arctic, several Arctic States established contaminant monitoring programmes to track levels of persistent organic pollutants (POPs), mercury and other contaminants in the Arctic environment. Thus, several contaminant monitoring programmes have been in operation since the 1990s, providing long-term environmental time series of POPs and other contaminants (Rigét et al., 2019; Wong et al., 2021). These datasets fulfil many purposes, for example

- evaluating the effectiveness of regulatory actions for problematic chemicals, such as global regulations under the Stockholm Convention (UNEP, 2017),
- raising awareness of potentially emerging issues, such as increasing concentrations of non-regulated chemicals in the Arctic environment (Vorkamp et al., 2011),
- providing empirical data from remote regions for use in risk assessments,
- documenting pollution levels in traditional food items used by local and Indigenous communities (AMAP, 2015),
- improving our understanding of the global fate of pollutants, including their long-range transport, distribution and accumulation in the Arctic environment, biomagnification and human exposure.

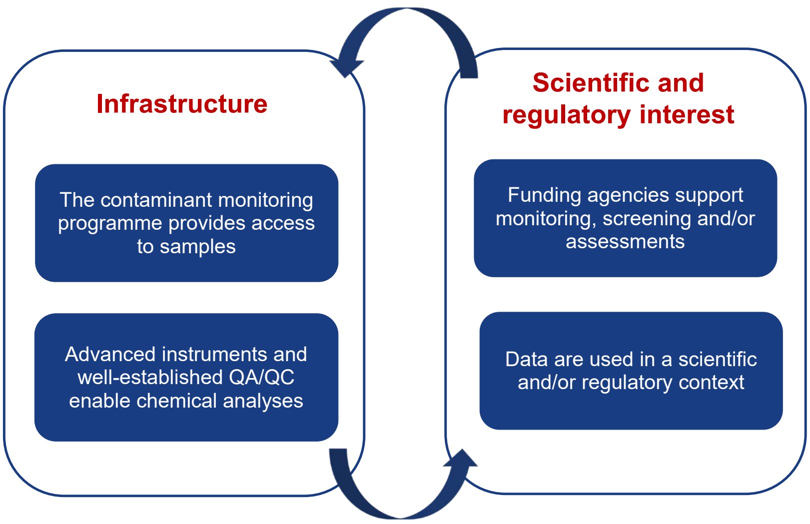

Figure 1: Framework of an Arctic contaminant programme enabling screening of chemicals of emerging Arctic concern

Based on long-term national funding, the contaminant monitoring programmes present a framework that can encompass reactions to emerging issues, including the screening of chemicals of emerging Arctic concern (CEACs). As illustrated in Figure 1, the programmes provide the infrastructure that ensures access to samples and laboratory equipment for chemical analyses, including well-established procedures of quality assurance and quality control (QA/QC).

The **AMAP Core Programme** was established in Greenland in 1994, to monitor POPs and other chemicals in biota and, as of 2008, in air (Bossi et al., 2013; Rigét et al., 2016). The biannual collection of biota samples is organised in collaboration with local hunters. All samples are stored in an Environmental Specimen Bank (Rigét et al., 2016). Since 2005, the programme has included the screening of CEACs, which are selected together with the Danish Environmental Protection Agency (EPA), based on their data needs for risk assessments and regulatory purposes.

The CEAC component of the programme has produced a number of retrospective time trend studies, for example covering perfluoroalkyl substances (PFAS), polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCDD) and endosulfane in ringed seals (Bossi et al., 2005; Rigét et al., 2006; 2013; Vorkamp et al., 2011; 2017). Figure 2 shows the time trend for PBDEs in ringed seals from East Greenland, originally performed as a retrospective time trend in 2005 and subsequently extended as part of the regular POP monitoring programme. In addition, screening studies have been performed for various CEACs and Arctic wildlife species, including novel brominated flame retardants (NBFRs), dechlorane plus, short-chain chlorinated paraffins (SCCPs), hexachlorobutadiene and octachlorostyrene in birds, seals and polar bears (Vorkamp et al., 2015; 2017).

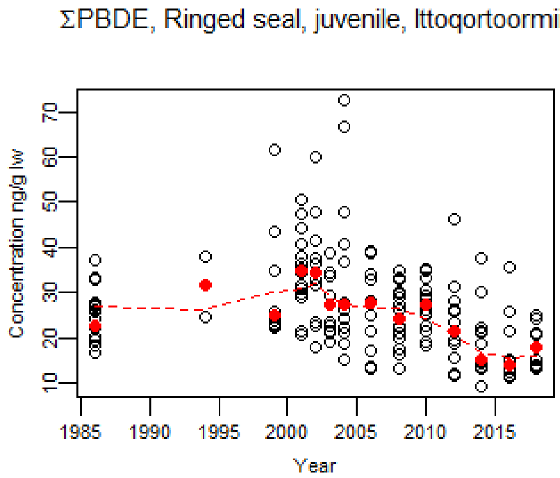

Figure 2: Concentrations of polybrominated diphenyl ethers (PBDEs), in ng/g lipid weight, in ringed seals from East Greenland, obtained via the AMAP Core Programme

Based on the findings for dechlorane plus, documenting its presence in Arctic biota, further research and monitoring studies have been carried out for dechlorane plus, including emission inventories (Hansen et al., 2020), a time trend in peregrine falcon eggs (Vorkamp et al., 2018) and a preliminary risk assessment (Vorkamp et al., 2019). Many of these results have been used in connection with the draft risk profile recently prepared by the POP Review Committee of the Stockholm Convention (UNEP, 2021). The screening studies of target compounds have been extended to *in silico* and non-target/suspect screening approaches (Muir et al., 2019; Hajeb et al., 2022). An ongoing project including air, biota and human serum samples from Greenland and the Faroe Islands is currently using suspect and non-target screening techniques to study the presence of theoretically identified Arctic contaminants and other compounds in the Arctic environment, based on the study by Muir et al. (2019).

All results from the AMAP Core Programme and associated studies feed into circumpolar AMAP assessments, such as those analysing time trends or CEACs (AMAP, 2016; 2017). The Danish EPA funds the active involvement of scientists from the Kingdom of Denmark in expert groups under AMAP preparing scientific assessment reports with science-based policy recommendations to decision makers in the Arctic Council and elsewhere. The AMAP POP expert group recently completed an assessment of the effects of climate change on POPs and CEACs, for example showing re-mobilization of chemicals in the Arctic environment and perturbations of the long-term time series along with changes in ecosystems and/or the physical environment (AMAP, 2021). The findings from this assessment are currently being transferred to a series of peer-reviewed articles.

The next assessment of the AMAP POP expert group will address local sources vs. long-range transport of Arctic contaminants. The CEAC report included examples that indicated local emissions of chemicals to the Arctic environment, for example as part of wastewater discharges (AMAP, 2017). Given the importance of Arctic data for risk assessment and regulatory purposes, such as the long-range transport as one of the screening criteria under the Stockholm Convention, a scientific assessment is needed of the presence of contaminants in the Arctic with regard to the sources they represent.

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Survey of emerging and legacy organic contaminants in the polar regions

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1. Introduction

Along with the rapid increase of world pollution and the quick development of economy and industry, a variety of chemical pollutants have been introduced into the environment in large quantities [1-4]. The persistent organic pollutants (POPs) have common characteristics of persistence, toxicity and bioaccumulation potential and tendency of long-range environmental transport (LRET)[5,6], and are subject to the Stockholm Convention to eliminate the POPs from the environment. Initially, twelve POPs have been recognized as causing adverse effects on humans and the ecosystem in 2004. Subsequently, sixteen newly chemicals were added to the Stockholm Convention in the following years until 2019[7], and more organic chemicals are under evaluation and will be reviewed by the POPs Review Committee. Besides the classic POPs, a numbers of organic chemicals have been found in the polar regions as emerging organic contaminants (EOCs)[8]. EOCs include alternative BFRs, short-chain PFASs and their precursors, pharmaceuticals and personal care products (PPCPs), organophosphate Esters (OPEs), phthalate esters (PAEs), chlorinated paraffins (CPs) and siloxanes.

POPs and EOCs in polar regions have become significant concern because of their persistence, bio-accumulative and toxic potential. Climate change can alter bio-geochemical cycling of POPs and EOCs, and amplify their effects to polar ecosystems. Global industrialization and reconstruction have reached out to both Arctic and Antarctic, which led increasing human activities such as tourist, shipping, resources exploration and construction of research stations. Occurrences of POPs and EOCs from long-range transport and local discharge have impressed fingerprints in the fragile polar ecosystems. Therefore, actions are urgently called to monitor the temporal trends of POPs and to investigate novel EOCs in polar regions.

2. Monitoring program in the Arctic

The Arctic Monitoring and Assessment Programme (AMAP) has been established since 1991 to implement components of the Arctic Environmental Protection Strategy (AEPS), and became a programme group of the Arctic Council. AMAP has launched several research programs for monitoring classic POPs and EOCs in air, sediment, and organisms in the pan Arctic. In the past decades, AMAP has published periodically assessment for classic contaminants, emerging chemicals with Arctic concern and climate change effects[9,10]. Scientific information has been transferred to support stakeholders of Arctic governments to take remedial and preventive actions relating to contaminants.

3. Monitoring program in the Antarctic

For the Antarctic, the Scientific Committee on Antarctic Research (SCAR) has a long and successful record of summarizing policy-relevant scientific knowledge to policy makers through its Groups such as Input Pathways of persistent organic pollutants to AntarCTica (ImPACT). The experiences of AMAP have been successfully transferred for observation and assessment of chemical contaminants in the Antarctic through research projects and activities of ImPACT[11].

4. POPs and EOCs in the polar regions

The data of legacy POPs in environmental media and biota exhibit decline trends in both the Arctic and the Antarctic by virtue of the global endeavor in banning their manufacture and usage. While, reemission of POPs that previously accumulated in polar environment have been observed, which can enter global cycle again following the process of ice retreat, glacier melting and permafrost throwing driven by global warming. On the other hand, a number of EOCs have been reported in different environmental matrices in the Arctic and Antarctic. Some EOCs such as per- and polyfluoroalkyl substances (PFASs), Chlorinated Paraffins (SCCPs and MCCPs) and organophosphate esters (OPEs) have been included in long-term atmospheric monitoring programs of AMAP. Screening survey for EOCs in environmental and biological matrices have been carried out through national and regional research programs. Data of EOCs in Antarctic are rare. Nevertheless, long-range environmental transport of EOCs have been highlighted with their occurrences in ice core, snow and lake waters in polar regions. Therefore, continually monitoring should be conducted for legacy POPs and EOCs in polar areas.Especially, investigation of EOCs in the Antarctic need to be strengthen through national and international research programs.

Among EOCs, PPCPs have shown the wide presence in both Arctic and Antarctic environment. High concentrations of PPCPs usually found in the coastal areas receiving effluents from WWTPs at research bases and settlements. The emission of PPCPs from human activities in the Arctic and Antarctic is a significant local source. In addition, personal care products such as fragrance materials (FMs), (UV filtres) UV-Fs, and cyclic volatile methylsiloxanes (cVMS) can be transported via air from low- and mid-latitude regions to polar regions. It is essential to include volatile and semi-volatile PPCPs in existing atmospheric monitoring programmes.

5. Recommendations for future research

Long-term monitoring programs of POPs at research bases need to be continued for air and precipitations. EOCs and transformation products should be considered to be incorporated in the monitoring program up on their physicochemical behavior.

Occurrence, bioaccumulation and biomagnification of POPs and EOCs in territory species and marine organisms in the Arctic and Antarctic should be extensively studied.

Sample bank for both environmental matrices and biological species should be initiated through national and international programs for retrospective analysis to assess alternative EOCs in the future.

Along with target analysis for legacy POPs and selected EOCs, non-targeted screening approaches using high-resolution mass spectrometry coupled to liquid or gas chromatography have risen as a new approach in analytical chemistry to identify and eventually quantify novel emerging chemicals.

Comprehensive observation coupled to multi-compartment models could be used to improve understanding of health impact of POPs and EOCs to the organisms and human beings in the polar regions.

Climate change is directly and indirectly affecting the sources, transport pathways, fate of POPs and EOCs. Thus, future research will need to understand the various biogeochemical and geophysical processes under climate change and anthropogenic pressures to be able to predict the environmental fates and toxicity risk of EOCs in the polar regions.

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Modeling transport of legacy and new priority substances to the Arctic

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Environmental fate and transport models for environmental pollutants provide a platform for integrated assessment of the 1) emissions, 2) measured levels, and 3) competing rates of transport through the environment, removal by degradation and irreversible sequestration (MacLeod et al. 2010; WEOG 2021). Models can also be applied to screen lists of chemicals for high potential to be contaminants of concern in areas like the Arctic (for example, Brown & Wania 2008, Reppas-Chrysovitsinos et al. 2017).

Several recent examples of integrated assessment of global pollutants that contaminate the Arctic were recently summarized in the report from the Western Europe and Others Group (WEOG) UN Region submitted as part of the effectiveness evaluation of the Stockholm Convention (WEOG 2021). The WEOG report illustrates that integrated assessments are slowly becoming more common, with examples in the literature for polychlorinated biphenyls (PCBs), hexachlorocyclohexanes (HCHs), DDT, polycyclic aromatic hydrocarbons (PAHs), perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), endosulfan, and dicofol. The main obstacles to composing integrated assessments are often a lack of emission inventories to drive the models, and a lack of adequately constrained physico-chemical property and degradability data for the pollutants.

The 2021 WEOG report highlights four recent integrated assessment studies that illustrate recent advances in modeling persistent organic pollutants that have global scale, and, in one case, a pollutant that could potential be considered as a POP candidate in the future. The four case studies are:

- McLachlan et al. (2018), who present an integrated assessment of one of the best-studied Stockholm Convention persistent organic pollutants, PCB153. They combined the BETR Global fate and transport model with the ACC-HUMAN bioaccumulation model to predict concentrations of PCB153 in human milk, and evaluated their predictions against data collected under the UNEP/WHO Global Monitoring Plan. The model results were highly correlated with the measurements ($p < 0.0001$) and PCB153 concentrations in human milk were predicted from emissions with a root mean squared error of a factor of 4.5. This study illustrates the potential for models to describe the entire chain of fate, transport, bioaccumulation and human exposure at the global scale in cases where knowledge of emission levels and trends, physico-chemical properties and degradability of the pollutant are well constrained.
- Li et al. (2015), who composed an integrated assessment of the pesticide dicofol, which was, at the time, under consideration as a POP candidate. The integrated assessment included development of a geographically resolved emission inventory and simulative modeling using the Globo-POP and BETR Global models. The study concluded that

proactive restrictions at the international level were warranted, and dicofol was added to the Stockholm Convention under Annex A (Elimination) in 2019.

- Li (2019), who presented an integrated assessment of tris-(1-chloro-2-propyl) phosphate (TCPP), which is detected globally in air and water and could be nominated as a POP candidate in the future. In this case there was no global emission inventory to use a basis for the assessment, so Li used a generic emission inventory based on the intensity of emissions of light from the Earth's surface to space at night as an initial starting point. The initial night-light emission inventory was scaled to achieve good agreement with measured levels of TCPP in the global environment in a set of scenarios that accounted for the large uncertainties in properties and degradability of TCPP. This case study illustrates the potential for integrated global assessments to identify research priorities and constrain uncertainties about emissions and properties of global pollutants even in the face of extremely high uncertainties.
- And, Zhang et al. (2017), who conducted a large-scale integrated assessment of emissions of perfluorooctane sulfonate (PFOS) and its transport in the Atlantic Ocean to the Arctic. Their model scenarios demonstrate the distribution of PFOS in the Atlantic Ocean and the response of PFOS concentrations to its phase-out in North America in 2000. Deep water formation in the North Atlantic Ocean was identified as a relevant loss process. Without that process, PFOS fluxes into the Arctic would be approximately 30% higher. This study illustrates the rapid advance of modeling capabilities for hydrophilic POPs like PFOS that are transported in the global oceans.

Models are also useful tools for identification and prioritization of chemicals of emerging Arctic concern. A notable example is the identification of potential POPs and planetary boundary threats among Arctic contaminants identified by the Arctic Monitoring and Assessment Programme (AMAP 2017, Reppas- Chrysovitsinos et al. 2017). Modeling using the OECD software tool for screening chemicals for persistence and long-range transport potential (the OECD Tool, Wegmann et al. 2009) and properties of chemicals that have been detected in the Arctic but are not currently the subject of international regulation allowed for the prioritization of potential POPs and to identify substances whose presence in the Arctic is likely the result of local use and emission rather than long-range transport. The study also demonstrated the feasibility of screening chemicals for potential to be planetary boundary threats due to a combination of high persistence and potential for global distribution in the atmosphere or oceans (MacLeod et al. 2014), and the work was later extended to consider over 8500 chemicals in use in the OECD (Reppas- Chrysovitsinos et al. 2018). Recently, Plaza-Hernandez et al. (2021) examined the feasibility of incorporating information on potential emissions of chemicals into screening assessments using data reported under the European REACH legislation.

Important research priorities to improve integrated assessments of chemicals that are known to be, or are suspected of being Arctic pollutants include:

- Improving methods for developing emission inventories for global environmental pollutants, including so called "top-down" methods in which emissions are inferred from observations using inverse modeling (Schenker et al. 2009, Li 2019).
- Expanding the predictivity of models of gas-particle partitioning of very low-volatility persistent organic pollutants such as highly brominated diphenyl ethers. Recent research

(Li et al. 2015) has demonstrated that the distribution of such chemicals between the apparent gas phase and aerosols in the atmosphere can be described by a conceptual model that assumes steady-state instead of the more common assumption of equilibrium. However, steady-state distribution models currently must be tuned to fit measurement data (Qin et al. 2021, MacLeod et al. 2021) and do not perform well when parameterized to predict, rather than describe, empirical data (Zhao et al. 2020).

- Persistent pollutants with novel combinations of properties present challenges for fate and transport models because they can fall outside the domain of applicability of the models. Micro- and nano-plastic are increasingly recognized as global pollutants and pollutants of the Arctic in particular (Lusher et al. 2015, Bergmann et al. 2019, Materic et al. 2022), and cannot be modeled using the tools developed for POPs. A new generation of global fate and transport models for microplastic and nanoplastic pollution are required to constrain the global mass balance for this persistent and poorly reversible contamination (MacLeod et al. 2021, Domercq et al. 2021)

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What are research needs for investigating contaminants under climate change impacts in polar regions?

