AMAP Assessment 2002:
Heavy Metals in the Arctic

Arctic Monitoring and Assessment Programme (AMAP), Oslo, 2005

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Executive Summary to the *Arctic Pollution 2002* Ministerial Report

The Arctic Monitoring and Assessment Programme (AMAP) was established in 1991 to monitor identified pollution risks and their impacts on Arctic ecosystems. In 1997 the first AMAP report, *Arctic Pollution Issues: A State of the Arctic Environment Report** was published.

The assessment showed that the Arctic is closely connected to the rest of the world, receiving contaminants from sources far outside the Arctic region. The report was welcomed by the Arctic Council Ministers, who agreed to increase their efforts to limit and reduce emissions of contaminants into the environment and to promote international cooperation in order to address the serious pollution risks reported by AMAP.

The AMAP information greatly assisted the negotation of the protocols on persistent organic pollutants (POPs) and heavy metals to the United Nations Economic Commission for Europe's Convention on Longrange Transboundary Air Pollution (LRTAP Convention). They also played an important role in establishing the need for a global agreement on POPs, which was concluded in 2001 as the Stockholm Convention. Persistence, long-range transport, and bioaccumulation are screening criteria under both the POPs protocol and the Stockholm Convention, to be applied to proposals to add substances to the agreements. Information from AMAP will be useful in this context in showing whether persistent substances are accumulating in the Arctic and are therefore candidates for control, and also in assessing the effectiveness of the agreements.

The Arctic Council also decided to take cooperative actions to reduce pollution of the Arctic. As a direct follow up of the AMAP reports, the Arctic Council Action Plan to Eliminate Pollution of the Arctic (ACAP) was created to address sources identified through AMAP. ACAP was approved in 2000 and several projects have begun. The AMAP information was also used in establishing priorities for the Arctic Regional Programme of Action to Prevent Pollution from Landbased Sources (RPA), developed by the working group on Protection of the Arctic Marine Environment (PAME), and adopted by the Arctic Council in 1998.

After the first assessment, AMAP was asked to continue its activities and provide an updated assessment on persistent organic pollutants (POPs), heavy metals, radioactivity, human health, and pathways in 2002. Five scientific reports and a plain-language report have been prepared. This Executive Summary provides the main conclusions and recommendations of the 2002 AMAP assessments.

International Agreements and Actions

As described above, the LRTAP Convention protocols and the Stockholm Convention are essential instruments for reducing contamination in the Arctic. However, they cannot have any effect until they are ratified and implemented.

It is therefore recommended that:
- **The UN ECE LRTAP Protocols on Heavy Metals and POPs be ratified and implemented.**
- **The Stockholm Convention on POPs be ratified and implemented.**

Specific recommendations for monitoring activities in support of these agreements are included in subsequent sections.

Persistent Organic Pollutants

The POPs assessment addresses several chemicals of concern, including both substances that have been studied for some time and chemicals that have only recently been found in the environment.

The 1997 AMAP assessment concluded that levels of POPs in the Arctic environment are generally lower than in more temperate regions. However, several biological and physical processes concentrate POPs in some species and at some locations, producing some high levels in the Arctic.

The present AMAP assessment has found that the conclusions and recommendations of the first assessment remain valid. In addition:

It has clearly been established that:
Certain Arctic species, particularly those at the upper end of the marine food chain as well as birds of prey, carry high levels of POPs. Marine mammals, such as polar bear, Arctic fox, long-finned pilot whale, killer whale, harbor porpoise, minke whale, narwhal, beluga, harp seal and northern fur seal, some marine birds including great skua, great black-backed gull and glaucous gull, and birds of prey such as peregrine falcon, tend to carry the highest body burdens.

Most of the total quantity of POPs found in the Arctic environment is derived from distant sources. The POPs are transported to the Arctic by regional and global physical processes, and are then subjected to biological mechanisms that lead to the high levels found in certain species. Several potential source regions have now been identified within and outside of the Arctic. A better understanding of local re-distribution mechanisms has also emphasized the important potential role of local processes and sources in determining observed geographical variability.

There is evidence that:
Adverse effects have been observed in some of the most highly exposed or sensitive species in some areas of the Arctic. Several studies have now been completed on a number of Arctic species, reporting the types of effects that have been associated in non-Arctic species with chronic exposure to POPs, of which there are several examples. Reduced immunological response in polar bears and northern fur seals has led to increased susceptibility

* AMAP, 1997. Arctic Pollution Issues: A State of the Arctic Environment Report. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway, xii+188 pp. *and*
AMAP, 1998. AMAP Assessment Report: Arctic Pollution Issues. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway, xii+859 pp.

to infection. Immunological, behavioral, and reproductive effects as well as reduced adult survival has been found in glaucous gulls. Peregrine falcons have suffered from eggshell thinning and reproductive effects. Reproductive effects in dogwhelks are associated with exposure to tributyltin.

It is therefore recommended that:

- **AMAP be asked to further enhance studies aimed at detecting effects in Arctic species relating to exposure to high levels of POPs and to integrate this information with an understanding of general population effects and health.** Without this understanding, it will not be possible to assess whether proposed and existing controls can be expected to afford the necessary protection (e.g., under the LRTAP and Stockholm agreements).

There is evidence that:

The levels of some POPs are decreasing in most species and media in the Arctic, but the rates vary in extent, location and media or species being studied. The decreases can be related to reduced release to the environment. For example, declines in alpha-HCH in air closely follow decreases in global usage, but declines in marine biota are much slower due to a huge reservoir of the substance in the global oceans.

For other POPs, declines are minimal and some levels are actually increasing, despite low current emissions. This illustrates the long period that may pass between the introduction of controls and the resulting decrease in levels in biota, as has been observed for PCBs, toxaphene, and beta-HCH.

It is therefore recommended that:

- **AMAP be asked to continue trend monitoring of POPs in key indicator media and biota.** This will enable assessment of whether the measures taken in the LRTAP Protocol and the Stockholm Convention are being effective in driving down POPs levels in the Arctic.

There is evidence that:

POPs substances other than those included in the LRTAP Protocol and Stockholm Convention may be at or approaching levels in the Arctic that could justify regional and global action. For example, levels of the brominated flame retardants such as polybrominated diphenyl ethers (PBDEs), polychlorinated naphthalenes (PCNs), and some current-use pesticides such as endosulfan have been monitored in Arctic air and biota. PBDEs are increasing in the Canadian Arctic.

It is therefore recommended that:

- **AMAP be asked to maintain a capacity to detect current-use POPs in the Arctic.** This will help ensure that Arctic States have an early opportunity to respond to a trend indicating Arctic accumulation, thus allowing a proactive approach to minimize the contamination rather than having to respond to a more serious situation later.

Heavy Metals

The heavy metals assessment focuses on mercury, lead, and cadmium.

It has clearly been established that:

In the Arctic, mercury is removed from the atmosphere and deposits on snow in a form that can become bioavailable. Enhanced deposition occurs in the Arctic. This recently discovered process is linked to polar sunrise, and is unique to high latitude areas. The resulting enhanced deposition may mean that the Arctic plays a previously unrecognized role as an important sink in the global mercury cycle.

