Journal Pre-proof

The role of the Arctic Monitoring and Assessment Programme (AMAP) in reducing pollution of the Arctic and around the globe

Lars-Otto Reiersen, Katrin Vorkamp, Roland Kallenborn

PII: S2666-4984(23)00067-4

DOI: https://doi.org/10.1016/j.ese.2023.100302

Reference: ESE 100302

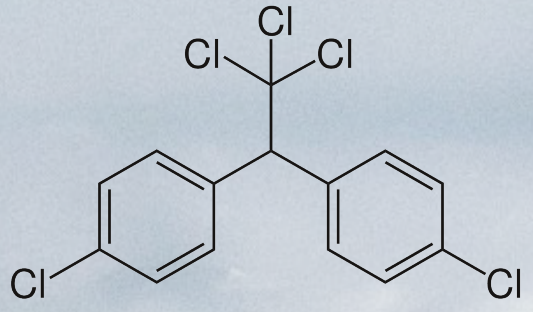
To appear in: *Environmental Science and Ecotechnology*

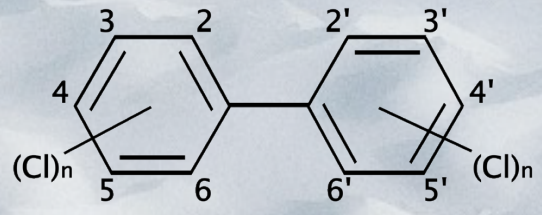
Received Date: 24 November 2022

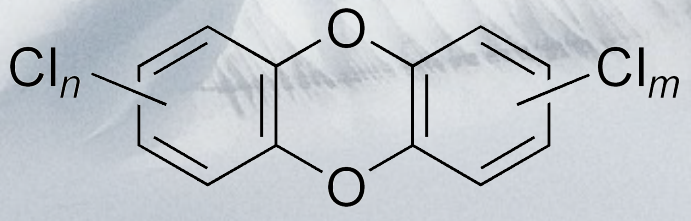
Revised Date: 20 July 2023

Accepted Date: 20 July 2023

Please cite this article as: L.-O. Reiersen, K. Vorkamp, R. Kallenborn, The role of the Arctic Monitoring and Assessment Programme (AMAP) in reducing pollution of the Arctic and around the globe, *Environmental Science and Ecotechnology* (2023), doi: https://doi.org/10.1016/j.ese.2023.100302.







AMAP

Information/Monitoring

Pollution of the Arctic: The role of the Arctic Monitoring and Assessment Programme (AMAP) in reducing pollution of the Arctic and around the globe

Lars-Otto Reiersen[a*], Katrin Vorkamp[b], Roland Kallenborn[c,d,e]

[a] Arctic Knowledge Ltd, Oslo, Norway, former Executive Secretary, Arctic Monitoring and Assessment Programme (AMAP)

[b] Department of Environmental Science, Aarhus University, Roskilde, Denmark

[c] International Joint Research Center for Arctic Environment and Ecosystem (IJRC-AEE), Polar Academy (PA), Harbin Institute of Technology, Harbin, P. R. China

[d] Faculty of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences (NMBU), Ås, Norway

[e] University of the Arctic (UArctic), Rovaniemi, Finland

* corresponding author. E-mail: lor@arcticknowledge.no

Abstract

This article presents the initiation and implementation of a systematic scientific and political cooperation in the Arctic related to environmental pollution and climate change, with a special focus on the role of the Arctic Monitoring and Assessment Programme (AMAP). The AMAP initiative has coordinated monitoring and assessments of environmental pollution across countries and parameters for the entire Arctic. Starting from a first scientific assessment in 1998, AMAP's work has been fundamental in recognizing, understanding and addressing environmental and human health issues in the Arctic, including those of persistent organic pollutants (POPs), mercury, radioactivity, oil, acidification and climate change. These scientific results have contributed at local and international level to define and take measures towards reducing the pollution not on in the Arctic, but of the whole globe, especially the contaminant exposure of indigenous and local communities with a traditional lifestyle. The lesson learned from the work in the Arctic can be beneficial for other places of the world where contaminants may accumulate and local and indigenous peoples are living in a traditional way, e.g. in Himalaya. Global cooperation is indispensable to reduce the long-range transported pollution in the Arctic.

Keywords

Climate change, heavy metals, human health, indigenous peoples, persistent organic pollutants, radioactivity

1. Introduction

The Arctic was for a long time seen as one of the last pristine areas of the globe. However, monitoring, research and assessments performed over the last 30 years have documented that the Arctic area (

Figure *1*) is not as pristine as earlier believed. Long-range transported pollutants reach the Arctic, as well as other remote areas all over the world.

Historically, sources of pollutants within the Arctic had especially been linked to industrial sites and military installations. Some of the highest emissions of sulfur dioxide (SO_2) and heavy metals have occurred from the large smelters at Norilsk on Taimyr Peninsula and on Kola Peninsula since the 1930ies (

Figure *1*). These smelters did not use filters to reduce the emissions, which caused significant pollution of forests and freshwater ecosystems, both in the immediate surrounding of the smelters and far away (AMAP, 1998) (Figure 2). The Arctic also held sources of radioactive substances, mainly the test site for nuclear weapons at Novaya Zemlja, the storage of radioactive fuel and waste on Kola peninsula and dumped materials (containers and nuclear submarines) in the Barents and Laptev See (

Figure *1*).

However, the main pollution issues of the circumpolar Arctic include the long-range transport of persistent organics pollutants (POPs) and mercury, primarily carried to the Arctic by air, rivers and ocean currents from Asia, North America and Europe (AMAP, 1997, 1998). The bioaccumulation of these chemicals in ecosystems and their ability to biomagnify in the food

chain has led to the exposure of Arctic coastal peoples to harmful chemicals through the consumption of traditional Arctic food, including marine mammals that are high in the food chain. Fish and sea mammals have been a significant part of the traditional diet of the Northern and Arctic indigenous and local peoples living along the coasts of North America, Northern Europe, Greenland, and Chukotka, providing nutrients and energy.

The objective of this paper is to describe and discuss the historical development leading to the Arctic Monitoring and Assessment Programme (AMAP). It addresses AMAP's impact on pollution control, both in the Arctic and around the world, the impact of global pollution control on pollutant levels in the Arctic, as well as current and future challenges.

Figure 1: The Arctic area as defined by the Arctic Monitoring and Assessment Programme (AMAP). The figure is modified from AMAP (1997).

2. From cold war to Arctic collaboration: The Arctic Environmental Protection Strategy (AEPS)

After the end of World War II the two military alliances, the North Atlantic Treaty Organization (NATO) and the Warsaw Pact, constructed military bases and radar installations in the Arctic, nuclear submarines were operating under the sea ice and military airplanes crossed the Arctic area armed with nuclear weapons (Figure 3). The cold war was also taking place in the Arctic. It lasted until the mid-1980ies when US President Ronald Reagan and Soviet Secretary General Michael Gorbachev started to communicate and agreed to reduce the nuclear arsenal and thereby the global nuclear threat. In 1987 Gorbachev held a speech in Murmansk to honor the citizens for their fight during World War II. In this speech he called for a change in the Arctic, to reduce the military activities and to turn the Arctic Ocean into an ocean of peace, science and prosperity (Gorbachev, 1987). He also called for a science cooperation in the Arctic and an environmental program focusing on Arctic pollution. Prior to his speech there had been some negotiations between the East and West about the possibility to initiate an Arctic science cooperation, and in 1990 the International Arctic Science Cooperation (IASC) was established (IASC, 2015). East and West were also represented in the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP), which began operations under the United Nations Economic

Commission for Europe (UN-ECE) in 1977 and initially focused on acid rain (Rothschild, 2016). It became a cornerstone of the Convention on Long-range Transboundary Air Pollution (CLRTAP), which was signed in 1979 and entered into force in 1983.

Figure 2: Emissions of SO_2 at Pechenga and Norilsk (A) and effects on forests in Russia, Finland and Norway (B) (AMAP, 1998, 2006)

Based on Gorbachev's speech, the Finnish government initiated diplomatic activities among the Arctic countries and organized an Arctic environmental meeting in Rovaniemi, Finland, in September 1989. This process led to the establishment of the Arctic Environmental Protection Strategy (AEPS) signed in Rovaniemi in June 1991 by the Ministers of Environment of the eight Arctic Countries. As part of this declaration, the Arctic Monitoring and Assessment Programme (AMAP) was established, with the mandate to monitor and assess the pollution of the Arctic environment (ocean, land, rivers and air) and associated pollutant exposure of humans, especially of Arctic indigenous and local communities, and to provide policy recommendations based on scientific assessments. At this meeting Norway offered to host the Secretariat for AMAP, where it was established in 1992 (AEPS, 1991 a&b, Stone, 2015).

Originally, groups under the AEPS included AMAP, a group on Conservation of Arctic Fauna and Flora (CAFF), on Emergency, Prevention, Preparedness and Response (EPPR) and on the Protection of the Arctic Marine Environment (PAME). These were established as Task Forces and later renamed as Working Groups, a permanent structure, at the first AEPS ministerial meeting in Nuuk, Greenland in 1993 (Ministry of Foreign Affairs Copenhagen, 1993). However, the Canadian government had reservations to the AEPS and worked towards an Arctic organization that had more focus on the Arctic indigenous peoples' situation and on security. In 1996, the Arctic Council was established in Ottawa, Canada, based on the AEPS structure and with the objective to continue the initiated work, with a stronger focus on Arctic indigenous peoples' health and lifestyle, but not including security (Arctic Council, 1996). Thus, AMAP, CAFF, EPPR and PAME became Working Groups under the Arctic Council.

3. Development of the Arctic Monitoring and Assessment Programme (AMAP)

Prior to the ministerial meeting in Rovaniemi in June 1991, a consultation meeting regarding

an Arctic monitoring programme had been held in Leningrad (today St. Petersburg) in March 1990 between Norwegian and Russian experts. Thereafter an international workshop was held in Oslo, Norway, in November 1990, where the draft program for AMAP was upgraded to secure linkages to ongoing research and monitoring programs, to ensure synergies and avoid overlap of work with, e.g., EMEP, the Oslo and Paris Commission for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) and the International Council for the Exploration of the Seas (ICES). These synergies have led to greater international awareness of pollution issues and attempts to integrate different aspects of pollution across geographical regions. Significant part of the AMAP draft program is reflected in the ministerial declaration of the meeting in Rovaniemi (AEPS, 1991 a&b).