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In the recent years, the level of interest in the climate of the polar regions is unprecedently increased, due to the discovery of the Antarctic ozone hole, the reduction of sea ice extension, the disintegration of floating ice shelves around Antarctica and the high levels of aerosol reaching the Arctic. This has been coupling with climate model predictions showing that the high latitude regions will warm more than other region on Earth. Nowadays, the entire international community is working to understand the main reason of the high latitude climate change in the context of increasing anthropogenic influence.

Polar regions are less contaminated than other parts of the world. Antarctica is isolated by the Southern Ocean, and it can consider a clean laboratory and only permanent settlements are present (Poland et al., 2003). On the contrary, the Arctic has permanent communities that by themselves contributes to environmental contamination. The regulatory regimes are quite different between two poles. The international Protocol on Environmental Protection to the Antarctic Treaty preserves the environment because it establishes a set of environmental principles for each activity. In contrast, the regulation of environmental preservation and contamination has been achieved through the initiatives of individual countries rather than as a result of international agreement.

Contamination in the polar regions can arise from distant sources and be transported to the regions by air or sea, or it can be the result of local activities. The contamination from remote sources through atmospheric pathways are commonly known as the grasshopper effect, the global distillation hypothesis, and long-range transport. These processes carry a broad range of organic and metal pollutants, acidifying compounds, and radioactive contaminants. The detection of persistent organic pollutants (POPs) and some metals in snow (Bargagli, 2008; Vecchiato et al., 2015) remote from human activity in Antarctica indicates that these are global transport mechanisms. Although the oceanic transport of persistent contaminants is often considered to be much less important than atmospheric transport, models which combine the transport of semi-volatile chemicals in air and water indicate that the overall transport of POPs to remote regions is accelerated with respect to models treating air and water separately (Beyer and Matthies, 2001).

Contamination in the Antarctic ecosystems was first reported in 1966 (Sladen et al., 1966), and since then there has been an increasing interest in studying and monitoring the presence of pollutants in this otherwise pristine area of the world. This awareness has been growing since the Arctic was first reported as a final sink for POPs (Ottar, 1981).

Several species can pollute the different environmental compartments in the polar regions. Levels of heavy metals and trace elements in the environment are generally determined by local geochemistry. Natural sources include rock, soil dust, volcanic eruptions, sea-salt spray, wild forest fires, continental and marine biogenic activity, and cosmic deposition. However, in some places, natural levels are swamped by significant anthropogenic emissions (Barbante et al., 2017). Some elements are essential for life (e.g., Cu, Fe and Zn) but can be present in the environment at toxic levels. Heavy metals (e.g., Cd, Hg and Pb) and trace elements can be emitted into the atmosphere where they are dispersed globally and can enter into various biogeochemical cycles after deposition. Anthropogenic emissions of toxic elements often have a higher bioavailability due to their chemical speciation or particle size. The chemical form defines the solubility of the compounds, altering their absorption, facilitating their entry into the food web and other geochemical cycles (Spolaor et al., 2012).

Human activities that increase atmospheric elemental concentrations often increase the atmospheric dust load. This can have a climatic effect by modifying the radiative balance of the Earth. Dust can reflect solar radiation, aerosols can act as cloud condensation nuclei, and dust deposited on snow and ice with a high black carbon content can accelerate snow melt by absorbing light more readily than fresh snow. The elemental content of the atmosphere is an important tracer of transport processes and marker for human activity that is preserved in the cryosphere.

Mercury emitted by anthropogenic and natural sources occurs in the atmosphere mostly in the gaseous elemental form (Hg^0), which has a long lifetime in tropical and temperate regions. Once deposited in terrestrial and aquatic ecosystems the metal is partly re-emitted into air, thus assuming the characteristics of global pollutants such as POPs (Bargagli, 2005). This metal is now acknowledged to be one of the most serious contaminants in polar ecosystems because of springtime Hg depletion events which have been reported in some coastal areas of the high Arctic (Schroeder et al., 1998) and Antarctica (Ebinghaus et al., 2002).

Another class of contaminants that have been introduced by human activities are radionuclides. Although low levels are produced naturally by the interaction of cosmic rays with the upper atmosphere, human activities have sharply increased their concentrations and the environmental radiation background (Paatero et al., 2012). It has been found that plutonium and tritium levels from free atmosphere nuclear weapons atmospheric testing in the middle of the 20th century has been detected in Alpine and Greenland ice (Gabrieli et al., 2011). Radionuclides are also known to have been released from long-term medium waste (e.g., operational waste) and high activity radioactive waste (spent nuclear fuel) storage facilities or during nuclear accidents.

Many organic compounds are naturally produced, but mankind has developed and introduced an enormous array of new compounds into the environment, all of which can reach the polar regions. It has been suggested that human activity really began to change the environment at the beginning of the 19th century with the introduction and use of the steam engine (Crutzen, 2006). The most common organic contaminats are POPs, that include several groups of chemicals with similar structures and physico-chemical properties that elicit similar toxic effects. This class of compounds includes well-known classes of contaminants: polychlorinated-biphenyls (PCBs), -dioxins (PCDDs), -furans (PCDFs), polybrominated-diphenyl ethers (PBDEs), -biphenyls (PBBs), perfluorinated compounds (PFCs) and other halogenated hydrocarbons, used as pesticides. They have been used extensively worldwide in agriculture (pesticides), industrial and health applications. These chemicals are synthetic, ubiquitous, show long-range transport potency, and many of them are hydrophobic; they bio-accumulate in organisms via respiration, dermal contact, and through diet (Wania, 2003). Moreover, other emerging contaminants are polluting the polar regions. For examples, the occurrence and the fate of Personal Care Products in the Antarctic and in the Arctic environments is still poor unknown (Vecchiato et al., 2018, 2017).

In this complex scenario, the research about contaminants in polar regions have to focus to define the trends and effects of pollutants. The definition of their sources and pathways needs a better understanding of these species considering their distribution in the different environmental compartments. For example, the developing of continental-scale monitoring programs to assess the long-term effects of persistent contaminants in the organisms and food chains and to predict possible responses of terrestrial and marine ecosystems to climate changes and anthropogenic activity.

Another important aspect is the investigation of new emerging contaminants, such as microplastics or some organic compounds (e.g., new personal care products, endocrine disruptors) recently emitted from the middle latitude that can be transported in the polar regions. The analytical challenge is to develop the most sensitive and selective methods to identify new markers, in particular organic compounds for which a limited number of species are investigated. Moreover, a particular attention will be dedicated to the new contaminants that will produce with the green deal of the entire world in the next future.

Climate change is expected to influence agriculture productivity. Some agricultural regions will be threatened by climate change, while others may benefit. Increasing of temperature bring beneficial effects in the high latitude regions where the poleward shift of the thermal limits of agriculture would increase the productive potential. In particular, the expansion of agriculture in the sub-Arctic areas will probably bring the increasing of contamination in the Arctic environment due to the use of fertilizers and pesticides.

Finally, the experimental observation should be linked with the modelling to define the most plausible scenarios, in order to define the best policy for mitigation of the contamination. So, there is a need to enhance or establish a coordinated network of long-term representative sites for monitoring of contamination in the polar regions. This monitoring should include the well-known and regulated contaminants, but the update of a Watch List should be mandatory to evaluate the real situation of contamination in the polar areas.

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Chemicals of emerging Arctic concern in a changing Arctic: Status and research needs

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Environmental pollutants are reported in Arctic samples since the late 1800s after the first description of “dirty snow” in the Eastern Arctic, originated from long-range atmospheric transport of early industrial atmospheric emission from the industrializing countries (Nansen and Sverdrup, 1897). After recoding considerably environmental consequences of petroleum related pollution in Arctic coastal areas, organic pollutants are monitored as relevant local Arctic pollutants (Malins, 1977).

Since the 1980s, only a selected number of persistent organic semi-volatile pollutants (POPs) are monitored regularly in Polar environments after they have been identified as relevant Arctic pollutants. POPs are today considered as environmental mobile and reaching Arctic environments through long-range atmospheric transport (LRAT).

Recently, highly sensitive trace analytical methods enabled the identification and quantification of an increasing number of contaminants of emerging concern in the Arctic environment (CEAC = contaminants of emerging Arctic concern). The newly published and updated Arctic Monitoring and Assessment Programme (AMAP) report on CEACs is an impressive testimony of the wide array of contaminants currently investigated and monitored in the Arctic Environment (AMAP, 2017). In total 12 pollutant groups comprising of several hundreds of contaminants are currently listed by AMAP as priority CEACs for future environmental monitoring.

The, here reported survey on CEACs (including microplastics = MP) revealed that also local sources are contributing to the pollutant profile in Arctic environments. The comprehensive profiling of POPs and CEACs in combination with elucidations of associated environmental processes allows a comprehensive evaluation of the human footprint in the Arctic. A series of recent studies in the Central and western Arctic reported on the presence and consequences of pharmaceuticals and personal care products (PPCPs) in the local environment (Kallenborn et al., 2017). Sewage related release was identified as most predominant emission source for PPCPs in the Arctic with more than 70% of PPCPs identified in sewage effluent samples (figure 1).

Such results provide important information on local pollutant sources and their potential consequences on the environment and the local populations. Human population structure in the Arctic is characterized by a decentralized, scattered distribution of minor settlements with a few cities as cultural and social centers. In addition, no local production of PPCPs is reported in the Arctic, thus potential release from production sides as pollutant source can be excluded. However, considerable knowledge gaps with respect to environmental mobility, transformation pathways, consequences for Arctic animals and humans, when unintendedly exposed, are identified. Comprehensive environmental studies on the fate, environmental toxicology and distribution profiles of pharmaceuticals applied in high volumes and released into the Nordic environment under cold Northern climate conditions should be given high priority by national and international authorities and funding agencies. This is also necessary to ensure that local food sources can also be harvested by the future generations of indigenous populations without any concern for health and well-being.

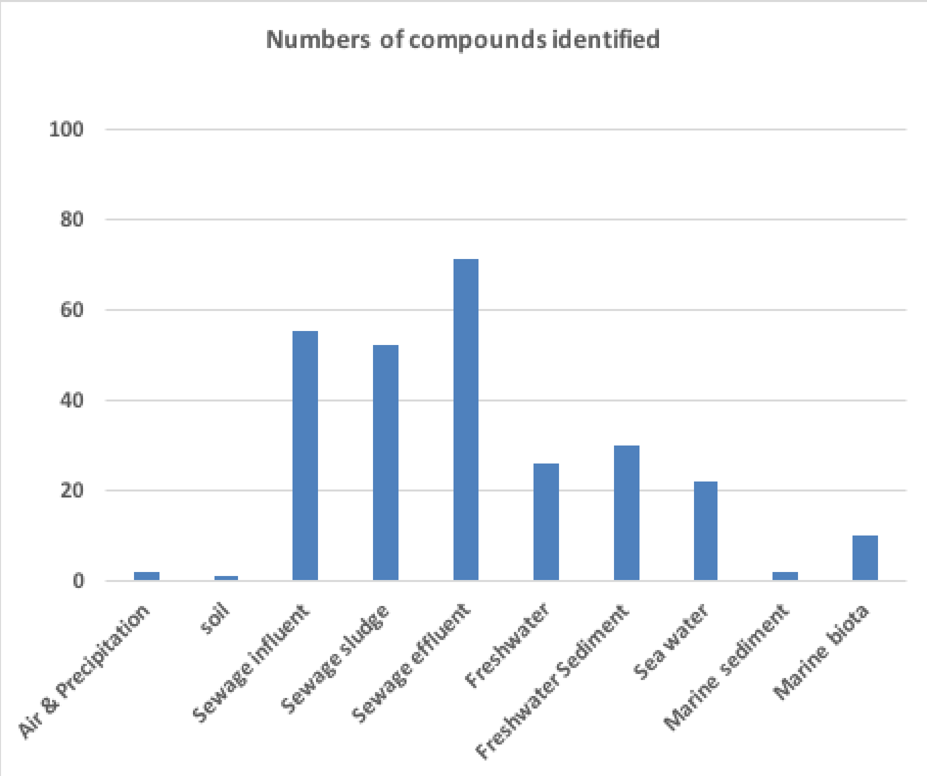

Figure 1: Relative abundance of PPCPs (max 110 compounds identified) in Arctic environmental samples (Kallenborn et al. 2017)

The following information is missing for and comprehensive risk assessment in Arctic environments when considering the environmental fate of CEACs:

- Medium- and long-term monitoring data are not available from national or regional monitoring activities
- A future research priority should be laid- upon time and spatial trend investigations for priority CEACs in Arctic environments.
- Comprehensive information on source apportionment and assessment of source strength is missing for a reliable risk assessment in the Arctic
- Scientific emphasis should be placed on environmental fate assessment including up-take into species exploited for human consumption.
- The elucidation of transformation processes and the risk evaluation of major transformation products as an integrated part of fate assessment is not available.
- Reliable scientific information on environmental toxicology and effects studies in the Arctic designed for priority CEACs including cocktail effects and information on non-target effect mechanisms is missing

Illustrated by several examples, the potential of such a comparative approach combining regulation, toxicological studies and CEAC monitoring will be highlighted and discussed. Possible implications of these complex research and assessment strategies for Polar environmental research, regional screening, monitoring activities and regulatory strategies not just for the Arctic environment will be provided. The close linkage between modern environmental chemistry, toxicology, fate modelling on the one side and monitoring, environmental assessment, and regulation is crucial to generate for balanced and sustainable pollution regulations in the Arctic. Potential conflict scenarios between environmental concerns and geopolitical, economic, and strategic interests in the region will be addressed.

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Addressing the impacts of climate change on contaminants in Antarctica: the work of the Subsidiary Group on Climate Change Response

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Introduction

Since widespread Antarctic meteorological records began in the 1950s, surface temperature trends within the area of Antarctic Treaty governance (south of latitude 60°S) have been characterized by a marked warming of the Antarctic Peninsula and Scotia Arc archipelagos. Previously, little significant temperature change was observed across the rest of the continent, but recent research has detected a significant warming trend at the South Pole. Along the Antarctic Peninsula and Scotia Arc archipelagos, the higher temperatures have resulted in the retreat of glaciers, the complete or partial collapse of a number of ice shelves and a greater frequency of precipitation occurring as rain rather than snow. It appears likely that the concentrations of atmospheric greenhouse gases will continue to rise, and under a business-as-usual scenario of continued greenhouse gas emission increases, Antarctic surface temperatures across the continent are expected to increase by ~4° C by 2100 compared with temperatures at end of the twentieth century. At a continent-wide scale, the higher temperatures are predicted to increase precipitation by about 30% and result in a 30% reduction in sea ice extent. Predicted warming could result in up to a three-fold increase in the area of ice-free ground in the central and northern Antarctic Peninsula, and ice retreat across coastal areas of continental Antarctica, with substantial impacts upon biological communities. Permafrost, snow and soil surface melting may cause mobilisation of soil pollutants from, for instance, waste dumps and other polluted sites associated with previous stations and activities, resulting in potentially adverse impacts upon local biological communities. Furthermore, climate change impacts on ocean and atmospheric circulation may impact the long-distance transportation of pollutants into Antarctica from other more populated areas of Earth.

The CEP Climate Change Response Work Programme

The Parties to the Antarctic Treaty, through the adoption of the Protocol on Environmental Protection to the Antarctic Treaty (1991) set aside Antarctica as a ‘natural reserve, devoted to peace and science’, and thereby committed themselves to comprehensive protection of the Antarctic environment, as well as dependent and associated ecosystems. The Committee for Environmental Protection (CEP) provides advice to the Antarctic Treaty Consultative Meeting (ATCM) on issues relevant to the Protocol including climate change and contaminants/pollution. The issue of climate change has been on the CEP agenda for the last 15 years and is now a top priority issue in the CEP five-year work plan. The Antarctic Climate Change and Environment (ACCE) Report (2009) presented a comprehensive review of scientific understanding of how the Antarctic climate is changing, how it is likely to change in the future, and what the associated environmental impacts might be (see: https://www.scar.org/policy/acce-updates/). The ACCE report was used as the basis for discussions at an Antarctic Treaty Meeting of Experts (ATME) on Climate Change held in 2010. The meeting generated 30 recommendations, which are subject to continuing consideration by the ATCM and CEP, and resulted in the development of the CEP Climate Change Response Work Programme (CCRWP) in 2015. In 2017, the CEP established the Subsidiary Group on Climate Change Response (SGCCR) to help the Committee in its consideration of how to address the implications of climate change for protection of the Antarctic environment.

The CCRWP was updated in 2016 and considers actions across a range of issues including:

- Enhanced potential for non-native species (NNS) introduction and establishment
- Change to the terrestrial (including aquatic) biotic and abiotic environment due to climate change
- Change to marine near-shore abiotic and biotic environment (excluding ocean acidification)
- Ecosystem change due to ocean acidification
- Climate change impact to the built (human) environment resulting in impacts on natural and heritage values
- Marine and terrestrial species at risk due to climate change
- Marine, terrestrial and freshwater habitats at risk due to climate change

Within the CCRWP, the issue of contamination is considered under the issue 'Climate change impact to the built (human) environment resulting in impacts on natural and heritage values'. In particular, the CCRWP identified the following Gaps/needs under this issue:

- Understanding how the abiotic terrestrial environment will change and how this might result in impacts on environmental or heritage values
- Understanding of effects of climate change on contaminated sites and implications for species/ecosystems (e.g., whether climate change will increase mobilization and exposure of species/ecosystems to contaminants and understanding how species/ecosystems will respond to exposure to such contaminants)
- Understanding what conservation/remedial interventions might be applicable to counteract these impacts

The CEP has made advances in the development of guidelines concerning the management of contaminated sites with the production of the Antarctic Clean-up Manual (Revision 2019; available at: https://documents.ats.aq/recatt/Att667_e.pdf). However, mindful of the potential threats posed by climate change and acknowledging that further research will be required to inform future policy and practical action, the CEP has identified the following research questions and science needs:

- Develop future spatial climate change predictions on the timescale of decades*
- Identify risk presented to Antarctic infrastructure by storms, sea level change, melting of permanent ice/flooding, permafrost melt, etc.*
- Research practical solutions to address climate change-related impacts on infrastructure*
- Assess the impact of plastic pollution on natural systems in light of climate change*
- Determine the origins and natural and anthropogenic transport routes of plastic pollution in the Antarctica marine and terrestrial environments*

- Research to inform the establishment of appropriate environmental quality targets for the repair or remediation of environmental damage in Antarctica
- Techniques to prevent mobilisation of contaminants such as melt water diversion and containment barriers
- Techniques for in-situ and ex-situ remediation of sites contaminated by fuel spills or other hazardous substances
- How will climate change affect mobilization and exposure of species/ecosystems to contaminants?*
- What is the susceptibility of microbial and macroscopic species in the Antarctic terrestrial environment to contaminants, including under warmer and wetter environmental conditions?*
- What is the susceptibility of near shore marine species to contaminants?*

* Questions/needs specifically linked to climate change

Conclusion

The Antarctic environment is presented with the dual challenges of climate change and the impacts of historical and on-going pollution originating from source within and outside Antarctica. The CEP has developed the CCRWP to identify actions needed to address the impacts of climate change in Antarctica. The scope of the problem is becoming clearer as a result of research activities undertaken by many National Antarctic Programmes. The use of existing technologies may help prevent local contamination events within Antarctica. However, the clean-up of existing contaminated ground would benefit from the further development of cost-effective methods suitable for the rapidly changing Antarctic environment.

