International Workshop on Monitoring Chemical Pollution in Antarctica
-Tackling future Challenges together

3rd-4th October 2024
Siena, Italy

Workshop Report

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Glossary

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

AMAP – Arctic Monitoring and Assessment Programme

AnMAP – Antarctic Monitoring and Assessment Programme

ATCM – Antarctic Treaty Consultative Meeting

CEACs – Chemicals of Emerging Arctic Concern

CECs – Contaminants of Emerging Concern

CEP – Committee for Environmental Protection

ESBs – Environmental Specimen Banks

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

LRET – Long-range environmental transport

Minamata Convention on Mercury – Entered into force 2017

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 harmonization of common measurement methods and monitoring tools, and operates extensive data bases on CECs

PFAS – Per- and polyfluoroalkyl substances

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

SCAR – Scientific Committee on Antarctic Research

Stockholm Convention – Stockholm Convention on Persistent Organic Pollutants

Target Analysis – Identification and quantification of contaminants in samples by chemical analytical methods using the respective pure chemicals as reference

Executive Summary

The International Workshop on Monitoring Chemical Pollution in Antarctica: Tackling Future Challenges Together (IWPTS), has been successfully held in Siena, Italy, in 3rd-4th October 2024. The workshop convened leading researchers and environmental stakeholders to address the critical issue of chemical pollution in the Antarctic region. This workshop underscored the growing concern about the presence and impact of persistent organic pollutants (POPs) and contaminants of emerging concern (CECs) in the Antarctic. Over two days of intensive discussions and collaborative sessions, participants explored the current state of knowledge, identified key challenges, and laid the groundwork for innovative explanations to protect Antarctica's ecosystems. The workshop was organized around four major scientific themes:

Environmental Fate and Transport of POPs and CECs in Antarctica

Discussions on the environmental fate and transport of POPs and CECs in Antarctica highlighted the complex pathways through which these chemicals reach and persist in this remote region. Participants presented how pollutants, originating from global industrial and agricultural activities, are transported via air masses, oceanic circulation, and cryosphere dynamics. The cold-trapping effect, unique to polar regions, was emphasized as a critical factor that facilitates the deposition and accumulation of POPs in Antarctic soil, ice and snow.

Oceanic processes, such as the Antarctic Circumpolar Current, play a significant role in redistributing pollutants within marine ecosystems, affecting biodiversity hotspots. Cryospheric processes, including ice melting and seasonal thawing, were identified as mechanisms that can release sequestered pollutants, potentially reintroducing them into aquatic and terrestrial ecosystems. The persistence of these chemicals raises concerns about bioaccumulation and biomagnification within the Antarctic food web, impacting species from krill to top predators like seals and penguins.

Future research priorities include improving models to predict pollutant transport and distribution under changing climatic conditions. Collaboration across disciplines and nations is essential to enhance understanding, address data gaps, and inform global efforts to moderate the impact of these pollutants on the Antarctic environment and its unique biodiversity.

Antarctic Environmental Specimen Banking

The establishment and maintenance of Antarctic Environmental Specimen Banks (ESBs) are increasingly recognized as critical for advancing research into environmental contamination and its impacts on the Antarctic ecosystems. These banks serve as repositories for biological and environmental samples, including ice cores, seawater, sediments, and tissues from key Antarctic

species. The existing ESBs enable retrospective analyses to detect changes in contamination levels over time, offering insights into long-term trends of POPs, CECs and heavy metals. A key advantage of specimen banks lies in their potential to bridge gaps in historical data, allowing scientists to study the onset and progression of chemical pollution even decades after the samples were collected. These banks also support multidisciplinary research, enabling correlations between chemical pollution, climate change, and ecological impacts. Moreover, they play a critical role in developing baselines against which future changes can be assessed, informing policy and conservation efforts.

Discussions highlighted the importance of international collaboration to standardize sample collection, storage protocols, and metadata documentation. Sustained funding and logistical support are essential to maintain these facilities and expand their scope, ensuring they remain a necessary resource for addressing emerging scientific questions and preserving Antarctic biodiversity.

National and International Antarctic Environmental Monitoring Programs

A detailed evaluation of current Antarctic environmental monitoring programs emphasized significant gaps in their ability to comprehensively track chemical pollution trends in the Antarctic. Participants highlighted the limitations of existing research programs, including inconsistent data collection methodologies, insufficient geographic coverage, and a lack of long-term monitoring efforts. These limitations weak the ability to detect temporal and spatial trends of POPs, CECs, and heavy metals across the pan-Antarctic region.

Expanding these programs was identified as essential to provide a more detailed and reliable understanding of chemical pollution and its impacts on the Antarctic ecosystem. Long-term monitoring is particularly essential for assessing how chemical pollutions are influenced by changing climatic conditions and understanding their bioaccumulation and biomagnification within Antarctic food webs.

International collaboration was recognized as a foundation of effective monitoring programs. Collaborative efforts via SCAR ImPACT or AnMAP allow resource sharing, enhance scientific capacity, and raise an incorporated approach to tackling pollution in the Antarctic. These initiatives are important for informing global policy and protection strategies.

Advanced Sampling and Analytical Technologies

Advances in analytical chemistry were highlighted as transformative for detecting and quantifying ultra-trace levels of chemical pollutants in the remote Antarctic environment. These breakthroughs have enabled scientists to measure POPs, CECs and heavy metals at levels previously undetectable, providing a more comprehensive picture of the Antarctic chemical pollution.

Novel sampling techniques, such as passive sampling devices for air and water were highlighted as essential tools for capturing pollutants in challenging and extreme conditions. These approaches not only improve the efficiency of sample collection but also reduce environmental disruption during fieldwork. Innovative analytical tools, including high-resolution mass spectrometry and advanced chromatography techniques, were showcased for their ability to identify and quantify pollutants with exceptional sensitivity and specificity. Such tools are critical for detecting low-abundance contaminants and characterizing complex pollutant mixtures.

Participants emphasized the importance of these technological advancements in understanding the extent, distribution, and ecological impact of pollution in Antarctica. Improved analytical capabilities also facilitate the study of temporal trends and pollutant behaviour in response to environmental changes, such as ice melt and ocean circulation. Future directions include the integration of these methods into standardized protocols and enhanced international collaboration to share expertise and technological resources.

Furthermore, the discharge of untreated or inadequately treated sewage by ships in polar regions remains a significant environmental concern. Participants discussed the negative impacts of sewage on the Antarctic, including PPCP and endocrine disrupting chemicals. Such discharges threaten biodiversity, particularly in the polar regions. Stricter enforcement of regulations under the International Maritime Organization (IMO), such as MARPOL Annex IV, was emphasized, alongside the need for advanced onboard wastewater treatment technologies. Enhancing compliance monitoring and fostering international cooperation are crucial to modifying the environmental impacts of sewage discharge in the Antarctic.

Overarching outcome of this workshop

The workshop has presented comprehensive monitoring and analytical tools, integrated scientific insights and policy recommendations. Key priorities included enhancing international cooperation, promoting interdisciplinary research, and supporting for precise regulations on chemical pollutions to prevent their release into the Antarctic ecosystem.

IWPTS confirmed the urgent need for collective action to moderate chemical pollution in Antarctica. By integrating global expertise and resources, the scientific and policymaking communities can ensure the protection of this unique Antarctica for the future planet.

1. Abstracts and Summary of the Presentations

Monitoring Chemical Pollution in Antarctica - A mission of the German Environment Agency

Claudia Röhl

German Environment Agency (UBA), Germany

The Antarctic region is facing significant challenges due to the increasing impact of human activities and the introduction of harmful chemical substances. The detection of DDT-related chemicals in Antarctic penguins in 1966 served as a clear indicator of the global consequences of human influence. Since then, research on chemical pollution in Antarctica has expanded significantly. Studies reveal that persistent organic pollutants (POPs) can enter Antarctic ecosystems through both long-range atmospheric transport and direct human activities, such as those associated with research stations and tourism. Evidence suggests that these pollutants accumulate along the Antarctic food chain, impacting species ranging from krill and fish to mussels, as well as birds such as giant petrels and penguins. Consequently, continuous and detailed monitoring of these pollutants in polar ecosystems is essential to understand and mitigate their effects.

The German Environment Agency (UBA) is one of the largest environmental agencies in Europe, employing approximately 1,800 people. Its guiding principle is environmental protection, which underscores its commitment to the early detection, assessment, and timely mitigation of environmental risks and threats. This mission is accomplished through a combination of in-house research and collaboration with scientific institutions both within Germany and internationally. Additionally, the UBA serves as a key point of contact for numerous international organizations.

Approximately five years ago, the UBA began to place greater emphasis on the issue of chemical pollution in polar regions. Evidence emerged indicating that long-regulated pollutants are being re-released into the environment due to the melting of polar ice masses, a direct consequence of climate change. It became evident that this issue had not yet been systematically studied at either the national or international level. Since then, the UBA has worked to strengthen its national partnerships with institutions such as the Helmholtz Center for Polar and Marine Research, the Alfred Wegener Institute, and Fraunhofer IME, a key partner of the German Environmental Specimen Bank, which has been operational for over 40 years. These collaborations aim to address the growing challenges posed by chemical pollution in polar ecosystems.

In 2022, in collaboration with Helmholtz Zentrum Hereon, an online workshop on Legacy and Emerging Contaminants in Polar Regions was organized, bringing together numerous international experts. This highly successful workshop highlighted the need for stronger networking and improved data accessibility through harmonized monitoring activities as critical steps to safeguard Antarctica's environmental status. As a result, the POLEMP project was launched last year to develop a concept for a polar environmental monitoring program focused on chemical pollutants in Antarctica. The goal of this project, in collaboration with national and international partners, is to compile data from chemical monitoring programs of selected Antarctic Treaty states. The aim is to establish a coordinated monitoring system in Antarctica, providing high-quality data to inform international activities, such as the Stockholm Convention, and to support effective and reliable chemical management and environmental policy. Since its inception, information papers on this subject have been consistently submitted to the annual Antarctic Treaty Consultative Meetings to share findings, highlight national efforts, and identify international collaborators.

The participants in this workshop include experts from the SCAR Action Group, the POLEMP Project, Antarctic Treaty consultative parties, and international environmental sample banks. A total of 57 participants are attending, with 37 present in person and 20 joining online, representing 17 different countries. Over the next few days, thought-provoking discussions will take place, research findings will be shared, and innovative solutions to address critical challenges will be explored. This collaboration is invaluable in understanding the impact of chemical pollutants on this fragile ecosystem and the broader global implications of these findings. Active participation, thoughtful questions, and collaboration among researchers and experts are encouraged. Together, these efforts can contribute to the preservation of Antarctica, ensuring that future generations can experience its unique beauty and biodiversity.

Future trends in polar research, the EU-PolarNet prioritization process

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The polar regions, with their rapidly changing environments and profound global significance, are at the forefront of contemporary scientific inquiry. As climate change accelerates and human activities increasingly encroach on these fragile ecosystems, the need for coordinated, strategic, and impactful polar research has never been greater. This speech addresses the future trends in polar research, focusing on the prioritization process adopted by EU-PolarNet to guide and optimize research efforts within Europe and beyond.

EU-PolarNet, a consortium established to integrate and enhance European polar research, plays a pivotal role in identifying and addressing key scientific and societal challenges in the Arctic and Antarctic regions. Through a systematic prioritization process, EU-PolarNet aims to streamline research initiatives, fostering collaboration across disciplines and countries, and ensuring that research outcomes are relevant and beneficial to policymakers, local communities, and the global scientific community.

This presentation will outline the comprehensive approach of EU-PolarNet in setting research priorities, emphasizing the integration of multidisciplinary perspectives, stakeholder engagement, and alignment with international polar research frameworks. Key focus areas include understanding climate dynamics, preserving biodiversity, enhancing resilience of polar ecosystems, and advancing sustainable development in polar regions. Furthermore, the speech will highlight the role of EU-PolarNet in facilitating knowledge exchange and collaboration between scientists, indigenous communities, and policymakers, thus ensuring that research is not only scientifically rigorous but also socially and ethically responsible.

In conclusion, the future of polar research will depend on the ability to prioritize effectively, collaborate widely, and innovate continuously. The EU-Polarnet prioritization process provides a robust framework for guiding European research towards addressing the most pressing challenges in polar regions, ultimately contributing to the sustainable stewardship of these critical areas of our planet.

Summary

In its second phase of the EU-PolarNet, the project involves approximately 25 members from 21 European countries. This project is crucial for advancing polar research and includes tasks such as establishing a prioritization process. This process gathers stakeholders and key policymakers to shape the future direction of polar research. A platform has been developed to provide an overview of European polar research and facilitate dialogue between researchers and policymakers, ensuring informed decision-making. A key objective of EU-PolarNet is to leave a legacy, including the establishment of a framework for European Polar Coordination Offices under the European Polar Board. This framework will continue to support the scientific community in the future.

A critical aspect of this project is the prioritization of research topics, which involves more than simply identifying areas of focus. It is a comprehensive process of evaluating and ranking topics based on their importance. This requires a collaborative and inclusive approach to address the most pressing research gaps, ensuring alignment with potential future funding opportunities. Looking ahead, one of the major challenges is the International Polar Year 2030, a pivotal milestone that the scientific community is currently transitioning toward. Several global initiatives, including the International Arctic Science Committee (IASC), SCAR, and the IPCC, are collaborating to guide future research projects. Additionally, key events such as the International Year for Glacier Preservation in 2025 and the UN Decade on the Cryosphere (2025-2034) will shape future research priorities, encompassing both polar regions and third poles, such as the Himalayas. The prioritization process will begin in the summer, ensuring transparency and inclusivity with input from all relevant stakeholders.

During the first phase of the EU-PolarNet project, five white papers were published and are available on the EU-PolarNet website. An Integrated European Polar Research Program was developed through a bottom-up approach, involving close interaction with stakeholders and rights holders. The project spans both Antarctica and the Arctic. In its second phase, the expertise base was expanded to include over 200 experts from various disciplines, such as solid Earth sciences, climate science, social sciences, and diplomacy. A core executive polar expert group of 30 members was selected to guide the prioritization process. The prioritization process began with the establishment of the expert group in 2021, followed by the collection of over 150 input documents, including national strategies, international polar research programs, and review papers.

After compiling and analyzing all inputs, a retreat in Venice was held to finalize a list of priority research topics, organized into four main pillars: the polar climate system, polar biodiversity, socio-economic aspects, and human impact on polar systems. The monitoring of chemical pollution in Antarctica is directly related to the latter. Each research priority was detailed, including its scope and

expected impacts. A key objective is to understand the cumulative effects of human activity on polar environments, biodiversity, and ecosystem functioning, particularly in the context of climate change. This encompasses factors such as tourism, renewable energy development, polar operations, and transport. Another focus is improving international and national governance systems to ensure environmental protection and peaceful cooperation in the Arctic and Antarctic. Efforts are also underway to develop indicators for assessing the state of the polar environment and implement long-term monitoring programs. These topics are outlined in an upcoming brochure, offering both concise and detailed descriptions.

Another key consideration is the large-scale initiatives that will require coordinated international efforts. One example of such an initiative is Antarctica InSync, a broad collaborative project that involves multiple nations and aims to synchronize observations of Antarctica and the Southern Ocean. The next steps in this project will involve clearly identifying research themes, with chemical pollution in Antarctica being a critical focus. To ensure the success of such initiatives, broad community engagement, addressing knowledge gaps, and long-term international collaboration will be essential. As we continue to develop these projects, we are working to secure support from national agencies and the European Commission to ensure that future research on these critical topics is well-funded and sustainable.

