# Chapter 8

# What is the Impact of Mercury Contamination on Human Health in the Arctic?

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## 8.1. Introduction

The subject of contaminants (including mercury; Hg) and human health has been addressed in three previous AMAP assessment reports (AMAP, 1998, 2003, 2009b), of which the two most recent comprised stand-alone human health assessment reports. These assessments, and particularly the most recent, have evaluated contaminant related exposure and effects within the broader context of overall human health in Arctic indigenous communities. When examined in this way, assessing the impacts that contaminants in the Arctic environment have on human health goes beyond typical contaminant related risk assessment with a focus on toxicological effects, and considers broader issues of social and cultural well being, and food security. As alluded to in Chapter 1, Arctic indigenous communities are particularly vulnerable to impacts of contaminants in their traditional/local foods for a number of reasons. Some of the most important foods, such as those derived from marine mammals and predatory fish species, often have elevated concentrations of contaminants which can lead to high levels of human dietary exposure and potential adverse health effects (AMAP, 1998, 2003, 2009b). These same foods, however, are often the most important and readily available source of those essential nutrients that are not easily found in generally accessible store-bought foods. The social, cultural, and spiritual health of indigenous communities is also closely tied to the harvesting, consuming, and sharing of traditional/local foods. Reducing these activities could have serious consequences for the continued integrity of some Arctic indigenous communities.

Mercury, along with several persistent organic pollutants (such as PCBs, chlordanes and toxaphenes) that are found at elevated concentrations in some Arctic populations, is a contaminant of major concern to health authorities in the Arctic. Among this group of contaminants, Hg toxicity is considered to be an important contributor to the overall health risk presented by contaminants in the environment. This chapter summarizes information on the impacts of Hg on human health taken primarily from the most recent AMAP human health assessment (AMAP, 2009b), with some additional updates from recent studies. In answering the primary question of this chapter – *What is the impact of mercury contamination on human health in the Arctic?* – the following sections illustrate links between findings presented in the rest of this assessment and their implications for human health.

## 8.2. What are the global influences on mercury exposure in northern peoples?

In this assessment, Chapters 2 through 4 address general and specific questions related to factors controlling Hg levels in the Arctic, including sources, transport, ecosystem processes, and the influence of climate change. As stated in Chapter 5, on average over 90% of the present-day Hg in Arctic wildlife is estimated to be of anthropogenic origin. While environmental characteristics of, and processes in, the Arctic play a large role in governing ecosystem uptake and accumulation of Hg, it is apparent that global anthropogenic factors make a critical contribution to the sources of Hg to the Arctic, as well as changes in climate that influence aspects of the Hg cycle leading to and including human exposure. Important from a human health perspective is that all of these factors influence the concentrations of Hg, particularly methylmercury (MeHg), in the fish and wildlife consumed by Arctic indigenous peoples.

Chapter 4 discusses the impact of climate change on the Hg cycle, including a number of aspects that may change human Hg exposure in the Arctic. For example, rising air temperatures associated with climate change may increase re-emissions of Hg from lower latitudes. At the same time, rising temperatures and incident solar radiation are increasing primary productivity and methylation of Hg within the Arctic. Climate change is therefore likely to have as yet undefined implications for the transfer of Hg through food webs, in particular marine food webs. It has been argued that the effect of climate change on methylation may be the most important effect from the perspective of human and wildlife health (Outridge et al., 2008). A study by Booth and Zeller (2005) modeled climate change impacts on Hg concentration in fish and pilot whales (*Globicephala melas*) in the Faroe Islands marine ecosystem. The results showed that increases in water temperature of 0.4 and 1.0 °C might result in average MeHg increases of between 1.7% and 4.4% respectively. The authors noted that pilot whales displayed a greater nominal change in MeHg concentration compared to cod, and that fishing mortality had a cumulative effect. When exposure levels for Faroe Islanders were calculated based on a dietary intake of whale meat (12 g/person/d) and cod (72 g/person/d), it was found that a large proportion of the general adult population would exceed the World Health Organization (WHO) tolerable weekly intake (TWI) limits of 1.6 µg/ kg body weight (bw) and the U.S. Environmental Protection Agency (EPA) reference dose (RfD) of 0.1 µg/ kg bw/d (equivalent to a TWI of 0.7 µg/ kg bw) under all simulated conditions (Booth and Zeller, 2005). The authors estimated that environmental inflow rates of Hg would need to be reduced by about 50% (under prevailing conditions) to achieve MeHg intake levels that fall below WHO guideline levels. It was further concluded that increasing methylation rates due to higher water temperatures are likely to lead to continuous increases in biota concentrations and therefore higher exposure levels for Faroe Islanders on the basis of the current marine-based diet. However, while the study considered the effects of higher water temperatures and altered fish and whale mortality rates on future marine methylation rates, other possible mechanisms by which climate change may increase methylation rates, such as higher oceanic productivity and organic carbon concentrations (Sunderland et al., 2009; Cossa et al., 2009), and increased MeHg outflows from rivers (see Chapter 4), were not included in the model. The predicted methylation rate increase of 1.7–4.4%, while of potential significance, may not accurately reflect the likely overall impact on methylation rates and the Hg concentration increases in Arctic marine biota that could result from a warming climate. The study by Booth and Zeller (2005) still serves as a good example of how two global issues, Hg emissions and climate change, may influence the exposure scenarios for Arctic people. Many factors have been identified in this assessment that influence Hg levels in different ecosystem components, each of which has the potential to influence human exposure through changes in concentration in traditional/local foods.

Anthropogenic sources of Hg that contribute to human exposure through general contamination of Arctic ecosystems are global in nature and largely located outside the Arctic region. Large industrial centers within the Arctic, particularly those that produce energy from coal also contribute to the global pool of Hg, although their contribution is relatively small (see Chapter 2). Local sources of Hg in the Arctic, can lead to increased Hg concentrations in surrounding ecosystems, which could lead to elevated levels of human Hg exposure. Examples include past Hg mining activities in Alaska (Gray et al., 2000) and tar sands development in northern Alberta, Canada (Timoney and Lee, 2009) which have lead to locally elevated levels of Hg in aquatic ecosystems. Hydroelectric dams that flood large areas of land are also known to cause increased levels of Hg in fish in the reservoirs that are created, which can also have downstream influences (see Section 5.4: Case Study 3).