Environmental specimen banks – experiences and challenges

Jan Koschorreck

German Environment Agency (UBA), German Environmental Specimen Bank

Environmental Specimen Banking, journeys through time for environmental protection

Environmental Specimen Banks (ESBs) systematically store high quality samples from the environment to support chemical management and innovative research for better environmental quality. They are operated by environmental agencies as part of the national long-term environmental research infrastructure or by environmental research institutes. ESB samples have been taken at regular intervals in freshwater, marine and/or terrestrial environments for many decades. Some ESB also sample human populations. ESB operations are subject to strict protocols for sampling, processing and archiving. Samples are stored in archives at low or ultra-low temperatures to ensure their long-term biological and chemical integrity.

The idea of environmental specimen banks goes back to the 1960s, the first ESBs were established in Sweden, Canada and Japan. Today, there are about 30 environmental specimen banks in Europe, North America, Asia, and Australia. Environmental agencies and scientific institutes collect environmental samples according to quality-assured protocols and store these materials in cold or cryogenic archives in a way that preserves their chemical and biological integrity over long periods of time.

The systematic use of high quality ESB data and samples has the potential to significantly improve our understanding of the fate of regulated and non-regulated pollutants in the environment. The archived samples can be used at any time, for example, to track changes in environmental exposure to a known contaminant and to test the effectiveness of regulatory use restrictions. Examples are metals and legacy chlorinated, brominated and fluorinated pollutants, which are regulated by regional chemicals management and the International Stockholm Convention. Furthermore, a main objective of the ESB chemicals strategy is the retrospective analysis of chemicals of concern: The samples are used to assess chemicals of emerging concern that were not known to be an environmental problem at the time of sampling or were not analytically detectable. Recent examples include new PFAS, including sum parameters, emerging chlorinated, brominated and organophosphorus flame retardants, chlorinated paraffins, microplastics and pharmaceuticals. Thanks to advances in molecular biology, it is now possible to use archived samples as collectors of DNA traces in the environment and to use eDNA data to assess biodiversity and specific molecular endpoints, e.g. population genetics and antimicrobial resistance. Finally, ESBs also help secure our future by providing samples to answer questions we are not aware of today or that may emerge as entirely new environmental problems.

Currently, the focus of chemicals assessment is shifting: Instead of only focusing on individual substances, their mixtures are now moving into the focus of research and authorities. Environmental specimen banks can make an important contribution to novel exposure assessment, as they archive many subsamples of the same samples, and with each chemical analysis of a subsample, new data on the exposure to chemical mixtures are developed. In addition, new analytical methods facilitate the simultaneous measurement of many analytes, allowing a more comprehensive picture of current and historical exposure to chemical mixtures than is possible for individual monitoring projects.

Consistent and interdisciplinary approaches that make better use of high-quality ESB samples can foster the importance of monitoring data in chemical management. Applying state-of-the-art analytical methods to ESB samples is a win-win situation for the value of ESB samples and our understanding of environmental quality. For example, non-target screening is a promising tool that is expected to provide many more data on the temporal occurrence of chemicals in ecosystems. ESB samples are also now being used for genetic approaches, including population genetics and environmental DNA, which reveal temporal changes in biodiversity and offer the potential for interdisciplinary links to this area of research. In addition, environmental and human samples stored in the database can provide valuable data for integrated exposure assessments in human biomonitoring programmes.

The application of the ESB concept to polar environments

Pollutant monitoring in the Arctic is generally much more systematic than in the Antarctic, and the data are used intensively by scientists and authorities. This includes environmental specimen banks that make temporal changes in the Arctic environment subject to research. Examples are environmental specimen banks operated by the US National Institute for Standards and Technology (NIST), Environment Canada, the Swedish National History Museum, University of Aarhus, and the Environment Agencies of Norway, Iceland and the Faroer Islands. In contrast, there is a lack of long-term, standardized monitoring programs with samples from Antarctica, along with corresponding specimen banking activities. One very valuable exception is the Antarctic Environmental Specimen Bank, located in the Department of Chemistry and Industrial Chemistry of Genoa University (Italy), which has been an important complement to the Italian National Antarctic Research Programme (PNRA) since 1994.

Environmental specimen banking for research and policy of today and as a commitment for future generations

In adopting the Protocol on Environmental Protection to the Antarctic Treaty (1991), the parties to the Antarctic Treaty designated Antarctica as a "nature reserve dedicated to peace and science," thereby committing themselves to comprehensive protection of the Antarctic environment and its ecosystems. Yet the future of pristine Antarctic ecosystems is at stake. There is growing evidence that Antarctica is increasingly exposed to chemical stressors: Expanding tourism and research can affect the local environment. Furthermore, Antarctica is impacted by global phenomena such as climate change and long-range transport of chemicals. To date, there is a lack of systematic approaches and data to study and assess chemical pollution of the Antarctic environment and to derive knowledge-based measures for its protection.

We propose to explore the use of environmental specimen banks to derive reliable trends in chemical exposures and their effects in the Antarctic environment. Such archives will enable researchers to study changes in Antarctica at any given time in a retrospective manner. By knowing the past, new generations of scientists can better understand the current state of the Antarctic environment and inform policymakers about reliable plans for protecting its future.

Monitoring programs and the impact assessment for contaminants on the Artic and the Antarctic ecosystems should be better connected with environmental specimen bank activities and knowledge gaps be closed. To gain practical experiences, UBA has initiated a case study together with the Helmholtz-Zentrum Alfred Wegner Institut (AWI) to explore the use of samples from penguin colonies, coastal fish and krill for contaminant analysis, including systematic archiving.

The role of the Italian Antarctic Environmental Specimen Bank in the study of chemical contamination in Antarctica

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The chemical contamination in Antarctica

Antarctica is one of the planet's last wildernesses, designed by the Antarctic Treaty in 1959 as a "natural reserve, devoted to peace and science''.[1] The Protocol on Environmental Protection to the Antarctic Treaty in 1991 established the protection of the Antarctic environment for its intrinsic value and its value as an area for the conduct of scientific research, in particular research essential to understanding the global environment.[2] Specifically, it proclaimed the cooperation among the States Parties (article 6), the prohibition of mineral resource activities (article 7) and the environmental impact assessment and minimization (article 8).

Nevertheless, present and future threats to the conservation of the Antarctic environment do exist, including chemical contamination issues, the introduction of non-indigenous species, human disturbance on flora and fauna, marine resource harvesting for human consumption, global climate changes (regional and global warming, ocean acidification, changes in sea-ice distribution), as well as futuristic mineral resources extraction (contemplated by the article 25.5) and permanent settlements.[3] In addition, there are nations outside the treaty, which are not bound by its provisions. The chemical contamination in Antarctica can be related to various circumstances, such as the research stations activities, tourism and fishing operations, vessels incidents, legacy contamination and long-range transport of pollutants from mid-latitudes. As a consequence, classical (e.g. heavy metals, polychlorinated biphenyls) and emerging (e.g. flame retardants, pharmaceuticals and personal care products, microplastics) contaminants can be found in Antarctica, as widely reported.[4,5,6,7,8,9,10,11.12]

An example of emerging contamination in Antarctica is represented by the occurrence of microplastics in the Southern Ocean.[10] Forty-four pieces of microplastics with sizes <5 mm were collected during a field survey in 2016, and the total particle counts at two stations near Antarctica were estimated to be in the order of 100,000 pieces/km^2.[13] Microplastics were also found in marine sediments[14] and sea-ice.[15] Potential sources of these contaminants are the wastewaters from personal care products and laundering synthetic fabrics, fishing activities and degradation of macroplastics, although transport from outside the Southern Ocean cannot be ruled out.[10] On the other hand, important analytical issues are associated with these and other reports, including dissimilar and not validated sampling and identification methods, incomparable units (particles/L, particles/km^2, g/km^2, particles/m tow for water samples) and suspicious wide range of reported concentration (from 10^{-6} to 10^2 particles/L for water samples).[10]

The role of the Antarctic Environmental Specimen Bank

In this context, the Antarctic Environmental Specimen Bank (ESB), located in the Department of Chemistry and Industrial Chemistry of Genoa University (Italy), and operating since 1994 within the Italian National Antarctic Research Programme (PNRA), is an important complement to the environmental monitoring and research programs, providing samples difficult to achieve, which can be used for real-time and retrospective monitoring of the Antarctic ecosystems.

In fact, in more than 25 years of activities, about three thousand specimens have been collected and properly stored in the Antarctic ESB and these samples constitute a valuable resource for the scientific community. The marine environment is by far the most represented, but samples from other ecosystems are currently available, including sea ice, snow, soil, lake sediments and atmospheric particulate. The sampling has been possible thanks to important infrastructures, mainly the two research stations (*Mario Zucchelli Station* on the coast and *Concordia Station*, in co-operation with France, on the Antarctic plateau) and the oceanographic ship *Laura Bassi* (which recently substituted the ship *Italica*), besides the facilities for sample storage, treatment and analysis at the Department in Genoa.

The objectives of the Antarctic ESB are similar to those of other environmental banks, but with some important peculiarities. A major aim of the bank is the retrospective analysis of the collected samples, both to control previous analytical data using more performant techniques and to include new parameters which have not been studied at the time of collection, such as microplastics and nanoparticles. The collection of samples from Antarctica is not an easy task, especially in order to preserve them for chemical measurements at the ultra-trace concentration level. So, another important aim is the supply and exchange of specimens to support various research studies. Moreover, the analysis of Antarctic specimens can provide background levels of contaminants, which can be very useful for a correct interpretation of other monitoring programs across the world. Finally, an important activity of the Antarctic specimen bank is the production and management of certified reference materials based on Antarctic matrices, such as sediment and specific organisms, like mussels and krill. In fact, in the assessment of chemical contamination, the quality control of the analytical data is a major issue, especially when facing extremely low concentrations and complex matrices.

Representative case studies

The Antarctic ESB has supported many research projects in Antarctica, and concurrently stimulated a great deal of research in the analytical and environmental chemistry fields, facing the challenges related to the ultra-trace analysis of polar matrices. This activity is briefly illustrated below via few, representative research works we recently focus on.

In a biomonitoring study,[16] eighty specimens of the scallop *Adamussium colbecki*, a key species for assessing the pollution in Antarctic coastal waters, were analyzed to quantify 23 trace elements and 150 persistent organic pollutants, including polychlorinated biphenyls, polychlorinated naphthalenes and polycyclic aromatic hydrocarbons. The samples, archived in the Antarctic ESB from 1996 to 2009, were simultaneously analyzed in 2014, using the most recent and performant analytical techniques, not yet available at the time of collection. It was found that metals concentrations were not affected by anthropogenic contributions, highlighting a natural accumulation with the age of the organism. Similarly, no temporal trend was evident for the organic pollutants, although local contamination was occasionally detected.

In another study,[17] several marine organisms (algae, mollusks, sea stars, sea urchins, sea worms, fish) from the same area, collected across the years and stored in the Antarctic ESB, were analyzed to investigate the accumulation of arsenic species through the marine food web. Again, the results highlighted a natural situation, with arsenic mainly present as non-toxic species, like arsenosugars and arsenobetaine, whose proportion was dependent on the trophic position of the organism. Total arsenic concentration increased through the food web, reaching few tens of part-per-million in top predators. However, the transfer of the arsenic through the Antarctic marine food web and the speciation patterns found in the organisms were similar to those reported for comparable organisms from other marine ecosystems, supporting the view that the high levels of arsenic occurring in marine samples is a natural phenomenon.

Finally, the natural and anthropogenic sources of atmospheric lead reaching Antarctica over the last fifty years were investigated by the analysis of 109 snow-pit samples collected from the East Antarctic Plateau.[18] It was found that the temporal variations of lead isotopic composition from 1970 to mid-1990s reflect the changes in the consumption of leaded gasoline in the Southern Hemisphere, whereas the subsequent increase of the lead isotope ratios can be ascribed to a shift toward the natural isotopic signature, in agreement with the concomitant decrease of total lead concentration. Accordingly, the anthropogenic lead contribution decreased from 61±3% in 1980-1990 to 49±10% in 2010-2017. Furthermore, the measured ratios suggested that Australia has been a significant source of anthropogenic lead to Antarctica, even in recent times.

Future challenges

The pristine nature of Antarctica offers a unique opportunity to investigate global pollution and climate change and to provide reference values for contaminants. Moreover, the Antarctic continent is worth being preserved as the ultimate "clean" place on Earth. However, data on classical and emerging pollutants in Antarctica are still scarce in comparison to data from the rest of the planet, and the monitoring activities in the Antarctic environment are expected to significantly increase in the future.

Challenges to the future conservation of Antarctica are related to improvements in the effective use of scientific information to speed the decision-making,[3] as well as in the efficacy and representativeness of the protected areas.[19] Moreover, there is a clear need to harmonize the analytical procedures and to build-up a more structured sample and data collection of environmental contamination across Antarctica. In this context, international cooperation and the ESBs networking can play a relevant role.

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Contaminants in the Arctic – sources, status and storage of the Norwegian Wildlife. A story about the Norwegian Environmental Specimen Bank

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The Norwegian Environmental Specimen Bank (N-ESB) was established in 2012, funded and initiated by the Norwegian Ministry of Climate and Environment. Operation and administration responsibilities were granted to a consortium, *CIENS*, consisting of several key environmental institutes in Norway, lead by the Norwegian Institute for Water Research (NIVA). Securing high-quality samples for future environmental researchers and future analytical methods for emerging contaminants is still our main objective. To do so we are relying on a continuous supply of representative samples from a variety of biological species and environmental compartments in addition to securing a geographical distribution covering the whole of Norway including the Arctic archipelago of Svalbard and parts of the North Atlantic.

In our facilities in Oslo, samples of the Norwegian environment are received, processed and stored in a large freezer room under strict protocols. Samples going into long-term storage are predefined by an expert group consisting of environmental professionals from a range of institutes and universities within Norway and Sweden. Their main responsibility is to secure a responsible and cost-efficient sampling program according to the ongoing national annual monitoring programs for contaminants. Within these programs, both heritage contaminants such as heavy metals, PCBs and PBDEs and emerging contaminant groups, such as a range of PFASs, siloxanes, dechloranes and phenolic compounds are studied in samples of air, water and biota (Bohlin Nizzetto et al., 2021; Grung et al., 2021; Jartun et al., 2021 and Schøyen et al., 2021). Combining the national monitoring programs for contaminants with the sampling for the N-ESB provides a continuous flow of samples annually representing the total Norwegian and Arctic environment.

Each of the ongoing monitoring programs uses state-of-the-art analytical techniques, often with full-scan chromatograms enabling scientists to scan for emerging contaminant compounds or groups retrospectively. Consequently, no samples stored in our facility have so far been provided to applicants wanting to study the presence of contaminants in our samples, because the latest technology has already been applied on those samples collected. Given that the N-ESB is quite new, we expect more applications for withdrawals in the years to come, as future scientists discover new contaminants and the analytical methods improve. One of our baseline objectives is to provide science with historical sample materials to study problematic contaminants, subsequently providing our national environmental authority with a scientific basis for future action plans against contamination.

Samples in the Norwegian Environmental Specimen Bank

As of 2022 approximately 50 000 samples of Norwegian and Arctic wildlife, air and sewage sludge are stored within our facility. Samples are collected from Norwegian mainland, Svalbard and areas of the North Sea (figure 1). Basic criteria for samples (species) selected for storage include:

- a nationwide geographical distribution
- sustainable population
- stationary in most phases of a life cycle
- potential for variance between urban and rural areas

Several of the heritage contaminants, such as Hg, PCBs and PBDEs tend to accumulate in lipid rich tissues and express a potential for biomagnification. Consequently, a number of top predators are selected for sampling, such as freshwater brown trout (*Salmo trutta*), marine fish cod (*Gadus morhua*), eagles and polar bears. In addition, samples from whole food chains, one freshwater and one marine, including all trophic levels from true primary consumers (e.g. zooplankton *Daphnia*) to top predators (e.g. brown trout), are collected annually. Brown trout are found in lakes across Norway, and cod is collected all along the Norwegian coastline in addition to areas of the open sea between Norway and Svalbard. Both aquatic and marine fish are transported whole in frozen condition to the N-ESB. Sampling is performed in collaboration with the Institute for Marine Research. Within our lab facilities, samples of muscle, liver, bile, brain, shells and otoliths are dissected, weighed and measured. Subsequently, all metadata for each individual fish are submitted to an online database.

Other biological samples include blue mussels (*Mytilus edulis*) of the Norwegian coastline, sea birds (eggs and feathers) and mammals such as otters and reindeer from sampling programs conducted by the Norwegian Institute for Nature Research (NINA).

Samples to the N-ESB are also collected from Arctic areas such as Svalbard and Jan Mayen. The Arctic includes some of the last wilderness areas in the world, vulnerable to anthropogenic impact. Even so the Arctic is often considered a final recipient for contaminants reaching the northern hemisphere by the means of long-range air and sea currents. But local contamination sources, such as increased anthropogenic activities in major settlements and mining areas, also contribute to the contamination of the Arctic as it does in other parts of the world. The Arctic provides important information about hazardous contaminants, and findings of contaminants in various materials are sending a message of persistency and global interaction. The Norwegian Polar Institute are conducting monitoring programs collecting samples of polar bear blood, ringed seals, arctic fox, reindeer, and a variety of arctic fish and birds for the Environmental Specimen Bank.