Challenges for environmental research and monitoring of the contaminants of emerging concern in the Antarctic

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The Antarctic faces growing threats from contaminants of emerging concern (CECs), including pharmaceuticals, personal care products (PPCPs), microplastics (MPs), and POPs. These pollutants, introduced through anthropogenic activities such as research station operations, tourism, and long-range atmospheric and oceanic transport, pose significant risks to the fragile polar ecosystems. Despite these challenges, monitoring and researching CECs in the Antarctic remains limited, primarily due to logistical and technological barriers. Harsh weather, remote locations, and limited infrastructure significantly constrain sampling efforts and long-term monitoring programs. Additionally, the detection and analysis of CECs often require advanced analytical techniques capable of identifying trace levels of contaminants in complex matrices, a capability that is not always readily accessible in the Antarctic. Furthermore, the ecological implications of CECs in the Antarctic remain poorly understood, with gaps in knowledge regarding their transport, transformation, and impacts on native species and food webs. These challenges are compounded by inadequate regulatory frameworks and international agreements, which is behind the rapid explosion of new pollutants globally.

To address these issues, there is an urgent need to develop standardized protocols for sampling and analysis, integrate advanced monitoring technologies, and foster international collaboration. A multidisciplinary approach combining environmental chemistry, toxicology, and ecosystem modeling is essential to identify risks and inform mitigation strategies. This work underlines the importance of prioritizing research on CECs in the Antarctic to protect its ecological integrity and ensure that this critical global biome remains a standard for environmental protection in the face of expanding anthropogenic pressures.

Summary

Numerous research initiatives are focused on studying various chemical groups in both the Antarctic and Arctic regions. For example, 12 initiatives have been identified as pertaining to Persistent Organic Pollutants (POPs) under the international Stockholm Convention. These chemicals are consistently monitored through national programs, which have achieved significant success in their regulation and management. Since the implementation of the ban, concentrations of these chemicals have declined both regionally and on a global scale. Furthermore, between 2009 and 2023, over 22 substances have been added to the list of regulated chemicals under the Stockholm Convention. Emerging POPs are also becoming a growing concern in these polar regions, necessitating continued vigilance and research.

Beyond legacy Persistent Organic Pollutants (POPs), other chemical groups are gaining increasing significance in environmental research. These include Pharmaceuticals and Personal Care Products (PPCPs), microplastics (with the most toxic components often being the fibers themselves), and antimicrobial agents such as liquid crystal monomers. These emerging contaminants represent a growing concern for the environmental science community, underscoring the importance of their inclusion in both national and international research programs.

In the context of Antarctic research, there are currently over 99 research stations distributed across the continent, with approximately 40 to 60 of these operating as permanent facilities that function year-round, including during the winter and summer seasons. Some stations operate on a seasonal basis, while others are in the sub-Antarctic region. For example, the German Neumayer Station III, which operates continuously throughout the year, plays an active role in environmental monitoring efforts.

Environmental pollution studies in Antarctica have been conducted for more than two decades, with numerous research groups collecting data from various regions across the continent. Key research sites, such as Zhongshan Station, have served as critical hubs for investigating classical POPs, including polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT). These studies have focused on multiple environmental matrices, such as air, seawater, and biota samples, particularly from penguins and fish. Additionally, research has extended to the analysis of POPs in snow and ice cores, providing valuable insights into historical contamination trends.

The working groups engaged in these studies are diverse and geographically widespread. For instance, the Spanish Antarctic station has emerged as a key hub for research on both classical POPs and CECs across various environmental matrices. Similarly, Italian researchers, led by Carlo Barbante and Simonetta Corsolini, have concentrated their efforts on sampling snow, air, and metals. Meanwhile, Chinese research stations, such as Zhongshan and Great Wall Stations, have been actively investigating pollutants in the Antarctic atmosphere for over 15 years.

Enhanced collaboration and stronger linkages among these research groups are anticipated in the coming years, with expanded interactions involving research stations from countries such as Poland, Portugal, and the United Kingdom. This growing network of international cooperation is expected to significantly advance the understanding of environmental pollution in polar regions and contribute to the development of more effective global environmental management strategies.

In addition, ongoing sampling programs are being conducted at multiple stations using both active and passive air samplers. For example, Norwegian researchers have been collecting data at the Troll Station for over two decades. Their studies on classic POPs, such as PCBs, HCH, and DDT, have identified distinct seasonal trends. It is anticipated that this program will continue in the future, with other stations adopting similar sampling methodologies to further enhance the global dataset on polar environmental pollution.

A recent collaboration with Chinese researchers at Zhongshan Station involved a comprehensive year-long air sampling campaign. The findings revealed distinct seasonal trends, with lower concentrations of pollutants observed during the winter months and higher levels detected during the summer. Contaminants of Emerging Concern (CECs), such as phthalate esters and organophosphate esters, were identified in aerosol particles, underscoring the presence of emerging environmental threats in the region. Additionally, certain newly regulated chemicals, such as UV328, have recently been added to the Stockholm Convention, reflecting their growing environmental significance. Personal care products, including fragrances, are also becoming a concern due to their widespread use and potential ecological impacts, necessitating further research and monitoring efforts.

A study was conducted to investigate the transport of chemicals from Germany to the Southern Hemisphere and along the Antarctic coastline, aiming to understand their pathways to Antarctica. The results demonstrated a clear decline in chemical concentrations from the Northern Hemisphere to the Southern Hemisphere, with relatively elevated levels observed near the Antarctic coast. This pattern suggests the re-emission of chemicals from melting snow and ice during the Antarctic summer, highlighting the role of seasonal processes in redistributing pollutants in polar regions.

Research at stations in Australia, Spain, and France supports the findings of chemical transport to Antarctica. A study conducted at the French-Italian Dome C station identified relatively elevated levels of per- and polyfluoroalkyl substances (PFAS) in surface snow, although these concentrations remained lower than those observed in other Antarctic or Arctic regions. These findings underscore the complexity of chemical transport mechanisms, which involve both long-range atmospheric movement and localized sources within Antarctica. Marine species, particularly penguins, are highly vulnerable to these contaminants. Research on PFAS in penguin eggs and bird feathers has revealed higher concentrations, demonstrating the direct environmental impact of these chemicals on Antarctic wildlife. Additionally, samples from penguin eggs, krill, and fish have been collected to investigate the presence of Contaminants of Emerging Concern (CECs) in Antarctic biota, further emphasizing the need for comprehensive monitoring and research in this fragile ecosystem.

A multi-departmental monitoring network is being planned for future implementation, leveraging research vessels from Germany and other nations to collect ocean and coastal samples. This network will integrate stations for air sampling, utilizing both active and passive methods, as well as monitoring snow and biota. The initiative aims to coordinate international efforts to improve the understanding of pollutant dynamics and their impacts on polar environments, with the goal of developing effective mitigation strategies to protect these vulnerable ecosystems.

Amplification and sinks of organic pollutants in Antarctica and the Southern Ocean

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Summary

Antarctica is encircled by the Antarctic Circumpolar Current, which acts as a natural barrier to the oceanic transport of organic pollutants. Despite this, pollutants have been detected in Antarctica, and their presence is primarily attributed to atmospheric transport and deposition. This raised an important question: why do we observe such a diverse range of pollutants, each with distinct properties, in this remote region?

Pollutants are often classified into three categories: flyers (volatile compounds that remain in the atmosphere), hoppers (compounds that cycle between the atmosphere and surfaces, such as legacy POPs like PCPs and PCBs), and swimmers (compounds that are waterborne). Based on this classification:

- Swimmers should theoretically not reach Antarctica, as oceanic transport is blocked by the Antarctic Circumpolar Current.
- Flyers should remain in the atmosphere and not accumulate in significant amounts on the continent.
- Only hoppers should be present in Antarctica, as they can undergo deposition processes that might bring them to the region.

However, observations contradict these assumptions. Compounds such as PFAS, fluorotelomers, and other chemicals have been detected in Antarctica, even though they do not align with the expected behavior of these categories. This indicates that the traditional framework of classifying pollutants as flyers, hoppers, or swimmers fails to explain their presence in Antarctica. Our research aimed to uncover why this classification system cannot accurately predict the distribution and behavior of pollutants in this unique environment.

Our research has focused on the amplification processes of organic pollutants in Antarctica, examining factors such as snow deposition and melting, rain events, the sea surface microlayer, and sea-spray aerosols. Biomagnification is another significant amplification mechanism, though it will not be addressed here, as it is assumed to be well-known. Most of the research has been conducted in the Western Antarctic Peninsula, particularly in regions such as the Bransfield Strait, the South Shetland Islands and the Bellignshousen Sea. Spain operates research stations at Livingston Island and Deception Island, which are also linked to this work.

Seawater samples were collected throughout the Antarctic summer, from December to late February or early March, during several austral summers. Analysis of PAHs revealed a noticeable increase in concentrations during the summer, primarily due to snowmelt. As snowpack accumulated during fall and winter begins to melt in the warmer months, it releases pollutants into the seawater, resulting in higher concentrations. This trend is closely linked to rising temperatures and is consistent across various pollutants studied. This pattern is also evident for legacy POPs, such as PCBs and organochlorine pesticides. Time-series data for PCBs from late December to early March show a slight increase in concentrations, with fluxes inversely related to salinity. Lower salinity levels indicate a greater influence of snowmelt, which drives an increase in pollutant concentrations and enhances volatilization. Snowmelt thus plays a critical role in the dynamics of POPs in coastal Antarctica. Studies on snow and ice, including pollutant concentration measurements and air-snow partition coefficients, further contribute to understanding pollutant transport mechanisms. High concentrations of PCBs and OPEs in snow are significant because, as snow melts and flushes into seawater, the seawater reflects the pollutants previously deposited by the snow.

The snowmelt-air fugacity ratio can theoretically be described as the product of the air-water partition coefficient and the snow-air washout ratio. By measuring pollutant concentrations in seawater and comparing them to the air-seawater fugacity ratio, a correlation is observed between the theoretical snow-air fugacity ratio and the measured sea-air fugacities of chemicals in coastal seawater. This indicates that snow plays a crucial role in driving the concentrations of POPs in coastal seawater. When analyzing this relationship across various chemicals, many semivolatile POPs show an amplification of approximately two orders of magnitude (10^2). For certain compounds, such as OPEs and volatile PFAS, the amplification can be much greater, ranging from 10^2 to as high as 10^6. This effect is especially pronounced for chemicals with higher volatility. This amplification also occurs with rain, which, like snow, acts as an amplifier, concentrating contaminants that can reach Antarctica. PFAS compounds, for example, are scavenged by snow from the atmosphere and associated with sea spray aerosols, which can transport these chemicals over long distances to Antarctica.

The investigation of PFAS in Antarctica focused on its presence in three key areas: the atmosphere, the sea surface microlayer (the thin layer at the air-water interface), and at a depth of 1 meter below the surface. Enrichment factors for PFAS in the surface microlayer ranged between 2 and 4, while the enrichment factors in sea-spray aerosols were 2 to 4 orders of magnitude larger. This suggests a significant amplification of pollutant concentrations in sea-spary aerosols mediated by the the sea surface microlayer. Snow and rain can scavenge these sea-spray aerosols and associated pollutants.

Recent studies on OPEs, including pesticides, revealed significant enrichment of these chemicals in the surface microlayer. This transport mechanism applies not only to highly mobile "swimmer" contaminants but also to semi-volatile compounds. Multi-sampling efforts around Livingston Island and Deception Island showed high OPE concentrations in seawater and plankton, comparable to or even exceeding PAH concentrations and significantly higher than those of PFAS and legacy POPs

In addition to estimating atmospheric inputs and examining snow enrichment, rain was also analyzed, revealing similar patterns. Interestingly, the primary input mechanisms for some OPEs are compound-dependent. For certain chemicals, diffusive air exchange appears to be the dominant input pathway, as indicated by the fugacity ratio between air and water, while for others, snowmelt is the primary source, as shown by the ratios between snow and water. These findings highlight that both snow and rain play significant roles in transporting semi-volatile compounds, but also influencing the behavior of various chemical groups, including "swimmers," and "flyers," such as PFAS.

Traditional classifications of contaminants as swimmers, flyers, or hoppers should be reconsidered. All persistent contaminants effectively act as hoppers. If a contaminant remains in the environment long enough, it can reach remote regions, like Antarctica, via various transport mechanisms, including grasshoping due to successive volatilization and adsorption, but also by wet deposition of atmospheric pollutants. These complex pathways demonstrate how pollutants are transported globally.

In Antarctica, two primary processes influence the fate of contaminants: biodegradation and the biological pump. Biodegradation is slow due to the region's low temperatures, while the biological pump is significant because Antarctic waters exhibit high biological productivity. Evidence of limited biodegradation is seen in time-series data for OPEs, normalized by PCB concentrations, which helps isolate the impact of the biological pump. These findings support previous studies on the microbial degradation of OPEs. The biological pump is particularly critical for OPEs, as they are ubiquitous in plankton and phytoplankton, reaching concentrations in the hundreds of nanograms per gram.

Overall, cryosphere-related transport and deposition, especially through snow and rain, play a crucial role in contaminant accumulation in Antarctica, amplifying pollutant concentrations. This effect is more pronounced in areas such as the Southern Shetland islands and Antarctic peninsula, where precipitation is more frequent. Ultimately, persistent enough chemicals, regardless of volatility, can eventually reach Antarctica, where the biological pump and microbial communities influence their fate after reaching Antarctic ecosystems.

Monitoring persistent organic pollutants at the Fildes Peninsula on King George Island in the Antarctic

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Due to the characteristics of persistence, toxicity, bioaccumulation, and long-range transport (LRT), POPs have attracted worldwide attention in recent years. Although the poles are recognized as pure and isolated regions, they are not immune to pollutant invasion through atmospheric/ocean transport, melting glaciers, animal migration, human activities, etc. To date, Chemicals of Emerging Concerns (CECs), including POPs, are proliferating. However, the environmental behaviors and healthy effects of POPs are not well understood, so it is necessary to conduct in-depth research on legacy and emerging POPs, especially in remote polar regions.

Our work is based on Chinese Antarctic scientific research expeditions over the years, with samples collected around the Chinese Great Wall Station in Fildes Peninsula, King George Island. Efforts were carried out on the long-term monitoring of POPs in the atmosphere, exploration of pollutant distribution and bioaccumulation in the terrestrial environments, and assessment of trophic transport in marine food webs. The target pollutants include legacy POPs like PCBs, OCPs, and PBDEs, as well as emerging POPs like PCNs, NBFRs, OPEs, etc. In general, POPs in the Antarctic environments remained at the lowest level in the world. Long-term monitoring of the atmosphere showed that POPs were on a downward trend over the range of 2010-2020, indicating the effectiveness of POPs restrictions by the SC. In the terrestrial environments, concentrations of POPs in natural soil, dung, moss, and lichen were analyzed, and bioaccumulation behaviors were observed from soil to vegetation. Results of the source identification showed that POPs in the Antarctic originated mainly from LRT, and local activities also had an impact. In marine food webs, differences existed in the trophic transport of various POPs, which were related to the physicochemical properties of pollutants. A significant positive correlation was found between the trophic magnification factors (TMFs) and the log K_{OW} of POPs, indicating that congeners with higher lipophilicity preferred to accumulate along the food webs.

In summary, we work on the occurrence and environmental behaviors of POPs in the Antarctic environments to provide a comprehensive understanding on a global scale. In future research, the following perspectives may play a key role: (1) long-term monitoring is required for POPs research in polar regions; (2) CECs should be given more attention to determine their environmental behaviors; and (3) international collaboration and more state-of-the-art techniques should be encouraged to promote the research.

Summary

Long-range transport of POPs is a primary pathway through which these chemicals reach the polar regions, although other routes also contribute. Recently, attention has increasingly shifted toward emerging contaminants—novel pollutants gaining recognition in the scientific community. In China, national policies now support more extensive research into these emerging chemicals. There is particular interest in identifying these pollutants, assessing their potential for long-range transport, and understanding their environmental impacts, particularly in polar regions.

China operates five Antarctic research stations, with the Great Wall Station being the first and offering the best research conditions. Since 2009, research at this station has been ongoing, with sampling conducted nearly every year. However, due to logistical constraints, sample analysis is carried out back in Beijing, where the institute is equipped with a state-of-the-art laboratory featuring high-resolution mass spectrometers, enabling precise detection of pollutants. The Great Wall Station, with its laboratory and power plant, is strategically positioned despite its limited area, surrounded largely by glaciers. Air samples are collected using both large-volume and passive sampling methods, in addition to various other environmental samples such as sediments, plants, and animals.