## 8.3. What are the dietary influences on mercury exposure?

Arctic indigenous peoples are primarily exposed to Hg through their diet, which includes traditional/local food items such as fish, seabirds and marine mammals. Other northern residents may also be exposed to Hg through their diet, however, for the purposes of assessments, there is a focus on Arctic indigenous peoples, in particular those that rely heavily on marine foods as part of their traditional diet as they constitute 'critical groups' for potential Hg exposure and health effects. Food security is becoming an increasingly important issue for Arctic communities, with a number of factors contributing to this. Although some studies (e.g., Furgal et al., 2001; Donaldson et al., 2006) have found that many people continue to eat traditional/local foods despite their knowledge of contaminants, there remains a risk that the consumption of foods that are in other respects a healthy and important part of traditional diets will be reduced as a result of concern about contaminants. For example, studies conducted in a few isolated indigenous communities in Arctic Canada found rates of expressed concern over traditional/local food availability ranging from 40% to 83% of the populations surveyed (AMAP, 2009b). In other circumpolar countries, the Survey of Living Conditions in the Arctic (SLICA) reported that only 14% of people in the circumpolar Arctic (Greenland, Chukotka, Alaska) were satisfied with the amount of fish and game available to them (Poppel et al., 2007). While the satisfaction rate was highest in Alaska at 40%, Greenland and Chukotka had very low rates of 9% and 6%, respectively. Among the many factors that lead to food insecurity, including availability and cost of healthy store-bought foods, some of the most important and regularly cited factors relate to accessibility of traditional/local foods. Accessibility to traditional/local foods is also dictated by a number of factors, including access to a hunter/fisher, cost of hunting/fishing, and the health and abundance of wildlife. The presence of Hg and other contaminants in fish and wildlife, and the related perception of diminished food quality and safety may exacerbate the issue of accessibility to traditional/local foods.

The situation is further complicated by the problem of 'nutrition transition', which has been taking place for indigenous peoples all over the world. A nutrition transition has been described in several studies (Daman et al., 2008) and is commonly associated with industrialization, urbanization, economic development, and globalization of markets. During nutrition transition, the traditional/local food diet is replaced by a more 'western', store-bought diet. The store-bought diet often consists of inexpensive foodstuffs that have high contents of refined carbohydrates and saturated fatty acids, but low contents of nutrients, vitamins and essential unsaturated fatty acids (Johnson-Down and Egeland, 2010 and references therein). Along with a more sedentary lifestyle, this diet can cause obesity and related diseases such as diabetes and coronary heart disease.

Health professionals therefore need to balance the health benefits of traditional diets against the increased health risks associated with the contaminants that they contain when developing advice on food consumption and related risk communication.

The potential importance of Hg levels in Arctic biota to human health becomes apparent when dietary surveys are conducted. For example, dietary surveys in 1999 to 2002 by the Alaskan Department of Fish and Game in northwestern Alaska showed that the average composition of subsistence harvest by rural residents comprised 60% fish, 14% marine mammals, 20% land mammals, and 2% each of plants, birds, and shellfish. When blood values of Hg (a measure of recent exposure) were compared in Alaskan non-fish consumers and fish consumers, it was found that the former had blood Hg values of less than 1 μg/L, while levels in people consuming large amounts of fish could be higher than 4.2 μg/L (AMAP, 2009b).

Arctic biota differ in their levels of Hg, depending on whether the animals are terrestrial or marine based, their level in the food web (i.e., the extent of biomagnification), their age, and feeding location (AMAP, 1998, 2004). There is also general spatial and temporal variation in biota levels across the Arctic. In the following discussion, Hg concentrations in some Arctic biota are summarized in relation to their importance for safe food consumption and possible exceedence of tolerable intake levels. It is also important to recognize that significant variation has been found in Hg concentrations in tissues and organs of the same animal species (in general increasing in the order fat, muscle, kidney and liver). This influences which parts of the animal may exceed guidelines for safe consumption and needs to be taken into account when developing dietary advice to limit, for example, Hg intake (AMAP, 1998, 2009b). It should also be noted that most of the monitoring data discussed are for measurements of total Hg (THg), not MeHg, and that the percentage of THg that is actually MeHg varies from species to species, and tissue to tissue, with muscle generally containing mostly MeHg and organs, such as liver and kidney containing mostly less toxic inorganic forms of Hg.

Mercury analyses were conducted on several types of mature fish in Alaska: northern pike (*Esox lucius*), Arctic grayling (*Thymallus arcticus*), whitefish (*Coregonus* spp.), burbot (*Lota lota*), Atlantic salmon (*Salmo salar*), and chinook (*Oncorhynchus tshawytscha*), chum (*O. keta*), coho (*O. kisutch*), and sockeye (*O. nerka)* salmon among others. Only pike exceeded the U.S. Food and Drug Administration (USFDA) action level for Hg of 1.0 mg/ kg and the critical value for human consumption of 0.3 mg/ kg set by the U.S. EPA (Jewett and Duffy, 2007). The estimated limit for consumption of pike was about one monthly meal for adults but only two meals per year for children. In contrast, MeHg concentrations in the most frequently consumed fish, such as salmon, cod, halibut, pollock, sole, and herring were very low.

Studies in Arctic regions including Canada, Greenland, and Russia reveal relatively high levels of Hg in marine mammals, as well as in some seabirds and predatory fish (see Chapters 5 and 6), although spatial and temporal variability in concentration can exist. Species that have been found to have higher Hg concentrations in some areas of the Arctic include seals and whales (meat and blubber), polar bear (*Ursus maritimus*) and some seabird species, although variation has been found in Hg concentration between the meat, fat, liver, and kidney within the same species, influencing which parts of the animal exceed safety guidelines or levels (AMAP, 1998, 2009b).

In Chukotka, the results of an unpublished study by Dudarev (referenced in AMAP, 2009b: p.45) suggest that seal had higher levels of Hg than terrestrial mammals, birds and fish. Mercury levels in seal meat exceeded the food safety limits in Russia for commercial and wild foods (RFSL) by 3 to 10 times; seal kidney by 10 times; and seal liver by 20 to 100 times. The highest Hg levels were observed in bearded seal (*Erignathus barbatus*), particularly in the liver. Meat of walrus (*Odobenus rosmarus*) and grey whale (*Eschrichtius robustus*) is less contaminated by Hg, with levels lower than the RFSL. However, kidney and liver of walrus had Hg levels two to four times higher than the RFSL. In whales, on the other hand, Hg levels in kidney are below the RFSL and the liver level is similar to the RFSL. The percentage of the population exceeding the RFSL levels was not reported. Mercury levels in subsistence-hunted whales were determined in a study looking at bowhead whale (*Balaena mysticetes*) and beluga (*Delphinapterus leucas*) in Alaska and grey whales in Chukotka (Dehn et al., 2006). While average THg levels were low in bowhead and grey whale meat (0.02 μg/g ww) and safe for consumption, beluga had high levels with an average of 1.12 μg/g ww, which exceeds several consumption guidelines (e.g., the USFDA action level for Hg of 1.0 mg/ kg).

In a summary of Russian data it was concluded that the overall levels of Hg in venison were low in the four main studied regions of Arctic Russia (Kola Peninsula, Nenets Autonomous Okrug, Taymir APO, Chukotka AO). However, in some regions the Hg levels in reindeer (*Rangifer tarandus*) kidney exceeded the food safety limits in Russia for commercial and wild foods (RFSL for kidney is 0.2 mg/ kg; AMAP, 2004) by up to 50%. In waterfowl, Hg levels were two to three times higher than the RFSL. Mercury levels were below Finnish reference values in most terrestrial-based traditional/local food items in Finland, which included reindeer, game, vegetables and berries (AMAP, 2009b). Mercury levels in most fish species were also below Finnish reference values (0.5 mg/ kg), except fish from new water reservoirs where old burbot and pike were found to exceed 1 mg/ kg.