In addition to samples of wildlife, moss surveys have been carried out in Norway every 5 years, studying the “stairstep moss” *(Hylocomium splendens*) across Norwegian mainland. It is widely distributed, easy to collect, and reflects atmospheric deposition of contaminants.

Samples of air are also collected for national monitoring programs and the N-ESB by the Norwegian Institute for Air Research (NILU). Two specific stations are included in the sampling for N-ESB, the Birkenes station on the southern tip of mainland Norway, and the Zeppelin station close to Ny-Ålesund in Svalbard. From both stations, two types of samples are collected using an active high-volume air sampler:

- particle bound contaminants

- gas phase contaminants

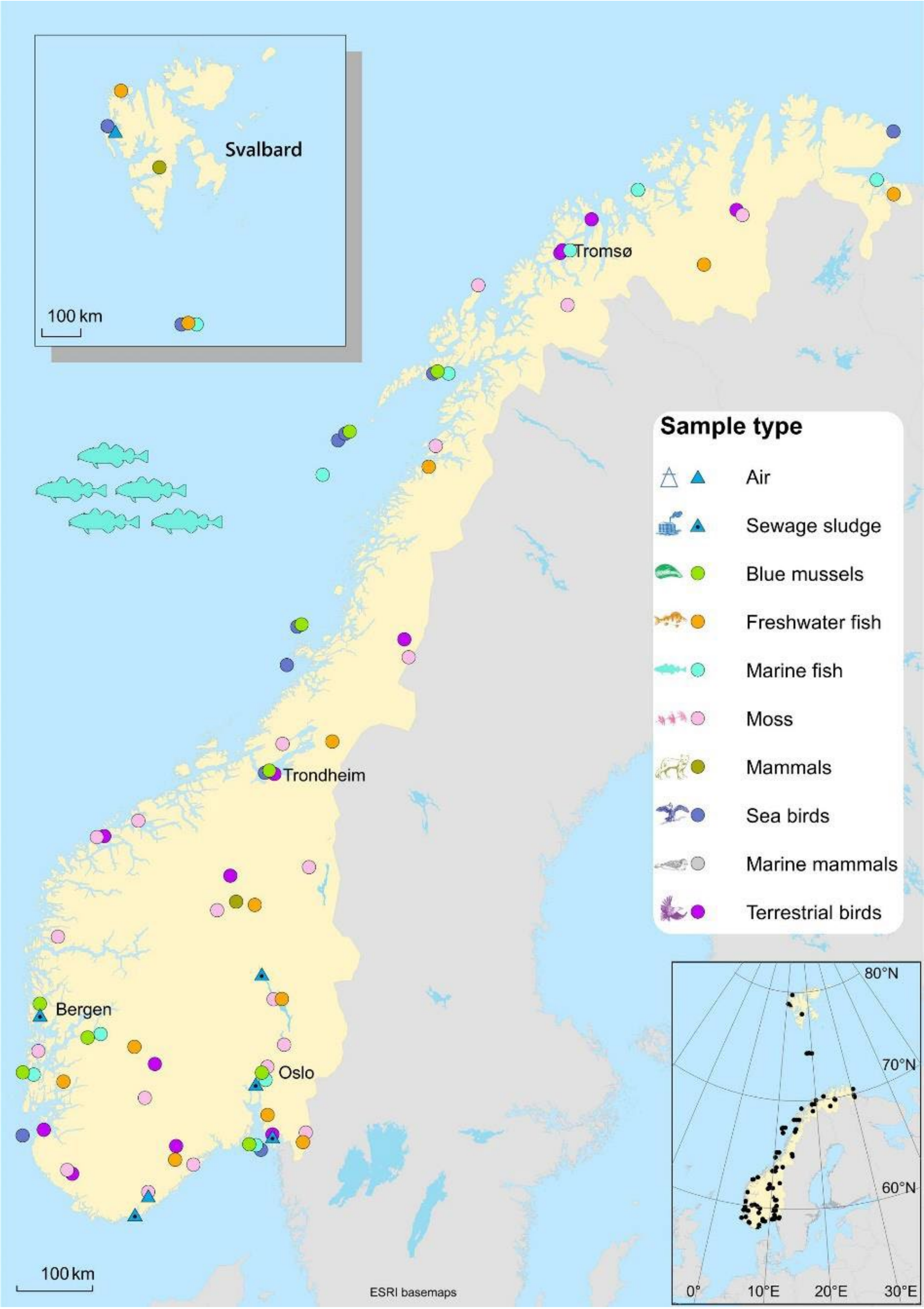

Figure 1. Map indicating the major sample types included in the Norwegian Environmental Specimen Bank.

Furthermore, samples of de-watered sewage sludge from 5 different wastewater treatment plants (WWTPs) are collected and stored in the N-ESB annually. These samples represent an important indicator for anthropogenic impact on the environment, as this material is also used as fertilizer in agricultural fields. Samples are collected as pooled monthly samples, a total of 2 kg material from each WWTP, and stored at -25°C in our facility.

Contamination control

Studies have shown that several contaminants, both heritage and emerging, are found in higher concentrations in samples of indoor air compared to outdoor air. Consequently, samples handled within the laboratories of any specimen bank could be exposed to contamination from air, dust, materials or instruments. To quantify the potential of contamination within our lab facility, we have included a monitoring program for indoor air, covering a wide range of potential contaminants. Sampling is performed using passive air sampling with different adsorbents to secure the capture of a wide range of chemicals from highly volatile compounds, such as siloxanes and short-chained PFASs, to heritage compounds such as PCBs, PBDEs and heavy metals. Adsorbents have been placed inside the various laboratories in the N-ESB, and in reference areas. We have also compared indoor monitoring between the N-ESB (new building, 10 years) and the Swedish ESB (old building, 100 years). Sampling has been performed in periods of both high activity in the lab and during vacant periods (summer holidays).

In general, heritage contaminants such as PCBs, some siloxanes and PFASs have been detected in higher concentrations in the old building compared to the N-ESB, with no significant variation between reference areas and the laboratory. Chlorinated paraffins (SCCP and MCCP) and some of the brominated flame retardants are found in higher concentrations within the newer building, probably arising from building materials and the ventilation system.

To limit the potential for cross contamination in all stages of sample preparation, i.e. from field work to final dissection and storage of samples in the lab, strict procedures are followed. In the field, the sample should not come into contact with any contaminated surfaces, such as plastics or Styrofoam. All surfaces are to be covered with aluminum foil. People involved in field work must refrain from all hygiene products 24 hours in advance, with the exception of one specific, pre-approved brand of soap.

A time capsule for the future

There are most likely thousands of potential harmful contaminants around us today, of which we have little or no knowledge. We may have indications of their presence, but we do not have proper analytical methods to detect all of them today. And we certainly do not know the combined effect that all chemical components around us may have upon humans or animals in the future. But science move forward, analytical instruments and detection limits improve. And the environmental specimen banks provide samples of the past for future scientists to study. The number of samples or amount of tissue stored in environmental specimen banks are, however, not infinite, making this a very valuable material. Consequently, we must be careful both when planning the deposit to the bank and in the evaluation of applications for withdrawal. Our samples represent time capsules, preserving the environmental status of our present time, so that these samples may be analyzed with the technology of the future.

PANGAEA – Data Publisher and World Data Center

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[2]. MARUM - Center for Marine Environmental Sciences, University of Bremen

The Core Trust Seal[1] certified data publisher for Earth and Environmental - PANGAEA has been active for almost 30 years. It is operated as a joint facility of the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (AWI) and the Centre for Marine Environmental Sciences (MARUM) at the University of Bremen. It is an Open Access library for archiving, publishing, and distributing georeferenced data from earth, environmental and biodiversity sciences. PANGAEA holds a mandate from the World Meteorological Organization (WMO)[2] and is accredited as a World Radiation Monitoring Center (WRMC)[3] . It was further accredited as a World Data Center by the International Council for Science (ICS)[4] in 2001.

Publishing in PANGAEA assures high quality data and metadata in compliance with the FAIR data principles[5] . It is equipped with a well-developed interoperability framework thus allowing the dissemination of metadata and data to international registries, data portals, and third-party service providers. Currently, PANGAEA provides access to over 400,000 datasets containing over 20 billion individual measurements, including those collected through over 600 national or international projects. Each published dataset can be cited with a specific data citation and an associated universally unique Digital Object Identifier (DOI) to cross-link to related resources such as manuscripts and data. A broad spectrum of contextual information ("metadata"), explaining the where, how, when, and why of a measurement is given. This harmonization and standardization promote not only readability and further processability by machines, but also a high degree of reusability of the data stock. In addition to the classic access to data via the website[6], an integrative use of data in the form of a DataWarehouse[7] and a set of tools for programmatic data processing are available for this purpose. Furthermore, PANGAEA supports scientists with data curation by trained field experts acting as data editors, including quality control of metadata and the development of ontologies and vocabularies according to international protocols and standards. The data publisher PANGAEA is acting as a generic and multidisciplinary platform. It has particular interest and expertise in handling polar region data and has been a reliable partner for the scientific community working in the Arctic or Antarctica during the last decades.

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1 https://www.coretrustseal.org

2 https://public.wmo.int/en/wmo-information-system-wis

3 http://bsrn.awi.de/

4 https://www.worlddatasystem.org/

5 Wilkinson, M. D., M. Dumontier, I. J. Aalbersberg, G. Appleton, M. Axton, A. Baak, N. Blomberg, J.-W. Boiten, L. B. da Silva Santos, P. E. Bourne, et al. 2016. The FAIR Guiding Principles for scientific data management and stewardship. Scientific Data 3:160018. https://doi.org/10.1038/sdata.2016.18

6 https://www.pangaea.de/

7 https://wiki.pangaea.de/wiki/Data_warehouse

The NORMAN Database System and activities of the NORMAN network with regard to Chemicals of Emerging Concern in polar regions

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Introduction

The wide-scope target and non-target screening of biota samples is becoming an important issue in NORMAN activities, since pollutants present in biota are with high probability bio-accumulative (B) and persistent (P), and thus fulfilling two out of three PBT criteria considered under REACH legislation. As a means of prioritising the most ubiquitous pollutants at the global scale there is a need to look at their occurrence in remote areas, including the Arctic region and Antarctica. NORMAN members have access to samples from these regions. It is expected that with the global warming the polar areas will become more accessible and, thus, more polluted from anthropogenic activities. There is an obvious need to establish a pollution baseline for as many chemicals as possible.

The specific objectives of the study were (i) to analyse a set of legacy 'benchmark' pollutants by target analysis, followed up by wide-scope target analysis of more than 2,300 substances and suspect screening of more than 65,000 compounds in each sample and (ii) compare the concentrations of detected substances with available toxicity threshold values as a part of their risk assessment. Ultimately, the feasibility of the NORMAN Database System (see **Figure 1**) has been tested whether the obtained data can be accommodated in its various modules, with a special focus on the upload of the non-target screening chromatograms (both LC-HR-MS and GC-APCI-HR-MS) into NORMAN Digital Sample Freezing Platform (DSFP) for future retrospective screening. A suitability of the automated tool for risk assessment and prioritisation of substances detected in Antarctica has been examined.

Abstract

An attempt has been made to develop a strategy for establishing a chemical pollution baseline in Antarctica by applying a holistic chemical screening of 14 samples provided by experts from the Ukrainian Vernadsky Antarctica Research Base. The samples represented various trophic levels from macrophytes, sea stars, sea urchins, fish up to top predators such as crabeater seal (placenta) and penguins. Both penguin muscle and egg samples were analysed. A special care was taken to exclude contaminants which might had been introduced due to sample handling. Next to target analysis of legacy pollutants, such as metals, dioxins and dioxin-like compounds and PBDEs an analysis of novel organophosphorus flame retardants and Dechlorane Plus were carried out. Additional wide-scope target screening comprised analysis of ca. 2,300 substances in each sample, whereas suspect screening provided information on presence/absence of 65,690 substances and semi-quantitative estimate of concentrations of detected substances. The acquired LC- and GC- HRMS chromatograms were uploaded to NORMAN Digital Sample Freezing Platform (DSFP) and thus made available for further retrospective screening – i.e.,

whenever the list of NORMAN suspect substances is updated, it is possible to go back to the archived (digitally frozen) samples and re-analyse them without the need for costly collection of new samples in the field.

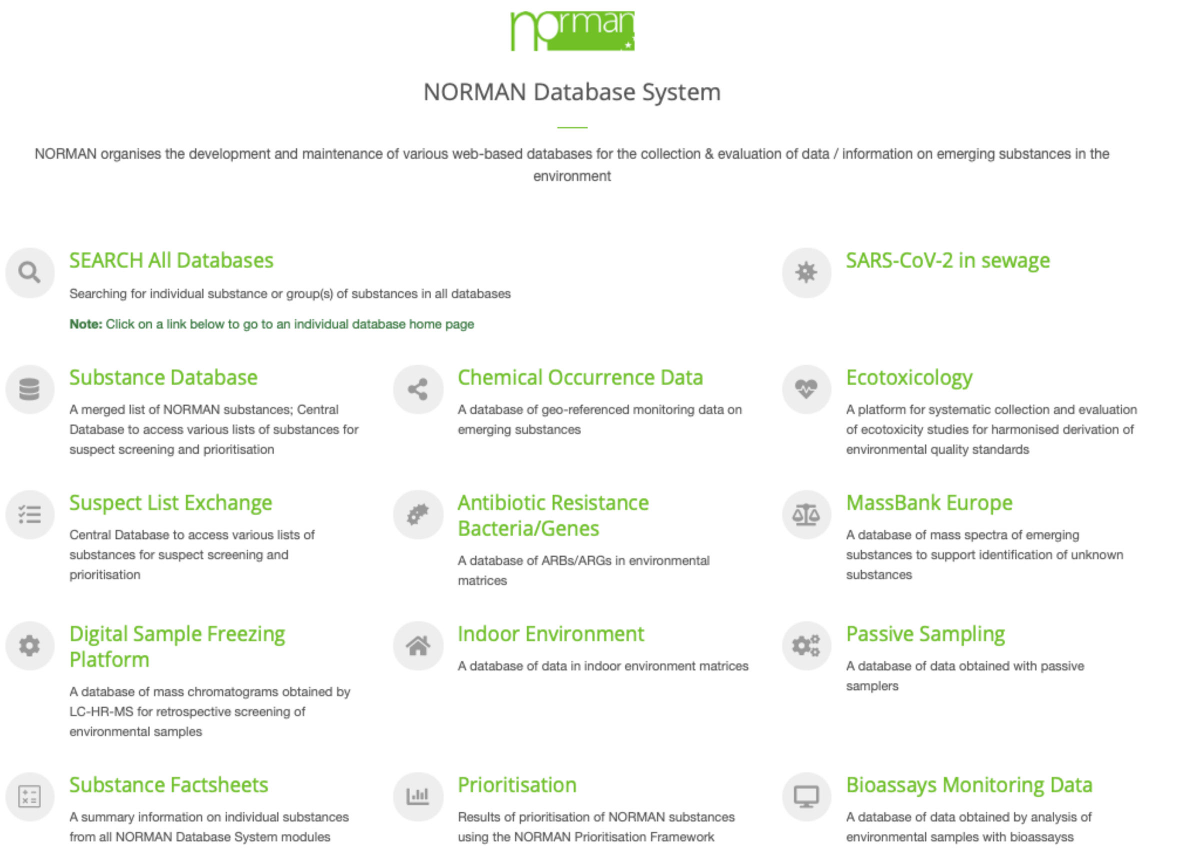

Figure 1: An open access NORMAN Database System, https://www.norman-network.com/nds/, (Dulio et al., 2020).

The concentrations of detected pollutants were compared against their toxicity threshold values available in the NORMAN Ecotoxicology Database (https://www.norman-network.com/nds/ecotox/). The values were derived from freshwater biota (fish) values. Obviously, there is a need to derive specific toxicity threshold values for individual trophic levels in future.

Samples

Biota samples from the lower trophic levels were gathered by experts from the Ukrainian Vernadsky Research Base, Antarctica in 2019 and 2020. The species, matrices and codes of the samples are listed in **Table 1**.

Table 1. List of studied 14 Antarctica samples.

<table>
<tr><th>Sample Code</th><th>Species</th><th>Matrix of analysis</th><th>Tier</th></tr>
<tr><td>Ant-2019-1</td><td>Sea stars
(Odontaster validus)</td><td rowspan="2">muscles</td><td rowspan="4">Tier I</td></tr>
<tr><td>Ant-2019-2</td><td>Sea urchin
(Sterechinus neumayeri)</td></tr>
<tr><td>Ant-2019-3</td><td>Macrophytes
(species: unknown)</td><td>macrophytes</td></tr>
<tr><td>Ant-2019-4</td><td>Fish
(Notothenia coriiceps)</td><td>muscles</td></tr>
<tr><td>Ant-2020-1</td><td rowspan="2">Weddell Seal (Leptonychotes weddellii)</td><td rowspan="2">placenta</td><td rowspan="10">Tier II</td></tr>
<tr><td>Ant-2020-2</td></tr>
<tr><td>Ant-2020-3</td><td rowspan="2">Gentoo Penguin (Pygoscelis papua)</td><td rowspan="4">muscles</td></tr>
<tr><td>Ant-2020-4</td></tr>
<tr><td>Ant-2020-5</td><td rowspan="2">Crabeater Seal
(Lobodon carcinophaga)</td></tr>
<tr><td>Ant-2020-6</td></tr>
<tr><td>Ant-2020-7</td><td rowspan="2">Adelie Penguin (Pygoscelis adeliae)</td><td rowspan="4">eggs</td></tr>
<tr><td>Ant-2020-8</td></tr>
<tr><td>Ant-2020-9</td><td rowspan="2">Gentoo Penguin (Pygoscelis papua)</td></tr>
<tr><td>Ant-2020-10</td></tr>
</table>

Results

All results of target analyses are available at NORMAN Database System – EMPODAT (https://www.norman-network.com/nds/empodat/) and in the LIFE APEX Database System (https://www.norman-network.com/apex/lacod/). The latter is providing more options regarding searches in biota matrices.