Sampling at the research station presents significant challenges due to harsh environmental conditions. Initially, samplers were placed outside, but this proved impractical for year-round operation. As a result, samplers were moved indoors to ensure continuous function. Given the low concentrations of POPs in the air, samples need to be collected over a full week (7 days) to gather sufficient data. Each sampling session captures approximately 2,000 cubic meters of air, and after each session, the samplers must rest for a week to maintain efficiency. Consequently, around 50 samples are collected annually. Due to logistical constraints, high-volume samplers are limited to accessible regions, while passive samplers are used in more remote areas. Plant samples are scarce and difficult to obtain, but a range of bulk samples, including crabs, shrimp, fish, and penguins, have been successfully collected. These samples are crucial for studying bioaccumulation and biomagnification in the local ecosystem.

Long-term monitoring, which spans nearly a decade, has revealed several key trends in pollutant concentrations. For POPs like PCBs and OCPs, there is a slight decrease in their levels over time. However, PBDEs exhibit fluctuating concentrations, suggesting the influence of local sources, as these compounds are commonly used as flame retardants. These pollutants can be detected at picogram-per-cubic-meter levels in the environment, including in soil and other matrices.

Interestingly, plant samples contain higher concentrations of these chemicals compared to soil samples. Elevated levels of PCBs and PBDEs are also found in penguin droppings and soil with amendments, highlighting the significant role of animal waste as a source of contaminants in the area. Notably, bioaccumulation of PCBs is observed in the marine food web, with a trophic magnification factor (TMF) of 2.4, although this trend does not apply to all OCPs. Some OCPs, such as HCB and HCH, show a dilution effect.

Emerging pollutants like polychlorinated naphthalenes (PCNs) are also being monitored. Their concentrations remain relatively high but show a decreasing trend, with minimal biomagnification observed in the food web. Novel brominated flame retardants (BFRs), such as DBDPE, are rapidly accumulating in both marine and terrestrial environments, signalling the growing environmental impact of these substances.

Trophic transfer studies show a slight decrease in the concentration of certain compounds, indicating a potential dilution effect. For OPEs, concentrations are significantly higher than those of novel flame retardants, with OPE levels being approximately 100 times greater. Previous findings by Jordi also identified OPEs as the dominant flame retardants in this environment. The most abundant bound residues are TEP and TICCP, but overall, there is a decreasing trend, which could indicate a positive development.

Antarctica serves as an ideal location for detecting a wide range of pollutants, including emerging contaminants, making it particularly valuable for bioaccumulation and biomagnification research. While concentrations of legacy pollutants show a decreasing trend, the presence of emerging contaminants continues to rise. Given the ongoing environmental changes, long-term studies are crucial, as a decade of research is insufficient to fully comprehend these trends. Expanding collaborations and utilizing innovative techniques, such as source tracing, will be essential for advancing understanding in this area.

The role of environmental specimen banks in monitoring environmental contamination

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Summary

The term "Today and Tomorrow" captures the dual purpose of the Environmental Specimen Bank. It serves as a retrospective tool, enabling analyses of past environmental conditions to better understand the development and evolution of environmental trends. Simultaneously, it is forward-looking, designed to address critical environmental research questions of the future, guiding scientific efforts and policies toward sustainable solutions.

This initiative is inherently multigenerational, as the specimens collected today will serve as valuable resources for future generations to study environmental conditions and track changes over time. These samples will act as historical archives, offering insights into past developments whenever questions arise about the state of the environment. Current environmental research benefits from extensive data gathered through various regulations, legislation, programs, and short-term projects, particularly in industrial regions where the focus is on understanding the impact of environmental stressors on biodiversity.

The workshop also highlights the need to expand research into the polar regions, especially the Arctic, where significant progress has been made through collaborations with Europe and the United States. In contrast, Antarctica remains relatively underexplored. Despite limited data, global challenges persist, such as the triple planetary crises of climate change, pollution, and biodiversity loss. To address these interconnected issues effectively, it is essential to integrate data from diverse stressors, phenomena, and regions to build a comprehensive, global understanding of ongoing planetary changes.

Environmental specimen banks are essential for providing data, methods, and tools for analyzing historical samples, allowing for the assessment of trends in environmental stressors and their impacts over time. These banks are integral to national monitoring programs, supporting both short- and long-term environmental assessments within systematic, quality-assured frameworks. In Sweden, for example, the Swedish Environmental Specimen Bank plays a crucial role in national monitoring by supplying reliable data. Specimen banks also help evaluate the effectiveness of environmental

policies and regulations, providing answers to critical questions, such as whether bans on harmful compounds or their replacements have improved environmental conditions.

Over the past 50 years, advancements in analytical chemistry and chemo-informatics have enhanced the ability to analyze historical samples, offering new insights. Specimen banks also prepare for unforeseen environmental issues, acting as a resource to understand their origins and progression. However, gaps remain in regions like South America, Africa, and parts of Antarctica. The Italian Environmental Specimen Bank, operating since 1994, serves as an important example of Antarctic contributions to global environmental research.

Chemical repositories and specimen banks are increasingly specialized and widespread across the globe. In Europe, Germany, Scandinavia, France and the UK have a history of specimen banking for the last decades. Notable initiatives in North America include the ESB at the National Institute of Standards and Technology (NIST) in Charleston together with the wildlife specimen bank and the Great Lakes Bank in Canada, In Asia, there are efforts in Australia, as well as in China, Republic of South Korea, and Japan, which hosts one of the world's oldest specimen banks. While preparing for discussions on specimen banking, I reviewed historical documents from the 1970s that address both the challenges and the requirements of establishing systematic specimen banks. These documents pose important questions still relevant today:

- Pollutant Monitoring: What types of pollutants should be prioritized for monitoring, and which species and specimens are best suited for this purpose?
- Storage Conditions: What are the optimal storage temperatures and conditions to preserve samples effectively?
- Protocol Harmonization: How can protocols between different specimen banks be harmonized to enable comprehensive, systematic comparisons of pollutants across regions?
- Collaboration Frameworks: What structures can foster greater cooperation and knowledge-sharing among banks?
- Utilizing Existing Expertise: How can we leverage the experience and insights of existing banks to inform new initiatives?
- Pilot Banks: What should pilot specimen banks look like, and how can we establish them successfully?

These questions remain highly relevant and align closely with the themes we are discussing today. By revisiting these foundational considerations, we can gain valuable insights into the evolution of specimen banking practices, especially regarding chemical management.

Significant progress has been made since the establishment of the first specimen banks, adapting to emerging challenges and evolving needs. This historical perspective informs current strategies for expanding and improving global specimen banking systems. A major issue in environmental science is the insufficient monitoring data, essential for developing early warning systems, a key aspect of Europe's "one substance, one assessment" strategy. As chemical management faces increased scrutiny from policymakers and the public, temporal trends in environmental data offer critical insights. Growing interest in weight-of-evidence approaches focuses on persistence, bioaccumulation, and mobility of chemicals, such as legacy POPs.

Discussions with experts, including those from the European Chemicals Agency (ECHA) in Helsinki, highlight the critical need for data from underrepresented regions like the polar areas. Monitoring in these regions is essential as persistent substances inevitably reach remote locations such as Antarctica over time. As emphasized earlier, persistence plays a key role in determining which compounds should be monitored in polar regions. Environmental monitoring programs, such as the Water Framework Directive, are increasingly focusing on emerging contaminants, including pharmaceuticals, pesticides, and biocidal products. These pollutants are also becoming increasingly relevant for monitoring in extreme environments like Antarctica. The primary objective is to develop non-toxic environment strategies while addressing the growing complexity of chemical mixtures and their impact on ecosystems and human health. Although legacy pollutants, including chlorinated, brominated, and fluorinated compounds, remain a priority, effective monitoring and regulation of contaminants of emerging concern (CECs) are essential to mitigate their long-term environmental and public health risks.

High-resolution mass spectrometry (HRMS) and non-target screening are crucial for environmental monitoring of mixtures. MPs, along with additives like phenol-benzotriazoles are now recognized under the Stockholm Convention for their role in long-range transport, complicating risk assessment and monitoring due to their ability to carry harmful substances.

Molecular analysis, particularly DNA and RNA-based methods, is emerging as a transformative tool in environmental monitoring and research. Unlike traditional chemical analyses, these techniques focus on genetic material, enabling the identification of taxa and biological communities through environmental DNA (eDNA) or RNA. Techniques such as DNA metabarcoding, which involves extracting and amplifying genetic material using tools like polymerase chain reaction (PCR), allow for the identification of species and communities from environmental samples. This approach, which compares genetic sequences to reference databases, enhances biodiversity monitoring, complementing chemical analyses and offering new possibilities for studying ecosystems, including in remote regions like Antarctica.

Environmental specimen banks are an essential tool for environmental monitoring, offering a diverse range of samples, including mussels, leaves, earthworms, and fish, for studies such as population genetics. Recent integration of transcriptomics into these analyses enhances the ability to monitor biodiversity and chemical data using the same samples and funding, improving resource efficiency. For instance, a suspended particulate matter sample from German rivers revealed over 200 vertebrate species, including fish, terrestrial vertebrates and birds. This highly sensitive method also identified around 850 aquatic and invertebrate taxa. Ongoing efforts are expanding to include microorganisms and fungi, improving taxonomic resolution and enabling temporal biodiversity tracking, all at a cost-effective price. The establishment of a sampling and analysis strategy for an Antarctic ESB should be aligned with recent developments in environmental chemistry and genetic analysis to allow for integrated monitoring and assessment approaches.

Specimen banking holds great potential for environmental research, with a focus on Antarctic specimens in the future. Researchers involved in specimen banking are encouraged to connect with the ESB network, part of the International ESB group, for collaboration and knowledge-sharing on various initiatives and projects. Started collecting and archiving samples from the Antarctic now will give us and future generations the material.

The Italian Antarctic Environmental Specimen Bank

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The Italian Antarctic Environmental Specimen Bank (BCAA) is placed at the Department of Chemistry and Industrial Chemistry of the University of Genoa, and it is operating since 1994 under the Italian Antarctic Research Program (PNRA). The BCAA is also associated to the Italian Antarctic National Museum since 2006, and it is part of the International Specimen Bank group. The main objectives of BCAA are: (i) retrospective control of the obtained analytical data in the context of the PNRA research projects; (ii) retrospective monitoring of the chemical contamination in Antarctica, including new parameters which have not been studied at the time of collection; (iii) supply and exchange of specimens, overcoming practical problems due to the sampling in remote areas; (iv) chemical characterization of collected samples, providing background levels of contaminants and their natural variability.

At present the total number of samples managed by the BCAA exceeds three thousand, including specimens from atmospheric, marine and terrestrial ecosystems. Several Antarctic reference materials (marine sediment and organisms) certified for trace elements are also available. In general, the biotic matrices are stored at –80°C in seven ULT freezers of 550 L each, and the abiotic matrices are kept at –25°C in two cold rooms of 20 m^3 each. The BCAA facilities also include a temperature monitoring system, a public database of stored samples, and laboratories for sub-sampling, sample treatment, and instrumental analysis of trace elements and organic pollutants.

In the past 30 years, the BCAA have 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. Representative examples of these studies include the biomonitoring of trace elements and POPs in coastal waters, the investigation of the natural occurrence of arsenic compounds in the marine food chain, the detection of flame retardants and MPs in fish.

Future trends of BCAA activities regard the prosecution of historic sequences of samples (mainly the scallop *Adamussium colbecki* and the benthic fish *Trematomus bernacchii*), the investigation of biogeochemical cycles of contaminants using isotopes, the implementation of “natural” archives such as ice and firn cores, and the strengthening of international cooperation towards a structured sample and data collection of chemical contamination across Antarctica.

Summary

The Italian Antarctic Environmental Specimen Bank operates under the Italian National Program of Research in Antarctica, which began in 1985. Established in 1994, the bank made significant strides with its partnership with the Italian National Antarctic Museum, enhancing financial stability and visibility, especially regarding its biological collections. In 2002, the bank joined the International Group of Environmental Specimen Banks, expanding its global network. This collaboration has fostered international partnerships, including agreements with institutions in South Korea, and facilitated involvement in various joint projects. For more detailed information, including the bank's sample database, please visit our website (https://bcaa.unige.it/en), where you can learn more.

The bank operates through three key infrastructures:

- **Mario Zucchelli Station:** Located on the Antarctic coast, this seasonal station operates from approximately October to February each year.
- **Dome C Station:** Situated inland on the Antarctic Plateau, this station is managed in collaboration with France. Dome C is unique as it is the only base in Antarctica co-managed by two nations. It operates year-round, with personnel continuing activities even during the harsh winter months.
- **Offshore Sample Collection:** In addition to Antarctic operations, some samples—particularly in earlier years—were collected in the Ross Sea using research vessels. Previously, the ship *Italica* was used for this purpose, whereas the ship *Laura Bassi* is currently operating.

These infrastructures support the bank's mission of collecting, preserving, and studying environmental specimens, enabling significant contributions to Antarctic research and global collaborations.

In Italy, the Antarctic Environmental Specimen Bank is housed within the Department of Chemistry and Industrial Chemistry at the University of Genoa. While our facilities are relatively small compared to other environmental specimen banks, they are well-equipped to meet our needs. We maintain two cold rooms for storing samples at -25°C, alongside seven ultra-low temperature freezers set at -80°C. Our storage protocol separates abiotic matrices, which are kept in the cold rooms, from biotic matrices, which are preserved in the freezers. To ensure optimal sample preservation, we have a temperature monitoring system that continuously verifies the conditions inside each freezer. In the event of a failure, the system is designed to send immediate alarm notifications. Additionally, we maintain a publicly accessible sample database. This database provides comprehensive information about available samples, sampling procedures, and related data, ensuring transparency and facilitating collaboration with the broader research community.

The environmental specimen bank operates within a larger analytical chemistry group, providing access to comprehensive laboratory facilities for sample preparation and instrumental analysis. Over nearly 30 years, it has collected more than 3,000 samples across various environmental compartments, focusing on the marine environment but also including lake, terrestrial, and atmospheric samples. Certified reference materials for Antarctic matrices, such as marine sediment, scallops, and krill, have been developed through research in the region. These materials, certified for heavy metals, could eventually support the certification of other organic pollutants and are available to the broader scientific community.

The bank's objectives align with those of other specimen banks but also include unique goals. These include retrospective validation of data and the re-evaluation of past research with advanced analytical methods. The bank also enables retrospective monitoring of chemical contamination, allowing researchers to explore new parameters and detect previously overlooked chemicals. Given the challenges and high costs of sample collection in Antarctica, the preserved specimens offer a valuable resource, enabling research without the need for return expeditions. Additionally, the bank supports biomonitoring programs by providing baseline data essential for interpreting findings in other environmental research projects.

Here are a few examples of past research based on samples collected from our bank:

- **Arsenic Compounds in Marine Organisms:** In previous studies, we investigated arsenic compounds in marine organisms. While arsenic is often associated with toxicity, many of its compounds are non-toxic or less toxic than inorganic arsenic. Therefore, it's crucial to distinguish between these different chemical forms. Using samples stored in our bank, we studied the occurrence, transport, and transformation of these chemicals in the marine environment. Biota, as Elena mentioned earlier, act as reactors, continuously transforming these compounds, making it fascinating to explore how this process occurs.
- **Flame Retardants in Fish:** In collaboration with Jan and his team, we studied the presence of flame retardants in fish. Our samples served as a baseline reference to help interpret results from environmental studies conducted in Germany.
- **Microplastics in Fish:** The CNR (National Research Council of Italy) conducted an analysis of MPs in fish collected in the late 1990s, a time when microplastic pollution had not yet been recognized as a significant issue. Their findings revealed that MPs were already present in these fish, likely due to the local impact of the Italian station.
- **Retrospective Monitoring of POPs in Mussels:** Another important example involves the retrospective biomonitoring of POPs in the mussel *Adamussium Colbecki*, a key organism

used for monitoring chemical contamination near the station. Nicola was involved in this research, which utilized advanced analytical techniques to analyze historical samples.