In Greenland, the results of Dietz et al. (1998a, 2000b) suggested that marine mammals had higher levels of Hg than terrestrial mammals, birds and fish. The highest Hg levels were observed in polar bear kidneys and hooded seal (*Cystophora cristata*) liver (Dietz et al., 1998a, 2000a). A comprehensive study of contaminant concentrations in the local diet in Greenland (Johansen et al., 2004) included Hg levels in the major animal species and tissues consumed by Greenlanders. Tissue from about 25 animal species was included in the study and, in general, contaminant levels were very low (less than 0.01 μg/g) in muscle and fat of terrestrial species, marine fish such as capelin (*Malotus villosus*) and Atlantic cod (*Gadus morhua*) liver, as well as seal blubber. Low to medium Hg levels (between 0.01 and 0.09 μg/g) were found in liver and kidney of many terrestrial species (including reindeer), marine fish (including Arctic char (*Salvelinus alpinus*) liver, salmon, Greenland cod (*Gadus ogac*), Atlantic cod muscle) as well as some whales (minke whale (*Balaenoptera acutorostrata*), beluga and narwhal (*Monodon monoceros*) blubber). High Hg levels (0.1 to 1 μg/g) were present in halibut, in seabirds and in seals and whales. Mercury concentrations above 1 μg/g were measured in liver and kidney of seals, beluga and narwhal. Methylmercury intake by consumers of these foods was found to vary with the season. For example, individual MeHg intakes of 66 μg/d were estimated in spring and 42 μg/d in autumn for West Greenlanders. This is a high intake, and one which exceeded the European Food Safety Authority's tolerable daily intake (TDI) of 0.23 μg/ kg bw/d and the U.S. EPA Reference dose of 0.1 μg/ kg bw/d (AMAP, 2009b).

A recent study compared dietary exposure of Hg to levels in the hair of preschool children in three regions in Nunavut: Kitikmeot (northwest), Baffin (northeast) and Kivalliq (south) (Tian et al., 2011). The estimated daily total Hg intake was positively related to hair Hg levels and varied between 0 and 200 μg/d, with a mean of 16.28 μg/d. The authors also noted a regional effect, with the estimated daily intake being significantly higher for children in Baffin (mean: 22.7 μg/d) compared to Kivalliq (mean: 10. 7 μg/d) and Kitikmeot (mean: 11.8 μg/d). Almost 59% of children exceeded the provisional tolerable weekly intake (PTWI) level for children of 1.6 μg/ kg bw/wk for MeHg (WHO, 1998).

In Nunavut children, the top contributors to Hg intake from the most commonly consumed traditional/local food items were beluga *muktuk* (33%), followed by narwhal *muktuk* (26%), and ringed seal (*Phoca hispida*) liver (15%). Together with fish (11%), caribou meat (6%) and ringed seal meat (5%), these food items accounted for over 95% of the total Hg intake. Although caribou meat was the most highly consumed traditional/local food item (30% of total traditional/local foods), it ranked only fifth on the contributors list for Hg intake due to its low Hg concentration (0.03 μg/g ww). Overall, only three traditional/local food items had THg concentrations above the 0.5 μg/g ww action level established by Agriculture Canada: ringed seal liver (10.5 μg/g ww), aged narwhal *muktuk* (0.8 μg/g ww), and caribou kidney (0.5 μg/g ww). It should be noted that although the average concentration of ringed seal liver was very high, 20% to 50% of that Hg was in a less toxic and less bioavailable inorganic form (Tian et al., 2011). In their review of dietary transition and contaminants, Hansen et al. (2008) concluded that marine mammal muscle, particularly ringed seal muscle, is the main source of dietary MeHg for Greenland Inuit. Organs, such as liver and kidney, were considered to be minor sources since most of the Hg in these organs is in an inorganic form.

The example of the total dietary assessment conducted in northern Canada provides valuable information about sources of dietary Hg exposure, which can only be determined with total dietary assessments. Unfortunately this type of assessment, that includes analyses of contaminant levels, has only been carried out in Greenland and Canada. The findings of several assessments conducted over the past 10 to 15 years suggest that some populations in Greenland and some Inuit communities in Canada exceeded the TDI values set for Hg (AMAP, 2009b).

Higher concentrations of Hg in human tissues in some areas have been linked to the higher consumption of marine mammals by indigenous people in those regions as part of their traditional diet. Previous human health assessments have shown a three- to ten-fold increase in Hg concentration in Inuit women of child-bearing age that consume marine mammals, when compared to people in other populations in the Arctic, that consume store-bought foods (AMAP, 1998, 2003). Despite the changes in many Arctic communities towards a more 'western' diet, in the Inuvik region (Canada), dietary studies indicated that the participants increased their traditional/local food consumption between 1998 and 2005/06, although the amount and type varied by community and population (Armstrong et al., 2007). There was a moderate but significant correlation between food intake and Hg concentration measured in the blood of Inuit and Dene-Metis mothers in Inuvik, with the main food sources for exposure to Hg suggested to be fish and marine mammal fat (Armstrong et al., 2007). A relationship between Hg blood levels and dietary nutrients (e.g., n-3 fatty acids) from particular food species is consistent with the connection between intake of marine mammal fat, contained in a variety of tissues (e.g., liver, muscle, skin), and pollutants such as Hg. Among Greenland Inuit, Deutch et al. (2007) found a strong correlation between plasma n-3 fatty acids and blood levels of Hg which were related to the consumption of marine mammal tissues, including fats.

## 8.4. How do human tissue mercury levels compare to guidelines?

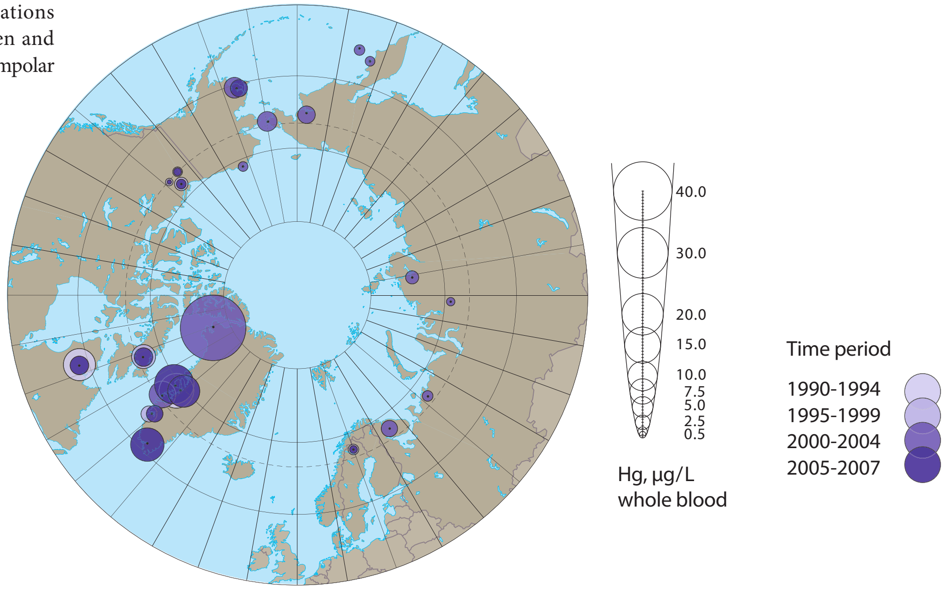
Sampling of Hg in human tissue (blood and hair) has taken place in several circumpolar countries since the early 1990s. Pregnant women have been a target population for biomonitoring of contaminants in the Arctic, because Hg can be transferred across the placental barrier and the developing fetus and children are particularly vulnerable to effects of Hg exposure. However, Inuit adults (men and women) have also been monitored in a few Arctic countries, and recently, the 2007-2008 Inuit Health Survey (www.inuithealthsurvey.ca) included a study on Hg exposure of children in Nunavut (as described in Section 8.3).