Figure 3: Map of military installations in 1988

In 1991, AMAP was given the mandate to monitor and assess the pollution of the Arctic from any sources. This wording was chosen to ensure that military sources were not excluded from the AMAP program (Figure 3) and enabled the comprehensive and integrative assessment of various aspects of Arctic pollution (Table 1). At the first AMAP meeting in Tromsø, Norway, in November 1991, three indigenous organizations were involved in the AEPS – the Nordic Saami Council, the Inuit Circumpolar Council (ICC) and the USSR Association of small peoples of the North (RAIPON). Observers were the United Nations Environmental Programme (UNEP), the UN-ECE, ICES, IASC, and three non-Arctic countries, i.e. the UK, Poland and Germany (AEPS, 1991a). It was one of the innovations in the AMAP concept that indigenous peoples' organizations were included as equal partners and participants in the program, together with the Arctic states, and that assessments were based on integrations of scientific and local/indigenous knowledge.

During the discussions in Tromsø in 1991, the Scandinavian countries were in favor of a mandatory pollution monitoring program in the Arctic, while the position of the USA was that all work should be based on voluntary contributions, which was the final decision. Later, the Senior Arctic Officials (SAOs), representatives of the Arctic countries' ministries of foreign affairs overseeing the work of the Arctic Council between ministerial meetings, decided that if two countries wanted to fund a project, it could be initiated even if other Arctic countries did not contribute to the project. This decision turned out to be a very efficient strategy for

financing the monitoring and assessment work as priorities differed between the Arctic countries. For example, at the beginning of the AMAP work, Norway and Russia were eager to analyze and reduce all types of radionuclide sources in the Barents region, while Canada and Denmark were interested to clarify the threats from pollutants to Arctic indigenous and local peoples. Canada and Sweden took the lead on POPs, and Finland was most concerned about the acidification of Northern lakes and forests, resulting from emissions from the Russian smelters.

Based on these national interests and following this collaborative approach, AMAP established six expert groups. Table 1 shows the priority areas for the first AMAP assessment performed over the period 1992-1997 and the lead countries for the work. The lead countries agreed to allocate necessary funding and personnel to secure the assessment work. The organizations for the Arctic Indigenous Peoples were also invited to nominate experts, but due to lack of national financial support, only few representatives took part during the first few years. Over the years all countries have contributed to all assessment groups, voluntarily, and thereby secured a comprehensive circumpolar coverage for monitoring and assessing the pollutants in question. However, the ice-covered Arctic Ocean has always been a data gap as no permanent stations exist and sampling had to rely on icebreaking ships of opportunities. Costs related to AMAP contributions, e.g. for monitoring and research programs and time for assessment experts, were generally covered from national budgets.

Table 1: Priority areas in the first AMAP assessment and associated lead Arctic countries 1992-1997 (AMAP, 1998)

Priority area	**Lead Arctic countries**
Persistent organic pollutants	Canada and Sweden
Mercury	Canada and Denmark
Oil pollution	Norway and USA
Radionuclides	Norway and Russia
Human health	Canada and Denmark
Adaptation Action for a Changing Arctic - Barents Sea - Bering/Chukchi Sea - Baffin/Davis Strait	Norway and Sweden - Finland, Norway, Russia and Sweden - Canada, Russia and USA - Canada and Denmark

4. Environmental monitoring and assessments performed by AMAP

After decisions on priority pollutants, a monitoring program was designed for the different parameters to generate the necessary data from Arctic ecosystems and humans to perform a state-of-the-art scientific assessment. A detailed monitoring program including integrated quality assurance and control (QA/QC) protocols was designed (AMAP, 1993, 2000) to ensure harmonization across the Arctic and with ongoing marine and atmospheric monitoring programs at lower latitudes. However, the primary responsibility for the implementation of monitoring activities was with the individual Arctic countries. The data obtained in the monitoring initiatives were assessed in a circumpolar perspective, following an assessment strategy developed by AMAP (AMAP, 1995). Over the years, both programs have been updated (AMAP, 1995, 2001).

The AMAP assessments are produced by scientific experts from the eight Arctic countries, representatives of Permanent Participants, i.e. organizations of indigenous peoples, and experts from countries and organizations that are observers to AMAP. Assessments undergo national reviews, to ensure completeness with regard to available data, and an international peer-review. While priority areas and assessment questions can be identified by policy makers, the scientific assessment process is conducted by independent scientific experts. The AMAP scientific assessment reports are signed off by the scientists involved, and all of them are listed as authors or contributors. The assessment reports, together with summaries for policy makers, are presented to Arctic ministers at the biannual ministerial meetings. Several assessments have also been published as scientific articles in the peer-reviewed scientific literature (e.g. AMBIO, 2011, Dietz et al., 2019, Science of the Total Environment, 2010).

The first comprehensive AMAP assessment was presented at the AMAP conference in Tromsø in April 1997. With 440 participants, this was the largest Arctic science conference ever held by that time. A few weeks later the key results and recommendations were presented to the AEPS ministerial meeting in Alta, Norway. The first scientific assessment report (AMAP 1998) was named the "brick stone" as it consisted of 871 pages addressing several aspects of Arctic pollution in a coherent manner. To make the results readable for politicians and the public a science writer was engaged to write the "layman" style report "Arctic Pollution Issues" (AMAP, 1997). In addition, a video was prepared to convey the observations and findings.

For most people, also scientists, some of the results were a surprise. The main source for the

pollutants of the Arctic was not as most people expected at that time – originating from the former Soviet Union (Figure 4)!

Figure 4: Newspaper article presenting the view at the time of Arctic pollution originating from the Soviet Union

The main results of the first assessment were as follows:

- **The POPs** observed in the Arctic ecosystems and humans such as organochlorine pesticides and industrial chemicals originated from all over the Northern hemisphere and were transported to the Arctic by the atmosphere, rivers and oceans. The atmospheric transport may only take a few days from the sources at mid-latitudes to the Arctic, while contaminant transport by the large rivers typically takes one to two years, and up to several years or even decades if contaminants are transported by ocean currents. Recent AMAP POP assessments have identified a number of new chemicals in Arctic ecosystems and documented that the changing climate influences the fate of contaminants in the Arctic (AMAP, 2017, 2021a).
- **Mercury** entering the Arctic was mainly carried by air in the gaseous phase, from all over the world, but the main sources were coal fired power plants in Southeast Asia (SEA), which is still valid today. No filters or scrubbers exist that can remove mercury from the gas phase. A new process was identified that takes place in the Arctic during the spring when the sun returns to the North: Photochemical reactions involving reactive halogens on frost flowers on the ice surfaces lead to the rapid release of accumulated mercury into the Arctic environment (Figure 5). Details on these processes can be found in the respective AMAP reports on mercury (AMAP, 1998, 2002, 2005, 2021b).
- **The acidification** of lakes and land in the North was mainly linked to the emissions from the smelters (Figure 2). Although large areas of the North American Arctic were considered to be vulnerable to acidification the assessment did not corroborate this anticipation (AMAP, 1998, 2006). In recent years, the acidification of the oceans has gained increasing interest. It is related to increases in dissolved CO_2 in the oceans and has been the subject of recent AMAP reports (AMAP, 2018).
- **The oil pollution** of the Arctic was low, except for some spill areas from corroded pipelines on the Russian tundra. Apart from these spills, the main source of oil pollution was linked to natural seeps, e.g., in the McKenzie River. However, if an oil spill

happened in the vicinity of the sea ice edge, it could stay in the area for years due to slow natural degradation and the lack of adequate cleaning equipment deployed along the Arctic coasts that can operate under sea ice condition. This is still the situation in the Arctic area today (AMAP 1998, 2010).

- **The human health** assessment documented that the Arctic indigenous and local communities in Northern Canada, Greenland, Alaska and the Faroe Islands consuming traditional food such as sea mammals and fish, had higher levels of POPs and mercury in their bodies than people living further south and closer to sources. This situation is caused by the long-range transport of these chemicals, their biomagnification in the food chain and a very slow environmental degradation, especially under low temperature. In recent years, internal exposure levels have decreased, presumably as a consequence of decreasing levels in the environment and changes in dietary habits (AMAP, 2021c). Several of these POPs found in mother milk and blood can have negative health effects, especially during pregnancy (Table 2). AMAP results confirmed that the traditional food that had secured the life of the Arctic indigenous and local peoples living along the coasts of Alaska, Northern Canada, Greenland and the Faroe Islands for generations was now contaminated with hazardous chemicals.
- Regarding the **radionuclide pollution of the Arctic**, AMAP documented that not all the radioactivity pollution of the Arctic originated from the former USSR as had been previously assumed (Figure 4). The main source of radionuclide exposure of people in the Arctic were tests of nuclear weapons performed at several locations of the world (Figure 6).
- **Risk communication** was an important aspect in this first assessment that required careful consideration. The human exposure levels in particular were very sensitive information to be conveyed to people in the Arctic. Young women were faced with the question if contaminant exposure levels could lead to health risks for their children. In order to ensure easily understandable and balanced information of local communities, including study participants, elder indigenous women worked together with the medical experts to communicate the findings and to give best advice.

Figure 5: Formation of reactive gaseous mercury (RGM) in the Arctic, in the presence of sunlight and bromine (AMAP, 2011a)

Figure 6: Sites with atmospheric testing of nuclear weapons since 1945 (AMAP, 1998 and references

276 therein)
277
278 New organic chemicals are produced and used on the global market, and some of them might
279 have properties that are similar to the POPs of the first assessment. Over the last few years,
280 AMAP has had a special focus on newly detected chemicals that are found in Arctic ecosystems
281 and humans, as a result of long-range transport and/or from local emission sources (AMAP
282 2017, 2021a). These have been categorized as **Chemicals of Emerging Arctic Concern**
283 **(CEACs)**. The detection of new chemicals in the Arctic, in particular in food items, is a health
284 concern for the peoples of the Arctic. Information on persistence, long-range transport and
285 bioaccumulation of unregulated chemicals is important for risk assessments, among others for
286 prioritization of contaminants and reviews of their POP characteristics for global regulations
287 under the UNEP Stockholm Convention on POPs.While the first assessment focused on
288 Mercury in the Arctic environment, it was also identified as a human health concern in the
289 AMAP 2002 human health assessment (AMAP 2003a). This and subsequent assessments
290 documented significant human exposure to mercury for indigenous and local people with a
291 high consumption of sea mammals, exceeding the mercury exposure of people mainly
292 consuming terrestrial food (Figure 7). A long-term study from the Faeroe Islands documented
293 that if mothers had an intake of whale meat more than twice a week, their newborn children
294 had an increased risk of irreversible neurobehavioral effects, as shown in repetition studies
295 performed at the age of 7 and 14. Table 2 shows observed effects in humans due to mercury
296 exposure (AMAP, 2003a, 2009, 2015a, 2021b).