These examples highlight the diverse applications of our specimen bank for investigating environmental contamination and chemical transformations over time.

In conclusion, the bank is actively engaged in the global network of environmental specimen banks. Recent visits have strengthened these connections, formalized through a memorandum of understanding. The collaboration between South Korea and Italy is particularly valuable due to the geographical proximity of their research stations, allowing for the study of similar environments. This international cooperation plays a vital role in advancing shared environmental research goals.

Looking ahead, future plans focus on several key areas. The historical sample collection will continue to expand, alongside extensive research into the biogeography and cycles of contaminants, using isotopes of heavy metals such as mercury, cadmium, and lead. Additionally, natural archives like snow and ice will be integrated into the research to study past environmental conditions through these matrices. Furthermore, ongoing participation in international programs will remain a priority, contributing to a comprehensive approach to investigating chemical contamination in Antarctica. These initiatives aim to enhance understanding of environmental changes and support global environmental science efforts.

Current Status of Antarctic Sample Collection and Proposed Methods for Biological Sample Processing at NESB, South Korea

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Our project, which started in 2022, aims to store and utilize samples over the long-term to monitor environmental pollution in Antarctica. The collection of Antarctic samples has been led by the Korea Polar Research Institute, using the King Sejong Station and Jang Bogo Station as bases. The samples have been stored at the National Environmental Specimen Bank at temperatures ranging from -80 to -150 ℃. A total of 164 samples, including lichen, moss, limpet, penguin feathers as well as seawater, marine sediment, sewage filter (POCIS: Polar Organic Chemical Integrative Sampler) samples and etc., have been collected since the 2022-2023 season from King Sejong Station, and a total of 70 samples, including starfish, scallop, penguin eggs as well as seawater, sediment, sewage filter (POCIS) samples and etc., have been collected since the 2017-2018 season from Jang Bogo Station are being stored.

Among these samples, lichen, moss, penguin samples (feathers and eggshells) are relatively easy to collect as a bio-indicator. Lichen and moss are known to be useful as samples for air pollution monitoring. However, depending on the purpose of use, a cleaning process is required before using them as analytical samples. In this study, procedures such as washing were established and applied to the lichens and mosses for PBDEs analysis. The BDE-209 concentrations in the washed samples were 71~92 % lower compared to the unwashed samples. Additionally, the sample standard error decreased in the washed samples, indicating increased homogeneity among the samples. Also, we established a washing procedure of feather samples using distilled water, acetone, and HNO3 solutions for organic and inorganic substances analyses, while of eggshell samples using distilled water and acetone solution for inorganic substance analysis. Given that these types of samples are used for chemical monitoring as common sample types across different Antarctic locations, the establishment of standardized processing procedures will be essential, and the results of this study are expected to provide valuable reference for that purpose.

Summary

South Korea operates two Antarctic research stations: King Sejong Station and Jang Bogo Station. King Sejong Station, established in 1988 on King George Island, monitors Antarctic Specially Protected Area (ASPA) 171. Meanwhile, Jang Bogo Station, located on the Ross Ice Shelf and established in 2014, oversees ASPA 178. Both stations are managed by the Korea Polar Research Institute.

In addition to these research stations, South Korea operates the National Environmental Specimen Bank, established in 2009, to monitor environmental pollution. This facility is capable of storing over 400,000 samples at temperatures below -150°C.

Since the 2022–2023 research season, various environmental samples, including lichen, moss, limpets, and penguin feathers, as well as seawater, marine sediment, and sewage filter samples (POCIS: Polar Organic Chemical Integrative Sampler), have been collected from King Sejong Station and stored for chemical analysis. Similarly, since the 2017–2018 season, samples such as starfish, scallops, penguin eggs, seawater, sediment, and sewage filter samples have been collected from Jang Bogo Station and preserved for research.

As part of our environmental pollution monitoring efforts in Antarctica, we have focused on biological sample types that are readily available in large quantities. For instance, lichen, mosses, bird feathers, and eggshells are relatively easy to collect and serve as valuable bioindicators. Specifically, lichen and mosses are particularly effective for monitoring air pollution, as they can detect contaminants such as mercury, heavy metals, and other toxic substances. Furthermore, juvenile penguin feathers can provide indirect insight into pollutant levels in their prey at breeding sites, while eggshells can indicate contamination within the mother's body. The inner membrane of the eggshell tends to accumulate higher levels of mercury, whereas the outer membrane and shell are useful for analyzing inorganic substances. Thus, these biological indicators are crucial for understanding pollutant dynamics in Antarctic ecosystems.

When it comes to air pollution monitoring, lichen and moss samples are highly useful. However, depending on their intended application, they may require a cleaning process before chemical analysis. Specifically, untreated samples may reflect both internal accumulation and short-term surface adsorption of contaminants, whereas cleaned samples primarily reflect long-term internal accumulation. By comparing both untreated and cleaned samples, it becomes possible to distinguish between these sources of contamination.

To explore this issue further, we conducted a review of twenty recent research papers on cleaning methods for Antarctic lichens and mosses. Our findings revealed that most studies focused on manual

removal of foreign materials or shaking the samples. Notably, three studies mentioned the use of purified water, but they lacked detailed procedures. To address this gap, we developed standardized washing protocols for chemical pollutant analysis. Additionally, four research papers from other continents provided more detailed cleaning methodologies. Building upon these insights, we established a cleaning procedure in which 2–3 g of lichen or moss samples were washed with 250 mL of purified water for 30 seconds, repeated four times, to ensure effective pollutant removal.

Our study results demonstrated significant differences between washed and unwashed samples, particularly regarding BDE 209 concentrations. In the lichen and moss samples, the washed samples showed 71% and 92 % lower BDE-209 concentrations, respectively, compared to the unwashed samples. Moreover, washed samples exhibited lower variability, as evidenced by a reduced relative standard deviation (RSD). For example, the RSDs for the washed lichen and moss samples decreased to 5% and 0.2%, respectively, indicating improved sample homogeneity. These findings underscore the importance of washing protocols in minimizing contamination variability and enhancing the consistency of pollutant analysis.

In addition to lichen and moss, we implemented a standardized washing protocol for juvenile penguin feathers to assess pollutant accumulation more accurately.

- Feather samples were shaken in distilled water for five minutes.
- The samples were then shaken in an acetone solution for another five minutes.
- Finally, they were shaken in a nitric acid solution for five minutes.
- This sequence was repeated three times.

Following the washing process, the feathers were dried and cut into smaller pieces for analysis. Our research focused on total mercury concentrations in the back feathers of juvenile chinstrap penguins. Interestingly, washed feathers exhibited higher mercury concentrations than unwashed ones. This discrepancy is likely due to the fact that unwashed feathers contained foreign materials such as soil, dust, and feces, which could dilute mercury concentrations and introduce variability.

To further examine these differences, feathers from five chinstrap penguins were divided into two groups: washed and unwashed. The variance in mercury concentrations, as indicated by standard error bars, was significantly reduced in the washed samples. More specifically, the relative standard deviation (RSD) for unwashed samples ranged from 9% to 90%, whereas it decreased to 1% to 3% for washed samples. This reduction in variability highlights that washing improves sample homogeneity, thereby ensuring more reliable pollutant analysis.

In addition to feather samples, a standardized washing process was also developed for eggs. Initially, surface debris was brushed off, and the contents were separated from the shells. Following this, the inner membrane, outer membrane, and outermost shell were cleaned using ultrasonic waves in purified water, with additional acetone washing treatments applied to the outer membrane and shell. Looking ahead, chemical analysis of these samples is scheduled for the near future.

This long-term project, launched in 2022, is expected to conclude in 2030, providing crucial insights into Antarctic environmental pollution and contributing to efforts aimed at protecting the Antarctic ecosystem.

Contaminants in Antarctica; Building a Framework for Policy Advice

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Global chemical production and usage far outweighs the capacity of current regulatory frameworks to effectively assess and manage safe chemical usage in a timely manner. For example, for adoption of a chemical under the Stockholm Convention for POPs, the criteria of both persistence and mobility are frequently assessed via theoretical modelling approaches; however, without accompanying environmental occurrence data, theorical predictions have substantial uncertainty. Evidence of chemical occurrence at Polar latitudes directly serves regulatory needs by reducing or removing such uncertainty, potentially supporting smoother, and expedited, adoption of new proposals. It is therefore important to ensure quality-assured chemical data is collated from both polar regions and communicated to policy makers.

The Antarctic Monitoring and Assessment Programme (AnMAP) was established to model the effectiveness of the Arctic Monitoring and Assessment Programme (AMAP) in ensuring sufficient and reliable chemical data from the Arctic, but rather from the Antarctic region. In order to facilitate continuous and quality assured chemical data from Antarctica, AnMAP advocates for inclusion of Antarctica into the Global Monitoring Plan (GMP) through systematic chemical measurements in air and seawater, as well as a standardised marine megafauna species (e.g. through the Convention for the Conservation of Antarctic Marine Living Resources Environmental Monitoring Program (CEMP), or the Humpback Whale Sentinel Program (HWSP)). Additionally, inclusion of the nearshore, ubiquitous, Antarctic amphipod, *Orchomenella franklini*, is recommended to evaluate local impacts. Finally, AnMAP advocates for communication between National Antarctic Programs (NAPs) and national environmental agencies with the view of extending existing national chemical monitoring programs of consultative parties, to their Antarctic operation.

Summary

The Antarctic Monitoring and Assessment Program (AnMAP) was a founding objective of the SCAR ImPACT action group since its establishment in 2017. This initiative is a collaborative effort among various organizations, aimed at providing reliable chemical data from Antarctica to support global chemical policy. The need for such data arises from the growing dependence on chemicals worldwide, which has led to an exponential increase in their use. This surge in chemical usage has put immense pressure on global chemical policies, which struggle to regulate the vast number of chemicals in circulation. The United Nations has recognized a triple crisis involving chemical pollution, biodiversity loss, and climate change, making the timing of AnMAP's work more critical than ever.

Polar regions are important in this context as both indicators and facilitators for chemical regulation. The Stockholm Convention, which classifies chemicals based on their persistence, bioaccumulation potential, and toxicity, underscores the importance of detecting these substances in polar regions, where they have not been used. Such detections provide strong evidence of their persistence and mobility, helping to expedite regulatory actions. While often viewed as remote and untouched, polar regions are not immune to chemical contamination, highlighting their global interconnectedness and the urgency of monitoring efforts.

AMAP has been engaging in environmental monitoring for over 30 years, aiming to support international efforts and moderate global threats from contaminants and climate change. AMAP's proactive approach emphasizes standardizing monitoring practices and effective knowledge dissemination. Building on AMAP’s success, AnMAP was officially established in 2023 as a joint initiative under SCAR in partnership with AMAP, UNESCO, and Griffith University. AnMAP’s strategic goals align with those of AMAP, aiming to establish sustained monitoring activities, extend national monitoring obligations to include Antarctica, and support global chemical policy initiatives. AnMAP also focuses on filling critical research gaps in understanding chemical pollution in Antarctica, some of which are more comprehensively studied in the Arctic. The program’s research priorities are guided by the 2021 Horizon Scan conducted by the ImPACT Action Group, which identified key focus areas for advancing knowledge in this field. These include:

- Identifying which chemicals are reaching Antarctica
- Understanding how chemicals behave in a changing Antarctic climate
- Assessing the impacts of chemical contaminants on Antarctic biodiversity
- Advancing circular surveillance and pollution monitoring

To maximize impact, it is recommended to prioritize achievable actions that align with the global monitoring plan (GMP) of the Stockholm Convention. This was highlighted in an information paper submitted to the ATCM in 2024. The proposal urges national and Antarctic programs, along with environmental agencies, to expand their monitoring efforts to include Antarctica. The GMP focuses on the core media of air, human breast milk, human hair, human blood, and seawater. Whilsthuman biomonitoring is not applicable in the Antarctic context, seawater and air should be incorporated. In terms of the biotic environment, several recommendations are made, firstly marine megafauna may be incorporated via e.g. The Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) ecosystem monitoring program (CEMP), or the Humpback Whale Sentinel Programme (HWSP) which already incorporates chemical pollution as an environmental tracer. Finally, inclusion of the nearshore, Antarctic amphipod, *Orchomenella franklini*, with a ubiquitous circum-Antarctic distribution is recommended for the assessment of local contamination.

AnMAP emphasizes the importance of sampling feasibility for securing continuous, standardized monitoring data, and biomonitoring species should be selected based on those that can provide reliable, standardized, and reproducible data for continuous, long-term monitoring. Whilst major expeditions typically have a specific study question in mind, and have the capacity to sample widely, these cannot realistically be repeated annually. By contrast, temporal trend collation requires access to the same sample types in a reliable manner, regardless of upheavals characteristic of polar research (funding, politics, weather, logistics, pandemics)

Once a robust monitoring program is established and generates valuable data, the next step is producing comprehensive assessments. These assessments are the ultimate outcome of monitoring efforts, offering highly informative insights, like those produced by AMAP. They serve as vital communication tools for a broad audience, including policymakers. A key aspect of these assessments is their stakeholder-driven nature, developed through continuous consultation with stakeholders is important. This dialogue ensures that the research addresses stakeholder needs, not just scientific priorities. The goal is to shorten the gap between scientific knowledge generation and its application in policy or practice, with stakeholder engagement being essential. Once an assessment topic is identified and approved, experts lead the development, aiming to produce credible, stakeholder-informed assessments trusted by both scientists and decision-makers.

Today, we are fortunate to have our executive board supporting us, comprising representatives from four partner organizations, as well as an advisory board. We're grateful for the guidance and support of these experts, who bring valuable insights not only from a scientific perspective but also from a policy standpoint. It's an exceptional group of professionals, and we deeply appreciate their contributions.

In summary, while chemical monitoring and environmental chemistry research in Antarctica are not unique, there is an increasing demand for enhanced monitoring within the Antarctic science community. This presents both a strength and an opportunity. The goal is to collaborate across disciplines and create an integrated monitoring network with multiple purposes. This network could incorporate chemical monitoring into broader initiatives such as the Southern Ocean Observing System(SOOS), and align efforts with organizations such as CCAMLR. The upcoming IPY represents an opportunity to establish lasting monitoring frameworks , such as permanent atmospheric stations, similar to the atmospheric observing system established in the previous IPY.

Practical steps towards a Structured Sample and Data collection of Environmental Contamination in Antarctica

Anette Küster

German Environment Agency

Antarctica is impacted by global issues such as climate change and long-range transport of chemical contaminants and pollutants. Furthermore, expanding tourism and research activities (including logistical activities serving their conduct or preparation) can affect the pristine environment. To date, there has been a lack of systematic approaches for gathering data to study and assess chemical pollution of the Antarctic environment and to derive knowledge-based measures for its protection. An international network that brings together all relevant actors and stakeholders is necessary to develop a more structured sampling and data collection on chemical contamination in the Antarctic. It is expected that systematic and efficient sampling and data collection will improve the effective use of scientific information to enhance decision-making and, consequently, the future conservation of the Antarctic environment and its dependent and associated ecosystems.

The German Environment Agency has therefore implemented a series of activities such as collaborative projects, workshops, publications, in order to promote and coordinate a more structured sample and data collection of environmental contamination in the Antarctic. National and international partners have been identified and contacted for an improved coordination of next steps. This network sees greater cooperation with and between the ESBs of Antarctic Treaty Parties, SCARs ImPACT Action Group, AnMAP, NAPs and Environmental Agencies as an opportunity to initiate a more structured sample and data collection of environmental contamination in the Antarctic. As next steps, long-term initiatives such as the ongoing InSync program should be used to i) expand geographic coverage of chemical contamination data for Antarctica, ii) ensure the continuity of long-term data on contaminants in Antarctica, iii) assess the long-term effects of persistent contaminants on the organisms and food webs and to predict future trends, iv) establish harmonised protocols and QA/QC (Quality Assurance/Quality Control) procedures for sampling, archiving, chemical analysis, sample and data storage and treatment, v) guarantee the quality of the analytical data, including intercalibration exercises and production/use of certified reference materials, vi) investigate contaminants of emerging concern (CEC), with particular attention to organic compounds as there is little environmental exposure data for these compounds to date and to vii) overcome the practical challenges of sampling in extreme environments and ensure that sufficient samples from the different available ecosystem types allow next-generation scientists to perform retrospective analyses and monitoring of the chemical contamination in Antarctica, considering chemicals which could emerge in the future.