### 8.4.1. Mothers, pregnant women, and women of child-bearing age

Among mothers, pregnant women, and women of child-bearing age, exposure to Hg appears to be greatest in Inuit from the eastern Arctic regions of Canada (i.e., Nunavut and Nunavik regions) and in Greenland (Figure 8.1; AMAP, 2009b). This spatial pattern is similar to that reported in the 2002 AMAP human health assessment (AMAP, 2003), which showed that elevated blood Hg levels in these regions was associated with high consumption of marine mammals (AMAP, 1998, 2005). The more recent results support the explanation that high human Hg intake is associated with consumption of marine foods, and in particular marine mammals. Yupik maternal blood levels of Hg in the Yukon-Kushokwim River Delta Region of Alaska were only slightly lower than levels in Inuit from the Nunavut and Nunavik regions of Canada. The lowest concentrations of Hg in maternal blood were measured in areas of Russia, Sweden, and the Inuvik region of Canada.

Comparisons of human blood Hg concentrations for different time periods can be made for a number of areas around the Arctic on the basis of a limited number of repeat studies. However, these need to be interpreted with caution due to the differences in populations sampled, number of samples collected, and time periods covered for different countries. Detailed studies of temporal trends, involving frequent sampling, have only been made in the Nunavik region of Arctic Canada, and in the Disko Bay and Nuuk areas of Greenland (Figure 8.2). Studies conducted with different numbers of samples and over different time periods indicate that maternal Hg blood levels have generally decreased in almost all circumpolar regions studied since the 1990s. This includes regions of Alaska (Yukon-Kushokwim River Delta region), Arctic Canada (Inuvik, Nunavut, Nunavik regions), and northern Sweden (Wennberg et al., 2007). Much of this decrease can probably be attributed either to a switch in diet away from more contaminated traditional/local foods (in some cases possibly associated with dietary advice, such as has been given on the Faroe Islands; AMAP, 2009b) or to the nature of traditional/local food items available in a given year. In Nunavik, for example, Hg levels in blood appear to have varied markedly from year to year due to variation in the levels in the biota used as traditional/local food (Dewailly et al., 2001). In contrast, pregnant Inuit women in Greenland (Disko Bay area and Nuuk) have shown no significant decline in THg

Figure 8.1. Total mercury concentrations in blood of mothers, pregnant women and women of child-bearing age in the circumpolar countries. Source: AMAP (2009b).




concentrations over a time period similar to the above studies (AMAP, 2009b).

Information on changes over time in Hg levels in potential food species is more extensive (Chapter 5) but may not necessarily reflect the trends in humans. Further monitoring and comparisons of biota and human Hg levels, especially for relevant tissues/organs and species used for food, will be useful to strengthen the understanding of the patterns currently observed.

Mercury blood guidelines have been established in Canada (Health Canada, 1984). Mercury concentrations of below 20 µg/L in human blood are considered to be within an acceptable range. Blood Hg concentrations of between 20 and 100 µg/L are classified as at 'increasing risk' and concentrations exceeding 100 µg/L in blood are classified as 'at risk'. The United States, in its re-evaluation of dietary guidelines for MeHg, applied a ten-fold safety factor to a Bench Mark Dose Level of 58 µg/L in the development of a TDI for which a reference dose of 0.1 µg/ kg bw/d was established (NRC, 2000). Consequently, it was suggested that 5.8 µg/L be used to assess risk based on blood concentrations. For comparative purposes, these guidelines and values were used in the AMAP 2009 human health assessment to interpret human contaminant data for all circumpolar countries (AMAP, 2009b).

Figure 8.3 indicates the proportion of mothers and women of child-bearing age that exceed the Canadian blood Hg guideline of 20 µg/L, and the more conservative U.S. guideline of 5.8 µg/L. Regions of Greenland and northern Canada had the highest proportion of mothers and women of child-bearing age exceeding the blood Hg values. Recent biomonitoring studies showed that the proportion of Inuit mothers exceeding both the Health Canada and U.S. guidelines has decreased from earlier studies (Figure 8.3). For example, between 1992 and 1999, 52% to 76% of Inuit mothers and women of child-bearing age from Nunavik, Canada, exceeded the U.S. guideline, compared to 31% to 61% between 2000 and 2007. Similarly, 68% of Inuit mothers from Nunavut, Canada, exceeded the U.S. guideline in 1997, compared to 32% between 2005 and 2007 (AMAP, 2009b).

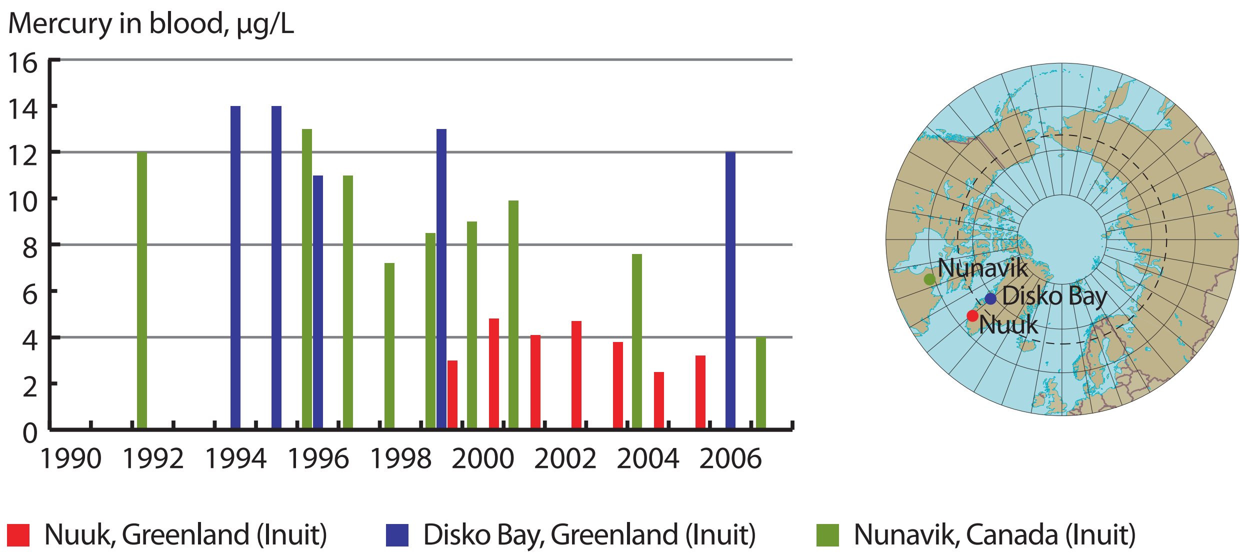



Figure 8.2. Temporal trends of mercury in maternal blood samples from Nunavik, Canada, and Disko Bay and Nuuk, Greenland. Source: AMAP (2009b).