There is evidence that:

Some of the deposited mercury is released to the environment at snowmelt, becoming bioavailable at the onset of animal and plant reproduction and rapid growth. Although poorly understood, this process may be the chief mechanism for transferring atmospheric mercury to Arctic food webs.

It is therefore recommended that:

- **The Arctic Council encourage expanded and accelerated research on critical aspects of the mercury cycle and budget in the Arctic.** Such research should include long-range transport, mercury deposition mechanisms, processes leading to biological exposure and effects, and the influence of climate variability and change on these processes.

There is evidence that:

Despite substantial mercury emission reductions in North America and Western Europe during the 1980s, global mercury emissions may, in fact, be increasing. Mercury emissions from waste incineration are likely underestimated. The burning of coal in small-scale power plants and residential heaters, principally in Asia, are major potential sources of current mercury emissions. These emissions are likely to increase significantly due to economic and population growth in this region.

It is therefore recommended that:

- **The Arctic Council promote efforts at global, regional, and national levels to quantify all sources of mercury and report results in a consistent and regular manner to improve emission inventories**. Particular efforts should focus on measuring contributions made by the burning of coal for residential heating and small-scale power plants as well as by waste incineration.

There is strong evidence that:

There is a trend of increasing mercury levels in marine birds and mammals in the Canadian Arctic, and some indications of increases in West Greenland. The effects of these levels are not well understood. However, there are also examples of stable or decreasing levels in other regions, perhaps indicating the importance of local or regional processes.

It is therefore recommended that:

- **AMAP be asked to continue temporal trend monitoring and the assessment of effects of mercury in key indicator media and biota.** This will enable assessment of whether the measures taken in the LRTAP Protocol are being effective in driving down mercury levels in the Arctic.

There is evidence that:
Current mercury exposures pose a health risk to some people and animals in the Arctic. These risks include subtle neurobehavioral effects.

It is therefore recommended that:
- **In view of the fact that reducing exposure to mercury can only be addressed by regional and global action to reduce worldwide emissions, and acknowledging the assessment for global action undertaken by UNEP and its resulting proposals, the Arctic Council take appropriate steps to ensure that Arctic concerns are adequately addressed and to promote the development of regional and global actions.**

It has clearly been established that:
Dramatic reduction in the deposition of atmospheric lead has occurred in Arctic regions where the use of leaded gasoline is banned. Arctic-wide elimination of leaded gasoline use will reduce lead exposure in other regions of the Arctic. Although levels in wildlife and fish have not measurably declined, likely reflecting continued uptake from the large reservoir of lead deposited in soils and sediments, lead levels in the environment are expected to diminish over time if current trends continue.

It is therefore recommended that:
- **The Arctic Council support continued efforts to eliminate the use of leaded gasoline in all Arctic regions.**

It has clearly been established that:
Certain regions of the Arctic contain elevated lead levels in the environment because of past or current use of lead shot by hunters. Even though lead shot is banned in Alaska, for example, lead blood levels in endangered US populations of Steller's eiders are above known avian toxicity thresholds for lead poisoning, which may be responsible for observed reduced breeding success. In Greenland, lead shot appears to be a significant source of human dietary exposure to lead.

It is therefore recommended that:
- **The Arctic Council encourage a complete ban on the use of lead shot in the Arctic, and that enforcement be improved.**

There is evidence that:
Cadmium levels in some seabirds is high enough to cause kidney damage. Monitoring data on cadmium in the abiotic and biotic environment to date provide no conclusive evidence of trends or effects. However, cadmium accumulates in birds and mammals and not enough is known about possible effects.

It is therefore recommended that:
- **The monitoring of cadmium in the Arctic be continued to support human exposure estimates.**

There is evidence that:
Levels of platinum, palladium, and rhodium have increased rapidly in Greenland snow and ice since the 1970s. These elements are used in automobile catalytic converters to reduce hydrocarbon pollution. The toxicity and bioaccumulation potential of these elements are largely unknown, which prevents assessment of their potential impact in the Arctic.

It is therefore recommended that:
- **AMAP be asked to consider the need to monitor trends of platinum, palladium, and rhodium in the Arctic.**

Radioactivity

The radioactivity assessment addresses man-made radionuclides and radiation exposures deriving from human activities.

It has clearly been established that:
In general, levels of anthropogenic radionuclides in the Arctic environment are declining. Most of the radioactive contamination in the Arctic land environment is from the fallout from nuclear weapons testing during the period 1945 to 1980. In some areas, the fallout from the Chernobyl accident in 1986 is a major source. For the Arctic marine environment, a major source of radionuclides is the releases from European reprocessing plants at Sellafield and Cap de la Hague.

However, releases from the reprocessing plants have resulted in increases in levels of some radionuclides in the European Arctic seas during recent years, in particular technetium-99 and iodine-129. The present doses to the population are low but the present levels of technetium in some marine foodstuffs marketed in Europe are above the EU intervention levels for food to infants and are close to the intervention level for adults.

The technetium information adds further weight to the recommendation made by AMAP to the Arctic Council in Barrow in 2000 that:
- **'The Arctic Council encourage the United Kingdom to reduce the releases from Sellafield to the marine environment of technetium, by implementing available technology.'**

There is evidence that:
Radionuclides in sediments are now a source of plutonium and cesium-137 to the Arctic. Earlier releases such as those from Sellafield that have deposited in sediments in the Irish Sea, especially cesium-137 and plutonium, have been observed to remobilize so that these deposits are now acting as sources to the Arctic. Thus, even if operational releases of these radionuclides from reprocessing plants are reduced, releases from environmental sources such as contaminated sediment in the Irish Sea and the Baltic Sea will be observed in the Arctic.

It is therefore recommended that:
- **The Arctic Council support a more detailed study on the remobilization of radionuclides from sediment and its potential effect on the Arctic.**

It is apparent that:
There is continuing uncertainty about the amount of radionuclides present at a number of sources and potential sources in the Arctic. Access to information about civilian and military sources continues to be a problem.

It is therefore recommended that:
- **The Arctic Council promote more openness of restricted information from any sources.**

It has clearly been established that:
Compared with other areas of the world, the Arctic contains large areas of high vulnerability to radionuclides. This is due to the characteristics of vegetation, animals, human diets, and land- and resource-use practices. On land in the AMAP area, there is considerable variation in vulnerability due to differences in these characteristics. In contrast, vulnerability associated with releases of radionuclides to the marine environment is relatively uniform and similar to that for other areas of the world. Maps of vulnerable areas, when combined with deposition maps, can be useful in an accident situation. The information on vulnerability is of importance for emergency planning.

It is therefore recommended that:
- **AMAP be asked to clarify the vulnerability and impact of radioactivity on the Arctic environment and its consequences for emergency preparedness planning.**

It is apparent that:
When performing risk reducing actions, close links to assessment programs are important and interventions should be prioritized in relation to the extent and magnitude of threats posed by nuclear activities, especially in respect to accidents. Interventions themselves can also have negative effects for humans and the environment, and careful judgments have to be made together with environmental impact assessments prior to carrying out a project. It is the view of AMAP that this has not always been done in interventions adopted to date.