Regarding metals, cadmium was detected at very high levels in the sea star sample, almost two orders of magnitude higher than that detected in fish. Lead concentrations were significantly higher in fish compared to other species. The concentrations of mercury exceeded the Environmental Quality Standard (EQS) value set for biota samples by the EU Water Framework Directive in eight (out of 14) samples. The highest total metals concentration was detected in macrophytes. Overall, the (top predators) samples collected in 2020 presented ca. one order of magnitude lower total metals concentration levels compared to the samples collected in 2019 (macrophytes, sea star, sea urchin, fish). For further conclusions, the different analysed sample species, their migration patterns and positioning in the food chain should be carefully considered.

The determination of dioxins and dioxin-like compounds as well as polybrominated flame retardants (PBDEs) was performed in four samples. PCB-DL present the most significant contribution to the total concentration of dioxins and dioxin-like compounds. Sea star sample was the most contaminated one with a total number of 24 detected dioxins and dioxin-like compounds (out of 29). The legacy (PBDEs) were determined in all four samples, while PBDE 47 exhibited the highest contribution to the total PBDEs concentrations. The total PBDEs concentrations exceeded the EQS value of 8.5 ng/kg in two out of four tested samples (sea star, sea urchin).

Figure 2. An overview of the substances (Y-axis) detected by suspect screening of 65,690 substances in the Antarctica samples (X-axis). Detected substances are marked with green colour. Colour scale indicates the logarithm of the concentration.

Five out of 13 PFRs were detected in the investigated samples. The highest number (4) of the studied PFRs was observed in the Tier I fish sample. Concentrations of Dechloran Plus, PCB-NDL and PBDEs in Tier II samples (top predators) were below their respective LODs.

In total 33 contaminants from different chemical classes were detected by the wide-scope target screening in 14 tested biota samples. In the overall pollution pattern, ca. 30% of the detected contaminants were industrial chemicals (mainly surfactants), 27% pharmaceuticals and their TPs, and 15% personal care products and plant protection products and their TPs. Methylparaben was the most frequently detected contaminant, being present in 93% of the tested samples. The wide-scope screening data were uploaded into the NORMAN Database System (NDS; https://www.norman-network.com/nds/empodat/).

Suspect screening of 65,690 SusDat substances revealed presence of 332 compounds, out of which 56 compounds were tentatively identified after the removal of wide-scope target compounds (presented above) and naturally occurring substances. A 'heat map' of these 56 substances is in **Figure 2**. All data and related raw mass chromatograms are stored in the NORMAN Digital Sampling Freezing Platform (DSFP; Alygizakis et al. 2019; https://norman-data.net/Verification/).

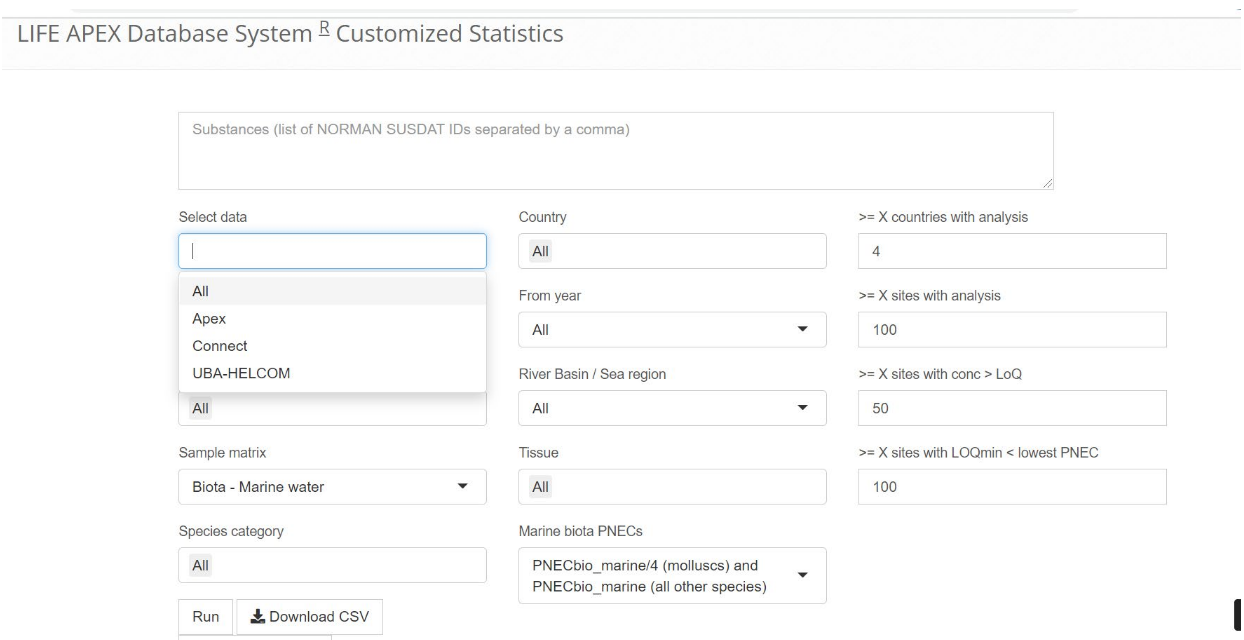

Figure 3. An automated tool allowing for categorization and prioritization of target analysis substances stored in the NORMAN Database System - EMPODAT.

In general, the contamination of the biota samples from Antarctica was lower compared to the similar screening exercises in Europe (e.g. Black Sea region, Danube River Basin, LIFE APEX programme) in terms of number of detected/determined contaminants and their concentrations.

An automated tool developed for both EMPODAT and LIFE APEX Database System allows for rapid prioritisation of detected substances using either comparison with their risk (toxicity threshold values), hazard (PBMT, CMR, ED properties) or exposure (Dulio et al, 2020).

Conclusions

Analysis of Antarctica biota samples by a battery of target, wide-scope target and suspect screening techniques have shown a presence of alarmingly high number of anthropogenic chemicals in this pristine region. All data are stored in both the NORMAN Database System and LIFE APEX Database System. Target analyses data are being shared on a regular basis with the European Commission Integrated Platform for Chemical Monitoring (IPCHEM).

It is recommended to store systematically data from further screening campaigns from polar regions in the NORMAN Database System (https://www.norman-network.com/nds/), which would allow for their systematic review and risk assessment in comparison with data from other European countries and globally.

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The Information Platform for Chemical Monitoring (IPCHEM)

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Introduction

Chemicals are everywhere, in the food we eat, in the air we breathe, in the clothes we wear, in the products we use. In order to develop and implement European legislation on chemicals and related environmental and health policies, we need to better understand and track the types and amounts of chemicals we might be exposed to. To address this need, the European Commission developed the Information Platform for Chemical Monitoring (IPCHEM).

IPCHEM is the EU reference access point for finding and retrieving chemical monitoring data. IPCHEM supports a coordinated approach for collecting, storing, sharing and assessing data on the occurrence of chemicals and chemical mixtures in humans and the environment. Data providers can share chemical monitoring data through the platform to maximise dissemination and data reuse across policy and research programs. Data users can discover, access and retrieve information on chemical occurrence and concentrations throughout Europe and beyond across different media.

Populating IPCHEM with further data sets to increase the geographical coverage and range of chemicals in different media is continuing with many data collections already in the pipeline. In addition to populating the modules with new data, a process to further develop (meta)data formats and functionality needs is continuously ongoing.

IPCHEM is gaining prominence as a core asset supporting the EU policy frameworks in the area of chemicals, and environmental and public health. For example, under the Regulation on Persistent Organic Pollutants, Member States have now also the possibility to provide environmental monitoring data on POPs via IPCHEM to fulfil their reporting obligations. The Chemicals Strategy for Sustainability (October 2020) aims to enhance data flows and reuse across EU policy frameworks.

The JRC leads the technical development and contributes to the development of case studies that illustrate how IPCHEM can help addressing policy and scientific questions.

Structure and content

The database is structured in four thematic modules: environmental monitoring, human biomonitoring, food and feed, products and indoor air. IPCHEM experienced a steep increase in the number of data collections and concentration measurements it includes in the last few years. The database currently incorporates over 450 million concentration measurements from more than 3000 substances and 179 data collections. Data streams coming from periodic regulatory monitoring and research consortia is continuously integrated following defined quality and harmonisation procedures [1].

For each data collection, metadata providing general information on the data set are publicly available. They include general information describing the underlying monitoring study, information on the monitoring purpose, on the data-providing organisation, conditions of data access, on sampling and analytical methods, and links to additional resources describing the data collection.

Monitoring data are reported at single measurement level or as aggregated data. The aim is to make data publicly available at the highest level of data granularity possible to facilitate the combined analysis for different purposes. Some of the data collections have however restricted access levels to specific user groups such as the European Commission and EU agencies, EU Member State national authorities or specific research consortia.

IPCHEM includes data collections covering different geographical areas. Some are focusing on a specific city or region, some are looking into a single country, while many are covering the whole EU. Some data collections from global partners are already incorporated with more to come in the pipeline.

The environmental module is the most populated module of IPCHEM comprising 18 data collections and 255 million concentration measurements. The environmental module provides information on concentrations of chemicals in water, air, soil and biota. Key data streams for this module come from EU Member States reporting under environmental legislation, provided via the European Environment Agency (EEA), who is the module coordinator. This includes mainly data on water and air quality [1].

Data Quality

IPCHEM integrates chemical monitoring data from various heterogeneous sources, of different level of spatial and temporal detail. However, in order to serve scientific and regulatory purposes, these data need to meet defined quality standards. Quality in this context goes far beyond the mere analytical data quality and requires a novel definition and standardised assessment of data quality criteria in terms of spatial, temporal, methodological and metrological traceability.

Data collections are integrated in close collaboration between the data provider and the IPCHEM team. The Quality Check rules defined in IPCHEM are embedded in the ETL (Extract, Transform and Load) data-harmonisation processing. This current way of quality checks has proven capable of detecting several hidden quality issues. The IPCHEM data integration team formally reports issues to the data provider. Issues are then corrected or flagged in the data records. Previews of metadata and data as well as a harmonisation report are shared with the data provider for verification and validation before making the data available to other users [2].

Finding and retrieving data from IPCHEM

IPCHEM offers two ways to explore occurrence data: (1) search by chemical, medium and country or (2) a multi-chemical search by location.

Most users currently start their search in IPCHEM using a chemical name or CAS-number. The search can be done considering all data collections in all modules of IPCHEM, or can be focused directly on a specific medium or country. IPCHEM displays the list of data collections that contain data on the chemical, media and countries of interest (Figure 1). More details on each data collection can be found in the metadata pages. The user can then enter one data collection at a time to look in more detail at the data. Besides online data filtering and visualisation features, data can be downloaded via the basket feature for further analysis offline.

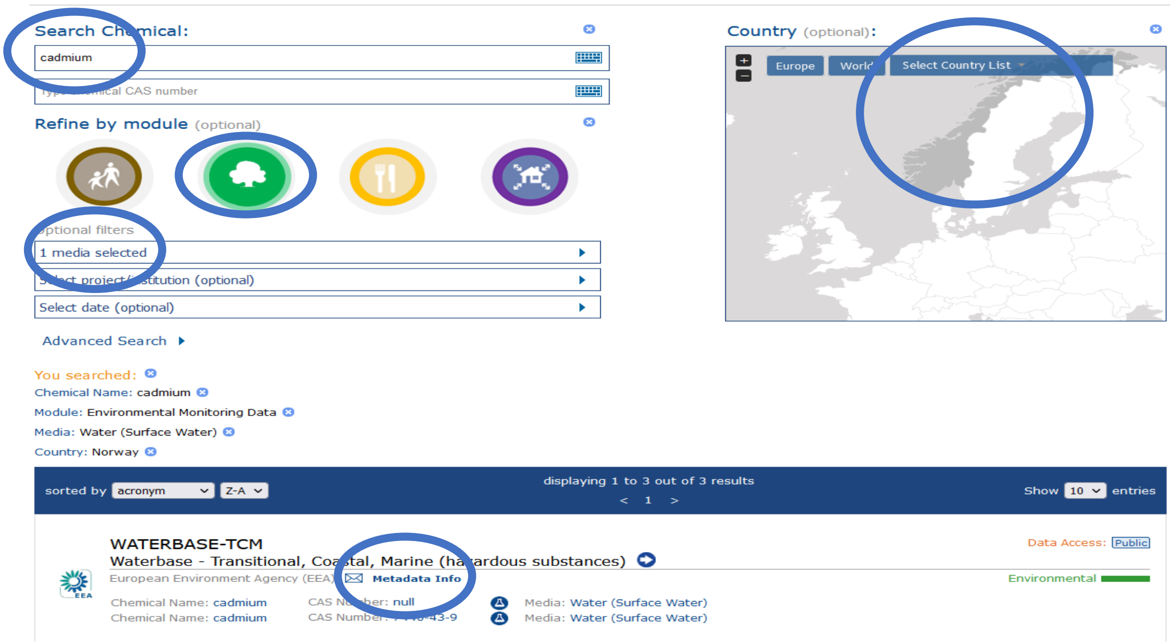

Figure 1: Example of data search by chemical (cadmium), module (environment), media (surface water) and country (Norway)

A second option for exploring the data is via the “IPCHEM Advanced Viewer”, which allows the user to start the search by selecting a geographical area or location (Figure 2). The user can enter the name of a location and define an area by setting a specific radius around that location. IPCHEM will show available measurements in that area, allowing then to filter for chemicals, media, and data collection. This helps getting an overview of available data in IPCHEM for a specific area, e.g. useful to assess co-exposure to multiple chemicals in one place.

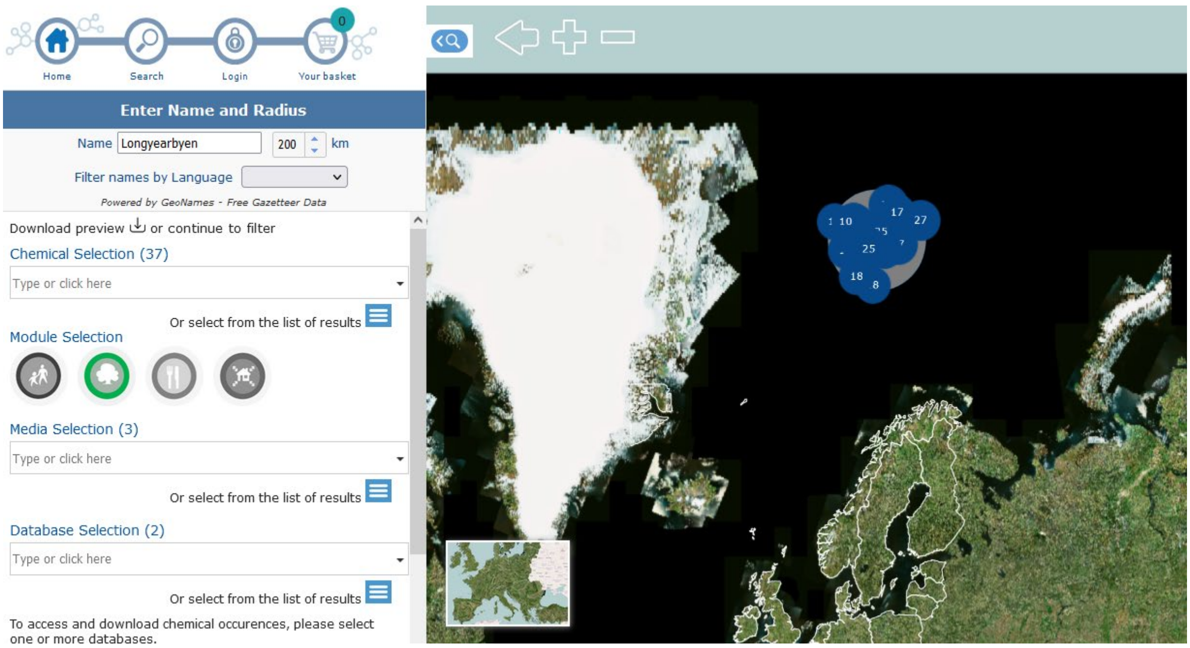

Figure 2. Example of data search by location (Longyearbyen) and module (environment)

This option is a pilot version which allows displaying and accessing those data collections for which the sampling locations are represented by geographical coordinates. The aim of the release of this Advanced Viewer is to collect feedback to further improve its design and implementation.

More detailed instructions can be found in the user guide and tutorials available on the IPCHEM webpage (https://ipchem.jrc.ec.europa.eu/).

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The international panel on chemical pollution (IPCP)'s initiative towards a global science-policy body on chemicals & waste

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12International Panel on Chemical Pollution, 8092 Zürich, Switzerland.
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The International Panel on Chemical Pollution (IPCP) was established in 2008 due to an increasing awareness of the chemical cocktail humans and the environment are exposed to, and due to the identification of a critical gap in the communication between science, policy and the public. The IPCP aims to provide leadership in identifying priority topics of concern and bridging the gap between science, policy and the public. The IPCP network is open to academic scientists from all over the world to become members. In addition, stakeholders such as policy makers, NGOs and industry will be invited to share their opinions and will be informed about outputs. IPCP aims to develop a scientifically sound and balanced view of major issues of chemical pollution and evaluate different options for chemicals management. Based on its scientific expertise, the IPCP supports political processes at the national and international level.

Over the next two decades, global chemical production is set to double, primarily outside of developed countries. Governments and stakeholders from industry, academia and civil society strive to address safety concerns and manage the risks associated with the production and use of chemicals and their hazardous wastes. The sound management of chemicals and waste is an important component to achieve sustainable, inclusive, and resilient human development as defined in the Sustainable Development Goals by 2030. However, the Strategic Approach to International Chemicals Management (SAICM) ended in 2020, and currently an Intersessional Process is taking place to define the sound management of chemicals and waste beyond 2020.

One key topic for discussion is whether the science-policy interface (SPI) within the chemicals and waste cluster should be strengthened, e.g., by establishing an intergovernmental mechanism.

In February 2019, the IPCP completed a Mapping and Gap Analysis report that reviews existing science-policy interface (SPI) bodies, identifies major existing gaps, and explores options for strengthening the SPI (1).