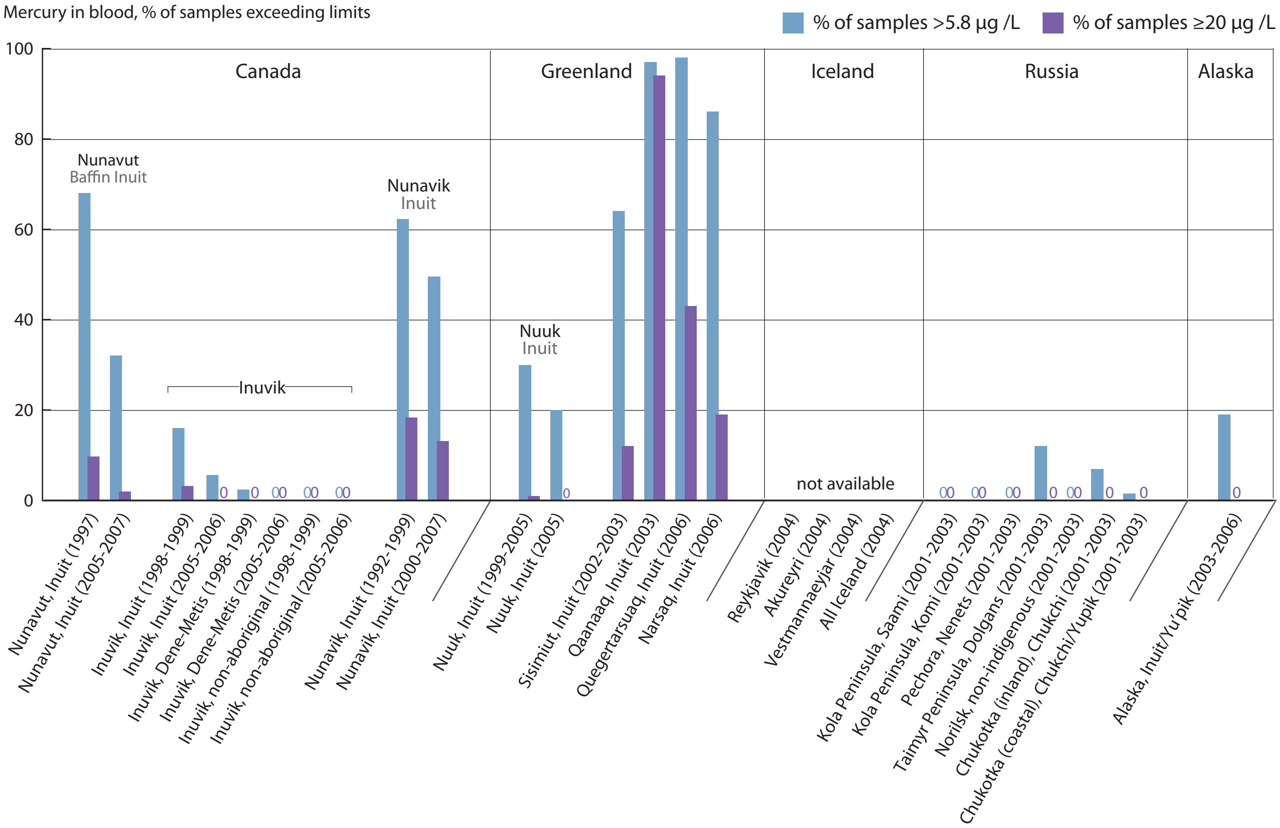



Figure 8.3. Exceedance of blood guideline values for (total) mercury in mothers and women of child-bearing age in different populations around the Arctic (comparable data not available from Norway, Sweden and Finland). Source: AMAP (2009b).

As expected, a smaller proportion of mothers and women of child-bearing age exceeded the higher Canadian guideline.

Following the successful implementation of a dietary intervention in the Faroe Islands that was aimed at reducing consumption of pilot whale meat, in 2007/09 only 0.6% of cord blood samples (n=500) exceeded 20 µg/L of mercury and 12.6% exceeded 5.8 µg/L. This represents a dramatic improvement compared to the 39.2% and 93.3% of samples (n=995) that exceeded the respective guidelines in 1986/87 (Pal Weihe, unpublished data).

Although the results of these analyses suggested declining Hg concentrations in a number of indigenous communities, significant percentages of women in recent years still exceeded guideline values in some parts of the Arctic, particularly in Greenland where some of the highest blood Hg concentrations have been found.

### 8.4.2. Adults (men and women)

Blood Hg levels have been monitored in Inuit adults (men and women) in Nunavik (Canada) and regions of Russia, as well as in Inuit men in regions of Greenland. The 2009 AMAP human health assessment (AMAP, 2009b) considered adult women in Greenland as women of child-bearing age (ages 20 to 50); as a result these were discussed in Section 8.4.1. In general, Hg concentrations are higher among men in Greenland than in men and women in Nunavik and regions of Russia. Blood Hg concentrations significantly decreased in adult Inuit men and women from Nunavik, Canada, between 1992 and 2004 despite several indications of increases in biota (Dewailly et al., 2007a,b; see also Chapter 5).

### 8.4.3. Children

The geometric mean concentration of THg in hair for Inuit children in Nunavut was 0.66 µg/g and no differences were found to exist between different ages or genders (Tian et al., 2011). However, statistically significant differences were observed between the three regions studied. Children in Baffin had higher hair Hg levels (1.14 µg/g) than children in Kivalliq (0.52 µg/g) or Kitikmeot (0.31 µg/g) (Tian et al., 2011). Based on the reference value for Hg in hair established by the World Health Organization of 2 µg/g (WHO, 1990), the study found that 25% of children had Hg levels that exceeded the guideline. When broken down by region, 39% of the children in Baffin exceeded the guideline, which was more than twice the percentage for Kivalliq (19%) and almost fourteen times higher than for Kitikmeot (2.9%).

