Executive Summary and Key Recommendations

Previous AMAP assessments of mercury in the Arctic published in 1997 and 2002, reported that a substantial amount of the mercury in the Arctic arrives via long-range transport from human sources at lower latitudes and that, owing to their traditional diet some Arctic populations receive high dietary exposure to mercury, raising concern for human health. This situation prompted calls by the Arctic Council for global action to reduce mercury emissions.

The previous AMAP assessments also identified fundamental questions regarding what controls mercury levels in the Arctic, and how (and when) these levels are likely to fall in response to controls on emissions. The cycling of methylmercury (one of the most toxic forms of mercury) is paramount in this respect. The likely impact of future climate change in altering mercury delivery and fate in the Arctic is also extremely important. The effects of mercury on biota may be particularly relevant for species at the limits of their tolerance to other stressors. The overarching goal of this assessment was therefore to update information relevant to answering the question: *What controls mercury levels in the Arctic and what are the effects on Arctic biota?*

Mercury continues to present risks to Arctic wildlife and human populations. Despite many remaining gaps in knowledge, this assessment confirms the need for concerted international action if mercury levels in the Arctic (and in the rest of the world) are to be reduced. It is of particular concern that mercury levels are continuing to rise in some Arctic species in large areas of the Arctic, despite reductions in emissions from human activities over the past 30 years in some parts of the world.

The human health components of this assessment reflect information on mercury and human health that was presented in the 2009 AMAP Assessment of human health in the Arctic. Risk communication and dietary advice have been used to reduce human mercury exposure in some regions of the Arctic; however, solutions that are more effective over the longer term still need to be found. Reducing human and environmental exposure to mercury in the Arctic will ultimately depend on global action to reduce the quantities of mercury entering the 'environmental reservoirs', in which mercury has already been accumulating as a result of human activities for several hundred years. It is therefore important that the momentum for global action is maintained.

Policy-relevant science recommendations

On supporting international processes

- *A legally-binding global agreement to control mercury emissions must be established to complement national and regional efforts to reduce environmental mercury concentrations and to lower human exposures to mercury in the Arctic. The Arctic Council should continue to support the ongoing intergovernmental negotiations under UNEP to develop a comprehensive, legally-binding global instrument that will significantly reduce global mercury use and releases.*
- *Existing international agreements such as those under the UN ECE LRTAP Convention, should continue to receive the support of the Arctic Council to ensure that the best-available scientific information from Arctic studies is made available to these processes.*

On reducing human exposure in the Arctic

- *Health authorities should collaborate with communities to develop effective, culturally appropriate communication strategies concerning contaminants and human health. Any advice to Arctic residents should include both the benefits of traditional/local food consumption and the results of risk assessments concerning contaminants, including mercury.*
- *Health authorities should work with relevant food agencies to promote the availability and consumption of imported food items with high nutritional value and to promote consumption of traditional/local foods such as fish and terrestrial mammals that have lower levels of mercury and high nutrient value.*

On reducing emissions from human activities

- *Support efforts by those countries where mercury emissions are increasing or have been identified as major global sources, to adopt measures and technologies that can reduce their mercury emissions. The support could include the transfer and sharing of knowledge on pre-treatment of raw materials and mercury capture technology, which have already been successfully implemented in a number of countries.*
- *Reduce human-induced re-emissions (e.g., by avoiding intentional burning and forest clearance) to slow re-emission of mercury to the global environment.*
- *Take advantage of co-benefits of reducing mercury emissions and other contaminants, including greenhouse gas and soot emissions to reduce global warming and related impacts.*

Where does mercury in the Arctic environment come from, and how does it get there?

Mercury enters the global environment from natural sources (such as volcanoes and weathering of rock that is naturally enriched in mercury) and from human activities (that either extract mercury for intentional uses or release mercury that is present as a natural impurity in fuels and other raw materials used for industrial processes). Coal burning is the main source of human emissions. Once released, naturally emitted mercury is indistinguishable from mercury from human sources. Humans have been mining and using mercury for thousands of years, however emissions from human activities have increased dramatically during the past 150 years due to industrialization. The total amount released to the air each year from present-day human sources is estimated at about 2000 tonnes. A further 3000 to 4000 tonnes are released to the air either from natural sources, or as a result of re-emission of mercury that has previously been deposited to surfaces, back into the air. It is important to recognize that much of the re-emitted mercury was originally released by human activities. Climate warming is likely to promote re-emission.

Mercury is transported to the Arctic by air currents (within a matter of days) and ocean currents (that may take decades) and by rivers. The form in which mercury is released and processes that transform mercury between its various chemical forms are key in determining how mercury is transported to the Arctic and what happens to it when it gets there.