297 In contrast to the exposure to POPs and mercury mainly occurring from the consumption of
298 high trophic-level marine species, the exposure to radionuclides is mainly related to a terrestrial
299 diet. Following the nuclear testing (Figure 6), radioactive emissions were transported from
300 these test sites with the atmosphere and deposited with precipitation. This led to a situation that
301 those Arctic inhabitants mainly living off terrestrial food, especially reindeer meat, e.g., the
302 reindeer herders and their families, were exposed to a higher radioactive dose than other Arctic
303 indigenous and local groups. On the other hand, their exposure to POPs and mercury was lower
304 because their intake of marine food was minor. The flow and bioaccumulation of radionuclides
305 in the terrestrial food chain is shown in Figure 8. The radioactive fallout accumulates in
306 mushrooms and lichen that are eaten by grazing reindeers and eventually find their way into
307 humans consuming reindeer meat. This holistic approach to exposure to different types of
308 harmful substances was a new concept developed through the AMAP work.

Surprisingly for most experts, the main source for ^{137}Cs (Cesium) observed in the Barents/Kara Seas was not related to Russian rivers and upstream Russian nuclear facilities, but originated from the UK reprocessing plant at Sellafield in the Irish Sea. For ^{99}I (Iodine) the main source was the Cap La Hague plant in France (**Error! Reference source not found.**).The accident at Chernobyl in Ukraine/USSR in 1986 is the third largest source of radioactivity affecting the Arctic, in particular southern Arctic areas. Later assessments showed that the Fukushima accident in Japan in 2011 could be traced in the Arctic, but at a very low level. The distribution by air is faster and more dangerous for humans than a leakage to and subsequent transport by the sea (Christensen et al., 1997).

Table 2: Health effects of persistent organic pollutants (POPs) and mercury observed in Arctic populations (AMAP, 2003a, 2009, 2015a, 2021b, 2021c)

Persistent organic pollutants (POPs)	**Mercury**
Immune system - Infectious diseases - Reduced effects of childhood vaccines Endocrine system - PFAS affects thyroid homeostasis during pregnancy - Interference with steroid hormone receptor functions - Low sperm concentrations - Reproductive hormone levels indicated lower Leydig cell capacity for testosterone production Type 2 diabetes associated with some POPs Potential neurobehavioral effects, also related to effects on Vitamin D Carcinogenicity	Neurobehavioral effects - on attention, memory and language - on visuospatial and motor functions - No evidence that selenium was a significant protective factor against methylmercury neurotoxicity. Cardiovascular effects, increased blood pressure More toxic if exposure occurs prenatally than postnatally Results at ages 7, 14 and 22 suggest that effects are permanent

Figure 7: Mercury concentrations in blood of mothers and women of child-bearing age. The figure was reproduced from AMAP (2021b), with permission from the Arctic Monitoring and Assessment

Programme (AMAP)

Figure 8: Deposition of ^{137}Cs over time and accumulation in the lichen-reindeer-human food chain, for Northern Finland (AMAP, 1998). “Reindeer” presents reindeer meat, “wholebody” refers to humans.

Figure *9*: Ocean transport of ^{137}Cs to the Arctic. The numbers in bold indicate the concentrations of ^{137}Cs, relatively to a maximum level of 1000 at the primary source. The years indicate the duration of transport, and the distance from the source [km] is given.

5. AMAP-related research and monitoring in Russia

Due to the situation in the Soviet Union in the 1990ies, financial resources were made available by the other Arctic countries and the Nordic Council of Ministers to support AMAP work in Russia. Specifically, the monitoring activities in Siberia (Tixi at the Lena River estuary) and Northwest Russia (Amderma) were upgraded, including the operation of monitoring stations for POPs and mercury in the atmosphere. The Typhoon laboratory at Obninsk was upgraded to deliver high quality analyses of POPs and mercury based on internationally accepted protocols and QA/QC standards including annual participation in international laboratory intercalibrations.

In addition to funds from most of the Arctic countries, the AMAP Secretariat succeeded to rise financial support in 2000 from the Global Environment Facility Programme (GEF), supported by UNEP and the World Bank, to perform a significant pollution assessment of Russian Arctic indigenous communities on Kola Peninsula, the Nenets area, Taimyr Peninsula and in Chukotka. These studies were co-led by RAIPON and the AMAP Secretariat. This project on “Persistent Toxic Substances, Food security and Indigenous peoples of the Russian North” (AMAP, 2004) was the most significant environmental and health study ever conducted in Russia at the time. The study documented for indigenous communities in Russia what AMAP had already observed in North America and Greenland, i.e. that indigenous people mainly consuming sea mammals and fish had higher levels of POPs and mercury than people with a different diet.

Fact sheets were produced to inform local communities on how to avoid these chemicals, together with local governments and the Indigenous Peoples Secretariat, an organization established to coordinate Indigenous peoples’ work under the AEPS, now part of the Arctic Council Secretariat. The study also documented that in addition to the long-range transport of contaminants, local emission sources existed that led to the contamination of drinking water

and ecosystems at large. These were mainly connected to old military installations, e.g., old rusty and leaking barrels and technical installations or abandoned radar stations leaking polychlorinated biphenyls (PCBs) and fuels into the environment (Figure 3; Figure 10).

The results were presented to the Russian government in 2004 and were followed by local actions to clean up contaminated sites and thereby reduce the exposure to the most potent contaminants in these regions, e.g., PCB and the insecticide DDT. Approximately six years later a study was performed to clarify if the information campaign and the local actions had been effective, generally showing decreased levels, but also indications of continuous emissions from local sources.

Figure 10: Barrels and old radar equipment at Franz Josef Land in 2004, presenting potential sources of oil, lubricants, polychlorinated biphenyls (PCBs) and warfare chemicals. Photos: Yuri Sychev

In May 1995, a study organized by the AMAP Secretariat in cooperation with the Russian Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet), with experts from Russia (mostly from the Navy) and from Norway, Sweden and Finland (only civilians) documented the significant nuclear sources in the Arctic and their potential threats for health and environment e.g., old nuclear submarines, nuclear waste (fluid and hard materials), power plants, etc. A report presenting these “hot spots” and also including options for cleanup and a rough cost estimate was produced and presented to the Barents Environmental Ministerial meeting in Rovaniemi, Finland in December 1995 (AMAP/NEFCO, 1995). In January 1996, this report was presented to the International Atomic Energy Agency (IAEA) in Vienna, Austria. The report, with its documentation and recommendations was an important basis for planning the cleanup actions of radioactive sources in Northwest Russia, decommissioning of 198 nuclear submarines of which 122 were in Northwest Russia, upgrading the safety procedures at the Kola Nuclear Power Plant, handling of radioactive fluid and hard waste, etc. Approximately €250 mill. (by 2010) plus in-kind contributions from Russa were spent on these actions.

6. Actions to reduce the pollution of the Arctic and the globe

Prior to the development and adoption of the UN Stockholm Convention on POPs, the only international agreement to reduce long-range transported pollution was CLRTAP under the UN-ECE. Experts from Canada and Sweden brought drafts of the AMAP 1998 assessment to

CLRTAP to inform about the presence of contaminants in the Arctic and their effects on indigenous populations (Stone, 2015, Steindal et al., 2021). The scientific data from AMAP documented the global dimension of the POP pollution and played a significant role in the establishment of the UN Stockholm Convention on POPs, which regulates chemicals on the basis of being persistent, transported over long distances, bioaccumulative and toxic. Arctic data were instrumental in the recognition of POPs as a global problem, which was caused by a variety of chemicals of different uses, but with similar physical-chemical properties favoring the transport to and accumulation in the Arctic environment. Data from the Arctic have provided evidence of persistence and long-range transport, and bioaccumulation, if measured in biota, and have been a substantial contribution to the risk assessments of new chemicals under the Stockholm Convention. Furthermore, the long-term monitoring of POPs in the Arctic has generated time series that are used to evaluate the effectiveness of these global regulations (e.g., Rigét et al., 2019). These data confirm that the regulations by the Stockholm Convention have had a significant effect in reducing the levels of POPs in the Arctic.

Similarly, the effects of long-range transported mercury on humans in the Arctic was conveyed to UNEP by experts from the Arctic countries and contributed to the UN Minamata treaty, signed in 2015 to reduce emissions of mercury (Stone, 2015, Platjouw et al., 2018). Phasing out coal-fired power plants as a significant source of mercury as well as CO_2 to the atmosphere will have the positive side-effect of reducing global CO_2 emissions as well. These international agreements have reduced the environmental levels of POPs and mercury and the associated human exposure, not only in the Arctic, but all over the world.

In addition to these long-term global conventions, actions on the regional scale have reduced the risks of contaminant exposure. Food advice was provided to the indigenous and local peoples living in the Arctic in order to reduce potential exposure risks. Local health experts in cooperation with leaders from local indigenous groups worked together to convey AMAP results and advise on their implications. The exact food advice was adjusted to the local situation and considered the importance of food security in the Arctic. Until one or two decades ago, alternative food sources to cover the need for energy and vitamins were not easy to provide in the North. In addition, the traditional local food has an important role in the cultural identity of many peoples, as well as a social function in the communities, which goes far beyond the role of food for energy and nutrition supply. Figure 11 shows an example from the Faroe Islands where food advice has considerably reduced the population's exposure to mercury, although Hg levels in pilot whales, an important exposure source, has increased at the same

time (AMAP, 2021b).

Figure 11: Summary of dietary advice given to the population of the Faroe Islands, along with mercury levels in human hair and blood as well as mercury levels in pilot whales. The figure was reproduced from AMAP (2021b), with permission from the Arctic Monitoring and Assessment Programme (AMAP).

Figure 12a shows decreasing levels of DDE (the persistent transformation product of the insecticide DDT) and mercury in the blood of people living in the Arctic. This decrease likely reflects a combination of results from food advice and generally decreasing levels in the environment, including Arctic animals (AMAP, 2015a). Table 2 shows observed effects related to POP and mercury exposure.