In February 2021, the IPCP, led by Zhanyun Wang, published a Policy Forum article calling for the establishment of a "**global science-policy body on chemicals and waste**" (2). The IPCP acknowledged that many countries and regional political unions have regulatory and policy frameworks for managing chemicals and waste associated with human activities to minimize harms to human health and the environment. These national and regional frameworks are complemented and expanded by joint international action, particularly related to pollutants that undergo long-range transport via air, water, and biota; move across national borders through international trade of resources, products, and waste; or are present in many countries. Despite some progress, the Global Chemicals Outlook (GCO-II) from the United Nations Environment Programme (UNEP) (3) called for "strengthen[ing] the science-policy interface and the use of science in monitoring progress, priority-setting, and policy-making throughout the life cycle of chemicals and waste." The IPCI analyzed the political and regulatory landscape and outlined recommendations for establishing an overarching body on chemicals and waste. In particular, four major gaps were identified:

(1) a lack of coverage: Only a limited part of chemicals and waste (e.g., POPs, mercury, ozone-depleting substances and replacements, and hazardous wastes) is addressed by interface bodies under the global agreements. The lack of science-policy coverage of many issues related to chemicals and waste limits the international community's ability to identify and address issues of concern in a timely and informed way (1,4).

(2) A lack of horizon scanning and early warning mechanisms: Most existing interface bodies are not tasked, on a regular basis, with monitoring scientific developments and providing early warnings on risks related to chemicals and waste in their specific areas.

(3) A lack of bidirectional communication: Most interface bodies focus on informing policy-makers about scientific evidence on specific issues but take limited action to communicate policy developments and policy-relevant scientific questions back to the scientific community. This lack of policy-to-science communication restricts the scientific community from responding to policy needs with timely research.

(4) the wider scientific community is not sufficiently involved: Participation of scientists and practitioners (e.g., lawyers and physicians), particularly academics, in science-policy interactions on chemicals and waste remains limited and often occurs in silos. The lack of engagement and participation reduces the visibility and importance of science-policy work and international chemicals and waste governance in general. Work at the science-policy interface on chemicals and waste is most often neither recognized nor rewarded for academics.

Given these four gaps, the IPCP called for the establishment of an overarching international body to facilitate and foster broad bidirectional science-policy interactions on chemicals and waste covering all chemicals and waste while avoiding duplication with existing interface bodies (gap 1).

This new panel would produce robust and authoritative scientific assessments for policy-makers, synthesizing the scientific basis and analyzing options for action based on regular horizon scanning and early warning of new and emerging issues (gap 2).

In addition, it would inform the scientific community in a timely fashion about international policy developments and highlight policy-relevant scientific questions (gap 3).

Such communication will help to increase participation by the scientific community in its work (gap 4).

Although the exact institutional design of this body must emerge from an international negotiation process, four core characteristics warrant consideration to ensure its scientific credibility, political legitimacy, and policy salience—critical factors for its effectiveness (1,5).

First, setting it up as an intergovernmental body will ensure salience of its work program and government ownership of its scientific assessments.

Second, having a clear definition of roles and responsibilities, a strict conflict-of interest policy, and a rigorous peer-review process will be critical to an objective, independent, and transparent work process and to the credibility and legitimacy of this body and its work.

Third, ensuring wide involvement of diverse and balanced scientists and practitioners will help provide comprehensive, authoritative, and widely usable assessments.

Fourth, active communication of its findings with policy-makers, the wider scientific community (including funding agencies), stakeholders, and the public will help raise overall awareness of, and participation in, sound management of chemicals and waste.

Not only can the overarching interface body on chemicals and waste learn from existing interface bodies, but it also may collaborate with them to conduct assessments that address multiple environmental and societal concerns in a synergistic manner. Setting up an overarching science-policy interface body on chemicals and waste will not solve all governance problems (e.g., a lack of effective national implementation and enforcement). However, it is a critical and necessary step toward strengthening informed policy-making for achieving the global sound management of chemicals and waste.

Subsequently, over 1,500 scientists from all over the world signed their support for establishing a global science-policy body on chemicals and waste.

Beyond the policy initiative on chemicals and waste, there is an independent network of scientists using passive samplers to advance the monitoring of organic contaminants in the waters of the world (6), which could potentially be leveraged to obtain trends in polar regions. Recent examples demonstrate the benefit of relying on passive samplers to determine trends, transport and fate of organic chemicals in the Arctic region (7,8).

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2 Reports of the Working Groups

Participants were randomly assigned to four working groups (WG) to discuss the following four key questions (KQ):

1. How can we raise awareness and visibility of polar contamination in the public, research community, and among policy makers?
2. Are established Arctic monitoring concepts a role model for the Antarctic environment?
3. How can we achieve a more systematic long-term monitoring and assessment of polar contamination through the integration of ESB concepts, data sharing and open access?
4. How can we prioritize monitoring activities to provide environmental policies and chemicals management with effective and robust monitoring data from polar environments?

WG I was asked to start with KQ 1, WG II with KQ 2, WG III with KQ 3, and WG IV with KQ 4. The presentations of the rapporteurs for each WG are given in the following subchapters.

Report of Working Group I

Rapporteurs: Hanna Joerss (Helmholtz-Zentrum Hereon), Roland Kallenborn (Norwegian University of Life Sciences)

Roxana Sühring (Ryerson University), Rainer Lohmann (University of Rhode Island, IPCP), Marco Grotti (University of Genoa, Italian Antarctic Environmental Specimen Bank), Morten Jahun (Norwegian Institute for Water Research, Norwegian Environmental Specimen Bank), Birte Jensen (German Environment Agency)

Key question 1: *How can we raise awareness and visibility of polar contamination in the public, research community, and among policy makers?*

Communicate through other channels than scientific publications only, e.g.

- TIER policy briefing documents (white papers)
- Popular science articles translated to languages of relevant local communities
- Active use of social media
- Changing Arctic Ocean article collection in Frontiers for Young Minds

https://kids.frontiersin.org/collections/11221/changing-arctic-ocean

- Dedicated school projects, for example direct contact of Italian high school students with researchers in Antarctica

https://www.italiantartide.it/scuola/

Challenges for scientists

- Different communication "language" - Scientific versus daily language
- Variety of channels for addressing the public (conventional media, social channels, others)

- Scientist - not rewarded, down-prioritized
- Have to take roles which they are not trained for and don‘t feel comfortable with (e.g. communicating with journalists, touching competitive industry/ producer interests, lobby activities)

Possible ways forward

- Establishment of a global science-policy body on chemicals and waste, promoted by IPCP

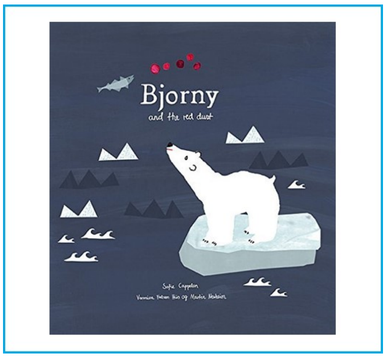

POLICY FORUM | ENVIRONMENTAL SCIENCE

We need a global science-policy body on chemicals and waste

ZHANYUN WANG, ROLF ALTENBURGER, THOMAS BACKHAUS, ADRIAN COVACI, MIRIAM L. DIAMOND, JOAN O. GRIMALT, RAINER LOHMANN, ANDREAS SCHÄFFER, MARTIN SCHERINGER, [...] NORIYUKI SUZUKI +3 authors Authors Info & Affiliations

SCIENCE • 19 Feb 2021 • Vol 371, Issue 6531 • pp. 774-776 • DOI: 10.1126/science.abe9090

- Make popular science communication a part of education programmes at universities
- Get practical advice from relevant organisations (NGOs, interest organisations etc.) such as the Green Science Policy Institute (https://greensciencepolicy.org/news-events/events/science-and-communication-strategy-workshop)
- Engage professionals/ specialists who are dedicated to this specific type of work (e.g. media scientists, science writers)
- Make open accessible and popular science communication a requirement to get funding/access to samples from specimen banks
- Take unconventional paths, as an example: children’s book to share results from a scientific report on PCBs in Svalbard



https://www.unis.no/bjorny-and-the-red-dust/

Report of Working Group II

Rapporteurs: Zhiyong Xie (Helmholtz-Zentrum Hereon), Xiangzhou Meng (Tongji University)

David Chung (National Institute of Environmental Research), Anna Maria Fioretti (Italian National Research Council), John Kucklick (National Institute of Standards and Technology), Sooyong Lee (National Institute of Environmental Research)

Key question 2: *Are established Arctic monitoring concepts a role model for the Antarctic environment?*

AMAP has carried out successful monitoring programs in the Arctic, and made periodically report for POPs, chemicals with emerging concern, modeling and climate change impacts.

A scientific society has been working closely drive AMAP monitoring program forward and guaranty their collaboration for fieldwork, data accumulation, and sample share. Specie bank or sample archive are running through research institutions with governmental funding program.

For Arctic activities, travel and logistic are somehow more convenient for launching monitoring program and developing laboratory infrastructures. It can be more complicated in the Antarctic in these aspects.

Therefore, an effective AnMAP organization or team will be a backbone for long-term and sustainable monitoring program in the Antarctic.

National and international funding program is needed to guaranty its success.

The SCAR ImPACT group maintains an active project database with the view of facilitating sharing of Antarctic access. There is a sample archive database for the purpose of sample sharing.

Harmonized monitoring (analytes, methods, matrices, timing) is key for ImPACT.

Suggestions for monitoring activities

- Selection of target compounds (metals, organic substances, etc) and species to monitor together at the Antarctic site of each nations.
- Sharing and notice the data of target compounds among research groups.
- Discussion and sharing of guideline or test methods for chemical monitoring.
- Supplying the Certified Reference Material related to matrix of species for quality control by NIST.

Report of Working Group III

Rapporteurs: Valeria Dulio (INERIS, NORMAN Association), Jan Koschorreck (German Environment Agency)

Cynthia de Wit (Stockholm University), Ralf Ebinghaus (Helmholtz-Zentrum Hereon), Heike Herata (German Environment Agency), Dmitriy Polovyanenko (Stockholm Convention Regional Centre in Russia), Heinz Rüdel (Fraunhofer IME), Jaroslav Slobodnik (NORMAN Association), Katrin Vorkamp (Aarhus University), Gesine Witt (Hamburg University of Applied Sciences)

Key question 3: *How can we achieve a more systematic long-term monitoring and assessment of polar contamination?*

- **AMAP has a well established dedicated monitoring programme** for Artic regions but we still have important data gaps, especially in the Antarctic regions.
- **Environmental Specimen Banks are a good concept** for long-term monitoring in polar regions: it allows retrospective spatial and temporal analysis
  - QA/QC programmes are key: levels are often very low => careful storing procedures to avoid contamination
  - Air and snow are important and established matrices for polar regions.
- **Vision: the ESB community joins forces**. Novel ESB for polar samples may not be located in the polar regions (rather in countries with easy access to resources, e.g. space, trained personnel, liquid nitrogen).
- **LIFE APEX is a good demonstrator to test the process**: sharing of existing samples, novel analytical methods (NTS), data sharing in open access database and in collaboration with AMAP and other networks (e.g., NORMAN).
- **We need a framework / infrastructure with stable funding** for long-term monitoring and ESB archiving (instead of one-off projects). Resources needed for different tasks: sampling, chemical analysis and archiving the samples and communicating the data.
- **QA/QC** should be ensured throughout the whole process
  - Guidelines for sampling, transport, storage etc.
  - Interlaboratory studies organised by expert organisations such as QUASIMEME
  - QA/QC checks of final reports (e.g. AMAP reports are all peer-reviewed).
- Data sharing, open-access
  - AMAP has a data centre[9] (NILU, ICES..), data upload is organised by the different countries at the national level.
  - Other databases such as NORMAN and IPCHEM should be harmonised and linked together (format harmonisation, etc.)
  - FAIR data principles, harmonised data reporting formats, interoperable databases.

[9] AMAP thematic data centres https://www.amap.no/about/data-compilation

Report of Working Group IV

Rapporteurs: Matthew MacLeod (Stockholm University)

Imogen Bailes (Lancester University), Juergen Gandrass (Helmholtz-Zentrum Hereon), Kevin Hughes (British Antarctic Survey), Michael Wenger (Polar Journal AG)

Key question 4: *How can we prioritize monitoring activities to provide environmental policies and chemicals management with effective and robust monitoring data from polar environments??*

- A broader scope of activities are needed than just "monitoring"!
- In the past "monitoring" meant analyzing selected substances very precisely and accurately to establish time series…
- CHALLENGE: Going forward we need to "monitor" more substances and also do discovery-oriented non-target and suspect screening.
- Passive sampling can play a bigger role, but quantitative analysis is also needed.
- ESBs and archived HRMS data can be exploited for retrospective analysis after suspect screening or non-target discovery of new chemicals of emerging Arctic/Antarctic concern.
- Level of ambition has to be consistent with available funding and priorities of funding agencies…
- Now: Individual countries "volunteer" monitoring to global reporting. There is a lack of prioritisation from nations to Antarctic monitoring (compared to the Arctic at least).
- We should not neglect monitoring of top-level predators, even if they are not best suited for "robust" monitoring data.
- An option for the future: Adopt an effect-based approach to monitoring. Monitor low-dose effects of mixtures of chemicals extracted from air, algae, soil, polar bear fat, etc… In cell-based assays, for example. This would be a complement to monitoring of the chemicals themselves. Similar indicators have been proposed for EU Water Framework Directive.

Key question 2: *Are established Arctic monitoring concepts a role model for the Antarctic environment?*

- AMAP has a track record of effectiveness and influence. Adopt the branding at least!
- Overlap of countries that contribute to AMAP with the AnMAP countries makes this a good starting point.

Key question 3: *How can we achieve a more systematic long-term monitoring and assessment of polar contamination through the integration of ESB concepts, data sharing and open access?*

- Environmental specimen banks for the Arctic seem to lack co-ordination with each other.
- Scientific Committee for Antarctic Research (SCAR) provides co-ordination for Antarctic specimen banks.
- Nations and scientists act independently, and informal networking is important. Formally, it is the responsibility of national contact points under international conventions to communicate into international efforts.

3 Outcome of the Workshop Questionnaire

Jürgen Gandraß

Institute of Coastal Environmental Chemistry, Helmholtz-Zentrum Hereon

Short introductory presentation on January 25th

The workshop aims to bring together science and important key players on contaminants in polar regions (figure 1).

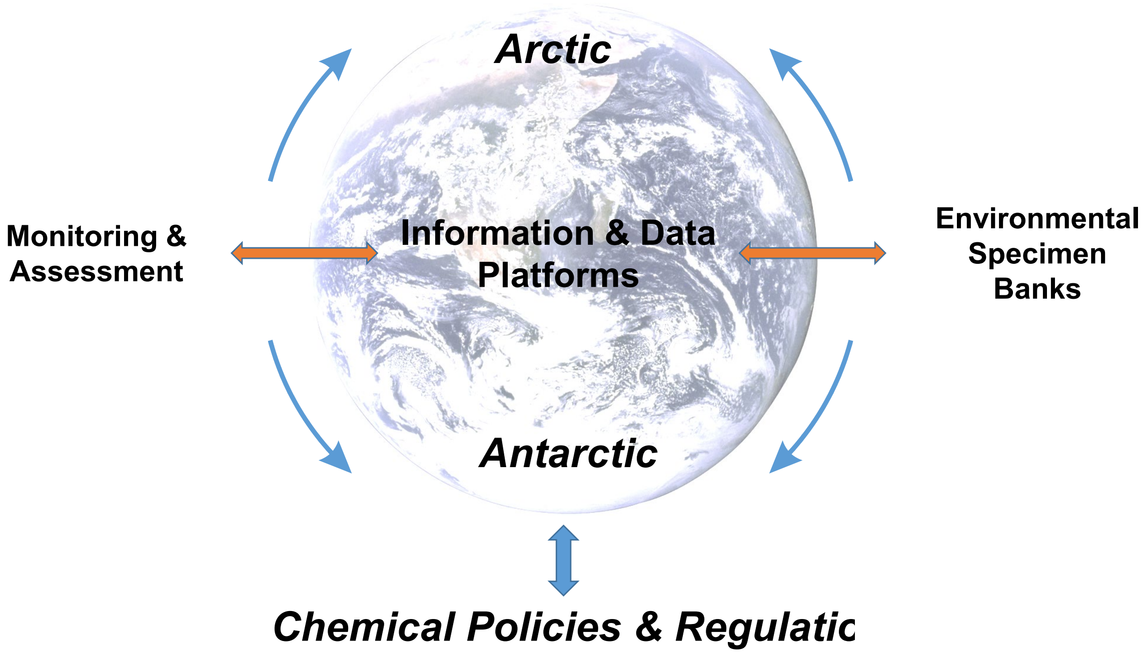


Fig. 1: Key players on contaminants in polar regions

We welcome 61 participants from four continents and 18 nations conducting substantial research in the Arctic or Antarctic and/or representing

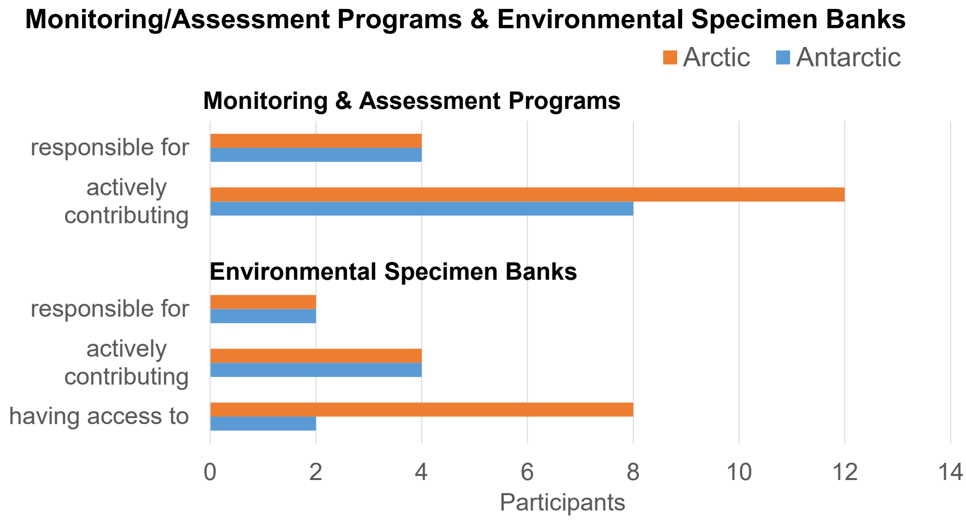
- Monitoring & Assessment Programs,
- Environmental Specimen Banks,
- Information & Data Platforms,
- International Networks & Initiatives,
- National Policy Advisors, and
- Supranational & International Chemical Policy & Regulation.