It has been estimated that about 100 tonnes of mercury are delivered to the Arctic Ocean from the air each year, with about the same amount in inflow from the Atlantic and Pacific Oceans, rivers and coastal erosion. Recent budget calculations suggest that Arctic Ocean seawater accumulates about 25 tonnes of mercury each year.

***In order to** improve validation of atmospheric modeling estimates, to constrain Arctic Ocean models and to improve Arctic mercury budgets, **it is recommended** to implement monitoring of mercury in air and mercury deposition at additional Arctic sites and to extend mercury measurements in the central basins of the Arctic Ocean.*

What is the fate of mercury entering the Arctic environment?

Mercury is mostly deposited from the air in inorganic forms. The pathways and chemical transformations of inorganic mercury in aquatic and terrestrial ecosystems are to a large extent influenced by organic carbon. Methylmercury is an organic form of mercury that bioaccumulates more readily than inorganic forms; it is also one of the most toxic forms of mercury. Sediments and wetlands in which oxygen levels are very low are the main sites of methylmercury formation in Arctic lakes and terrestrial environments. In the marine environment, methylmercury is formed in seabed sediments, and possibly by bacteria in the mid-water column of the Arctic Ocean.

The rate of methylmercury production (and destruction) in the physical environment, and its transfer within food webs, governs mercury accumulation in Arctic biota. Methylmercury biomagnifies through food chains and dietary intake is the main source of mercury exposure in top predators. Atmospheric mercury depletion events enhance deposition of mercury from the air to snow and ice surfaces, however it is now understood that a large fraction of this deposited mercury is re-emitted from the snowpack within a few days. The role of these events as a source of mercury to Arctic food webs remains unclear.

Less is known about mercury dynamics and pathways in the ocean than the atmosphere. There are virtually no time-series datasets with which to evaluate what is happening in ocean pathways, but budget calculations suggest that at present about 75 to 90 tonnes of mercury are exported from the Arctic Ocean in ocean outflow each year and that about 110 tonnes are deposited in Arctic Ocean shelf and deep ocean sediments.

How does climate change influence Arctic mercury?

Climate change (and its associated impacts on the environment) is already having discernable effects on some aspects of the transport pathways and behavior of mercury within the Arctic, and may further increase Arctic ecosystem and human exposure to mercury. The potential for future profound effects is large. For example, warmer and longer ice-free seasons could promote the production of methylmercury, one of the most toxic forms of mercury to biota. At the same time a loss of sea ice may reduce the mercury burden of the Arctic Ocean, by providing more water surface area for gaseous mercury to escape or by reducing release of bromine that is believed to promote atmospheric mercury deposition in the Arctic. Large quantities of mercury, accumulated during previous millennia and including recent emissions from human activities, are currently stored in permafrost, soils, sediments and glaciers. A portion of this mercury could be remobilized if these stores are disrupted by climate change.

Are mercury levels in Arctic biota increasing or decreasing, and why?

Studies suggest that there has been a ten-fold increase in mercury levels in upper trophic level marine animals (beluga, ringed seal, polar bear, birds of prey) over the past roughly 150 years. Over 90% of the present-day mercury in these animals, and possibly some Arctic human populations, is therefore believed to have originated from human sources. The average rate of increase in wildlife species over the past 150 years is 1% to 4% per year.

Most of the time-series datasets showing increasing trends in recent decades are for marine species, followed by predatory freshwater fish species. No significant recent increases were found for terrestrial animals. The fact that trends are increasing in some marine species in Canada and West Greenland despite reductions in North American emissions is a particular cause for concern, as these include species used for food. Increasing trends are less apparent in northern Europe, and trends are mostly downward in this area, possibly reflecting their closer proximity to areas where emissions are declining.

Several factors, including factors influenced by climate change, can affect mercury accumulation in biota, particularly in species at the tops of food chains. The extent to which mercury concentrations in Arctic animals are being affected by regional shifts in emissions of mercury, from source regions in Europe and North America to those in Asia, is currently not clear.

In order to *monitor the impacts of climate change, human emissions and the effectiveness of mitigation strategies for mercury,* ***it is recommended*** *to continue monitoring of temporal trends of mercury in air, humans and wildlife, and extend coverage of such monitoring in particular in Alaska and the Russian Arctic.*

What are the toxicological effects of mercury in Arctic biota?