Figure 12b: Concentration development of p,p'-DDE (A) and mercury (B) in blood of Inuit from Greenland and Nunavik, Canada (AMAP, 2015a)

7. Climate change

Climate and ozone/UV were part of the first AMAP assessment report in 1998 but covered only 50 pages of the 871-page report! In the 1990ies the political focus was mainly on ozone and UV due to the ozone hole observed over Antarctica. The AMAP assessment did not find a similar ozone depletion over the Arctic (AMAP, 1998). Regarding climate change, the conclusions of the first AMAP assessment in 1998 were: There are three signals observed over the Arctic, some areas are warming, part of the ocean is cooling and for some areas there is no clear signal.

Since 1998, climate change has gained importance in AMAP, also related to combined effects with pollutants in the Arctic (AMAP, 2021a). At the 1997 AEPS ministerial meeting in Alta it was decided, based on a proposal by the USA, that AMAP should prepare a more comprehensive climate assessment report. The first meeting of the Assessment Steering Group for the climate assessment was held at the US National Oceanic and Atmospheric Administration (NOAA) center, Silver Spring Washington DC, in 1999. At this meeting a close cooperation started between AMAP, IASC and CAFF on an assessment related to climate

change, the Arctic Climate Impact Assessment (ACIA) (AMAP, 1999).

In November 2004, the ACIA report was presented at a science conference in Reykjavik, Iceland, and the following week to the Arctic Council ministerial meeting. A key conclusion was that climate change was not a future scenario, but already ongoing "now". Another important conclusion was that the melting of land and sea ice would make new resources accessible (e.g. minerals and marine species) and open a commercial shipping route between Northwest Europe and Northern Asia. This would reduce the traditional route via the Suez Canal by 40% (ACIA, 2004, 2005).

This result triggered interest among many non-Arctic countries to call for an observer status at the Arctic Council e.g., China, Japan, South Korea, Singapore, the EU, etc. They wanted to learn more about the accessibility to the new resources such as minerals, oil and gas and fisheries, and not least about the general effects of a changing climate that would also affect lower latitudes.

Since 2004, AMAP has delivered several climate-related assessments, e.g., related to contaminants (AMAP, 2003b, UNEP/AMAP, 2011) as well as Short Lived Climate Forcers such as black carbon (AMAP/Bluestein, 2008, AMAP, 2011b, 2015b, 2021d) and methane (AMAP, 2015c). A report on the Arctic Ocean acidification documented that the cold Arctic seas would become acidic faster than warmer oceans would because cold water can store more CO_2. Some of the Arctic Sea may become corrosive within the next decade (AMAP, 2018). The same process takes place in Antarctic oceans.

A bilateral agreement between the Intergovernmental Panel on Climate Change (IPCC) chair Robert Watson and the ACIA chair Robert Corel in October 2000 ensured collaboration between the organizations. The AMAP climate assessments have been made available to the work of the IPCC and several lead authors have contributed to the work by both organizations, but the content has not always found its way into their reports, due to some obstacles in the process, e.g. number of pages allocated to the polar areas.

8. Sustaining Arctic Observing Network (SAON)

During the AMAP assessments some obstacles were met, related to accessing geographical areas for observations and to the use of stored data at private and governmental institutions.

Some institutes requested payment for data to be used in assessments. These institutes view their data as their "family silver" that could be sold several times to different users. In addition, data sharing was not necessarily beneficial for a young researcher's career who was expected to be the first author of a publication. The willingness to share data was not credited. In an attempt to overcome some of these obstacles, AMAP and IASC took an initiative in the mid-1990ies to improve the observation network and the access to data (Arctic Council, 2006). In 2011 the Arctic Council established the Sustaining Arctic Observing Network (SAON: https://www.arctic-council.org/projects/saon/). SAON has improved the availability of Arctic monitoring and research data to international networks and agreements such as EMEP, OSPAR, Working Groups of the Arctic Council as well as the UN Stockholm and Minamata Conventions.

In 2017, the existing collaboration on environmental research and monitoring in the Arctic was extended to other fields of research. An Arctic research agreement was negotiated under the Arctic Council umbrella and signed by Ministers of Science of the Arctic countries. The first Arctic Science Ministerial Meeting was held in the USA in 2016, two more ministerial meetings have been held subsequently, one in Berlin in 2018 (co-hosted by Finland, Germany and the EU) and a partly virtual meeting in 2021 (co-hosted by Iceland and Japan) (Arctic Science Ministerial, 2021). Despite discussing observing networks and data sharing continuously, these issues have not been fully resolved yet.

–

9. Inspiration from the Arctic collaboration

9.1 Hindu Kush Himalaya (HKM) – International Centre for Integrated Mountain Development (ICIMOD)

A substantial part of the chemical pollutants transported to the Arctic is produced, used and released in SEA. Significant pollution and contaminant exposure also occurs locally in these emission areas. If actions can be taken in SEA to reduce/stop the pollution in the region, it will have positive effects not only for the Hindu Kush Himalaya (HKM) region, but also other areas of the world, including the Arctic.

ICIMOD is an intergovernmental knowledge and learning center that develops and shares research, information, and innovations to empower people in the eight regional member

countries of the HKM – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan. The head office is in Kathmandu, Nepal. The AMAP Secretariat was invited to inform about the Arctic Council and AMAP, the scientific and outreach work and AMAP's products. They also informed about the impacts these reports had for international agreements, such as the UN Stockholm and Minamata Convention, and about regional actions, such as food advice to the local and indigenous Arctic people.

Several meetings and workshops have been held in Kathmandu, Nepal and Tromsø, Norway. Inspired by the AMAP work ICIMOD established HIMAP (Himalaya Monitoring and Assessment Program) and in 2019 a comprehensive climate and environmental report of 600 pages was delivered to the IPCC (Wester et al., 2019).

9.2 Antarctica

Over the years there have been contacts between the AMAP Secretariat and scientists working in the Antarctic region to benefit from AMAP's expertise for a POP monitoring program in the Antarctic area (Bengtson Nash, 2011). Recently, an Antarctic Monitoring and Assessment Programme (AnMAP) has been proposed, and advice has been sought from the AMAP Secretariat and scientists involved in AMAP regarding the AMAP experience of harmonizing monitoring initiatives and implementing new technologies in contaminant monitoring. This is an ongoing process.

10 Reflections and recommendations

The development of AMAP happened on the positive political wave after the cold war and the speech held by Michael Gorbachev in 1987 and systematized, expanded, coordinated and improved Arctic research and monitoring. This process has provided very important information for a better understanding of the pollution and climate change of the Arctic, its ecosystems and human inhabitants, in circumarctic assessments involving indigenous peoples. It has also provided the necessary scientific documentation for global actions to reduce the pollution and exposure of humans in the Arctic, but also all over the world. This scientific work has been a significant peace process to keep the Arctic as a low-tension area where one could solve questions through dialogue and joint work. A process that other parts of the world could learn from.

There are still significant pollutant questions to be handled, especially how to incorporate risks

for Arctic pollution in approval systems for use of new chemicals, with could be POPs, e.g. including documentation related to toxicity and persistence at low temperatures, the interactions between lower latitudes and the Arctic – and vice versa.

Today – in September 2022, with the conflict in Ukraine, the Arctic Council and its working groups are put on hold. The near future of the next five to ten years may not see the same positive cooperation as had been the situation from 1987 until the winter of 2021/2022. Given the rapid changes in the Arctic, a disruption in collaboration and science-based policy advice can have dramatic consequences for the Arctic environment.

Science cooperation is an important contributor to peace and prosperity, as Michael Gorbachev called for in 1987. While this article was in preparation, he passed away on the 30th of August 2022. The hope is that new leaders can stand up like him and continue the work initiated in 1987.

Acknowledgements

The authors wish to acknowledge the scientists and local communities involved in the AMAP monitoring and assessments as well as the reviewers of the scientific assessments. This long-term work would not have been possible without the dedicated contributions from the AMAP Working Group and the Secretariat. The AMAP work benefitted from financial support by the Arctic countries, the Nordic Council of Ministers, the Nordic Environment Finance Corporation (NEFCO) and the Global Environment Facility Programme (GEF).

References

ACIA, 2004. Impacts of a warming Arctic: Arctic Climate Impact Assessment. Cambridge University Press. iv+140pp.

ACIA, 2005. Arctic Climate Impact Assessment. Cambridge University Press. v+1042pp.

AEPS, 1991a. Arctic Environmental Protection Strategy, 45pp.

AEPS, 1991b. Declaration on the protection of the Arctic environment, 5pp.

AMAP, 1993. The Monitoring Programme for Arctic Monitoring and Assessment Programme, AMAP. AMAP Report 93:3. Arctic Monitoring and Assessment Programme, Oslo, Norway. 144 pp.

AMAP, 1995. Guidelines for the AMAP Assessment. AMAP report 95:1. Arctic Monitoring and Assessment Programme, Oslo, Norway. iii+64 pp.

AMAP, 1997. Arctic Pollution Issues: A State of the Arctic Environment Report. Arctic Monitoring and Assessment programme, Oslo, Norway. xii+188 pp.

AMAP, 1998. AMAP Assessment Report: Arctic Pollution Issues. Arctic Monitoring and Assessment Programme, Oslo. xii+859 pp.

AMAP 1999. Minutes from the First meeting of the Assessment Steering Group (ASG-II) of the Arctic Monitoring and Assessment Programme. Silver Spring, MD, USA, 8-10 March 1999. Arctic Monitoring and Assessment Programme, Oslo, Norway. 9+32pp.

AMAP, 2000. Report from the Expert Meeting on Sampling and Analyses of Persistent Toxic Substances (PTS). AMAP Report 2000:6, Arctic Monitoring and Assessment Programme, Oslo, Norway, 31pp+7 Appendixes.

AMAP, 2001. Guidelines for the AMAP Phase 2 Assessments. AMAP Report 2001.1. Arctic Monitoring and Assessment Programme, Oslo, Norway 53pp.

AMAP, 2002. Arctic Pollution. Persistent Organic Pollutant, Heavy Metals, Radioactivity, Human Health, Changing Pathways. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xii+112pp.

AMAP, 2003a. AMAP Assessment 2002: Human Health in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xiv+137pp.

AMAP, 2003b. AMAP Assessment 2002: The Influence of Global Change on Contaminant Pathways to, within, and from the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xii+65pp.