## 8.5. What are the health effects of mercury in humans?

The presence of Hg and other contaminants in the Arctic environment can have many impacts on human health. As discussed, the perception and knowledge of potential risks associated with contaminants can turn people away from traditional/local foods, even when they represent the most healthy food choice. This can lead, among other things, to a degradation of cultural identity, economic stress arising from the high cost of healthy store-bought foods, and potential nutritional deficits arising from the consumption of poor quality store-bought foods. There are also toxicological risks associated with Hg in country foods. The following section provides a brief synopsis of the potential effects that Hg can have on human health and concludes with a summary of epidemiological studies that have been carried out on populations that are, or have been, chronically exposed to Hg through their diet.

### 8.5.1. Mercury toxicity

The 2002 AMAP human health assessment gave a detailed summary of the potential toxic effects that Hg can have on human biological systems (AMAP, 2003). These include effects on the reproductive, immune, and neurological systems by several modes of action. More recently, the 2009 AMAP human health assessment suggested that Hg can also have adverse effects on the cardiovascular system (AMAP, 2009b). Chapter 6 of this assessment provides a detailed assessment of Hg toxicity and effects in Arctic wildlife. In its review of various Hg toxicity studies, Chapter 6 provides further detail on the modes of toxicity that Hg and MeHg exhibit in Arctic biota (mammals, birds and fish).

The primary Hg exposure pathway for Arctic residents is through consumption of fish and marine mammals. Even though Hg is consumed in both inorganic and organic (methylated) forms, human health risks arising from this exposure are thought to be associated with MeHg only. Inorganic forms of Hg found in fish and mammal tissues are much less bioavailable and therefore do not bioaccumulate in humans. Exposure to inorganic Hg, particularly high doses of elemental Hg, can have adverse health effects, but these are mostly restricted to cases of occupational exposure and are not discussed in this chapter.

High concentrations of dietary MeHg exposure are suspected to have a negative effect on birth weight. In a study of Greenlanders that examined associations between smoking, birth weight and contaminant exposure, only a weak association between lower birth weight and Hg was found in West Greenlanders, while none was identified in East Greenlanders. Smoking on the other hand was strongly associated with low birth weights. The study results suggested that nutritional factors, primarily high levels of n-3 fatty acids, associated with marine mammal consumption may have had a protective effect (AMAP, 2003).

Methylmercury exposure can also have an effect on immune function by altering the relative abundance of TH-lymphocytes, which play a role in determining an individual's immune responsiveness. This is primarily described by the relative abundance of Th1- and Th2-lymphocytes, of which Th1-lymphocytes are typically dominant in individuals with normal immune function. Cases where Th2-lymphocytes are dominant are associated with hyper-immunity which leads to such afflictions as asthma, skin rashes and auto-immunity. Mercury, both in organic and inorganic forms, has also been shown to have cytotoxic activities for cellular components of the immune system in several species of rodent. This type of toxicity can alter non-specific cellular defense mechanisms, decrease activation markers of T-cells, and affect the functions of B-cells, resulting in reduced humoral mediated response. Finally Hg exposure has been shown to impair host resistance to bacterial and viral infections in laboratory animals (AMAP, 2003).

A number of neurological effects of MeHg exposure have been documented in the literature and in epidemiological studies looking at fetal and neonatal development. These findings are discussed along with other epidemiological studies towards the end of this section. Neurological effects of Hg in wildlife are discussed in Section 6.3.1. It is well established that MeHg is a potent neurotoxin that can cause irreparable damage to the central nervous system. While the biological mechanisms responsible for this damage are not well understood, oxidative stress is suspected to be a significant contributor. There are likely to be several mechanisms by which MeHg may cause damage by oxidative stress (AMAP, 2009b). Methylmercury can promote the formation of hydrogen peroxide and enhance subsequent production of lipid peroxides and reactive hydroxyl radicals, which can then alter membrane structure or disrupt mitochondrial function. The increase of reactive oxygen species takes place via deregulation of mitochondrial electron transport as well as through glutathione depletion (AMAP, 2003). Methylmercury also has an inhibitory effect on antioxidant processes by binding to relevant enzymes such as free-radical-quenching enzymes, or it can influence the intracellular oxygen status by binding to glutathione. The notion of Hg-induced oxidative stress is supported by findings that MeHg neurotoxicity can be inhibited by various antioxidants including selenium (Se) and N-acetyl-L-cysteine, a precursor of glutathione. Methylmercury exposure may diminish defense mechanisms against oxidative stress by limiting the availability of glutathione, while Se may afford protection by favoring the destruction of hydrogen peroxide (AMAP, 2003 2009b). Section 6.2.2.2 provides a detailed discussion of Se–Hg interactions in wildlife, including some of the inhibitory effects that Se seems to have on MeHg toxicity.

One of the main recommendations arising from the 2002 AMAP human health assessment was the need to assess the toxicity of Arctic contaminants as a group, and not as single chemical toxicants (AMAP, 2003). In the intervening years, some progress has been made through laboratory studies toward understanding how the contaminant mixture affects biological systems. In doing so, the toxicological study of Arctic contaminants has been better able to reproduce the contaminant exposure experienced by northern populations. In these studies, the effects of MeHg along with other persistent organic pollutants (POPs) and heavy metals have been examined under various exposure scenarios to assess their combined toxicological effects.

The 2009 AMAP human health assessment reports on a study conducted by Health Canada that looked at effects of a specific contaminant mixture (including POPs and MeHg) on reproduction and development in rats (AMAP, 2009b). The mixture was designed to produce, in rat dams, a similar contaminant profile to that found in the maternal blood of Inuit. Rats in the high-dose group experienced several adverse effects including: decreases in maternal weight gain during lactation and in offspring weight gain that persisted into adulthood; increased mortality rates in pups prior to weaning (interestingly, it was noted that overall mortality rates for the offspring in this study were considerably lower than those reported by others using lower doses of only MeHg); changes in organ weight, and biochemical and histopathological changes in liver (see also Section 6.3.2.1), thyroid, and spleen; decrease of pre-weaning neuromuscular development (grip strength) and hyperactivity at post natal day (PND) 16 which did not persist through PND 48; affected learning and memory in adults; and dose-dependent changes in brain dopamine and serotonin levels at PND 35 in high-dose group pups. The only effect seen in all dose groups was an indication of either altered motor performance or decreased reactivity to a novel environment. Preliminary results from the study also indicated that each of the dose groups induced some measured changes in offspring bone development. Blood Hg concentrations measured in the lowest dose group were comparable to blood concentrations measured in humans living in the Canadian Arctic (AMAP, 2009b), whereas the high-dose group had blood concentrations that were 100 times higher.

A second series of mixture studies conducted by Health Canada researchers examined the potential impact of individual components of the chemical mixture (Hg, PCBs and organochlorine pesticides). Comparisons of the toxicity of the full mixture against specific components of the mixture indicated that the increase in pup mortality induced by the full mixture could be attributed to the MeHg component, although the interactions with the POP mixture warrants further investigation owing to the apparent improved survival rates observed with the mixture. The researchers also examined expressions of genes involved in cerebellum nerve cell functions and found that the full mixture produced minimal changes in gene expression, whereas individually, PCB, MeHg and the organochlorine pesticide components all altered the expression of a number of genes, pointing to another area for further research (see also Section 6.3.4). Effects on learning and memory were apparently elicited primarily by MeHg and PCBs and appeared to be additive. The findings of these studies using the rat model supported observations reported in some epidemiological studies of infants and children (AMAP, 2009b).