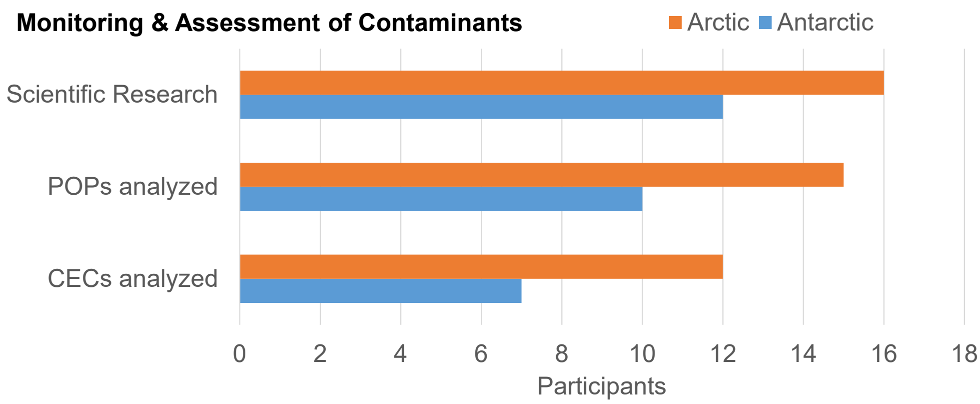
*Participants responsible/actively contributing to **Monitoring & Assessment Programs**, 26 in total*

*Participants responsible/actively contributing/having access to **ESBs**, 14 in total*

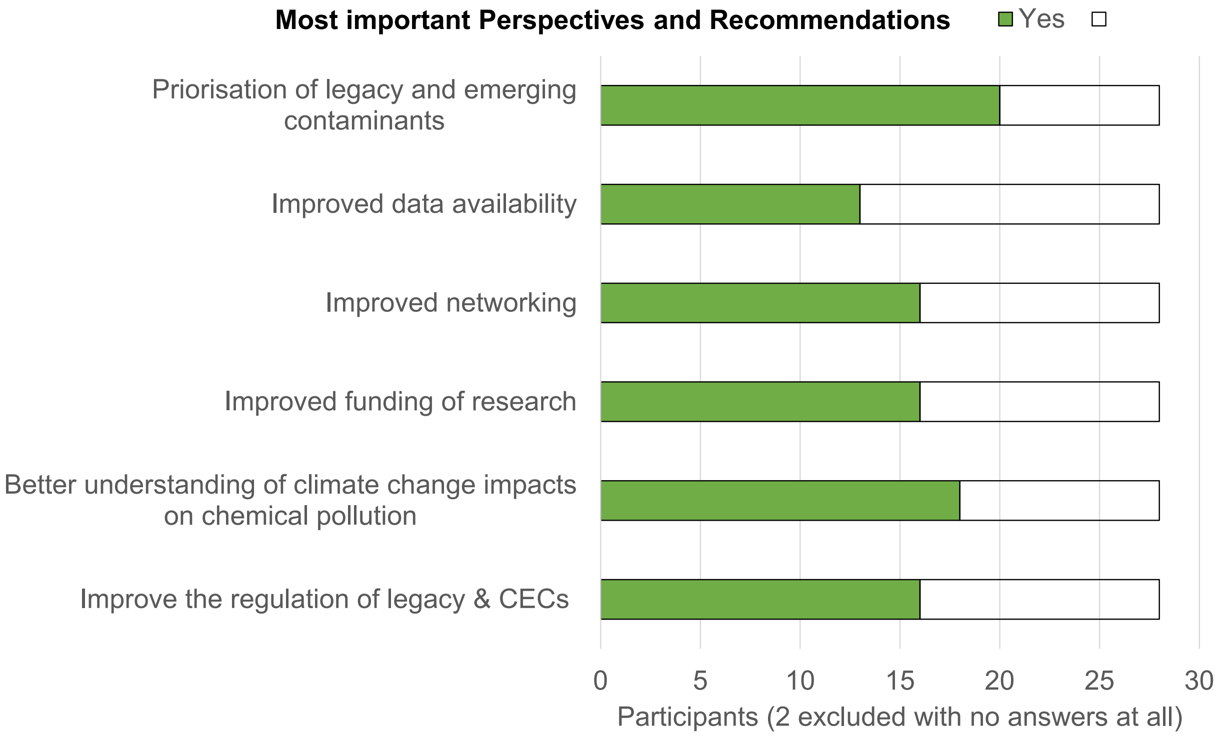
Fig. 2: Overview on participants involved in Monitoring & Assessment Programs or Environmental Specimen Banks (ESBs)

Presentation on January 26th





Future Perspectives and Recommendations

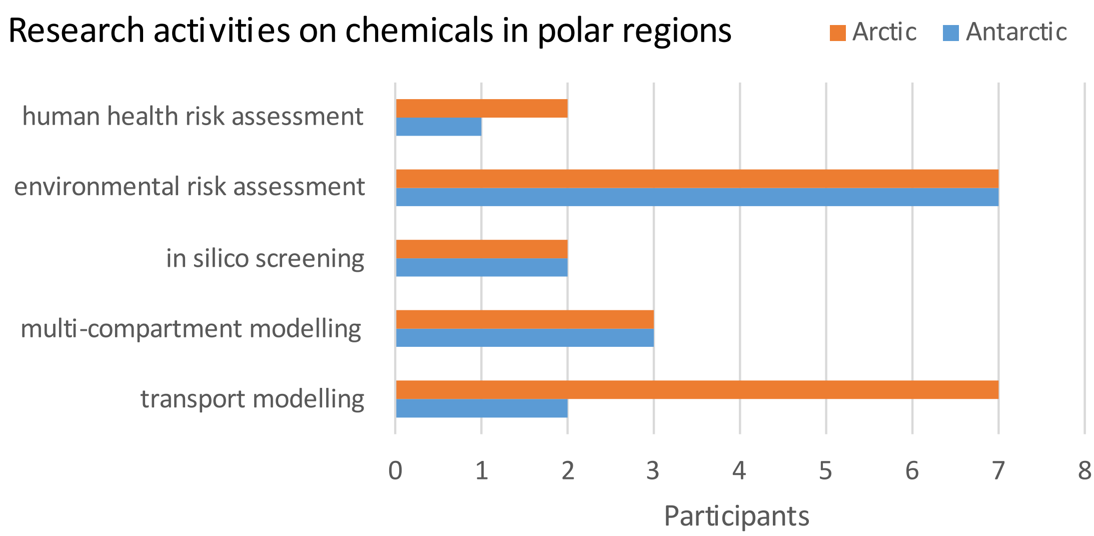


- Based on past experience, it seems that **information on chemicals in the Antarctic is scarce compared to data in the Arctic**.
- Our research team at the Australian **Antarctic** Division is concerned with the full suite of contaminants that affect Antarctic terrestrial, freshwater and marine environments in a range of matrices (soil, freshwater, seawater, and marine sediments). Much of our work has to date focused on legacy contaminants including metals and hydrocarbons as a result of **past waste disposal practices and accidental fuel spills**, as well as complex **sewage effluents which and are likely to contain a range of CECs**. Most of our research is around locally derived contamination as opposed to globally transported contamination, although the contribution of these sources is a topic of interest. Our research is largely focused on **assessing the risk of contamination, and putting in place procedures to minimise this and to remediation and restore contaminated sites**.
- **Data for POPs and CECs** in the **Arctic** are largely **lacking for the Russian** part of the Arctic, so **circumpolar trends** can not be studied.
- Investigation of **chemical mixtures and different pollutants as a multiple stressor** problem for the Arctic ecosystem (e.g. microplastics and plastic additives as co-contaminants).
- **Suspect screening and non-target analysis** (NTA) of organic contaminants in selected matrices/locations **to support prioritisation activities**.
- International efforts to **identify potential new POPs** through **mining of global chemical usage data coupled with physical property data**. A broader effort to **check these**

suspected POPs lists using **ESBs** and **NTA** screens of Arctic and Antarctic samples would be a good international exercise.

- **ESBs** systematically sample … in such a way, that **present and future generations** can use the samples to **assess the relevance of well known but also emerging stressors**.
- How historical samples from ESBs and **new genetic methods using eDNA** (environmental DNA) can respond to **biodiversity loss** by adding temporal trends that were previously missing for assessment.
- As drafter of **POP dossiers** …, we are interested in collecting **information on emerging contaminants in polar regions**. … for deciding on **new substances to be proposed to the Stockholm Convention** on POPs. … having **access to public databases** with monitoring data in the Arctic and Antarctic. **It is important that this information is publically available as POP dossiers are non-confidential**.
- In view of **interpreting data** … reported if **measurements are done far away from point sources** for the chemical of interest as we are interested in **long-range environmental transport processes**.
- It would be great to have further information on **concentration of substances in the seawater/oceans far away from point sources** (measurements in both the dissolved phase and particulate phase).

Supplemental Material



Tables for “*POPs / CECs investigated in the Arctic and the Antarctic*” and “*Environmental Specimen Banks for the Arctic and the Antarctic*” are included in Appendix IV.

Appendix I – Workshop Program

Act now – Legacy and Emerging Contaminants in Polar Regions

Online Workshop January 25th 11:00 – 16:30 CET and January 26th 11:00 – 16:30 CET

Workshop Chairs - Heike Herata (German Environment Agency, UBA), Ralf Ebinghaus (Helmholtz-Zentrum Hereon)

January 25th

10:45 CET **Technical introduction** for all participants attending online

11:00 CET **Opening** Christoph Schulte (German Environment Agency), Ralf Ebinghaus (Helmholtz-Zentrum Hereon)

11:10 CET **Results of the Workshop-Questionnaires** (Jürgen Gandraß, Helmholtz-Zentrum Hereon)

11:15 CET Session "**Polar regions in a global perspective**"
Chair: Ralf Ebinghaus, Helmholtz-Zentrum Hereon

- Cristina de Avila, Safe & Sustainable Chemicals, European Commission (11:15 - 11:30)
  The EU Chemicals Strategy for Sustainability and the polar regions: opportunities for a higher level of protection from contaminants
- Dmitriy Polovyanenko, Stockholm Convention Regional Centre Russia (11:30 - 11:45)
  Activities of the Russian Stockholm Convention Regional Centre including the Arctic region
- Cynthia de Wit, Stockholm University (11:45 - 12:00)
  AMAP work on POPs/CEACs in the context of regional to global perspectives
- Susan Bengtson-Nash, University of Griffith (12:00 – 12:15)
  The Antarctic Monitoring and Assessment Programme; Modelling Antarctic Progress on Arctic successes
- Discussion (12:15 - 12:35)

12:35 CET Break

12:45 CET Session "**Lessons learned: Legacy and emerging contaminants in polar regions**"
Chair: Cynthia de Wit, Stockholm University

- Katrin Vorkamp, Aarhus University (12:45 – 13:05)
  Contaminants in the Arctic – screening, monitoring and assessment

- Zhyiong Xie, Helmholtz-Zentrum Hereon (13:05 – 13:25)
  Survey on contaminant pollution in polar regions
- Matthew MacLeod, Stockholm University (13:25 – 13:45)
  Modeling legacy contaminant transport to the Arctic and for new priority substances
- Discussion (13:45 - 14:05)

14:05 CET Break

14:35 CET Session "***The influence of Climate Change: Scientific and policy needs***"
Chair: Roxana Sühring, Ryerson University

- Elena Barbaro, University of Venice (14:35 – 14:55)
  What are research needs for investigating contaminants under climate change impacts in polar regions?
- Roland Kallenborn, Norwegian University of Life Sciences (14:55 – 15:15)
  Chemicals of emerging Arctic concern in a changing Arctic: Status and research needs
- Kevin Hughes, British Antarctic Survey (15:15 – 15:35)
  Addressing the impacts of climate change on contaminants in Antarctica: the work of the Subsidiary Group on Climate Change Response
- Discussion (15:35 – 15:55)

15:55 CET **Breakout groups on key questions**

Group 1 starting with KQ 1, Rapporteurs Roland Kallenborn (Norwegian University of Life Sciences) & Hanna Joerss (Helmholtz-Zentrum Hereon)

Group 2 starting with KQ 2, Rapporteurs Xiang-Zhou Meng (Tongji University) & Zhiyong Xie (Helmholtz-Zentrum Hereon)

Group 3 starting with KQ 3, Rapporteurs Jan Koschorreck (German Environment Agency) & Valeria Dulio (NORMAN Association)

Group 4 starting with KQ 4, Rapporteurs Mathew MacLeod (Stockholm University) & Pernilla Bohlin-Nizzetto (Norwegian Institute for Air Research) (tbc)

Key Questions (KQ)

1. How can we raise awareness and visibility of polar contamination in the public, research community, and among policy makers?
2. Are established Arctic monitoring concepts a role model for the Antarctic environment?
3. How can we achieve a more systematic long-term monitoring and assessment of polar contamination through the integration of ESB concepts, data sharing and open access?
4. How can we prioritize monitoring activities to provide environmental policies and chemicals management with effective and robust monitoring data from polar environments?

16:25 CET **Summary and Closing of Day 1**
Heike Herata (German Environment Agency, UBA), Ralf Ebinghaus (Helmholtz-Zentrum Hereon)

16:30 CET End of day 1

January 26th

11:00 CET **Wrap up of Day 1**
Heike Herata (German Environment Agency, UBA), Ralf Ebinghaus (Helmholtz-Zentrum Hereon)

11:10 CET **Outcome Breakout Groups**

Outcome Breakout Group 1 (11:10 - 11:20)

Outcome Breakout Group 2 (11:20 - 11:30)

Outcome Breakout Group 3 (11:30 - 11:40)

Outcome Breakout Group 4 (11:40 - 11:50)

11:50 CET Session "***Linking Environmental Specimen Banks and research operations in the polar environment***"
Chair: Rebecca Pugh, National Institute of Standards and Technology

- Jan Koschorreck, German Environment Agency (11:50 – 12:10)
  Environmental specimen banks – experiences and challenges
- Marco Grotti, University of Genoa (12:10 – 12:30)
  The role of the Italian Antarctic Environmental Specimen Bank in the study of chemical contamination in Antarctica
- Morten Jartun, Norwegian Institute for Water Research (12:30 – 12:50)
  Contaminants in the Arctic – sources, status and storage of the Norwegian Wildlife
- Discussion (12:50 – 13:10)

13:10 CET Break

15:45 CET **Results of the Workshop-Questionnaires – Recommendations and Perspectives**
(Jürgen Gandraß, Helmholtz-Zentrum Hereon)

15:55 CET **Act now - towards sustainable polar environments – Open discussion**
Moderator: Jürgen Gandraß, Helmholtz-Zentrum Hereon

16:20 CET **Closing statements**
Heike Herata (German Environment Agency, UBA), Ralf Ebinghaus (Helmholtz-Zentrum Hereon)

16:30 CET End of Workshop

Appendix II – List of Participants

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Appendix III –Workshop Questionnaire

Questionnaire

The questionnaire aims to prepare the UBA/Hereon Workshop on January 25th-26th 2022

"Act now – Legacy and Emerging Contaminants in Polar Regions"

The outcome of the questionnaire will be presented at the workshop and will be included in the workshop proceedings. Please mark applying checkboxes and use free text fields for detailed information, remarks or comments.

A General

Name and position

(Only for internal use, aggregated outcome of questionnaire will be provided in workshop proceedings.)

Institutions, networks and affiliations

☐ National

☐ International

☐ Responsible for or ☐ actively contributing to ☐ arctic and/or ☐ antarctic monitoring & assessment programs

☐ Responsible for or ☐ actively contributing to or ☐ having access to ☐ arctic and/or ☐ antarctic specimen banks

☐ Conducting scientific research on legacy and/or emerging contaminants in ☐ the Arctic and/or in ☐ the Antarctic

B Monitoring & Assessment of Contaminants in Polar Regions

B.1 Arctic

Please provide information on chemical substances/matrices ☐ analysed ☐ and/or used for ☐ transport and/or ☐ multi-compartment modelling and/or exposure modelling and/or ☐ *in silico* screening exercises and/or ☐ environmental and/or ☐ human health risk assessment

☐ POPs/matrices

☐ CECs/matrices

Please provide information on data accessibility (URLs, data platforms, metadata) and most important reports or publications

☐ Open access data

☐ Data on request

☐ Relevant national and/or international reports or publications

B.2 Antarctic

Please provide information on chemical substances/matrices ☐ analysed ☐ and/or used for ☐ transport and/or ☐ multi-compartment modelling and/or exposure modelling and/or ☐ *in silico* screening exercises and/or ☐ environmental and/or ☐ human health risk assessment

☐ POPs/matrices

☐ CECs/matrices

Please provide information on data accessibility (URLs, data platforms, metadata) and most important reports or publications

☐ Open access data

☐ Data on request

☐ Relevant national and/or international reports or publications

C Environmental Specimen Banks (ESBs)

C.1 Responsible or involved in management

Responsible or involved in management of ☐ arctic or ☐ antarctic ESB

Name & host institution

What specimens are or are planned to be collected and stored?

What sampling sites are included?

Are specimens used for current monitoring of chemicals; if yes – which chemicals?

Are specimens used or planned to use for retrospective studies of chemicals; if yes – which chemicals?

Access to metadata of collected/stored specimens and results of monitoring/retrospective studies

Do you enable access to stored specimens for scientific studies upon request?

If yes, for which retrospective time period are samples available?

C.2 Having access to ESBs and use stored specimens

Having access to ☐ arctic and/or ☐ antarctic ESBs and use of stored specimens

ESBs

Specimens received or planned to receive from ESB

Specimens are used or planned to be used for ☐ current monitoring and/or ☐ retrospective studies of chemicals; if yes – which chemicals?