AMAP, 2004, Persistent toxic substances, food security and indigenous peoples of the Russian north. Final report. Global Environmental Facility, United Nations Environmental Programme, Arctic Monitoring and Assessment Programme and Russian Association of the Indigenous Peoples of the North, Siberia and Far East. AMAP, Oslo. Norway. 192pp.

AMAP, 2005. AMAP Assessment 2002: Heavy Metals in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xiv+137.

AMAP, 2006. AMAP Assessment 2006: Acidifying Pollutants, Arctic Haze and Acidification in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xii+112pp.

AMAP, 2009. AMAP Assessment 2009: Human Health in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xiv+254.

AMAP, 2010. Assessment 2007: Oil and Gas Activities in the Arctic – Effects and Potential Effects, Volume 2. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. vii+277pp.

AMAP, 2011a. AMAP Assessment 2011: Mercury in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xiv + 193 pp.

AMAP, 2011b. The Impact of Black Carbon on Arctic Climate. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. 70pp.

AMAP, 2015a. AMAP Assessment 2015: Human Health in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. vii+165 pp.

AMAP, 2015b. AMAP Assessment 2015: Black carbon and ozone as Arctic climate forcers. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. vii+116 pp.

AMAP, 2015c. AMAP Assessment 2015: Methane as an Arctic climate forcer. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. vii+139pp.

AMAP, 2017, AMAP Assessment 2016: Chemicals of Emerging Arctic Concern. Arctic Monitoring and Assessment Programme (AMAP), Oslo. Norway. xvi+353pp.

AMAP, 2018. AMAP Assessment 2018: Arctic Ocean Acidification. Arctic Monitoring and Assessment Programme (AMAP), Tromsø, Norway. vi+187pp

AMAP, 2021a. AMAP Assessment 2020: POPs and Chemicals of Emerging Arctic Concern: Influence of Climate Change. Arctic Monitoring and Assessment Programme (AMAP), Tromsø, Norway. viii+134pp.

AMAP, 2021b. AMAP Assessment 2021: Mercury in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Tromsø, Norway. 324pp.

AMAP, 2021c. AMAP Assessment 2021: Human Health in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Tromsø, Norway. x+240pp

AMAP, 2021d. Impacts of Short-lived Climate Forcers on Arctic Climate, Air Quality, and Human Health, Summary for Policy-makers. Arctic Monitoring and Assessment Programme (AMAP), Tromsø, Norway. 20pp.

AMAP/Bluestein et al., 2008. Sources and Mitigation Opportunities to Reduce Emissions of Short-term Arctic Climate Forcers. AMAP Technical Report No. 2 2008. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. 14pp

AMAP/NEFCO, 1995. The Nordic Environment Finance Corporation (NEFCO) Barents Region Environmental Programme. Phase 1 report. Proposals for environmentally sound investment projects in the Russian part of the Barents region. Volume two: radioactive contamination. Prepared by AMAP Expert Group. Oslo, Norway. 41pp.

AMBIO, 2011. Arctic Cryosphere: Changes and Impacts. AMBIO Vol 40. Supplement 1. Special Report. Springer.

Arctic Council, 1996. Declaration on the establishment of the Arctic Council. Joint communique of the governments of the Arctic Countries on the establishment of the Arctic Council, Ottawa, Canada, September 19. 5pp.

Arctic Council, 2006, Salekhard declaration on the occasion of the tenth anniversary of the Arctic Council the Fifth AC Ministerial Meeting the 26th of October 2006, Salekhard, Russia. 11pp.

Arctic Science Ministerial, 2021, Joint Statement of the Ministers. On the occasion of the Third Arctic Science Ministerial, 9 May 2021, Tokyo, Japan. Ministry of Science and Culture,

673 Iceland and Ministry of Education, Culture, Sport, Science and Technology, Japan. 10pp.

674 Bengtson Nash, S., 2011. Persistent organic pollutants in Antarctica: current and future
675 research priorities. *Journal of Environmental Monitoring* 13, 497-504.

676 Christensen, G.C., G.N. Romanov, P. Strand, B. Salbu, S.V. Malyshev, T.D. Bergan, D.
677 Oughton, E.G. Drozhko, Y.V. Glagolenko, I. Amundsen, A.I. Rudjord, T.O. Bjerk and B. Lind,
678 1997. Radioactive contamination in the environment of the nuclear enterprise "Mayak" PA.
679 Results from the joint Russian-Norwegian field work in 1994. *Science of the Total Environment*
680 202, 237-248,

681 Dietz, R., R.J. Letcher, J.-P. Desforges, I. Eulaers, C. Sonne, S. Wilson, E. Andersen-Ranberg,
682 N. Basu, B.D. Barst, J.O. Bustnes, J. Bytingsvik, T.M. Cielielski, P.E. Drevnick, G.W.
683 Gabrielsen, A. Haarr, K. Hylland, B.M. Jenssen, M. Levin, M.A. McKinney, R.D. Nørregaard,
684 K.E. Pedersen, J. Provencher, B. Styrishave, S. Tartu, J. Aars, J.T. Ackerman, A. Rosing-
685 Asvid, R. Barrett, A. Bignert, E.W. Born, M. Branigan, B. Braune, C.E. Bryan, M. Dam, C.A.
686 Eagles-Smith, M. Evans, T.J. Evans, A.T. Fisk, M. Gamberg, K. Gustavson, C.A. Hartman, B.
687 Helander, M.P. Herzog, P.F. Hoekstra, M. Houde, K. Hoydal, A.K. Jackson, J. Kucklick, E.
688 Lie, L. Loseto, M. Mallory, C. Miljeteig, A. Mosbech, D.C.G. Muir, S.T. Nielsen, E. Peacock,
689 S. Pedro, S.H. Peterson, A. Polder, F.F. Rigét, P. Roach, H. Saunes, M.-H.S. Sinding, J.U.
690 Skaare, J. Søndergaard, G. Stenson, G. Stern, G. Treu, S.S. Schuur and G. Víkingsson, G.,
691 2019. Current state of knowledge on biological effects from contaminants on arctic wildlife
692 and fish. *Science of the Total Environment* 696, 133792.

693 Gorbachev, M., 1987. The Speech in Murmansk at the ceremonial meeting on the occasion of
694 the presentation of the Order on Lenin and the Gold Star Medal to the city of Murmansk.
695 October 1, 1987. Novosti Press Agency, Moscow 23-31pp.

696 IASC, 2015, The International Arctic Science Committee (IASC) after 25 years. IASC,
697 Potsdam. 127 pp.

698 Ministry of Foreign Affairs Copenhagen, 1993. The Nuuk Declaration on Environment and
699 Development in the Arctic. The Arctic Environment: Second Ministerial Conference, 16
700 September 1993 – Nuuk, Greenland. Report. Ministry of Foreign Affairs, Copenhagen, 22p.

701 Platjouw, F.M., E.H. Steindal and T. Borch, 2018. From Arctic Science to International Law:
702 The Road towards the Minamata Convention and the role of the Arctic Council. *Arctic Review*
703 *of Law and Politics* 9, 226-243.

704 Rigét, F.F., A. Bignert, B. Braune, M. Dam, R. Dietz, M. Evans, N. Green, H. Gunnlaugsdóttir,
705 J. Kucklick, R. Letcher, D. Muir, S. Schuur, C. Sonne, G. Stern, G. Tomy, K. Vorkamp and S.
706 Wilson, 2019. Temporal trends of persistent organic pollutants in Arctic marine and freshwater
707 biota. *Science of the Total Environment* 649, 99-110.

708 Rothschild, R., 2016. Détente from the air: Monitoring of air pollution during the cold war.
709 *Technology and Culture* 57 (4), 831-865.

710 Science of the Total Environment, 2010. Special Issue: Levels, trends and effects of legacy and
711 new persistent organic pollutants in the Arctic: An AMAP Assessment. Elsevier, Volume
712 408/15, 200pp.

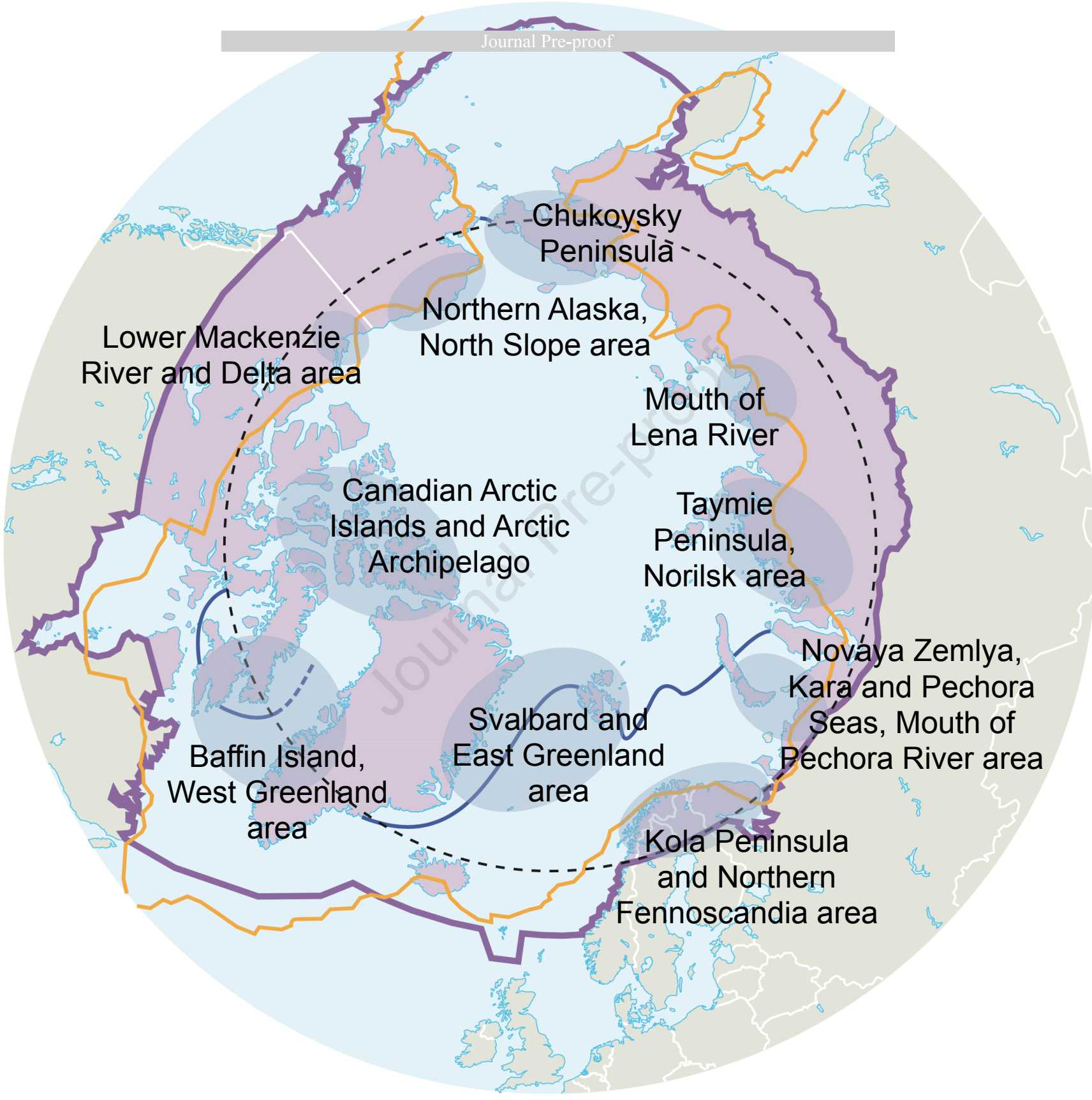
713 Steindal E.H., M. Karlsson, Hermansen, E.A., T. Broch and F.M. Platjouw F.M., 2021.
714 Addressing Multiple Stressors Under the Stockholm Convention. *Arctic Review on Law and*
715 *Politics* Vol. 12, 2021, pp. 80–107.