### 8.5.2. Epidemiological studies

The effects of high level pre-natal exposure to MeHg are fairly well known from publicized cases in Japan and Iraq where children born to accidentally exposed women displayed a range of symptoms including mental retardation, severe sensory impairment, seizures and general paralysis (AMAP, 2003). Since the 1970s, growth and developmental effects of pre-natal MeHg exposure have been studied in nine large birth-cohort and retrospective studies around the world. Additionally, three well designed, prospective, longitudinal studies of children have examined neurobehavioral effects related to Hg exposure in the Faroe Islands, New Zealand and the Seychelles (INAC, 2009). Other cohort studies have been conducted in Michigan, Madeira, Brazil, French Guyana, Philippines, Greenland, and in Cree and Inuit from northern Quebec. In each of these studies the source of MeHg was from the consumption of fish and marine foods (mainly fish, but also marine mammals in the Faroe Islands and Inuit regions such as Greenland and northern Quebec).

Most of these studies looked for associations between Hg exposure and various endpoints assessed at birth. There were no conclusive results indicating a Hg-associated decrease in birth weight; however, in the Faroe Islands, a doubling of cord-blood Hg was associated with lower infant weight at 18 months and persisted to 42 months of age. In the Philippines, where MeHg exposure was two times higher than in the Faroe Islands, there was no association between MeHg and birth weight, but there was an association between MeHg and smaller head circumference at birth. In Michigan, where Hg exposure was half that of the Seychelles cohort, exposure to Hg was related to an increased incidence of pre-term deliveries (less than 35 weeks) (INAC, 2009).

The Faroe Islands study revealed several associations between Hg exposure and neurobehavioral outcomes, including a decreased neurological optimality score in newborns; decreased performance in domains of language, attention, and memory; and decreased auditory and visual brain processing in seven-year olds, which persisted at 14 years of age (INAC, 2009). Similar associations were observed at six to seven years of age in children from New Zealand. In the Seychelles, however, similar endpoints of neurodevelopment revealed no associations with pre-natal MeHg exposure. It was proposed that MeHg toxicity observed in the Faroe Islands cohort might have been potentiated by simultaneous PCB exposure, which was about three to four times higher than in other cohorts. When the results of all the cohorts were looked at in greater detail it was proposed that differences in maternal diet during pregnancy may have an impact on fetal susceptibility to MeHg exposure and that potential neurobehavioral effects of MeHg exposure could be found in the domains of verbal function, visio-motor integration and attention. Another commonly reported effect of pre-natal MeHg exposure has been the latency of brainstem auditory-evoked potentials, a measure of auditory processing. Cohort studies in the Faroe Islands, Spain, and Greenland each reported associations between latencies and MeHg exposure (INAC, 2009).

Some studies summarized by Yokoo et al. (2003) reported neurobehavioral symptoms of low-level MeHg exposure in adults, including vision (chromatic discrimination, contrast sensitivity, peripheral fields) and psychomotor functions (tremor, dexterity, grip strength, complex movement sequences, hand-eye coordination, rapid alternating movement). Among Brazilian adults living in fishing communities of the Pantanal region, they found that hair Hg levels (between 0.56 and 13.6 μg/g) were associated with alterations of fine motor speed, dexterity and concentration. Further effects were related to disruptions of verbal learning and memory. All of the observed effects increased with hair Hg concentration.

One of the more commonly reported effects of chronic low level dietary exposure to MeHg in adults is an increased risk of cardiovascular effects. The 2009 AMAP human health assessment discussed this subject in the context of Arctic populations (AMAP, 2009b), while another review by Mozaffarian (2009) gave further details with a particular focus on risks and benefits of fish consumption for cardiovascular health. Both reviews cover a Finnish study that found the risk of coronary heart disease in men who consumed freshwater fish to be significantly associated with Hg concentrations in hair. Mercury has been found to promote lipid peroxidation resulting in the formation of low-density lipoproteins which have been implicated as initiators of arteriosclerosis.

Previous observations in the same population also associated increased risk of death from coronary heart disease to low serum concentrations of Se, an antioxidant that can block the Hg-induced lipid peroxidation process. Like the Finnish men, Inuit consume high concentrations of MeHg in fish and marine mammals, yet mortality from coronary heart disease is extremely low. It is possible that Inuit are protected by the high levels of Se and polyunsaturated fatty acids that are also contained in the marine foods. The Faroe Islands cohort study examined potential associations between pre-natal Hg exposure and cardiovascular development. The study showed that pre-natal Hg exposure was associated with increased blood pressure and reduced heart rate variability in seven-year old children (AMAP, 2003). A follow-up study at age 14 showed that these effects were still present, although significantly less severe. The interactions between nutrients (mainly Se and n-3 polyunsaturated fatty acids), MeHg and cardiac effects were examined in the Inuit Health Survey of Nunavik, Quebec. The study looked at the activity of Paraoxonase 1 (PON1), an enzyme thought to play a role in cardiovascular disease by metabolizing toxic oxidized lipids associated with low density lipoprotein (LDL) and HDL. Preliminary results suggest that MeHg exposure may have a slight inhibitory effect on PON1 activity which seems to be offset by Se intake. Further investigation is underway to look at other markers of cardiovascular disease, such as relation between PON1 activity, the concentration of oxidized LDL and the thickness of the carotid artery *intima media*, the latter being a biomarker of atherosclerosis (AMAP, 2009b). It is thought that cardiovascular effects associated with low level Hg exposure may be of even greater public health significance compared to some other end points such as neurotoxicity.

## 8.6. What are the risk communication / risk management strategies used to address dietary mercury exposure in the Arctic?

Most risk communication in the Arctic regarding contaminants involves messages about contaminants in general, or groups of contaminants (e.g., POPs). This may be because it is difficult to separate the health effects of isolated contaminants, given differences in contaminant toxicity through mixtures or contaminant-nutrient interactions. That said, risk communication specifically related to Hg is most prominent in the Faroe Islands. Biomonitoring and epidemiological studies have driven efforts to reduce Hg exposure of the Faroese for about three decades. When effects of pre-natal exposure to Hg were observed in children, health authorities focused their attention on reducing exposure to Hg in the meat of pilot whales, the main source of exposure (Weihe et al., 2003). Risk communication focused on the adverse impacts of Hg and POPs and how to avoid these contaminants, while providing information about healthy dietary alternatives. Risk communication in the Faroe Islands has resulted in a marked dietary change, with reduced amounts of pilot whale meat and blubber now present in the diet, particularly among pregnant women (Budtz-Jørgensen et al., 2007). Much of the success has been attributed to the simplicity of communicating about the risks of Hg contamination when it is related to a single species, the pilot whale, as well as easy access to unpolluted fish alternatives from the ocean.