Additional information on focus of studies, e.g. on transport and fate of chemicals, climate change

Please provide information on data accessibility (URLs, data platforms, metadata) and relevant national/international reports or publications

D Future perspectives and recommendations

Please indicate most important perspectives and recommendations for actions on contaminants in polar regions:

☐ Priorisation of legacy and emerging contaminants in polar regions

☐ Improved data availability ☐ Improved networking ☐ Improved funding of research

☐ Better understanding of climate change impacts on chemical pollution in polar regions

☐ To improve the regulation of legacy and emerging contaminants

☐ To better connect and correlate Arctic and Antarctic findings

Others:

Appendix IV – Outcome Workshop Questionnaire – Supplemental Material

***Table**: POPs / CECs investigated in the Arctic and the Antarctic*

Arctic - POPs
Analysis and environmental RA: PCBs, DDTs, organochlorine pesticides, PBDEs, HBCDD in reindeer, Arctic char, pike from Sweden
Arctic - CECs
Environmental RA: emerging brominated and chlorinated flame retardants in Arctic biota within the AMAP program
References & Data
www.amap.no: all scientific reports and summaries for policy makers on POPs and chemicals of emerging Arctic concern available as pdf files.

Arctic - POPs
Legacy POPs (Trace element, PCBs, DDTs etc) in marine mammal tissues and seabird eggs
Arctic - CECs
PFAS, brominated flame retardants, in marine mammal tissues and seabird eggs
References & Data
www.nist.gov, See AMAP website. We contribute data to AMAP assessment reports

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Arctic - POPs
PBDEs, Arctic seabirds (black-legged kittiwakes, northern fulmar). OCPs, Arctic seabirds (black-legged kittiwakes, northern fulmar)
Arctic - CECs
alternative BFRs, Arctic seabirds (black-legged kittiwakes, northern fulmar). Dechloranes, Arctic seabirds (black-legged kittiwakes, northern fulmar). PFAS, Arctic seabirds (black-legged kittiwakes, northern fulmar). OPEs PBDEs, Arctic seabirds (black-legged kittiwakes, northern fulmar), sediment, water, air
References & Data
AMAP, 2021. AMAP Assessment 2020: POPs and Chemicals of Emerging Arctic Concern: Influence of Climate Change. Arctic Monitoring and Assessment Programme (AMAP), Tromsø, Norway. viii+142pp

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***Table**: POPs / CECs investigated in the Arctic and the Antarctic (continued)*

Arctic - POPs & CECs
PFAS, BFRs, nBFRs, cVMS, PCBs, oPFRs, phenols, UV-chemicals
References & Data
Environmental contaminants in an urban fjord (Grung et al., 2021; Ruus et al., 2020)
Contaminants in coastal waters of Norway (Schøyen et al., 2021)
Monitoring of environmental contaminants in freshwater (Jartun et al., 2021)
Monitoring of environmental contaminants in air and precipitation - 2020 (Bohlin Nizzetto et al., 2021)

Arctic - POPs
All POPs (according to the Stockholm Convention) / biota, air, water (passive sampling), snow, human serum
Arctic - CECs
Measurements: Non-regulated flame retardants and PFAS, chlorinated paraffins, plastic additives / biota, air, plastics; Non-target and suspect screening / biota, air, human serum; plastics; In silico screening: All compounds in databases
References & Data
ICES database; EBAS database
AMAP reports (www.amap.no).
Wong, F.; Hung, H.; Dryfhout-Clark, H.; Aas, W.; Bohlin-Nizzetto, P.; Breivik, K.; Mastromonaco, M.N.; Brorström-Lundén, E.; Ólafsdóttir, K.; Sigurðsson, Á.; Vorkamp, K.; Bossi, R.; Skov, H.; Hakola, H.; Barresi, E.; Sverko, E.; Fellin, P.; Li, H.; Vlasenko, A.; Zapevalov, M.; Samsonov, D.; Wilson, S. (2021). Time trends of persistent organic pollutants (POPs) and chemicals of emerging Arctic Concern (CEAC) in Arctic air from 25 years of monitoring. Science of the Total Environment 775, 145109. https://doi.org/10.1016/j.scitotenv.2021.145109
Vorkamp, K.; Balmer, J.; Hung, H.; Letcher, R.; Rigét, F.F. (2019) A review of chlorinated paraffin contamination in Arctic ecosystems. Emerging Contaminants 5, 219-231. https://doi.org/10.1016/j.emcon.2019.06.001
Vorkamp, K.; Balmer, J.E.; Hung, H.; Letcher, R.J.; Rigét, F.F.; de Wit, C.A. (2019). Current-use halogenated and organophosphorous flame retardants: A review of their presence in Arctic ecosystems. Emerging Contaminants 5, 179-200. https://doi.org/10.1016/j.emcon.2019.05.004
Rigét, F.F.; Bignert, A.; Braune, B.; Dam, M.; Dietz, R.; Evans, M.; Green, N.; Gunnlaugsdóttir, H.; Kucklick, J.; Letcher, R.; Muir, D.; Schuur, S.; Sonne, C.; Stern, G.; Tomy, G.; Vorkamp, K.; Wilson, S. (2019). Temporal trends of persistent organic pollutants in Arctic marine and freshwater biota. Science of the Total Environment 649, 99-110. https://doi.org/10.1016/j.scitotenv.2018.08.268

***Table**: POPs / CECs investigated in the Arctic and the Antarctic (continued)*

Arctic - POPs
POPs from the list of Stockholm Convention including polycyclic aromatic hydrocarbons and other organic contaminants / Matrices - water, soils, bottom sediments, industrial waste
References & Data
Reports for Ministry of Natural Resources and Environment of the Russian Federation and other organisations. National reports from The Ministry of Natural Resources and Environment of the Russian Federation

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Arctic - POPs
PCBs, OCPs, PBDEs, PAHs, PFAS - in water and air
Arctic - CECs
PCBs, OCPs, PBDEs in snow and blubber
Antarctic - CECs
OPFRs - in water and air
References & Data
Yeung, L.W.Y.; Mabury, S.; Dassuncao, C.; Zhang, X.; Sunderland, E.S.; Lohmann, R. Vertical Profiles, Sources and Transport of PFASs in the Arctic Ocean. Environ Sci Technol 2017, 51, 6735-6744. http://dx.doi.org/10.1021/acs.est.7b00788. Khairy, M.; Brault, E.; Dickhut, R.; Harding, K. C.; Harkonen, T.; Karlsson, O.; Lehnert, K.; Teilmann, J.; Lohmann, R. Bioaccumulation of PCBs, OCPs and PBDEs in Marine Mammals From West Antarctica. Front. Mar. Sci. 2021, 8, 1738. https://doi.org/10.33

Antarctic - POPs
Air, seawater, sea-ice, biota (invertebrates, fish, seabirds, cetaceans)
Antarctic - CECs
humpback whale blubber; planned non-target analysis of air and sea-water
References & Data
Published data is available in journal supplementary information documents and/or open access databases such as the Australian Antarctic Database .

***Table**: POPs / CECs investigated in the Arctic and the Antarctic (continued)*

Arctic & Antarctic - POPs & CECs
PAHs and fragrances in snow and seawater
References & Data
Vecchiato, M., Barbaro, E., Spolaor, A., Burgay, F., Barbante, C., Piazza, R., & Gambaro, A. (2018). Fragrances and PAHs in snow and seawater of Ny-Ålesund (Svalbard): Local and long-range contamination. Vecchiato, M., Gregoris, E., Barbaro, E., Barbante, C., Piazza, R., & Gambaro, A. (2017). Fragrances in the seawater of Terra Nova Bay, Antarctica. Science of The Total Environment, 593, 375-379.Environmental Pollution, 242, 1740-1747.

Arctic - POPs
Air - gas + particulate phase (PM10)
PCBs, HCB, DDTs, HCHs, Chlordanes, PBDEs, HBCDs, PAHs, PFAS
Arctic - CECs
Air - gas + particulate phase (PM10)
SCCPs, MCCPs, Siloxanes (cVMS), OPFRs, nBFRs, Phthalates, Dechloranes, volatile per- and polyfluorinated/chlorinated substances, NTS
Antarctic - POPs
Air - gas + particulate phase (PM10)
PCBs, HCB, DDTs, HCHs, Chlordanes, PBDEs
Antarctic - CECs
Air - gas + particulate phase (PM10)
SCCPs, MCCPs, Siloxanes (cVMS)
References & Data
EBAS - POPs
Monitoring of environmental contaminants in air and precipitation, Annual reports - Norwegian Environment Agency

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Arctic - POPs - Aqueous, soil/sediment, biota, Human
Arctic - CECs - Biosolids, sewage, biota, water Sediment/soil
Antarctic - POPs - Air, soil, biota
Antarctic - CECs Air, soil, biota
References & Data
researchgate.com; scholar.google.com, https://www.nmbu.no/ans/roland.kallenborn, https://app.cristin.no/persons/show.jsf?id=60777

***Table**: POPs / CECs investigated in the Arctic and the Antarctic (continued)*

Arctic & Antarctic - POPs - Snow, firn, ice, air
Arctic & Antarctic - CECs - Snow, firn, ice
References & Data
Data on request as Excel files. ACS Earth & Space Chemistry 2020, 4, 2096-; 2021, 5,2534-

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Antarctic - POPs & CECs
PCBs, PBDEs and other brominated flame retardants/tissue of fish and bird
References & Data
Hendrik Wolschke, Xiang-Zhou Meng, Zhiyong Xie, Ralf Ebinghaus, Minghong Cai. Novel flame retardants (N-FRs), polybrominated diphenyl ethers (PBDEs) and dioxin-like polychlorinated biphenyls (DL-PCBs) in fish, penguin, and skua from King George Island, Antarctica. Marine Pollution Bulletin. 2015, 9, 513-518

Arctic & Global - Modelling
POPs - PCBs in multimedia environment in compartment and transport models. HCHs global transport modeling.
CECs - Compartment modeling of siloxanes in water and sediment in a case study on Svalbard.
In-silico screening of potential planetary boundary threats. New model for fate and transport of micro- and nano-plastics.
References & Data
Open source models - https://github.com/BETR-Global/BETR-Global-4.0; https://github.com/Nano2PlastProject
Domercq, P., Praetorius, A., & MacLeod, M. (2021). The Full Multi: An open-source framework for modelling the transport and fate of nano-and microplastics in aquatic systems. Environmental Modelling & Software, 105291.
Plaza-Hernández, M., Legler, J., & MacLeod, M. (2021). Integration of production and use information into an exposure-based screening approach to rank chemicals of emerging Arctic concern for potential to be planetary boundary threats. Emerging Contaminants, 7, 213-218.
Abrahamsson, D. P., Warner, N. A., Jantunen, L., Jahnke, A., Wong, F., & MacLeod, M. (2020). Investigating the presence and persistence of volatile methylsiloxanes in Arctic sediments. Environmental Science: Processes & Impacts, 22(4), 908-917.
McLachlan, M. S., Undeman, E., Zhao, F., & MacLeod, M. (2018). Predicting global scale exposure of humans to PCB 153 from historical emissions. Environmental Science: Processes & Impacts, 20(5), 747-756.
Reppas-Chrysovitsinos, E., Sobek, A., & MacLeod, M. (2017). Screening-level exposure-based prioritization to identify potential POPs, vPvBs and planetary boundary threats among Arctic contaminants. Emerging Contaminants, 3(2), 85-94.
MacLeod, M., Breitholtz, M., Cousins, I. T., Wit, C. A. D., Persson, L. M., Rude´n, C., & McLachlan, M. S. (2014). Identifying chemicals that are planetary boundary threats. Environmental science & technology, 48(19), 11057-11063.
Wöhrnschimmel, H., MacLeod, M., & Hungerbuhler, K. (2013). Emissions, fate and transport of persistent organic pollutants to the Arctic in a changing global climate. Environmental science & technology, 47(5), 2323-2330.

***Table**: Environmental Specimen Banks for the Arctic and the Antarctic*

Norwegian Environmental Specimen Bank, Ministry of Climate and Environment
Samples: Brown trout, perch, cod, vendace, E.smelt, blue mussels, bird eggs, reindeer, arctic fox, otter, polar bear (blood), seals, air, moss, sewage sludge.
Sampling sites: Norway mainland, Svalbard, North sea
Included in several monitoring projects (e.g. PFAS, BFRs, nBFRs, cVMS, PCBs, heavy metals + +)
Samples are available for applications (research)
Sample availabilty: Approx. 2000 - this date
Access to samples: Upon request, and after evaluation of an appointed expert committee.
Some data available at www.miljoprovebanken.no

Environmental Specimen Bank (ESB Norway), NIVA
NILU contribute with air samples - passive air samples + active air samples (PM10 on filters)
Sampling sites: For air samples - Zeppelin, Arctic and Birkenes, southern Norway
Chemical monitoring: Yes, in the national monitoring programme for atmospheric contaminants.
Retrospective studies: Yes, no details available.
Access to metadata specimens & study results: yes
Specimens access on request: yes
Sample availability: Air samples from 2014.

Access to **Norwegian Environmental Specimen Bank**
Samples received: Biota, sediment, air
Analysed: PPCPs, OPFR, Plasticisers
Retrospective studies: Environmental pollutants as indicators for the anthropogenic component of Arctic climate change
https://miljoprovebanken.no/english/

***Table**: Environmental Specimen Banks for the Arctic and the Antarctic (continued)*

ESB Aarhus University (AMAP Core Programme)
Biota samples from Greenland
Several sampling sites in Greenland
Chemical monitoring: POPs and Chemicals of Emerging Arctic Concern
Retrospective studies: Specimens have been used repeatedly for retrospective time trends, of PBDEs, HBCD, PFAS, endosulfan, dechlorane plus
Results of screening studies and retrospective time trends have been published in the scientific literature, for example:
Specimens access on request
Sample availabilty: This varies for species/tissues. Most go back to 1980s or early 1990s.
Vorkamp, K.; Bossi, R.; Rigét, F.F.; Skov, H.; Sonne, C.; Dietz, R. (2015). Novel brominated flame retardants and dechlorane plus in Greenland air and biota. Environmental Pollution 196, 284-291. 10.1016/j.envpol.2014.10.007
Rigét, F.; Bossi, R.; Sonne, C.; Vorkamp, K.; Dietz, R. (2013). Trends of perfluorochemicals in Greenland ringed seals and polar bears: indications of shifts to decreasing trends. Chemosphere 93, 1607-1614. 10.1016/j.chemosphere.2013.08.015
Vorkamp, K.; Bester, K.; Rigét, F.F. (2012) Species-specific time trends and enantiomer fractions of hexabromocyclododecane (HBCD) in biota from East Greenland. Environmental Science & Technology 46, 10549-10555. 10.1021/es301564z

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National Institute of Standards and Technology (NIST) Biorepository, hosted by NIST and located in Charleston, South Carolina at the Hollings Marine Laboratory
Marine mammal tissues are regularly collected through the Alaska Marine Mammal Tissue Archival Project (AMMTAP), a collaboration with the National Oceanic and Atmospheric Administration (NOAA). AMMTAP samples are archived as part of the National Marine Mammal Tissue Bank at the NIST Biorepository. In addition, seabird egg contents/shells are collected and archived as part of the Seabird Tissue Archival and Monitoring Project (STAMP) in Alaska.
Marine mammals (AMMTAP) are collected opportunistically through strandings and during planned subsistence harvests with the Alaskan Native American communities throughout Alaska. Seabird eggs (STAMP) are collected from colonies throughout Alaska in coordination with the US Fish and Wildlife Service (USFWS).
20 marine mammal species, including beluga whale, bowhead whale, ringed seal, and Norther fur seal. Seabird eggs include common and thick-billed murres and glaucous and glaucous-winged gulls.
Chemical monitoring: Yes, legacy and emerging POPs
Retrospective studies: Yes, this is the primary reason samples are collected and archived as a part of AMMTAP and STAMP. Legacy and emerging POPs are measured along with trace elements.
Access to samples: Available upon request to the NIST Biospecimen Science Group. Formal tissue access policies are established and made available to the scientific community.
AMMTAP (marine mammal samples) - was established in 1987 and collections continues today.
STAMP (sebird egg contents) - was established in 1999 and collections continue today.
NIST contributes data to AMAP assessment reports, see AMAP website.

***Table**: Environmental Specimen Banks for the Arctic and the Antarctic (continued)*

Access to **ESB Environment and Climate Change Canada**
Samples received: Arctic seabirds (northern fulmar, black-legged kittiwakes, thick-billed murres, black guillemot, common eider)
Microplastics, OPEs, suspect screening for persistent, mobile, and toxic plastic additives (PMT plastic additives)
Investigation of plastic particles as long-range transport vehicles for PMT plastic additives, investigation to what extend plastic particles act as "passive donors" for PMT plastic additives to the birds and into water

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ESB N.N. Vorozhtsov Novosibirsk Institute of Organic Chemistry SB RAS
Soils and bottom sediments from Siberian and Arctic region
Sampling sites: territory of industrial enterprises, energy companies in Siberian and Arctic region
Analysis for research and analytical control - POPs including polycyclic aromatic hydrocarbons and other organic contaminants
No access to stored specimens

Antarctic Environmental Specimen Bank at Department of Chemistry and Industrial Chemistry, University of Genoa
Samples: seawater, sea ice, suspended particulate matter, marine sediment, fish, molluscs, sponges, lake water, macro-algae, lake sediment, snow, firn, soil, mosses, atmospheric particulate matter
Sampling sites: many sites in the Northern Victorial Land and East Antarctic Plateau
Chemical monitoring: trace elements, POPs
Retrospective studies: trace elements, POPs
Access to metadata specimens & study results: yes
Specimens acces:s on request
Sample availability: back to 1995

***Table**: Environmental Specimen Banks for the Arctic and the Antarctic (continued)*

ESB Griffith University
Krill and humpback whale tissues
Sampling sites: circum-polar
Chemical monitoring: Yes - OC pesticides
Retrospective studies: Yes - CEACs
Access to metadata specimens & study results: Not at present due to active use of specimens
Sample access: yes, for some of the collection
Sample availability: 2006 to present

Australian Antarctic Division
Samples: Mainly near shore coastal marine invertebrates and terrestrial micro-invertebrates
Sampling sites: Mostly close to Australia's 3 Antarctic stations, Casey, Davis and Mawson
Not generally used to monitor chemical body/tissue burdens. This is a reference collection, mainly for taxonomic/identification purposes from ecological biodiversity studies.
Retrospective studies: No. Mostly stored in ethanol or formalin so may not be appropriate for chemical analysis
Access to data: https://data.aad.gov.au/
Access to samples: Assessed on a request by request basis

Yangtze Environmental Specimen Bank
Samples: Fish and other species
Sampling sites: Zhongshan Station in Antarctic, sampling sites in the Yangtze River Delta, the Bohai Sea, and the upstream of the Yangtze River.
Sample access: no access