Summary

The German Environment Agency (UBA) serves as the central environmental authority under the Federal Ministry for the Environment. Its responsibilities include providing advice to the federal government, conducting environmental monitoring and assessments, supervising research projects such as the POLEMP Project, and preparing national and international reports. UBA also enforces environmental laws and regulations, particularly in the context of implementing European and international legislation at the national level. Additionally, the agency focuses on informing the public and promoting environmental protection and nature conservation through various initiatives.

This framework establishes the context for UBA's work at the intersections of environmental policy and monitoring, particularly in the Antarctic. Germany has been an Antarctic Treaty Consultative Party since 1979, and UBA is tasked with developing Antarctic environmental protection goals in line with national legislation. The agency monitors environmental conditions in the Antarctic and participates in discussions and preparations within the Antarctic Treaty Consultative Meetings (ATCM). UBA has actively contributed to ongoing discussions in the Committee for Environmental Protection (CEP). Within the CEP 5-year work plan, the long-range and local chemical pollution in Antarctica has been classified as a top priority; a decision reaffirmed during last year´s ATCM. The general process for the annual meetings starts with the submission of information and working papers for discussion within the Committee for Environmental Protection (CEP). During the ATC Meeting, the results of the CEP discussions will be reported and forwarded to the ATCM committee. The ATCM subsequently issues decisions, resolutions, or measures, which are communicated to national parties and ministries for implementation.

UBA reviews and assesses existing environmental and chemical substance regulations, such as those established under the Stockholm Convention and the Minamata Convention on Mercury. Colleagues at UBA contribute data to the global monitoring plan and are involved in promoting and establishing methods for international chemical management. This collaborative effort involves team members actively submitting data and participating in regulatory processes that inform these decisions.

At UBA the topic of chemical pollution in Antarctica was addressed some years ago, when the issue of reemission of regulated substances by melting ice masses gained attention. A growing number of publications highlighted the topic, prompting UBA to engage with the National Antarctic

Programme leader, the Alfred-Wegener- Institute. Together with the German Environmental Specimen Bank, discussions were held on establishing a more structured approach to sample and data collection at the national level. As a first step, a pilot project focusing on studying contaminants in eggs of the emperor penguin was initiated.

This initiative builds on the experience and standards established by environmental specimen banks and aims on developing a structured approach to monitoring chemical pollution in the Antarctic. From 2021 to 2023, together with colleagues from Helmholtz-Centre Hereon, two research projects were awarded and completed. Firstly, a comprehensive review of available data from polar regions, focusing on legacy and emerging organic contaminants in polar regions was conducted and publishes and and secondly, an international workshop on legacy and emerging contaminants in polar regions, was held and organised in 2022. As a result of this workshop, we the "Berlin Statement erlin statement on legacy and emerging contaminants in polar regions" was published. A significant milestone that expanded our network and advanced discussions on the critical issue of chemical pollution in polar regions. At the moment, UBA is involved in several projects on chemical pollution in the Antarctic. One of these is the POLEMP project. Other projects focus on initial steps towards an integrated chemical and biological pollution and impact assessment and the discharge of greywater and blackwater from ships into the polar marine environment.

On the international level, Antarctica InSync is a global effort to synchronize research across Antarctica and the Southern Ocean. A national InSync workshop has already been hosted as part of the initiative. Topics related to chemical pollution and the fingerprint of human activities have been submitted under this initiative. Discussions have also focused on national networks within the InSync framework, with plans to engage international collaborators, including those involved in the POLEMP project. To strengthen these efforts, a dedicated working group involving both, national and international experts, is being considered. Those interested in contributing are encouraged to reach out to facilitate incorporation into the ongoing discussions. This initiative already involves a few partners, including colleagues from countries like Australia, South Korea, and Italy, among others. If there are any national workshops planned in the InSync partner countries, it would be beneficial to coordinate efforts and align on shared objectives. This coordination could be a practical next step toward implementing comprehensive chemical monitoring programs. Fieldwork, as highlighted during our national workshop, is central to advancing this initiative, and we look forward to fostering collaborations to achieve these goals.

In addition, a number of information papers and a working paper were submitted during the last year´s ATCM (Antarctic Treaty Consultative Meeting) sessions. These papers have received co-sponsorship and collaboration from several countries, including Australia, Italy, South Korea, Portugal, Sweden, the UK and the US. Their support is greatly appreciated and efforts are underway to engage additional partners. Submitting papers with the support of multiple parties increases their impact. The next ATCM will be held in Milan, Italy, from 27 June to 3 July 2025. The initial stages of planning a side-event in during this year´s ATCM are underway. As part of this initiative, a report on the outcomes and scope of this workshop will be considered for presentation. Suggestions and input from other Parties are welcome and contributions are encouraged.

Atmospheric monitoring of POPs at the Trollhaugen observatory

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Persistent organic pollutants (POPs) are a group of man-made chemicals often used as industrial chemicals, pesticides and flame retardants. POPs are of international concern due to their toxicity and potential to bioaccumulate. They are spread to all global regions due to their high persistence and long-range transport potential. The Stockholm Convention is a global treaty to protect human health and the environment from POPs, and national and regional monitoring networks provide data under the Global Monitoring Plan.

The atmosphere represents an important pathway for the long-range transport of POPs to remote areas. Polar regions are of particular interest because POPs can be transported by successive volatilisation and deposition steps from temperate regions towards cooler regions, where they tend to deposit. Despite the geographical isolation and limited local sources, both the Arctic and Antarctica are affected by POPs from populated/industrialised regions, in the northern and southern hemispheres, respectively. Hence, atmospheric monitoring of POPs in polar regions aims to improve the understanding of their long-range transport and assess temporal trends. For more than 20 years, numerous POPs have been monitored in air at the Zeppelin Observatory, located at Svalbard in the Arctic, and the Troll Observatory at Dronning Maud land in Antarctica. Air samples have been collected using a high-volume sampler and are analysed with accredited methods at NILU's laboratory. The data from Troll is reported to the international database EBAS with atmospheric measurement data and will in the future be provided to the newly established AnMAP.

The detection of many of the POPs in Antarctic air reflects their potential for long-range transport to the area. Declining time trends reflects the reduction in primary emissions due to regulations. By monitoring from pole-to-pole, a comparison of the long-term trends and effectiveness of regulatory actions between southern and northern hemispheres is enabled.

Summary

NILU focuses on identifying Persistent Organic Pollutants (POPs), which we have already discussed extensively. These pollutants are characterized by their slow degradation in the environment, their toxicity, and their potential to bioaccumulate in living organisms, leading to increased concentrations the higher up in food chains. Some of these compounds also possess properties that allow them to volatilize in temperate regions and the atmosphere is one of their main routes of transportation. Via air masses they can be transported over long distances and deposit in cooler regions. For this reason, POPs may be present in remote areas, such as the Antarctic. These characteristics have resulted in the implementation of international regulations to restrict their use and emissions.

Monitoring is important in order to evaluate the effects of regulatory actions. NILU has on behalf of the Norwegian government measured POPs continuously for more than 30 years at the Zeppelin Observatory at Svalbard in the Arctic, and nearly 20 years at the Troll Observatory in the Antarctic. Despite regulations, emissions persist due to legacy sources, such as old products and contaminated soil. Hexachlorobenzene (HCB) is an example of a compound that also may form during various combustion processes. Monitoring of these compounds therefore remains important.

Data collected through our monitoring efforts is submitted to the international database EBAS (ebas.nilu.no), which includes atmospheric data from 84 countries and more than 1,000 monitoring stations. Looking ahead, data from Troll will also support the recently established Antarctic and Arctic Monitoring Program.

In NILU's monitoring program, air sampling is conducted using a high-volume sampler (from Digital). The sampler draws air through a filter and an absorbent of polyurethane foam, using a pump with accurate flow rate. Atmospheric particles are collected on glass fiber filters, while gaseous compounds are captured by the absorbent. Sampling in Antarctica presents significant logistical challenges due to its remote location and distance from populated sources. However, with support from the Norwegian Polar Institute, NILU successfully manage full-year handling of the high-volume sampler.

Once the samples arrive at the lab in Norway, they are analyzed using accredited methods. The process begins with extraction using a specialized setup, followed by cleaning by adding concentrated acid and silica fractionation. The instrumental analysis is performed with high-resolution mass spectrometry (HRMS).

In the monitoring program, hexachlorobenzene (HCB) is detected in all samples and exhibited higher concentrations compared to other POPs. This is likely due to HCB being a byproduct of combustion and manufacturing processes, suggesting that sources of this compound still exist. PCBs

are also analyzed. Among the PCBs, certain congeners, such as PCB-47, are detected in relatively high concentrations. Additionally, DDEs—breakdown products of DDT—dominated among the detected compounds, reflecting the possible influence of secondary emissions on concentration levels.

The monitoring data also reveal seasonal patterns for these POPs, which vary across different compounds. Notably, concentrations tend to peak during the Antarctic winter. This is likely influenced by seasonal changes in atmospheric circulation patterns, as well as the potential for elevated emissions during the Antarctic summer. However, further investigation is needed to examine these factors. The data is also used to investigates long-term trends, expressed in terms of half-lives. Positive half-lives are observed for PCBs and DDTs are observed, indicating decreasing trends. This reflects reductions in primary emissions, likely due to the impact of regulatory measures.

HCB, however, presents a different trend, with a slight increase and a doubling time of approximately 20 years. This may be attributed to an increase in secondary emissions or possibly changes in primary emissions. When comparing with data from the Zeppelin Observatory in the Arctic, the concentrations are generally lower at the Troll Observatory. Overall, the detection of POPs in Antarctic air highlights the potential for long-range atmospheric transport to the region.

By monitoring from pole to pole, we are able to compare the trends between the Northern and Southern Hemispheres, providing valuable insights into the global distribution and regulation of POPs.

The Discharge of Grey and Black Water by Ships in the Polar Regions Scope, Impacts and Regulatory Options

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Global climate change can be clearly observed in the polar regions, the Arctic and Antarctic. In addition to changes in weather patterns and ocean currents, the melting of glaciers and ice sheets is leading to new shipping routes, particularly in the Arctic, which in turn is leading to an increase in the number of ships overall. The number of cruise industry activities is also steadily increasing in the polar regions. This is accompanied by the risk of marine environmental pollution, which can also be caused by the discharge of domestic waste water from shipping. Since the regions have sensitive ecosystems, effective marine environmental protection is required by regulating shipping and the discharge of waste water.

The project focused on a number of different aspects, starting with a detailed examination of the ship traffic in the polar regions and the legal requirements for handling waste water. With regard to the regulation of discharges, global regulations such as Annex IV of the MARPOL Convention apply. Additional requirements for polar waters are contained in the Polar Code. In the Arctic, the discharge of sewage does not require a separate permit or authorization. In particular, there are no requirements for the discharge of grey water that is not mixed with black water. The discharge regulations contained in MARPOL Annex IV and the Polar Code also apply in the Antarctic. In addition, further special legal requirements must be observed, which are regulated in the Environmental Protocol and the national law. Essentially, these are matters relating to approval procedures for discharges of black and grey water.

Another aspect was the sampling of untreated grey water, the influent and effluent of sewage treatment systems on 11 ships for analysis of typical sewage parameter, heavy metals and micropollutants. The results were subjected to a review for its potential harm to the marine environment in the polar regions considering the geographical discharge locations.

Finally, proposals for measures were drawn up, which can be summarized in four categories: regulation of discharges, regulation of wastewater flows, regulation of operations and further measures on micropollutants.

The project was initiated by the German Environment Agency. The final report is currently being prepared.

Summary

The project began at the end of 2021 and is scheduled to run for a total of 35 months. A draft final report has recently been completed. The presentation will introduce the project partners and provide details about the scope and background of the project, the methodologies used, and how the study was conducted. Key results, including proposed measures and options, will be shared, along with a brief outlook on current developments at the international level, particularly within the International Maritime Organization (IMO).

In the project, the affiliated institute at the university, along with the subsidiary, the Testing Institute for Wave Water Technology, played a central role. The focus has primarily been on the approval of decentralized water and wastewater treatment systems, some of which are used for landfill applications but have always included marine applications as well.

Type approval testing is conducted for large-scale treatment systems, oily water separators, and ballast water treatment systems.

Marine traffic in polar regions has been steadily increasing, raising concerns for these highly sensitive marine environments. Shipping activities contribute to various sources of pollution, and wastewater management remains a significant challenge. Current regulations under the MARPOL Convention, particularly Annex IV, the Polar Code, and associated guidelines, predominantly focus on black water. However, there are few to no regulations addressing grey water discharges.

Furthermore, these regulations lack legal requirements for maintaining wastewater records or monitoring discharges. The type approval and operation of marine sewage treatment systems are based solely on a one-time approval process. For example, marine sewage systems undergo a land-based type approval test lasting only ten days. In contrast, land-based treatment systems must be tested according to European standards for a minimum of 38 weeks.

Additionally, there are no binding obligations for operational monitoring, no effluent standards that must be consistently met, no record-keeping requirements, and no mandated management plans.

This lack of regulation makes it difficult to enforce effluent limits or ensure proper system maintenance and operation.

One of the project's goals was to address this gap by collecting data on the quality and quantity of both black and grey water discharges, particularly in polar regions. The project aimed to provide valuable insights into wastewater characteristics and contribute to better wastewater management outcomes.

A series of recommendations and measures has been developed to minimize the negative impacts of wastewater discharges. To provide an overview and highlight key differences, a significant bottleneck exists when comparing marine wastewater management to land-based systems. Onboard vessels, wastewater streams are divided into two main categories:

- Black water, which includes sewage from vacuum systems and wastewater from hospital facilities.
- Grey water, which encompasses all other wastewater streams, such as those from kitchens, showers, and laundry facilities.

A major issue arises from the current regulatory framework. Under existing definitions in the regulations, only black water from vacuum systems is classified as wastewater, or "sewage," while grey water remains largely unregulated. This creates a loophole, allowing vessels to discharge grey water within polar regions, even within 12 nautical miles of land or near ice shelves.

Although black water constitutes only 10% of the total wastewater volume, it contains a significant load of carbon and nutrients. However, grey water—while less concentrated—accounts for half of the total nutrient and carbon load. This makes its impact equally concerning, if not more so, due to the sheer volume involved.

More than a decade ago, some initial observations highlighted these concerns. Two projects were conducted that studied the impacts of grey water discharge by using mussels as bioindicators. These findings were later submitted to the IMO’s Marine Environment Protection Committee (MEPC), signalling the need for stronger regulations to address grey water discharges.

The first initiative examined 32 ships and revealed that none of them met the effluent standards required for type approval. This study was later expanded, and the findings were summarized in a statement worth citing from the MEPC 71 document, which highlighted that the majority of ships were discharging virtually untreated raw sewage from type-approved sewage treatment plants into the sea. This alarming discovery prompted MEPC to recognize the urgent need to improve these standards.

As part of this project, an evaluation of ship traffic in polar regions was conducted. Additionally, a questionnaire was developed for ship owners to gather crucial data and address gaps in the currently available information. Building on this, sewage record books, often maintained as part of internal company policies, particularly by cruise liners, were analyzed. These records provided valuable insights, including documented routes where wastewater discharges had occurred.

A review of the state-of-the-art wastewater treatment systems installed on ships was also conducted. Over the past decade, significant advancements have been made in treatment technology, and the review aimed to assess the current capabilities and limitations of these systems.