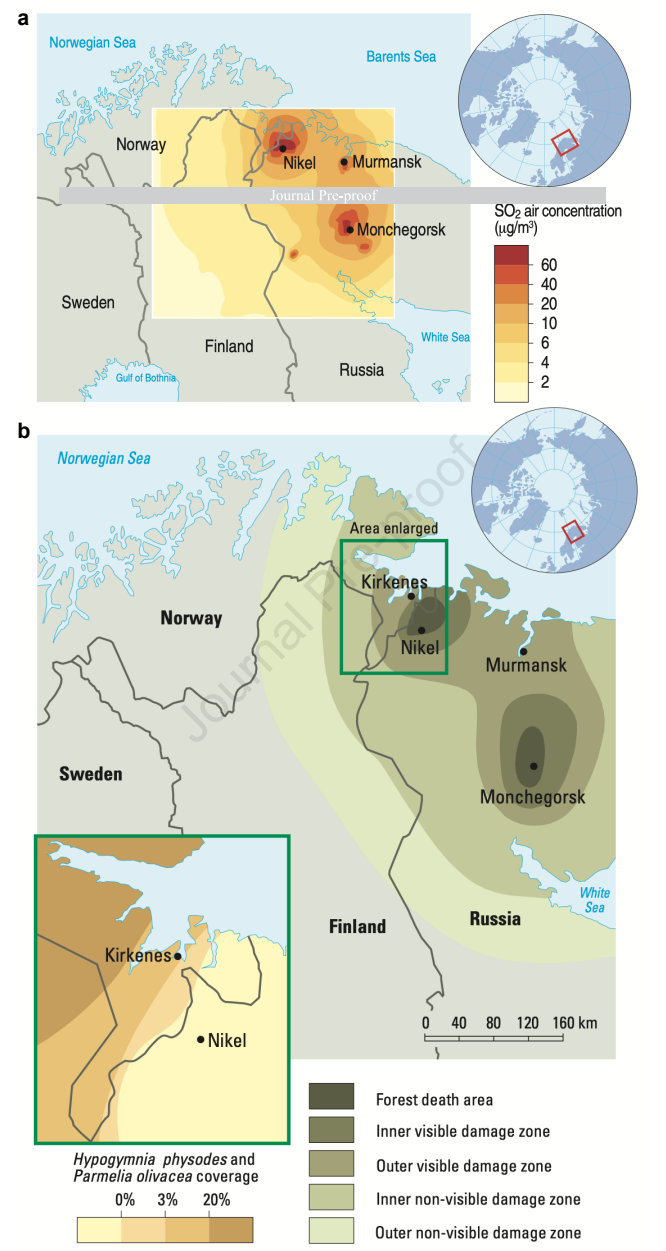
716 Stone, D.P., 2015. The Changing Arctic Environment, The Arctic Messenger. Cambridge
717 University Press. Cambridge, UK. 360pp.

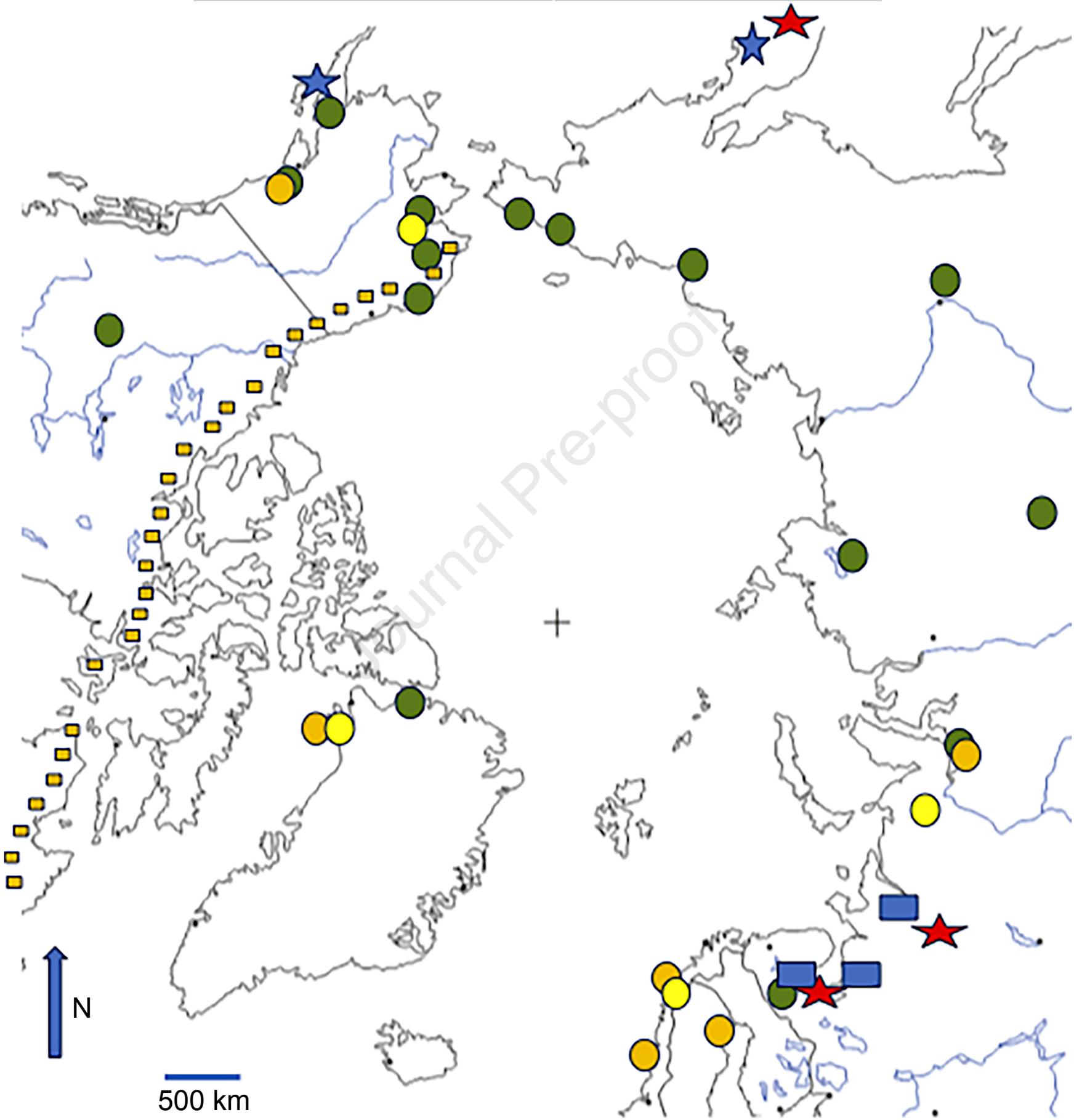
718 UNEP/AMAP, 2011. Climate Change and POPs: Predicting the Impacts. Report of the
719 UNEP/AMAP Expert Group. Secretariat of the Stockholm Convention, Geneva. 62pp.

720 Wester, P., A. Mishra, A. Murkherji and B. Shrestha (eds), 2019. The Hindu Kush, Himalaya
721 Assessment: Mountains, climate change, sustainability and people. ICIMOD, HIMAP,
722 Springer Nature Switzerland AG, Cham. xxii+627pp.

723




a
Norwegian Sea
Barents Sea
Norway
Nikel
Murmansk
Journal Pre-proof
Monchegorsk
Sweden
Finland
White Sea
Russia
Gulf of Bothnia
SO2 air concentration (μg/m3)
60
40
20
10
6
4
2
b
Norwegian Sea
Area enlarged
Kirkenes
Norway
Nikel
Murmansk
Sweden
Monchegorsk
White Sea
Finland
Russia
0 40 80 120 160 km
Kirkenes
Nikel
Hypogymnia physodes and Parmelia olivacea coverage
0% 3% 20%
Forest death area
Inner visible damage zone
Outer visible damage zone
Inner non-visible damage zone
Outer non-visible damage zone



CANADA'S NATIONAL NEWSPAPER

The Globe and Mail

Sunrise 7:45 Sunset 4:42
Windy, flurries
High -3
Weather details on page 2

145th YEAR, NO. 43,378 ■ THURSDAY, DECEMBER, 15, 1988

Soviet, European pollution threatens health in Arctic

BY MATTHEW FISHER
The Globe and Mail

CHESTERFIELD INLET, NWT

Canadian scientists fear that the health of Canada's 22,000 Inuit has been put at risk by pollution from chemicals used primarily in agriculture and industry in the Soviet Union and Europe.

The chemicals, including PCBs and DDT, have entered the fragile Arctic ecosystem and are being found in the fish and animals that form the basis of the Inuit diet.

PCBs, polychlorinated biphenyls, have been linked to cancer in laboratory animals and to brain, liver and other defects in humans. The pesticide DDT was banned in the early 1970s in Canada and the United States.

Federally financed research conducted over the past four years in the Far North has found dozens of toxic substances in every part of the Arctic food chain, from bottom-feeding sea organisms to seals, polar bears and Inuit mothers' milk.