It is therefore recommended that:
- **Risk and impact assessment programmes be performed prior to implementation of action to reduce risk.**
- **Risk and impact assessments, including accident scenarios, be performed with regard to the transport of nuclear waste and fuel within the Arctic and nearby areas and with regard to planned storage and reprocessing within the Arctic and nearby areas.**

It is apparent that:
The protection of the environment from the effects of radiation deserves specific attention. The current system of radiological protection is entirely based on the protection of human health. This approach can fail to address environmental damage in areas such as the Arctic that have low human population densities. Recently, an international consensus has emerged that the rapid development of a system and a framework for the protection of the environment needs further effort. The International Union of Radioecology (IUR), with support from AMAP, was one of the first international organizations to promote and present such a system and framework.

It is therefore recommended that:
- **AMAP be asked to take an active part in the continued efforts to address environmental protection, with special responsibility for the Arctic.** This should include the task of adding the need for protection of the environment into monitoring strategies and assessment tools.

It is noted that:
Since the previous AMAP assessment, nuclear safety programmes have been implemented in Russia at some nuclear power plants and other nuclear installations relevant to the Arctic.

It is therefore recommended that:
- **The Arctic Council continue its cooperation with Russia to improve the safety and safeguarding of nuclear installations and waste sites.**

Human Health

The human health assessment considered health risks associated with exposure to contaminants in relation to other lifestyle factors determining health. This assessment has extended geographical coverage and confirmed the conclusions and recommendations from the first assessment.

It has clearly been established that:
The highest Arctic exposures to several POPs and mercury are faced by Inuit populations in Greenland and Canada. These exposures are linked mainly to consumption of marine species as part of traditional diets. Temporal trends of human exposures to POPs have so far not been observed. Exposure to mercury has increased in many Arctic regions while exposure to lead has declined.

It is therefore recommended that:
- **The monitoring of human exposure to mercury, relevant POPs, including dioxins and dioxin-like compounds and other chemicals of concern, be continued in order to help estimate risk, further elaborate geographical trends, and begin to establish time trends of exposure.**

There is evidence that:
Subtle health effects are occurring in certain areas of the Arctic due to exposure to contaminants in traditional food, particularly for mercury and PCBs. The evidence suggests that the greatest concern is for fetal and neonatal development. In the Arctic, human intake of substances with dioxin-like effects is a matter of concern, confirmed by recent results from Greenland. Increasing human exposure to current-use chemicals has been documented, for example for brominated flame retardants. Others such as polychlorinated naphthalenes (PCN) are expected to be found in human tissues. Some of these compounds are expected to add to the total dioxin activity in humans. The AMAP human health monitoring program includes a number of measures of effects, ranging from biomarkers of effects at the molecular level to epidemiological outcomes.

It is therefore recommended that:
- **The human health effects program developed by AMAP be more extensively applied in order to provide a better base for human risk assessment especially concerning pre- and neonatal exposures.**

It has clearly been established that:
In the Arctic, diet is the main source of exposure to most contaminants. Dietary intake of mercury and PCBs ex-

ceeds established national guidelines in a number of communities in some areas of the Arctic, and there is evidence of neurobehavioral effects in children in some areas. In addition, life-style factors have been found to influence the body burden of some contaminants, for example cadmium exposure from smoking. In the Arctic region, a local public health intervention has successfully achieved a reduction of exposure to mercury by providing advice on the mercury content of available traditional foods. The physiological and nutritional benefits of traditional food support the need to base dietary recommendations on risk-benefit analyses. The health benefits of breast-feeding emphasize the importance of local programs that inform mothers how adjustments within their traditional diet can reduce contaminant levels in their milk without compromising the nutritional value of their diet.

It is therefore recommended that:
- **In locations where exposures are high, carefully considered and balanced dietary advice that takes risk and benefits into account be developed for children and men and women of reproductive age.** This advice should be developed by national and regional public health authorities in close consultation with affected communities.
- **Studies of the nutrient and contaminant content of traditional food items be promoted in order to assess their benefits and to estimate exposures as a basis for public health interventions.**
- **Breast-feeding continue to be recognized as a practice that benefits both mother and child.** Nonetheless, if contaminant levels increase or more information indicates increased risk, the potential need for restrictions should continue to be evaluated.

It is noted that:
From the Arctic human health perspective, it is of utmost importance that considerations for global actions against POPs and mercury take into account the concerns for Arctic human health. The Stockholm Convention and the LRTAP protocols should be properly monitored in the Arctic to determine whether their implementation is effective in protecting human health.

It is therefore recommended that:
- **AMAP participate in the global monitoring of human exposure to be established under the Stockholm Convention on POPs.**
- **The Arctic Council monitor proposals for global action on mercury being undertaken by UNEP, and contribute as necessary to ensure that Arctic concerns related to human health are adequately addressed.**

Changing pathways

The assessment of changing pathways provides an introduction to the types of changes on contaminants pathways to, within, and from the Arctic that might be expected as a result of global climate change and variability.

There is evidence that:
The routes and mechanisms by which POPs, heavy metals, and radionuclides are delivered to the Arctic are strongly influenced by climate variability and global climate change. These pathways are complex, interactive systems involving a number of factors, such as temperature, precipitation, winds, ocean currents, and snow and ice cover. Pathways within food webs and the effects on biota may also be modified by changes to climate. Studies using global change scenarios have indicated the potential for substantial changes in atmospheric and oceanographic pathways that carry contaminants to, within, and from the Arctic. These effects mean that climate-related variability in recent decades may be responsible at least in part for some of the trends observed in contaminant levels.

It is therefore recommended that:
- **AMAP be asked to further investigate how climate change and variability may influence the ways in which POPs, heavy metals, and radionuclides move with respect to the Arctic environment and accumulate in and affect biota.** This will enable Arctic States to better undertake strategic planning when considering the potential effectiveness of present and possible future national, regional, and global actions concerning contaminants.

Chapter 7

Conclusions and Recommendations

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The distribution of heavy metals among the various environmental compartments of the Arctic is dynamic and reflects natural sources, environmental processes, and a range of environmental factors that affect biological uptake. Superimposed on these natural patterns are anthropogenic inputs of metals. A continuing challenge in assessing the levels, trends, and effects of heavy metal contamination in the Arctic is showing the extent to which observed patterns reflect natural processes or anthropogenic inputs.

The second AMAP assessment has extended the understanding of anthropogenic sources, transport processes, trends, and effects of metals in the Arctic. This chapter provides a summary of the principal findings that emerged from the evaluation of the AMAP Phase II data and, where appropriate, in combination with the AMAP Phase I data. Many observations were consistent between the two assessments; as summarized in section 7.1. The principal results of the second AMAP assessment are provided in section 7.2. Tables 7.1 and 7.2 present an overview of the combined AMAP Phase II and AMAP Phase I results for the terrestrial, freshwater and marine environments. Conclusions and recommendations are presented in section 7.3 based on scientific results.

7.1. Phase I and Phase II – common observations

Data collected for the second AMAP assessment complement rather than duplicate earlier work. Many of the findings from AMAP Phase I were confirmed during the second assessment. These include the following.