The onboard technologies installed for wastewater treatment were a central focus of our analysis. In addition, we conducted a comprehensive onboard sampling campaign, analyzing both treated wastewater from installed systems and untreated greywater, which can still legally be discharged into the sea. In total, samples were collected from 11 vessels, including cruise ships of various sizes, expedition vessels, and research vessels.

The data reveal significant variability in the concentrations of various pollutants. This variability is typical for evacuation processes and discharge concentrations. For example, vessel number three, a medium-sized cruise ship with approximately 3,100 people onboard, had advanced treatment systems featuring a membrane bioreactor. Despite this, it recorded a high concentration of 42.1 µg/L of ibuprofen in its wastewater. During a 49-day operation, the ship discharged 17,000 cubic meters of wastewater, resulting in a total discharge of over 700 grams of ibuprofen into the environment. These findings highlight the need for stricter controls and better treatment systems. The full details will be available in the final report, which is expected to be published by the German Environment Agency in 2025.

Ten key measures have been identified, grouped into four categories. The first and most important proposal focuses on the need to regulate wastewater discharges to minimize their environmental impact. One potential option is to designate polar waters as a 'special area,' implementing stricter discharge regulations. However, it is important to note that such designations currently apply only to passenger vessels operating in these waters. Additionally, existing regulations primarily address effluent parameters for nitrogen and phosphorus but do not account for critical pollutants, such as heavy metals or micropollutants.

Alternatively, local discharge bans could be implemented in polar waters to further minimize pollution. This approach would require enforceable operational standards monitored by authorities, such as port state control. There is also a pressing need to ban the use of certain systems, such as scrubbers and disinfection systems, which are currently permitted under MARPOL and the Polar Code for discharges outside 12 nautical miles from the nearest land or ice shelf, despite the lack of effluent standards or approval requirements. These systems should be prohibited outright.

Mandatory record-keeping of wastewater discharges and operational data must also be introduced, extending beyond current practices in international waters. Additionally, as highlighted earlier, grey water discharges should be regulated alongside black water to close existing gaps.

Another critical issue is the lack of regulation for by-products of wastewater treatment, such as primary sludge, surplus sludge, and residues from screening processes. These materials are currently not defined or addressed in existing regulations. Addressing this gap is essential to improve environmental outcomes.

Finally, there is a need for stricter operational and environmental regulations for wastewater treatment systems. The performance of these systems heavily depends on the qualifications and training of the personnel operating them. Therefore, new requirements should include mandatory personnel training and qualifications, as well as the implementation of a wastewater management plan onboard. This plan should be subject to review and approval by regulatory authorities to ensure compliance and effectiveness.

Where possible—acknowledging the challenges in polar regions—onshore disposal should be utilized to manage micropollutants effectively. Through literature research, it was identified that information on the performance of large-scale treatment systems onboard vessels is very limited. Enhancing treatment technologies is a necessary and detailed measure to reduce marine pollution.

One specific measure that has been identified the elimination of benzotriazoles, commonly used as corrosion inhibitors in dishwasher cleaning agents. This would address a significant pollution source and could be implemented relatively easily.

As for regulatory developments, the IMO has recognized the need for improved wastewater regulations. A working group was established within the Sub-Committee on Pollution Prevention and Response (PPR) to the MEPC several years ago. Currently, the type approval guidelines for wastewater treatment systems are under review. Additionally, an implementation guideline is being developed to include monitoring requirements and enhanced operational standards for these systems.

During this review period, a structured experience-building phase has also been initiated. This phase aims to establish guidance for data collection, and member states have been invited to contribute further information.

A new project assessing the performance improvements of existing wastewater treatment systems focuses on identifying how better operation and maintenance practices can enhance system performance. Insights from the earlier project have also been included in the ongoing review process under the IMO framework.

Contaminants in the Southern Ocean Foodweb - A Portuguese perspective

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This presentation explored the dynamics of chemical contaminants, sources, bioavailability, and biomagnification in the Southern Ocean food web, with an emphasis on mercury. Focusing on Portuguese-led research within the scope of the Portuguese Polar Program. We explore both anthropogenic and natural sources of contamination, particularly volcanic activity on Deception Island, which has been identified as a significant contributor to elevated mercury levels in the region. Experimental studies shed light on how marine organisms, from phytoplankton to top predators, respond to chronic exposure to these contaminants, and how they became bioavailable to the marine environment. Notably, Antarctic krill showed spatial and biological variations in mercury accumulation, indicating the role of sea ice in the bioavailability of contaminants. Cephalopods and fish studies show that these groups could be a good bioindicator for temporal trend of contaminants, as mercury levels in these organisms correlate with global emission of this contaminant. Results suggest that changes in the food web are likely to affect the pathway of mercury to Southern Ocean top predators, stressing the crucial role of Antarctic krill in this ecosystem. The findings emphasize the need for continued research on the impact of contaminants in polar ecosystems and underscore the importance of international collaboration in addressing environmental challenges in these vulnerable regions. The research also demonstrates the potential of using biota as effective environmental indicators of contaminant levels, providing valuable insights into the health of ecosystems and the pathways of contaminants.

Summary

Films and media often portray the legendary Portuguese explorers as true heroes who navigated the oceans in wooden vessels. These adventurers crossed the southern seas and became some of the first to recognize the presence of the vast southern oceans. However, formal scientific exploration in Portugal began around 1405, coinciding with the early years of the International Polar Year and the establishment of the Portuguese Polar Program. In 2007, the APECS Portugal was founded, creating a platform for individuals involved in polar and Antarctic science in Portugal to collaborate more effectively. It served as a unifying link for those conducting polar research to work together toward common goals. Regarding contaminants, several institutes in Portugal are dedicated to studying pollutants in Antarctica, including advanced research facilities in Lisbon.

Contaminants can originate from natural sources or anthropogenic activities, with impacts ranging from localized effects to those transported over long distances. When considering the Southern Ocean and Antarctica, it is often assumed that most contaminants are carried there from other parts of the world. However, we must not overlook the natural contributions, such as those from megafauna activity, which can also have significant environmental impacts.

One notable study conducted in the Drake Passage, particularly around Deception Island in subantarctic settings, examined the pathways and speciation of mercury in this region. The research revealed that the majority, if not all, of the mercury present on the island originates from volcanic activity. Moreover, the study detected notably high levels of methylmercury, underscoring the importance of natural sources in the region's contaminant profile.

The mercury levels found in this study, particularly within the cove of the still-active volcano, were 13 times higher than any previously reported levels in the Southern Ocean. This indicates that the unique environmental conditions on this island not only promote the accumulation of mercury but also facilitate its methylation. This process makes mercury more bioavailable, increasing its incorporation into the food web. The study also examined other trace elements, including selenium, copper, calcium, and lithium, and determined that these elements originate from natural sources in their elemental form. No evidence linked these contaminants to anthropogenic sources.

However, it’s important to acknowledge that human activities still play a role in impacting the Antarctic environment. For instance, areas like King George Island and the South Shetland Islands, which are heavily visited by scientists and tourists, show direct signals of human impact, making them some of the most affected regions in Antarctica.

Studies by Anna and Isabelle have shown that trace contamination levels on certain islands are higher than those on less human-impacted islands. Some of these elevated levels, particularly in areas like the bay, can be directly linked to the impacts of human activities. This highlights the need for

increased knowledge, as even scientific activities can pose a threat to the environment. It emphasizes the importance of implementing precise, more controlled management programs to mitigate the environmental impact in the Southern Ocean.

Moving on to experimental studies, one study conducted in Deception Island evaluated the energy efficiency of plants in mercury-rich, highly contaminated waters. As expected, standard plant cultures showed a decline in energy efficiency under high mercury conditions, indicating the acute effects of mercury on the plants' nutrient processing abilities. However, when plants were collected from Deception Island itself, there were no significant differences, suggesting that the plants there had adapted to the high mercury concentrations. This finding shows that locations like Deception Island could serve as an ideal natural laboratory for studying chronic adaptations in plants and other species to elevated contaminant levels, particularly mercury. Linking this to food webs, a recent study explored the bioavailability of trace contaminants by incorporating crows and algae. The researchers collected soil samples, added them to water, and tested how efficiently trace elements and contaminants were bioavailable to the biotic and microbiological components of the ecosystem.

Contamination levels of total and organic mercury were examined in Antarctic krill, one of the most important species in the Southern Ocean's food web. The findings were somewhat surprising. Juvenile Antarctic krill were found to have higher concentrations of mercury than adults, which may be due to females transferring some contaminants through their eggs. As a result, juveniles begin their life cycle already burdened with high levels of contaminants.

The concentrations of contaminants were 5-7 times higher in the Southern Ocean islands. We were able to link this to the presence of sea ice, which acts as a trap for contaminants during the winter. As the sea ice melts in the summer, microorganisms incorporate these contaminants, which then enter the food web. This highlights the Southern Ocean as a unique environment, where various factors influence contamination levels. It's also crucial to consider the role of krill, as studies estimate that between 400,000 to 100 million tons of krill are consumed by Southern Ocean predators every year, including humans.

Based on the lowest mercury concentration found in this study, we calculated that about 1.4% of mercury is bioavailable through krill and can be incorporated into the food chain. This emphasizes not only krill's importance in the food web but also its role in contaminant transfer. It is noted that many of our contamination studies began with dissecting krill, progressing from basic analysis to more complex investigations of different tissues and ages. When you think about cephalopods or krill, they play a significant role in understanding the impacts of contaminants in marine ecosystems.

Into the Antarctica Research Station Environmental sample collection and tracking human footprints through passive sampling of polycyclic aromatic hydrocarbons in inland lakes

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China's first Antarctic research station, the Great Wall Station, was established on the Fildes Peninsula of King George Island in West Antarctica on February 15, 1985. Subsequently, four additional research stations—the Zhongshan Station, the Kunlun Station, the Taishan Station, and the Qinling Station—were constructed in 1989, 2009, 2014, and 2024, respectively. These stations are strategically located across different regions of Antarctica and provide essential support for visiting scientists, offering comprehensive scientific laboratories for research.

In 2012, an investigation was conducted to assess the occurrence of freely dissolved polycyclic aromatic hydrocarbons (PAHs) in selected inland lakes of Antarctica using polyethylene (PE)-based passive samplers. The study aimed to validate the utility of PE-based passive samplers in polar regions and identify potential sources of PAHs to evaluate the impact of human activities in Antarctica. The measured concentrations of PAHs ranged from 14 to 360 ng L^{-1}, with the highest values detected near the Russian Progress II Station, highlighting the significant influence of human activities on PAH loading in Antarctica. The PAH concentrations in the inland lakes were within the upper range of levels observed in aquatic environments from remote and background regions globally.

The composition profiles of PAHs indicated that their presence in the inland lakes was primarily attributed to local oil spills, supported by numerous reports of fuel spillage from ship and plane incidents in Antarctica in recent years. These findings suggest that local human activities, rather than long-range transport, are the dominant sources of PAH contamination in inland lakes. The study demonstrated that PE passive samplers are effective tools for monitoring trace organic contaminants in extremely remote areas. Snowmelt incorporating spilled fuel may also play a significant role in contributing to PAH loadings in inland lakes.

For future research in Antarctica, projects based at research stations offer a viable option for long-term monitoring of persistent organic pollutants (POPs). Additionally, greater attention should be given to local sources of contamination and the development of standardized operation procedures. For passive sampling, the identification and use of ideal and efficient adsorption materials are essential to enhance sampling accuracy and efficiency.

The APECS Portugal perspective on chemical pollution in Antarctica

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In the last decades Southern Ocean and Antarctic ecosystems have become more susceptible to chemical stressors and anthropogenic pollutants that are released from ships and research stations, arrive in ocean currents, are transported in the atmosphere, or are ingested by the species. This threatened has led many research groups to turn their focus to the chemical pollution field, having contributed to the increase of monitorization programs, creation of interdisciplinary projects and consequently to the involvement of more Early Career Researchers (ECRs). Currently, these topics have never been so much mentioned in daily news (i.e.: newspapers, tv, debates, forums, etc.) and social media. Yet, the real knowledge or perception of the society regarding these issues remains uncertain. Within this context ECRs can play a crucial role in enhancing education and outreach activities about polar regions, bridging these gaps. They are vital contributors to scientific development and a fundamental part to combat misconceptions, through their scientific, educational, and outreach activities.

In this presentation we aim to highlight work performed by ECRs from APECS Portugal during the International Polar Weeks in schools (since 2009), institutes and forums, annual workshops to university students, and the use of social media to, disseminate science and evaluate the potential of this platform to evaluate public knowledge and shape future generations. Furthermore, we will present the engagement of Portugal, more specific of the Portuguese ECRs in chemical pollution research in the different dimensions of the Southern Ocean and Antarctica ecosystem. We will also showcase their role as important drivers of this research field in the last 10 years in Portugal.

Summary

Plastic pollution exists in various forms, including macroplastic, microplastic, and nanoplastic pollution. This research primarily focuses on microplastic pollution, although these three types are interconnected. Larger plastic particles in the ocean can degrade into progressively smaller particles over time. MPs, specifically, are defined as plastic fragments or primary plastic sources smaller than 5 mm. Scientific studies have shown that microplastic pollution is pervasive throughout aquatic environments. These human-made particles originate from diverse sources, leading to variations in their chemical additives, shapes, sizes, and colors. An important consideration is that MPs in oceans degrade at a slower rate, which affects their persistence and bioavailability to marine organisms. This persistence creates significant threats to biodiversity, which can be grouped into three main topics, such as, organisms interacting with MPs, MPs acting as vectors for contaminants, and MPs facilitating organism dispersion.

When discussing interactions between organisms and MPs, we are often familiar with instances involving larger plastic particles, such as macroplastics, which cause ingestion or entanglement. For example, seabirds in Portugal are frequently observed attempting to consume plastic debris found on beaches. However, increasing evidence shows that MPs are ingested by species across various trophic levels worldwide, including in remote ecosystems like Antarctica and the Southern Ocean. The ingestion of MPs poses significant risks due to the accumulation of toxic compounds associated with these particles, which can lead to severe health issues in marine organisms. To better understand and address these interactions, researchers analyze stomach contents or gut samples of collected specimens. In cases where organisms cannot be captured, scats (feces) can serve as a proxy to study microplastic ingestion.

Our former research project was conducted focusing on the collection of scats from three species of penguins over several years and across various colonies. This study was one of the first to document the presence of microplastic particles in penguins from the Antarctic Peninsula. Notably, the findings revealed that MPs were consistently detected across different years and colonies. Furthermore, the abundance and levels of these plastic particles were remarkably similar across species, years, and locations. Building on this foundation, recent work has shifted to studying sub-Antarctic seabirds, such as petrels. Specimens of these seabirds, found deceased in colonies, were collected to analyze their stomach contents for microplastic presence. Under strictly controlled conditions to prevent contamination, microplastic particles were discovered in the stomachs of some individuals. This finding underscores an important consideration: macroplastic particles present in the stomach can degrade into smaller fragments due to the digestion process. Consequently, these species may already harbor MPs while also generating additional particles through the breakdown of ingested macroplastics.

Detecting these small plastic particles, such as MPs, requires careful methodology. Given their tiny size, they must be observed by the means of microscope. The stomach contents are subjected to a digestion process, after which smaller fragments are filtered and examined. Visual identification, based on characteristics like shape, size, and color, is an initial step. However, chemical analysis is crucial to confirm the material as plastic. Interestingly, these studies have identified more microplastic particles in large sub-Antarctic seabirds than initially anticipated.

MPs serve as vectors of contaminants, posing a significant environmental issue. These particles, inherently problematic due to their presence in organisms, contain chemical additives like brominated flame retardants, plasticizers, and bisphenol compounds, incorporated during manufacturing to enhance durability. When MPs enter aquatic environments, they can adsorb additional contaminants such as POPs and mercury, further amplifying their impact. As a result, organisms ingest not only MPs and their additives but also the absorbed toxic substances, causing serious health risks.