The potential magnitude of the problem is such that "the Inuit might have to go on a diet of chicken and beef," said Dennis Gregor of Environment Canada's water quality branch in Regina. He is in charge of a special study of toxic substances found in Arctic snow.

"That would require a huge diet and cultural change. It would not be good for them," Mr. Gregor said.

The chief medical officer for the Northwest Territories, David Kinloch, said: "We are finding a whole range of toxic substances. . . For the people of the Northwest Territories it is a very fundamental question — the contamination of their food supply."

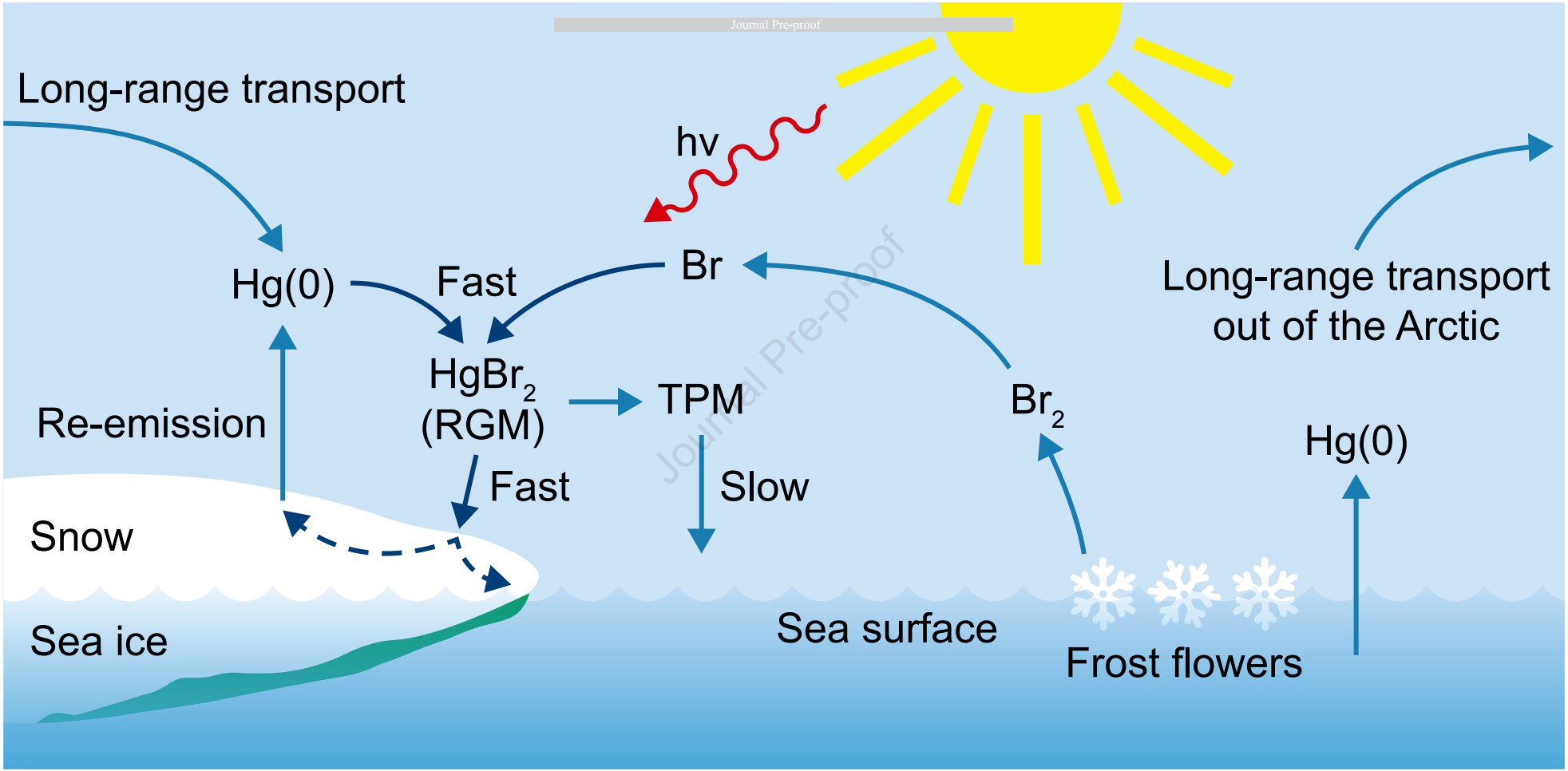
The inter-departmental project to identify the contaminants and analyze the risk they pose to Inuit and Arctic wildlife "is our highest priority," said the program's co-ordinator, Grant Bangay, director of regional planning and resources for the Department of Indian Affairs and Northern Development.

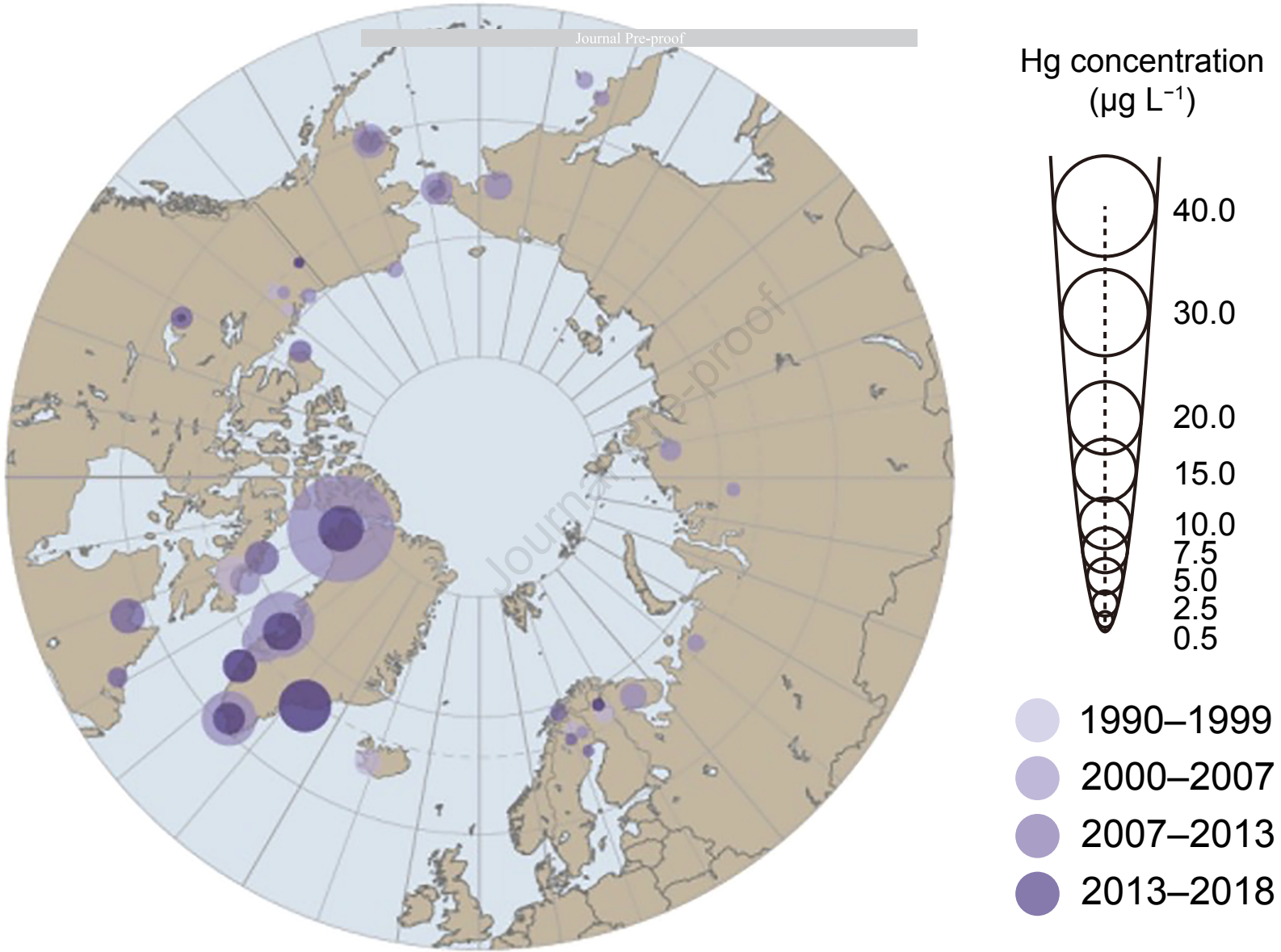
While it is too early to draw categorical conclusions from the research, Hiram Beaubier, director-general of natural resources and economic development for the department, said: "We acknowledge the significance of the problem. We are now preparing a report on its magnitude. . . It is being looked at very, very carefully. We are taking it very seriously."