1. The metals in the Arctic biosphere of greatest toxicological concern continue to be mercury (Hg) and cadmium (Cd). These metals occur in some Arctic biota at concentrations that may have health implications for individual animals or for human consumers. Reductions in atmospheric lead (Pb) levels are promising but due to problems identified with the use of Pb shot in waterfowl hunting, Pb remains a concern in some areas.
2. Levels of metals in Arctic soil, lakes, rivers, and oceans generally fall within global ranges for the same elements. The geographical distribution of Pb, Cd, Hg, and copper (Cu) in marine sediments appears related to the geological provinces of the Arctic.
3. While still difficult to establish spatial patterns and temporal trends for metals in the Arctic due to data limitations, increasing trends in Hg in some areas and more widespread decreasing trends in Pb have been documented.
4. The current assessment presents important new data from Alaska and Russia, filling geographical gaps in spatial coverage that were identified in the first AMAP assessment. Additional data were gathered for the evaluation of temporal trends. To improve detection of trends, statistical analyses suggest that many ongoing studies involving annual sampling need to be extended for reliable time trend evaluation.
5. Challenges associated with finding observable effects in Arctic biota and linking these to heavy metals remain considerable. Current tools are limited.

7.2. Phase II – summary of results

New data collected for the second AMAP assessment contributed significantly to the available information on heavy metals in the Arctic. Key new results on Hg, Pb, and Cd, and on other heavy metals, are described in the following sections. In addition, Tables 7.1 and 7.2 provide a compilation of data available from both AMAP Phase I and AMAP Phase II. This compilation summarizes the current state of knowledge and highlights data gaps.

7.2.1. Mercury

Mercury emissions appear to be increasing globally, despite temporary reductions in the 1990s from the implementation of better emission controls in some regions. When Hg reaches the Arctic it undergoes chemical transformations that lead to enhanced deposition during polar sunrise in the spring. A well-known neurotoxicant in its methylated form, there is now evidence that in certain regions of the Arctic, Hg environmental levels are increasing.

7.2.1.1. Sources

1. Coal burning, waste incineration, and industrial processes worldwide affect environmental inputs of Hg, even to remote regions, including the Arctic.
2. Based on 1995 emission inventories, a total of 1475 t/yr (66%) of Hg were released to the atmosphere from stationary fossil fuel combustion, with other sources including non-ferrous metal production (164 t, 7%) cement production (133 t, 6%), waste disposal (109 t, 5%), iron and steel production (29 t, 1%) as well as other sources (325 t, 15%) for a total of 2235 t emitted in 1995.

3. Emissions data from 1995 show that the majority was released from Asia (1121t, 50%). Emissions from other source regions include Africa (389t, 17%), Europe (313t, 14%), North America (215t, 10%), Australia and Oceania (113t, 5%), and South America (84 t, 4%).

4. Major emissions from fossil fuel combustion declined in Europe and North America, primarily during the 1980s and 1990s from emission controls. However, these declines are now being offset by increased emissions in Asia.

7.2.1.2. Transport pathways and transformation processes

5. Following emission to the atmosphere in gaseous form, Hg interacts, transforms, and is transported in the atmosphere over very short (e.g., one to two days in the spring in the Arctic) to very large time and space scales (e.g., one to two years for elemental Hg). Since elemental Hg has a long residence time in the atmosphere, it undergoes global scale atmospheric transport. This represents a major pathway to the Arctic environment.

6. Based on recent models, there are differences between the relative contributions of source regions to different receptor regions. Surface air is more affected by local sources. Contributions from global sources are transported at higher atmospheric levels.

7. Recently discovered transformation of elemental Hg during polar sunrise suggests that the Arctic is a global sink for Hg. Ground level ozone and elemental Hg depletions at Alert in the Canadian High Arctic provided the first evidence that conditions exist in the upper Arctic following polar sunrise that promote depletion of atmospheric elemental Hg and could explain springtime episodic Hg depletion events. Mercury depletion events have now been documented in multiple coastal locations during Arctic spring including Alert, Canada; Barrow, Alaska; Ny-Ålesund, Svalbard; and Station Nord, Greenland.

8. At Barrow, the Hg deposition mechanism has been linked with the formation of reactive gaseous mercury in the near surface air, the formation of fine particulate Hg in air, and the deposition to, and accumulation of Hg in the snowpack.

9. Mercury depletion events observed during polar sunrise are estimated to lead to the deposition of 100 to 300 tonnes of total Hg per year in the Arctic.

10. An estimated 50% ± 25% of Hg deposited on the snowpack is retained until snowmelt when it is released to the environment. In Barrow, large pulses of Hg with measured concentrations in the range 10-80 ng/L are delivered to tundra in percolation and runoff waters. Mercury that is bioavailable during periods of high biotic activity can be taken up by bacteria and potentially methylated to forms that can bioaccumulate and cause effects in developing biota. This is potentially a key step in the pathway for Hg accumulation in Arctic biota.

7.2.1.3. Spatial patterns and temporal trends

11. Long-term time series (more than 100 years) derived from sediment, ice, and peat bog cores provide evidence of increased Hg fluxes in many but not all areas of the Arctic since the pre-industrial period.

12. Of the few long-term temporal trend data sets available on Hg levels in biota, tissue levels have increased since pre-industrial times. Mercury concentrations in contemporary beluga whale (*Delphinapterus leucas*) teeth collected in the Mackenzie Delta region were 4 to 17 times higher than levels found in teeth from the pre-industrial period (1450-1650 AD). Present-day Hg concentrations in seal and human hair from Greenland are two to four times higher than in samples from the fifteenth century. Mercury levels in modern human hair from the Canadian Arctic are also several times higher than in pre-industrial (fifth and twelfth century) hair samples. Mercury in human teeth (without Hg amalgam fillings) collected in the 1970s in Norway was 13 times higher than in human teeth from the twelfth century.

13. In studies where dated lake sediments or peat bog cores were used, increased Hg levels in the surface layers were found and interpreted as evidence of increased Hg fluxes. While confounding factors must be considered when interpreting trends using lake sediment and peat bog data, increased Hg concentrations in sediments of the Pechora River and lake sediments in the region between Russia and Norway present a potential risk to freshwater organisms.

14. Shorter (up to ca. 30 year) time series were used to identify more recent trends. Significant increasing temporal trends in Hg over the last 20 to 30 year period were found in marine mammals and seabirds from the Canadian Archipelago (Beaufort Sea to Northwest Greenland) and are cause for concern. In the northeast Atlantic region, decreasing trends in Hg were observed in some fish and mussels around Iceland and western Norway. Decreasing trends were also found in some terrestrial mammals in inland western Canada (Yukon). The European Arctic shows no increasing trends in Hg.

15. The cause for apparent differences in temporal trend patterns between regions is unknown. However, the pattern coincides with the distribution of atmospheric bromine, ice cover, and other factors that could be influenced by the recently discovered atmospheric Hg depletion events that appear to increase atmospheric-surface Hg flux rates.

16. The utility of retrospective temporal trend studies based on archived samples has been clearly demonstrated. Time series of at least 10 years and up to 30 years are required to provide sufficiently powerful trend detection. With a few notable exceptions, available time series of metal concentrations in biota in the Arctic are too short to reliably detect changes of interest. However, the number of series now approaching ten or more years in length is encouraging.

Table 7.1. Summary of regional and local impacts on marine ecosystems.

	Seawater	Sediment	Algae
1. Concentrations of metals exceeding average global background			
1.1 Regional	None	None	None
1.2 Local	At point sources such as mining areas in Canada and Greenland as well as some Russian estuaries (scale <30 km)	At point sources such as mining areas in Canada and Greenland as well as some Russian estuaries (scale <30 km)	At point sources such as mining areas in Canada and Greenland as well as some Russian estuaries (scale <30 km)
2. Spatial patterns within the Arctic			
2.1 Regional	None	Sediment seems to folow geological provinces over the Arctic	None
2.2 Local	Enrichment near point sources. Increasing natural Cd from inner fjords toward the sea	Enrichment near point sources. Increasing natural Cd from inner fjords toward the sea	Enrichment near point sources. Increasing natural Cd in individuals from inner fjords toward the sea
3. Temporal trends within the Arctic			
3.1.Regional	Higher Pb levels than in prehistoric time	Hg concentrations in sediment from a number of Arctic areas show levels elevated or increasing in recent sediments	Unknown
4. Observed biological effects attributable to metals			
4.1 Regional	Not applicable	Not applicable	Not likely
4.2 Local	Not applicable	Not applicable	Possible combined effect in some Russian estuaries.

Legend:
Blue AMAP Phase I findings
Black AMAP Phase II findings

Unknown: Insufficient data to reach a conclusion.
None: No trend or effect documented from a fair amount of data.
Combined: Contamination by metals may and probably does contribute to some effects caused primarily by other factors.

Invertebrates	Fish	Seabirds	Marine mammals
Cd high in Arctic mussels and prawns	None	None	Cd is elevated in some Arctic marine mammals
At point sources such as mining areas in Canada and Greenland as well as some Russian estuaries (scale <30 km)	At point sources such as mining areas in Canada and Greenland as well as some Russian estuaries (scale <30 km)	None	None
Cd concentrations appear higher in Alaska than in the other Arctic areas, except in central West Greenland, which is known to have locally high Cd levels in biota. Hg in mussels shows no clear spatial pattern	Cd concentrations are highest in fish from Greenland and Alaska, intermediate in Canada, and lowest in the Faroe Islands. No Hg trends documented.	Cd and Hg concentrations in seabirds from the Barents Sea are lower than in Greenland, Canada and northwest Siberia. Within the Canadian Arctic, Hg levels in seabird eggs are generally higher at high latitude sites.	The highest Cd concentrations are found in ringed seals from West Greenland and eastern Canada, concentrations in Alaska are intermediate, and are lowest at sites in Labrador and Svalbard. Hg concentrations are highest in central Arctic Canada, intermediate in Alaska and Greenland, and lowest in the Norwegian Arctic.
Enrichment near point sources. Increasing natural Cd in individuals from inner fjords toward the sea	Enrichment near point sources. Increasing natural Cd in stationary fish from inner fjords toward the sea	Higher Cd and Hg concentrations were found in seabirds from Ny Ålesund compared to the rest of the Barents Sea	Not likely as few marine mammals are stationary
Unknown. Decreasing Hg trend observed in some mussels around Iceland and western Norway.	Unknown. Decreasing Hg trend observed in some fish around Iceland and western Norway.	Moderate to no increase in Hg. Significant increase of Hg in seabirds from the Canadian Archipelago.	Hg levels in seal tissue from northern Canada and Greenland as well as in toothed whales, are increasing. Concentrations of Hg in beluga teeth have increased 4- to 17-fold since the pre-industrial period. Cd has not increased.
Not likely	Not likely	None of the seabird Hg values reported under Phase II, were above toxicity thresholds. Cd high enough in some areas to pose a threat for kidney damage	Cd high enough in some areas to pose a threat for kidney damage. Pathological investigations on ringed seal, beluga, and bowhead whale have not identified Cd-related effects.
Possible combined effect in some Russian estuaries.	Possible combined effect in some Russian estuaries.	Hg levels in up to 30% of eggs from American peregrine falcon suffering reduced productivity exceeded the critical threshold for reproductive effects. Cd high enough in some areas to pose a threat for kidney damage	Cd high enough in some areas to pose a threat for kidney damage.

Table 7.2. Summary of regional and local impacts on terrestrial and freshwater ecosystems.

	Air/atmospheric deposition	Freshwater	Sediment	Soil
1. Concentrations of metals exceeding average global background				
1.1 Regional	Recently discovered transformation of elemental Hg during polar sunrise suggests that the Arctic is a global sink for Hg; 100-300 tonnes of total Hg are deposited per year in the Arctic.	None	None	None
1.2 Local	Kola Peninsula	At 'hot spots' of human/ industrial activity such as smelter complexes of the Kola Peninsula (scale 10-100 km)	At 'hot spots' of human/ industrial activity such as smelter complexes of the Kola Peninsula (scale 10-100 km)	At 'hot spots' of human/ industrial activity such as smelter complexes of the Kola Peninsula (scale 10-100 km)
2. Spatial patterns				
2.1 Regional	South to north decrease Seasonal patterns indicate different sources in different seasons. Hg high in Chukchi Seas snow	None	High Hg concentrations in Arctic Lakes. Regional differences in Hg time signal	Kola/northern Scandinavia enrichment in Cu and Ni
2.2 Local	Decrease with distance from the source region. Concentrations and effects due to Kola Peninsula industry are highest around Monchegorsk	Enrichment near point sources (Russian rivers, lakes of Kola Peninsula)	Gradients near point sources (Cu and Ni)	Gradients near point sources (Cu and Ni)
3. Temporal trend				
3.1 Regional	A decrease over the last 2 decades. Strong seasonal variation; the highest values seen in winter.	Unknown in freshwater, but large increases found relative to pre-industrial levels in ice cores	Recent Arctic-wide increase in surficial Hg concentrations in Arctic Lakes	Unknown
3.2 Local	A decrease over the last 5 years in the Kola Peninsula. Winter concentrations higher than in summer.	Unknown; however, a 20% increase in Hg has been detected in Ice cores between 1967 and 1989	Unknown	Unknown
4. Observed biological effects attributable to metals				
4.1 Regional	Not Applicable	Not Applicable	Not Applicable	Not Applicable
4.2 Local	Not Applicable	Not Applicable	Not Applicable	Not Applicable

Legend:

BlueAMAP Phase I findings
Black AMAP Phase II findings

Unknown: Insufficient data to reach a conclusion.
None: No trend or effect documented from a reasonable amount of available data.
Combined: Contamination by metals may and probably does contribute to some effects caused primarily by other factors.

Vegetation	Birds	Fish	Mammals
None	High Cd in kidney of ptarmigan	None	High Cd in reindeer/caribou kidney
At 'hot spots' of human/ industrial activity such as smelter complexes of the Kola Peninsula (scale 10-100 km)	Cd in kidney of ptarmigan high in Yukon/NWT	High Hg in fish of NWT	Unknown
Enrichment of Cu and Ni in Kola/northern Scandinavia	None	None	None
Gradients near point sources (Cu and Ni)	Cd in ptarmigan high in YukonPb in herbivores in Russia greater in east than west	Highest values for Hg occur in Canada	Cd in caribou kidney higher in Yukon than in NWT. In Norway, Cd in reindeer/moose kidney increases along N-S gradient. In Russia, Pb in reindeer liver/muscle are higher in east than in west
Unknown Post-industrial increase of Hg in peat bogs from 7-14 times	Unknown	Inconsistent pattern for Hg in fish from different regions	Unknown in land mammals due to short data series. Indications of Hg increase in humans since pre industrial times. Possible decrease in Norway since 1970
In Scandinavia, decreasing Pb and Cd levels measured using the moss monitoring technique clearly reflect changes in atmospheric deposition associated with emission reductions	Unknown	No trends in Hg, Cd, Pb, and Cu in fish based on up to 28 years of monitoring in northern Sweden	Unknown in most areas due to short time series. Decreasing Hg trend in some terrestrial mammals from Yukon, Canada. Indications of increase of Cd in liver, but stable in muscle. Pb concentrations decreased significantly in liver but showed no change in muscle. Hg concentrations in liver and muscle showed no change in reindeer from northwestern Sweden from 1983 to 2000
Combined effects	Combined effects Reduced reproduction in eiders in Alaska was reported as a result of ingestion of lead shot. Other reports included incidents of Pb poisoning in other waterfowl.	Combined effects	Combined effects
Combined effects close to point sources can cause tree death, defoliation and decline in growth	Cd in some ptarmigans from Yukon is high enough to cause kidney damage. Local displacement of birds close to point sources og metals due to lack of food and area degradation	Combined effects observed. Additional information from experimental studies available	Cd in some moose and caribou from Yukon are high enough to cause kidney damage. Possible still births due to Hg

17. Spatial patterns of Hg levels in fish and shellfish are not yet clear. However, recent work has revealed that Canadian subsistence consumption advisory limits for Hg in muscle tissue of piscivorous freshwater fish are exceeded over extensive areas of Canada. Increased circumpolar data coverage is needed to identify potential spatial patterns for these species.

18. Mercury levels in seabirds were generally lower in the Barents Sea than in Greenland, Canada, and northwest Siberia, except for four species of eider, which had similar Hg levels in all these areas. In northeast Siberia, long-tailed ducks (oldsquaw, *Clangula hyemalis*) and herring gulls (*Larus hyperboreus*) show elevated Hg levels compared to Greenland and eastern Canada. Within the Canadian Arctic, Hg levels in seabird eggs are generally higher at sites at higher latitudes.

19. Mercury levels in ringed seal (*Phoca hispida*), beluga whales, and polar bear (*Ursus maritimus*) in western Arctic Canada were found to decrease to the east. New data from Alaska and from western Canada for beluga whales, and new data from East Greenland (Tuna) for polar bear, are generally consistent with this spatial pattern. However, polar bear from Alaska had lower Hg levels than polar bear from western Arctic Canada. Mercury levels in ringed seal from Labrador were variable and in some cases similar to levels reported for the western Canadian Arctic in the first AMAP assessment, and higher than those found in Greenland, Svalbard, and Alaska.

7.2.1.4. Effects

20. Limited work on the effects of Hg on Arctic biota has been completed. Of the 152 new seabird liver and kidney samples reported, none were above toxicity thresholds previously established for Hg in non-Arctic species tested in the laboratory. Further assessment will require more sensitive measures of effects in Arctic species.

21. Mercury levels in up to 30% of eggs from American peregrine falcon (*Falco peregrinus anatum*) exceeded the critical threshold for reproductive effects. The falcon is suffering from reduced productivity, but no causal association has yet been established.

22 It is uncertain whether Hg poses a health threat to the most highly exposed groups of marine mammals found in the western Canadian Arctic, and pilot whales (*Globicephala melas*) from the Faroe Islands.

7.2.2. Lead

The reduction of Pb emissions through the decreased use of leaded gasoline around the globe is among the more successful regulatory actions in recent times. As a result, Pb deposition has decreased, although Pb levels in Arctic biota do not yet reflect this change. Lead shot from hunting remains a problem.

7.2.2.1. Sources and pathways

1. Vehicular traffic represents the primary source of atmospheric emissions of Pb (88739 t, 74%). Non-ferrous metal production is second (14815 t, 12%), then stationary fossil fuel combustion (11690 t, 10%), iron and steel production (2926 t, 2%), waste disposal (821 t, <1%), and cement production (268 t, <1%) for a total of 119259 t.

2. The largest contributions of Pb are emitted from Asia (51212 t, 43%). Other emissions come from Europe (28091 t, 24%), North America (17015 t, 14%), Africa (11349 t, 10%), South America (9118 t, 8%), and Australia and Oceania (2474 t, 2%).

3. Of global emissions, the regions emitting the most airborne Pb to the Arctic include Europe and the Asian part of Russia. Between 2% and 5% of the total anthropogenic Pb emissions from these areas is deposited in the Arctic.

4. Riverine transport of Pb to the Arctic Basin is comparable to the amount transported by the atmosphere.

7.2.2.2. Spatial patterns and temporal trends

5. Based on the Greenland Summit deep-drilling program ice core-based reconstruction of Arctic maximum metal deposition fluxes, there was a 12-fold increase in Pb deposition during the 1960s and 1970s. However, due to significant earlier contributions of Pb that had occurred by 1800, maximum deposition fluxes in the 1970s represent a 200-fold increase over pre-industrial levels.

6. Elimination of Pb additives in gasoline by environmental regulation during the 1970s and 1980s, particularly in Europe and North America, is believed directly responsible for recent decreasing trends in Pb emissions. Industrial emissions are also being reduced. These reductions are, in part, a side effect of measures introduced to reduce emissions of particles and acidifying gases.

7. Based on trends in stable Pb isotope ratios at the Greenland Summit site, the region is influenced by both North American and Eurasian air masses. The North American Pb contribution showed a rapid decline following the introduction of unleaded gasoline.

8. In Scandinavia, decreasing Pb levels measured using the moss monitoring technique clearly reflect changes in atmospheric deposition associated with emission reductions. While Pb levels in moss samples provide an effective monitor for changes in atmospheric deposition, decreasing Pb emissions are not yet reflected in the tissues of Arctic biota, where Pb levels appear to be stable.

9. Waterfowl and human subsistence exposures appear to continue in some areas (e.g., Alaska, Greenland) due to the presence in the environment of Pb shot used for hunting.

7.2.2.3. Effects

10. Reduced reproduction in eiders (*Somateria mollissima*) in Alaska was reported as a result of ingestion of Pb shot. Other reports included incidents of Pb poisoning in other waterfowl.

7.2.3. Cadmium

Cadmium levels in the Arctic environment have increased since pre-industrial times but it remains difficult to separate anthropogenic and natural sources where higher concentrations are found in wildlife. Although levels in some wildlife and marine organisms are high enough for concern, effects have not yet been detected in wild populations.

7.2.3.1. Sources and pathways

1. Based on 1995 emission inventories, non-ferrous production of zinc (Zn) and Pb is the major source of global anthropogenic Cd emissions to the atmosphere (2171 t, 73%). Other sources include stationary fossil fuel combustion (691 t, 23%) with relatively small amounts released from iron and steel production (64 t, 2%), waste disposal (40 t, 1%), and cement production (17 t, <1%) for a total of 2983 t.
2. The major contributor of Cd emissions is Asia (1463 t, 49%), then North America (482 t, 16%), South America (452 t, 15%), Europe (362 t, 12%), Africa (172 t, 6%), and Australia and Oceania (52 t, 2%). Emissions are declining in Europe and North America.
3. Less than 2% of airborne Cd emitted into the global atmosphere is deposited in the Arctic.
4. Riverine transport of Cd to the Arctic Basin is comparable to the amount transported by the atmosphere.

7.2.3.2. Spatial patterns and temporal trends

5. Data from the Greenland Summit ice core indicate that since the onset of the Industrial Revolution (i.e., 1800 AD), an eight-fold increase in deposition fluxes for Cd occurred with maximum levels reached during the 1960s and 1970s.
6. Since the 1970s (i.e., subsequent to the ice core maximum), monitoring records of moss in northern Sweden indicate that atmospheric deposition of Cd is decreasing. Recent declines may be related to a two- to three-factor decline in Cd global emissions from non-ferrous metal processing during the 1980s and 1990s.
7. In one of the longest records available on tissue concentrations of metals in Arctic biota, a statistically significant increase in Cd was found in liver of reindeer (*Rangifer tarandus*) collected in northern Sweden between 1983 and 1999. Concentrations in muscle tissue, however, did not increase.
8. Cadmium concentrations in tissues of some terrestrial birds and mammals are high compared with global background levels. Cadmium concentrations in marine organisms from large parts of the Arctic exceed levels in other regions of the globe. However, Cd levels in Arctic biota and the biotic environment, in general, do not appear to be increasing.
9. Cadmium in shellfish may be associated with local sources, as found in central west Greenland. Due to poor circumpolar coverage for fish, only limited spatial comparisons are possible. Some differences in Cd concentration are found among sub-regions, but these probably reflect natural rather than anthropogenic causes.
10. Spatial patterns in concentrations of Cd found in seabirds may be partly explained by differences in overwintering areas used by different populations. In general, seabirds appear to have higher Cd levels in northeast Siberia and lower levels in the Barents Sea.
11. The highest concentrations of Cd in ringed seals, beluga whales and polar bears reported from the eastern Canadian Arctic and northwest Greenland during the first AMAP assessment are partly confirmed by new data. Cadmium concentrations in ringed seals from the eastern Canadian Arctic and Greenland were higher than in Alaska and Svalbard. Cadmium levels in polar bears from Alaska were similar to those observed previously in western Canada.

7.2.3.3. Effects

12. Cadmium levels in some reindeer/caribou, moose (*Alces alces*), and ptarmigan (*Lagopus mutus*) from the Yukon Territory (Canada) as well as those in seabirds and marine mammals from northwest Greenland and the Faroe Islands may be high enough to cause kidney damage.
13. Pathological investigations on ringed seal, beluga and bowhead whale (*Balaena mysticetus*), including examinations of animals with Cd levels above expected effects thresholds, have not identified Cd-related effects.

7.2.4. All metals

7.2.4.1. Sources and pathways

1. The three main anthropogenic sources of heavy metals to the atmosphere are fossil fuel combustion, non-ferrous metal production, and waste incineration. Of these, emissions from waste incineration are the least understood and probably underestimated, introducing uncertainty in source inventory emission estimates for all metals and particularly for Hg.
2. Asian sources of emissions to the global environment are clearly the largest for all metals. Of these emissions, an estimated five to ten percent are deposited in the Arctic. Given expected population increases and predominant use of small coal heating fires in China, this region is likely to become an in

creasingly important anthropogenic source of heavy metals to the Arctic, even as industrial emissions are reduced in other regions owing to technological advances.

3. The highest concentrations of atmospheric heavy metals in Arctic air occur in the vicinity of smelter complexes on the Kola Peninsula and at Norilsk in Russia, and result from emissions from these smelters.

4. All heavy metal concentrations show strong seasonal variation above the Arctic Circle (High Arctic). During winter, about two-thirds of the heavy metals (except Hg) in air in the High Arctic are transported from Eurasia, particularly from the Kola Peninsula, the Norilsk region, the Urals, and the Pechora Basin. Five to ten percent of these emissions are deposited in the High Arctic. The remaining third in High Arctic air in winter is transported from industrial regions in Europe and North America. In summer, local sources dominate the contamination of the High Arctic.

5. Although atmospheric transport represents a major transport mechanism to the Arctic, particularly for Hg, rivers provide another major transport mechanism for some metals reaching the Arctic Ocean. Riverine transport pathways are equally important for Pb and Cd and rivers provide the main transport mechanism for Zn.

7.2.4.2. **Spatial patterns and temporal trends**

6. Concentrations of heavy metals measured in air on the Kola Peninsula are comparable to concentrations found in the most polluted regions of Europe and North America. With the exception of regions around point sources, however, concentrations in High Arctic air are one order of magnitude lower than concentrations in other remote non-Arctic locations and about two orders of magnitude lower than concentrations around major point sources on the Kola Peninsula. Exceptions in the Arctic include both reactive gaseous Hg and particulate Hg that can exceed non-Arctic values by several orders of magnitude.

7. Concentrations of most heavy metals measured in subarctic air have decreased over the last two decades. Exceptions are vanadium (V) and nickel (Ni), where increased emissions have been attributed to increased use of oil combustion to replace coal combustion in the power generating industry.

8. Soils respond slowly to changes in atmospheric deposition and provide a reservoir of contaminant elements that can be taken up by organisms as they interact with soils. However, moss reflects contemporary atmospheric deposition of heavy metals.

7.2.4.3. **Effects**

9. Evidence of biological effects is clearest around smelters and foundries in the Arctic where obvious changes occur in the surrounding ecosystem from a combination of sulfur fumigation and deposition of both acids and heavy metals (e.g., Cu, Ni).

10. Other than point source problems, there are few studies on biological effects on Arctic plants and animals, and fewer still that link effects in Arctic biota to heavy metal pollution.

11. Critical tissue effect thresholds are unknown for most Arctic species making the potential risks associated with observed tissue levels difficult to interpret or predict. In several cases, observed tissue levels in Arctic biota exceed exposure thresholds for effects in non-Arctic species.

7.2.4.4. **Emerging issues**

12. Greenland ice cores and recent snow samples reveal a recent and significant increase in the platinum group elements platinum (Pt), palladium (Pd), and rhodium (Rh). Concentrations of Rh in the late 1990s were 40 to 120 times higher than in ancient ice indicating that deposition of these elements in the Greenland Arctic is virtually all from industrial sources. Deposition is probably related to the increasing use of catalytic converters in automobiles. There is no indication of deposition rates stabilizing or decreasing. The toxicity and bioaccumulation potential for these elements is largely unknown, thus there is little information from which to assess likely implications of environmental increases for soils, plants, wildlife, and humans.

13. Hydrology, currents, ice, winds, and temperature are the major factors in determining the main pathways of contaminant transport, and consequently past and present fluxes of heavy metals to the Arctic. These factors are already being influenced by observed climatic changes, and more changes are predicted to occur in the future. As a result, significant alterations in metal transport pathways can be expected. This may be particularly important for Hg flux since the Hg cycle may be impacted in several ways (e.g., the influence of annual ice extent and open water on reactive halogen chemistry, changes in organic carbon cycling in the upper ocean).

7.3. Conclusions and recommendations

Based on scientific findings, the following is concluded, and recommendations for action are suggested.

7.3.1. **Mercury**

1. In the Arctic, Hg is removed from the atmosphere and deposits on snow in a form that is bioavailable (i.e., can be taken up by some microorganisms). This recently discovered process is linked to polar sunrise, and appears to be unique to high latitude areas. The resulting enhanced deposition may mean that the Arctic plays a previously unrecognized role as an important sink in the global Hg cycle. Some of the Hg deposited on snow is released to the environment at snowmelt in bioavailable forms at the onset of animal and plant reproduction and rapid growth.

Although poorly understood, this process may be the chief mechanism for transferring atmospheric Hg to Arctic food webs.

Recommendation:

- Expand and accelerate research on critical aspects of the Hg cycle and budget in the Arctic. Such research should include long-range transport and transformation processes, Hg deposition mechanisms, Hg transformation at snowmelt to bioavailable forms, the dynamics of uptake by biota leading to exposure, and effects on reproduction and growth.

2. Despite substantial Hg emission reductions in North America and Western Europe during the 1980s, global Hg emissions may, in fact, be increasing. Mercury emissions from waste incineration are probably underestimated. The burning of coal in small-scale power plants and residential heaters, principally in Asia, are major potential sources of current Hg emissions. These emissions are likely to increase significantly due to economic and population growth in this region.

Recommendation:

- Promote efforts at global, regional and national levels to better quantify all sources of Hg and report results in a consistent and regular manner to improve emission inventories. Particular effort should focus on estimating contributions made by burning coal for residential heating and small-scale power plants as well as by waste incineration.
  Continue to implement technologies that reduce Hg emissions and look for alternative strategies to reduce emissions not readily amenable to current approaches.

3. There is a trend of increasing Hg levels in marine birds and mammals in some regions of the Canadian Arctic, and some indications of increases in West Greenland (Kitaa). The effects of these levels are not well understood. However, there are also examples of stable or decreasing levels in other regions, perhaps indicating the importance of local or regional processes.

Recommendation:

- Continue temporal trend monitoring to obtain longer, more statistically reliable trend analysis, and assess the effects of Hg in key indicator media and biota. These data will enable assessment of whether the measures taken in accordance with the LRTAP (Long-range Transboundary Air Pollution) Protocol are effective in reducing Hg levels in the Arctic.

4. Current Hg exposures may pose a health risk to some people and animals in the Arctic. These risks may include subtle neurobehavioral effects as well as possible reproductive effects. Reducing exposure to Hg can only be addressed by regional and global action to reduce worldwide emissions.

Recommendations:

- Acknowledge the assessment for global action undertaken by the United Nations Environmental Program and its resulting proposals and take appropriate steps to ensure that Arctic concerns are adequately addressed. Promote the development of regional and global actions.
- Study effects in Arctic species that exhibit Hg at tissue levels of concern. Focus on effects monitoring, critical tissue effect thresholds, relationships between indicators of exposure (e.g., biomarkers) and observed effects in Arctic biota. Fill existing data gaps.

7.3.2. Lead

1. Significant reduction in the deposition of atmospheric Pb occurred in Arctic regions where the use of leaded gasoline was banned. Arctic-wide elimination of leaded gasoline use will reduce Pb exposure in other regions of the Arctic. Although levels in wildlife and fish have not measurably declined, probably reflecting continued uptake from the large reservoir of Pb deposited in soils and sediments, Pb levels in the environment are expected to diminish over time if current trends continue.

Recommendation:

- Support continued efforts to eliminate the use of leaded gasoline in all Arctic regions.

2. Certain regions of the Arctic (e.g., Alaska, Greenland) contain elevated Pb levels in the environment because of past or current use of Pb shot by hunters.

Recommendation:

- Encourage a complete ban on the use of Pb shot in the Arctic and improve enforcement.

7.3.3. Cadmium

1. Based on existing toxicity thresholds for non-Arctic species, Cd levels in some Arctic seabirds are high enough to cause kidney damage. However, monitoring data on Cd in the abiotic and biotic environment to date provide no conclusive evidence of trends or effects. None-the-less, Cd accumulates in birds and mammals and not enough is known about possible effects.

Recommendation:

- Continue monitoring Cd in the Arctic to support human and wildlife exposure estimates.

7.3.4. All heavy metals

1. Levels of Pt, Pd, and Rh have increased rapidly in Greenland snow and ice since the 1970s. These elements are used in automobile catalytic converters to reduce hydrocarbon pollution. The toxicity and bioaccumulation of these elements is largely unknown, which prevents assessment of their potential impact in the Arctic.

Recommendation:

- Monitor trends of Pt, Pd, and Rh in the Arctic.

2. Climate change is already influencing Arctic hydrology, currents, ice, winds, and temperature which are the major factors determining pathways of contaminant transport, and consequently past and present fluxes of heavy metals to the Arctic. More changes are predicted to occur in the future. As a result, significant alterations in metal transport pathways can be expected.

Recommendations:

- Continue mass balance studies and assessment of transport pathways for heavy metals, in air, rivers, and oceans across the Arctic.
- Expand research to better understand the processes of climate change that may influence spatial patterns and temporal trends.

3. Conclusions from this assessment are constrained by the limited availability of data for establishing spatial patterns and temporal trends, and understanding transport pathways and transformation processes that lead to environmental exposure. To improve detection of trends, better temporal and spatial coverage, harmonization of sampling, analytical, and reporting protocols, and improved understanding of key processes are required.

Recommendations:

- Generate contemporary inventories for Hg, Pb, Cd and the emissions of other priority contaminants, spatially distributed for use in hemispheric-scale models.
- Continue process studies to evaluate observed geographical differences and spatial patterns in the Arctic to obtain the 10 to 20 years of data using consistent protocols that are required to recognize emerging patterns. Increase efforts on assessing spatial patterns for more spatially fixed environmental media such as soils and vegetation.
- Support long-term time series data collection for biotic tissues. Develop studies that evaluate the relationship between soft and hard tissue concentrations in biota that will improve links between long-term time series and contemporary concentrations.
- Extend the length of existing temporal monitoring studies of biota, and initiate the collection and banking of biota specimens in areas not currently covered (e.g., North Atlantic marine mammals and birds; Russian biota in general).
- Continue work to develop standard protocols for sampling, analysis, and reporting among the AMAP countries to ensure inter-comparability of data sets.

4. The current absence of observable effects in Arctic biota from exposure to heavy metals does not confirm that effects are not occurring. Data sets that link exposure pathways, tissue concentrations, and a range of subtle responses to heavy metal exposure are needed to better identify effects.

Recommendation:

- Conduct effects studies in priority species experiencing heavy metal exposures of concern that link exposure profiles with tissue concentrations within individual animals and include an assessment of histopathological, behavioral, and reproductive parameters.