Many plastic additives are classified as endocrine-disrupting chemicals (EDCs), which can interfere with hormonal systems in organisms. Studies have documented widespread EDCs in the environment, showing their potential to cause endocrine disruption, inflammation, oxidative damage, and developmental issues. For instance, even low concentrations of phthalates have been linked to immunotoxicity, neurotoxicity, and reproductive system impairments. Understanding the levels of MPs and associated chemical contaminants in wildlife is crucial for evaluating their toxicity and ecological impact. Given the increasing prevalence of microplastic pollution, comprehensive research is essential to determine how these particles and their chemical burdens affect the health of organisms and ecosystems, ultimately guiding strategies for mitigation and management.

MPs contribute significantly to organism dispersion by serving as transport vectors for species. While large plastic debris on beaches often hosts organisms like mollusks and crustaceans, MPs typically provide habitats for smaller species such as bacteria. This transport of non-native species can lead to ecological disruptions, impacting biodiversity and ecosystem services. These effects are particularly severe in fragile environments like polar, oceanic, and Antarctic regions, which are highly susceptible to ecological changes.

In the Southern Ocean and Antarctica, microplastic pollution is present throughout aquatic ecosystems but at lower levels compared to other regions. This relative scarcity is attributed to the circumpolar current, which isolates these areas. Nonetheless, MPs are introduced through atmospheric transport, ocean currents, and increasing direct sources such as tourism, fishing, scientific activities, and research stations. Studies have identified MPs in sediments, water columns, and local biota, highlighting their widespread impact. Despite advances in understanding microplastic abundance, significant knowledge gaps remain regarding specific species, including flying seabirds, cephalopods, myctophids, and large marine mammals, which are harder to study. Additionally, further research is crucial to uncover the chemical composition, toxicity, and combined effects of MPs, environmental pollutants, and climate change, as these pose pressing threats to Antarctic ecosystems.

Increased monitoring efforts are essential to generate comparable data and enhance understanding of the fate, extent, and effects of microplastic pollution. MPs pose a significant problem not only due to the presence of the particles themselves but also because of their potential toxic effects on species. With rising top predator pressures in recent years, it is critical to collect more data on environmental concentrations and conduct tests to explore the combined effects of MPs and other stressors.

By improving data collection and analysis, more effective precautionary measures can be proposed to mitigate this growing issue, particularly in sensitive polar regions. Although these areas remain less impacted compared to other parts of the world, their unique ecosystems make them especially vulnerable. Collaborative efforts among research groups focusing on polar environments are vital to compile and compare existing data, providing a clearer picture of the scope and impact of microplastic pollution. Preliminary analyses indicate that chemical concentrations associated with MPs in polar species are lower compared to other regions, such as Portugal. However, the increasing presence of these pollutants highlights the need to understand their long-term implications on wildlife and ecosystems in the Antarctic.

2. Discussion and Summary

Discussion of Session 1

Topic 1: The Synergy Between EU-Polarnet and Antarctic Initiatives

The polar environment has long been a focal point for large-scale international initiatives, particularly in Antarctica. EU-Polarnet, a significant collaborative framework, is scheduled to conclude in December 2024. As this initiative transitions into its next phase, there is a valuable opportunity to leverage its momentum for new projects and initiatives in Antarctica. Unique benefits can arise from collective responsibility and the shared efforts of participating nations, including Germany, Italy, France, Korea, the United States, Canada, South Africa, and others. By enhancing effective coordination among these countries, outcomes can be maximized, and the challenges of polar research addressed more efficiently.

This collaborative approach highlights the critical importance of global cooperation, as no single nation possesses the resources or expertise required to achieve the necessary progress in isolation. Coordinated actions in Antarctica can serve as a model for international partnerships, demonstrating how shared responsibilities can lead to transformative advancements in polar science and environmental stewardship. Such efforts not only advance scientific understanding but also reinforce the principles of multilateralism and collective action in addressing global environmental challenges.

Topic 2: Environmental Contaminants in Antarctica – Understanding Sources and Local Impacts

The source of DBDPE likely plays a significant role in the observed contamination patterns. DBDPE has increasingly replaced deca-BDE (BDE-209) in industrial applications, with demand surging in recent years. Notably, China has emerged as a major producer, generating substantial quantities annually. The rapid detection of DBDPE in Antarctica is likely attributable to long-range atmospheric transport mechanisms, which can deliver such contaminants to remote regions within a few years. This phenomenon is not unique to Antarctica; similar substitution trends and contamination patterns have been observed in ecosystems worldwide, highlighting the global nature of POPs distribution.

Efforts to manage local contamination during sampling are ongoing, but addressing this issue effectively requires global collaboration. While elevated contaminant concentrations in Antarctic samples may appear concerning, they do not inherently indicate harm. Comprehensive risk assessments are essential to evaluate potential risks accurately.

Local contamination remains a critical consideration in polar research, particularly concerning emerging chemicals such as PFAS, organophosphates, and pharmaceuticals and personal care products (PPCPs). Despite efforts to minimize contamination, eliminating it is challenging. Well-designed sampling strategies are essential to mitigate this issue. For example, sampling stations are typically located far from populated areas, and measures such as the placement of a dedicated container at the Norwegian Troll Station have been implemented to reduce contamination. These approaches effectively minimize the environmental impact of research activities and potential tourism. Additionally, analyzing data using specific ratios or tracers can help distinguish between pristine Antarctic conditions and influences from local sources. Such considerations are vital when planning and conducting sampling activities at research stations to ensure the accuracy and reliability of results.

Topic 3: Understanding Contaminant Transformation in Polar Regions

When discussing contaminants, the focus is often on their sources and pathways. However, an equally important aspect is their degradation processes, including microbial and photochemical degradation. As highlighted in the second presentation, photochemical reactions can play a significant role in contaminant transformation. For instance, studies on bisphenol E in ice have demonstrated its degradation through photochemical reactions, leading to the formation of other bisphenol species with hydroxy groups. This underscores the importance of conducting both targeted and non-targeted analyses to identify transformation products. While challenging, such analyses are essential to understanding contaminant behavior. Snow and ice act as reactors, with ice exhibiting different characteristics compared to seawater. Each environmental matrix has the potential to transform original contaminants, often resulting in reduced levels of the parent compound due to these reactions. Although the system is highly complex, advancing research efforts to investigate these transformation products is critical for improving our understanding of contaminant dynamics in polar environments.

The topic of transformation products derived from original chemicals, such as POPs or emerging substances, is a crucial area of focus in polar research. This issue, highlighted by Elena, emphasizes the importance of understanding how these products evolve in various environmental contexts. Several research groups participating in this workshop, including those led by Jordi and Susan, have initiated work on non-target analyses to address this challenge. It would be valuable to share insights on methodologies and strategies for identifying these transformation products across different environmental matrices. This collaborative effort can significantly enhance our ability to track and understand chemical transformations in polar regions.

Discussion of Session 2

Topic 4: Accessing Environmental Specimen Banks (ESBs) for Research

Access to materials from Environmental Specimen Banks (ESBs) varies depending on the specific bank and its policies, influenced by the availability of samples and conservation priorities.

Norwegian Specimen Bank: Accessing materials can be complex. Researchers must complete detailed forms, which can be time-consuming, and there are associated costs. The bank, managed by the Norwegian EPA, is careful about sharing too many samples to ensure resources are preserved for future generations.

German Specimen Bank: Germany follows a different approach by homogenizing all samples. This results in an average of 2 kg of material, divided into 200 sub-samples of 10 g each. These sub-samples are distributed for current research while reserving some for future use.

General Sharing Policies: Each specimen bank has its own policies for material access. Typically, researchers need to inquire directly and follow the bank's application procedures. Most banks require a policy framework for sharing materials, and the resulting data from studies must be incorporated into the bank's database.

Data Sharing and Transparency: Researchers are encouraged to publish their findings as open-access publications to benefit the wider scientific community. Furthermore, the data must comply with FAIR principles (Findable, Accessible, Interoperable, and Reusable), ensuring public accessibility and alignment with modern data-sharing standards.

Although access policies vary across banks, collaboration and transparency are highly encouraged. Researchers should directly contact the relevant ESBs, obey to their guidelines, and contribute to the global repository of knowledge by sharing data openly and responsibly.

Topic 5: Improving Access to Environmental Data Banks and Standardizing Sampling Procedures

Currently, there is no common database that consolidates the content of multiple environmental data banks. While there is a loose international collaboration among banks, with a shared website, users can access individual databases for countries like Italy and others. However, the idea of creating an internationally accessible interface that allows users to explore various databases, understand their terms of use, and access related information is a valuable one. It is acknowledged as a good idea for future development to create a unified system that would streamline access and promote better global cooperation in environmental research.

To ensure the accuracy of the results and account for potential contamination, blanks are routinely collected alongside actual samples. These field blanks are essential, especially due to the very low concentration of analytes in the samples.

For any matrix, field blanks are prepared in the same way as the actual samples but without including the sample material. For example, during snow sampling, an empty container is used while replicating the entire snow collection process in the field. This ensures that any potential contamination during the collection process is accounted for.

The same approach is applied in atmospheric particle sampling to ensure that the entire process, from collection to handling, is consistent.

In addition to field blanks, reagent and laboratory blanks are also used to control for contamination during the analysis process.

Topic 6: Standardizing Sampling Procedures

Currently, each specimen bank follows its own SOPs, and this includes differences in methodology and protocols. However, as the field moves toward a more unified approach, establishing standardized procedures across different banks is seen as a critical step for the future.

Moving towards a unified program requires the development and adoption of standardized SOPs, which will ensure consistency and quality control across various environmental monitoring activities.

A key element in this process will be the production of certified reference materials, which will play a significant role in harmonizing procedures and maintaining high-quality standards across all specimen banks.

Efforts are underway to improve access to environmental data through a more interconnected system, and steps are being taken to standardize procedures across specimen banks. The use of blanks in sample collection ensures the accuracy of data, while the standardization of SOPs and certified reference materials will help ensure the consistency and quality of environmental monitoring globally.

Topic 7: Storage of Ultra-Pure Water and Solvents in Sample Preparation

During the cleaning procedure, blanks are prepared, but ultra-pure water is not stored directly in the tank. Instead, other solvents are used to clean the bio-samples. Currently, ultra-pure water or similar substances are not stored as part of the process. The focus remains on using appropriate solvents during cleaning, but there is no storage of these substances for future use in the sample preparation process.

Topic 8: The Role of NORMAN Network

The NORMAN Network is a powerful example of how grassroots initiatives can drive change in environmental science and policy, particularly in chemical monitoring and regulating non-regulated contaminants. This European project aimed to address the "vicious cycle" of reactive legislation by developing standardized methods, creating robust data storage systems, and improving science-to-policy communication. Over time, the network grew into an independent entity with more than 100 institutions, contributing to significant advances in chemical monitoring and influencing European regulations like the EU Water Framework Directive.

the NORMAN Network is involved in not only advancing scientific knowledge and creating comprehensive databases but also in influencing public awareness and policy decisions. By focusing on non-regulated contaminants and fostering international collaboration, these networks are helping to address urgent environmental challenges and push for more effective legislative frameworks in regions like Antarctica and the Arctic.

Discussion of Session 3

Topic 9: Routine Monitoring of Chemicals in Antarctica: Global and National Perspectives

The Routine Monitoring of Chemicals initiative, like frameworks such as the Stockholm Convention, involves a list of priority chemicals for monitoring. This list is dynamic and not fixed; if sufficient evidence emerges, new chemicals can be proposed for inclusion. A dedicated committee evaluates whether these new substances meet the criteria for addition to the routine monitoring program. However, gaining support for such additions is a thorough and structured process.

Researchers are fundamentally motivated by scientific discovery. However, when working within a government framework, there is an added responsibility to respond to the needs of ministries and policymakers. To balance these priorities, we have established a clear distinction between research activities and policy-driven functions, which we refer to as monitoring for management purposes. Understanding and maintaining this balance between scientific inquiry and practical policy needs is crucial for better coordination of research and monitoring efforts.

These two roles, guided by distinct motivations, influence the reasons behind conducting research, monitoring, or any related activities. To move toward better coordination, it is essential to clarify the objectives and understand the balance between the drive for scientific discovery and the practical need to address societal concerns.

Expertise and knowledge are of limited value if confined to the academic or institutional domain—they must be communicated effectively to policymakers, managers, and the public. This is a critical but complex discussion, deserving of focused attention. In fact, these issues could easily form the basis of an entire workshop dedicated to exploring and resolving them. Bridging the divide between research, policy, and societal impact is both challenging and essential.

Topic 10: Integration of National Programs into an International Framework

The Antarctic Monitoring and Assessment Program (AnMAP) plays an advisory role, particularly during the startup phase. The immediate focus for the next two years is stakeholder engagement, which includes working closely with policymakers. The initial eight months of the project have concentrated on Australia, but as we move forward, it will be crucial to involve all the consultative bodies. This process involves identifying the relevant ministers and stakeholders from each nation.

To effectively engage these stakeholders, it would be helpful to collaborate with colleagues who are familiar with their national ministers or the appropriate departments. The goal is to engage those with a vested interest and refine the program's priorities based on the needs of various consultative parties. This approach will allow for more strategic targeting of efforts as we aim to integrate national programs into the broader international framework.

Topic 11: Regulatory Requirements and International Collaboration for Monitoring Pollutants

What are the regulatory requirements or international agreements regarding interactive and official monitoring programs, specifically for emissions from research stations and tourism? It seems that fully established programs are currently lacking, though this is a potential area for future development. This process is comparable to the United Nations, where achieving consensus among stakeholders can be complex. Raising awareness and presenting concerns to the public is essential, as evidenced by effective policy-maker engagement. However, creating a strong case, supported by data and evidence, is necessary. Archives with expertise in particles and techniques could play a key role in advancing this effort.

International collaboration on monitoring pollutants is of significant interest to all participants, both in-person and online. Each country operates its own national programs, with some longstanding and others more recent. Despite these variations, every country contributes to a shared global effort. The challenge now is to explore effective ways to enhance international collaboration.

The integration of national research programs in Antarctica, as discussed during the workshop, is a key challenge. While organizations like AnMAP and others are addressing this issue, integrating different national programs remains difficult. This is a critical area for progress, and efforts will focus on summarizing the workshop's insights into a document that supports this integration. However, achieving this will be challenging.

Indeed, integrating national research programs is the most critical challenge. It is vital for AnMAP and ESBs to collaborate, as we all need to contribute to answering this question. When writing research proposals and engaging with our administrations, it’s essential that our institutions work together at a higher level, beyond individual efforts.

There is a very interesting graphic novel from two French authors, Emmanuel Lepage and Francois Lepage. This kind of initiatives are still interesting to document and show how scientific activities go on there: https://www.futuropolis.fr/9782754816090/antarctique.html.

Discussion of Session 4

Topic 12: Managing Tourism in Antarctica and Its Environmental Impact

The increasing number of tourists, especially with more ships gaining access to Antarctica and the decreasing cost of visits, is concerning. Currently, the region is mostly accessible to the wealthy, but as prices become more affordable, even people with limited means are able to visit. The idea of reducing the number of ships is valid, but it’s complex because it raises questions about who should be allowed to visit and how access should be regulated. This issue involves not only regulating ships but also evaluating the impact of wastewater produced by these tourists. The effect on both the land and the waters where tourists travel must be carefully assessed. This issue requires further attention and must be considered alongside other environmental concerns.

Furthermore, tourism in Antarctica has risen intensely in recent years, and this trend is likely to continue. Our project aims to address the environmental impacts of tourism, particularly the role of chemists in assessing the presence of micropollutants from wastewater treatment systems. Discussions about limiting the number of people allowed to land in Antarctica are already underway, but this is just the beginning. There is a need for further dialogue on how to manage the environmental impact of tourism, particularly regarding the introduction of contaminants to the polar regions, which has not been adequately addressed so far. More awareness and action are required to mitigate these risks.

Topic 13: Assessing Chemical Effluents from Research Stations and Ships

A question was raised regarding the screening of effluents from ships, particularly with the increasing focus on effluents from research stations. Have there been any surveys conducted to assess the types of containers used at research stations and on ships, especially concerning the chemicals they use? This information could be valuable for modeling purposes and understanding the broader environmental impact.