Risk communication in other regions of the Arctic (e.g., Arctic Canada and Russia) provides advice on contaminants in general. This advice is less prescriptive and emphasizes food choices with lower contaminant levels, while emphasizing that the benefits of eating nutritious traditional/local foods outweigh the risks due to contamination. Further understanding of the contaminant levels in indigenous peoples, health effects from contaminants in the diet, and the most effective risk communication schemes will help mitigate the effects of contamination from global and dietary influences, and will reduce the need for indigenous people to have to choose between nutritious traditional/local foods and store-bought foods which bring other health risks.

## 8.7. Conclusions and recommendations

Conclusions (in numbered bullets) are organized under section headings, followed by knowledge gaps / recommendations (in italics) when appropriate.

### What are the global influences on mercury exposure in northern peoples?

1. The accumulation of anthropogenically emitted Hg from global sources in Arctic ecosystems has resulted in elevated levels of Hg in fish and wildlife that represent an important part of the diet of northern peoples. Global climate change is also resulting in increased levels of Hg in Arctic biota and thereby contributing to higher levels of dietary exposure.

*Monitoring is urgently needed to ensure early detection of climate-induced human health threats related to contaminants. Essential monitoring elements include contaminant levels in humans and wildlife food species, zoonotic diseases in wildlife, and observations of environmental parameters such as water quality, ice, permafrost, and weather.*

*Improved predictive models of contaminant transport and behavior in the Arctic are needed to understand the likely impacts of climate change with respect to contaminants. The models require improved comprehensive circumpolar monitoring of environmental matrices integrated with weather and climate data.*

*A global agreement to control Hg emissions should be pursued to complement national and regional efforts to reduce environmental Hg concentrations and to lower human exposure to Hg in the Arctic.*

### What are the dietary influences on mercury exposure?

2. The dominant sources of dietary Hg exposure are from consumption of marine mammal tissues and fish. The highest levels of dietary exposure occur among Inuit communities that regularly consume the tissues of marine mammals. These same foods that contribute to Hg exposure also represent a valuable source of essential nutrients, like polyunsaturated fatty acids, and also represent immeasurable social and cultural value to communities.

3. Transition to a more commercially-based diet and difficulty in obtaining traditional/local foods, combined with the prevalent condition of food insecurity in some communities all have the potential to lower dietary exposure to Hg, but these changes may come at serious nutritional cost and associated health risk.

*More research about determinants of food choices and availability is needed to provide better dietary advice relevant to local conditions and preferences. This research should focus on differences by age and gender.*

*Because consumption of imported food is likely to continue increasing in most of the Arctic, health authorities should work vigorously with local and national food agencies to promote the availability and consumption of imported food items with high nutritional value.*

*To maximize the benefits of traditional/local food use and reduce the risks associated with the intake of contaminants in some traditional/local foods (e.g., certain marine mammals), health authorities should promote improved access to and consumption of local traditional/local foods such as fish and terrestrial mammals that have lower levels of POPs and metals and high nutrient value.*

*Studies should combine human biomonitoring of contaminants with total diet studies in the Arctic in order to produce better exposure estimates and better dietary advice.*

### How do human tissue mercury levels compare to guidelines?

4. A significant proportion of people from communities in the eastern Canadian Arctic and Greenland still exceed U.S. and Canadian tissue Hg guidelines. In some populations, however, an overall decline has been noted in the proportion of Arctic people that exceed these guidelines. It is tempting to suggest that lower levels of Hg in the environment, brought about through regional action to reduce Hg emissions, is responsible for the decline; however, the temporal trends in biota discussed in Chapter 5 do not support this explanation. It is more plausible that changes in diet through 'nutritional transition' and/or risk management and communication with regard to Hg and other contaminants in the environment are the likely causes.

*Continued monitoring of legacy POPs, Hg, and lead in humans and traditional/local foods is needed to obtain valid exposure trends and to track the effectiveness of national, regional, and international action to reduce releases.*

*Because the exposure level to MeHg continues to be high in some Arctic populations, continued monitoring of temporal trends is warranted.*

### What are the health effects of mercury in humans?

5. It has been shown that exposure to Hg at the current levels in the Arctic can have adverse impacts on human health, particularly for the developing fetus and children, although further research is required to determine if the subtle effects of Hg on human health are persistent.

*Further research is needed on the relationship between Hg and cardiovascular disease in Arctic populations. Contaminant-nutrient interactions should be further investigated in prospective Arctic cohort studies.*

### What are the risk communication / risk management strategies used to address dietary mercury exposure in the Arctic?

6. Risk communication strategies vary between different regions of the Arctic and must be tailored to meet the specific needs of the target population and should contain balanced messages regarding contaminant risks and dietary nutrition. In the case of the Faroe Islands, consumption advisories directed specifically at reducing the consumption of pilot whale have been successful in reducing Hg exposure among pregnant women. In Arctic Canada, dietary advice related to contaminants in general has promoted consumption of a varied traditional diet with further promotion of nutritious species known to be low in contaminants, particularly for women of child-bearing age.

*Regional health authorities should collaborate with communities to develop effective, culturally appropriate communication strategies concerning contaminants and human health. Communication efforts should be evaluated with respect to their impacts on the intended audience.*

*Dietary advice to Arctic residents should include both the benefits of traditional/local food consumption and the results of technical risk assessments concerning contaminants.*

*Risk perception, dietary patterns, and determinants of food choice should be taken into account in the development of communication materials.*

*AMAP should improve the distribution and availability of its reports and information to the general public, health authorities, and scientists in or working in the Arctic. Possible steps include greater prominence on internet search engines and an increased presence at meetings and conferences.*

### Further general recommendations from the 2009 AMAP human health assessment (AMAP, 2009b):

*The human health assessment process initiated through AMAP should be continued with the aim of pursuing a more holistic health impact assessment of the influences of environmental pollution on the health of Arctic peoples and the associated risk factors affecting them. This effort should be coordinated with related public health work initiated through the Sustainable Development Working Group.*

*Considering the importance of general health and the influence of changing diets and contaminants on disease outcomes, more effort needs to be made to systematically collect, analyze, and report on the health status of Arctic populations and especially indigenous peoples.*

*It is very important to maintain and expand current human population cohorts in the Arctic as identified in this assessment, such as those in Canada, Greenland, and the Faroe Islands. Only long-term prospective studies will provide the information needed to track adverse health outcomes associated with contaminants and changing conditions related to climate change, socio-cultural conditions, and diet.*

*Uniform reporting of key health status indicators should occur every three to five years, should include trend information, should* *be broken down by age and gender, and should be provided by all circumpolar jurisdictions at appropriate regional levels.*

*Because genotype may influence responses to contaminants, more knowledge about genetic variability and susceptibility among Arctic peoples is needed. Including genetics in studies that examine lifestyle and contaminant interactions will provide better insight into individual and population vulnerability to contaminants.*

*Public health officials should continue to recommend breast feeding among Arctic populations as a healthy practice which optimizes infant growth and development. However, there is a need to reduce contaminant levels in breast milk through national, regional, and international action to reduce pollution and through relevant food advice to women of child-bearing age.*