Arctic biota, especially higher trophic level predators are mainly exposed to mercury (mostly as methylmercury) through their diet. The presence or absence of other contaminants and nutrients (such as selenium) is believed to affect the toxicity of mercury and its impact in some Arctic species, including humans. For example, there is some evidence that selenium, if present in large enough quantities, can act as an antioxidant, providing wildlife and humans with some protection from methylmercury.

Some Arctic species, in particular marine top predators, exhibit levels of mercury in their tissues and organs that are believed to exceed thresholds for biological effects. In the past, these thresholds have been largely derived from laboratory studies on non-Arctic species, but in recent years knowledge arising from studies of Arctic species has increased.

Those species where thresholds are exceeded include a number of species of toothed whale, polar bears and some bird species. Polar bears and marine birds can excrete mercury through replacement of hair and feathers. Toothed whales appear to be one of the most vulnerable groups, with high concentrations of mercury recorded in brain tissue and associated signs of neurochemical effects. Evidence of increasing trends in mercury in some biota in Arctic Canada and Greenland is therefore a concern with respect to human and ecosystem health.

What are the likely changes in mercury concentration in the Arctic atmosphere and ocean under future emissions scenarios?

Global mercury emissions to air have been fairly constant since around 1990, but with emissions decreasing in Europe and North America and increasing in Asia. East Asia currently contributes about 50% of global mercury emissions to air from human sources. There are indications that, after decreasing from a peak in the 1970s, global emissions from human sources may be starting to increase again. If measures are not taken to reduce emissions, models suggest that global emissions could increase by 25% by 2020.

Models suggest that East Asia may now be responsible for much of the present-day mercury deposition in the Arctic. However, emissions scenarios project that if currently available emission reduction measures are implemented globally, then mercury deposition in the Arctic might be expected to decrease by as much as 20% by 2020 (relative to 2005 levels). There are no reliable global estimates of mercury released to the marine and freshwater environments.

Control technologies installed at industrial facilities remove mercury that would otherwise be emitted to air. There is little information about the ultimate fate of the mercury removed in this way and about how the mercury-containing wastes are subsequently disposed of. However, it can be assumed that these technologies will reduce the amount of mercury that is transported to the Arctic, by concentrating it, at least temporarily, in material that is disposed of in the source regions.

The atmosphere responds relatively quickly to changes in mercury emissions, but the large reservoirs of mercury in soils and ocean waters mean that there may be a long lag time (of the order of tens of decades) before changes in mercury inputs are reflected in the concentrations in these media, and thus in wildlife taking up mercury from them.

What is the impact of mercury contamination on human health in the Arctic?

Some Arctic human populations, especially some indigenous communities that consume large quantities of certain species of freshwater fish or marine mammal tissues for their traditional/local food, receive high dietary exposure to mercury. This raises concerns about human health effects, such as effects on brain development, and effects on the reproductive, immune and cardiovascular systems.

Exposure at current levels in the Arctic can have adverse impacts on human health, particularly for the developing fetus and children. Pregnant women, mothers and children are critical groups for monitoring and measures to reduce dietary exposure. There has been an overall decline in the proportion of Arctic people that exceed (U.S. and Canadian) blood mercury guidelines, but a significant proportion of people including women of child-bearing age from communities in the eastern Canadian Arctic and Greenland still exceed these guidelines. Dietary advice has been effective in reducing mercury exposure in some critical groups, but such advice needs to be carefully formulated to balance risks and benefits of traditional/local food consumption. The general dietary transition from traditional/local to more 'western' diets is also reducing mercury exposure, but at the same time is raising risks of other conditions or diseases associated with a western diet and lifestyle (such as obesity, diabetes, and heart disease). Since traditional/local foods low in mercury are not always available to Arctic indigenous people, the achievement of declining mercury levels in the environment is imperative to allow for the safe promotion of traditional/local food consumption.

Gaps in knowledge remain

The scientific background document to this assessment details recommendations to address this issue. Some of the main areas identified include:

- Further improving understanding of atmospheric mercury depletion events, with a particular focus on understanding how much of the deposited mercury is readily available to biota.
- Investigating further the fate of mercury entering marine systems.
- Ascertaining how methylmercury enters Arctic food webs and better understanding the Arctic marine methylmercury cycle.
- Developing a more detailed understanding of the impact of climate change on mercury.
- Undertaking further wildlife studies to measure mercury levels in different tissues and organs to assess mercury-induced health effects.
- Exploring the effects of multiple stressors (both chemical and environmental) and nutritional factors on the toxicity of mercury in biota.
- Addressing key knowledge gaps to reduce uncertainty in mercury models.
- Gathering more accurate information on worldwide economic and social variables, to improve future emissions scenarios.
- Studying the health impacts of mercury in human populations and determinants of food choice and availability.