Efforts have primarily focused on sampling effluents from ships rather than research stations. A comprehensive questionnaire was developed to gather information, but one of the challenges encountered was the reluctance of people to provide such data. The questionnaire was also quite lengthy, requiring multiple individuals to complete it. While there are ongoing campaigns promoting proper waste management and the understanding that waste should not be disposed of in toilets, these practices are not yet standardized or regulated. Furthermore, no established limit values for micropollutants exist, either on land or on ships. Although some data has been collected, it remains difficult to determine whether the levels are significant or within acceptable limits. This underscores the need for further action and regulation to establish clear standards for waste management and effluent limits.

Topic 14: Linking Ecological Effects to Their Causes Using eDNA Metabarcoding

New techniques, such as eDNA metabarcoding, offer valuable insights into biodiversity and ecological effects, allowing us to observe changes in ecosystems. These methods provide powerful tools to monitor biodiversity and detect stressors like invasive species. However, linking these observed effects to specific causes, such as invasive species, remains challenging but feasible.

The potential exists to connect biodiversity changes to specific causes by integrating eDNA data with chemical analysis, bioassays, and environmental factors. This will help us identify dominant stressors and drivers of change, including invasive species and their impact on native ecosystems.

While eDNA metabarcoding can identify the presence of species and track biodiversity changes, there is still a need for more research to directly link these changes to specific causes, such as environmental pollutants or invasive species. Integrating this data with chemical and ecological data will be essential for understanding the full picture.

Panel Discussion

Topic 15: The Purpose and Motivation Behind Chemical Monitoring in Antarctica

Chemical monitoring in Antarctica serves multiple purposes, each contributing to our understanding and protection of this unique environment. The motivations can be grouped into several key areas:

Health of the Antarctic Ecosystem: Monitoring is crucial for assessing the health of the Antarctic ecosystem, particularly in light of emissions from tourism, research activities, and minimal land use. This is vital for ensuring that human activities do not disrupt the delicate balance of the ecosystem.

Global Contamination Risk Assessment: Another major goal is to gather data on global contamination levels, which can be used for risk assessments. This data helps improve chemical market safety by providing insights into the presence and impact of contaminants worldwide, even in remote environments like Antarctica.

Nature Conservation and Biodiversity Protection: Finally, a key motivation is to address nature conservation concerns, focusing on protecting the unique biodiversity of the Antarctic continent and surrounding oceans. Understanding the extent of contamination and its potential effects on biodiversity is critical for developing conservation strategies.

Topic 16: Open Science and Access to Chemical Monitoring Data in Antarctica

The issue of open science and access to research data is particularly relevant in the field of chemical monitoring in Antarctica. With the increasing number of emerging contaminants, new publications addressing these issues are being released frequently. However, many of these publications are often behind paywalls or are available through subscription-based models, which limits their accessibility.

Promoting Open-Access Publishing: A key goal should be to publish chemical monitoring data in an open-access format. This would allow a wider audience to engage with and benefit from the research, maximizing its reach and impact. Open-access publishing line up with the principles of open science, where research is freely available to all, enabling collaboration and transparency.

Collaborative Databases and Resources: As highlighted in the discussion, various databases and repositories are already available to help make data more accessible. Rebecca Pugh pointed out the Global Registry of Scientific Collections (https://scientific-collections.gbif.org/), which provides an excellent starting point for identifying samples being collected worldwide. However, its effectiveness depends on the willingness of researchers to submit their data. This registry is not limited to environmental specimen banks and includes various types of biospecimen and data repositories, which can be extremely useful for accessing relevant information for environmental research.

International Collaboration for Data Sharing: It is emphasized that compiling materials and data into accessible arrays will help facilitate collaborative efforts. The interaction between researchers and the sharing of references through online platforms can significantly enhance the reach and utility of chemical monitoring data. Sharing databases such as the International Society for Biological and Environmental Repositories (ISBER), which includes detailed information on biospecimen and environmental specimen banks, also plays a key role in promoting open science and improving data accessibility.

By encouraging open-access publication and participating in global data-sharing initiatives, researchers can contribute to the global effort of monitoring and understanding the chemical impacts on the Antarctic environment.

Topic 17: Challenges and Solutions for Data Sharing in Environmental Monitoring

The process of sharing environmental data, especially in collaborative settings like Antarctic research, presents several challenges. One of the main obstacles is ensuring that data can be easily compared across different studies, particularly when researchers use varied analytical techniques. Here are some key considerations and strategies to address these challenges:

Variation in Analytical Techniques: Different research groups may use different methods, which can lead to variations in the data due to factors such as sensitivity, detection limits, and measurement protocols. To address this, standardization of methods, when possible, is essential. Developing common guidelines or protocols for data collection and analysis would enable better comparison of results. However, even with standard methods, calibration and validation of equipment and techniques need to be considered to ensure data consistency.

Data Standardization and Metadata: A critical factor for improving data sharing and comparison is the inclusion of standardized metadata. By providing clear, detailed metadata alongside the raw data (e.g., information on sampling locations, methodologies, and conditions), researchers can ensure that their data is understandable and usable by others. This makes it easier for scientists to compare datasets even if the analytical methods differ.

Initiatives for Open Data in Europe: It is highlighted an ongoing initiative in Europe, where taxpayer-funded data must be made publicly available. This effort is helping ensure transparency and accessibility of environmental data across member states. Such initiatives demonstrate the importance of making data accessible for broader scientific use, including by researchers working in diverse contexts like Antarctica.

Responsibility for Antarctic Data: A significant question raised was who will take responsibility for making Antarctic data publicly accessible. Unlike in Europe, where efforts are underway to ensure visibility and accessibility of data, similar initiatives for Antarctica are still lacking. This creates a clear gap in data management and sharing. If a project were proposed to address this gap, the argument for funding would be strong, as the data is urgently needed for monitoring the health of Antarctic ecosystems and understanding global environmental trends.

By addressing these challenges through standardized methods, robust metadata, and collaborative initiatives, researchers can make their data more accessible, comparable, and valuable to the broader scientific community. This would ultimately improve the quality of environmental monitoring and support more informed decision-making in areas like conservation and chemical safety.

Topic 18: Effective Communication of Environmental Research in Antarctica

While publishing research in open-access journals is a valuable part of disseminating scientific findings, it does not necessarily guarantee that the broader public or relevant stakeholders will engage with the work. An important point was raised about the limitations of open-access publication, noting that simply making research available online doesn't address the issue of effective communication. Here are key strategies for improving the communication of research findings.

Beyond publishing, active Communication is key: Open-access publication allows for wider access to research, but most people, including key decision-makers, do not actively seek out scientific articles. To raise awareness and ensure research reaches a broader audience, researchers need to go beyond publishing in journals. This includes directly engaging with stakeholders, such as policymakers, the media, and the public, to ensure that the findings are communicated clearly and meaningfully.

Engagement with Policymakers and Journalists: Scientists should not wait for policymakers and journalists to approach them; instead, they need to proactively reach out to these groups. Policymakers often lack detailed knowledge of specific scientific issues, so it is crucial to present research findings in a way that highlights their relevance to policy decisions. Engaging with journalists is also important, as they can help disseminate information to the public and bring attention to pressing environmental issues. Researchers should collaborate with journalists to craft compelling narratives that emphasize the significance of their findings.

Communicating the Broader Impact of Antarctic Research: The environmental issues in Antarctica are not only local but also have global implications, with many contaminants originating from other regions. For these issues to gain traction, they need to be framed in a way that emphasizes their broader environmental and geopolitical significance. This could involve highlighting the global reach of pollutants or the potential impacts of climate change in Antarctica, making the case for international cooperation and urgent action.

Engagement in Antarctic Treaty Meetings and International Collaboration: Successful communication also involves engaging with international bodies, such as the Antarctic Treaty System, where research findings can be discussed and influence policy decisions. However, progress in these areas can be slow due to the need for consensus among treaty nations. If even one country opposes a proposed initiative, it can delay the process for a year. Therefore, it is essential for researchers to push their findings through the appropriate channels, ensuring that the scientific community, policymakers, and the public understand the urgency and significance of the issues at hand.

While open-access publication is an important step in sharing research, it is equally important for researchers to actively engage with the public, policymakers, and the media. By doing so, they can ensure that their findings not only reach a wider audience but also have a meaningful impact on policy and global environmental efforts.

Topic 19: Balancing Scientific Research and Public Engagement in Antarctic Science

There is no inherent conflict between scientific publications and outreach to the public. As scientists, our primary responsibility is to conduct meaningful research that delves into the processes, transformations, and sources of compounds, as highlighted in recent discussions. This depth is crucial to our role. However, effective communication is equally important. Beyond collecting data, we must ensure our research is accessible to the broader public. This is particularly vital in the context of Antarctic research, which naturally attracts public interest more than many other scientific topics. The unique nature of Antarctica offers a compelling opportunity for public engagement through platforms like television, social media, and public events. For example, the Italian National Program for Research in Antarctica emphasizes public outreach, sharing findings through school initiatives, television appearances, and other accessible platforms to explain the significance of Antarctic studies. Thus, we can—and should—conduct accurate scientific research while simultaneously ensuring its value is recognized by both the scientific community and the public.

The collaboration between research institutions and the state administration for Antarctic stations is important. While scientists address specific scientific questions and conduct pilot studies, these findings often inform future routine monitoring. Once a research approach is validated, the Polar Research Institute can adopt it into standardized monitoring protocols, ensuring that both exploratory research and long-term monitoring complement each other, enhancing our understanding of the polar regions.

The Polar project has been actively engaging both the scientific community and the Antarctic Treaty Consultative Meeting (ATCM) to discuss progress and results. A presentation will be given at the ATCM to highlight the project's achievements and objectives over the past year. Incorporating public involvement, as suggested by Michael, is a new approach that had not been previously considered for the project.

The ATCM has seen challenging discussions among contracting parties from various countries, particularly regarding emerging issues such as chemical pollution, which has gained increasing attention over the past decade. Engaging a broader range of stakeholders, including the public, could be pivotal in advancing these topics and ensuring that key issues are addressed.

A follow-up workshop is already planned, building on the success of the first workshop, which aimed to involve a diverse group of experts, including those from the SCAR community. The next workshop, potentially scheduled for next year or 2026, will focus on expanding participation by including additional stakeholders. This will be an opportunity to integrate public engagement into the Polar project and promote wider involvement in shaping the initiative's future direction

Topic 20: Young Scientists in Antarctic Research

The integration of young scientists into the Antarctic research community is quite challenging, as it is a relatively small field. At the upcoming national conference, young scientists will have an opportunity to engage with senior researchers, which provides valuable networking and knowledge exchange. However, several areas for improvement remain, many of which are specific to individual countries. For instance, there is a need for more scholarships, early postdoctoral positions, and support to help young scientists remain in their home countries while continuing their research.

Additionally, while the focus is not necessarily on large facilities in Antarctica, resources such as scholarships and specialized courses like basic life support and survival training for extreme environments would be incredibly beneficial. However, a significant challenge, particularly in our country, is the instability in research careers. Opportunities are limited, especially within the polar research field.

Building international connections is important, and events like this provide opportunities to establish such networks. These connections not only help create more career opportunities but also contribute to advancing research. Sharing experiences and recommendations in these settings is essential for career development, especially for early-career scientists.

3. Perspectives

This workshop has provided a valuable opportunity for collaboration. While each country is working to further collaboration within its own borders, we are all united in our efforts internationally. There have been discussions about how we should share our data and whether it is necessary to store it in a centralized database. Only publishing the data in open access formats or sharing it with the public will not be sufficient. In my opinion, one of the next necessary steps will be to establish a database. Although we have not yet decided which specific database to use, we are discussing this in the polar project and evaluating the best approach for data generation. The methodology for analysing pollutants, such as mercury or PFAS, may vary, but there must be clear guidelines for ensuring high-quality data. This database should also include best practice information on chemical analysis.

It is an appropriate time to enhance these efforts collectively, but practical steps need to be taken first. By the end of this process, there will certainly be opportunities, but the same discussions we had in this workshop will continue. Therefore, it is essential to use the next few years to move forward. We have already gathered insights from our questions, and while no one directly asked Susan and me, I will share the results with you. We surveyed participants on their most pressing questions regarding chemical monitoring in national and international programs. Most respondents identified the following priorities:

information on ongoing and future projects they could join

information on available scientific partnerships

information on financial support

information on best practices.

Additionally, the fifth most important need was information on whom to contact within agencies, ministries, and institutions. The least ranked concern was logistical information. This feedback was quite interesting. Given the practical nature of these questions, it may be useful to conduct another survey in the future to gather more responses. This would help refine our next steps.

Appendix I – Workshop Program

AGENDA

International Workshop on Monitoring Chemical Pollution in Antarctica

Tackling future Challenges together

3rd-4th October 2024

Siena, Italy

Meeting link: https://bcaa.unige.it/en/POLEMP_workshop

Day 1: 03.10.2024		
10:00-13:30	Registration	
12:00-12:45	Lunch	
12:45 – 12:55	Welcome and Introduction	Claudia Röhl German Environment Agency (UBA), Germany
12:55-13:15	Future trends in polar research, the EU-Polarnet prioritization process	Carlo Barbante University Ca'Foscari Venice, Italy
Session 1: Environmental Fate and Transport of POPs and CECs in Antarctica Chair: Simonetta Corsolini, Nicoletta Ademollo		
13:15 – 13:30	Challenges for environmental research and monitoring of the contaminants of emerging concern in the Antarctic	Zhiyong Xie Hereon, Germany
13:30 – 13:45	Amplification and sinks of organic pollutants in Antarctica and the Southern Ocean	Jordi Dachs IDAEA-CSIC, Spain
13:45 – 14:00	Monitoring persistent organic pollutants at the Fildes Peninsula on King George Island in the Antarctic	Qinghua Zhang Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences (RCEES), China

14:00 – 14:15	Discussion	
14:15 – 14:45	Coffee Break	
Session 2: Antarctic Environmental Specimen Banking Chair: Marco Grotti, Jan Koschorreck		
14:45 – 15:00	The role of environmental specimen banks in monitoring environmental contamination	Jan Koschorreck UBA, Germany
15:00 – 15:15	The Italian Antarctic ESB	Marco Grotti University Genova, Italy
15:15 – 15:30	Current status of Antarctic sample collection and proposed methods for biological sample processing at NESB, South Korea	Jangho Lee NESB, South Korea
15:30 – 16:30	Panel discussion and summary	
17:00 – 18:00	City tour	
19:00	Social Dinner	
Day 2: 04.10.2024		
Session 3: National and International Antarctic Environmental Monitoring Programs Chair: Anette Küster, Susan Bengtson Nash		
09:00 – 09:15	Contaminants in Antarctica; Building a Framework for Policy Advice	Susan Bengtson Nash Griffith University, Australia
09:15 – 09:30	Practical steps towards a Structured Sample and Data collection of Environmental Contamination in Antarctica	Anette Küster UBA, Germany
09:30 – 09:45	The Norwegian chemical monitoring program in Antarctica	Helene Halvorsen NILU, Norway
09:45 – 10:00	Discussion	
10:00 – 10:30	Coffee Break	

Session 4: Advanced sampling and analytical technologies Chair: Zhiyong Xie, Jordi Dachs		
10:30 – 10:45	Discharge of Sewage by Ships in the Polar Regions	Markus Joswig PIA at RWTH Aachen University, Germany
10:45 – 11:00	Contaminants in a Southern Ocean Food web	José Seco MARE, University of Coimbra, Portugal
11:00 – 11:15	Sample collection and pretreatment for emerging contaminants in the Antarctic	Xiangzhou Meng Tongji University, China
11:15 – 12:00	The APECs Portugal perspective on chemical pollution in Antarctica	Joana Fragao MARE, University of Coimbra, Portugal
12:00 - 12:15	Discussion	
Discussion Jan Koschorreck, Marco Grotti, Anette Küster, Simonetta Corsolini, Zhiyong Xie		
12:15 – 12:30	Panel discussion and summary	
12:30 – 14:00	Lunch	
Close the meeting		

Appendix II – List of Participants

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