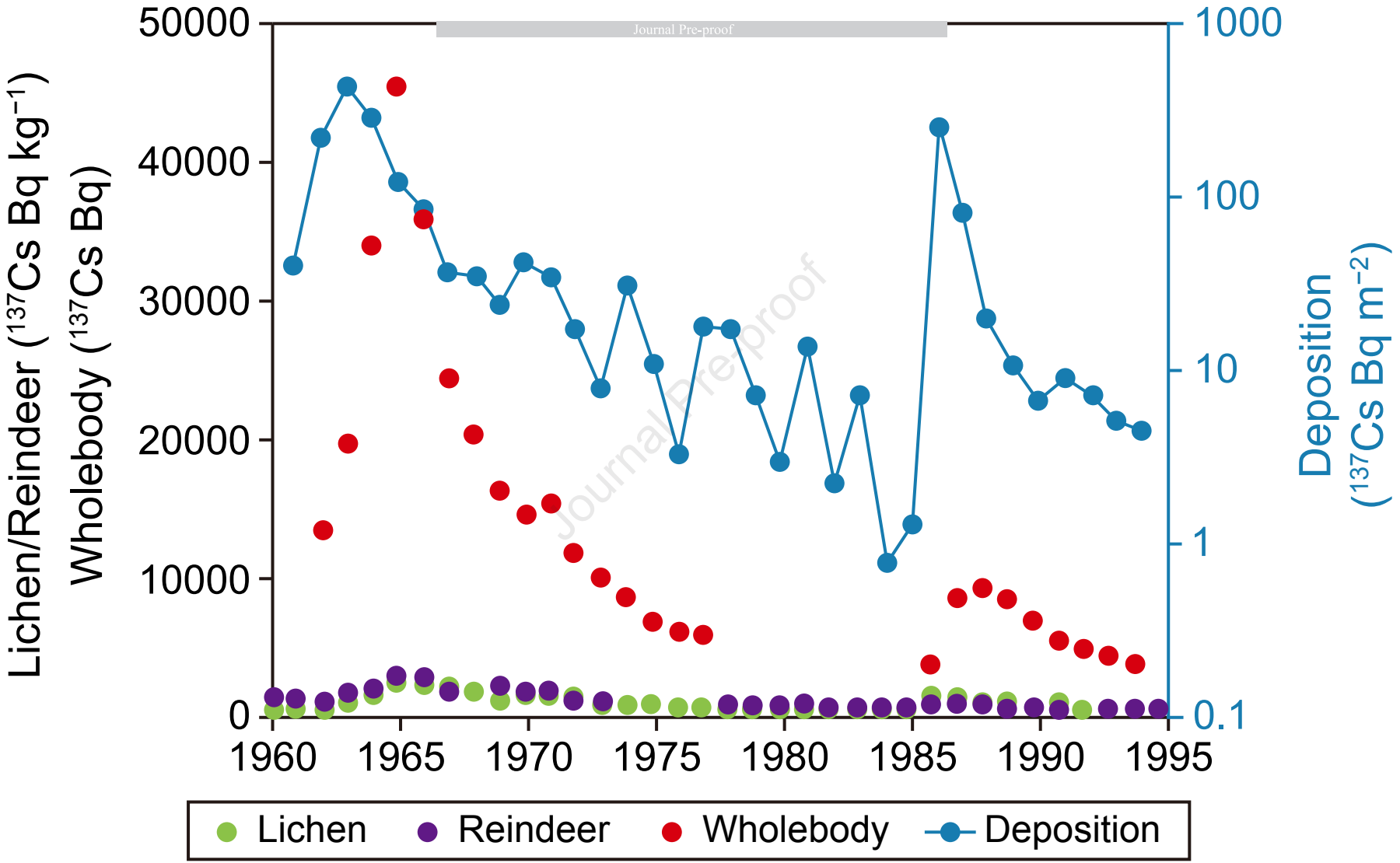
Once the situation and its effect on native northerners is better understood, the department will use "a reasoned and sensible approach" to advise those affected, Mr. Bangay said.

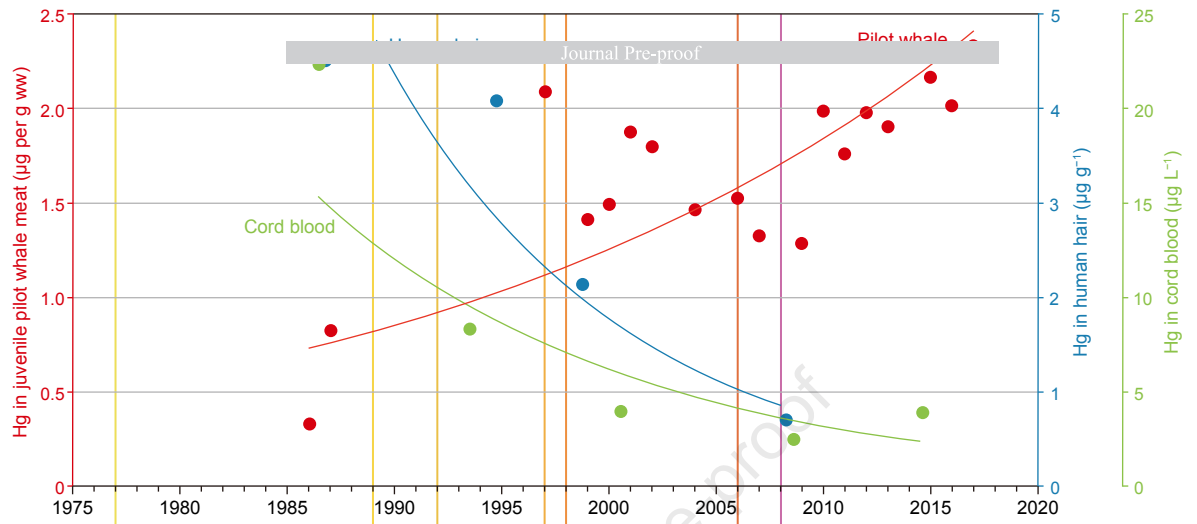
Both Mr. Bangay and Mr. Beaubier said they were concerned that the problem

NATIVE — Page A2









Recommendaton to cease consumption of pilot whale

Effects from MeHg exposure in children still stectable during adolescence

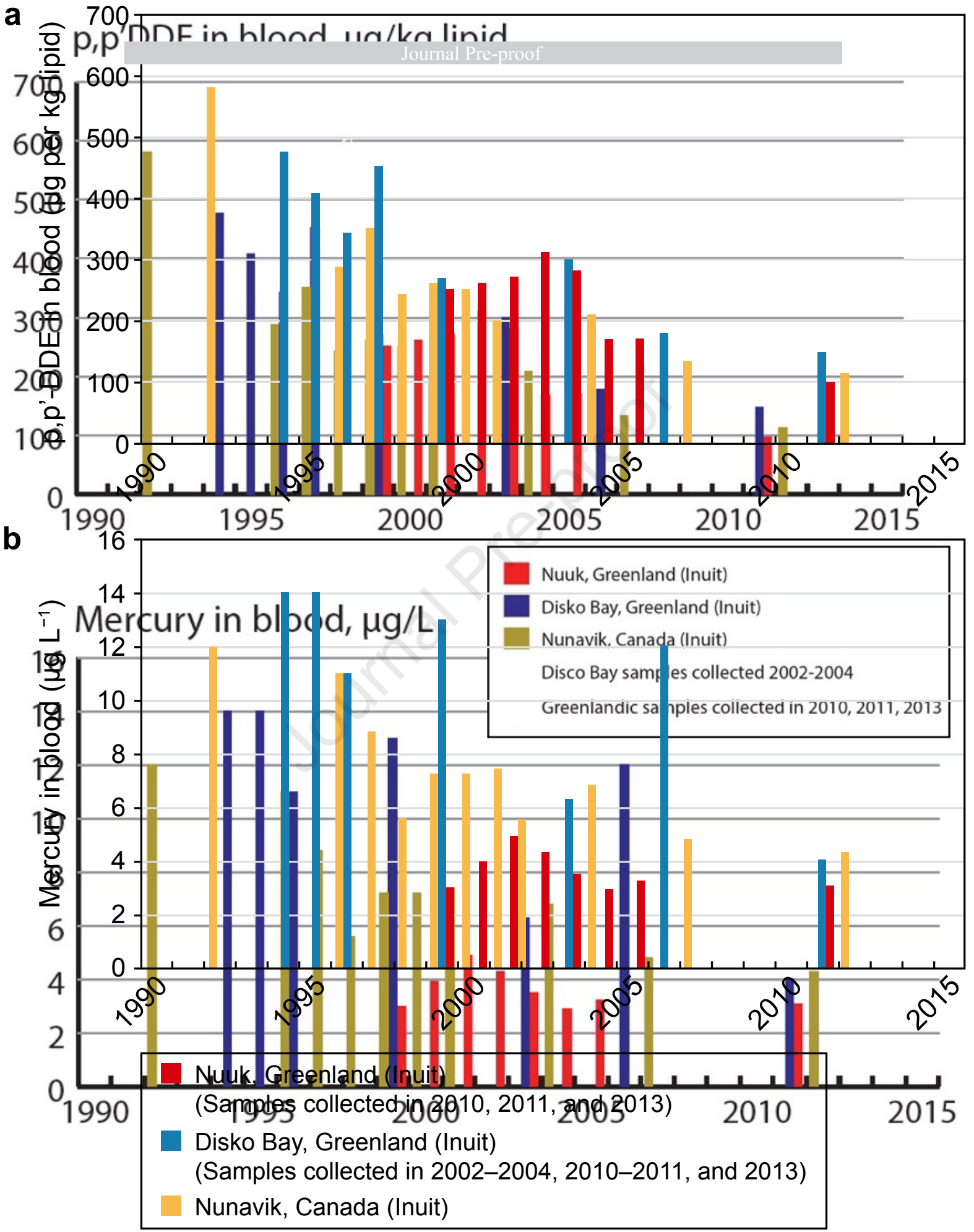
Women: advised not to eat blubber until having given birth to children and to abstain from eating pilot whale meat within three months of planning to become pregnant or breast feeding
Adults: advised not to consume pilot whale blubber and meat more than once or twice a month
General population: advised not to eat liver and kidneys

High MeHg concentrations in material hair and cord blood
Effects on brain fuction, decreased heart rate cariability and increased blood pressure in children due to prenatal MeHg exposure

Umbilical cord blood from 1023 births showed a median blood-mercury concentration of 24.2 µg L^{-1} and 25% of samples exceeded 40 µg L^{-1}

High level of mercury in pilot whale meat
General population advised to limit consumption to: 150–200 g whale meat per week; 100–200 g whale blubber per month; no liver or kidneys

High level of mercury in pilot whale meat, kidney, and liver
First recommendation to the general population to limit the consumption to only one main meal of meat weekly and avoid liver annd kidneys.



The role of the Arctic Monitoring and Assessment Programme (AMAP) in reducing pollution in the Arctic and around the globe

Lars-Otto Reiersen[a*], Katrin Vorkamp[b], Roland Kallenborn[c,d,e]

[a] Arctic Knowledge Ltd, Oslo, Norway, former Executive Secretary, Arctic Monitoring and Assessment Programme (AMAP)

[b] Department of Environmental Science, Aarhus University, Roskilde, Denmark

[c] International Joint Research Center for Arctic Environment and Ecosystem (IJRC-AEE), Polar Academy (PA), Harbin Institute of Technology, Harbin, P. R. China

[d] Faculty of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences (NMBU), Ås, Norway

[e] University of the Arctic (UArctic), Rovaniemi, Finland

* corresponding author. E-mail: lor@arcticknowledge.no

Highlights

- AMAP has monitored and assessed Arctic pollution since 1991.
- The main source of Arctic pollution is long-range transport from lower latitudes.
- AMAP data have been fundamental in developing international chemical regulations.
- Food advice has reduced contaminant exposure in local communities.
- Other monitoring and assessment frameworks have been developed after AMAP's model.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: