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CANADIAN ARCTIC CONTAMINANTS ASSESSMENT REPORT

Human Health Assessment

2017

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Human Health Assessment 2017

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FOREWORD

The Northern Contaminants Program (NCP) is pleased to present the Canadian Arctic Contaminants Assessment Report - Human Health 2017. This publication is a Canadian specific summary of an Arctic Council report from the Artic Monitoring and Assessment Programme (AMAP) on human health in the Arctic published in 2015. This report also holds content not presented in the AMAP report including an important discussion on risk communication and the chemicals management regime within Canada. The intention of this report is to provide a comprehensive assessment of contaminants in Canada's Arctic, and the impact they have on the Canadian Arctic population.

The information presented within this report covers the spectrum of contaminants related human health in the Canadian Arctic. This includes an examination of Traditional Foods and the northern diet, human exposure and contaminant levels, health outcomes related to contaminant exposure, and, communication about contaminants.

Managed by Crown-Indigenous Relations and Northern Affairs Canada, the NCP, which was established in 1991, is a co-operative effort involving the federal departments of Health, Environment and Climate Change, and Fisheries and Oceans, the three territorial governments, the governments of Nunavik and Nunatsiavut, northern Indigenous organizations, and key academic networks. The NCP co-ordinates monitoring and research of northern contaminants nationally and provides the research necessary to take action internationally. The NCP addresses concerns about exposure to elevated levels of contaminants in fish and wildlife species that are important to the traditional diets of northern Aboriginal peoples.

The NCP is considered a model program for conducting monitoring and research in the North in a way that engages Indigenous organizations and communities in all aspects of the program, from management decisions about program direction, to community based monitoring of wildlife. Even so, after 25 successful years, the NCP is still finding ways to improve and to better serve Arctic indigenous communities. In recent years this has included an increased effort to expand human health monitoring in the Canadian Arctic to ensure residents and health authorities have the most up to date information on contaminant exposure in order to make informed decisions on their health and health policy. As the NCP looks to the future, traditional knowledge and knowledge coproduction will continue to inform communication strategies to ensure Arctic residents have a more holistic understanding of how contaminants and other environmental stressors are effecting their environment and communities.

Further information about the Northern Contaminants Program is available on the NCP website at www.science.gc.ca/ncp.

Thank you to all those who contributed to this report.

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25 YEARS ANS
Northern Contaminants Program
Programme de lutte contre les contaminants dans le Nord

Executive Summary

Introduction

The Northern Contaminants Program (NCP) undertook this assessment to address concerns about potential human health risks associated with exposure to environmental contaminants from a diet that includes traditionally prepared and harvested foods from local northern ecosystems. Traditional food, also known as country food, is central to the social, cultural, economic, and spiritual well-being of Inuit, Dene, and Métis in the North and, for many, is essential for their overall food security.

This report is the fourth human health assessment as part of the Canadian Arctic Contaminants Assessment Reports (CACAR) that summarizes the state of knowledge on contaminants and human health in northern Canada. The overall objective of this report is to provide the most up-to-date knowledge on contaminant exposure patterns in northern Canada, methods for describing these human exposures, potential health outcomes related to contaminants, and contaminant management and communication efforts that concern Indigenous people living in northern Canada.

Traditional food and the northern diet

Traditional foods such as marine mammals, fish, terrestrial animals, and birds are nutritious dietary choices for children and adults living in northern Canada. When northern diets include traditional foods, intakes of protein and many dietary nutrients tend to be higher. This is especially important for young people and children. The collection of traditional foods also has economic benefits. For people with access to hunting and fishing equipment, these foods are often more affordable than market food. However, the current Inuit diet across the Arctic is suboptimal, where about one quarter to one third of total calories consumed come from high sugar foods and drinks. Although country food use is culturally specific and varies widely throughout the Arctic, the overall trend shows that younger generations are consuming less traditional food than their elders.

Traditional food can also be a main source of exposure to environmental contaminants in the North. Dietary choice in northern Canada, and therefore extent of exposure to contaminants from traditional food, is a complex issue because the substantial benefits of collecting and consuming traditional foods may be offset by concern about contaminants. Dietary substitutions may help northerners to reduce contaminant exposures. For instance, in the case of mercury, substituting traditional foods high in mercury for others lower in mercury is one way to lower mercury intake, while still promoting consumption of healthy levels of important nutrients like selenium and omega-3 fatty acids. It is critical that dietary substitutions and intervention strategies are designed at the regional level to make sure they are relevant to the different contaminant sources, dietary preferences, and food availability scenarios for people across northern Canada.

Human exposure and contaminant levels

Findings from this assessment show that levels of POPs have declined by up to 80% across the 20 years (1992–2013) that contaminants have been measured in blood samples from pregnant Inuit women from Nunavik. At the same time, blood concentrations for total mercury and lead have decreased by about 60% in these pregnant women. The proportion of Inuit pregnant women (and Inuit women of childbearing age) from Nunavik exceeding *the provisional interim blood guidance value for methylmercury* has been decreasing overall since 1992. Similarly, the proportion of these women who are exceeding *the blood lead intervention level* and *the guideline for lead in whole blood of pregnant women* has been decreasing steadily over time in Nunavik, with exceedances approaching zero since 2004.

It is generally expected that differences in contaminant body burdens will usually reflect differences in traditional lifestyles and especially dietary habits. When blood data was examined for Inuit women of childbearing age from across northern Canada, POP and metal levels were generally higher for Inuit from coastal communities in Nunavik (in northern Québec) and Nunavut, where marine mammals were more likely to be consumed, compared with Inuit from Nunatsiavut (in northern Labrador) and the Inuvialuit Settlement Region (in the Northwest Territories). During the Inuit Health Survey conducted in 2007-2008, Inuit men reported eating larger portions of traditional foods and ate these foods more frequently than Inuit women. As well, older adults often ate more traditional food than younger adults. When contaminants were measured in the blood of participants from the Inuit Health Survey, body burdens of many POPs and metals were frequently higher in Inuit men compared with Inuit women, often by as much as two- or three-fold, and older people tended to have higher contaminant body burdens than younger people.

Mechanistic modelling studies can help to explain findings from northern studies by simulating the exposure of Indigenous Arctic populations to contaminants. Some mechanistic modelling studies have observed that the main determinant of some relationships between body burden and age is the length of time elapsed since the peak in exposure for long-lived contaminants whose production and use are subject to international agreements, such as PCBs. These age trends are often more pronounced among Arctic populations, as older generations of northerners tend to have a higher dietary intake of traditional food than younger generations, implying a higher intake of contaminants throughout life. Mechanistic modelling studies have also predicted that Inuit living in northern Canada may have potentially greater POP exposures due to the presence of some marine mammals in their diet.

These findings from mechanistic modelling studies may help to explain the observation that levels of several POPs (and also some metals) were generally between two- and eleven-fold higher among Inuit men and women from the Inuit Health Survey (2007-2008) and the Nunavik Inuit Health Survey (2004) compared to the general Canadian population in southern Canada (2007-2009). Results from the Nunavik Child Development Study also suggest that Inuit children from Nunavik experienced higher exposures to mercury and lead than children from the general Canadian population during the period 2000 to 2009.

Future work in exposure studies

Northern studies have observed that the developing fetus is sensitive to some contaminant exposures, and there is on-going concern with mercury exposures in particular. Some traditional foods are significant dietary sources of mercury, namely predatory fish and specific parts of marine mammals, but many of these traditional foods are also rich sources for selenium and other nutrients. While time trends for contaminants have been determined for pregnant Inuit women from Nunavik through continued sampling of maternal blood, additional studies are required to ascertain contaminant trends for women of childbearing age and pregnant women from the other three Inuit regions. The co-location of biomonitoring studies in people and wildlife is also encouraged, as this would permit researchers to create direct links between site-specific exposures and measured body burdens.

The importance of consuming specific traditional foods that may contain high concentrations of mercury is also a knowledge gap. On-going consideration of the interests of northern communities during future studies that examine contaminants in traditional food will ensure these specific exposures are being investigated within the context of the regional exposure issue. As well, this approach would ensure that any important health, dietary, or contaminant issues that may arise will be addressed with the communities in the most appropriate cultural health context.

Some research suggests that traditional food may not be the only source of contaminant exposures for northerners. Routes of exposure to PBDEs (a group of chemicals used as flame retardants) appear to vary across the Arctic, and the association between PBDE concentrations in human blood and the consumption of traditional food is unclear. The contribution of dietary and non-dietary sources to PBDE exposures in northern Canada warrants further investigation to improve the understanding of PBDE exposures from traditional food compared to other sources, such as dust in the home.

As noted in prior assessments, cadmium is also an exception, where Inuit men and women have shown similar blood concentrations within each of the four northern Inuit regions. Smoking, a major source of cadmium exposure, was highly prevalent amongst participants from the Inuit Health Survey (2007-2008) and the Nunavik Inuit Health Survey (2004), with about 70% of people smoking. Blood cadmium levels among non-smoking study participants from the Inuit Health Survey were about 3 to 10 times less than for than for the general Inuit population. Sustained efforts on anti-smoking campaign are needed to address this on-going public health issue.

The identification and measurement of new chemicals in commerce that might be transported to the Arctic and bioaccumulate in wildlife and northern people are on-going research needs that will require substantial investment of resources to ensure methods are available to measure these chemicals in people. The expansion of northern biomonitoring to include chemicals that are studied under other national programs would support public health efforts of risk management groups, potentially permit the examination of chemical exposures from local sources, and, overall, provide a better understanding of the full chemical exposure profile of northern populations.

In general, the interpretation of human levels of contaminants is a complex undertaking that often requires using computational tools to increase the understanding of data from exposure studies. There are numerous potential applications for these tools in the Arctic that may assist northerners in managing risks of exposure and for making informed dietary choices. The on-going investment of resources for the development of appropriate computational tools is encouraged.

Health outcomes related to contaminant exposures

The measurement of elevated contaminant levels among northerners has raised concern because many of these widespread environmental contaminants are known for their adverse effects on neurodevelopment. In response to this concern, several prospective longitudinal cohort studies of pregnant women, infants, and children have been conducted globally, some on Arctic populations, to assess the effects of prenatal exposures to mercury, PCBs, and lead.

In this assessment, many key findings involving the effects of prenatal contaminant exposures on child health in Canada come from the Nunavik Child Development Study, a prospective mother-child cohort study. Between 2005 and 2010, nearly 300 eleven-year-old children in Nunavik were tested for growth, visual, motor, cognitive, and behavioural development. Comparisons have been made with results from this cohort obtained at a younger age and also to results reported from child cohort studies in other circumpolar Arctic countries.

Additionally, findings for the effects of contaminants on health outcomes for adults in northern Canada have primarily come from two cross-sectional health surveys conducted in Nunavik in 1992 and 2004. Some preliminary data are also available from the Inuit Health Survey (2007-2008) in the other three northern Inuit regions in Canada.

The results from the Nunavik Child Development Study suggest that the composition of PCB congeners found in people in northern Canada may have less toxicity than those in southern populations. With the implementation of the Stockholm Convention, environmental PCB concentrations are expected to now be in decline. The combined effects of these two factors may change the concern of PCB exposure on the health of northerners in the future. Health studies that examine on-going and future PCB exposures for Indigenous people in northern Canada could provide confirmation of these assumptions.

At the same time, some new and emerging contaminants, such as PFOS and PBDEs, are now being found in Arctic biota and humans. There is preliminary evidence that both groups of chemicals have potential effects on the thyroid and the endocrine system. NCP studies that include new and emerging contaminants will permit the NCP to assess whether the next generation of chemicals may become a health concern in the North.

New data related to the role of mercury and POPs on cardiovascular disease risk factors collected from several cross-sectional studies conducted in the circumpolar Arctic have also been inconsistent. These inconsistencies may be due to the relatively small number of samples collected during each separate study; however, combining datasets may provide more power to elucidate potential effects of contaminants on health. As well, circumpolar studies outside of Canada have examined associations between Type 2 diabetes and POP exposures. It is recommended that Canadian studies also examine this association.

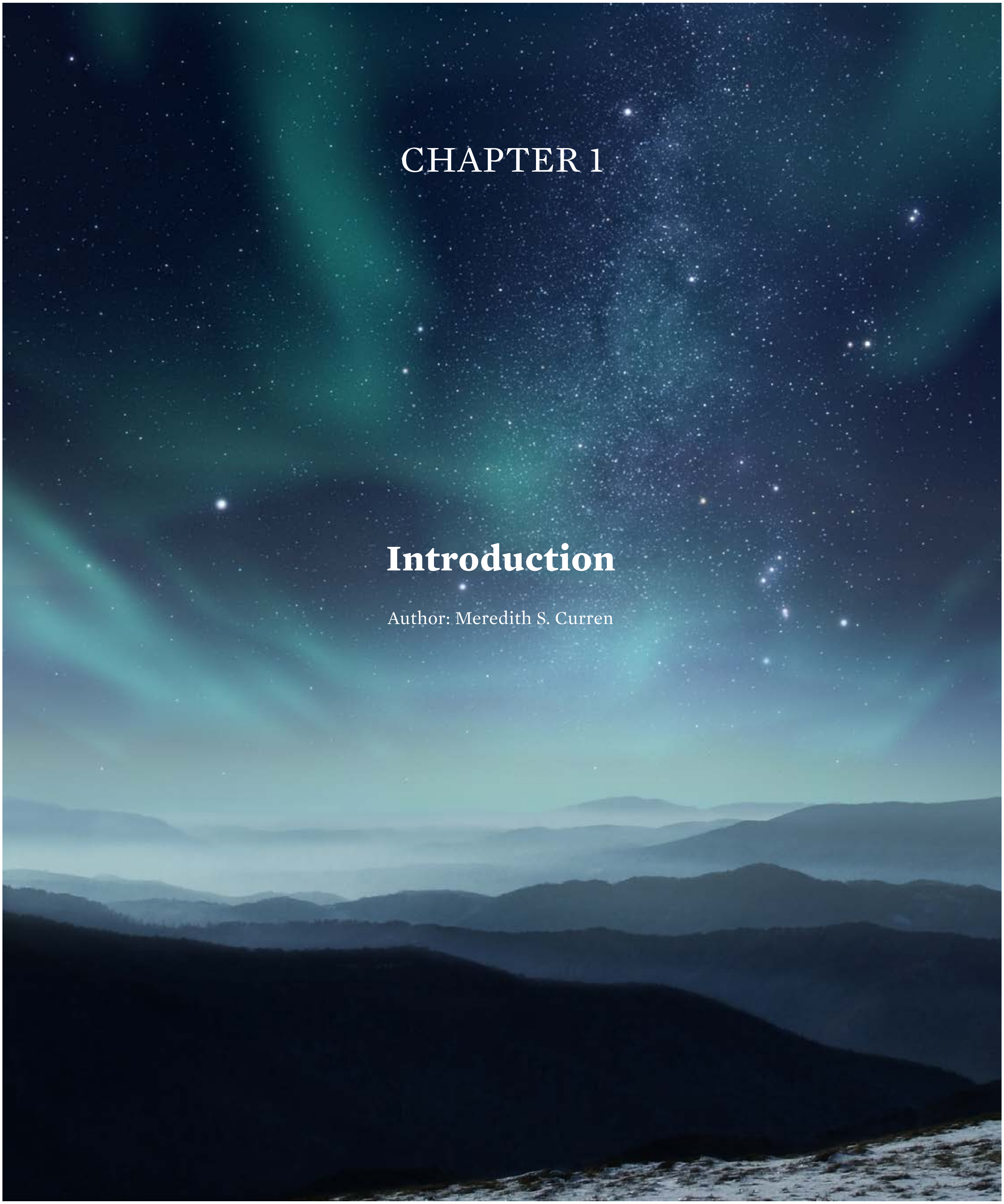
There is increasing evidence that some chemical forms of selenium found in traditional food (with naturally high concentrations of selenium) may be of lower toxicity than other chemical forms of selenium that are often found in selenium dietary supplements, in drinking water, or in occupational settings. More research is needed on the chemical forms of selenium present in selenium-rich traditional northern diets. While selenium is an essential nutrient for human health, it can also be toxic at elevated exposures, leading to selenosis. However, in some cases, selenium has been found to be a beneficial cofactor for mercury and POP effects on risk of cardiovascular disease. Selenosis has not been specifically observed or monitored in Canadian Inuit populations. Both the benefits and potential risks of elevated selenium consumption from a traditional diet warrant further investigation.

Communication about contaminants

The NCP is a best practice program model that supports capacity building, and it ensures participation of northern Indigenous people in program management, research, and information dissemination. Since the early years of the NCP, benefit-risk communication has been undertaken by Indigenous partners and territorial and regional health authorities. Health messages created during NCP projects have focused on the amount and types of traditional food consumed, as well as the benefits of traditional food consumption. However, the communication of research results and advisories to northern communities remains a challenging task due to the complexity of balancing the social, cultural, economic, spiritual, and nutritional benefits of consuming traditional foods with the potential health risks from contaminant exposures.

Positive experiences in communicating research results in the North have been found when studies are designed and completed through a partnership approach between researchers and northern communities. Effective northern communication tools include those that permit easy understanding of research results and make results accessible past study completion, such as through the creation of visual banners or signs posted in public locations. On the other hand, communication tools that contain complex scientific language are sometimes difficult for community members to understand.

Overall, local health advisories in northern regions are important interim measures to address contaminant exposures until concentrations in traditional food decline to safe levels. However, the rapid dispersal of messages meant for one group or location can create anxiety and confusion in other areas where an advisory does not apply, or is not intended. Moreover, key information can be misconstrued if language is changed during subsequent reporting through the media and social media. Continuous communication is therefore required locally to reinforce the validity of messages for specific audiences and to prevent confusion in other communities. There is also a need to conduct evaluations after risk communication activities, to ensure that messages were released and received as planned and expected.



CHAPTER 1

Introduction

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Author: Meredith S. Curren

1.1 What is the Northern Contaminants Program?

The Northern Contaminants Program (NCP) addresses concerns about potential human health risks associated with exposure to environmental contaminants from a diet that includes traditionally prepared and harvested foods (traditional food) from local northern ecosystems. Traditional food, also known as country food, is central to the social, cultural, economic, and spiritual well-being of Inuit, Dene, and Métis in the North and, for many, is essential for their overall food security. Many of the contaminants that are found in traditional food are released to the environment in southern regions and are transported to the Arctic via long-range atmospheric transport, waterways, and ocean currents.

Persistent organic pollutants (POPs) are a group of contaminants found in the northern environment that tend to be resistant to biodegradation, usually highly lipophilic (fat soluble), and capable of bioaccumulation and biomagnification in the food chain (Van Oostdam et al., 2005; Donaldson et al., 2010). Concern about the transport of contaminants with these types of characteristics over long distances and beyond national borders has led to the development and implementation of international agreements to eliminate or restrict POPs (UNEP, 2009; see also Chapter 4).

The highest levels of POPs are often found in the fatty tissues of long-lived marine mammals and other predatory species. Similarly, methylmercury, the most toxic form of mercury produced during the natural process of mercury methylation in marine and fresh waters, biomagnifies in the northern food web and collects at higher concentrations in the muscle and organ tissues of predatory fish and fish-eating animals (Kirk et al., 2012). The chemical and physical properties that result in the transportation of contaminants such as POPs and mercury across long distances before they bioaccumulate in biota and biomagnify in the northern food web have been examined extensively as part of northern environmental research (e.g. Northern Contaminants Program, 2013; Braune et al., 2015).

Historically, northern Indigenous people have experienced particularly high exposure to POPs, mercury, and other metals due to the high proportion of marine mammals, fish, terrestrial animals, and birds in the traditional food component of their diet. The goal of the NCP has been the same since its inception in 1991:

"To work toward reducing and, wherever possible, eliminating contaminants in traditionally harvested country food, while providing information that assists individuals and communities in making informed decisions about food use."

1.2 What are the NCP contaminants of concern?

The contaminants of interest for the NCP are prioritized into two general groups: 1) persistent organic pollutants (POPs), and 2) heavy metals, including mercury, lead, and cadmium.

Persistent organic pollutants and heavy metals represent the core contaminants in the biomonitoring program of the NCP. Most POPs were first used in industry, agriculture, or for vector control several decades ago and include organohalogen chemicals such as dichlorodiphenyltrichloroethane (DDT), polychlorinated biphenyl (PCB) congeners, and polybrominated diphenyl ether (PBDE) congeners. Mercury and other metals such as lead and cadmium are included in the NCP biomonitoring program because elevated levels of these metals have also been observed in northern people or traditional foods for many years. On-going monitoring of POPs and metals has permitted the examination of exposures over time and across the different regions of northern Canada. Monitoring of new and emerging contaminants, such as decabromodiphenyl ether (deca-BDE, or PBDE-209) and organophosphorus flame retardants (OPFRs), allows the NCP to assess whether the next generation of chemicals used during the production of commercial products will become a health concern in the Arctic.

There are currently (as of 2016) 31 POPs that are subject to international agreements, such as under the Stockholm Convention (UNEP, 2009). Each year, new and emerging contaminants are nominated to the Stockholm Convention and undergo thorough assessment to determine if they qualify as POPs. Arctic biomonitoring data is considered crucial to these assessments. As well, the collection of biomonitoring data for mercury from northern Canada has been used to inform the Minamata Convention on Mercury, a global treaty concerning anthropogenic mercury emissions and releases that was adopted in 2013 and may now be ratified by signatory countries (UNEP, 2015). An important role for the NCP is to continue providing monitoring data on contaminants that are already covered by these Conventions for the purpose of effectiveness evaluation. However, it is also very important that the NCP provide information on newer contaminants that are under consideration for inclusion in international agreements.

The NCP supports contaminants monitoring and research for northern people and their environment alike. These complementary areas of investigation ensure knowledge gained on contaminants in the northern ecosystem is transferred to the assessment of human health risks. NCP human biomonitoring studies (Chapter 2) that investigate changing levels of POPs and metals in northern populations, in conjunction with NCP environmental monitoring results for contaminants in other media (e.g. air, animals, fish) (Northern Contaminants Program, 2013; Braune et al., 2015), can be an essential part of determining whether risk reduction programs nationally and globally are adequate for the protection of health in the North. As well, human biomonitoring studies can provide insight on the relationship between contaminants exposures and human health outcomes. NCP studies that examine the potential impact of contaminants on human health (Chapter 3) help to identify people who might be especially vulnerable to contaminant exposures, and they also provide a health context during the communication (Chapter 4) of exposure information back to communities that rely on traditional food consumption. Importantly, the inclusion of POPs and metals in the NCP program supports Canada's commitment to monitor these chemicals in vulnerable Canadian populations and also under international agreements (see Chapter 4).

Selenium, an essential element that is naturally present in high concentrations in some northern traditional food (and, by extension, in Indigenous populations consuming these foods) has recently been included in the NCP program. While selenium is an important nutrient that may have potential protective properties against mercury exposure and toxicity, there is also the possibility of toxic effects of selenium at high dietary exposures (see Chapter 3). NCP research seeks to better understand healthy levels of selenium consumption from traditional food.

1.3 What NCP human health research and monitoring results are available to date?

The NCP has conducted three human health assessments as part of the Canadian Arctic Contaminants Assessment Reports (CACAR) that have summarized the state of knowledge on contaminants and human health in northern Canada: CACAR-I in 1997 (Gilman et al., 1997; Van Oostdam et al., 1999), CACAR-II in 2003 (Van Oostdam et al., 2003, 2005), and CACAR-III in 2009 (Van Oostdam et al., 2009; Donaldson et al., 2010). The current report represents the fourth human health assessment (CACAR-IV) and adds knowledge to the three previous reports by presenting results of recent human biomonitoring studies in northern Canada, introducing methods that are used to describe and interpret contaminant exposure data from the Arctic, discussing relevant research from the Arctic on potential health outcomes related to exposure to contaminants, and highlighting issues and best practices for managing risk of exposure to contaminants and communicating contaminant information in the northern regions. Some of the Canadian research presented here was also included in a circumpolar Arctic assessment on human health and contaminants carried out under the Arctic Monitoring and Assessment Programme (AMAP; AMAP 2015).

Following recognition in the 1980s that contaminants were travelling to the Canadian Arctic through long range transport, the first phase of the NCP (1991 – 1996) provided a strong baseline of understanding on the sources and pathways of exposure, spatial patterns, levels, and health implications of contaminants. The CACAR-I assessment described the issue of environmental contaminants in the Arctic and provided evidence that the major sources of these contaminants were human activities outside of the Arctic (Gilman et al., 1997; Van Oostdam et al., 1999).

The second phase of the NCP (1997 – 2002) increased the understanding of contaminant exposures in people across the North by expanding on earlier monitoring studies. Factors that influenced traditional food consumption were taken into account, such as the age and sex of study participants and the dietary preferences of the different Indigenous groups living in the Canadian Arctic (i.e. Inuit, First Nations, and Métis). CACAR-II also provided early insight on both the value and challenges for conducting epidemiological studies in the North in order to identify potential health outcomes related to contaminants (Van Oostdam et al., 2003, 2005).

Importantly, the second assessment concluded that the nutritional benefits of traditional food and their contribution to the total diet were substantial, and, in general, these benefits outweighed the risks from exposure to contaminants. This information was integral to efforts that followed for the risk management of environmental contaminants and for the communication of potential human health risks for northern communities.

The third phase of the NCP, which got underway in 2002, aimed to provide new information on geographical and temporal trends for contaminant levels in northern people, present research results on possible health outcomes related to current levels of contaminants, identify new contaminants of concern, and provide additional knowledge for risk characterization and communication about contaminants in traditional food. The third assessment of contaminants and human health identified several major knowledge gaps that have guided the most recent research under the NCP (Van Oostdam et al., 2009; Donaldson et al., 2010):

- New human biomonitoring studies need to be undertaken in order to better understand how contaminant levels are changing across northern Canada. This information is important for determining the effectiveness of national and international agreements for controlling the use of chemicals.
- More research is required to identify regional levels of contaminants in traditional foods. New and emerging contaminants need continued monitoring in Arctic people and their diets as current exposure trends are very uncertain.
- More research is needed to identify and characterize possible health outcomes in infants and children that are associated with prenatal exposure to contaminants in northern regions where there are exposure levels of concern to public health authorities.
- The interactions between nutrients present in fish and marine food and the effects of contaminants on human health and child development need to be further studied. Further investigation of the genetic specificity of fish- and marine mammal-eating populations is also required.
- Further experimental and epidemiological work is needed on the role of methylmercury and POPs exposure in the development of cardiovascular diseases and diabetes, or on metabolic syndrome.
- Evaluations of prior risk communications about contaminants should be conducted in collaboration with appropriate public health authorities to assess what factors influence the success and effectiveness of communication activities and to determine the appropriate context for their delivery.
- Risk-benefit evaluations and comparisons should be made with special reference to the most highly exposed communities and vulnerable groups.

1.4 What is the objective of the current assessment?

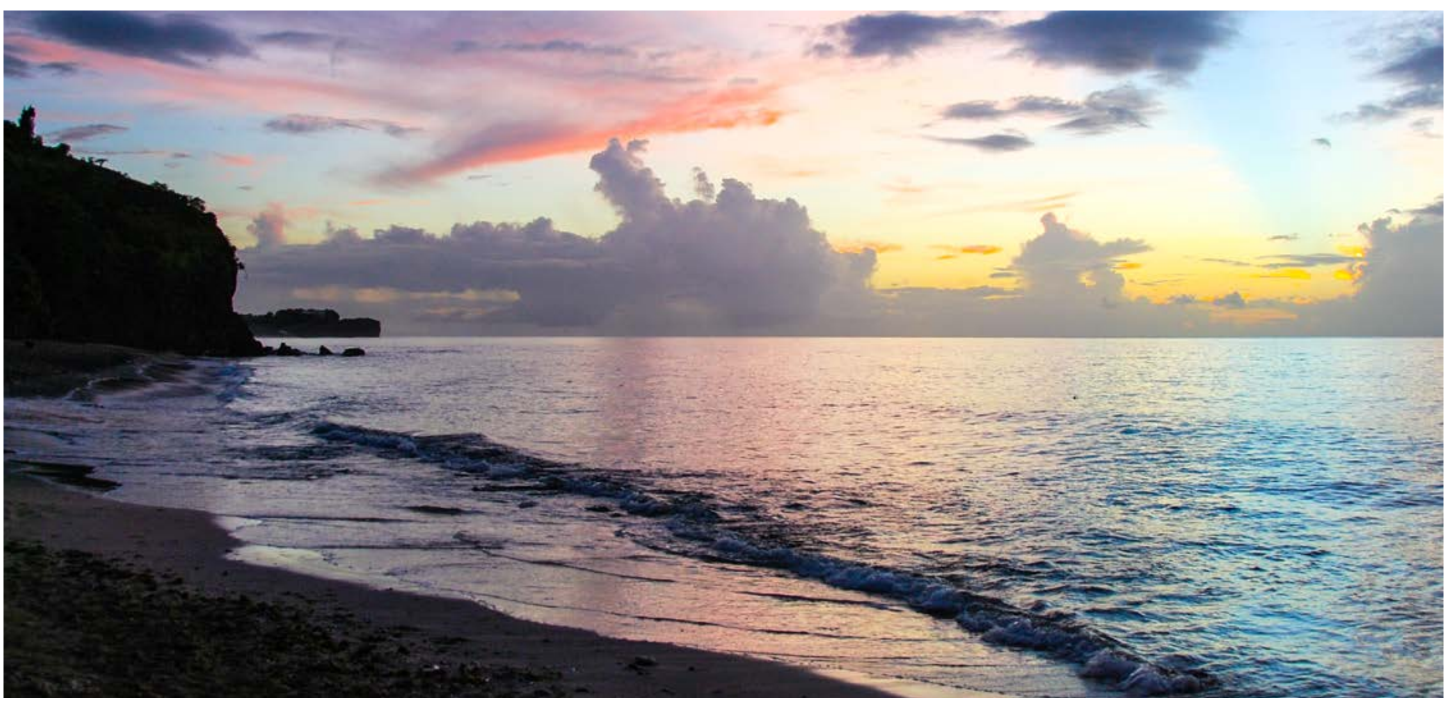
The overall objective of the CACAR-IV human health assessment report is to provide the most up-to-date knowledge on contaminant exposure patterns in northern Canada, methods for describing these human exposures, potential health outcomes related to contaminants, and contaminant management and communication efforts that concern people in northern Canada. While recent Canadian results have also been reported in a circumpolar Arctic context in the recent AMAP human health assessment (AMAP, 2015), this CACAR-IV human health assessment focuses uniquely on Canadian results (and related health outcome studies from other Arctic countries), and it includes additional national, territorial, and regional context and information.

The CACAR-IV human health assessment describes activities for new or on-going population cohorts in northern Canada, as well as population biomonitoring studies in northern regions or communities where there is a specific concern about exposure to contaminants. These studies provide information for tracking exposures and potential health outcomes related to contaminants, and they provide insight on the impact of dietary changes for contaminants exposure and the intake of healthy nutrients from traditional foods. While the focus of this assessment is on results from the Human Health subprogram of the NCP, results from some studies conducted under the Environmental Monitoring and Research subprogram have been referenced in order to add context to the human health results, particularly for the case where environment and human health studies are co-located.

The specific objectives of the current assessment are listed below:

- Assess new biomonitoring results (since CACAR-III) for POPs, metals, and new and emerging contaminants over time and across geographic regions in northern Canada.
- Increase the understanding of relationships between health outcomes in northern people and their exposure to POPs and metals during different life stages, with particular focus on the fetus, children, and youth.
- Describe some activities for the management of chemicals found to be harmful to people and their environment, within Canada and internationally.
- Examine current knowledge on perspectives of Indigenous people concerning the suitability of recent communication efforts on the issue of contaminants in traditional food.
- Highlight methods describing contaminant exposures that might assist with the interpretation of changing human levels of contaminants in northern Canada, predict the presence of new and emerging contaminants in the Arctic, provide insight to health outcome studies, or inform risk characterizations that consider the consumption of contaminants in traditional food.
- Identify knowledge gaps for the next phase of NCP research.

Throughout this assessment, studies that address specific regional concerns are often discussed separately from larger studies that provide information that is broadly representative of populations across northern Canada. For this reason, the information in this report is sometimes organized by study type or name and not by northern region.



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References for Chapter 1

AMAP. AMAP Assessment 2015: Human Health in the Arctic. Oslo: Arctic Monitoring and Assessment Programme (AMAP); 2015.

Braune B, Chételat J, Amyot M, Brown T, Clayden M, Evans M, et al. Mercury in the marine environment of the Canadian Arctic: Review of recent findings. Sci Total Environ. 2015;509-510:67-90.

Donaldson SG, Van Oostdam J, Tikhonov C, Feeley M, Armstrong B, Ayotte P, et al. Environmental contaminants and human health in the Canadian Arctic. Sci Total Environ. 2010;408(22):5165-234.

Gilman A, Dewailly É, Feeley M, Jerome V, Kuhnlein H, Kwavnick B, et al. Chapter 4: Human Health. In: Jensen J, Adare K, Shearer R (Eds). Canadian Arctic Contaminants Assessment Report. Ottawa: Indian and Northern Affairs Canada; 1997.

Kirk JL, Lehnherr I, Andersson M, Braune BM, Chan L, Dastoor AP, et al. Mercury in Arctic marine ecosystems: Sources, pathways and exposure. Environ Res. 2012;119:64-87.

Northern Contaminants Program. Canadian Arctic Contaminants Assessment Report On Persistent Organic Pollutants. Muir D, Kurt-Karakus P, Stow J (Eds). Ottawa: Aboriginal Affairs and Northern Development Canada; 2013.

UNEP. The Stockholm Convention on POPs. Geneva: United Nations Environment Programme (UNEP); 2009. Available: http://chm.pops.int/Portals/0/download.aspx?d=UNEP-POPS-COP-CONVTEXT-2009.En.pdf.

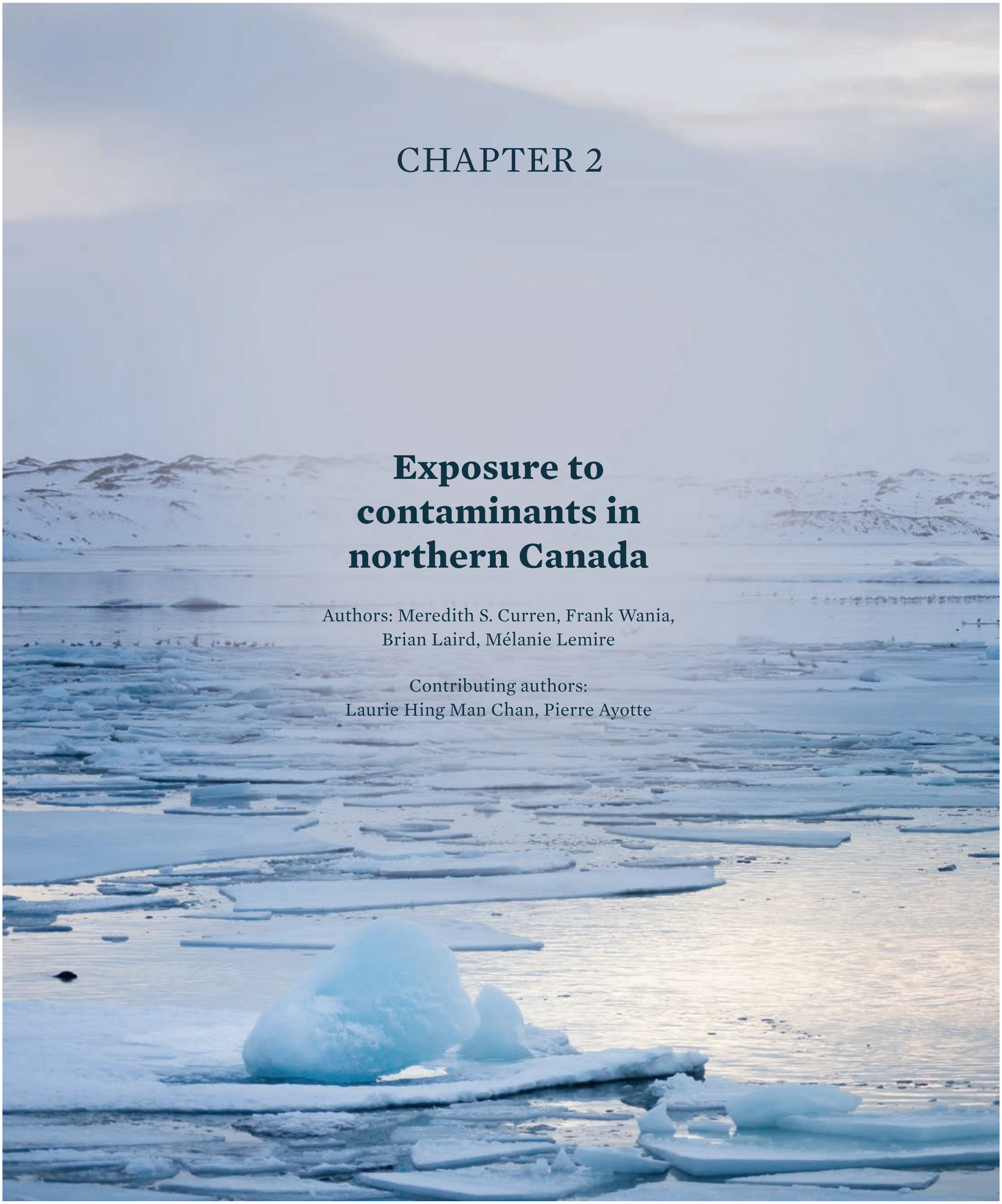
UNEP. The Minimata Convention on Mercury. Geneva: United Nations Environment Programme (UNEP); 2015. Available: www.mercuryconvention.org.

Van Oostdam J, Gilman A, Dewailly É, Usher P, Wheatley B, Kuhnlein H, et al. Human health implications of environmental contaminants in Arctic Canada: a review. Sci Total Environ. 1999;230:1-82.

Van Oostdam J, Donaldson S, Feeley M, Tremblay N. Canadian Arctic Contaminants Assessment Report II: Human Health. Ottawa: Department of Indian Affairs and Northern Development; 2003.

Van Oostdam J, Donaldson SG, Feeley M, Arnold D, Ayotte P, Bondy G, et al. Human health implications of environmental contaminants in Arctic Canada: a review. Sci Total Environ. 2005;351-352:165-246.

Van Oostdam J, Donaldson S, Feeley M, Tikhonov C. Canadian Arctic Contaminants and Human Health Assessment Report: Human Health 2009. Ottawa: Department of Indian Affairs and Northern Development; 2009.



CHAPTER 2

Exposure to contaminants in northern Canada

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Chapter 2: Exposure to contaminants in northern Canada

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This chapter discusses the benefits of consuming traditional food and reviews some of the most recent scientific knowledge on the levels of nutrients and contaminants in traditional foods consumed in northern Canada. Information is also provided on measured concentrations of persistent organic pollutants (POPs) and metals (e.g. mercury, lead) (see Chapter 1) in Indigenous people from northern Canada during recent Arctic-wide and regionally specific population biomonitoring studies. Where possible, this chapter presents temporal trends for contaminants in northerners and explores why these contaminant levels in Indigenous people might be changing over time. Exposure data for northerners is placed in a national context by also presenting biomonitoring data for people living in southern Canada.

The interpretation of human levels of contaminants is a complex undertaking that often requires using computational tools (e.g. dose models, mechanistic models) to increase the understanding of biomonitoring data and for describing the potential risks of contaminant exposures for people. This chapter introduces several modelling approaches that have been developed and used in northern and southern Canada and elsewhere in the world for describing chemical exposures. There are numerous potential applications for these modelling tools in the Arctic that may assist northerners in managing risks of exposure and for making informed dietary choices; for example, for calculating the impact of dietary changes on nutrient or contaminant levels, making sense of changing contaminant levels in the environment and in people, or predicting what new or emerging contaminants might persist and bioaccumulate in the Arctic environment and show potential as a contaminant of concern for northerners.

2.1 Traditional food and contaminants

The collection and consumption of traditional food such as marine mammals, fish, terrestrial animals, and birds is essential to the physical and cultural well-being of Indigenous people in northern Canada (AMAP, 2009; Donaldson et al., 2010). The third CACAR assessment (Van Oostdam et al., 2009; Donaldson et al., 2010) described that traditional food is an important contributor of key dietary nutrients. For example, on days when adult Inuit consumed traditional food, intakes of numerous vitamins and minerals were significantly higher than on days without traditional food consumption (Kuhnlein et al., 2004). There are also economic benefits. A 2006 market food cost survey observed that the weekly cost of a food basket for northerners in remote communities was approximately double the weekly cost in southern Canadian cities or in northern communities where market food was more accessible (CIRNAC, 2006). For people with access to hunting and fishing equipment, traditional food is often more affordable than market food (Chan et al., 2006). For example, fish is a staple food available throughout the year in the community of Tulita in the Northwest Territories, where certain fish species were consumed by up to 76% of participants during a community survey in 2010 - 2011 (Delormier, 2012).

The nutritional value of traditional food was reinforced during a study of preschool Inuit children from Nunavik. A total of 245 children (mean age 25 months) attending childcare centres in 10 communities of Nunavik were recruited between 2006 and 2010 (Gagné et al., 2012). Thirty-six percent of these children had consumed at least one traditional food item on the day of the recall. In spite of a low traditional food intake, children who consumed traditional food had significantly higher intakes of protein, omega-3 fatty acids, iron, phosphorus, zinc, copper, selenium, niacin, pantothenic acid, riboflavin, and vitamin B12 compared with children who did not report eating traditional food. The children who consumed traditional food also had lower intakes of energy and carbohydrate. Caribou and Arctic Char were most commonly consumed by children from this study and also by adult Inuit from the International Polar Year Inuit Health Survey (IHS) in 2007-2008 conducted in the Inuvialuit Settlement Region (ISR) of the Northwest Territories (NWT), Nunavut, and Nunatsiavut (Laird et al., 2013a) and from the Nunavik Inuit Health Survey in 2004 (Lemire et al., 2015).

Dietary choice in the Arctic, and therefore extent of exposure to contaminants in traditional food, is a complex contemporary issue in northern Canada because the substantial cultural, economic, and nutritional benefits of some traditional foods (Donaldson et al., 2010; Egeland et al., 2011) may be offset by concern about exposure to contaminants. For example, an analysis of the diet for 2074 adult participants from the IHS in the ISR, Nunavut, and Nunatsiavut determined that ringed seal liver was the single largest traditional food source of mercury (59% of mercury intake). Although ringed seal liver was also an excellent source of selenium (19% of selenium intake), the high contribution of this food to mercury exposure created concern because consuming ringed seal liver disproportionately elevated mercury intake relative to nutrient intake (Laird et al., 2013a).

Dietary substitutions may provide a means to mitigate exposure to contaminants such as mercury, while ensuring the on-going consumption of important nutrients. The dietary survey conducted as part of the IHS determined that the average amount of Arctic Char meat consumed by most Inuit (378 grams per week) was about 10-fold higher than for ringed seal liver (32.7 grams per week), but consumption of Arctic Char accounted for only 8.4% of estimated mercury intake. Arctic Char was also the primary source for two important omega-3 fatty acids (eicosapentaenoic acid (EPA) at 38% and docosahexaenoic acid (DHA) at 32%), and it accounted for 7.3% of selenium intake (Laird et al., 2013a).

A computational method evaluated what the dietary intakes of mercury, selenium, EPA, and DHA would be if ringed seal meat, ringed seal blubber, beluga muktuk (also called mattaaq in Nunavik), or Arctic Char were substituted in place of ringed seal liver in the diet of IHS participants (Laird et al, 2013a). This exercise demonstrated that the substitution of ringed seal liver with other traditional foods would decrease mean mercury intake by 58%, while decreasing mean selenium intake between 10% and 18% and negligibly affecting omega-3 fatty acid intake. The replacement of ringed seal liver with ringed seal blubber also lowered mean mercury intake by 57% and increased EPA (25%) and DHA (24%) intakes.

It is critical to note that such dietary substitutions may prove to be relevant for only specific regions or subpopulations and should not be taken as wholesale recommendations for Inuit. Instead, communication and intervention strategies should be designed at the regional level to ensure that they are relevant to the varying exposure levels and sources present for the communities or regions that might be considering dietary substitutions (Laird et al., 2013a).

In Nunavik, most traditional foods consumed were shown to be generally low in mercury with the exception of beluga meat, ringed seal liver, and Lake Trout, which presented very high concentrations of mercury in samples collected from different regions of Nunavik between 1996 and 2013 (Lemire et al., 2015). Beluga hunting is a very important subsistence activity in some Nunavik villages, and beluga mattaaq, made of beluga skin and fat, is a valued Inuit delicacy often shared between villages in Nunavik. Conversely, beluga meat, both raw or air-dried (also known as nikku), tends to stay in the villages and is consumed where the whales are hunted. While beluga mattaaq is only moderately high in mercury, very high concentrations of mercury are found in beluga meat and especially beluga nikku because the air drying process concentrates mercury in the dried meat three to four times on a gram for gram basis (wet weight to dry weight comparison).

Data analysis from the Nunavik Inuit Health Survey conducted in 2004 showed significantly higher blood mercury concentrations in people from the beluga-hunting villages of the Hudson Strait compared to other regions in Nunavik. Beluga meat and nikku, not a staple of most Inuit diets, were shown to be the most important contributors to mercury intake in the Hudson Strait region, where beluga meat and nikku accounted for 66% of mercury intake compared with about one-third of the mercury intake for Inuit from the eastern coast of the Hudson Bay and the Ungava Bay. For Inuit women of childbearing age from Eastern Hudson Bay and Ungava Bay villages, mercury intake from beluga meat and nikku was significantly lower than for Inuit women from the Hudson Strait region, but still contributed to most of mercury intake compared to other traditional foods. Seal liver, primarily consumed by older Inuit men, was also an important exposure source for mercury especially in view of the low amount of seal liver that was typically consumed even within this group (Lemire et al., 2015). More studies are ongoing in Nunavik to better understand site-specific variations of mercury concentrations in Lake Trout as well as the importance of Lake Trout consumption within Nunavik villages, particularly among Inuit women of childbearing age.

Further compounding the issue of the healthfulness of traditional food is the observation that changing dietary preferences have resulted in lower traditional food consumption by younger generations of Indigenous people. As the Nunavik Inuit Health Survey from 2004 shows, traditional food consumption is low (16% of total energy intake), particularly among young adult Inuit (at 11%) (Blanchet and Rochette, 2008). Overall, the current Inuit diet across the Arctic is suboptimal, where about one quarter to one third of total calories consumed is coming from high sugar foods and drinks (e.g. potato chips, soda pop, juices), particularly among younger generations (Blanchet and Rochette, 2008; Egeland, 2010a, 2010b, 2010c).

2.2 Human biomonitoring in northern Canada

2.2.1 Measuring contaminants in people

Human biomonitoring studies determine if a person has been exposed to a particular chemical by measuring that chemical, its metabolite(s), or its adduct(s) (the combination of two chemical compounds) with macromolecules in human tissue or fluids. The ideal biomarker of contaminant exposure would be sensitive to changes in short-term or long-term exposure (or both), non-invasive, inexpensive to collect and measure, easy to store and then ship from remote communities, have a suitably low limit of detection, have a strong inter-laboratory comparability, and be directly relatable to clinically-relevant guidelines (see Section 2.2.5). Despite tremendous advances in the development of biomarkers and exposure assessment methods, few biomarkers meet all of these conditions. When choosing between fluids and tissues for the selection of biomarkers to include within a northern biomonitoring study, researchers must often weigh a number of criteria, including sampling considerations and distribution in the body.

2.2.1.1 Sampling considerations

Numerous fluids and tissues (e.g. hair, blood, urine, fingernails/toenails, breast milk) can be collected for chemical analysis within a biomonitoring study. Invasiveness of the sample collection method can affect participation rates from study volunteers. Using less invasive sampling methods, such as hair or fingernail/toenail collection, can sometimes offer advantages over more invasive methods, such as the collection of blood or breast milk. An important caveat is that, in some cultures, hair can be of high spiritual value and significance, undermining its utility as a sample in some communities. As well, there is an absence of reference values for biomarkers in fingernails and toenails, and the large time frame represented by the slow growth of nail segments limits their clinical usefulness.

Blood collection has therefore become common in biomonitoring studies, even though it is an activity with some potential risk (albeit small) for the participant (e.g. possible laceration, fainting, blood-borne infection transmission). For this reason, blood collection must be performed by a licensed health professional, such as a registered nurse or phlebotomist. In small remote communities with no health clinics, it can be difficult to access personnel with the necessary skill and certifications to allow for blood collection, handling, and shipment. This is particularly the case for biomonitoring projects operating under participatory, community-based sample collection frameworks. Sometimes hair and urine can be collected instead of blood if these samples are suitable for measuring the contaminant of interest.

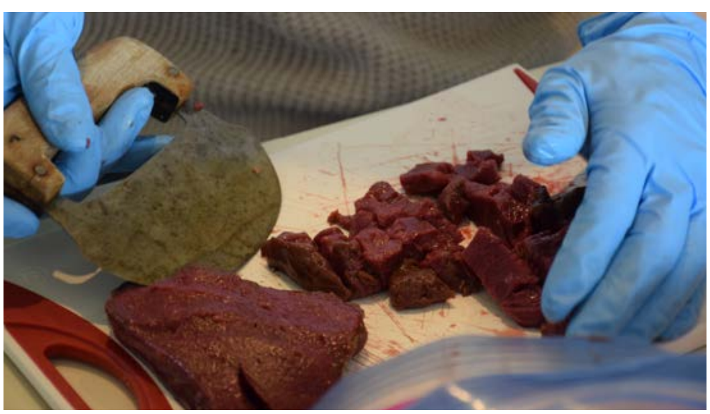
2.2.1.2 Distribution in the body

The optimal tissue or fluid for assessing human exposures often differs from one chemical stressor to another. The choice between different tissues and fluids may depend to a large extent on toxicokinetics, that is, the distribution in the body of a chemical of potential concern (Sexton et al., 2004). For example, POPs are lipophilic, persistent, and bioaccumulative contaminants that are poorly excreted in urine and are generally best measured in the lipid of blood samples (Phillips et al., 1989). In contrast, chemicals with short biological half-lives that are rapidly excreted in urine, either as the parent compound or a metabolite, are best sampled through urine collection (Sexton et al., 2004). For metals such as mercury, toxicokinetic differences between chemical forms can also be of great importance when selecting a tissue or fluid. For example, urine is best suited for the measurement of inorganic mercury, while total mercury (the sum of the inorganic and organic forms of mercury) is usually measured in blood or hair. Methylmercury can also be measured specifically in blood, although the measurement of total mercury is more common because it is less costly and, in non-occupationally exposed populations, circulating mercury is mostly made up of methylmercury (National Research Council, 2000). Total mercury was measured in the studies reported in this chapter and is commonly referred to as simply ‘mercury’ unless noted otherwise. In this report, the concentration of total mercury in blood is taken as a reasonable biomeasure of methylmercury exposure.

Total mercury was measured in the studies reported in this chapter and is commonly referred to as simply ‘mercury’ unless noted otherwise.

The collection of hair can, if the hair sample is sufficiently long, help characterize the extent to which individual and population exposure to mercury has varied over several months of exposure (Legrand et al., 2005a). The concentration of mercury incorporated into hair follicles is highly proportional to circulating mercury concentrations in the blood, although there is a delay of about 20 days between peak mercury as measured in blood and that measured in hair closest to the scalp (Hislop et al., 1983; Clarkson and Magos, 2006). On average, the hair to blood ratio is 250:1 (Legrand et al., 2010); however, inter-individual variation in mercury deposition rates into hair is considerable for a variety of reasons, thus hair sampling and the application of a hair-to-blood ratio has been called into question for clinical management (Liberda et al., 2014).

Consequently, some exposure scientists advocate for inclusion of periodic measurements of total mercury in blood for clinical management decisions (Liberda et al., 2014). The use of a two-pronged mercury exposure assessment strategy (i.e. through the measurement of mercury in both hair and blood) also has a number of advantages. This twin approach can provide insight on recent exposures as well as variation in exposure across time, since mercury in blood reflects recent exposure, while mercury in hair reflects blood concentrations at the time the hair was formed. In addition, valuable information can be obtained on the respective reliability of the two exposure measures for managing risk at the population and individual levels (Liberda et al., 2014). A common growth rate of 1.1 cm per month is assumed for scalp hair; however, the ability to reconstruct mercury exposures based upon measurements in distal hair segments might be limited by inter-individual differences in hair growth rates (Boischio and Cernichiari, 1998; Legrand et al., 2010).



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2.2.2 Introduction to NCP biomonitoring

The NCP has developed a human biomonitoring program that builds on baseline data obtained from most northern regions during the early to mid-1990s. The CACAR-III report described continuation of maternal biomonitoring in the Inuvik Region of the Northwest Territories (Armstrong et al., 2007) and the Baffin Region of Nunavut (Potyrala et al., 2008), where pregnant women volunteered to participate in follow-up studies across two time periods (1997-1999 and 2005-2007). The CACAR-III report also included information from regular biomonitoring for adults in Nunavik, including pregnant women, over multiple time periods (1992-2007), the most comprehensive dataset of this type to date. These regional studies indicated that among Inuit, Dene/Métis, and non-Indigenous groups sampled during the period 2005-2007, the Inuit continued to have the highest tissue levels of most POPs and metals that have been found in the northern traditional diet. However, examination of study results from both the baseline and follow-up studies indicated most contaminant levels have been declining in maternal blood. While a number of maternal contaminant levels were less than one-half the levels they were approximately 10 years earlier, cadmium levels were observed to increase in the Inuvik, Baffin, and Nunavik regions among young women and mothers. This was linked to increased smoking in this age group (Benedetti et al., 1994; Butler Walker et al., 2006). High smoking rates remain a significant public health issue for northern health authorities (Egeland 2010a, 2010b, 2010c).

Prior northern biomonitoring studies have often focused on pregnant women in order to obtain exposure data that might be linked to potential health impacts for the unborn child. Increasingly, NCP studies are extending tissue collection to both sexes across a broader age range in northern Canada, such as through the 2007-2008 Inuit Health Survey. The IHS was undertaken to provide the first comprehensive cross-sectional study of Inuit health in the ISR, Nunatsiavut, and Nunavut (Saudny et al., 2012). The survey randomly selected households in each of thirty-three coastal and three inland communities in these three northern regions and recruited 2595 Inuit participants. Of the 2595 individuals who participated in IHS, 2172 provided blood samples for the measurement of contaminants. The human biomonitoring component of the IHS was designed to address the data gap posed by small sample sizes of previous studies. The primary objective of the IHS was to conduct blood sampling in order to determine the current exposure levels of metals and POPs for Inuit from these three regions.

Metals and POPs exposure data are also available from continued biomonitoring of pregnant Inuit women from Nunavik in the Hudson Strait region and the eastern coast of the Hudson Bay and the Ungava Bay as part of the 2004 Nunavik Inuit Health Survey (Rochette and Blanchet, 2007). The 2004 Nunavik Inuit Health Survey was conducted among the Inuit population living in the 14 villages of Nunavik, all of which are coastal villages. Participants from 18 to 74 years of age were asked to complete a food frequency questionnaire and a 24-hour dietary recall and to participate in a clinical session. Blood concentrations for metals and POPs were measured in 914 study participants in 2004. Maternal biomonitoring has also been conducted most recently in the Ungava Bay and Hudson Bay regions of Nunavik, from 2011 – 2013.

The use of similar random sampling strategies for these large surveys in the ISR, Nunavut, Nunatsiavut, and Nunavik (Rochette and Blanchet, 2007; Saudny et al., 2012) has enabled reliable comparisons of biomonitoring data within and between studies to highlight

Inuit Health Survey - Amundsen Taloyoak - August 2008 contaminant exposure patterns across time for Inuit adults living in northern Canada; however, side-by-side comparisons of the data from the IHS (2007-2008) and from Nunavik (2004) should nonetheless be performed with suitable caution because these studies were performed four years apart. Changes in human levels of contaminants across this intervening period may be due, in part, to dietary transitions, to changes in environmental levels of these contaminants, or both occurring simultaneously. These variables were not accounted for during the side-by-side comparisons presented in this chapter. Finally, blood concentrations of contaminants have been measured for Inuit children in Nunavik collected through the Nunavik Child Development Study (NCDS; see Chapter 3 for details) (Muckle et al., 1998; Muckle et al., 2001; Dallaire et al., 2003).

Biomonitoring samples collected during the Inuit Health Survey, the Nunavik Inuit Health Survey, Nunavik pregnant women biomonitoring, and the Nunavik Child Development Study were analysed by the Centre de Toxicologie du Québec (CTQ) of the Institut national de santé publique du Québec (INSPQ). The CACAR-III health report described in detail laboratory procedures used to measure contaminants in biological samples, accreditation of the CTQ lab, and several external quality assessment schemes that the CTQ successfully participates in both nationally and internationally.

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2.2.3 POPs and metals in adult Inuit

Concentrations of POPs among women of childbearing age who participated in the Inuit Health Survey in the ISR, Nunavut, and Nunatsiavut (2007 - 2008) and the Nunavik Inuit Health Survey (2004) are presented in Table 1. Concentrations among men and women (18 years and older) of the general northern adult Inuit population are presented in Table 2. Although Nunavik biomonitoring data from 1992 - 2004 were also included in the CACAR-III report for several POPs and metals, they are repeated here for comparison purposes.

From the side-by-side data comparisons in Table 1, geometric mean blood concentrations of nearly all measured POPs (with the exception of PBDEs) were highest among Inuit women of childbearing age from Nunavik and most often lowest among Inuit women of childbearing age from Nunatsiavut. POP levels in Nunavik participants were higher than for women of childbearing age from Nunavut by as much as two-fold, and were between two and fifteen times higher than most POP concentrations measured in women from Nunatsiavut. Women of childbearing age from the ISR generally showed POPs concentrations in between those observed for women of childbearing age from Nunatsiavut and Nunavut. Similar observations are made for total mercury, lead, and cadmium amongst Inuit women of childbearing age from these four regions, although there tended to be smaller differences in blood concentrations for these women between regions for these metals. In women of childbearing age from Nunavut and Nunavik, where higher amounts of selenium-rich marine mammals are consumed, geometric mean selenium concentrations were marginally higher and levels varied widely among participants.

Table 1 - Blood concentrations of persistent organic pollutants (µg/kg plasma lipid) and metals (µg/L whole blood) for Inuit women of childbearing age from the Inuit Health Survey (Inuvialuit Settlement Region, Nunavut, Nunatsiavut) and the Nunavik Inuit Health Survey. Data are presented as geometric means (range) (Egeland, 2010a, 2010b, 2010c; AMAP, 2015; Ayotte personal communication, 2015; Chan personal communication, 2015).

	Inuvialuit Settlement Region	**Nunavut**	**Nunavik**	**Nunatsiavut**
Year	2007–2008	2007–2008	2004	2007–2008
Mean age (range) (years)	28 (18–39)	28 (18–39)	28 (18–39)	30 (20–39)
Sample size	n=74	n=485[a]	n=283	n=61[b]
Persistent Organic Pollutants				
Oxychlordane	8.5 (0.4–220)	22 (0.4–420)	34 (2.3–440)	2.5 (0.4–59)
trans-Nonachlor	17 (0.8–460)	34 (0.8–440)	62 (4.7–1000)	4.1 (0.7–85)
p,p'-DDT	5.0 (2.0–65)	6.8 (2.1–98)	8.5 (1.3–130)	4.5 (2.8–6.9)
p,p'-DDE	80 (13–1000)	150 (1.8–2700)	280 (27–3100)	56 (13–240)
HCB	16 (1.6–300)	32 (1.4–290)	37 (4.1–650)	8.7 (1.9–120)
β-HCH	3.7 (0.8–72)	5.5 (0.7–110)	4.8 (0.7–40)	1.6 (0.6–12)
Toxaphene Parlar 26	2.0 (0.3–96)	6.1 (0.3–98)	8.1 (0.4–200)	0.8 (0.3–15)
Toxaphene Parlar 50	2.9 (0.3–150)	8.4 (0.4–130)	15 (0.4–310)	0.9 (0.3–20)
PCB-99	4.5 (1.6–65)	8.9 (1.7–150)	14 (1.4–140)	3.2 (1.7–17)
PCB-118	4.6 (0.8–94)	7.5 (0.7–98)	13 (1.9–190)	2.9 (0.7–37)
PCB-138	8.9 (0.8–180)	20 (0.8–390)	40 (3.7–310)	7.0 (1.0–93)
PCB-153	18 (0.8–250)	47 (0.9–1000)	82 (5.7–550)	18 (2.2–300)
PCB-180	7.4 (0.8–84)	22 (0.9–850)	38 (3.3–350)	11 (1.1–240)
PBDE-47	9.9 (2.1–680)	8.8 (1.7–480)	6.6 (1.5–340)	7.0 (1.7–110)
PBDE-99	3.3 (1.1–180)	2.6 (1.1–100)	<LOD[c]	2.4 (1.1–30)
PBDE-100	2.5 (1.1–130)	2.6 (0.9–380)	<LOD[c]	2.2 (1.1–38)
PBDE-153[e]	3.4 (1.1–60)	3.3 (1.1–84)	1.9 (1.1-60)	2.9 (1.1–36)
PBDE-209[f]	16 (4.0–190)	14 (4.4–410)	NR[d]	6.9 (3.9–55)
Metals				
Total mercury	2.1 (0.5–39)	5.0 (0.5–52)	8.4 (0.2–160)	1.7 (0.1–25)
Lead	18 (4.5–92)	22 (5.1–290)	27 (6.6–210)	15 (5.6–63)
Selenium	240 (150–550)	290 (85–2000)	280 (91–1300)	190 (140–530)
Cadmium	1.6 (0.1-6.6)	2.1 (0.02-9.8)	3.4 (0.2-12)	1.5 (0.09-9.3)

[a] n=491 for metals
[b] n=60 for metals
[c] <LOD: over 60% of the observations were below the method limit of detection
[d] NR: no record
[e] n=132 for Nunavut. Data only shown for Nunavut participants sampled in 2008.
[f] n=71 for Inuvialuit Settlement Region and n=131 for Nunavut. Data only shown for Nunavut participants sampled in 2008.

Table 2 - Blood concentrations of persistent organic pollutants (µg/kg plasma lipid) and metals (µg/L whole blood) for adult Inuit men and women from the Inuit Health Survey (Inuvialuit Settlement Region, Nunavut, Nunatsiavut) and the Nunavik Inuit Health Survey. Data are presented as geometric means (range) (Egeland, 2010a, 2010b, 2010c; AMAP, 2015; Ayotte personal communication, 2015; Chan personal communication, 2015).

	Inuvialuit Settlement Region		**Nunavut**		**Nunavik**		**Nunatsiavut**	
	Men	**Women**	**Men**	**Women**	**Men**	**Women**	**Men**	**Women**
Year	**2007–2008**	**2007–2008**	**2007–2008**	**2007–2008**	**2004**	**2004**	**2007–2008**	**2007–2008**
Mean age (range) (years)	46.2 (18–81)	42.6 (18–90)	42.2 (18–89)	40.7 (18–90)	37.0 (18–74)	37.3 (18–74)	45.7 (18–89)	43.4 (20–79)
Sample size	n=92	n=187	n= 650	n=977	n=408	n=506	n=98	n=165
Persistent organic pollutants								
Oxychlordane	91 (1.1–1800)	34 (0.4–2900)	100 (0.3–3700)	56 (0.4–3900)	66 (0.9–1600)	66 (2.3–2700)	14 (0.5–210)	8.0 (0.4–230)
trans-Nonachlor	170 (1.6–3100)	63 (0.8–1200)	150 (0.8–2100)	80 (0.8–2500)	120 (1.5–3900)	120 (4.7–3700)	23 (0.7–390)	14 (0.7–340)
cis-Nonachlor	23 (0.4–360)	9.0 (0.4–220)	24 (0.3–400)	14 (0.4–440)	16 (0.2–410)	18 (0.4–590)	4.2 (0.3–98)	2.6 (0.3–72)
p,p'-DDT	16 (2.7–270)	10 (2.0–170)	12 (2.1–180)	10 (2.0–190)	10 (0.9–140)	13 (1.3–250)	4.4 (2.0–29)	4.2 (2.2–20)
p,p'-DDE	470 (9.4–8200)	240 (13–3300)	410 (1.4–4300)	280 (1.5–7700)	460 (13–7000)	470 (27–8300)	190 (19–2800)	150 (13–2800)
HCB	100 (1.6–1700)	54 (1.6–990)	97 (1.7–1100)	71 (1.4–1800)	51 (1.6–1200)	64 (4.1–1200)	26 (1.3–170)	21 (2.0–200)
β-HCH	28 (0.8–380)	13 (0.8–520)	19 (0.7–360)	12 (0.6–250)	8.1 (0.8–130)	8.1 (0.7–200)	3.9 (0.6–37)	3.5 (0.6–30)
Mirex	16 (0.8–230)	6.0 (0.6–150)	14 (0.5–720)	6.0 (0.5–730)	13 (0.5–290)	8.7 (0.6–640)	7.2 (0.6–100)	3.3 (0.6–55)
Toxaphene Parlar 26	20 (0.3–660)	8.5 (0.3–270)	20 (0.3–400)	14 (0.4–580)	11 (0.2–410)	15 (0.4–510)	2.7 (0.3–140)	1.8 (0.3–42)
Toxaphene Parlar 50	28 (0.3–860)	12 (0.3–370)	28 (0.3–430)	19 (0.4–730)	20 (0.2–720)	26 (0.4–890)	3.9 (0.3–190)	2.5 (0.3–60)
PCB-99	28 (1.7–260)	14 (1.6–260)	26 (1.8–540)	18 (1.7–650)	23 (0.5–530)	26 (1.4–850)	9.2 (1.7–150)	6.5 (1.7–99)
PCB-118	28 (0.8–620)	16 (0.8–240)	20 (0.7–490)	17 (0.7–630)	18 (0.5–500)	24 (1.9–710)	11 (0.7–120)	9.0 (0.7–170)
PCB-138	69 (0.9–860)	30 (0.8–450)	69 (0.7–1300)	43 (0.8–2000)	77 (3.0–1400)	73 (3.7–2500)	39 (0.7–670)	24 (1.0–440)
PCB153	150 (1.9–2700)	62 (0.8–4400)	200 (0.7–5700)	110 (0.8–6200)	190 (6.3–3400)	160 (5.7–5800)	110 (1.3–1600)	61 (2.2–1300)
PCB-180	70 (2.2–1300)	26 (0.8–3000)	110 (0.8–4800)	51 (0.9–4800)	110 (6.2–1900)	75 (3.3–3500)	94 (0.7–930)	44 (1.1–900)
PBDE47	6.6 (1.7–250)	8.8 (1.7–680)	7.9 (1.5–1600)	7.9 (1.4–520)	5.9 (1.6–100)	5.9 (1.3–340)	9.6 (1.2–570)	7.1 (1.6–220)
PBDE-99	2.3 (1.1–75)	2.8 (1.0–180)	2.4 (0.7–310)	2.4 (0.7–140)	<LOD[a]	<LOD[a]	2.9 (1.1–250)	2.3 (0.9–42)
PBDE-100	2.1 (1.1–48)	2.5 (1.0–130)	2.4 (0.7–230)	2.3 (0.7–380)	<LOD[a]	<LOD[a]	2.6 (0.8–120)	2.2 (0.9–76)

continued ↓

PBDE-153[c]	4.7 (1.1–82)	3.5 (1.0–230)	5.7 (1.2–240)	3.4 (1.1–84)	4.0 (1.1-140)	2.1 (1.1-.60)	6.9 (1.4–48)	3.7 (1.1–150)
PBDE-209[d]	28 (3.9–700)	20 (3.5–2300)	28 (4.4–7000)	19 (4.0–6000)	NR[b]	NR[b]	8.7 (2.8–370)	6.8 (3.1–200)
Metals								
Total Mercury	5.6 (0.3–50)	4.1 (0.1–55)	9.4 (0.1–110)	7.9 (0.1–130)	9.2 (0.1–240)	12 (0.2–160)	4.2 (0.2–50)	2.8 (0.1–25)
Lead	45 (8.1–220)	28 (4.5–190)	46 (7.4–380)	32 (5.1–400)	46 (9.1–500)	34 (5.8–310)	40 (8.4–170)	22 (5.6–160)
Selenium	320 (160–1300)	290 (150–1200)	350 (130–2800)	340 (85–2500)	280 (130–3500)	300 (120–2400)	230 (150–1500)	200 (140–960)
Cadmium	1.3 (0.02-7.3)	1.3 (0.1-6.7)	1.7 (0.02-11)	1.8 (0.02-11)	2.9 (0.2-12)	3.0 (0.2-15)	1.0 (0.08-7.2)	1.2 (0.09-10)

[a] <LOD: over 60% of the observations were below the method limit of detection
[b] NR: no record
[c] n=92/186 for Inuvialuit Settlement Region men/women, n=191/281 for Nunavut men/women, and n=98/166 for Nunatsiavut men/women measured in 2008
[d] n=91/181 for Inuvialuit Settlement Region men/women, n=187/277 for Nunavut men/women, and n=98/164 for Nunatsiavut men/women measured in 2008

Different patterns of exposure for POPs, mercury, and lead are observed across the North when Inuit men and women spanning all ages are considered separately in Table 2. While Inuit women of childbearing age from Nunavik tended to have higher blood concentrations for these contaminants than women of childbearing age from the other three Inuit regions, men from the ISR, Nunavut, or Nunatsiavut frequently showed higher mean concentrations of these contaminants compared with Nunavik adults. Moreover, while concentrations of POPs and metals were most often highest in men from these three regions compared with women, often by as much as two- or three-fold, examination of the geometric mean concentration data in Table 2 does not show a clear difference in exposure by sex for POPs and metals in participants from Nunavik. Blood concentrations for men and women from Nunavik were often quite similar, although mercury concentrations were higher in women. Cadmium is an exception; cadmium concentrations were higher in Nunavik than the other regions, and men and women had similar concentrations within each of the four regions.

It is generally expected that differences in POP body burdens will usually reflect differences in traditional lifestyles and especially dietary habits. Elevated POP concentrations observed in people from the eastern Arctic in particular (i.e. Nunavut and Nunavik) have long been attributed to higher historical consumption of marine mammals (Kuhnlein et al., 2000; Potyrala et al., 2008). Body burdens for contaminants in mothers can be further offset by breastfeeding, parity, and other maternal characteristics (Longnecker et al., 1999; Curren et al., 2015), which likely explains, in part, why men frequently have higher tissue concentrations for POPs than women. Regional differences become more apparent when POP levels are compared between Inuit and non-Inuit groups. An analysis of the 2005-2007 maternal datasets from the Inuvik and Baffin Regions noted that Inuit mothers from Baffin had higher geometric mean concentrations (adjusted for age, time spent breastfeeding, traditional food consumption, and/or smoking during pregnancy) for several POPs and also mercury and selenium than Inuit mothers from Inuvik who, in turn, often had significantly higher adjusted blood concentrations than Dene/Métis mothers

(Curren et al., 2015). These observations are consistent with prior northern biomonitoring studies funded by the NCP that have found Inuit who reside in eastern Canadian Arctic coastal areas such as the Baffin Region of Nunavut tend to consume substantially more marine mammal meat and fat (Kuhnlein et al., 2000; Potyrala et al., 2008) than western Indigenous groups (Kuhnlein et al., 2000; Armstrong et al., 2007).

POPs are characterized by extremely long elimination half-lives in humans (measured in years); therefore, their concentrations in people are likely reflective of lifetime accumulation rather than recent intake (Binnington et al., 2014). In other words, older people are expected to have higher body burdens for POPs than younger people, especially if they have been high consumers of traditional food and particularly marine mammals throughout their lives (see also Section 2.3.4.6). This likely explains why women of childbearing age from all four Inuit regions (age range 18 to 39 years) in Table 1 had lower concentrations of POPs in their blood compared to the combined results for adult Inuit women (age range 18 to 90 years) in Table 2.

These observations on sex and age are supported by dietary information collected during the IHS (Egeland 2010a, 2010b, 2010c), which indicated that men ate larger portions of traditional foods and more frequently than women, and that older adults (more than 40 years old) ate more traditional food than younger adults (less than 40 years old). Indeed, blood concentration data for total PCBs, toxaphene, chlordane, the sum of p,p'-DDT and p,p'-DDE, and lead increased with age for both male and female participants from the IHS (Laird et al, 2013b). The sum of three polybrominated diphenyl ethers (PBDE-47, PBDE-99, and PBDE-100) is a clear exception that did not show an age trend for either sex.

Polybrominated diphenyl ethers (PBDEs) have been used as flame retardants in a variety of commercial goods found in the home. Body burdens for PBDEs in Inuit men and women appear to have different relationships with sex, age, and by region compared with other POPs (see also Section 2.3.4.6). Examining the data in Table 2, blood concentrations for PBDEs tended to be lower in adult Inuit from Nunavik compared to the other three regions, and they were otherwise generally similar between men and women from the ISR, Nunavut, and Nunatsiavut. Although there is evidence that PBDEs bioaccumulate in the Arctic marine food web (Tomy et al., 2008, 2009), the ingestion of indoor house dust has been reported as the primary route of exposure to PBDEs outside of the Arctic for all life stages other than the infant (Jones-Otazo et al., 2005; Lorber, 2008; Johnson-Restrepo and Kannan, 2009; Frederiksen et al., 2010), while infants are thought to be exposed primarily through the ingestion of mother's breast milk (Jones-Otazo et al., 2005; Johnson-Restrepo and Kannan, 2009). Exposure from sources other than traditional foods may explain why it was observed during the cross-sectional study for Nunavik Inuit adults in 2004 that, unlike PCBs, PBDE-47 concentrations decreased with age, and, further, consumption of marine mammals was negatively associated with PBDE-47 concentrations in plasma. It was noted that PBDE-153 concentrations had a significant positive association with age, which suggests other routes of exposure to PBDE-153 that might include the diet (Dallaire et al., 2009).

Blood concentrations for PBDE-209 appear to show yet another exposure pattern, where Inuit from the ISR and also Nunavut had exposure levels 2 to 3 times higher than Inuit from Nunatsiavut. PBDE-209 was also the PBDE congener with the highest mean concentration for Inuit (no data for PBDE-

209 is available for Inuit from Nunavik). In general, PBDE concentrations have been shown to be greater in lower trophic level animals than higher trophic level animals, and bioaccumulation of PBDE-209 (and also PBDE-47) through the food web appears to differ across the eastern and western Arctic (Tomy et al., 2008, 2009). Additionally, the proportion of total PBDEs in wildlife attributed to PBDE-209 has been shown to vary depending on trophic level and Arctic region (Tomy et al., 2008, 2009).

Taken together, these different and sometimes contradictory PBDE study results for both people and wildlife emphasize that routes of exposure to PBDEs for northerners may be varied across the Arctic. The extent of exposure from traditional food compared to other sources, such as dust in the home (or other exposure pathways that have not yet been recognized), still remains largely unclear.

2.2.4 Temporal trends for pregnant Inuit women and children from Nunavik

Concentrations of POPs in pregnant Inuit women from Nunavik can be examined across time because extensive sampling has occurred between 1992 and 2013 in Nunavik for a total of 11 data points. Maternal biomonitoring has been conducted most recently in the Ungava Bay and Hudson Bay regions of Nunavik from 2011 - 2013 (data from 2011 and 2012 are combined together). The blood concentration data in Tables 3 and 4 indicate decreasing trends across 1992 - 2013 for 11 POPs (see also Figures 1 - 2). Overall, levels of POPs have declined by about 80% across the 20 years that biomonitoring has been used to monitor contaminants exposure in pregnant Inuit women from Nunavik.

Similarly, blood concentrations for total mercury have decreased by nearly 60% in pregnant Inuit women from Nunavik. Analysis of available data is on-going in order to better understand whether the driving factor for this decrease is related to lower consumption of traditional foods high in mercury (or readily absorbed mercury), a decrease in mercury deposition, bioaccumulation, biomagnification, or rate of methylation in the Arctic environment, a shift in the consumption of different traditional foods, or several of these variables occurring simultaneously. Conversely, selenium concentrations have decreased by less than 20% over 20 years and may suggest a dietary transition towards traditional food items lower in mercury, but this also remains to be confirmed. Indeed, some traditional foods in Nunavik are significant dietary sources of mercury, namely predatory fish and specific parts of marine mammals (Lemire et al., 2015), but many traditional foods are also rich sources for selenium (see Section 2.1).

With respect to lead, between 1992 and 2013 maternal blood concentrations decreased by over 60%, likely related to the 1999-2000 multiple Nunavik stakeholder intervention to ban lead shot ammunition in Nunavik after the Government of Canada regulated the use of lead shot for hunting in 1999 (Couture et al., 2012).

Blood data is also available for a select number of POPs in pregnant Inuit women from Nunavik in 2004, 2011 - 2012, and 2013 (Table 4). Temporal trends were assessed from all 3 data points for toxaphene and from 2 data points (excluding 2013) for PBDE-47, PBDE-153, pentachlorophenol (PCP), perfluorooctane sulfonate (PFOS), and perfluorooctanoic acid (PFOA). These POPs showed significant declines (approximately two-fold) in maternal blood from 2004 to 2011 - 2012 or 2013. Again, the exception is PBDE-153, which increased between 2004 and 2011-2012 in Inuit mothers from Nunavik.

Table 3 - Temporal trends for blood concentrations of persistent organic pollutants (POPs) (µg/kg plasma lipid) and metals (µg/L whole blood) in pregnant Inuit women from Nunavik. Data are presented as geometric means (range). Results are presented for contaminants with a minimum of 60% of the observations above the method limit of detection (LOD) (AMAP, 2015; Ayotte personal communication, 2015).

Year	1992	1996	1997	1998	1999	2000	2001	2004	2007	2011-2012	2013	p<0.05[a]
Mean age (range) (years)	24 (18–35)	24 (17–34)	25 (15–41)	25 (15–37)	26 (17–36)	26 (17–39)	27 (17–39)	27 (18–42)	24 (18–37)	24 (18–39)	24 (18–41)	
Sample size (POPs only)	n=11	n=25	n=53	n=46	n=26	n=36	n=20	n=29	n=39	n=112	n=95	
Oxychlordane	77 (32–240)	41 (6.1–180)	48 (8.6–390)	34 (7.0–340)	47 (15–140)	40 (7.5–210)	36 (8.2–130)	35 (<LOD –230)	22 (<LOD–180)	20 (<LOD–120)	22 (0.9–130)	<0.0001
trans-Non-achlor	110 (49–320)	66 (15–250)	75 (14–330)	55 (17–580)	61 (21–170)	61 (13–300)	53 (12–200)	66 (14–410)	44 (2.5–260)	37 (<LOD –220)	42 (2.0–220)	<0.0001
cis-Nonachlor	28 (11–84)	14 (5.8–40)	16 (3.7–61)	9.6 (<LOD –110)	13 (<LOD –31)	14 (1.7–66)	9.6 (<LOD –35)	10 (2.3–62)	7.0 (<LOD –42)	5.3 (<LOD –41)	5.9 (<LOD–29)	<0.0001
p,p’-DDE	640 (290–1600)	290 (71–1000)	370 (59–1400)	270 (67–2300)	290 (140–900)	270 (64–1300)	230 (54–1700)	230 (55–930)	150 (30–720)	120 (11–520)	130 (22–480)	<0.0001
p,p’–DDT	26 (9.5–96)	17 (4.2–63)	18 (<LOD–86)	13 (<LOD –130)	8.6 (<LOD –46)	11 (<LOD –68)	6.6 (<LOD –38)	9.1 (<LOD –44)	5.5 (<LOD –50)	4.4 (<LOD–33)	NR[b]	<0.0001
HCB	95 (47–220)	41 (15–120)	51 (9.2–190)	36 (6.7–350)	37 (15–100)	37 (12–110)	34 (11–140)	36 (8.9–170)	22 (5.1–83)	18 (<LOD –110)	20 (<LOD–92)	<0.0001
β-HCH	12 (2.3–30)	4.7 (<LOD–14)	6.5 (<LOD–24)	5.3 (<LOD –31)	5.4 (<LOD –11)	5.6 (<LOD –16)	NR[b]	4.4 (0.8–23)	3.8 (1.1–26)	2.4 (<LOD –16)	2.4 (LOD–19)	<0.0001
Mirex	13 (5.6–29)	10 (2.3–36)	10 (<LOD–60)	6.5 (<LOD–32)	9.7 (<LOD–39)	9.2 (<LOD–47)	7.3 (<LOD–30)	4.0 (<LOD–24)	2.0 (<LOD–16)	3.0 (<LOD–19)	3.0 (<LOD–24)	<0.0001
PCB-138	110 (45–220)	58 (10–210)	69 (12–310)	46 (13–390)	62 (17–220)	56 (7.9–300)	53 (11–170)	37 (8.6–120)	22 (3.0–91)	17 (<LOD –77)	19 (2.0–120)	<0.0001
PCB-153	170 (71–290)	110 (19–410)	130 (23–610)	83 (83–710)	120 (29–470)	97 (15–500)	82 (16–420)	72 (32–250)	40 (4.5–220)	39 (2.4–230)	40 (3.5–320)	<0.0001
PCB-180	90 (34–150)	43 (7.6–190)	51 (11–220)	35 (12–280)	53 (14–380)	42 (5.0–260)	44 (7.5–240)	32 (4.9–130)	16 (2.0–95)	17 (<LOD –160)	17 (1.7–200)	<0.0001
Sample size (Metals only)	n=11	n=25	n=53	n=27	n=16	n=29	n=19	n=31	n=42	n=111	n=95	p<0.05[a]
Total mercury	12 (3.6–33)	13 (4.2–29)	11 (3.8–44)	7.2 (3.2–27)	8.5 (2.6–31)	9.0 (1.8–38)	9.9 (1.6–33)	7.6 (1.2–30)	4.0 (0.7–24)	5.0 (0.2–40)	5.2 (0.3–32)	<0.0001
Lead	41 (8.3–170)	48 (17–140)	56 (10–260)	54 (27–130)	53 (19–110)	44 (10–140)	33 (5.2–130)	19 (5.8–85)	16 (6.6–77)	13 (2.7–230)	14 (4.2–62)	<0.0001
Selenium	NR[b]	370 (190–620)	320 (190–980)	290 (180–470)	300 (150–580)	340 (190–1200)	260 (200–390)	270 (130–700)	230 (130–710)	320 (120–3000)	300 (130–1400)	0.0068
Cadmium	3.2 (0.4-7.5)							2.7 (0.3-8.0)	1.9 (0.2-7.6)			

[a] Special analysis as in Donaldson et al., 2010 using regression adjusted for age and region (Hudson or Ungava) and smoking status (smoker vs. non-smoker). Values <LOD were replaced by LOD/2.

[b] NR: no record

Table 4 - Temporal trends for select persistent organic pollutants in pregnant Inuit women from Nunavik. Concentrations for toxaphenes and PBDEs are shown in plasma (µg/kg lipids) and concentrations for PFOS, PFOA, and PCP are shown in whole blood (µg/L). Data are presented as geometric means (range). Results are presented for contaminants with more than 60% of data detected (AMAP, 2015; Ayotte personal communication, 2015).

Year	2004	2011-2012	2013	p<0.05[a]
Sample size	**n=31**	**n=112**	**n=95**	
Toxaphene Parlar 26	9.8 (<LOD–70)	4.5 (<LOD– 49)	5.8 (<LOD–47)	0.0252
Toxaphene Parlar 50	17 (<LOD–130)	7.1 (<LOD–65)	9.1 (<LOD–63)	0.008
PBDE-47	7.7 (<LOD–33)	<LOD	NR[c]	
PBDE-153	2.0 (<LOD–12)	2.9 (<LOD–15)	NR[c]	0.0399[b]
PFOS	9.8 (3.1–20)	3.9 (0.7–23)	NR[c]	<0.0001[b]
PFOA	NR[c]	0.7 (0.2–2.4)	NR[c]	
PCP	0.5 (0.2–1.5)	0.3 (<LOD–1.8)	NR[c]	<0.0001[b]

[a] Based on orthogonal polynomial contrast, adjusted for age and region (Hudson and Ungava). Values <LOD were replaced by LOD/2.
[b] *p*-value based on ANOVA test, adjusted for age and region
[c] NR: no record

Figure 1 - Geometric mean concentrations for six persistent organic pollutants in pregnant Inuit women from Nunavik over the period 1992-2013.

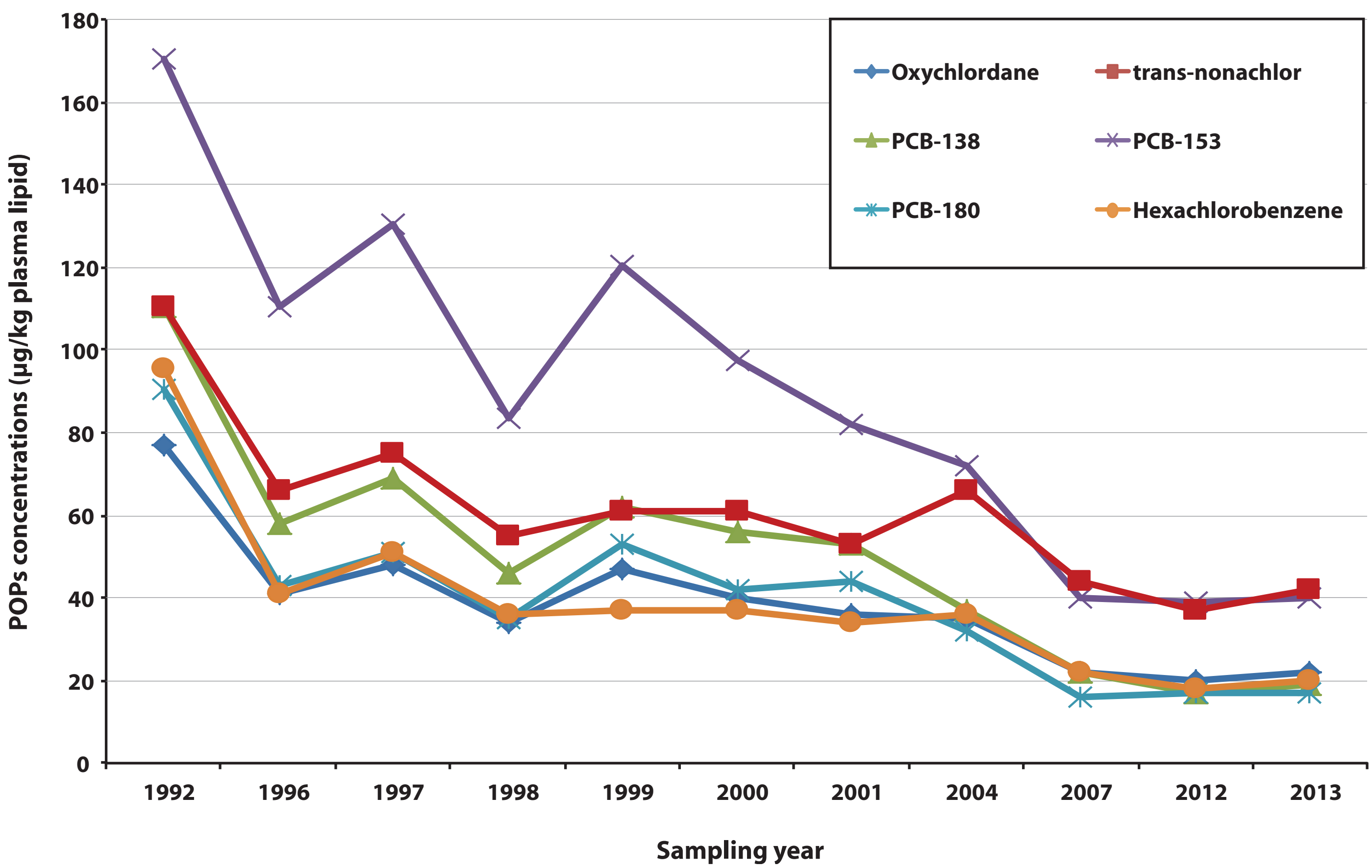
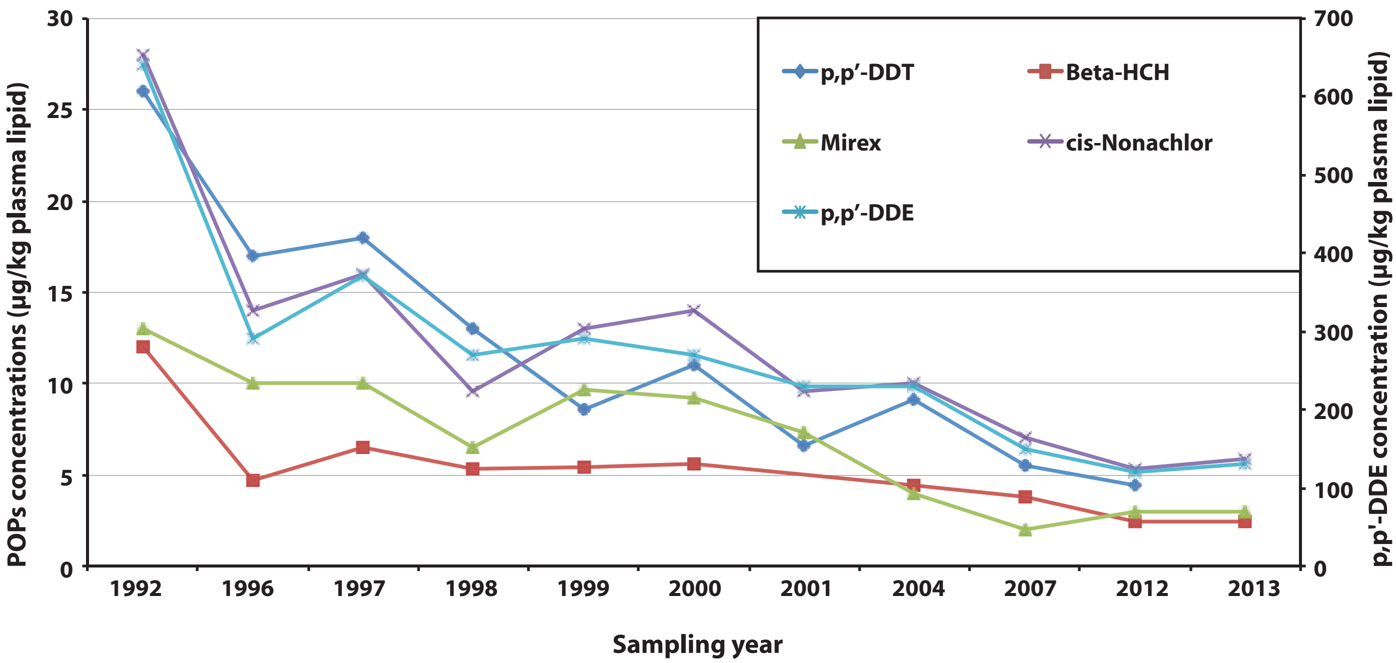


Figure 2 - Geometric mean concentrations for five persistent organic pollutants in pregnant Inuit women from Nunavik over the period 1992-2013 (p,p'-DDE is shown on the secondary axis).



Concentrations of contaminants among children who participated in the Nunavik Child Development Study (see Chapter 3 for additional details) are presented in Table 5. Blood samples were collected from the same children between 2000 and 2002 (average age 5 years old) and between 2005 and 2007 (average age 11 years old). Concentrations of several POPs declined in children's blood by more than 40% across these two time points. This decrease is likely influenced by several factors, including the lowering of environmental levels for some of these contaminants and the duration of breastfeeding. NCDS mothers were reported to have breastfed one or more children for 0.1 to 108 months (Boucher et al., 2010), thus exposures to POPs through breast milk were expected to vary for NCDS children. After breastfeeding ceased and these children matured from toddlers to pre-teenagers, their POPs concentrations were expected to decrease because their rate of growth likely exceeded the rate of contaminant uptake from food (Quinn et al., 2011). It seems less likely that dietary transitions away from traditional food would explain declining POP concentrations for these NCDS children, as results from several recent northern dietary studies have described that older children are more likely to eat traditional foods than younger children (Gagné et al., 2012). Similar to POPs, blood concentrations for mercury, lead, and selenium in NCDS children were observed to decrease across the two time points and age groups.

Table 5 - Blood concentrations of persistent organic pollutants (µg/kg plasma lipid) and metals (µg/L whole blood) in children from the Nunavik Child Development Study. Concentrations for PFOS, PFOA, TBBPA and PCP are shown in whole blood (µg/L). Data are presented as geometric means (range) (AMAP, 2015; Ayotte personal communication, 2015).

Year	**2000–2002**	**2005–2007**
Mean age (range) (years)	5.4 (4.7–6.2)	11.3 (10.2–14.3)
Sample size	n=93	n=93
Persistent organic pollutants		
Oxychlordane	40 (2.9–620)	24 (0.5–240)
trans-Nonachlor	56 (4.1–710)	40 (1.4–350)
p,p'-DDE	290 (38–3100)	170 (23–1800)
p,p'-DDT	7.8 (1.7–95)	4.5 (1.2–31)
HCB	47 (10–280)	26 (4.2– 150)
β-HCH	6.6 (1.9–44)	3.1 (0.6–21)
Mirex	4.1 (1.1–72)	2.3 (0.6–29)
Toxaphene Parlar 26	NR[a]	3.1 (0.4–23)
Toxaphene Parlar 50	NR[a]	5.1 (0.4–35)
PCB-99	19 (2.2–210)	8.8 (0.8–84)
PCB-118	16 (1.8–130)	8.4 (0.8–50)
PCB-138	54 (7.4–590)	23 (2.3–180)
PCB-153	84 (7.5–1500)	45 (3.5–430)
PCB-180	31 (2.6– 520)	18 (1.0–220)
PBDE-47	NR[a]	14 (2.5–710)
PBDE-99	NR[a]	4.0 (1.4–190)
PBDE-100	NR[a]	3.4 (1.2–110)
PBDE-153	NR[a]	6.0 (0.6–120)
PFOS	NR[a]	9.2 (1.9–32)
PFOA	NR[a]	2.5 (1.1–12)
TBBPA[b]	NR[a]	0.01 (0.01–0.05)
PCP	NR[a]	1.4 (0.3–15)
Metals		
Total mercury	5.9 (0.2–38)	3.2 (0.10–28)
Lead	41 (10–370)	22 (5–130)
Selenium	330 (160–2600)	190 (71–750)

[a] NR: no record
[b] Tetrabromobisphenol A

2.2.5 Blood guideline exceedances for mercury and lead

Exceedances of blood guidelines have been calculated from total mercury and lead concentrations in whole blood for adult Inuit from the four northern Inuit regions (Inuvialuit Settlement Region, Nunavut, Nunatsiavut, and Nunavik). The blood guidelines referenced in Tables 6 and 7 are summarized here:

- The guideline of 50 μg/L for lead in whole blood of pregnant women (Centers for Disease Control and Prevention, 2010).
- The blood lead intervention level of 100 μg/L in whole blood for adults and children (Health Canada, 1994).
- The provisional interim blood guidance value for methylmercury of 8 μg/L in whole blood for pregnant women, women of childbearing age, and children of both sexes (Environment Canada, 2010).
- The guidance value for methylmercury of 20 μg/L in whole blood for older women and adult men (Environment Canada, 2010).

The exceedance data in Table 6 show that older adult Inuit women (46 – 90 years) from Nunavut had higher relative frequencies of total mercury and lead concentrations above the respective guidelines for these metals in whole blood than adult Inuit women (46 – 90 years) from the ISR or Nunatsiavut. When blood concentrations for women of childbearing age (18 - 45 years) are compared against the lower provisional interim blood guidance value of 8 μg/L methylmercury in whole blood, 42.5% of these women of childbearing age from Nunavut exceeded this guidance value in 2007-2008 (the lower provisional interim blood guidance value of 8 μg/L methylmercury in whole blood also applies specifically if a woman is pregnant or is planning to become pregnant and is older than 45 years old). While a slightly lower proportion of pregnant women from Nunavik exceeded this guidance value in both 2011-2012 (36%) and 2013 (37.9%) (Table 7), the proportion of women exceeding the 8 μg/L methylmercury interim blood guidance value has been decreasing overall since 1992 in Nunavik. It is evident that the proportion of pregnant women and women of childbearing age exceeding the 100 μg/L blood lead intervention level and the 50 μg/L lead guideline has also been decreasing steadily over time in Nunavik.

Interestingly, although a higher proportion of men from Nunavut exceeded the blood guidance value for methylmercury compared with men from the other regions, the percentage of men exceeding the blood lead intervention level was higher in the ISR compared with that of men from Nunavut or Nunatsiavut, despite Inuit men from Nunavut having a slightly higher geometric mean blood concentration for lead.

Approximately ten percent of adult participants from the IHS in Nunavut showed whole blood concentrations in 2007 - 2008 above the blood lead intervention level (Fillion et al., 2014). These participants who presented blood lead levels of 100 μg/L or higher, as well as adults and children from their households, were invited to provide new blood samples in 2012. During this follow-up with 100 adults and 56 children, dust was identified as the likely predominant source for lead in the households with the highest blood lead levels in the occupants. Moreover, lead isotope ratios found in the environment, when compared with those in the blood of participants, suggested that lead from paint and ammunition could be contributing to the lead burden in house dust. Exposure to lead from country food was relatively low in this follow-up study (Fillion et al., 2014).

One of the main hurdles facing environmental health scientists has been the small number of clinical guidelines that can be used to assist in the interpretation of biomonitoring data for individuals and to inform clinical decisions concerning adverse effects of chemicals (Morello-Frosch et al., 2009). There are a limited number of chemicals for which there is sufficient data to derive a tissue-based guideline; however, blood guidelines have been described for mercury and lead in Section 2.2.5. The decades-old Health Canada PCB guideline (now considered historical and inactive) was meant to be compared to measures of Arochlor 1260 equivalents in whole blood, an analytical method in use at the time the guideline was established. Use of the Aroclor 1260 standard is rare today for the measurement of PCBs in blood collected during biomonitoring studies (Liberda et al., 2007).

Fortunately, other tools have been developed to interpret biomonitoring data. One such tool is the development of Biomonitoring Equivalents (BEs), which are estimations of the concentration of a chemical's biomarker in biological tissue or fluid (such as blood or urine) that are consistent with existing exposure guidance values, such as a Tolerable Daily Intake (Hays et al., 2008). BEs can be used as a screening tool to place biomonitoring data in a public health risk context at the population level. Because of the general assumptions introduced into the estimations, BEs are intended for a population-wide analysis and not specifically for individual comparison. It is generally unadvisable to use BEs for the interpretation of contaminant biomonitoring results for individuals (i.e. clinical management); however, professional judgment may occasionally enable BEs to be compared to smaller regional or sub-population biomonitoring results (LaKind et al, 2008).

BEs have been developed for over 100 compounds (Hays et al., 2007; Hays et al., 2008; Kirman et al., 2011; Krishnan et al., 2011), including POPs measured in NCP studies, such as hexachlorobenzene (HCB) (Aylward et al., 2010; St-Amand et al., 2014). Additional work on the application of BEs for interpreting Arctic biomonitoring data would assist researchers and public health practitioners when interpreting exposure data at the population level in the North. For example, a whole blood equivalent has been calculated for selenium in humans (480 μg/L; Hays et al. 2014) based on the Tolerable Upper Intake Level (UL) for selenium (400 μg/day) established by the Institute of Medicine for intake from food and supplements (Institute of Medicine, 2000). However, it still needs to be determined whether there is a selenium threshold that is more appropriate for northern communities with high selenium intake and where specific foods of marine origin have been shown to be uniquely high in selenium.

Given that BEs can be used as a screening tool at the population level, but not at the individual level, the successful communication of BEs within NCP studies will require the development of communication materials specific to northern populations (LaKind et al., 2008). It is worth considering that the lack of clinically-relevant tissue-based guidelines for interpreting most biomonitoring results at the individual level has the potential to give study participants a sense that researchers are withholding information relevant to their and their families' health. Therefore, the co-development of communication frameworks with community partners, local knowledge holders, public health scientists, and risk communication experts that stress transparency, confidence and uncertainty, uses and limitations of BEs, and the individual's right-to-know will be of particular importance to biomonitoring projects in northern Canada.

Table 6 - Guideline exceedances (%) for total mercury and lead in whole blood of adult Inuit from the Inuit Health Survey (2007-2008; Inuvialuit Settlement Region (ISR), Nunavut, Nunatsiavut), including women of childbearing age (18 – 45 years), women (46 – 90 years), and men (18 – 89 years) (Chan personal communication, 2016).

Sample	**n**	**Total mercury**		**Lead**	
		≥ 8 µg/L[a]	**≥ 20 µg/L[b]**	**≥ 50 µg/L[c]**	**≥ 100 µg/L[d]**
Women of childbearing age (18-45 years)					
ISR	103	15.6	--	6.8	0
Nunavut	644	42.5	--	15.0	3.3
Nunatsiavut	88	6.2	--	10.2	1.1
All 3 regions	835	35.3	--	13.5	2.6
Women (46-90 years)					
ISR	84	--	16.7	--	8.3
Nunavut	333	--	41.8	--	16.2
Nunatsiavut	77	--	0	--	3.9
All 3 regions	494	--	31.0	--	13.0
Men (18-89 years)					
ISR	92	--	12.0	--	16.3
Nunavut	650	--	29.4	--	12.3
Nunatsiavut	98	--	3.1	--	6.1
All 3 regions	840	--	24.4	--	12.0

[a] Provisional interim blood guidance value for methylmercury in children, pregnant women, and women of childbearing age (Environment Canada, 2010)
[b] Guidance value for methylmercury in blood of adults (Environment Canada, 2010)
[c] Guideline for lead in blood of pregnant women (Centers for Disease Control and Prevention, 2010)
[d] Blood lead intervention level for adults and children (Health Canada, 1994)

Table 7 Guideline exceedances (%) for total mercury and lead in whole blood of Inuit women from Nunavik, including women of childbearing age (WCBA) and pregnant women (PW) (AMAP, 2015).

Sample		**n**	**Mean age (range) (years)**	**Total mercury**	**Lead**	
				≥ 8 µg/L[a]	**≥ 50 µg/L[b]**	**≥ 100 µg/L[c]**
1992	*WCBA*	170	28 (18–39)	76.2	73.8	26.2
1996–1997	*PW*	78	25 (15–41)	71.8	60.3	11.5
1998–1999	*PW*	43	25 (15–37)	51.2	48.8	16.3
2000–2001	*PW*	47	26 (17–39)	61.7	38.3	8.5
2004	*WCBA*	283	28 (18–39)	53.2	15.8	2.9
2004[d]	*PW*	31	27 (18–42)	51.6	6.4	0
2007	*PW*	42	24 (18–37)	16.7	4.8	0
2011–2012	*PW*	111	24 (18–39)	36	3.6	1.8
2013	*PW*	95	24 (18–41)	37.9	1.0	0
p-trend[e]				<0.0001	<0.0001	<0.0001

[a] Provisional interim blood guidance value for methylmercury in children, pregnant women, and women of childbearing age (Environment Canada, 2010)
[b] Guideline for lead in blood of pregnant women (Centers for Disease Control and Prevention, 2010)
[c] Blood lead intervention level for adults and children (Health Canada, 1994)
[d] Not included in the trend test
[e] Based on Cochrane-Armitage trend test

2.2.6 Comparison between northern and southern Canada

Blood concentrations for several POPs and metals in northern adult Inuit who participated in the Inuit Health Survey (2007-2008) and the Nunavik Inuit Health Survey (2004) are presented beside data for the general population of Canada from Cycle 1 (2007-2009) (Health Canada, 2010a) of the nationally representative Canadian Health Measures Survey (CHMS) (Haines and Murray, 2012) in Tables 8 and 9. This provides a side-by-side comparison of Canadian biomonitoring data from northern and southern Canada across similar time periods using large samples that are representative of the sampled populations in their respective Canadian regions.

The data in Tables 8 and 9 suggest that northern Inuit have experienced higher exposures to some POPs, mercury, lead, and cadmium, as well as higher intakes of selenium, compared with people living in southern Canada. Smoking, a major source of cadmium exposure, was highly prevalent amongst participants of the Inuit Health Survey and the Nunavik Inuit Health Survey, with about 70% of these Inuit populations smoking (Fontaine et al., 2008; Egeland, 2010a, 2010b, 2010c). However, the mean blood cadmium level (0.28 µg/L) among study participants from the Inuit Health Survey who were non-smokers was about 3 to 10 times less than for the general Inuit population sampled during the IHS (Laird et al., 2013b).

Levels for oxychlordane, PCB-153, PCB-180, mercury, lead, and selenium were generally between two- and eleven-fold higher among Inuit men and women from the four regions of northern Canada compared to participants from Cycle 1 of the CHMS, although geometric mean POP and selenium blood levels for adult Inuit from Nunatsiavut (who, historically, have tended to consume lower amounts of marine mammals) were often similar to or even lower than the geometric mean concentrations observed in southern Canada during the period 2007-2009. Mean PBDE-47 concentrations were higher in CHMS men and women than in Inuit adults from the four northern regions. However, when CHMS data for women of childbearing age are examined by country of birth, it appears that women of childbearing age born outside of Canada have experienced higher exposures to several POPs than women born in Canada. These foreign-born women of childbearing age had contaminant body burdens that were often similar to Inuit women of childbearing age from the ISR and Nunatsiavut. Moreover, the mean p,p'-DDE levels in foreign-born women of childbearing age from the CHMS appear to be two- to ten-fold higher than for Canadian-born women of childbearing age in southern Canada and from the northern Inuit regions.

These observations are supported by biomonitoring data for expectant first-time mothers from the Inuvik and Baffin Regions and from five centres in southern Canada as part of a maternal biomonitoring study conducted by the Commission of Environmental Cooperation (CEC) (Curren et al., 2014). Examination of blood samples taken during the time period 2005-2007 for these NCP and CEC studies revealed significant differences in concentration for several POPs, mercury, and lead between the pregnant women from northern and southern Canada, after adjusting for age. The highest age-adjusted geometric mean levels of POPs and metals were usually observed among Inuit from the two northern regions. Southern Canadian mothers from the CEC study who were born outside of Canada showed the highest individual concentrations of p,p'-DDE and β-hexachlorocyclohexane (β-HCH), although northern mothers as a group showed a higher age-adjusted geometric mean concentration for β-HCH, and Inuit mothers from Baffin also had higher levels of p,p'-DDE (Curren et al., 2014). PBDE-153 concentrations were significantly higher in the southern women.

Table 8 Blood concentrations of select persistent organic pollutants (µg/kg plasma lipid)[a] for Inuit from the Inuit Health Survey (2007-2008; Inuvialuit Settlement Region (ISR), Nunavut, Nunatsiavut) and the Nunavik Inuit Health Survey (2004), and for the general Canadian population from Cycle 1 (2007-2009) of the Canadian Health Measures Survey (CHMS). Data are presented as geometric means (Egeland, 2010a, 2010b, 2010c; Health Canada, 2010a; Curren et al., 2014; Ayotte personal communication, 2015).

Sample (age range; years)	Oxychlordane	p,p'-DDE	β-HCH	PCB-153	PCB-180	PBDE-47
Women of childbearing age						
CHMS Cycle 1 (20-39)	**2.3**	**100**	**4.8**	**8.2**	**5.8**	**11**
CHMS Cycle 1, Canadian-born only (20-41)	**2.1**	**67**	**2.6**	**7.2**	**5.3**	**12**
CHMS Cycle 1, Foreign-born only (20-41)	**3.3[E]**	**500[E]**	[F]	**15[E]**	**8.9[E]**	**<LOD[E]**
ISR (18–39)	8.5	80	3.7	18	7.4	9.9
Nunavut (18–39)	22	150	5.5	47	22	8.8
Nunavik (18–39)	34	280	4.8	82	38	6.6
Nunatsiavut (20–39)	2.5	56	1.6	18	11	7.0
Adult women						
CHMS Cycle 1 (20-79)	**4.4**	**170**	**7.5**	**18**	**15**	**10**
ISR (18–90)	34	240	13	62	26	8.8
Nunavut (18–90)	56	280	12	110	51	7.9
Nunavik (18–74)	66	470	8.1	160	75	5.9
Nunatsiavut (20–79)	8.0	150	3.5	61	44	7.1
Adult men						
CHMS Cycle 1 (20-79)	**4.0**	**130**	**5.5**	**18**	**16**	**9.7**
ISR (18–81)	91	470	28	150	70	6.6
Nunavut (18–89)	100	410	19	200	110	7.9
Nunavik (18–74)	66	460	8.1	190	110	5.9
Nunatsiavut (18-89)	14	190	3.9	110	94	9.6

[a] CHMS Cycle 1 (2007-2009): Lipids were measured in serum, while the chemical was measured in plasma
[E] Warning that high sampling variability is associated with these estimates. Results should be interpreted with caution.
[F] The user is advised that these estimates are of unacceptable quality, as determined by Statistics Canada's release guidelines, and are suppressed.

Table 9 Blood concentrations of select metals (µg/L whole blood) for Inuit from the Inuit Health Survey (2007-2008; Inuvialuit Settlement Region (ISR), Nunavut, Nunatsiavut), the Nunavik Inuit Health Survey (2004), and the Nunavik Child Development Study, and for the general Canadian population from Cycle 1 (2007-2009) of the Canadian Health Measures Survey (CHMS). Data are presented as geometric means (Egeland, 2010a, 2010b, 2010c; Health Canada, 2010a; Curren et al., 2014; Ayotte personal communication, 2015; Chan personal communication, 2015; Health Canada special analysis, 2015).

Sample (age range; years)	Total mercury	Lead	Selenium	Cadmium
Children				
CHMS Cycle 1 (6-11)	0.27	9.0	190	0.10
Nunavik, 2000-2002 (4.7-6.2)	5.9	41	330	NR[a]
Nunavik, 2005-2007 (10.2-14.3)	3.2	22	190	NR[a]
Women of childbearing age				
CHMS Cycle 1 (20-39)	0.70	8.9	200	0.36
CHMS Cycle 1, Canadian-born only (15-41)	0.54	8.1	200	0.32
CHMS Cycle 1, Foreign-born only (15-41)	1.1[E]	11	200	0.40
ISR (18–39)	2.1	18	240	1.6
Nunavut (18–39)	5.0	22	290	2.1
Nunavik (18–39)	8.4	27	280	3.4
Nunatsiavut (20–39)	1.7	15	190	1.5
Adult women				
CHMS Cycle 1 (18-79)	0.80	13	200	0.46
ISR (18–90)	4.1	28	290	1.3
Nunavut (18–90)	7.9	32	340	1.8
Nunavik (18–74)	12	34	300	3.0
Nunatsiavut (20–79)	2.8	22	200	1.2
Adult men				
CHMS Cycle 1 (18-79)	0.81	17	210	0.37
ISR (18–81)	5.6	45	320	1.3
Nunavut (18–89)	9.4	46	350	1.7
Nunavik (18–74)	9.2	46	280	2.9
Nunatsiavut (18-89)	4.2	40	230	1.0

[a] NR: no record

[E] Warning that high sampling variability is associated with these estimates. Results should be interpreted with caution.

Blood concentration data for metals in children from Cycle 1 of the CHMS (6 - 11 years old) and from two age groups in Nunavik (average ages 5 and 11) are also presented in Table 9. Although the age ranges for the northern and southern children are not the same, and growth effects and other factors are expected to influence blood concentrations in these groups of children, these data provide some indication that the Inuit children from Nunavik experienced markedly higher exposures to mercury and lead as they have aged compared with children from the general Canadian population. The pattern of exposure for selenium is less clear. Although the geometric mean concentration for selenium in children from Nunavik at age 5 was nearly double the value for children from Cycle 1 of the CHMS, after the children from Nunavik reached age 11 they showed the same geometric mean selenium value as the CHMS children.

2.2.7 Population biomonitoring in northern Canada

Over the past decade, a variety of biomonitoring studies designed to characterize specific human exposures to environmental and occupational chemicals have been undertaken in northern Canada. Collectively, these efforts have focused upon specific population groups that: 1) have not been included within nationally-representative biomonitoring studies that examine the general population, such as the Canadian Health Measures Survey (Haines and Murray, 2012), or within studies that have otherwise provided broad coverage of people living in Canada, such as the Maternal-Infant Research on Environmental Chemicals (MIREC) study in southern Canada (Arbuckle et al., 2013) and the IHS in northern Canada (Saudny et al., 2012), 2) have not been included within population biomonitoring initiatives among First Nations in the ten provinces (e.g. First Nations Food, Nutrition, and Environment Study (FNFNES), First Nations Biomonitoring Initiative (FNBI)) (Chan et al., 2011; Assembly of First Nations, 2013), and 3) are likely to face elevated exposures relative to the general Canadian population.

At times, population biomonitoring in northern Canada has included the regular collection of biological samples in specific workplace settings, as required within occupational hygiene legislation in some Canadian jurisdictions and elsewhere. For example, arsenic exposures for individuals working on the clean-up of the Giant Mine in Yellowknife are regularly measured and reported to the Worker's Safety and Compensation Committee of the Northwest Territories. In addition to such occupational biomonitoring, population-level biomonitoring studies have investigated contaminant exposures among specific First Nations, Métis, or Inuit communities in northern Canada.

2.2.7.1 Tulita Mercury Study

Tulita is a Dene/Métis community within the Sahtu Region of the Northwest Territories. In 2010, the Department of Health and Social Services of the Northwest Territories documented that the level of mercury had increased in some predatory fish species (e.g. Walleye, Lake Trout) in two lakes (Kelly Lake, Lac Ste. Therese) in the Sahtu Region (DHSS, 2010). A dietary advisory recommended that the general population should eat no more than 2 servings per week of Lake Trout from Kelly Lake, while women of childbearing age should eat no more than 2 servings per month. Additionally, it was noted that mercury concentrations in predatory fish in Lac Ste. Therese had tripled since the early 1990s and had reached levels so high that the advisory recommended consumption of these fish should be avoided altogether.

The mercury advisory (DHSS, 2010) caused a large degree of concern amongst many community members in Tulita, which led to the creation of a participatory, community based biomonitoring project to more precisely characterize exposure and risk (Delormier, 2012). To this end, 68 Tulita residents, including children (less than 12 years), adults (18 - 64 years), and elders (greater than 65 years) participated in the mercury biomonitoring project. Mercury concentrations were measured in hair specimens collected from participants in Tulita during the summer (2010) and winter (2011) seasons. Additionally, participants completed a dietary questionnaire describing the frequency by which they consumed locally-harvested predatory and non-predatory fish species.

The residents of Tulita found reassurance in the fact that, despite increases in mercury concentrations in predatory fish species in some nearby lakes, mercury exposures within their community remained low. Of the 68 participants who provided hair samples for mercury exposure analysis, fewer than 5% of participants exceeded 5 μg/g in hair, a screening value considered acceptable for this study; however, none exceeded the higher level of 25 μg/g , which was the threshold that the investigators determined would warrant immediate intervention by a health care professional (Delormier, 2012). Furthermore, of the most susceptible individuals within their community (e.g. children, women of childbearing age), none exceeded a mercury level that would warrant any further follow-up. Qualitative interviews with eight Tulita residents outlined the tremendous importance of fish to the diet and culture of Dene and Métis people (see also Chapter 4) (Delormier, 2012).

2.2.8 Known effective partnership approaches for biomonitoring in northern Canada

2.2.8.1 Biomonitoring in the Dehcho and Sahtu regions

An NCP-supported biomonitoring project, led by researchers at the University of Waterloo, the Sahtu Renewable Resources Board, and the Dehcho Aboriginal Aquatic Resources and Ocean Management (Dehcho AAROM), is being undertaken in the Dehcho and Sahtu regions of the Northwest Territories. Altogether, the Dehcho and Sahtu regions, which include a wide range of communities from small to large, are home to approximately 6,500 First Nations and Métis people. Traditional food, including moose and wild-harvested fish such as Walleye, Northern Pike, Lake Trout, and Lake Whitefish, are integral to the health, wellness, and food security of Indigenous communities within the Northwest Territories (Berti et al., 1998, Kuhnlein et al., 2004, Nakano et al., 2005, Kuhnlein and Receveur, 2007). However, since 2007, concerns regarding methylmercury exposure have prompted a series of dietary advisories suggesting that people limit their consumption of predatory fish (e.g. Lake Trout, Northern Pike, Walleye) from specific lakes in the Dehcho and Sahtu regions (DHSS, 2012). Additionally, because of high cadmium levels, an advisory was issued by the territorial government that people limit their consumption of liver and kidney of moose harvested from the southern Mackenzie Mountains (DHSS, 2009). The presence of contaminants such as mercury and cadmium may have impacted the safety of these significant cultural dietary staples and potentially undermined the food security of these Indigenous communities in the Northwest Territories.

Pilot work was undertaken in 2014 - 2016 to support the creation of a human biomonitoring project in the Dehcho and Sahtu regions of the Northwest Territories. These activities included team member participation within the 3rd Annual Return to Country Foods Workshop in Jean Marie River, the Sahtu Cross-Cultural Research Camp (along the Mackenzie River between Norman Wells and Fort Good Hope), as well as community consultations in the Jean Marie River, Kakisa, Tulita, and Deline communities of the Northwest Territories. These community visits directly shaped several aspects of the biomonitoring project work plan, including the selection of communities, development of a local capacity building plan, design of public consultation meetings, selection of contaminants of concern, and design of participant inclusion criteria. Additionally, these meetings enabled the research team to consult with community leaders and members to learn about local concerns, priorities, and research interests. Most importantly, these conversations have facilitated the establishment of trust and dialogue and reinforced a shared perspective that the proposed work should fit within the context of traditional food promotion within the Northwest Territories. The outcomes of these consultations were formalized into bilateral Community Research Agreements that outlined the scope of the project, the procedures to be undertaken, the responsibilities of the researchers and the participating First Nations community, as well as a data management plan.

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Successful biomonitoring initiatives within northern Indigenous communities in Canada, such as those described in Section 2.2, have been built upon reciprocal partnerships and meaningful consultation (Delormier, 2012; Saudny et al., 2012). Among the most important of these partnerships are the ones built with community members and leaders. Community engagement is important because the effectiveness of risk management decisions is often predicated on the extent to which communities have been included within the exposure and risk characterization processes (Friendship and Furgal, 2012). Such partnerships and engagement is particularly important to the establishment of trust, opening pathways for knowledge to be exchanged and jointly developed (Friendship and Furgal, 2012). However, in addition to the relationships that must be forged with communities, numerous other interested parties must be engaged, such as territorial or regional public health authorities, hunting and trapping associations, the local or regional health unit and clinic staff, the relevant Regional Contaminants Committee, and Indigenous advocacy groups.

The inclusion of federal representatives (e.g. Health Canada) can be particularly useful for ensuring that the methods used during northern research are consistent with those used within other biomonitoring studies in Canada. Such inter-study consistency is crucial to being able to adequately answer a key question implicit to most northern biomonitoring projects: *has the community in question faced elevated exposures relative to the general Canadian population?* Additionally, community partners are advocating for stronger linkages to be made between the work of environmental health scientists and public health researchers. These linkages are seen as ways to break down silos between disciplines and ensure that public health research remains informed by environmental science and vice versa (Lafontaine, 2014).

There are a variety of frameworks by which individuals and organizations can be engaged within biomonitoring research. For example, in the case of the Inuit Health Survey, Steering Committees were struck within each of the three participating regions (e.g. Nunavut, Nunatsiavut, and the ISR) (Saudny et al., 2012). Due to differences in capacity, as well as differences in governance structures between regions, the composition of each Steering Committee was specifically tailored for each region. It is best practice to determine the structure of a Steering Committee through inclusive conversations among affected communities and interested parties, rather than attempting to impose a Steering Committee structure designed in a different time, place, or context.

Regardless of the structure of a Steering Committee (or even if a Steering Committee should be created), dialogue with community members early-on and throughout a human biomonitoring study is important to ensure that the study adequately addresses the interests and concerns of community members. The topics of conversation within this dialogue will change for each situation, place, and community; however, common themes include the identification of contaminants and exposure routes of concern, the decision of who to include and who not to include within the sampling (e.g. children, pregnant women, new mothers), and developing strategies related to the return of results. As much as possible, these conversations are best carried out through face-to-face meetings well before a biomonitoring research proposal is prepared. Thereafter, it is often in the interest of all involved to incorporate these conversations into bilateral Community Research Agreements that formalize the expectations and responsibilities of both the community and the project investigator.

2.3 Methods for assessing human exposure to contaminants

2.3.1 Complementary approaches for describing human exposures: internal versus external dose

The development of effective risk management approaches to contaminant-related concerns depends upon up-to-date and culturally-relevant contaminant risk characterizations. In turn, the utility of these risk characterizations are based on the availability of representative and precise exposure measures. Generally, there are two distinct yet complementary modelling approaches for describing human contaminant exposures: internal and external dose models (Sexton et al., 2004).

In the first approach, chemical exposures are directly evaluated by measuring an 'internal dose', that is, the concentration of chemicals in biological tissues or fluids of individuals who participate in biomonitoring studies (see Section 2.2.1; Sexton et al., 2004). Oftentimes, biomonitoring is referred to as the gold-standard because it provides a direct measure of the internal level of a contaminant after it has been incorporated into the body and to which health outcomes are closely tied. However, biomarkers of exposure typically cannot provide evidence of which source or sources are driving exposure because they represent the sum of all sources of a chemical (Metcalf and Orloff, 2004). A growing set of Biomonitoring Equivalents and tissue-based guidelines (see Section 2.2.5) are available to exposure scientists and public health researchers to interpret biomonitoring data in a health-risk context.

Researchers may also attempt to reconstruct contaminant exposures faced by individuals and populations according to the levels of those contaminants in the environment, as well as the extent to which those individuals and populations interact with their environment. In terms of the assessment of dietary exposure, which is a particularly important exposure pathway for northerners, estimations of 'external dose' undertaken through dose reconstructions can be impacted by a number of factors. These factors are related to sometimes substantial levels of uncertainty within the input variables for the dose reconstruction models (e.g. contaminant bioavailability in foods, contaminant concentrations in foods as they are prepared and consumed, an individual's bodyweight). Additionally, the interpretation of estimates of dietary external dose can be impeded by uncertainty from the results of Food Frequency Questionnaires (FFQ), for which respondents may over-report consumption of particular foods by merging or mixing similar food types (e.g. Delormier, 2012), or they may under-report energy intake (Dhurandhar et al., 2015).

Nonetheless, dose reconstructions based upon environmental concentrations of contaminants offer several advantages. As such dose reconstructions are based upon estimates from each source, measures of external dose can provide critical information on the primary contributors of exposure (Health Canada, 2010b). Such details regarding the drivers of exposure are particularly important to the development of strategies aimed at decreasing contaminant exposure levels. Furthermore, the use of such dose reconstruction approaches facilitate the design of models that may be able to predict future exposures based upon changes in dietary patterns, chemical production and emissions, or climate variables (see Section 2.3.3). These measures of external dose can be readily compared to toxicological guidance values (e.g. Tolerable Daily Intake of a chemical) developed by national or international agencies (e.g. Health Canada, 2010c; JECFA, 2010).

Dietary exposure characterizations related to contaminants in traditional or market foods have occasionally included attempts to assess the correlation between external dose estimates and biomonitoring-based measures of internal dose. For example, when the dietary intake of two metals from traditional food were compared to whole blood concentrations of these same metals among Inuit, researchers observed correlations of less than 1.0 for selenium (0.44) and mercury (0.41) (Laird et al., 2013a). Similar strengths in correlation have been reported in other studies internationally (Mahaffey, 2004; AMAP, 2009; Liang et al., 2013).

There are many reasons that explain why correlation coefficients between external dose estimates and internal dose measures rarely exceed 0.5. For example, the types of dietary surveys (e.g. FFQs) essential for such dose reconstructions have considerable uncertainty, typically requiring participants to recollect their food choices over the previous one to twelve months. As a consequence, the food consumption rates generated from FFQs are prone to recall bias and, in the case of exposures from traditional food, have been shown to overestimate contaminant exposure and risk (e.g. Delormier, 2012). Furthermore, for PCBs and other POPs, measured blood concentrations are likely related to lifetime exposure patterns across many years or even decades (Quinn and Wania, 2012; Quinn et al., 2012; Binnington et al., 2014). Additionally, measures of internal versus external dose do not necessarily aggregate exposures over the same period. For example, an external dose reconstruction for mercury may reflect average exposure over the previous year, whereas actual blood concentrations better represent exposures over the previous month (Legrand et al., 2005b). Seasonal differences in exposure can further widen the difference between measures of external versus internal dose of contaminants, particularly in the North where traditional foods are often consumed at specific times of year based on seasonal availability.

In addition to the uncertainty brought by FFQs, the relationship between external and internal dose of contaminants depends upon the inter-food variation in a chemical's oral bioavailability, which refers to the fraction of an ingested chemical that is absorbed and circulated within the body (Versantvoort et al., 2005). Within dose reconstruction, chemical bioavailability is often assumed to be 100% even though physiochemical and physiological limits on dissolution and absorption may exist for chemicals in some foods, but not in others, potentially undermining the relationship between external and internal dose (Health Canada, 2004; Versantvoort et al., 2004). For example, if the bioavailability of a chemical in a particular food is assumed to be 100%, but it is in fact 25%, then measures of internal dose are likely to be four-fold lower than estimated from the external dose. Therefore, exposure scientists have started to develop *in vitro* gastrointestinal (GI) models as affordable and reliable tools for the measurement of metal bioaccessibility in foods (Laird et al., 2009; Calatayud et al., 2012; Laird and Chan, 2013). Metal bioaccessibility, which represents the fraction of metal solubilized into simulated GI fluids, may be used to adjust exposure and risk estimates according to limitations on chemical dissolution in the GI tract after oral exposure (Torres-Escribano et al., 2011).

The bioaccessibility of six metals, including cadmium and mercury, were measured in 11 types of traditional food from British Columbia that are commonly consumed by Indigenous people in northern Canada (Laird and Chan, 2013). This research, which utilized a simulated GI tract for the estimation of metal bioaccessibility, demonstrated that average mercury bioaccessibility in fish and shellfish was typically around 50%, and that mercury in salmon eggs was even less bioaccessible. Additionally, it was shown that the average cadmium bioaccessibility in moose kidney and liver was 68% and 48%, respectively. Such bioaccessibility constraints may explain in part why a study among First Nations in northern Québec could find no association between organ meat consumption and blood cadmium concentrations, despite the fact that high concentrations of this metal are typically detected in organ meats (Charania et al., 2014). Given the advisory from the Government of the Northwest Territories suggesting that people restrict their organ meat consumption from mountain moose (DHSS, 2009), these results are especially relevant to Indigenous people who consume wild game.

Typical bioaccessibility models like those described, above, cannot account for food-specific differences in absorptive processes at the intestinal wall. Therefore, GI models have increasingly been integrated with Caco-2 cells, an in vitro human cell-line that models the function of enterocytes (i.e. intestinal absorptive cells) (Hwang and Shim, 2008; Moreda-Pineiro et al., 2011; Calatayud et al., 2012). Such Caco-2 models have also reported the *in vitro* transport of both mercury and selenium from traditional food to be significantly less than 100% (Ayotte, 2014). For example, average mercury transport across the Caco-2 cell line ranged from less than 10% (ringed seal liver) to about 60% (Arctic Char). In contrast, average selenium transport was consistently 60% for ringed seal liver, ringed seal meat, beluga meat, Lake Trout, and Arctic Char (Ayotte, 2014).

It has not yet been demonstrated whether the results generated by the *in vitro* approaches described above (e.g. bioaccessibility models, Caco-2 models) will improve the accuracy of dose reconstruction efforts. For example, although these *in vitro* studies show mercury bioaccessibility to often be less than 100%, previous work using methylmercury radioisotopes spiked into seafood showed an absorption rate of approximately 95% (Miettinen et al., 1971). Thus, further research investigating the validity of these *in vitro* models is an important next step before such results can be readily incorporated into risk characterizations and into the development of risk management strategies.

2.3.2 Introduction to mechanistic modelling

A variety of 'mechanistic models' have been developed over the last 10 years that aim to simulate the exposure of Indigenous Arctic populations to persistent organic pollutants. These models have already found use in a diverse range of applications, including studies seeking to:

- Identify the properties of contaminants capable of accumulating in the Arctic human food chain and to identify chemicals used in commerce that may have such properties.
- Understand the impact of dietary change on human contaminant exposures, whereby those dietary transitions may be permanent or temporary.
- Characterize infant exposure to POPs during epidemiological studies and identify age periods of increased susceptibility to adverse effects.
- Enhance the understanding of human biomonitoring studies conducted in the Canadian Arctic by trying to reconcile measured concentrations of POPs and estimates of dietary intake.

For more than 40 years, scientists have sought to describe the bioaccumulation of environmental contaminants in different organisms (e.g. traditional food and other biota) mechanistically (Neely et al., 1974). These models integrate mechanistic descriptions of the processes that lead to chemical uptake in, and chemical loss from, an organism in the form of a mass balance equation (Mackay and Fraser, 2000). They range in complexity from models that treat the organism as a single compartment to so-called physiologically based pharmacokinetic (PBPK) models that distinguish different organs and tissues (e.g. Nichols et al., 1990). When several of these single organism models are combined, it is possible to simulate the transfer and accumulation of contaminants in an entire food chain. Such food chain bioaccumulation models have been developed first for aquatic food chains (Thomann, 1989; Thomann et al., 1992; Gobas, 1993; Campfens and Mackay, 1997; Arnot and Gobas, 2004) and later also for terrestrial food chains (Armitage and Gobas, 2007).

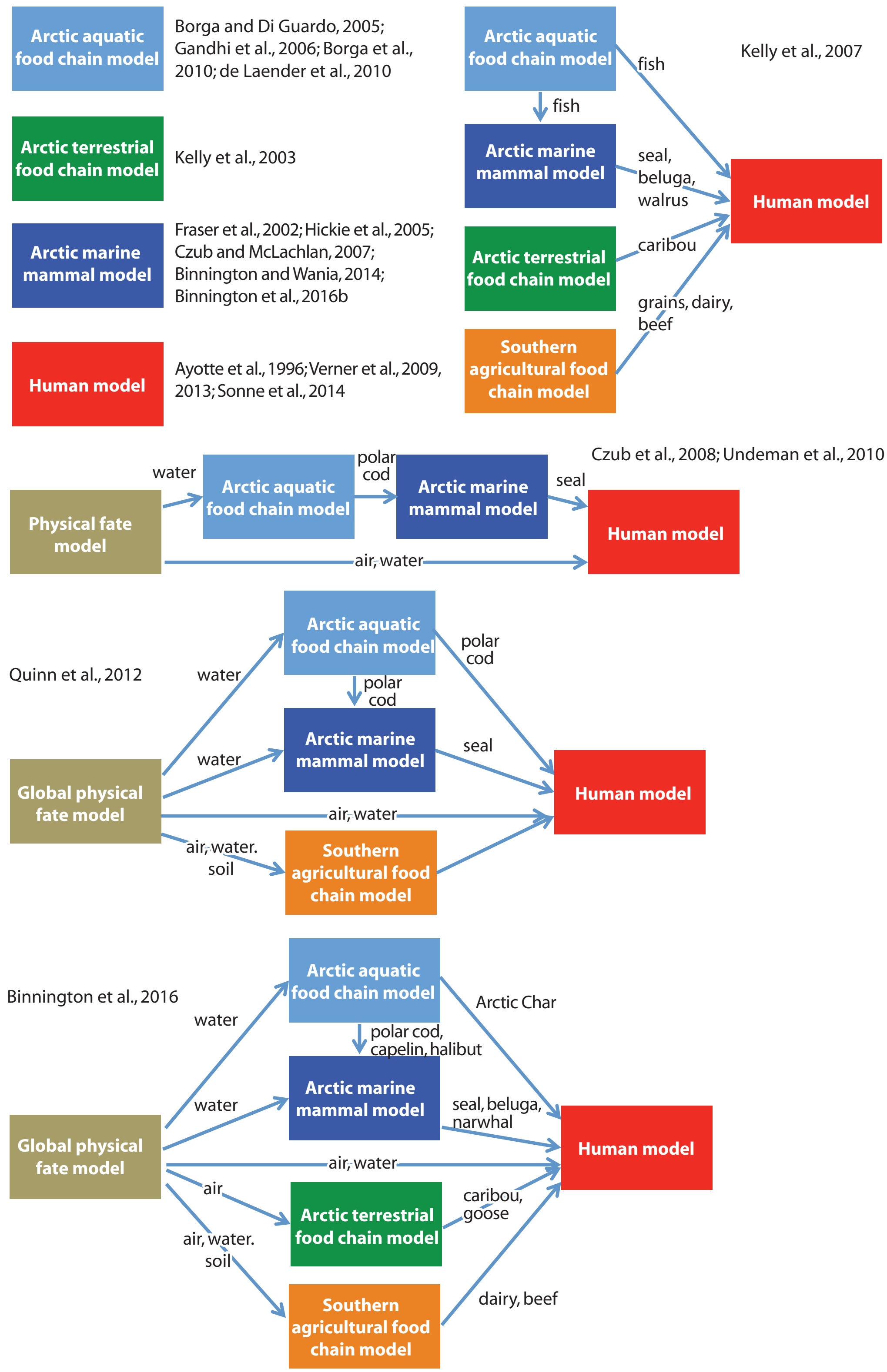
Eventually, it was realized that similar model approaches can also serve in the simulation of human exposure to environmental contaminants. This instigated the development of models that describe contaminant bioaccumulation in the food chains that provide for human food (McLachlan, 1994) and the integration of those food chain models with models of bioaccumulation in humans (Moser and McLachlan, 2002). ACC-human, the first such human food chain bioaccumulation model by Czub and McLachlan (2004a, 2004b), included both an agricultural and an aquatic food chain. It is even possible to go further and use environmental fate models to calculate the environmental concentration levels in media such as air, water, soil and sediment from the rate of contaminant emission into the environment (Mackay, 1991) and input those concentrations into the human food chain calculations. Such models or model combinations then seek to simulate mechanistically the entire sequence of events linking emissions into the environment with the residue levels in the human body. Examples of such models are the steady-state model RAIDAR (Arnot et al., 2006) and the dynamic CoZMoMAN model that allows for time-variant emissions and therefore also time-variant exposure (Breivik et al., 2010).

Not all human contaminant exposure models seek to include the contaminants transfer through the food chain in the simulation. Such models are essentially single organism models that require the (possibly time-variant) contamination of food to be supplied as an input parameter. Like any single organism model, the complexity of these models can range from simple single compartment models (e.g. Alcock et al., 2000; Lorber 2002; Ritter et al. 2009) to complex PBPK models (e.g. Carrier et al., 1995; Kreuzer et al. 1997; Beaudouin et al., 2010).

2.3.3 Mechanistic models of contaminant exposures for Arctic Indigenous populations

The unusually high exposure of Indigenous populations of the Arctic to POPs and the associated health concerns create a strong incentive for developing the capability to simulate their contaminant exposure mechanistically. Stand-alone models of human bioaccumulation can be directly applied to Indigenous populations (e.g. Verner et al., 2009, 2013; Sonne et al., 2014), possibly allowing for specific physiological or demographic characteristics of the population in a model's parameterization, which is the process of defining the parameters that a model requires as input. For example, Ayotte et al. (1996) allowed for a longer nursing period when applying the PBPK model by Carrier et al. (1995) to an Inuit population from Nunavik. On the other hand, the unique diet of Arctic Indigenous populations means that human bioaccumulation models that include the prediction of dietary contamination need to be modified. In particular, they should include a mechanistic description of contaminant bioaccumulation in aquatic and terrestrial Arctic food chains that lead to important traditional food species. Over the last decade, considerable progress has been made toward the development of such models. Figure 3 shows the structure of various models and model approaches that have been developed for describing organic chemical transport through Arctic food chains.

Figure 3 - Illustration of how various environmental fate, food chain, and single organism models have been combined to describe the accumulation of persistent organic pollutants in Arctic food chains and Indigenous people.



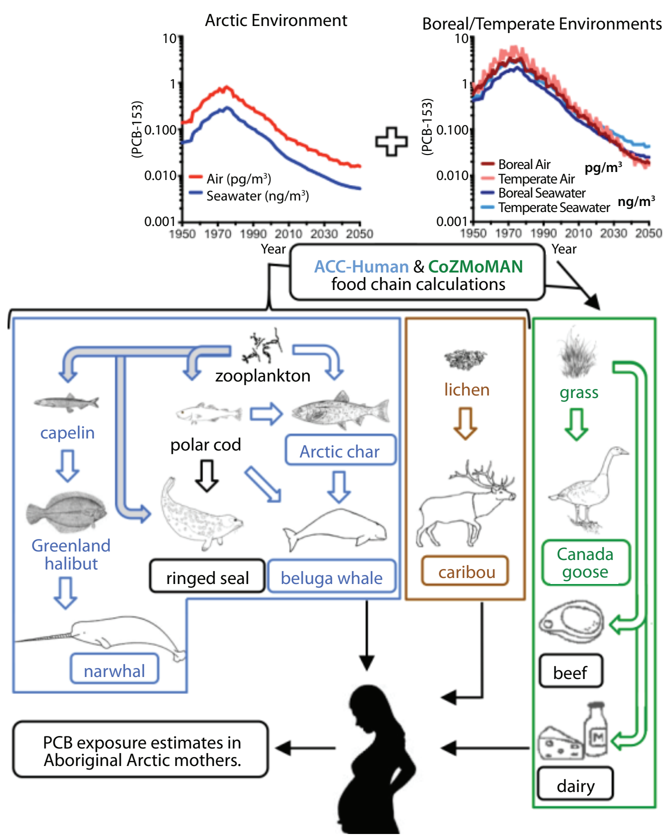
In order to serve in the exposure assessment of Arctic Indigenous populations, an Arctic marine food chain model needs to include the marine mammals that are part of the traditional northern diet. This is particularly important as marine mammal-based traditional food is expected to often be the main route of contaminant exposures for Arctic Indigenous populations. Single organism models of contaminant bioaccumulation have been developed and evaluated for a number of Arctic marine mammals, including the harp seal (*Phoca groenlandica*) (Fraser et al., 2002), Arctic ringed seal (*Phoca hispida*) (Hickie et al., 2005; Czub and McLachlan, 2007), beluga whale (*Delphinapterus leucas*), bowhead whale (*Balaena mysticetus*) (Binnington and Wania, 2014), and narwhal (*Monodon monoceros*) (Binnington et al., 2016a).

Remarkably, one of the first models of terrestrial food chain bioaccumulation of POPs was developed for the lichen-caribou-wolf food chain of the Canadian Arctic (Kelly and Gobas, 2003). The caribou (*Rangifer tarandus*) is the terrestrial organism most important as a traditional food species for Arctic Indigenous populations, and it is also included in the Arctic food chain model by Binnington et al. (2016a).

There have now been several studies where Arctic food chain models have been integrated with a human exposure model. The first such effort by Kelly et al. (2007) is only documented in the most rudimentary fashion, but suggests that exposure of an "Arctic Indigenous human (Inuit)" was calculated assuming that the diet is composed of a "combination of Arctic fish and wildlife (meat from caribou, ringed seals, walrus, and beluga whales) and agricultural products originating from southern Canada such as grains, beef, dairy" (Supporting Online Material of Kelly et al., 2007). Czub et al. (2008) created an Arctic version of the ACC-human human food chain bioaccumulation model by integrating the Arctic ringed seal model from Czub and McLachlan (2007) and thereby creating a zooplankton/amphipods–polar cod (*Boreogadus saida*)-ringed seal (*Phoca hispida*)-Inuit food chain model.

While neither terrestrial food organisms nor food from the South was considered in that model, Quinn et al. (2012) added southern agricultural food chain calculations when using the Arctic version of ACC-human. Recently, Binnington et al. (2016a) have expanded the Arctic ACC-human model by adding three whale species (beluga, narwhal, bowhead), caribou, and Canada goose, and also adding Arctic Char, which is more important for human dietary consumption than Arctic Cod in the North. Figure 4 summarizes the flow of PCBs from the Arctic and southern environments to the Inuit through the various food chains considered within the expanded Arctic ACC-human model.

Figure 4 - Schematic representation of the dietary relationships considered within the Arctic version of the ACC-human model (Binnington et al., 2016a[1].



1 Reprinted from Environment International, Volumes 92-93, Binnington MJ, Curren MS, Quinn CL, Armitage JM, Arnot JA, Chan HM, Wania F. Mechanistic polychlorinated biphenyl exposure modeling of mothers in the Canadian Arctic: The challenge of reliably establishing dietary composition. Pages 256-268, Copyright (2016), with permission from Elsevier.

2.3.4 Using mechanistic models to describe northern contaminant exposures

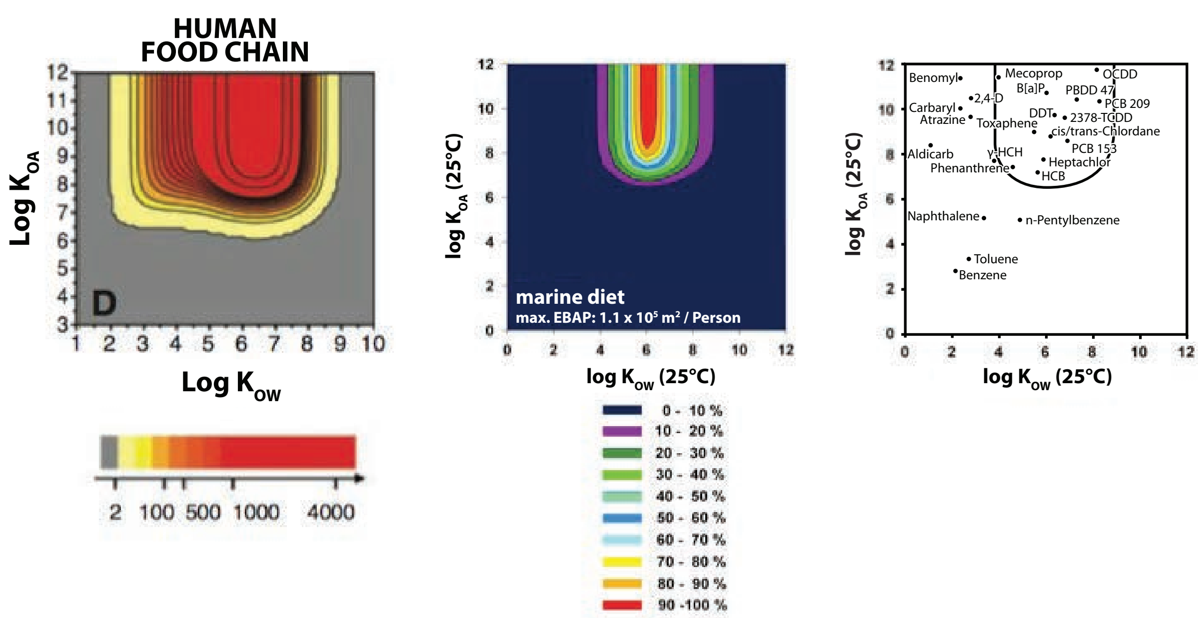
Models of contaminant exposures for Arctic Indigenous people have been applied for a wide range of studies, which are described in the following sections.

2.3.4.1 Develop new models to predict contaminants that enter the Arctic food chain

The first two studies relying on an Arctic human food chain bioaccumulation model used it for the same purpose: to identify the chemical partitioning properties that allow persistent organic chemicals to accumulate in Inuit consuming a traditional diet that includes marine mammals (Kelly et al., 2007; Czub et al., 2008). Both studies further used a similar approach by calculating and plotting the potential for bioaccumulation in a two dimensional space defined by the equilibrium partitioning properties between air, water and octanol (Figure 5).

The results are highly consistent, even though Czub et al. (2008) assumed exposure to be exclusively due to the consumption of seal blubber, while Kelly et al. (2007) assumed a more varied Inuit diet that included a number of traditional food species (seal, walrus, beluga, caribou), in addition to food imported from the South. Both studies identified chemicals that are not too volatile (having an octanol-air partitioning coefficient above 10^7) and have high, but not extreme, hydrophobicity (having an octanol-water partitioning coefficient between 10^4 and 10^9) as particularly susceptible to accumulation in the Inuit; maximum bioaccumulation in either study was

Figure 5 - Results of human food chain calculations by Kelly et al. (2007)[1] (left) and Czub et al. (2008)[2] (middle), indicating with red colors the combination of partitioning properties (namely the logarithm of the equilibrium partitioning coefficients between octanol and water log K_{OW} and octanol and air K_{OA}) that allow for efficient accumulation of an organic contaminant in the Inuit food chain. The plot on the right identifies the location of a number of chemicals in the partitioning space defined by log K_{OW} and K_{OA}. Reprinted (adapted) with permission from Czub et al. (2008). Copyright 2008 American Chemical Society.



1 From Kelly et al. (2007). Reprinted with permission from the American Association for the Advancement of Science (AAAS).

2 Reprinted (adapted) with permission from Czub et al. (2008). Copyright 2008 American Chemical Society.

predicted for substances with an octanol-water partitioning coefficient of 10^6 to 10^7 (Figure 5). Czub et al. (2008) explained the thresholds: marine mammals and humans efficiently exhale volatile compounds with an octanol-air partitioning coefficient below 10^7, whereas compounds with an octanol-water partitioning coefficient below 10^4 and above 10^9 do not bioaccumulate because of rapid gill elimination by fish and inefficient dietary absorption by fish and mammals, respectively. That the area of elevated bioaccumulation potential extends to somewhat lower octanol-water partitioning coefficients in the partitioning space by Kelly et al. (2007) is due to the inclusion of dietary items from terrestrial organisms.

A contaminant not only has to be capable of efficient Arctic food chain bioaccumulation to achieve elevated levels in Arctic Indigenous populations, but also needs to be able to reach the Arctic from its site of release in the global environment by means of long-range transport. Czub et al. (2008) therefore combined the calculation of human food chain accumulation with calculations of global scale fate and transport. Those calculations revealed that "a chemical's potential to bioaccumulate has a stronger impact on the overall potential to become an Arctic contaminant in humans than its potential for long-range transport".

2.3.4.2 Identify new commercial chemicals of concern in the Arctic food chain

Kelly et al. (2007) and Czub et al. (2008) both recognized that their study results could serve in the identification of potentially bioaccumulative substances among the large number of chemicals in commerce. Brown and Wania (2008) built upon the model results presented in Czub et al. (2008) to screen a set of more than 100,000 commercial chemicals for those that have predicted partitioning properties favouring long-range transport to the Arctic and accumulation in the Arctic human food chain. When additionally eliminating chemicals that were predicted to be readily degradable in the atmosphere, only about 2% of the screened chemicals had predicted properties that would to allow them to become Arctic contaminants. Of these, again only a subset had production volumes sufficiently high to warrant concern as global contaminants. Gawor and Wania (2013) used a similar approach to identify those chemicals in complex mixtures of halogenated substances that have properties favoring global long-range transport and accumulation in the Arctic human food chain. For example, short chain chlorinated paraffins with 5 to 6 chlorines and medium chain chlorinated paraffins with 6 to 7 chlorines were identified as having the highest combined potential for accumulating in Inuit relying on a traditional diet. Zhang et al. (2010) noted that such a screening process relying on the comparison of predicted chemical partitioning properties relative to a threshold value is susceptible to errors; for example, because of uncertain property predictions.

In an additional application of this approach, the compounds currently assessed as part of the third phase of the Chemicals Management Plan (see Chapter 4) were placed on the map of elevated Arctic Contamination and Bioaccumulation Potential (AC-BAP) generated by Czub et al. (2008) based on their estimated partitioning properties (Lan, 2015; Figure 6). While a fairly large number of these chemicals have predicted partitioning properties resembling those of Arctic contaminants, most will be degraded too rapidly to reach the Arctic or accumulate in the food chain. However, a small number of these chemicals are estimated to be reasonably persistent in the environment and to undergo only very limited metabolism in higher organisms. Listed in Table 10, these chemicals almost all contain highly fluorinated alkyl-chains. It should be noted that a few of these substances are acids and would be expected to occur in ionic form, while the estimated partitioning properties are those for the neutral form. While neither the global fate nor the food chain bioaccumulation model used in the generation of the AC-BAP map are suited for ionic chemicals, similar ionic perfluorinated alkyl chemicals are known to reach the Arctic and accumulate in the Arctic food chain (e.g. longer chain perfluorinated carboxylic acids).

2.3.4.3 Compare northern and southern exposures to contaminants

Kelly et al. (2007) and Czub et al. (2008) highlighted the high magnitude of bioaccumulation calculated for the Arctic human food chain. Using the ratio between concentrations in humans and in primary producers (e.g. plants and phytoplankton) as a measure, Kelly et al. (2007) predicted chemical amplification up to 4000-fold. Using the environmental bioaccumulation potential that relates the amount of chemical in one human to the size of the human's environment that contains the same amount of chemicals, Czub et al. (2008) noted a bioaccumulation potential for Inuit that exceeded that estimated for a southern Swedish population by two orders of magnitude. According to Czub et al. (2008) this "can, to a large extent, be attributed to the presence of a marine mammal in the food web".

Undeman et al. (2010) expanded on this aspect, by explicitly comparing several hypothetical human populations in terms of their capability to accumulate organic chemicals from the environment in which they live and from which they source their food. These populations, which included an Inuit population, differed both in terms of the living environment and in terms of their dietary habits. By expressing the accumulation potential relative to a southern Swedish reference population eating a mixed diet of beef, dairy, and fish, Undeman et al. (2010) calculated an exposure susceptibility index (ESI). Again, they calculated and plotted this parameter ESI in a two dimensional space defined by the equilibrium partitioning properties between air, water, and octanol (Figure 7).

The analysis suggested that the Inuit have an exposure susceptibility to most persistent organic pollutants that exceeds that of the reference population by a factor of 100 (red area in Figure 7) and for some chemical property combinations (with an octanol-water partitioning coefficient around 10^6 and an octanol-air partitioning coefficient around 10^{11}) even up to a factor 1000. Only for substances with very low volatility (octanol-air partitioning coefficient above 10^{10}) and substances with a high bioaccumulation potential in the agricultural food chain (octanol-water partitioning coefficient around 10^3 and octanol-air partitioning coefficient around 10^4) is the exposure susceptibility of the Inuit population within the same order of magnitude as that of the Swedish reference population. Undeman et al. (2010) concluded that this high susceptibility of the Inuit to persistent organic pollutant exposure could not be explained by the characteristics of the physical environment in which they live, but rather by the presence of a seal in the marine food web. They wrote: "A long lifetime and high body temperature, ingestion rate, and dietary absorption efficiency combined with a slow depuration rate makes the seal a highly potent magnifier of persistent organic contaminants."

Interestingly, the presence of a marine mammal in the human food chain had a markedly different impact on the exposure susceptibility of Inuit to degradable organic chemicals. When assuming that the simulated hypothetical contaminants had a degradation half-life in humans and mammals of 30 days, the strong exposure susceptibility of the Inuit was no longer apparent (Undeman et al., 2010). Instead of biomagnifying the persistent contaminant, the seal acted as filter that removed the degradable contaminant before it could reach the human.

Figure 6 - Placement of chemicals from the third phase of the Chemicals Management Plan within the partitioning space defined by the logarithm of the octanol-air and the air-water equilibrium partitioning coefficients. Also shown is the area of elevated Arctic Contamination and Bioaccumulation Potential (AC-BAP) as derived from model calculations by Czub et al. (2008).

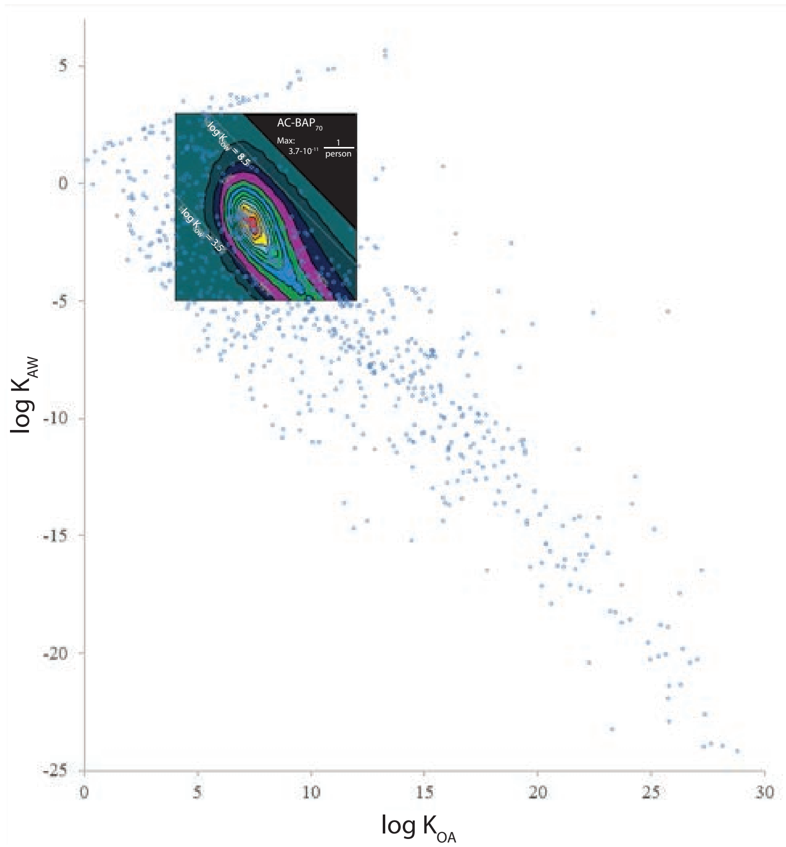


Figure 7 - Exposure susceptibility index (ESI) indicating the relative bioaccumulation capability of an Inuit eating a traditional diet relative to a southern Swede eating a mixed temperate diet, calculated by a combination of an environmental fate and a human food chain bioaccumulation model for hypothetical, persistent chemicals across a range of octanol-water and octanol-air equilibrium partitioning coefficients. Reprinted (adapted) with permission from Undeman et al. (2010). Copyright 2010 American Chemical Society.

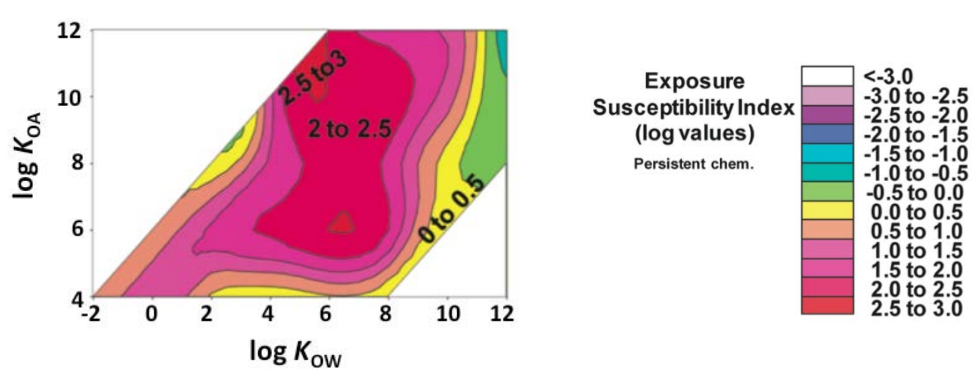


Table 10 Chemicals from the third phase of the Chemicals Management Plan that combine partitioning properties corresponding to a high Arctic Contamination and Bioaccumulation Potential (AC-BAP) with high predicted persistence.

CAS	Name	HL_{human} [a]	$HL_{environment}$ [b]
68957619	1-Hexanesulfonamide, N-[3-(dimethylamino) propyl]-1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-, monohydrochloride	841	months
68555760	1-Heptanesulfonamide, 1,1,2,2,3,3,4,4,5,5,6,6,7,7,7-pentadecafluoro-N-(2-hydroxyethyl)-N-methyl-	1857	months
68555759	1-Hexanesulfonamide, 1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-N-(2-hydroxyethyl)-N-methyl-	496	weeks-months
68957608	1-Pentanesulfonamide, N-[3-(dimethylamino)propyl]-1,1,2,2,3,3,4,4,5,5,5-undecafluoro-, monohydrochloride	225	months
67940027	1-Heptanesulfonamide, N-[3-(dimethylamino) propyl]-1,1,2,2,3,3,4,4,5,5,6,6,7,7,7-pentadecafluoro-, monohydrochloride	3146	recalcitrant
68555737	1-Heptanesulfonamide, N-ethyl-1,1,2,2,3,3,4,4,5, 5,6,6,7,7,7-pentadecafluoro-N-(2-hydroxyethyl)-	2505	months
34455033	1-Hexanesulfonamide, N-ethyl-1,1,2,2,3,3,4,4, 5,5,6,6,6-tridecafluoro-N-(2-hydroxyethyl)-	671	weeks-months
68555726	1-Pentanesulfonamide, N-ethyl-1,1,2,2,3,3,4,4,5,5,5-undecafluoro-N-(2-hydroxyethyl)-	179	weeks-months
6130434	Heptanoic acid, tridecafluoro-, ammonium salt	87	weeks-months
60270555	1-Heptanesulfonic acid, 1,1,2,2,3,3,4,4,5,5,6,6,7,7,7-pentadecafluoro-, potassium salt	1640	months
25567559	Phenol, tetrachloro-, sodium salt	42	weeks
67584627	Glycine, N-ethyl-N-[(pentadecafluoroheptyl)sulfonyl]-, potassium salt	1267	weeks-months
70225160	1-Hexanesulfonic acid, 1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-, compd. with 2,2'-iminobis[ethanol] (1:1)	438	weeks-months
67584536	Glycine, N-ethyl-N-[(tridecafluorohexyl)sulfonyl]-, potassium salt	339	weeks-months

[a] Human biodegradation half-life in days predicted as in Arnot et al. (2014)
[b] Approximate length of time for a chemical to biodegrade into its initial metabolite based on the primary survey model output from Biowin (EPISUITE)

2.3.4.4 Understand reasons why human contaminant levels are declining in the Arctic

One of the key advantages of a human exposure model that includes contaminant transfer through the food chain is the possibility to explore the impact of permanent or temporary dietary shifts on contaminant exposure. As long as the dietary items that are being substituted are part of the model, there is no need to provide empirical data on contamination levels in different foodstuffs. A major dietary shift occurring in Canada's North is the intergenerational transition from a diet dominated by traditional food to one dominated by food imported from the south. Because of differences in the contaminant loads in traditional and imported food, this transition can be expected to influence long-term trends in the exposure of Arctic Indigenous populations. Specifically, because marine mammals have generally higher contamination levels than store bought foods from the South, a dietary transition away from traditional food derived from marine mammals may have contributed to the observed decline in exposure to a number of POPs during the last two decades.

Quinn et al. (2012) demonstrated how a mechanistic modelling approach that includes an estimation of the contamination of both traditional and imported food could be used to quantify the extent to which either the intergenerational dietary transition or the declining environmental contamination levels have contributed to the reduction in Inuit PCB exposure. The calculations for the Arctic marine food chain (based on the Arctic version of the ACC-human model by Czub et al., 2008) and the southern agricultural food chain (based on the original ACC-human model by Czub and McLachlan, 2004) were both driven by concentration data generated by a global fate model, which in turn was fed with global scale, historical PCB emissions. The decline of these emissions over time was predicted to decrease the PCB-153 body burden of 30-year old female Inuit by 6 to 13-fold from 1980 to 2020. How much the dietary transition away from marine mammal food can add to this rate of decline depends on the extent, the timing, and the rate of that transition and also on what foods are being substituted for the marine mammals. Because the parameters describing the transition are not known very well and also differ by region, community, family, or by individuals within the Canadian Arctic, Quinn et al. (2012) performed calculations assuming a number of hypothetical, yet realistic, transition scenarios, which suggested that the dietary transition may be responsible for another 2 to 50-fold decline in the four decades since 1980. Even though the estimations were based on hypothetical scenarios, they clearly indicated that a dietary transition from traditional to market food is bound to have a notable effect on temporal trends in human contaminant exposure in the Arctic.

Binnington et al. (2016a) attempted to take these calculations out of the realm of the hypothetical by adopting the Quinn et al. (2012) approach, but using temporal data on dietary composition and PCB body burden in pregnant women from the Inuvik Region (Northwest Territories) and Baffin Region (Nunavut). Counter to expectations, the data on dietary composition suggested a strong increase in the intake of traditional food derived from marine mammals between 1997 and 2007 in these communities. As a result, the dietary composition data had to be judged as not sufficiently reliable to serve in the quantitative assessment of the impact of the dietary transition on declining PCB levels. While not satisfying, it implies that an analysis based on hypothetical, yet plausible dietary input data (Quinn et al., 2012) is currently preferable to one that is using empirical data judged unreliable (Binnington et al., 2016a).

2.3.4.5 Explore the effect of dietary change on human exposure to contaminants

While Quinn et al. (2012) and Binnington et al. (2016a) explored the effect on PCB exposure of dietary transitions occurring at the population level, Binnington et al. (2016b) used the same models to study the impact of temporary dietary transitions on the exposure of women of childbearing age to PCBs. Specifically, scenarios reflecting the following situations were investigated: 1) reduced intake of traditional food derived from marine mammals with the intention of reducing contaminant exposure, 2) increased intake of traditional food derived from marine mammals with the intention of increasing nutrient intake, and 3) substitution of traditional food derived from caribou with traditional food from marine mammals because of diminishing availability of caribou. The impact of the dietary change on the intake of mercury and nutrients was also taken into account, although only the exposure to PCB was based on mechanistic model calculations.

This study revealed the markedly different effects on PCB body burdens to changes in the amounts of marine mammals consumed. Because of the very long elimination half-life of PCBs from the human body, temporary reductions in the consumption of marine mammal lipids were largely ineffective in lowering concentration levels, confirming earlier results of simulations that explored the effectiveness of fish consumption advisories (Binnington et al., 2014). On the other hand, temporary increases in marine mammal intake can very rapidly result in higher PCB exposure concentrations. However, the study also showed that in those women of childbearing age that had a low baseline consumption of traditional food, the supplementation of the diet with modest amounts of marine mammals can be nutritionally beneficial without necessarily causing undue risk from contaminant exposure.

2.3.4.6 Make sense and use of biomonitoring data

Human exposure models are also increasingly used to understand and explain trends observed in biomonitoring data, e.g. statistical associations between contaminant concentrations in study participants and parameters such as age (Quinn and Wania, 2012), body mass index (Xu et al., 2014), parity, and breastfeeding (Quinn et al., 2011). While statistical associations do not confirm causal relationships, reproducing an observed trend with a mechanistic model can lend support to an explanation. While much of this work has not been done explicitly with Arctic human biomonitoring data, the findings are directly applicable to Indigenous groups from Canada's North.

For example, Quinn and Wania (2012) used the CoZMoMAN model to explain why PCB levels tend to increase with age in cross-sectional human biomonitoring studies. Higher PCB levels in older individuals are due to these individuals having experienced high PCB exposure in the past and having retained much of that body burden over time; in other words, the body has a 'memory' of elevated exposure that occurred in the past. The main determinant of the body burden age relationship is the length of time elapsed since the peak in exposure (Ritter et al., 2011; Quinn and Wania, 2012). Among Arctic populations this age trend is even more pronounced, as older generations have had and tend to have a higher dietary intake of traditional food than younger ones (see Section 2.3.4.4), implying a higher intake of PCBs throughout life (Quinn et al., 2012). During times of increasing exposures, that is, during the 1950s and 1960s for most POPs and the more recent past for other POPs such as PBDEs, one would expect the younger study participants to have higher body burdens (Quinn and Wania, 2012). A key finding in this analysis, which could be compellingly illustrated with the help of models (Ritter et al., 2011; Quinn and Wania, 2012; Nøst et al.

2013), was the realization that body burden–age relationships for population cross sections and individuals over time are not equivalent. Interestingly, the same is true for such relationships observed for long-lived wildlife, including many of the marine mammals that are a part of the traditional diet consumed in parts of the Arctic (Binnington and Wania, 2014).

It is also possible to use human exposure models to derive additional information from human biomonitoring data, specifically to estimate the intake of a contaminant and its elimination half-life from the human body (Ritter et al., 2009, 2011). The model essentially serves in the selection of values for these parameters that best reproduce the observed human concentration trends with age and time. Sometimes such studies confirm the elimination half-lives from earlier studies (Ritter et al., 2009; Bu et al., 2015) while at other times they reveal inconsistencies in the data. Specifically, neither for North America (Wong et al., 2013) nor for Australia (Gyalpo et al., 2015) was it possible to reconcile intake estimates (accounting for dietary and dust intake), measured body burdens, and reported elimination half-lives for PBDEs. In both cases, the intake estimates were judged to be too low, indicative of an unrecognized exposure pathway. Human exposure models have not been applied in this way to biomonitoring data from Arctic Indigenous populations. One reason may be that the intergenerational dietary transition occurring in Arctic communities is profoundly influencing contamination trends with time and age (see Section 2.3.4.4). While accounting for this transition in a model simulation is possible in principle (Quinn et al., 2012), the data required to describe it in the model are currently of insufficient quality (Binnington et al., 2016a).

2.3.4.7 Understand the relationships between childhood exposures and health outcomes

The studies that have used stand-alone human exposure models within the context of Indigenous populations from the Canadian Arctic (Verner et al., 2009, 2010, 2013, 2015) almost exclusively aimed to improve the characterization of exposure for Inuit participating in the Nunavik Child Development Study (Muckle et al., 2001). The models essentially serve in the interpolation or extrapolation of measured concentrations with age, thereby allowing for the estimation of exposure during windows of developmental susceptibility even if no measurements were made during those windows.

Two papers describe the evaluation of the performance of two versions of the model when applied to the Nunavik cohort. In the first of these papers, Verner et al. (2009) took an existing PBPK model, expanded it by inclusion of a nursing infant, and then tested whether the model, when supplied with maternal blood level measured at the time of delivery, can predict the concentrations of various POPs in breast milk, cord blood, and infant blood. Four years later, Verner et al. (2013) presented a simplified version of the model that considered the lipid compartments of mother and child only, added some individual physiologic parameters, breastfeeding duration, and the levels of POPs measured in maternal blood at delivery, cord blood, or breast milk, and then calculated the infants' exposure at 6 months of age. Simulated levels explained three quarters of PCB levels measured in blood at age 6 months when based on maternal or cord blood and somewhat less when based on breast milk concentrations. Haddad et al. (2015) further used the model by Verner et al. (2013) to derive infant-to-mother ratios of external dose and body concentration at different ages and for different POPs. Haddad et al. (2015) also used the data from the Nunavik cohort by Muckle et al. (2001) to evaluate the performance of the model.

These models were then used in epidemiological studies to predict the exposure of the Inuit infants from the Nunavik cohort to PCB-153 during every month of their first year of life and to relate it to the outcome of behavioural tests (attention, activity) performed at age 11 months (Verner et al., 2010) and 5 years (Verner et al. 2015) (see Chapter 3).

2.3.5 Evaluating mechanistic models of contaminant exposure for Arctic Indigenous populations

Many of the studies applying the human food chain models introduced in the previous sections had no intention of predicting the actual concentration levels in Arctic Indigenous populations and individuals, but made use of hypothetical scenarios and hypothetical contaminants (e.g. Kelly et al. 2007; Czub et al., 2008; Undeman et al., 2010) to explore various features of bioaccumulation in the Arctic human food chain (see Section 2.3.4). Nevertheless, Czub et al. (2008) confirmed that their simulations are reasonable by comparing ratios between the body burden in one Inuit and the cumulative global emissions (the fraction of the global emissions that is found in one individual eating Arctic ringed seal): the ratio of 3×10^{-12} person^{-1} derived using the combination of Globo-POP and Arctic ACC-human for entirely persistent contaminants with a log K_{OA} of 9.5 and log K_{AW} of -2 was identical to the ratio obtained by dividing measured body burden of PCB-153 in women of childbearing age from Western Greenland by the total global emissions of this congener (Breivik et al., 2007). While such perfect agreement is almost certainly to some extent fortuitous, it "lends confidence to the model's ability to predict chemical transfer to the Arctic and bioaccumulation in humans" (Czub et al., 2008).

Binnington et al. (2016a) directly predicted the exposure arising from historical, global emissions of PCBs using dietary intake data reported for young mothers in the Inuvik and Baffin regions. The predicted concentrations were either within the same order as the measured concentrations or somewhat higher (Binnington et al., 2016a). The predictions were also very sensitive to the assumed intake of marine mammal lipids. Because this intake was rather uncertain, so was the predicted concentration.

Because of the large number of participants, the average of the dietary data collected as part of the Inuit Health Survey may be more reliable. Laird et al. (2013b) reported geometric mean total PCB concentration of 13.0 µg/L in all IHS participants and 5.34 µg/L in all IHS female participants between 18 and 40 years of age. Binnington et al. (2016b) calculated total PCB concentrations between 21.5 and 41.3 µg/L for women of childbearing age eating the average reported diet of participants in the Inuit Health Survey. For women of childbearing age, the marine mammal intake in their average diet was likely overestimated because it was based upon the higher marine mammal intake in men and older women. If it was more realistically assumed that women of childbearing age eat one third of the traditional food in the average IHS diet, the calculated PCB concentration was between 4.2 and 8.3 µg/L. This level of model-measurement agreement, although again to some extent likely fortuitous, is very encouraging.

Evaluations of the Arctic food chain models for substances other than PCBs are rare, because historical, global scale emissions are not available for many persistent organic chemicals. However, considering the concern that exposure of Indigenous Arctic populations to mercury elicits, it would be desirable to achieve similar capabilities for mechanistically based exposure prediction and characterization to mercury in the future.

References for Chapter 2

Alcock RE, Sweetman AJ, Juan C-, Jones KC. A generic model of human lifetime exposure to persistent organic contaminants: Development and application to PCB-101. Environ Pollut. 2000;110(2):253-65.

AMAP. AMAP Assessment 2009: Human Health in the Arctic. Oslo: Arctic Monitoring and Assessment Programme (AMAP); 2009.

AMAP. AMAP Assessment 2015: Human Health in the Arctic. Oslo: Arctic Monitoring and Assessment Programme (AMAP); 2015.

Arbuckle TE, Fraser WD, Fisher M, Davis K, Liang CL, Lupien N, et al. Cohort profile: The Maternal-Infant Research on Environmental Chemicals research platform. Paediatr Perinat Epidemiol. 2013;27(4):415-25.

Armitage JM, Gobas FAPC. A terrestrial food-chain bioaccumulation model for POPs. Environ Sci Technol. 2007;41(11):4019-25.

Armstrong B, Tofflemire K, Myles E, Receveur O, Chan L. Monitoring temporal trends of human environmental contaminants in the NWT study. Department of Health and Social Services, Government of the Northwest Territories; 2007.

Arnot JA, Gobas FAPC. A food web bioaccumulation model for organic chemicals in aquatic ecosystems. Environ Toxicol Chem. 2004;23(10):2343-55.

Arnot JA, Mackay D, Webster E, Southwood JM. Screening level risk assessment model for chemical fate and effects in the environment. Environ Sci Technol. 2006;40(7):2316-23.

Arnot JA, Brown TN, Wania F. Estimating screening-level organic chemical half-lives in humans. Environ Sci Technol. 2014;48(1):723-30.

Assembly of First Nations. First Nations Biomonitoring Initiative: National Results (2011). Ottawa: Assembly of First Nations; 2013. Available: http://www.afn.ca/uploads/files/afn_fnbi_en_-_2013-06-26.pdf.

Aylward LL, Hays SM, Gagné M, Nong A, Krishnan K. Biomonitoring equivalents for hexachlorobenzene. Regul Toxicol Pharmacol. 2010;58(1):25-32.

Ayotte P, Carrier G, Dewailly É. Health risk assessment for Inuit newborns exposed to dioxin-like compounds through breast feeding. Chemosphere. 1996;32(3):531-42.

Ayotte P. Country foods and cardiovascular health in Nunavik: studying the complex balance between selenium and environmental contaminants (year 2). In: Synopsis of Research Conducted under the 2013-2014 Northern Contaminants Program. Ottawa: Aboriginal Affairs and Northern Development Canada; 2014.

Beaudouin R, Micallef S, Brochot C. A stochastic whole-body physiologically based pharmacokinetic model to assess the impact of inter-individual variability on tissue dosimetry over the human lifespan. Regul Toxicol Pharmacol. 2010;57(1):103-16.

Benedetti JL, Dewailly É, Turcotte F, Lefebvre M. Unusually high blood cadmium associated with cigarette smoking among three subgroups of the general population, Quebec, Canada. Sci Total Environ. 1994;152:161–7.

Berti PR, Receveur O, Chan HM, Kuhnlein HV. Dietary exposure to chemical contaminants from traditional food among adult Dene/Metis in the western Northwest Territories, Canada. Environ Res. 1998;76(2):131-42.

Binnington MJ, Quinn CL, McLachlan MS, Wania F. Evaluating the effectiveness of fish consumption advisories: Modeling prenatal, postnatal, and childhood exposures to persistent organic pollutants. Environ Health Perspect. 2014;122(2):178-86.

Binnington MJ, Curren MS, Quinn CL, Armitage JM, Arnot JA, Chan HM, et al. Mechanistic polychlorinated biphenyl exposure modeling of mothers in the Canadian Arctic: The challenge of reliably establishing dietary composition. Environ Int. 2016a;92-93:256-68.

Binnington MJ, Curren MS, Chan HM, Wania F. Balancing the benefits and costs of marine mammal traditional food substitution by aboriginal Arctic women of childbearing age: Impacts on persistent organic pollutant, mercury, and nutrient intakes. 2016b;94:554-66..

Binnington MJ, Wania F. Clarifying relationships between persistent organic pollutant concentrations and age in wildlife biomonitoring: Individuals, cross-sections, and the roles of lifespan and sex. Environ Toxicol Chem. 2014;33(6):1415-26.

Boischio AAP, Cernichiari E. Longitudinal hair mercury concentration in riverside mothers along the upper Madeira River (Brazil). Environ Res. 1998;77(2):79-83.

Blanchet C, Rochette L. Nunavik Inuit Health Survey 2004. Nunavik Inuit Health Survey 2004. Qanuippitaa? How are we? Nutrition and food consumption among the Inuit of Nunavik. Insititut national de santé publique du Québec (INSPQ) and Nunavik Regional Board of Health and Social Services; 2008.

Borgå K, Di Guardo A. Comparing measured and predicted PCB concentrations in Arctic seawater and marine biota. Sci Total Environ. 2005;342(1-3):281-300.

Borgå K, Saloranta TM, Ruus A. Simulating climate change-induced alterations in bioaccumulation of organic contaminants in an Arctic marine food web. Environ Toxicol Chem. 2010;29(6):1349-57.

Boucher O, Bastien CH, Saint-Amour D, Dewailly É, Ayotte P, Jacobson JL, et al. Prenatal exposure to methylmercury and PCBs affects distinct stages of information processing: An event-related potential study with Inuit children. Neurotoxicology. 2010;31(4):373-84.

Breivik K, Sweetman A, Pacyna JM, Jones KC. Towards a global historical emission inventory for selected PCB congeners - A mass balance approach. 3. An update. Sci Total Environ. 2007;377(2-3):296-307.

Breivik K, Czub G, McLachlan MS, Wania F. Towards an understanding of the link between environmental emissions and human body burdens of PCBs using CoZMoMAN. Environ Int. 2010;36(1):85-91.

Brown TN, Wania F. Screening chemicals for the potential to be persistent organic pollutants: A case study of Arctic contaminants. Environ Sci Technol. 2008;42(14):5202-9.

Bu Q, MacLeod M, Wong F, Toms LML, Mueller JF, Yu G. Historical intake and elimination of polychlorinated biphenyls and organochlorine pesticides by the Australian population reconstructed from biomonitoring data. Environ Int. 2015;74:82-8.

Butler Walker J, Houseman J, Seddon L, McMullen E, Tofflemire K, Mills C, et al. Maternal and umbilical cord blood levels of mercury, lead, cadmium, and essential trace elements in Arctic Canada. Environ Res. 2006;100(3):295-318.

Calatayud M, Devesa V, Virseda JR, Barbera R, Montoro R, Velez D. Mercury and selenium in fish and shellfish: Occurrence, bioaccessibility and uptake by Caco-2 cells. Food Chem Toxicol. 2012;50(8):2696-702.

Campfens J, Mackay D. Fugacity-based model of PCB bioaccumulation in complex aquatic food webs. Environ Sci Technol. 1997;31(2):577-83.

Carrier G, Brunet RC, Brodeur J. Modeling of the toxicokinetics of polychlorinated dibenzo-p-dioxins and dibenzofurans in mammalians, including humans. Toxicol Appl Pharmacol. 1995;131(2):253-66.

Centers for Disease Control and Prevention. Guidelines for the identification and management of lead exposure in pregnant and lactating women. Atlanta: U.S. Department of Health and Human Services; 2010. Available: http://www.cdc.gov/nceh/lead/publications/leadandpregnancy2010.pdf.

Chan HM, Fediuk K, Hamilton S, Rostas L, Caughey A, Kuhnlein H, et al. Food security in Nunavut, Canada: barriers and recommendations. Int J Circumpol Health. 2006;65:416-31.

Chan HM, Receveur O, Sharp D, Schwartz H, Ing A, Tikhonov C. First Nations Food, Nutrition, and Environment Study (FNFNES): Results from British Columbia (2008/2009). Prince George: University of Northern British Columbia, 2011.

Charania NA, Tsuji LJS, Martin ID, Liberda EN, Coté S, Ayotte P, et al. An examination of traditional foods and cigarette smoking as cadmium sources among the nine First Nations of Eeyou Istchee, Northern Quebec, Canada. Environ Sci Process Impacts. 2014;16(6):1422-33.

Clarkson TW, Magos L. The toxicology of mercury and its chemical compounds. Crit Rev Toxicol. 2006;36(8):609-62.

Couture A, Levesque B, Dewailly É, Muckle G, Déry S, Proulx J-. Lead exposure in Nunavik: From research to action. Int J Circumpol Health. 2012;71(1).

Curren MS, Davis K, Liang CL, Adlard B, Foster WG, Donaldson SG, et al. Comparing plasma concentrations of persistent organic pollutants and metals in primiparous women from northern and southern Canada. Sci Total Environ. 2014;479-480(1):306-18.

Curren MS, Liang CL, Davis K, Kandola K, Brewster J, Potyrala M, et al. Assessing determinants of maternal blood concentrations for persistent organic pollutants and metals in the eastern and western Canadian Arctic. Sci Total Environ. 2015;527-528:150-8.

Czub G, McLachlan MS. A food chain model to predict the levels of lipophilic organic contaminants in humans. Environ Toxicol Chem. 2004a;23(10):2356-66.

Czub G, Wania F, Mclachlan MS. Combining long-range transport and bioaccumulation considerations to identify potential Arctic contaminants. Environ Sci Technol. 2008;42(10):3704-9.

Czub G, McLachlan MS. Bioaccumulation potential of persistent organic chemicals in humans. Environ Sci Technol. 2004b;38(8):2406-12.

Czub G, McLachlan MS. Influence of the temperature gradient in blubber on the bioaccumulation of persistent lipophilic organic chemicals in seals. Environ Toxicol Chem. 2007;26(8):1600-5.

Dallaire F, Dewailly É, Muckle G, Ayotte P. Time trends of persistent organic pollutants and heavy metals in umbilical cord blood of Inuit infants born in Nunavik (Québec, Canada) between 1994 and 2001. Environ Health Perspect. 2003;111:1660-4.

Dallaire R, Ayotte P, Pereg D, Déry S, Dumas P, Langlois É, et al. Determinants of plasma concentrations of perfluorooctanesulfonate and brominated organic compounds in Nunavik Inuit adults. Environ Sci Technol. 2009;43(13):5130-36.

De Laender F, Van Oevelen D, Frantzen S, Middelburg JJ, Soetaert K. Seasonal PCB bioaccumulation in an Arctic marine ecosystem: A model analysis incorporating lipid dynamics, food-web productivity and migration. Environ Sci Technol. 2010;44(1):356-61.

Delormier T. Examining benefits and risks of traditional and market food: Hair mercury analysis and communicating research results in the community of Tulita, NWT. 2012. In: Synopsis of Research Conducted under the 2011-2012 Northern Contaminants Program. Ottawa: Aboriginal Affairs and Northern Development Canada; 2012.

Department of Health and Social Services (DHSS). Limit consumption of moose organs from the southern Mackenzie Mountains in the Dehcho, due to high cadmium levels. Yellowknife: Government of the Northwest Territories; 2009. Available: http://www.hss.gov.nt.ca/advisory/limit-consumption-moose-organs-southern-mackenzie-mountains-dehcho-due-high-cadmium-levels.

Department of Health and Social Services (DHSS). Increase in mercury levels in Trout Lake, Cli Lake, Ste. Therese and Kelly Lake. Yellowknife: Government of the Northwest Territories; 2010. Available: http://www.hss.gov.nt.ca/advisory/increase-mercury-levels-trout-lake-cli-lake-ste-therese-and-kelly-lake.

Department of Health and Social Services (DHSS). Mercury levels in fish. Yellowknife: Government of the Northwest Territories; 2012. Available: http://www.hss.gov.nt.ca/health/environment-and-your-health/mercury-levels-fish.

Dhurandhar NV, Schoeller D, Brown AW, Heymsfield SB, Thomas D, Sørensen TIA, et al. Energy balance measurement: when something is not better than nothing. Int J Obes. 2015;39:1109-1113.

Donaldson SG, Van Oostdam J, Tikhonov C, Feeley M, Armstrong B, Ayotte P, et al. Environmental contaminants and human health in the Canadian Arctic. Sci Total Environ. 2010;408(22):5165-234.

Egeland, GM. Inuit Health Survey 2007-2008: Nunavut. Ste-Anne-de-Bellevue: Centre for Indigenous Peoples' Nutrition and Environment; 2010a. Available: http://www.mcgill.ca/cine/files/cine/adult_report_nunavut.pdf.

Egeland, GM. Inuit Health Survey 2007-2008: Nunatsiavut. Ste-Anne-de-Bellevue: Centre for Indigenous Peoples' Nutrition and Environment; 2010b. Available: http://www.mcgill.ca/cine/files/cine/adult_report_-_nunatsiavut.pdf.

Egeland, GM. Inuit Health Survey 2007-2008: Inuvialuit Settlement Region. Ste-Anne-de-Bellevue: Centre for Indigenous Peoples' Nutrition and Environment; 2010c. Available: http://www.mcgill.ca/cine/files/cine/adult_report_-_inuvialuit.pdf.

Egeland GM, Johnson-Down L, Cao ZR, Sheikh N, Weiler H. Food insecurity and nutrition transition combine to affect nutrient intakes in Canadian Arctic communities. J Nutr. 2011;141(9):1746-53.

Environment Canada. Risk management strategy for mercury. Ottawa: Environment Canada; 2010. Available: http://publications.gc.ca/collections/collection_2010/ec/En14-20-2010-eng.pdf.

Fillion M, Blais JM, Yumvihoze E, Nakajima M, Workman P, Osborne G, et al. Identification of environmental sources of lead exposure in Nunavut (Canada) using stable isotope analyses. Environ Int. 2014;71:63-73.

Fontaine J, Dewailly É, Benedetti J-, Pereg D, Ayotte P, Déry S. Re-evaluation of blood mercury, lead and cadmium concentrations in the Inuit population of Nunavik (Québec): A cross-sectional study. Environ Health Global Access Sci Sour. 2008;7.

Fraser AJ, Burkow IC, Wolkers H, Mackay D. Modeling biomagnification and metabolism of contaminants in harp seals of the Barents Sea. Environ Toxicol Chem. 2002;21(1):55-61.

Frederiksen M, Thomsen C, Frøshaug M, Vorkamp K, Thomsen M, Becher G, et al. Polybrominated diphenyl ethers in paired samples of maternal and umbilical cord blood plasma and associations with house dust in a Danish cohort. Int J Hyg Environ Health. 2010;213(4):233-42.

Friendship KA, Furgal CM. The role of Indigenous knowledge in environmental health risk management in Yukon, Canada. Int J Circumpol Health. 2012;71.

Gagné D, Blanchet R, Lauzière J, Vaissière E, Vézina C, Ayotte P, et al. Traditional food consumption is associated with higher nutrient intakes in Inuit children attending childcare centres in Nunavik. Int J Circumpol Health. 2012;71(1).

Gandhi N, Bhavsar SP, Gewurtz SB, Diamond ML, Evenset A, Christensen GN, et al. Development of a multichemical food web model: Application to PBDEs in Lake Ellasjøen, Bear Island, Norway. Environ Sci Technol. 2006;40(15):4714-21.

Gawor A, Wania F. Using quantitative structural property relationships, chemical fate models, and the chemical partitioning space to investigate the potential for long range transport and bioaccumulation of complex halogenated chemical mixtures. Environ Sci Process Impacts. 2013;15(9):1671-84.

Gobas FAPC. A model for predicting the bioaccumulation of hydrophobic organic chemicals in aquatic food-webs: application to Lake Ontario. Ecol Model. 1993;69(1-2):1-17.

Gyalpo T, Toms L-, Mueller JF, Harden FA, Scheringer M, Hungerbühler K. Insights into PBDE uptake, body burden, and elimination gained from Australian age–Concentration trends observed shortly after peak exposure. Environ Health Perspect. 2015;123(10):978-84.

Haddad S, Ayotte P, Verner M-. Derivation of exposure factors for infant lactational exposure to persistent organic pollutants (POPs). Regul Toxicol Pharmacol. 2015;71(2):135-40.

Haines DA, Murray J. Human biomonitoring of environmental chemicals-early results of the 2007-2009 Canadian Health Measures Survey for males and females. Int J Hyg Environ Health. 2012;215(2):133-7.

Hays SM, Becker RA, Leung HW, Aylward LL, Pyatt DW. Biomonitoring equivalents: A screening approach for interpreting biomonitoring results from a public health risk perspective. Regul Toxicol Pharmacol. 2007;47(1):96-109.

Hays SM, Aylward LL, LaKind JS, Bartels MJ, Barton HA, Boogaard PJ, et al. Guidelines for the derivation of Biomonitoring Equivalents: Report from the Biomonitoring Equivalents Expert Workshop. Regul Toxicol Pharmacol. 2008;51(3):S4-S15.

Hays SM, Macey K, Nong A, Alyward LL. Biomonitoring equivalents for selenium. Regul Toxicol Pharmacol. 2014;70(1):333-339.

Health Canada. Update of evidence for low-level effects of lead and blood lead intervention levels and strategies: final report of the working group. Ottawa: Federal-Provincial Committee on Environmental and Occupational Health, Environmental Health Directorate; 1994:42.

Health Canada. Federal Contaminated Site Risk Assessment in Canada. Part I: Guidance on Human Health Preliminary Quantitative Risk Assessment. Ottawa: Health Canada; 2004.

Health Canada. Report on human biomonitoring of environmental chemicals in Canada: Results of the Canadian Health Measures Survey Cycle 1 (2007–2009). Ottawa: Health Canada; 2010a.

Health Canada. Federal Contaminated Site Risk Assessment in Canada, Part I: Guidance on Human Health Preliminary Quantitative Risk Assessment (PQRA), Version 2.0. Ottawa: Health Canada; 2010b.

Health Canada. Federal Contaminated Site Risk Assessment in Canada, Part II: Health Canada Toxicological Reference Values (TRVs) and Chemical-Specific Factors, Version 2.0. Ottawa: Health Canada; 2010c.

Hickie BE, Muir DCG, Addison RF, Hoekstra PF. Development and application of bioaccumulation models to assess persistent organic pollutant temporal trends in Arctic ringed seal (Phoca hispida) populations. Sci Total Environ. 2005;351-352:413-26.

Hislop JS, Collier TR, White GP, Khathing D, French, E. The use of keratinised tissues to monitor the detailed exposure of man to methylmercury from fish. In: Clinical Toxicology and Clinical Chemistry of Metals. New York: Academic Press; 1983.

Hwang HJ, Shim SM. Impact of sodium copper chlorophyllin on mercury absorption using an in vitro digestion with human intestinal cell model. Food Sci Biotechnol. 2008;17(3):564-8.

CIRNAC. Northern Food Basket: Baffin Region, Nunavut. Ottawa: Ministry of Indian and Northern Affairs Canada (CIRNAC); 2006. Available: [http://www.ainc-inac.gc.ca/nth/ fon/fm/pubs/nfbar/nfbar-eng.asp#chp4](http://www.ainc-inac.gc.ca/nth/fon/fm/pubs/nfbar/nfbar-eng.asp#chp4).

Institute of Medicine. Dietary reference intakes for vitamin C, vitamin E, selenium, and carotenoids: a report of the Panel on Dietary Antioxidants and Related Compounds, Subcommittees on Upper Reference Levels of Nutrients and of Interpretation and Use of Dietary Reference Intakes, and the Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, Food and Nutrition Board, Institute of Medicine. Washington (DC): National Academy Press; 2000.

JECFA. Joint FAO/WHO Standards Programme Codex Alimentarius Commission: 33rd Session. Geneva: 2010.

Johnson-Restrepo B, Kannan K. An assessment of sources and pathways of human exposure to polybrominated diphenyl ethers in the United States. Chemosphere. 2009;76(4):542-8.

Jones-Otazo HA, Clarke JP, Diamond ML, Archbold JA, Ferguson G, Harner T, et al. Is house dust the missing exposure pathway for PBDEs? An analysis of the urban fate and human exposure to PBDEs. Environ Sci Technol. 2005;39(14):5121-30.

Kelly BC, Ikonomou MG, Blair JD, Morin AE, Gobas FAPC. Food web-specific biomagnification of persistent organic pollutants. Science. 2007;317(5835):236-9.

Kelly BC, Gobas FAPC. An Arctic terrestrial food-chain bioaccumulation model for persistent organic pollutants. Environ Sci Technol. 2003;37(13):2966-74.

Kirman CR, Aylward LL, Hays SM, Krishnan K, Nong A. Biomonitoring equivalents for DDT/DDE. Regul Toxicol Pharmacol. 2011;60(2):172-80.

Kreuzer PE, Csanády GA, Baur C, Kessler W, Päpke O, Greim H, et al. 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) and congeners in infants. A toxicokinetic model of human lifetime body burden by TCDD with special emphasis on its uptake by nutrition. Arch Toxicol. 1997;71(6):383-400.

Krishnan K, Adamou T, Aylward LL, Hays SM, Kirman CR, Nong A. Biomonitoring equivalents for 2,2’,4,4’,5-pentabromodiphenylether (PBDE-99). Regul Toxicol Pharmacol. 2011;60(2):165-71.

Kuhnlein HV, Receveur O, Chan HM, Loring E. Assessment of dietary benefit/risk in Inuit communities. Montreal: Center for Indigenous Peoples’ Nutrition and Environment (CINE), McGill University; 2000.

Kuhnlein HV, Receveur O, Soueida R, Egeland G. Arctic indigenous peoples experience the nutrition transition with changing dietary patterns and obesity. J Nutr. 2004;134:1447-53.

Kuhnlein HV, Receveur O. Local cultural animal food contributes high levels of nutrients for Arctic Canadian indigenous adults and children. J Nutr. 2007;137(4):1110-4.

Lafontaine C. A Return to Country Food: 3rd Annual Workshop. Jean Marie River: 2014.

Laird BD, Shade CW, Gantner N, Chan HM, Siciliano SD. Bioaccessibility of mercury from traditional northern country foods measured using an in vitro gastrointestinal model is independent of mercury concentration. Sci Tot Environ. 2009;407:6003-8.

Laird BD, Goncharov AB, Egeland GM, Chan HM. Dietary advice on Inuit traditional food use needs to balance benefits and risks of mercury, selenium, and n3 fatty acids. J Nutr. 2013a;143(6):923-30.

Laird BD, Goncharov AB, Chan HM. Body burden of metals and persistent organic pollutants among Inuit in the Canadian Arctic. Environ Int. 2013b;59:33-40.

Laird BD, Chan HM. Bioaccessibility of metals in fish, shellfish, wild game, and seaweed harvested in British Columbia, Canada. Food Chem Toxicol. 2013;58:381-7.

LaKind JS, Aylward LL, Brunk C, Dizio S, Dourson M, Goldstein DA, et al. Guidelines for the communication of Biomonitoring Equivalents: Report from the Biomonitoring Equivalents Expert Workshop. Regul Toxicol Pharmacol. 2008;51(3):S16-S26.

Lan Y. Evaluation of BCF, BAF and LRTP model predictions of heterogeneous pollutants. M. Env. Sci. thesis, University of Toronto, September 2015, 36 pages.

Legrand M, Sousa Passos CJ, Mergler D, Chan HM. Biomonitoring of mercury exposure with single human hair strand. Environ Sci Technol. 2005a;39(12):4594-8.

Legrand M, Arp P, Ritchie C, Chan HM. Mercury exposure in two coastal communities of the Bay of Fundy, Canada. Environ Res. 2005b;98:14-21.

Legrand M, Feeley M, Tikhonov C, Schoen D, Li-Muller A. Methylmercury blood guidance values for Canada. Can J Public Health. 2010;101(1):28-31.

Lemire M, Kwan M, Laouan-Sidi AE, Muckle G, Pirkle C, Ayotte P, et al. Local country food sources of methylmercury, selenium and omega-3 fatty acids in Nunavik, Northern Quebec. Sci Total Environ. 2015;509-510:248-59.

Liang P, Qin YY, Zhang C, Zhang J, Cao YC, Wu SC, et al. Plasma mercury levels in Hong Kong residents: In relation to fish consumption. Sci Tot Environ. 2013;463:1225-9.

Liberda EN, Tsuji LJS, Wainman BC. Is there a need to revise Health Canada's human PCB guidelines? Can J Public Health. 2007;98(5):407-11.

Liberda EN, Tsuji LJS, Martin ID, Ayotte P, Dewailly É, Nieboer E. The complexity of hair/blood mercury concentration ratios and its implications. Environ Res. 2014;134(0):286-94.

Longnecker MP, Klebanoff MA, Gladen BC, Berendes HW. Serial levels of serum organochlorines during pregnancy and postpartum. Arch Environ Health. 1999;54(2):110-4.

Lorber M. A pharmacokinetic model for estimating exposure of Americans to dioxin-like compounds in the past, present, and future. Sci Total Environ. 2002;288(1-2):81-95.

Lorber M. Exposure of Americans to polybrominated diphenyl ethers. J Expo Sci Environ Epidemiol. 2008;18(1):2–19.

Mackay, D. Multimedia Environmental Models: The Fugacity Approach: Lewis Publishers/CRC Press. Boca Raton: 1991.

MacKay D, Fraser A. Bioaccumulation of persistent organic chemicals: Mechanisms and models. Environ Pollut. 2000;110(3):375-91.

Mahaffey KR. Fish and shellfish as dietary sources of methylmercury and the omega-3 fatty acids, eicosahexaenoic acid and docosahexaenoic acid: risks and benefits. Environ Res. 2004;95(3):414-28.

McLachlan MS. Model of the fate of hydrophobic contaminants in cows. Environ Sci Technol. 1994;28(13):2407-14.

Metcalf SW, Orloff KG. Biomarkers of exposure in community settings. J Toxicol Environ Health Part A. 2004;67(8-10):715-26.

Miettinen JK, Rahola T, Hattula T, Rissanen K, Tillander M. Elimination of 203Hg-methylmercury in man. Ann Clin Res. 1971;3(2):116-22.

Moreda-Pineiro J, Moreda-Pineiro A, Romaris-Hortas V, Moscoso-Perez C, Lopez-Mahia P, Muniategui-Lorenzo S, et al. In-vivo and in-vitro testing to assess the bioaccessibility and the bioavailability of arsenic, selenium and mercury species in food samples. Trends Analyt Chem. 2011;30(2):324-45.

Morello-Frosch R, Brody JG, Brown P, Altman RG, Rudel RA, Perez C. Toxic ignorance and right-to-know in biomonitoring results communication: a survey of scientists and study participants. Environ Health. 2009;8.

Moser GA, McLachlan MS. Modeling digestive tract absorption and desorption of lipophilic organic contaminants in humans. Environ Sci Technol. 2002;36(15):3318-25.

Muckle G, Dewailly É, Ayotte P. Prenatal exposure of Canadian children to polychlorinated biphenyls and mercury. Can J Public Health. 1998;89(SUPPL. 1):S20-5.

Muckle G, Ayotte P, Dewailly É, Jacobson SW, Jacobson JL. Prenatal exposure of the Northern Québec Inuit infants to environmental contaminants. Environ Health Perspect. 2001;109(12):1291-9.

National Research Council. Toxicological Effects of Methylmercury. The National Academies Press: Washington; 2000.

Nakano T, Fediuk K, Kassi N, Kuhnlein HV. Food use of Dene/Metis and Yukon children. Int J Circumpol Health. 2005;64(2):137-46.

Neely WB, Branson DR, Blau GE. Partition coefficient to measure bioconcentration potential of organic chemicals in fish. Environ Sci Technol. 1974;8(13):1113-5.

Nichols JW, McKim JM, Andersen ME, Gargas ML, Clewell III HJ, Erickson RJ. A physiologically based toxicokinetic model for the uptake and disposition of waterborne organic chemicals in fish. Toxicol Appl Pharmacol. 1990;106(3):433-47.

Nøst TH, Breivik K, Fuskevåg O-, Nieboer E, Odland JØ, Sandanger TM. Persistent organic pollutants in Norwegian men from 1979 to 2007: Intraindividual changes, age-period-cohort effects, and model predictions. Environ Health Perspect. 2013;121(11-12):1292-8.

Phillips DL, Pirkle JL, Burse VW, Bernert Jr. JT, Henderson LO, Needham LL. Chlorinated hydrocarbon levels in human serum: Effects of fasting and feeding. Arch Environ Contam Toxicol. 1989;18(4):495-500.

Potyrala M, Brewster J, Tofflemire K, Receveur O, Chan HM, Sobol I. The Anaana Project (Inuit prenatal health survey). Department of Health and Social Services, Government of Nunavut; 2008.

Quinn CL, Wania F, Czub G, Breivik K. Investigating intergenerational differences in human PCB exposure due to variable emissions and reproductive behaviors. Environ Health Perspect. 2011;119(5):641-6.

Quinn CL, Armitage JM, Breivik K, Wania F. A methodology for evaluating the influence of diets and intergenerational dietary transitions on historic and future human exposure to persistent organic pollutants in the Arctic. Environ Int. 2012;49:83-91.

Quinn CL, Wania F. Understanding differences in the body burden-age relationships of bioaccumulating contaminants based on population cross sections versus individuals. Environ Health Perspect. 2012;120(4):554-9.

Ritter R, Scheringer M, MacLeod M, Schenker U, Hungerbühler K. A multi-individual pharmacokinetic model framework for interpreting time trends of persistent chemicals in human populations: Application to a postban situation. Environ Health Perspect. 2009;117(8):1280-6.

Ritter R, Scheringer M, MacLeod M, Moeckel C, Jones KC, Hungerbühler K. Intrinsic human elimination half-lives of polychlorinated biphenyls derived from the temporal evolution of cross-sectional biomonitoring data from the United Kingdom. Environ Health Perspect. 2011;119(2):225-31.

Rochette L, Blanchet C. Methodological report. Inuit Health Survey 2004 Quanuippitaa? How are we?. Quebec: Institut national de santé publique du Québec (INSPQ) & Nunavik Regional Board of Health and Social Services (NRBHSS); 2007.

Saudny H, Leggee D, Egeland G. Design and methods of the Adult Inuit Health Survey 2007-2008. Int J Circumpol Health. 2012;71.

Sexton K, Needham LL, Pirkle JL. Human biomonitoring of environmental chemicals. Am Scientist. 2004;92(1):38-45.

Sonne C, Gustavson K, Rigét FF, Dietz R, Krüger T, Bonefeld-Jørgensen EC. Physiologically based pharmacokinetic modeling of POPs in Greenlanders. Environ Int. 2014;64:91-7.

St-Amand A, Werry K, Aylward LL, Hays SM, Nong A. Screening of population level biomonitoring data from the Canadian Health Measures Survey in a risk-based context. Toxicol Lett. 2014;231(2):126-34.

Thomann RV. Bioaccumulation model of organic chemical distribution in aquatic food chains. ESandT Contents. 1989;23(6):699-707.

Thomann RV, Connolly JP, Parkerton TF. An equilibrium model of organic chemical accumulation in aquatic food webs with sediment interaction. Environ Toxicol Chem. 1992;11(5):615-29.

Tomy GT, Pleskach K, Oswald T, Halldorson T, Helm PA, Macinnis G, et al. Enantioselective bioaccumulation of hexabromocyclododecane and congener-specific accumulation of brominated diphenyl ethers in an eastern Canadian Arctic marine food web. Environ Sci Technol. 2008;42(10):3634-9.

Tomy GT, Pleskach K, Ferguson SH, Hare J, Stern G, Macinnis G, et al. Trophodynamics of some PFCs and BFRs in a western Canadian Arctic marine food web. Environ Sci Technol. 2009;43(11):4076-81.

Torres-Escribano S, Ruiz A, Barrios L, Velez D, Montoro R. Influence of mercury bioaccessibility on exposure assessment associated with consumption of cooked predatory fish in Spain. J Sci Food Agric. 2011;91(6):981-6.

Undeman E, Brown TN, Wania F, McLachlan MS. Susceptibility of human populations to environmental exposure to organic contaminants. Environ Sci Technol. 2010;44(16):6249-55.

Van Oostdam J, Donaldson S, Feeley M, Tikhonov C. Canadian Arctic Contaminants and Human Health Assessment Report: Human Health 2009. Ottawa: Department of Indian Affairs and Northern Development; 2009.

Verner M-, Ayotte P, Muckle G, Charbonneau M, Haddad S. A physiologically based pharmacokinetic model for the assessment of infant exposure to persistent organic pollutants in epidemiologic studies. Environ Health Perspect. 2009;117(3):481-7.

Verner M-, Plusquellec P, Muckle G, Ayotte P, Dewailly T, Jacobson SW, et al. Alteration of infant attention and activity by polychlorinated biphenyls: Unravelling critical windows of susceptibility using physiologically based pharmacokinetic modeling. Neurotoxicology. 2010;31(5):424-31.

Verner M-, Sonneborn D, Lancz K, Muckle G, Ayotte P, Dewailly E, et al. Toxicokinetic modeling of persistent organic pollutant levels in blood from birth to 45 months of age in longitudinal birth cohort studies. Environ Health Perspect. 2013;121(1):131-7.

Verner M-, Plusquellec P, Desjardins JL, Cartier C, Haddad S, Ayotte P, et al. Prenatal and early-life polychlorinated biphenyl (PCB) levels and behavior in Inuit preschoolers. Environ Int. 2015;78:90-4.

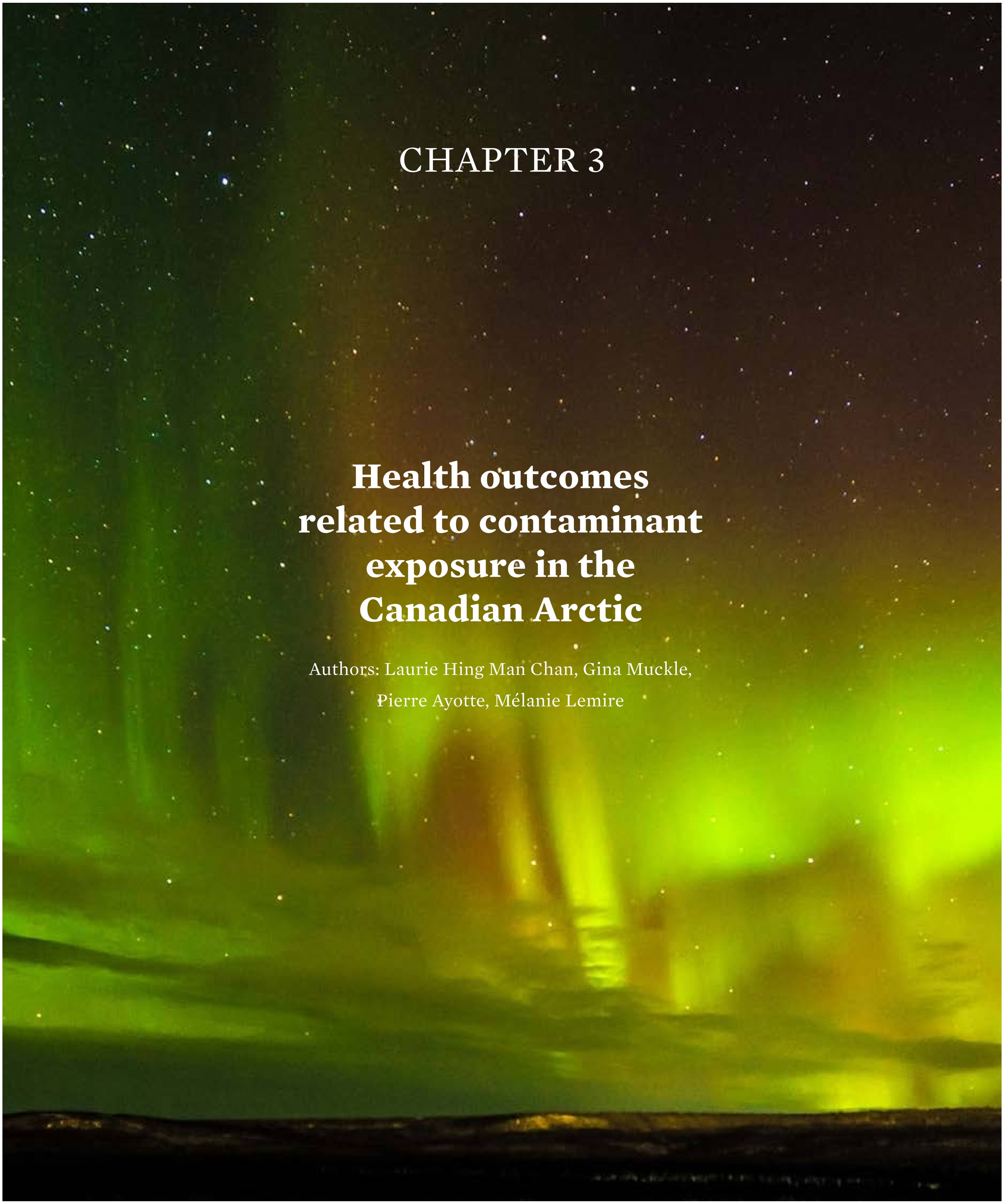
Versantvoort C, van de Kamp E, Rompelberg CJM. Development and applicability of an in vitro digestion model in assessing the bioaccessibility of contaminants from food. Bilthoven: RIVM (320102002); 2004.

Versantvoort CHM, Oomen AG, Van de Kamp E, Rompelberg CJM, Sips A. Applicability of an in vitro digestion model in assessing the bioaccessibility of mycotoxins from food. Food Chem Toxicol. 2005;43(1):31-40.

Wong F, Cousins IT, MacLeod M. Bounding uncertainties in intrinsic human elimination half-lives and intake of polybrominated diphenyl ethers in the North American population. Environ Int. 2013;59:168-74.

Xu F, Armitage JM, Wania F. Unravelling the relationship between body mass index and persistent organic pollutant concentrations in humans. Presentation at the 24th Annual Meeting SETAC Europe Basel, Switzerland, May 11-15, 2014.

Zhang X, Brown TN, Wania F, Heimstad ES, Goss K-. Assessment of chemical screening outcomes based on different partitioning property estimation methods. Environ Int. 2010;36(6):514-20.



CHAPTER 3

Health outcomes related to contaminant exposure in the Canadian Arctic

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3.1 Introduction

The findings of elevated contaminant exposure among northerners during biomonitoring studies in the circumpolar Arctic have raised concern, especially related to the health consequences of the exposures (AMAP, 2015). Since the 1990s, many epidemiological studies have been conducted in Canada to evaluate possible health impacts of contaminant exposure on the health of northern Indigenous people. Previous CACAR reports (Gilman et al., 1997; Van Oostdam et al., 1999, 2003, 2005, 2009; Donaldson et al., 2010) presented early findings from the Nunavik Child Development Study (NCDS), a prospective mother-child cohort study situated in Nunavik (northern Québec), on the long-term effects of PCBs, mercury, and other contaminants on children's growth and development (summarized in Table 1). Results from other cross-sectional studies on the development of biomarkers for immune functions and on the role of contaminant exposure on the emergence of chronic diseases, such as cancer and cardiovascular disease, have also been described in these previous assessment reports.

Table 1 Summary of findings from the Nunavik Child Development Study (NCDS) at the 11-year follow-up.

	Lead	Mercury	PCBs
Prenatal Exposure	▪ Smaller height ▪ Poorer early processing of visual information ▪ Lower estimated IQ ▪ Poorer working memory	▪ Poorer early processing of visual information ▪ Alteration of attentional mechanisms modulating processing of sensory information ▪ Lower estimated IQ ▪ Poorer comprehension and perceptual reasoning ▪ Poorer immediate memory and recollection of information stored into memory ▪ Increased risk of attention problems and ADHD behaviour	▪ Poorer information processing when the information is being consciously evaluated
Childhood Exposure	▪ Increased risk of ADHD behaviour, especially the hyperactive-impulsive type ▪ Deficit in response inhibition	▪ Decreased heart rate variability	▪ Reduced physical growth (height, weight, head circumference, body mass index) ▪ Non-optimal cognitive processes associated with error monitoring, which result in reduced efficiency during cognitive tasks ▪ Poorer immediate memory

Numerous studies have demonstrated the vulnerability of fetal brain development to environmental exposures (World Health Organization, 2006). The U.S. National Academy of Sciences has estimated that as much as 25% of learning disability cases are attributable either to known toxic substances or to interactions of environmental exposure with genetic predispositions (National Academy of Science, 2000). This is of significance considering that, according to the 2003 National Survey of Children's Health conducted in the United States, approximately 6.4% of children have developmental behavioural problems and 10% have a learning disability (Blanchard et al., 2006). As noted by a World Health Organization expert committee (World Health Organization, 2006), addressing gaps in knowledge of the causes of learning and other developmental disabilities requires the design and implementation of prospective longitudinal cohort studies of pregnant women, infants, and children with assessment of their exposure at critical windows of development, along with sensitive health endpoints across the full continuum of development. Several such studies, including some on Arctic populations, have been conducted to date to assess the effects of prenatal exposure to mercury, PCBs, and lead, since these widespread environmental contaminants are known for their adverse effects on neurodevelopment (Grandjean and Landrigan, 2006).

Most of the recent key findings involving effects of prenatal contaminant exposure on child health in Canada come from the NCDS. The NCDS was designed to extend previous findings on the effects of POPs, mercury, and lead on child health and development by following a sample of mother-child dyads.

The NCDS was started by the Nunavik Cord Blood Monitoring Program, through which exposure to environmental contaminants was determined from umbilical cord blood samples obtained from almost all Nunavik infants born between 1994 and 2001 (Muckle et al., 1998; Dallaire et al., 2003). Between 1995 and 2001, pregnant Inuit women identified from their participation in the Nunavik Cord Blood Monitoring program from the three largest communities of the Hudson Bay coast were invited to participate in a first follow-up (Muckle et al., 2001), which allowed testing of 190 infants at 6 and 12 months of age. Between 1999 and 2001, 110 preschool aged children who had not participated in the follow-up during infancy, but from whom cord blood had been collected, underwent neuromotor and neurophysiological testing (Després et al., 2005; Saint-Amour et al., 2006). Between 2005 and 2010, 294 eleven-year-old children were tested for growth, visual, motor, cognitive, and behavioural development, whether or not they had been assessed during the infancy or preschool periods. This chapter focusses on the findings from the 11 year-old child cohort study (2005-2010). Comparisons are made with results from this cohort obtained at a younger age, in addition to results reported from child cohort studies in other circumpolar Arctic countries.

Findings for the effects of contaminants on health outcomes for adults in northern Canada primarily come from the detailed analysis of the results of two cross-sectional health surveys conducted in Nunavik in 1992 and 2004. The Nunavik Health Survey, Qanuippitaa? How are we?, was conducted between August 30 and October 1 of 2004 on the scientific research vessel CCGS Amundsen. The Nunavik research team visited the 14 communities of Nunavik and recruited 917 participants (Rochette and Blanchet, 2007; Ayotte et al., 2011; see also Chapter 2). Biological samples collected from the Nunavik Health Survey participants were analyzed for persistent organic pollutants (POPs) identical to those analyzed during the 1992 Santé Québec Health Survey (Ayotte et al., 1997; Valera et al., 2013a). Concentrations of contaminants such as PBDEs, PFOS, hydroxy-PCBs, methyl-sulfone PCBs, and chlorophenols were also determined for the same participants in blood plasma (Dallaire et al., 2009a, 2009b).

Some preliminary data are also available from another cross-sectional study, the Inuit Health Survey (IHS), conducted in 2007-2008 in the other Inuit regions in Canada (Saudny et al., 2012; see also Chapter 2). The IHS was a comprehensive study that included the measurement of dietary intake of contaminants, contaminant body burden, as well as other determinants of health and their relationship with health outcomes of the participants. It was the first time that such a complete set of data had been collected from Inuit in Nunavut, the Inuvialuit Settlement Region (ISR) of the Northwest Territories, and Nunatsiavut. Of the 2595 individuals who participated in IHS, 2172 provided blood samples for the measurement of contaminants. The body burden of several metals (e.g. cadmium, lead) and POPs (e.g. PCBs, p,p'-DDT and p,p'-DDE, toxaphene, chlordane, PBDEs) were measured for Inuit participants from 36 communities (Laird et al., 2013). Results of the biomonitoring of environmental contaminants are presented in Chapter 2.

3.2 Health outcomes for children

3.2.1 Fetal and childhood growth

Weight, height, and head circumference were measured at birth and during childhood in the NCDS. Statistical analyses were conducted to model the longitudinal relations between exposure variables and growth outcomes in newborns and in children. Detailed results of these analyses are presented in Dallaire et al. (2014). Prenatal exposure to PCB-153 and lead was not associated with fetal growth in the NCDS. Prenatal exposure to lead, but not childhood lead exposure, was related to a shorter height in childhood. Prenatal lead exposure was also reported to be associated with lower weight among female but not male children up to 5 years of age in Mexico City (Afeiche et al., 2011). Plasma PCB levels from eleven year-old children were moderately related to smaller height, weight (controlled for height), head circumference, and body mass index at school-age. While prenatal PCB exposure was reported to be associated with lower body weight among children at 4 years old in Michigan (Jacobson et al., 1990), association between postnatal PCB exposure and growth among children need to be further studied.

In the NCDS sample of children followed up to 11 years of age, *in utero* exposure to PCB-153 was not related to fetal growth, but, in another sample from Nunavik (n=248 pregnant women), cord blood PCB-153, hexachlorobenzene, and mercury concentrations were related to a shorter duration of pregnancy, and their associations with reduced fetal growth were mediated through their relation with a shorter gestation duration (Dallaire et al., 2013). In this study, prenatal total mercury exposure was associated with a reduction of almost 8 days in gestation on average. In contrast, increased docosahexaenoic acid (DHA) intake during pregnancy was found to prolong gestational length, which indirectly had a significant positive effect on birth weight, length, and head circumference. These data suggest that total mercury intake from fish, seafood, and marine mammals can potentially affect fetal growth by reducing pregnancy duration. However, omega-3 fatty acids such as DHA that are also found in fish and marine mammals can attenuate the negative effects on fetal growth by prolonging pregnancy duration. Therefore, the net effects will likely depend on the combined dietary intake of mercury and DHA from specific compositions of a marine diet.

Consistent with results from the NCDS, cord blood lead concentrations were not related to fetal growth in other studies (Greene and Ernhart, 1991; Gonzalez-Cossio et al., 1997; Hernandez-Avila et al., 2002; Gundacker et al., 2010), with one exception in a Swedish population (Osman et al., 2000). The NCDS is the first study providing empirical evidence that prenatal lead exposure is related to poorer growth at school-age since no other studies have documented effects on physical growth after 4 years of age.

In the NCDS, cord blood PCB-153 concentrations were not associated with child growth, but blood PCB-153 concentrations measured in the children at 11 years of age were associated with reduced weight, height, head circumference, and body mass index for children (Dallaire et al., 2014). Similar results of postnatal PCB effects on child growth were reported by a longitudinal study that examined associations between serum dioxins and PCBs and assessed growth measurements among 499 peripubertal Russian boys (aged 8 to 9 years) in Chapaevsk, Russia. The authors reported that exposures to dioxins and PCBs were associated with reduced BMI, height, and height velocity (rate of increase in height) after 3 years of follow-up (Burns et al., 2011). A similar association between PCB exposure and reduced BMI, but not height, was seen in a less exposed population of Flemish adolescents (Dhooge et al., 2010), whereas no PCB-height associations were seen in 8 year-old children in a low-exposure sample from Germany (Karmaus et al., 2002). Thus, the hypothesis that PCB exposure adversely affects skeletal growth and weight during childhood has received some (although inconsistent) empirical support from studies with moderately to highly exposed cohorts.

3.2.2 Vision

Acuity, colour perception, and contrast sensitivity were assessed in the NCDS, and none of the environmental contaminants under study were associated with these clinical assessments (personal communication with Dave Saint-Amour). Visual evoked potentials (VEPs) were measured and no significant association was found with PCB exposure. However, cord blood mercury level was significantly associated with a reduction of the N75 amplitude at the highest contrast level and with a delay of the N75 latency at lower contrast. Prenatal exposure to lead was related to a delay of the N150 latency at most contrast levels (Jacques et al., 2011). Cord blood plasma DHA level was associated with shorter latencies of the N1 and P1 components of the color VEPs, and no effects were found for current omega-3 fatty acid body burden on motion-onset VEPs (Ethier et al., 2012).

The significant association between cord mercury and N75 amplitude at the highest contrast level suggests that this deficit may predominantly involve the parvocellular system, which is specialized in high-contrast vision, visual acuity, and colour vision. In support of this hypothesis, deficits in acuity and colour vision have been reported in association with prenatal mercury exposure in other studies (Cavalleri et al., 1995; Ventura et al., 2004; Fillion et al., 2011). However, in a VEP study involving school-age children from Greenland, no neurotoxic effect was seen on visual processing in relation to prenatal mercury exposure (Weihe et al., 2002). The lack of significant results in Greenlandic children may be due to differences in testing protocols: VEP latency was measured, but not VEP amplitude, and with only one type of high-contrast stimulus (reversal checkerboard). Similarly, VEP alterations were not observed in 7 year-old Faroese children (Grandjean et al., 1997; Murata et al., 1999), but, again, VEPs were elicited using only checkerboard stimuli presented exclusively at high levels of visual contrast. Findings from these two studies strongly influenced the selection of the VEP protocol for the NCDS: it was designed to assess both latency and amplitude at multiple contrast levels to increase the detection sensitivity to subtle effects. By manipulating visual contrast levels, the NCDS protocol was designed to optimally detect subtle effects.

Changes in VEP latency in association with cord mercury concentrations were previously reported in preschoolers from Nunavik (Saint-Amour et al., 2006). NCDS results at age 11 show that this negative effect on latency persists at school age. This is the first prospective longitudinal study linking prenatal lead exposure to a long-term deficit in early visual processing in children. A similar neurotoxic effect of lead was found in cognitive electrophysiological testing of Nunavik children at preschool age (Boucher et al., 2009).

The visual brain effects reported for NCDS participants are subclinical since visual acuity in these children was within the normal range. Nevertheless, this study suggests that heavy metal exposure during the prenatal period can affect the development of visual processing. This study also demonstrates beneficial effects of DHA intake during gestation on visual system function at school age.

3.2.3 Intellectual function and cognitive development

In the NCDS, intellectual function was documented with The Wechsler Intelligence Scales for Children (WISC-IV). It includes 10 subtests that focus on verbal ability, visuo-spatial reasoning, working memory, and information processing speed. Only three verbal subtests include questions about things that may be unfamiliar to Inuit children, and they were substituted by two verbal tests (the Boston Naming Test (BNT) and the Delis-Kaplan Verbal Fluency (V-F) test) that include only items familiar to Inuit. Because the standard verbal subtests were not used, scores obtained were considered as estimates of intellectual quotient (IQ). Two of the exposures - prenatal mercury and prenatal lead - were related to poorer IQ after adjustment for exposures to the other contaminants, DHA, and selenium, in addition to the other potential confounding variables (Jacobson et al., 2015). The mercury effect became stronger when cord blood DHA was entered into the regression model, indicating that the beneficial effect of prenatal DHA tended to obscure the adverse effects of prenatal mercury exposure. Verbal comprehension and perceptual reasoning were the indices most sensitive to prenatal mercury exposure. Similarly, in cohort studies from the Faroe Islands, associations between prenatal exposure to mercury and neurobehavioural deficits at school age were strengthened after fatty acid adjustment (Choi et al., 2014). The NCDS did not demonstrate adverse effects of prenatal PCB exposure on IQ as reported in children from Michigan (Jacobson and Jacobson, 1996) and Oswego (Stewart et al., 2008). These results suggest that the PCB mixture to which NCDS children were exposed in Nunavik could have different neurotoxicity than in the other studies. Further toxicological studies are needed to confirm this.

The classical IQ tests involving neurobehavioural testing were complemented by cognitive electrophysiological assessments using event-related potentials (ERPs) to identify subclinical alterations for NCDS participants (Boucher et al., 2010). ERPs and traditional neurobehavioural assessments were also used to evaluate memory function (Boucher et al., 2011; Boucher et al., 2012a) in this cohort. Results obtained through both neurobehavioural and ERP testing suggest that prenatal mercury exposure is associated with poorer attentional mechanisms, memory performance, and intellectual function, while prenatal exposure to lead was related to poorer intellectual function. As well, current body burden of PCBs was related to poorer cognitive processing of information and memory performance.

The mercury effects seen in the NCDS corroborate those reported in the Faroe Islands (Grandjean et al., 1992). Cohort studies in the Faroe Islands conducted since the 1980s have demonstrated that children exposed to methylmercury *in utero* exhibit decreased motor function, attention span, verbal abilities, memory, and other mental functions (Grandjean et al., 1997). Overall, the Faroese study found that a doubling of the prenatal mercury exposure for a child resulted in a developmental delay of one to two months at the age of seven years, that is, at the age when the child is expected to enter school. This delay corresponds to about 1.5 IQ points (Grandjean and Herz, 2011). No effects were found on school performance at age 16 years, and only small effect on educational achievements was observed at age 22 years (Debes et al., 2013).

Unlike the results of the NCDS, most of the previous studies that have examined long-term effects of prenatal lead exposure have not found effects on IQ (e.g. Dietrich et al., 1987; McMichael et al., 1988; Bellinger et al., 1992). Investigators for the Faroese birth cohort also examined the effect of prenatal lead exposure in the presence of similar molar-level exposure to mercury. Clinical examinations of the children in the cohort were conducted at age 7 and at age 14. Overall, cord blood lead concentration showed no clear pattern of association with cognitive functions (i.e. attention, language, visuospatial reasoning, and memory) in the cohort. However, in subjects with low prenatal mercury exposure (the lowest quartile maternal hair mercury concentration of less than 2.61 µg/g), and after inclusion of statistical interaction terms, lead-associated adverse effects on cognitive functions were observed. The interaction terms between lead and mercury suggested that the combined effect of the exposures was less than additive (Yorifuji et al., 2011). Analysis of NCDS data also showed positive associations between cord blood DHA concentrations and performance on neurobehavioural assessments of memory, which were observed regardless of PCB and mercury exposures (Jacobson et al., 2015). These results suggest that omega-3 fatty acids provide significant benefits to child development and need to be considered in future studies on effects of contaminants on child development.

3.2.4 Child behaviour

Boucher et al. (2012b) reported results for NCDS participants of behavioural assessments based upon two questionnaires completed by each child's classroom teacher. The Teacher Report Form from the Child Behavior Checklist (Achenbach and Rescorla, 2001) provided scores for attention and internalizing and externalizing problems. The Disruptive Behavior Disorders Rating Scale (Pelham et al., 1992) provided four clinical diagnoses: attention deficit hyperactivity disorder (ADHD) – inattentive type, ADHD – hyperactive-impulsive type, oppositional defiant disorder, and conduct disorder. From the Teacher Report Form results, cord blood mercury concentrations were significantly related to attention problems, and child blood lead concentrations were associated with externalizing problems. Consistent results were obtained with the Disruptive Behavior

Disorder Rating Scale: compared with children in the lowest tertile of cord blood mercury concentrations, children in the second and third tertiles were at greater risk for ADHD – inattentive type, and those in the third tertile were also at greater risk for ADHD – hyperactive-impulsive type. For current blood lead concentrations, children in both the second and third tertiles were at greater risk for ADHD – hyperactive-impulsive type than those in the first tertile.

The NCDS was the first study to demonstrate that prenatal mercury exposure constitutes a risk factor for ADHD symptomatology at school age. The increased risk of attention deficit reported is consistent with findings from a neuropsychological assessment in the Faroe Islands cohort and findings from an ERP assessment conducted on a sub-sample of the NCDS cohort. In the Faroese, where the mean cord blood mercury concentration was similar to that found in the NCDS study, prenatal mercury exposure was associated with impaired performance in attention tasks at 7 and 14 years of age (Grandjean et al., 1997; Debes et al., 2006). A re-analysis of these data showed a specific effect on sustained attention (Julvez et al., 2010), a neuropsychological domain particularly affected in ADHD – inattentive type (Egeland and Kovalik-Gran, 2010). In the NCDS, prenatal mercury exposure was found to alter primary attentional mechanisms modulating early processing of sensory information (Boucher et al., 2010). The increased incidence of teacher-reported ADHD symptoms in the NCDS indicates that the adverse effects on attention previously linked to prenatal mercury exposure in neuropsychological assessments are clinically significant and likely to interfere with learning and performance in the classroom.

In 110 Nunavik children assessed at 5 years of age, child blood lead concentrations were also associated with higher levels of impulsivity, irritability, and inattention (Plusquellec et al., 2010) and with multiple aspects of neuromotor function (Després et al., 2005; Fraser et al., 2006). These results relating to postnatal lead exposure replicate those of several previous studies where childhood lead exposure was associated with ADHD (reviewed in Eubig et al., 2010). Although the main source of lead exposure in Nunavik (via lead shot) is unique in the lead exposure literature, the NCDS study results replicate findings from many previous lead studies linking low-level childhood lead exposure to ADHD.

The NCDS investigators evaluated the association between prenatal and postnatal PCB-153 levels and inattention (n=97) and activity (n=98) for children at 5 years of age (Verner et al., 2015). Cord plasma PCB-153 concentrations were not found to be associated with inattention and activity, and estimated infant PCB-153 levels at 2 months was associated with greater duration of inattention (Verner et al., 2015). These results suggest that there are postnatal windows of development during which children are more susceptible to neurotoxicants such as PCBs.

In addition to contaminant exposure, Desrosiers et al. (2013) showed that prenatal cigarette smoke exposure for NCDS children was associated with increased externalizing behaviours and attention problems on the Teacher Report Form and higher prevalence of ADHD assessed on the Disruptive Behavior Disorders Rating Scale. Co-exposure to lead and mercury did not appear to exacerbate tobacco effects, suggesting that these substances act independently.

3.2.5 Heart function and blood pressure

Modified heart rate variability (HRV) is a common measure of risk factors for a number of diseases, including myocardial infarction, congestive heart failure, diabetic neuropathy, depression, and post-cardiac transplant. After controlling for confounders including child's age, sex, birth weight, BMI, height, and maternal smoking during pregnancy, cord blood mercury concentrations were found to not be related to heart rate variability (HRV) parameters at 11 years of age (Valera et al., 2012) for NCDS participants. However, child blood mercury concentrations were associated with decreased overall HRV. These associations remained significant after adjusting for concentrations of cord blood mercury, omega-3 fatty acids, and selenium.

In contrast, prenatal and childhood exposures to mercury were not related to blood pressure (BP) at 11 years of age. The negative findings with regard to mercury and BP from the NCDS are divergent with earlier studies that reported a positive association between prenatal methylmercury exposure and BP (both diastolic and systolic) in 7 year-old Faroese children (Sorensen et al., 1999) and between prenatal methylmercury exposure and diastolic BP in 15-year old boys in the Seychelles (Thurston et al., 2007). However, the average cord blood mercury concentration was about 1.5-fold higher among Faroese children (Grandjean et al., 1992) than in the NCDS, and hair mercury at age 7 was 3 times higher than found in the NCDS. Prenatal mercury exposure was also higher in the Seychelles study than in the NCDS (Thurston et al., 2007). The predictive value of effects of mercury on HRV parameters observed in the NCDS in healthy children and risk to chronic cardiomatabolic diseases is unknown. Nevertheless, results from the NCDS and the Faroese cohorts (Sorensen et al. 1999; Grandjean et al., 2004) provide evidence that mercury exposure during childhood is related to cardiac autonomic activity at school age.

3.2.6 Immune function

Dewailly (2000) provided some preliminary evidence that the risk of otitis media increased with prenatal exposure to p,p'-DDE, hexachlorobenzene, and dieldrin among children in Nunavik. The NCDS has not investigated the effects of contaminant exposure on the immune functions of children. The Faroese cohort studies showed that elevated exposures to PCBs and perfluorinated compounds in Faroese children were associated with reduced humoral immune response to routine childhood immunizations (Heilmann et al., 2006; Heilmann et al., 2010; Grandjean et al., 2012a). These findings suggest a decreased effect of childhood vaccines and may reflect a more general immune system deficit. The clinical implications of insufficient antibody production emphasize the need for prevention of exposures to immunotoxic substances and for assessment of risk related to exposure to these contaminants.

3.3 Health outcomes for adults

3.3.1 Cardiovascular Effects

There is increasing evidence that methylmercury exposure may increase the risk of cardiovascular diseases in adults, but the findings are still inconclusive. Valera et al. (2013b) evaluated the results obtained from the Santé Québec health survey conducted in 1992 in Nunavik that included 313 Inuit adults. The results indicated that the resting heart rate (HR) increased with blood methylmercury concentrations after adjusting for confounders including age, sex, fasting glucose, low-density-lipoprotein (LDL)-cholesterol, high-density-lipoprotein (HDL)-cholesterol, triacylglycerol, alcohol consumption, smoking, physical activity, the anti-hypertensive treatment, as well as some contaminants (lead and total PCBs) and fish nutrients (omega-3 fatty acids). An increase of 6.9 beats per minute between individuals in the fourth (28.4-112.0

ug/L) and first (0.8-8.8 ug/L) quartile of blood methylmercury concentrations was observed. However, no significant associations were observed between blood methylmercury and systolic BP, diastolic BP, or pulse pressure. In contrast, results from the Nunavik Health Survey in 2004, Qanuippitaa? that included 732 Inuit adults showed that blood total mercury concentrations were associated with higher BP and pulse pressure. In multivariate analyses, mercury was associated with increasing systolic BP (beta=2.14; P=0.0004), whereas the association with diastolic BP was near the significance level (beta=0.96; P=0.069) after adjusting for the effect of fish-derived nutrients (omega-3 fatty acids and selenium) and other confounders such as age, sex, HDL-cholesterol, LDL-cholesterol, triglycerides, insulin sensitivity, physical activity, socioeconomic status, smoking, and alcohol consumption (Valera et al., 2009).

Ayotte et al. (2011) studied the relationship between blood total mercury concentrations and paraoxonase 1 (PON1) activity in 896 adult participants in Qanuippitaa? in 2004 in Nunavik. PON1, an enzyme located in the HDL fraction of blood lipids, may protect against coronary heart disease by metabolizing toxic oxidized lipids associated with LDL and HDL. In this study, blood mercury concentrations were inversely associated with PON1 activity, whereas blood selenium concentrations were positively associated with PON1 activity. These results suggest that mercury exposure exerts an inhibitory effect on PON1 activity, which seems to be offset by selenium intake. Laird et al. (2015) measured PON1 activity and metal concentrations in blood collected from 2172 adult participants of the Inuit Health Survey in 2007-2008. Sociodemographic, anthropometric, and lifestyle variables were also assessed and controlled as covariates. PON1 activity was positively associated with selenium blood concentrations, but was negatively associated with cadmium blood concentrations. No association was observed between PON1 activity and mercury or lead concentrations in blood. Both of these studies showed the positive effects of selenium on increasing PON1 activity, but the effects of mercury were inconsistent.

Selenium and health in the Arctic

Selenium is an essential element found in high concentrations in local marine foods consumed by Inuit. Across the Arctic, Inuit have the highest average, but also the most variable, blood levels of selenium (Hansen et al, 2004; Laird et al., 2013; Lemire et al., 2015; see Chapter 2) reported to date. As outlined in Chapter 2, beluga and narwhal mattaaq, Inuit delicacies highly appreciated in different regions of the Arctic, are exceptionally high dietary sources for selenium (Wagemann et al., 1996; Laird et al., 2013; Lemire et al., 2015). Several other local foods such as marine mammal organs, walrus meat, eggs from several fish species, and caribou organs are also very high in selenium (Ayotte et al., 2014; Lemire et al., 2015). Selenium bioacessibility and bioavailability in these foods is generally high (60%) and is less variable than for mercury (Ayotte et al., 2014).

For fish and marine mammal eating populations, there is increasing evidence suggesting that high dietary selenium intake may play a role in offsetting some deleterious effects of methylmercury exposure among adults, including negative outcomes on motor and visual functions, prevalence of age-related cataracts, and cardiometabolic risk factors such as increased blood pressure, inhibition of PON1 activity, and an increase in oxidative stress biomarkers (Valera et al, 2009; Lemire et al., 2010, 2011; Ayotte et al., 2011; Alkazemi et al., 2013; Fillion et al., 2013).

In this context, high selenium may exert beneficial effects on the same health outcomes affected by methylmercury. Selenium may partially mitigate deleterious pro-oxidant effects of methylmercury (Sakamoto et al., 2013) and may directly bind to methylmercury or to inorganic mercury following in situ demethylation, thereby reducing its availability for target proteins and organs (Khan and Wang, 2009).

Conversely, in other regions of the world, high selenium intake has been associated with adverse health outcomes. Sensory and motor symptoms have been reported among patients with very high dietary selenium intake in China where mineral coal rich in selenium was used to fertilise local crops and for indoor cooking purposes (Yang et al., 1983; Liu et al., 2007). However, a later study that examined the same population reported that the adverse effects may have been caused by co-exposure to other contaminants found in the coal in China (Liu et al., 2007). Increased risk of amyotrophic lateral sclerosis was reported among individuals with high selenium intake in Italy (Vinceti et al., 2014). However, these adverse effects were caused by exposure to high levels of inorganic selenium in water (Vinceti et al., 2014). Similar high blood selenium levels were reported in Inuit in Greenland (Hansen et al., 2004) and in residents of the whale consuming communities in Japan (Nakamura et al., 2014). There were no recorded clinical symptoms in Greenland, and no observable adverse effects were reported in Japan. However, neither of these studies specifically investigated for selenium-related effects.

Supra-nutritional intake of selenium, usually in the form of organic selenium produced from enriched yeast, has been associated with the occurrence of Type 2 diabetes, hypercholesterolemia, and hypertension (Rayman and Stranges, 2013). These cardiometabolic perturbations were reported at much lower intake than among Inuit populations. In these countries, the use of selenium-enriched foods and selenium supplements and fertilizers has increased markedly in recent years (Rayman and Stranges, 2013). Results from human studies are still inconsistent, and it is not clear whether an increase in circulating selenium is the cause or the consequence of dysregulated pathways in carbohydrate or lipid metabolism (Stranges et al, 2010; Steinbreinner et al., 2011; Rayman and Stranges, 2013).

While blood selenium is the selenium biomarker used in the Arctic studies, plasma selenium is the biomarker most often used in other epidemiological studies (Rayman, 2012). In addition to these two biomarkers, several other biomarkers (e.g. selenium-containing enzymes such as selenoproteins and small selenium compounds) have been identified (Xia et al., 2010), and these may help to better characterize selenium status in Inuit. Recently, a novel seleno-containing organic compound, selenoneine, has been shown as the major form of selenium in Bluefin tuna and other marine organisms (Yamashita et al., 2010). This selenium-analog to ergothioneine, a powerful antioxidant, could contribute to the scavenging of reactive oxygen species that are involved in the etiology of chronic diseases or methylmercury toxicity. Different "methylated/non-methylated" ratios of selenoneine have been observed in human blood and urine, indicating their active metabolism and suggesting a promising metabolic role of these redox metabolites in humans (Klein et al., 2011). A recent study that examined a Japanese fish-eating population showed that selenoneine is primarily found in the cellular fraction of the blood compartment. Both selenoneine and methylmercury concentrations in the cellular fraction significantly increased together with marine fish consumption, while serum selenium and serum mercury remained low despite increasing fish intake (Yamashita et al., 2013).

Recently, preliminary findings from a study in the Canadian Arctic have revealed exceptionally high selenoneine concentrations in Inuit blood and beluga mattaaq (Ayotte et al., 2015). Other selenoneine dietary sources and selenoneine synthesis pathways in marine Arctic ecosystems remain to be identified. Molecular physiologic and toxicologic mechanisms for selenoneine in humans and marine animals are still unclear. In vitro studies are required, especially in erythrocytes, to understand the underlying molecular mechanisms of potential selenoneine and methylmercury interactions. In addition, further studies are needed to examine associations between high selenium and selenoneine intake from marine foods, new biomarkers for selenium status, and potential health impacts including neurologic and cardiometabolic functions. Similarly, more studies are needed in order to better elucidate whether high selenium intake from a marine diet will assist in mitigating the adverse effects of methylmercury exposure at different life stages in northern communities.

Alkazemi et al. (2013) measured blood mercury and selenium and plasma levels of F2-isoprostanes (F2-IsoPs) and F2-isofurans (F2-IsoFs) in 233 Inuit adult participants of the Inuit Health Survey. F2-IsoPs and F2-IsoFs are two whole-body oxidative stress biomarkers. They found that F2-IsoPs were inversely correlated with blood selenium, but were not correlated with blood mercury. IsoFs were inversely correlated with blood selenium and were positively correlated with both mercury and the mercury-to-selenium ratio. These results suggest that selenium and mercury status and their interactions are possible factors modulating F2-IsoP and F2-IsoF levels, such that the Inuit may be protected from mercury-induced oxidative stress because of their high selenium status, lowering their risk of cardiovascular diseases.

Similar inconsistent mercury results have been reported from research conducted in the circumpolar Arctic. In Faroe Island participants, high blood pressure was found to be associated with mercury exposure as measured by total mercury concentrations in toenail, hair, and whole blood samples among male whale hunters (Choi et al., 2009). However, in Greenland, no association was found between mercury exposure (measured as total mercury concentrations in whole blood) and high blood pressure (Nielsen et al., 2012).

Valera et al. (2013a) analyzed the data collected from 315 Inuit adults who participated in the Santé Québec health survey conducted in the 14 villages of Nunavik in 1992 and found that total PCBs as well as the sum of non-dioxin-like PCBs were associated with higher risk of hypertension. Furthermore, the risk of hypertension increased in association with higher plasma concentrations of PCB congeners 101, 105, 138, and 187. The associations were only significant after adjusting for PUFA concentrations in blood as confounders. When organochlorine contaminants were considered, p,p’-DDE was associated with increased risk of hypertension, while inverse associations were observed with p,p’-DDT, β-HCH, and oxychlordane (Valera et al., 2013a).

In contrast, a study in Greenland involving 1614 Inuit adults found no association between blood pressure and POPs exposure (Valera et al., 2013c). Only when the analyses were stratified by age category (18-39 and ≥ 40 years) was an association observed between increased risk of hypertension and total dioxin-like PCBs among the youngest participants, while a borderline protective effect was observed for total non-dioxin-like PCBs among the oldest participants. Higher risk of hypertension was also associated with increasing p,p'-DDT concentrations among the youngest participants.

Overall, there is an inconsistency in results obtained from different studies in both the Canadian and circumpolar Arctic of the effects of exposure to Arctic contaminants on cardiovascular disease. Additional research is needed to elucidate the impact of mercury and POPs on blood pressure and other risk factors for cardiovascular disease, while also taking into consideration the co-exposure of confounders such as PUFAs and selenium.

3.3.2 Endocrine effects

3.3.2.1 Thyroid

Dallaire et al. (2009a) measured four thyroid parameters (i.e. thyroid-stimulating-hormone (TSH), free thyroxine (fT4), total triiodothyronine (tT3), and thyroxine-binding globulin (TBG)) and concentrations of 41 contaminants, including PCBs and their metabolites, organochlorine contaminants, PBDEs, PFOS, and a measure of dioxin-like compounds in plasma samples from 623 Inuit adults who participated in the Nunavik Health Survey, Qanuippitaa?, in 2004. A significant reduction of tT3 concentrations was found to be associated with levels of 14 PCB congeners, 7 hydroxylated PCBs, all methylsulfonyl metabolites of PCBs, 2 organochlorine contaminants, and PFOS. Circulating TBG concentrations, the predominant thyroid hormone carrier protein in humans, were inversely related to 8 PCBs, 5 hydroxylated PCBs, 3 organochlorine contaminants, and PFOS. These results show that exposure to several POPs was associated with modifications of the thyroid parameters in adult Inuit, mainly by reducing tT(3) and TBG circulating concentrations. In contrast, blood PBDE-47 concentration was positively related to tT(3).

While results of this study provide a wealth of information on the relationship between blood POP concentrations and thyroid parameters, it has a key limitation in that effects of individual POPs on thyroid hormone status was not evaluated by controlling for other POPs because of high intercorrelations between these compounds. Some POPs, including hydroxylated metabolites of PCBs, PCP, and PFOS, compete with thyroxin (T4) for binding sites on transthyretin (TTR), a T4 transport protein found in plasma and cerebrospinal fluid (Gutleb et al., 2010). Audet-Delage et al. (2013) tested this hypothesis and studied the relationship between blood concentrations of these POPs and the concentration of circulating T4 bound to transthyretin (T4-TTR) in 120 Inuit women (18-39 years old) who participated in the Nunavik Health Survey, Qanuippitaa?, in 2004. They found no relationship between the POPs and T4-TTR concentrations and concluded that plasma levels of these TTR-binding compounds in Inuit women of childbearing age are not high enough to affect TTR-mediated thyroid hormone transport.

Similar observations of an association between exposure to POPs and an impact on thyroid function and hormone levels are reported in research conducted in southern Canada. A study conducted with 115 young adults of the Akwesasne Mohawk Nation examined the relationship between exposure to POPs and anti-thyroid peroxidase antibody (TPOAb) as a tool in the evaluation of thyroid dysfunction (Schell et al., 2009). Overall, 18 participants (15.4%) had TPOAb levels above the normal laboratory reference range (23% of females, 9% of males). Also, after stratifying by breastfeeding status, participants who were breastfed showed positive relationships between TPOAb levels and all PCB groupings (except groups comprised of non-persistent PCBs) and with p,p'-DDE, HCB, and mirex. No effects were evident among non-breastfed young adults.

These studies show associations between body burden of POPs and thyroid parameters. The overall clinical implications require elucidation. The potential effects of emerging POPs such as PFOS and PBDE-47 on thyroid homeostasis also require further investigation because concentrations of these contaminants found in Inuit from Nunavik are generally lower or similar to levels found the adult population in southern Canada (AMAP, 2015).

3.3.2.2 Aryl hydrocarbon receptor

The aryl hydrocarbon receptor (AhR) is involved in the regulation of biological responses to planar aromatic hydrocarbon contaminants such as dioxin and co-planar PCBs. This receptor has been shown to regulate xenobiotic-metabolizing enzymes such as cytochrome P450 and mediates the toxicity of these compounds. Medehouenou et al. (2010) studied the relationship of POPs in plasma with AhR mediated transcriptional activity from 874 Inuit adults who participated in the Qanuippitaa? study in Nunavik in 2004. Several sociodemographic, anthropometric, dietary, and lifestyle variables were accounted for as possible modulating factors of the AhR mediated activity in multivariate statistical analyses. PCB-153 concentrations in plasma were found to be moderately correlated to AhR-mediated activity. The authors suggest that AhR-mediated transcriptional activity of plasma extracts from Inuit participants is linked to their organochlorine contaminant body burdens, most likely those including dioxin-like PCBs, polychlorinated dibenzo-p-dioxins, and polychlorodibenzofurans. Participant's age and omega-3 fatty acid concentrations in erythrocyte membranes (an index of marine food consumption) were also positively associated with plasma AhR mediated activity, whereas a negative association was noted with body fat mass. While AhR mediated transcriptional activity measures may prove useful in investigating possible associations between exposure to AhR agonists and adverse health outcomes, the authors note significant differences in methodologies between laboratories undertaking research in this area and urge caution when comparing results directly.

Research conducted in the circumpolar Arctic has further analyzed the possible correlation between POP levels and AhR-mediated transcriptional activity. Some studies have further examined estrogen (ER) and androgen (AR) mediated activity.

In a comparison between 70 Inuit women from Greenland (median age 35) and 22 Danish women (median age 24), POP concentrations in plasma sampled from Inuit were more than ten times higher than the POP levels found in Danish women. AhR levels were also higher in Inuit than Danish women and were positively associated with POP levels. No correlations between AhR mediated transcriptional activity and plasma POPs were found for the Danish samples (Bonefeld-Jorgensen and Long, 2010; Long and Bonefeld-Jorgensen, 2012). In contrast, male serum POP concentrations among Greenlanders were significantly higher, AhR and ER mediated activity were lower, and there was a tendency towards higher AR activity compared to similar data collected for male Europeans (Bonefeld-Jorgensen and Long, 2010). In another study conducted with Greenland Inuit, a general inverse relationship was found for higher serum POP concentrations and ER, AR, and AhR mediated activity. The authors concluded that the inverse relationship between the dioxin-like induced AhR activity and ER activity supports findings that dioxins may exert an anti-estrogenic effect and that serum POP levels in Greenlandic Inuit may have hormone disrupting potential (Bonefeld-Jorgensen and Long, 2010; Kruger et al., 2012).

The relationship between serum levels of POPs, perfluorinated compounds (PFCs), some metals, and the total concentration of serum POPs with ER, AR and AhR mediated activity was further studied in a case-control study including samples from 31 breast cancer patients and 115 controls collected from Greenland 2000-2003 (Bonefeld-Jorgensen et al., 2011). A positive association between serum POP levels and the risk of breast cancer was found, although the incidence of breast cancer among the Greenland Inuit is generally lower than for western populations. The POP related serum agonistic AhR-mediated activity was associated with the risk of breast cancer, that is, it was lower in breast cancer cases compared to controls, although the significance of this result disappeared upon adjustment for the corresponding confounders (i.e. age, BMI, pregnancy, breastfeeding history, and cotinine). Further investigations are needed to verify these conclusions from the Greenland study.

Additional research on reproductive hormones has also been conducted in the circumpolar Arctic. A study in men from Greenland and three European cohorts (Swedish fishermen and fishermen's wives, Warsaw Poland, and Kharkiv Ukraine) reported a positive association between PCB-153 exposure and luteinizing hormone (LH) for Greenlandic Inuit men (Bonde et al., 2008). Analysis of a pooled dataset for samples from the four centres showed a positive association between p,p'-DDE concentrations and follicle-stimulating hormone (FSH) levels. In contrast, Grandjean et al. (2012b) reported that sex hormone binding globulin (SHBG) levels increased with higher PCB exposures, both prenatally and currently. It was speculated that PCB-induced hepatic SHBG synthesis could play a possible role in the observed SHBG increase associated with PCB exposure, although this possibility remains to be substantiated (Grandjean et al., 2012b). Haugen et al. (2011) studied differences between POP exposures for men sampled in southern and northern Norway (above the Arctic Circle). No geographical differences in levels of PCB-153 or sperm parameters were observed. However, the levels of p,p'-DDE were higher in the South than in the North, as were the levels of total and free testosterone. FSH levels were lower in the South. The regional differences observed for levels of p,p'-DDE, testosterone, and FSH were not reflected in the semen quality (Haugen et al., 2011).

Another study on testicular function was conducted in the Faroe Islands where there is known high exposure to PCBs in males in comparison to exposures to PCBs in Danish men. Sperm concentrations for the Faroese men were lower than for the Danish men. However, semen volume was higher, thus the total sperm counts did not differ. Similarly, overall motility and morphology did not differ between the Faroese and Danish males (Halling et al., 2013). Also in the Faroe Islands, 438 adolescent boys at age 14 participated in a study that examined the relationship between POPs exposure and possible endocrine disruption (Grandjean et al., 2012b). Higher prenatal PCB exposure was associated with lower serum concentrations of both LH and testosterone. In addition, SHBG was positively associated with both prenatal and current PCB exposures. p,p'-DDE concentrations were highly correlated with PCB concentrations and showed slightly weaker associations with the hormone profile. These findings suggest that delayed puberty with low serum LH concentrations associated with developmental exposure to non-dioxin-like PCBs may be due to a central hypothalamo-pituitary mechanism.

3.3.2.3 Bone effects

A total of 194 Inuit women aged 35-72 who participated in Nunavik Health Survey, Qanuippitaa?, in 2004 were assessed for a relationship between bone strength and body burden of dioxin-like compounds using the AhR mediated transcriptional activity as a measure for dioxin-like compounds and specific dioxin-like PCBs in plasma (Paunescu et al., 2013a). Neither total plasma dioxin-like compounds nor specific dioxin-like PCBs were associated with the bone stiffness index after adjustment for several confounders and covariates. These study results do not support an association between exposure to dioxin-like compounds and bone strength as measured with the stiffness index by ultrasonography in Inuit women of Nunavik. However, a descriptive cross-sectional study conducted with Cree women of Eastern James Bay (Canada) investigated the relationship between plasma concentrations of dioxin-like compounds and bone quality parameters. PCB-105 and PCB-118 concentrations, but not the total dioxin-like compound concentration, were inversely associated with the stiffness index (Paunescu et al., 2013b).

3.3.2.4 Carcinogenic effects

Ravoori et al. (2008) studied the DNA-damaging potential of PCBs by measuring blood PCB and a wide array of DNA adducts collected from 103 Inuit (70 women and 33 men) in Salluit, Nunavik. The study results showed that the known oxidative lesion, 8-oxodG, was predominant, accounting for 51%, 54%, and 57% of the total DNA adduct burden in the low, medium, and high PCB exposure groups, respectively. While some individual adducts appear to accumulate with increasing PCB levels, a definitive association between PCBs and other newly detected DNA adducts could not be made. Further investigation of 83 Inuit in the same region (56 women and 27 men) showed that the DNA adduct levels were inversely associated with PCB and selenium levels. In the high selenium/PCB ratio group, selenium had significantly negative effects on 8-oxodG and total adducts, while there was no correlation within the low selenium/PCB ratio group. These results suggest that selenium has a mitigating effect in reducing DNA adducts, and that there may be a protective effect of selenium on the potentially damaging effect of PCBs on DNA (Ravoori et al., 2010).

Overall, there were no overt clinical outcomes associated with contaminant exposure among the residents in the Canadian Arctic. However, elevated exposures to lead, PCBs, and mercury during pregnancy were associated with adverse neuro-developmental effects among children. Among adults, elevated exposure to mercury was found to be associated with risk factors for cardiovascular effects in Nunavik, and elevated exposure to POPs were associated with risk factors for hormonal and metabolic disorders. On the other hand, nutrients found in the same food source, such as selenium and omega-3 fatty acids, showed protective effects.

References for Chapter 3

Achenbach TM, Rescorla L. Child Behavior Checklist for Ages 6-18. Burlington: ASEBA; 2001. Available: http://www.aseba.org/forms/schoolagecbcl.pdf.

Afeiche M, Peterson KE, Sánchez BN, Cantonwine D, Lamadrid-Figueroa H, Schnaas L, et al.. Prenatal lead exposure and weight of 0- to 5-year-old children in Mexico City. Environ Health Perspect. 2011;119(10):1436-41.

Alkazemi D, Egeland GM, Roberts II LJ, Chan HM, Kubow, S. New insights regarding tissue Se and Hg interactions on oxidative stress from plasma IsoP and IsoF measures in the Canadian Inuit population. J Lipid Res. 2013;54(7):1972-79.

AMAP. AMAP Assessment 2015: Human Health in the Arctic. Oslo: Arctic Monitoring and Assessment Programme (AMAP); 2015.

Audet-Delage Y, Ouellet N, Dallaire R, Dewailly É, Ayotte P. Persistent organic pollutants and transthyretin-bound thyroxin in plasma of Inuit women of childbearing age. Environ Sci Technol. 2013;47(22):13086-92.

Ayotte P. Country foods and cardiovascular health in Nunavik: studying the complex balance between selenium and environmental contaminants (year 2). In: Synopsis of Research Conducted under the 2013-2014 Northern Contaminants Program. Ottawa: Aboriginal Affairs and Northern Development Canada; 2014.

Ayotte P. Do country food nutrients protect against mercury toxicity and cardiometabolic diseases? Integrating data from cutting-edge science and mobilizing knowledge towards Nunavimmiut health. In: Synopsis of Research Conducted under the 2014-2015 Northern Contaminants Program. Ottawa: Aboriginal Affairs and Northern Development Canada; 2015.

Ayotte P, Dewailly É, Ryan JJ, Bruneau S, Lebel G. PCBs and dioxin-like compounds in plasma of adult Inuit living in Nunavik (Arctic Quebec). Chemosphere. 1997;34(5-7):1459-68.

Ayotte P, Carrier A, Ouellet N, Boiteau V, Abdous B, Sidi EA, et al. Relation between methylmercury exposure and plasma paraoxonase activity in Inuit adults from Nunavik. Environ Health Perspect. 2011;119(8):1077-83.

Bellinger DC, Stiles KM, Needleman HL. Low-level lead exposure, intelligence and academic achievement: a long-term follow-up study. Pediatr. 1992;90(6):855-61.

Blanchard LT, Gurka MJ, Blackman JA. Emotional, developmental, and behavioral health of American children and their families: a report from the 2003 National Survey of Children's Health. Pediatr. 2006;117(6):e1202-12.

Bonde JP, Toft G, Rylander L, Rignell-Hydbom A, Giwercman A, Spano M, et al. Fertility and markers of male reproductive function in Inuit and European populations spanning large contrasts in blood levels of persistent organochlorines. Environ Health Perspect. 2008;116(3):269-77.

Bonefeld-Jorgensen EC, Long, M. Dioxin-like activity in the blood of Greenlandic Inuit and Danish women: a pilot study. Int J Circumpol Health. 2010;69(2):181-94.

Bonefeld-Jorgensen E C, Long M, Bossi R, Ayotte P, Asmund G, Kruger T, et al. Perfluorinated compounds are related to breast cancer risk in Greenlandic Inuit: a case control study. Environ Health. 2011;10:88.

Boucher O, Muckle G, Saint-Amour D, Dewailly É, Ayotte P, Jacobson SW, et al. The relation of lead neurotoxicity to the event-related potential P3b component in Inuit children from Arctic Québec. Neurotoxicology. 2009;30(6):1070-77.

Boucher O, Bastien CH, Saint-Amour D, Dewailly É, Ayotte P, Jacobson JL, et al. Prenatal exposure to methylmercury and PCBs affects distinct stages of information processing: an event-related potential study with Inuit children. Neurotoxicology. 2010;31(4):373-84.

Boucher O, Burden MJ, Muckle G, Saint-Amour D, Ayotte P, Dewailly É, et al. Neurophysiologic and neurobehavioral evidence of beneficial effects of prenatal omega-3 fatty acid intake on memory function at school age. Am J Clin Nutr. 2011;93(5):1025-37.

Boucher O, Burden MJ, Muckle G, Saint-Amour D, Ayotte P, Dewailly É, et al. Response inhibition and error monitoring during a visual go/no-go task in Inuit children exposed to lead, polychlorinated biphenyls, and methylmercury. Environ Health Perspect. 2012a;120:608-15.

Boucher O, Jacobson SW, Plusquellec P, Dewailly É, Ayotte P, Forget-Dubois N, et al. Prenatal methylmercury and postnatal lead exposure: Risk factors for attention deficit hyperactivity disorder among Inuit children in Arctic Québec. Environ Health Perspect. 2012b;120(10):1456-61.

Burns JS, Williams PL, Sergeyev O, Korrick S, Lee MM, Revich B, et al. Serum dioxins and polychlorinated biphenyls are associated with growth among Russian boys. Pediatr. 2011;127(1):e59-68.

Cavalleri A, Belotti L, Gobba F, Luzzana G, Rosa P, Seghizzi P. Colour vision loss in workers exposed to elemental mercury vapour. Toxicol Lett. 1995;77:351-356.

Choi AL, Weihe P, Budtz-Jorgensen E, Jorgensen PJ, Salonen JT, Tuomainen TP, et al. Methylmercury exposure and adverse cardiovascular effects in Faroese whaling men. Environ Health Perspect. 2009;117(3):367-72.

Choi AL, Mogensen UB, Bjerve KS, Debes F, Weihe P, Grandjean P et al. Negative confounding by essential fatty acids in methylmercury neurotoxicity associations. Neurotoxicol Teratol. 2014;42:85-92.

Dallaire F, Dewailly É, Muckle G, Ayotte P. Time trends of persistent organic pollutants and heavy metals in umbilical cord blood of Inuit infants born in Nunavik (Québec, Canada) between 1994 and 2001. Environ Health Perspect. 2003;111(13):1660-64.

Dallaire R, Dewailly É, Pereg D, Dery S, Ayotte P. Thyroid function and plasma concentrations of polyhalogenated compounds in Inuit adults. Environ Health Perspect. 2009a;117(9):1380-86.

Dallaire R, Ayotte P, Pereg D, Déry S, Dumas P, Langlois E, et al.. Determinants of plasma concentrations of perfluorooctanesulfonate and brominated organic compounds in Nunavik Inuit adults (Canada). Environ Sci Technol. 2009b;43(13):5130-6.

Dallaire R, Dewailly É, Ayotte P, Forget-Dubois N, Jacobson SW, Jacobson JL, et al. Exposure to organochlorines and mercury through fish and marine mammal consumption: associations with growth and duration of gestation among Inuit newborns. Environ Int 2013;54:85-91.

Dallaire R, Dewailly É, Ayotte P, Forget-Dubois N, Jacobson SW, Jacobson JL, et al. Growth in Inuit children exposed to polychlorinated biphenyls and lead during fetal development and childhood. Environ Res. 2014;134:17-23.

Debes F, Budtz-Jorgensen E, Weihe P, White RF, Grandjean P. Impact of prenatal methylmercury exposure on neurobehavioral function at age 14 years. Neurotoxicol Teratol. 2006;28(5):536-47.

Debes F, Grandjean P, Ludvig A, Budtz-Jørgensen E. Educational outcomes in relation to methylmercury exposure and cognitive test performance. Edinburgh: ICMGP - International Conference on Mercury as a Global Pollutant; 2013.

Després C, Beuter A, Richer F, Poitras K, Veilleux A, Ayotte P, et al. Neuromotor functions in Inuit preschool children exposed to Pb, PCBs, and Hg. Neurotoxicol Teratol. 2005;27(2):245-57.

Desrosiers C, Boucher O, Forget-Dubois N, Dewailly É, Ayotte P, Jacobson SW et al. Associations between prenatal cigarette smoke exposure and externalized behaviors at school age among Inuit children exposed to environmental contaminants. Neurotoxicol Teratol, 2013;39:84-90.

Dewailly É, Ayotte P, Bruneau S, Gingras S, Belles-Isles M, Roy R, et al. Susceptibility to infections and immune status in Inuit infants exposed to organochlorines. Environ Health Perspect. 2000;108(3):205-11.

Dhooge W, Den Hond E, Koppen G, Bruckers L, Nelen V, Van De Mieroop E, et al. Internal exposure to pollutants and body size in Flemish adolescents and adults: Associations and dose-response relationships. Environ Int. 2010;36(4):330-7.

Dietrich KN, Krafft KM, Bornschein RL, Hammond PB, Berger O, Succop PA, et al. Low-level fetal lead exposure effect on neurobehavioral development in early infancy. Pediatrics. 1987;80(5):721-30.

Donaldson SG, Van Oostdam J, Tikhonov C, Feeley M, Armstrong B, Ayotte P, et al. Environmental contaminants and human health in the Canadian Arctic. Sci Total Environ. 2010;408(22):5165-234.

Egeland J, Kovalik-Gran I. Validity of the factor structure of Conners' CPT. J Atten Disord. 2010;13(4):347-57.

Ethier AA, Muckle G, Bastien C, Dewailly É, Ayotte P, Arfken C, et al. Effects of environmental contaminant exposure on visual brain development: A prospective electrophysiological study in school-aged children. Neurotoxicology. 2012;33:1075-85.

Eubig PA, Aguiar A, Schantz SL. Lead and PCBs as risk factors for attention deficit/hyperactivity disorder. Environ Health Perspect. 2010;118(12):1654-67.

Fillion M, Philibert A, Mertens F, Lemire M, Passos CJ, Frenette B, et al. Neurotoxic sequelae of mercury exposure: An intervention and follow-up study in the Brazilian Amazon. EcoHealth. 2011;8:210-222.

Fillion M, Lemire M, Philibert A, Frenette B, Weiler HA, Deguire JR, et al. Toxic risks and nutritional benefits of traditional diet on near visual contrast sensitivity and color vision in the Brazilian Amazon. Neurotoxicology. 2013;37:173-81.

Fraser S, Muckle G, Despres C. The relationship between lead exposure, motor function and behaviour in Inuit preschool children. Neurotoxicol Teratol. 2006;28(1):18-27.

Gilman A, Dewailly É, Feeley M, Jerome V, Kuhnlein H, Kwavnick B, et al. Chapter 4: Human Health. In: Jensen J, Adare K, Shearer R (Eds.) Canadian Arctic Contaminants Assessment Report. Ottawa: Indian and Northern Affairs Canada; 1997.

Gonzalez-Cossio T, Peterson KE, Sanin LH, Fishbein E, Palazuelos E, Aro A, et al. Decrease in birth weight in relation to maternal bone-lead burden. Pediatrics. 1997;100:856-862.

Grandjean P, Weihe P, Jorgensen PJ, Clarkson T, Cernichiari E, Videro T. Impact of maternal seafood diet on fetal exposure to mercury, selenium, and lead. Arch Environ Health. 1992;47(3):185-95.

Grandjean P, Weihe P, White RF, Debes F, Araki S, Yokoyama K, et al. Cognitive deficit in 7-year-old children with prenatal exposure to methylmercury. Neurotoxicol Teratol. 1997;19(6):417-28.

Grandjean P, Murata K, Budtz-Jorgensen E, Weihe P. Cardiac autonomic activity in methylmercury neurotoxicity: 14-year follow-up of a Faroese birth cohort. J Pediatr. 2004;144(2):169-76.

Grandjean P, Andersen EW, Budtz-Jorgensen E, Nielsen F, Molbak K, Weihe P. Serum vaccine antibody concentrations in children exposed to perfluorinated compounds. Jama. 2012a;307(4):391-97.

Grandjean P, Gronlund C, Kjaer IM, Jensen TK, Sorensen N, Andersson AM, et al. Reproductive hormone profile and pubertal development in 14-year-old boys prenatally exposed to polychlorinated biphenyls. Reprod Toxicol. 2012b;34(4):498-503.

Grandjean P, Herz KT. Methylmercury and brain development: imprecision and underestimation of developmental neurotoxicity in humans. Mt Sinai J Med. 2011;78(1):107-18.

Grandjean P, Landrigan PJ. Developmental neurotoxicity of industrial chemicals. Lancet. 2006;368:2167–78.

Greene T, Ernhart CB. Prenatal and preschool age lead exposure: Relationship with size. Neurotoxicol Teratol. 1991;13:417-427.

Gundacker C, Frohlich S, Graf-Rohrmeister K, Eibenberger B, Jessenig V, Gicic D, et al. Perinatal lead and mercury exposure in Austria. Sci Total Environ. 2010;408:5744-49.

Gutleb AC, Cenijn P, Velzen M, Lie E, Ropstad E, Skaare JU, et al. In vitro assay shows that PCB metabolites completely saturate thyroid hormone transport capacity in blood of wild polar bears (Ursus maritimus) Environ Sci Technol. 2010;44(8)3149-54.

Halling J, Petersen MS, Jorgensen N, Jensen TK, Grandjean P, Weihe P. Semen quality and reproductive hormones in Faroese men: a cross-sectional population-based study of 481 men. BMJ Open. 2013;3(3).

Hansen JC, Deutch B, Pedersen HS. Selenium status in Greenland Inuit. Sci Total Environ. 2004;331(1-3):207-14.

Haugen TB, Tefre T, Malm G, Jonsson BA, Rylander L, Hagmar L, et al. Differences in serum levels of CB-153 and p,p’-DDE, and reproductive parameters between men living south and north in Norway. Reprod Toxicol. 2011;32(3):261-67.

Heilmann C, Grandjean P, Weihe P, Nielsen F, Budtz-Jorgensen E. Reduced antibody responses to vaccinations in children exposed to polychlorinated biphenyls. PLoS Med. 2006;3(8):e311.

Heilmann C, Budtz-Jorgensen E, Nielsen F, Heinzow B, Weihe P, Grandjean P. Serum concentrations of antibodies against vaccine toxoids in children exposed perinatally to immunotoxicants. Environ Health Perspect. 2010;118(10):1434-38.

Hernandez-Avila M, Peterson KE, Gonzalez-Cossio T, Sanin LH, Aro A, Schnaas L, et al. Effect of maternal bone lead on length and head circumference of newborns and 1-month-old infants. Arch Environ Health. 2002;57:482-488.

Jacobson JL, Jacobson, SW, Humphrey, HE. Effects of exposure to PCBs and related compounds on growth and activity in children. Neurotoxicol Teratol, 1990;12(4):319-26.

Jacobson JL, Muckle G, Ayotte P, Dewailly É, Jacobson SW. Relation of prenatal methylmercury exposure from environmental sources to childhood IQ. Environ Health Perspect. 2015;123(8):827-33.

Jacobson JL, Jacobson SW. Intellectual impairment in children exposed to polychlorinated biphenyls in utero. New Engl J Med. 1996;335(11):783-89.

Jacques C, Levy E, Muckle G, Jacobson SW, Bastien C, Dewailly É, et al. Long-term effects of prenatal omega-3 fatty acid intake on visual function in school-age children. J Pediatr. 2011;158(1):83-90.

Julvez J, Debes F, Weihe P, Choi A, Grandjean P. Sensitivity of continuous performance test (CPT) at age 14 years to developmental methylmercury exposure. Neurotoxicol Teratol. 2010;32:627-32.

Karmaus W, Asakevich S, Indurkhya A, Witten J, Kruse H. Childhood growth and exposure to dichlorodiphenyl dichloroethene and polychlorinated biphenyls. J Pediatr. 2002;140:33-39.

Khan MA, Wang F. Mercury-selenium compounds and their toxicological significance: towards a molecular understanding of mercury-selenium antagonism. Environ Toxicol Chem. 2009;28(8):1567-77.

Klein M, Ouerdane L, Bueno M, Pannier F. Identification in human urine and blood of a novel selenium metabolite, Se-methylselenoneine, a potential biomarker of metabolization in mammals of the naturally occurring selenoneine, by HPLC coupled to electrospray hybrid linear ion trap-orbital ion trap MS. Metallomics. 2011;3(5):513-20.

Kruger T, Long M, Ghisari M, Bonefeld-Jorgensen EC. The combined effect of persistent organic pollutants in the serum POP mixture in Greenlandic Inuit: xenoestrogenic, xenoandrogenic and dioxin-like transactivities. Biomarkers. 2012;17(8):692-705.

Laird BD, Goncharov AB, Chan HM. Body burden of metals and persistent organic pollutants among Inuit in the Canadian Arctic. Environ Int. 2013;59:33-40.

Laird BD, Goncharov AB, Ayotte P, Chan HM. Relationship between the esterase paraoxonase-1 (PON1) and metal concentrations in the whole blood of Inuit in Canada. Chemosphere. 2015;120:479-85.

Lemire M, Fillion M, Frenette B, Mayer A, Philibert A, Passos CJS, et al. Selenium and mercury in the Brazilian Amazon: Opposing influences on age-related cataracts. Environ Health Perspect. 2010;118(11):1584-9.

Lemire M, Fillion M, Frenette B, Passos CJS, Guimarães JRD, Barbosa F, et al. Selenium from dietary sources and motor functions in the Brazilian Amazon. Neurotoxicology. 2011;32(6):944-53.

Lemire M, Kwan M, Laouan-Sidi AE, Muckle G, Pirkle C, Ayotte P, et al. Local country food sources of methylmercury, selenium and omega-3 fatty acids in Nunavik, Northern Quebec. Sci Total Environ. 2015;509-510:248-59.

Liu GJ, Zheng LG, Duzgoren-Aydin NS, Gao LF, Liu JH, Peng ZC. Health effects of arsenic, fluorine, and selenium from indoor burning of Chinese coal. In: Reviews of Environmental Contamination and Toxicology. 2007;189:89-106.

Long M, Bonefeld-Jørgensen EC. Dioxin-like activity in environmental and human samples from Greenland and Denmark. Chemosphere. 2012;89(8):919-28.

Medehouenou TC, Larochelle C, Dumas P, Dewailly É, Ayotte P. Determinants of AhR-mediated transcriptional activity induced by plasma extracts from Nunavik Inuit adults. Chemosphere. 2010;80(2): 75-82.

McMichael AJ, Baghurst PA, Wigg NR, Vimpani GV, Robertson EF, Roberts RJ. Port Pirie Cohort Study: environmental exposure to lead and children's abilities at the age of four years. New Engl J Med. 1988;319(8):468-75.

Muckle G, Dewailly É, Ayotte P. Prenatal exposure of Canadian children to polychlorinated biphenyls and mercury. Can J Public Health. 1998;89(SUPPL.1):S20-5.

Muckle G, Ayotte P, Dewailly É, Jacobson SW, Jacobson JL. Prenatal exposure of the northern Québec Inuit infants to environmental contaminants. Environ Health Perspect. 2001;109:1291-99.

Murata K, Weihe P, Araki S, Budtz-Jorgensen E, Grandjean P. Evoked potentials in Faroese children prenatally exposed to methylmercury. Neurotoxicol Teratol. 1999;21:471-472.

Nakamura, M, Hachiya N, Murata K-, Nakanishi I, Kondo T, Yasutake A, et al. Methylmercury exposure and neurological outcomes in Taiji residents accustomed to consuming whale meat. Environ Int. 2014;68:25-32.

National Academy of Science. Scientific Frontiers in Developmental Toxicology and Risk Assessment. Washington, DC: National Academy of Sciences Committee on Developmental Toxicology; 2000. Available: http://www.nap.edu/openbook.php?record_id=9871&page=R1.

Nielsen AB, Davidsen M, Bjerregaard P. The association between blood pressure and whole blood methylmercury in a cross-sectional study among Inuit in Greenland. Environ Health. 2012;11:44.

Osman K, Akesson A, Berglund M, Bremme K, Schutz A, Ask K, et al. Toxic and essential elements in placentas of Swedish women. Clin Biochem. 2000;33:131-138.

Paunescu AC, Ayotte P, Dewailly É, Dodin S. Dioxin-like compounds are not associated with bone strength measured by ultrasonography in Inuit women from Nunavik (Canada): results of a cross-sectional study. Int J Circumpol Health. 2013a;72.

Paunescu AC, Dewailly É, Dodin S, Nieboer E, Ayotte P. Dioxin-like compounds and bone quality in Cree women of Eastern James Bay (Canada): a cross-sectional study. Environ Health. 2013b;12(1):54.

Pelham WE, Gnagy E, Greenslade KE, Milich R. Teacher ratings of DSM-III-R symptoms for the disruptive behavior disorders. J Am Acad Child Adolesc Psychiatry. 1992;31:210-28.

Plusquellec P, Dewailly É, Muckle G, Ayotte P, Bégin G, Desrosiers C, et al. The relation of environmental contaminants exposure to behavioral indicators in Inuit preschoolers in Arctic Quebec. Neurotoxicol. 2010;31(1):17-25.

Ravoori S, Ayotte P, Srinivasan C, Pereg D, Robertson LW, Russell GK, et al. DNA damage associated with PCBs in the whole blood cells of Inuit. Environ Toxicol Pharmacol. 2008;25(2):273-76.

Ravoori S, Srinivasan C, Pereg D, Robertson LW, Ayotte P, Gupta RC. Protective effects of selenium against DNA adduct formation in Inuit environmentally exposed to PCBs. Environ Int. 2010;36(8):980-86.

Rayman MP. Selenium and human health. Lancet. 2012;379(9822):1256-68.

Rayman MP, Stranges S. Epidemiology of selenium and type 2 diabetes: can we make sense of it? Free Radic Biol Med. 2013;65:1557-64.

Rochette L, Blanchet C. Methodological report. Inuit Health Survey 2004 Quanuippitaa? How are we?. Quebec: Institut national de santé publique du Québec (INSPQ) & Nunavik Regional Board of Health and Social Services (NRBHSS); 2007.

Saint-Amour D, Roy MS, Bastien C, Ayotte P, Dewailly É, Despres C, et al. Alterations of visual evoked potentials in preschool Inuit children exposed to methylmercury and polychlorinated biphenyls from a marine diet. Neurotoxicology. 2006;27(4):567-78.

Sakamoto M, Yasutake A, Kakita A, Ryufuku M, Chan HM, Yamamoto M, et al. Selenomethionine protects against neuronal degeneration by methylmercury in the developing rat cerebrum. Environ Sci Technol. 2013;47(6):2862-8.

Saudny H, Leggee D, Egeland G. Design and methods of the Adult Inuit Health Survey 2007-2008. Int J Circumpol Health. 2012;71.

Schell LM, Gallo MV, Ravenscroft J, DeCaprio AP. Persistent organic pollutants and anti-thyroid peroxidase levels in Akwesasne Mohawk young adults. Environ Res. 2009;109(1):86-92.

Sorensen N, Murata K, Budtz-Jorgensen E, Weihe P, Grandjean P. Prenatal methylmercury exposure as a cardiovascular risk factor at seven years of age. Epidemiology. 1999;10:370-75.

Steinbrenner H, Speckmann B, Pinto A, Sies H. High selenium intake and increased diabetes risk: Experimental evidence for interplay between selenium and carbohydrate metabolism. J Clin Biochem Nutr. 2011;48(1):40-5.

Stewart PW, Lonky E, Reihman J, Pagano J, Gump BB, Darvill T. The relationship between prenatal PCB exposure and intelligence (IQ) in 9-year-old children. Environ Health Perspect. 2008;116(10):1416-22.

Stranges S, Navas-Acien A, Rayman MP, Guallar E. Selenium status and cardiometabolic health: State of the evidence. Nutr Metab Cardiovasc Dis. 2010;20(10):754-60.

Thurston SW, Bovet P, Myers G, Davidson PW, Georger LA, Shamlaye C, et al. Does prenatal methylmercury exposure from fish consumption affect blood pressure in childhood? Neurotoxicology. 2007;28:924-30.

Valera B, Dewailly É, Poirier P. Environmental mercury exposure and blood pressure among Nunavik Inuit adults. Hypertension. 2009;54(5):981-86.

Valera B, Muckle G, Poirier P, Jacobson SW, Jacobson JL, Dewailly É. Cardiac autonomic activity and blood pressure among Inuit children exposed to mercury. Neurotoxicology. 2012;33(5):1067-74.

Valera B, Jørgensen ME, Jeppesen C, Bjerregaard P. Exposure to persistent organic pollutants and risk of hypertension among Inuit from Greenland. Environ Res. 2013a;122:65-73.

Valera B, Dewailly É, Poirier P. Association between methylmercury and cardiovascular risk factors in a native population of Québec (Canada): a retrospective evaluation. Environ Res. 2013b;120:102-8.

Valera B, Ayotte P, Poirier P, Dewailly É. Associations between plasma persistent organic pollutant levels and blood pressure in Inuit adults from Nunavik. Environ Int. 2013c;59:282-9.

Van Oostdam J, Gilman A, Dewailly É, Usher P, Wheatley B, Kuhnlein H, et al. Human health implications of environmental contaminants in Arctic Canada: a review. Sci Total Environ. 1999;230:1-82.

Van Oostdam J, Donaldson S, Feeley M, Tremblay N. Canadian Arctic Contaminants Assessment Report II: Human Health. Ottawa: Department of Indian Affairs and Northern Development; 2003.

Van Oostdam J, Donaldson SG, Feeley M, Arnold D, Ayotte P, Bondy G, et al. Human health implications of environmental contaminants in Arctic Canada: a review. Sci Total Environ. 2005;351-352:165-246.

Van Oostdam J, Donaldson S, Feeley M, Tikhonov C. Canadian Arctic Contaminants and Human Health Assessment Report: Human Health 2009. Ottawa: Department of Indian Affairs and Northern Development; 2009.

Ventura DF, Costa MT, Costa MF, Berezovsky A, Salomao SR, Simoes AL, et al. Multifocal and full-field electroretinogram changes associated with color-vision loss in mercury vapor exposure. Vis Neurosci. 2004;21:421-29.

Verner MA, Plusquellec P, Desjardins JL, Cartier C, Haddad S, Ayotte P, et al. Prenatal and early-life polychlorinated biphenyl (PCB) levels and behavior in Inuit preschoolers. Environ Int. 2015;78:90-4.

Vinceti M, Mandrioli J, Borella P, Michalke B, Tsatsakis A, Finkelstein Y. Selenium neurotoxicity in humans: Bridging laboratory and epidemiologic studies. Toxicol Lett. 2014;230(2):295-303.

Wagemann R, Innes S, Richard PR. Overview and regional and temporal differences of heavy metals in Arctic whales and ringed seals in the Canadian Arctic. Sci Total Environ. 1996;186(1-2):41-66.

Weihe P, Hansen JC, Murata K, Debes F, Jorgensen PJ. Neurobehavioral performance of Inuit children with increased prenatal exposure to methylmercury. Int J Circumpol Health. 2002;61:41-49.

World Health Organization. Principles for evaluating health risks in children associated with exposure to chemicals. Geneva: Environmental Health Criteria #237; 2006. Available: http://www.who.int/ipcs/publications/ehc/ehc237.pdf?ua=1.

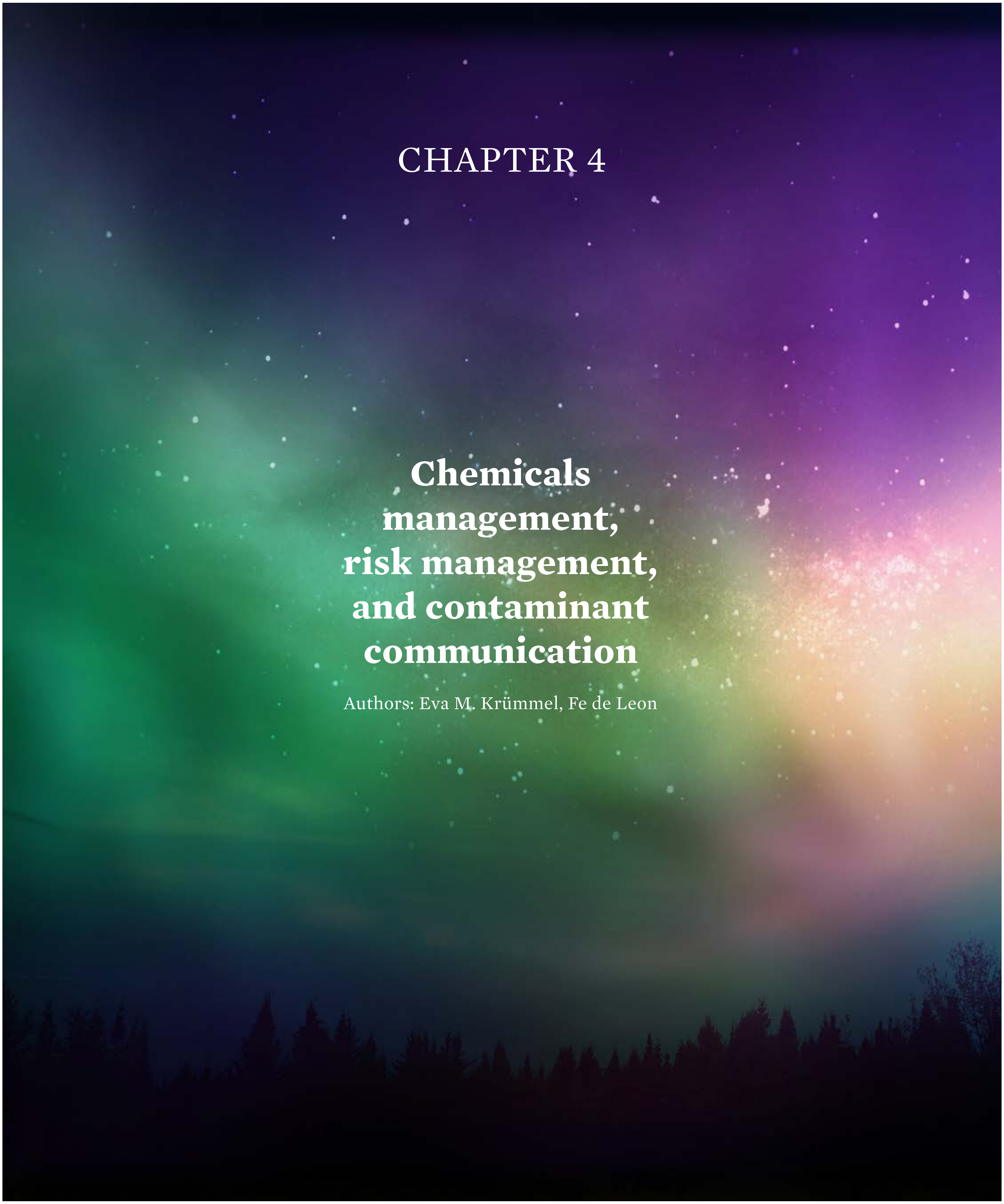
Xia Y, Hill KE, Li P, Xu J, Zhou D, Motley AK, et al. Optimization of selenoprotein P and other plasma selenium biomarkers for the assessment of the selenium nutritional requirement: A placebo-controlled, double-blind study of selenomethionine supplementation in selenium-deficient Chinese subjects. Am J Clin Nutr. 2010;92(3):525-31.

Yamashita Y, Yamashita M. Identification of a novel selenium-containing compound, selenoneine, as the predominant chemical form of organic selenium in the blood of Bluefin tuna. J Biol Chem. 2010;11;285(24):18134-8.

Yamashita M, Yamashita Y, Ando T, Wakamiya J, Akiba S. Identification and determination of selenoneine, 2-selenyl-N α, N α, N α -trimethyl-l-histidine, as the major organic selenium in blood cells in a fish-eating population on remote Japanese islands. Biol Trace Elem Res. 2013;156(1-3):36-44.

Yang GQ, Wang SZ, Zhou RH, Sun SZ. Endemic selenium intoxication of humans in China. Am J Clin Nutr. 1983;37(5):872-81.

Yorifuji T, Debes F, Weihe P, Grandjean P. Prenatal exposure to lead and cognitive deficit in 7- and 14-year-old children in the presence of concomitant exposure to similar molar concentration of methylmercury. Neurotoxicol Teratol. 2011;33(2):205-11.



CHAPTER 4

Chemicals management, risk management, and contaminant communication

Authors: Eva M. Krümmel, Fe de Leon

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This chapter outlines how chemicals management and communication about contaminant issues are inter-related. It describes how contaminants are managed on national, regional, and international levels, provides a background about the history of contaminant communication within the Northern Contaminants Program, and summarizes perspectives of Indigenous people concerning the suitability of recent national and international communication efforts on the issue of contaminants in traditional food.

4.1 An overview of the assessment and management processes of chemicals in Canada

Chemicals are part of the everyday lives of Canadians. Chemicals are used during industrial processes and in agricultural applications, and they are found in many commercial and personal care products. However, some chemicals may pose risks to the environment and to the health of people in Canada. Releases of chemicals in southern regions have resulted in elevated contaminant levels in the Arctic environment that have been associated with a range of human health outcomes (see Chapter 3).

There are over 23,000 chemicals (substances) in commercial use (manufactured, imported, or used) in Canada (Global Affairs Canada, 2009), and the Government of Canada assesses approximately 500 chemicals through the New Substances Notification process each year. Chapter 2 describes that levels for many POPs and metals are declining in the North, achieved in part through effective national and international efforts that are described in this chapter (section 4.6 and see also Chapter 1). Looking forward, multi-stakeholder studies that include new and emerging contaminants will permit the NCP to assess whether the next generation of chemicals may become a health concern in northern Canada.

At the federal level, there are many measures in place to protect Canadians and the environment from the risks of potentially harmful chemicals. Key legislation allows the federal government to manage chemicals in order to protect human health and the environment. This legislation includes the *Canadian Environmental Protection Act, 1999* (CEPA; Government of Canada, 2015a), the *Pest Control Products Act*, the *Canada Consumer Product Safety Act*, and the *Food and Drugs Act*. CEPA is the cornerstone of federal environmental legislation for assessing and managing chemicals in Canada. Key principles and goals such as sustainable development, pollution prevention, virtual elimination of persistent, bioaccumulative, and toxic chemicals, and the precautionary principle (United Nations, 1999) form the foundation of CEPA and provide guidance for assessing and managing chemicals in Canada (Environment and Climate Change Canada, 2010). The precautionary principle and weight of evidence are two approaches applied during the risk assessment of chemicals under CEPA. Chemicals that are assessed under CEPA and meet the criteria for toxicity as set out in section 64 of the Act are subject to risk management measures (Government of Canada, 2011).

On May 4, 1994, Environment Canada published the Domestic Substances List (DSL) in Part II of the Canada Gazette. When it was created, the DSL was an inventory of approximately 23,000 substances manufactured in, imported into, or used in Canada on a commercial scale (Government of Canada, 2011). It is based on substances present in Canada, under certain conditions, between January 1, 1984 and December 31, 1986; however, many of these chemicals have been in the Canadian market for many decades. Chemicals not listed under the DSL are considered 'new' chemicals (for the purpose of CEPA) and are subject to pre-import or pre-manufacture notification under the New Substances Notification Regulations. In addition to the assessment and management of chemicals, CEPA addresses other environmental matters such as products of biotechnology, disposal of hazardous and non-hazardous waste materials, environmental emergency planning, and environmental protection pertaining to government operations on federal and Indigenous land. CEPA outlines opportunities for public participation, and it has established the CEPA Environmental Registry, a source of current information related to CEPA.

Under CEPA, the Government of Canada assesses chemicals through a risk-based approach. To ensure a systematic review of all substances on the DSL, CEPA included a legal obligation for Environment and Climate Change Canada (previously Environment Canada) and Health Canada to systematically examine all chemicals known to be in commerce in Canada (CEPA section 73). The categorization process outlined in Figure 1 was completed in 2006 (Government of Canada, 2011).

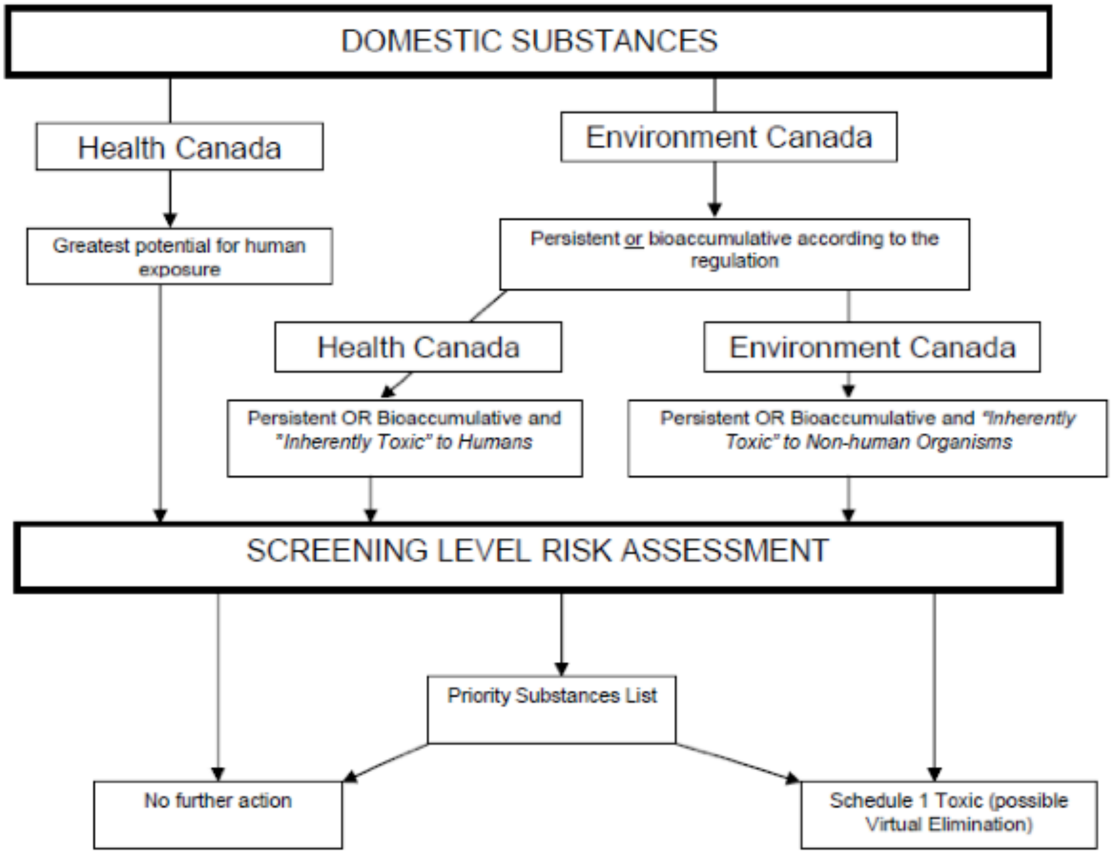
The criteria used to categorize DSL chemicals under CEPA included whether the chemical is persistent (P) or bioaccumulative (B) and, if either one is the case, whether the chemical is also inherently toxic (T) to human or non-human organisms. The degree of potential human exposure is also evaluated. The categorization process identified approximately 4,300 chemicals as priorities for further assessment (Government of Canada, 2011).

Chemicals that meet the toxicity criteria under section 64 of CEPA may be added to the List of Toxic Substances, also known as Schedule 1 of CEPA. Following the decision to recommend listing under Schedule 1, a risk management instrument will be developed. CEPA specifies timelines to complete the development of a proposed risk management instrument for toxic chemicals, which includes public comment periods (CEPA sections 91 and 92).

4.2 The Chemicals Management Plan

The Government of Canada launched the Chemicals Management Plan (CMP) in 2006. It is a world-leading approach to chemicals management that aims to protect human health and the environment by assessing substances of concern and taking action to manage those substances found to be harmful. CMP activities are conducted under the authority of CEPA. The CMP is aligned with the Strategic Approach to International Chemicals Management, a voluntary international framework with the overall objective of achieving the sound management of chemicals so that, by 2020, chemicals are produced and used in ways that minimize significant adverse impacts on human health and the environment (Government of Canada, 2011). The CMP, which is now in its third phase of implementation, set a 2020 goal to address the 4,300 chemicals identified through the DSL categorization process. In addition to

Figure 1 Categorization and screening level risk assessment processes for chemicals listed under the Domestic Substances List under the Canadian Environmental Protection Act, 1999 (Environment and Climate Change Canada, 2004).



risk assessment and risk management, other elements of the CMP include information gathering and reporting (e.g. updates to the DSL Inventory), environmental monitoring and human biomonitoring, surveillance, research, public outreach, compliance, and enforcement. These elements were undertaken to inform risk assessments as well as the development of risk management and communications strategies.

Human biomonitoring for the general population in Canada, which has been used to assist risk assessment and risk management, is performed every two years by Statistics Canada through the Canadian Health Measures Survey (CHMS; Haines and Murray, 2012). This work is carried out in partnership with Health Canada and the Public Health Agency of Canada (see also Chapter 2). Human biomonitoring in southern Canada differs from biomonitoring done through the NCP with regard to the chemicals covered, the make-up of study participants, and the communication plans or products. The CHMS has measured a broad range of chemicals (including POPs and metals) in the Canadian population aged 3 to 79 years living in the ten provinces, which covers approximately 96% of Canada's population.

The CHMS does not include persons living in the three territories, on reserves and other Indigenous settlements in the provinces, full-time members of the Canadian Forces, the institutionalized population, or residents of certain remote regions. To fill some of these gaps, Health Canada provides funding to the NCP to enhance northern biomonitoring, and Health Canada has also implemented the national First Nations Biomonitoring Initiative for First Nations people living on reserve in southern Canada (FNBI; Assembly of First Nations, 2013). Other Canadian biomonitoring initiatives include the national Maternal-Infant Research on Environmental Chemicals (MIREC) study, which measures chemicals in pregnant women and infants in ten cities across Canada (Arbuckle et al., 2013).

Phase 1 of the CMP focused on approximately 200 high-priority chemicals identified during categorization (the Challenge) and approximately 160 high priority petroleum chemicals (the Petroleum sector stream approach). Phase 1 also included a rapid screening process for another 1,000 chemicals that met the criteria from the DSL categorization process, but were low volume and did not require further assessment (Government of Canada, 2011).

Phase 2 (2012-2016) of the CMP has focused on assessments of chemicals through nine chemical groups with structural or functional similarities. The Substance Groupings Initiative creates assessment and management efficiencies, informs decisions on potential substitutions, and considers international actions for key chemicals. Under each grouping, the number of chemicals and the approach to be taken to complete risk assessments differ. Chemical groups of potential relevance to the northern regions include selenium-containing substances (29 substances) and certain organic flame retardants (10 substances) (Government of Canada, 2011).

The CMP also includes key commitments to conduct re-evaluations and special reviews of pesticides under the *Pest Control Products Act* (PCPA; Government of Canada, 2006). Pesticides are subject to a rigorous pre- and post-market risk assessment by Health Canada's Pest Management Regulatory Agency (PMRA) prior to being allowed for import, manufacture, sale, or use in Canada. Pesticides are re-evaluated on a 15-year cycle based on modern science to verify the continued acceptability of health and environmental risks and value. Special reviews are conducted when there are reasonable grounds to believe that the health or environmental risks of the pesticide are, or its value is, unacceptable, or when an Organisation for Economic Co-operation and Development (OECD) member country prohibits all uses of a pesticide for health or environmental reasons. For chemicals with multiple uses, assessments may be conducted under CEPA (industrial and manufacturing) as well as under the PCPA (pest control) to evaluate the risks associated with pesticide applications. Some chemicals (e.g. endosulfan, lindane) have undergone re-assessments under the PCPA (Health Canada, 2009, 2011) and have also been subject to global actions (e.g. listing under the Stockholm Convention).

Several committees have been established under the CMP to facilitate CMP activities. In Phase 1, the Challenge Advisory Panel focused on weight of evidence and the precautionary principle in their review of risk assessment results. In Phase 2, the Science Committee has contributed expertise pertaining to scientific considerations for risk assessments. The Government also established a Stakeholder Advisory Council (SAC) for each phase of the CMP, obtaining participation by multiple stakeholders including industry, health organizations and professionals, national Indigenous organizations, and environmental non-governmental organizations. Members of the SAC include the Inuit Tapiriit Kanatami (ITK), the Assembly of First Nations (AFN), and the Métis National Council.

Since 2006, the CMP has " *…led to the assessment of 2,700 substances, where close to 400 substances have been found harmful and nearly 80 risk management actions have been put in place to address risks from these harmful substances. Since 2006, an additional 4,500 notifications* *for new substances were assessed prior to their introduction into the Canadian market."* (Environment and Climate Change Canada, 2015)

Phase 3 of the CMP was launched May 30, 2016 and will be completed by 2020. This phase will aim to address the approximately 1,500 chemicals remaining from the DSL categorization.

The Prohibition of Certain Toxic Substances Regulations, 2012 (the Prohibition Regulations) developed under CEPA prevent potential risks of harm to the Canadian environment and, where applicable, to human health. The Prohibition Regulations are a multi-substance (multi-chemical) risk management instrument used to prohibit the manufacture, use, sale, offer for sale, and import of toxic chemicals listed to the regulations and products containing these chemicals, with a limited number of exemptions (Government of Canada, 2012). These regulations are relevant to the Arctic in that they prohibit a number of chemicals that are subject to environmental long-range transport, including mirex and hexachlorobenzene.

The Prohibition Regulations are Environment and Climate Change Canada's main tool for implementing Canada's obligations under the Stockholm Convention for Persistent Organic Pollutants (POPs). The Prohibition Regulations impose restrictions on activities that occur within Canada. Recent proposals to include five additional toxic substances for prohibition or restriction in Canada are being considered for the following: hexabromocyclododecane (HBCD), perfluorooctanoic acid, its salts, and its precursors (collectively referred to as PFOA), long-chain perfluorocarboxylic acids, their salts, and their precursors (collectively known as long-chain PFCAs), polybrominated diphenyl ethers (PBDEs), and perfluorooctane sulfonate (PFOS), its salts, and its precursors (Government of Canada, 2015b), some of which have been measured in the North through the NCP. Once finalized, the amended Prohibition Regulations will replace the existing *Polybrominated Diphenyl Ethers Regulations* and *Perfluorooctane Sulfonate and its Salts and Certain Other Compounds Regulations*. HBCD, PFOS, and select PBDEs have also been listed to the Stockholm Convention for elimination (HBCD, PBDEs) or restriction (PFOS).

4.3 National contaminant communication

Under the CMP, the Government of Canada has prepared a number of publications on chemicals, including fact sheets that describe risks associated with chemicals in the Canadian market and outline approaches to be taken by the Government and people living in Canada to reduce exposure risks. Other publications have included technical reports that describe results from the first three cycles of biomonitoring under the CHMS (Health Canada, 2010, 2013, 2015).

CHMS biomonitoring results are made available through national reports (Health Canada, 2010, 2013, 2015) that are often accompanied by additional Health Fact Sheets describing risks associated with specific chemicals covered in the CHMS biomonitoring program. Additional CMP communication materials include Progress Reports and the CEPA Annual Report. Specific surveys such as the FNBI and MIREC have communication products designed for each study (Assembly of First Nations, 2013; Arbuckle et al., 2013).

Areas of overlap between the CMP and the NCP include risk and contaminant communication activities, along with research direction. An example may be obtained from the Risk Management Scope for Selenium and its Compounds under the Selenium-containing Substance Grouping (Government of Canada, 2015c). This document outlines that although Health Canada does not issue advisories for country foods, it will provide risk assessments and opinions on potential risks when requested by relevant public health authorities. It also describes that "*Any subsequent risk management advice developed from these assessments, such as issuing a consumption advisory, would be taken by the relevant public health authority*." The Risk Management Scope document also recommends additional research on selenium for the NCP's annual Call for Proposals, "*including looking for evidence of selenosis and/or other health effects related to selenium in Inuit populations with high blood levels of selenium*". These aspects for research on selenium exposure have since been included in the annual NCP Call for Proposals.

The Stakeholder Advisory Council has provided a mechanism for national Indigenous organizations to contribute input to the chemical review and communication processes under the CMP. While northern regional organizations and territorial governments have not been directly engaged in the CMP through the SAC, there have been recent activities that have involved the NCP network of northern Indigenous partners, research scientists, and territorial and regional health authorities. For example, staff working under the CMP provided a briefing at the fall 2014 NCP Management Committee meeting, and they hosted a teleconference with NCP stakeholders in the summer of 2015 on the draft Screening Assessment Report and Risk Management Scope documents for selenium and its compounds under the Substance Groupings Initiative of the Chemicals Management Plan.

4.4 Overview of contaminant communication in the Canadian Arctic

Beginning in the 1980s, studies by Canadian scientists (e.g. Kinloch and Kuhnlein, 1988; Kinloch et al., 1992; Kuhnlein et al., 2001) have observed high concentrations of PCBs and other POPs in wildlife from northern Canada, as well as in some northern people. A project was carried out between 1985 and 1987 in the Inuit community of Qikiqtarjuaq (Broughton Island) in Nunavut (Kinloch and Kuhnlein, 1988), which was known to have relatively high levels of traditional food harvests. The communication of the Broughton Island study results, that is, that breast milk samples showed high levels of PCBs, caused alarm and confusion in northern communities at the time (Usher et al., 1995). It was reported that many people ceased to eat traditional foods altogether, which led to more immediate health problems and undermined the nutritional benefits of a diet consisting of traditional food. Further contaminants research found that blood and breast milk of Inuit women from the Hudson Bay region also showed elevated levels of POPs (Dewailly et al., 1989). PCB concentrations in blood of many individuals living in the Arctic, including two-thirds of those under 15 years of age, were above 5 µg/L, which was considered to be an exceedance of tolerable blood levels at the time (Kinloch et al. 1992).

The apprehension created during the communication of the Broughton Island study results highlighted the need for work on contaminants and risk communication to be undertaken concurrently, as well as the necessity of including Indigenous representation when addressing health concerns. In response, a five-year plan for the NCP was developed by a technical committee of federal and territorial government experts and five Indigenous parties: the Council for Yukon Indians (now Council of Yukon First Nations), the Dene Nation, the Métis Nation-Northwest Territories, the Inuit Tapirisat of Canada (now Inuit Tapiriit Kanatami, ITK), and the Inuit Circumpolar Conference (now Inuit Circumpolar Council, ICC).

The NCP is a best practice program model that supports capacity building, and it ensures participation of northern Indigenous people in program management, research, and information dissemination. Since the early years of the NCP, benefit-risk communication has been undertaken by Indigenous partners and territorial and regional health authorities. Health messages have focused on the amount and types of traditional food consumed, as well as the benefits of traditional food consumption. However, the communication of research results and advisories to northern communities remains a challenging task due to the complexity of balancing the social, cultural, economic, spiritual, and nutritional benefits of consuming traditional foods with the potential health risks associated with contaminant levels in some traditional foods. The processes followed within the NCP, and particularly within the different northern regions, are described in more detail in the following sections.

4.5 Regional chemicals management and contaminant communication

Chemicals management and contaminant communication follow similar processes in each of the Canadian northern regions and are guided by the NCP management structure. Each region has a Regional Contaminants Committee (RCC), whose membership differs from region to region. The RCCs provide a connection and facilitate the communication between the NCP, northern researchers, territorial and regional health authorities, and communities. The Inuit regions (i.e. Nunatsiavut, Nunavik, Nunavut, and the Inuvialuit Settlement Region) additionally have Inuit Research Advisors (IRAs) that form part of the RCCs. The RCCs review NCP research proposals, make recommendations, and ensure that regional interests or concerns are addressed in an appropriate manner. RCCs are also integral to the development of communication plans for disseminating research results or health advisories to communities.

4.5.1 Nunatsiavut

The RCC in Nunatsiavut is the Nunatsiavut Government Research Advisory Committee (NGRAC). The NCRAC includes members from the Nunatsiavut Government (i.e. Departments of Lands and Natural Resources, Health and Social Development, and Culture, Recreation and Tourism), the IRA for Nunatsiavut, and representatives from ITK and the NCP Secretariat. The NGRAC requires that research project results are reported back to the NGRAC prior to being communicated outside of Nunatsiavut. If contaminant levels are high and there may be a health risk, the results of concern are evaluated by the Department of Health and Social Development who, in consultation with other Departments of the Nunatsiavut Government, will make recommendations for further actions, including a communication plan.

4.5.1.1 Example of contaminant communication in Nunatsiavut: The Nunatsiavut Inuit Health Survey

In order to obtain an overview of the health status and living conditions of Inuit in Nunatsiavut, the Nunatsiavut Inuit Health Survey (see also Chapters 2 and 3) was undertaken in 2008. This participatory health survey covered adult Nunatsiavummiut 18 years and older in five communities (Nain, Hopedale, Postville, Makkovik, and Rigolet). Project activities included completing a household survey (to assess overcrowding, disabilities, and food security), a health survey (to assess chronic disease risk, nutrition, physical activity, and mental health), and a contaminant survey (to assess environmental exposure of Inuit to contaminants). Blood samples from 264 participants were analyzed for POPs and metals. The work was guided by a Nunatsiavut Steering Committee, which included membership from the Nunatsiavut Government (Departments of Health and Social Development and Land and Natural Resources), the Labrador-Grenfell Regional Health Authority, the University of Toronto, and McGill University.

Generally, contaminant levels were found to be relatively low in Nunatsiavut. Key messages from the contaminant portion of the Inuit Health Survey in Nunatsiavut included (Egeland, 2010a):

"*Country foods like arctic char, caribou meat, ringed seal meat, ringed seal liver, and ringed seal blubber are great sources of selenium, polyunsaturated fatty acids, and omega 3- fatty acids. Each of these nutrients are vitally important for our health.*"

"*Country foods also contain contaminants like heavy metals and persistent organic pollutants. Current exposure levels for Inuit in Nunatsiavut are generally below guideline levels of concern.*"

To communicate the results, a regional report was prepared with a plain language executive summary (Egeland, 2010a). Fully translated versions of the report are available, and individual results were communicated directly to survey participants. If desired by survey participants, Labrador-Grenfell Health clinics and physicians were available for individual appointments. In addition, public presentations describing results from the survey were given in each community, and presentations and briefings were provided directly to each Inuit Community Government and to health employees from the Nunatsiavut Government Department of Health and Social Development and Labrador-Grenfell Health. Contact information was provided for people in each community for further possible questions.

4.5.2 Nunavik

The RCC in Nunavik is the Nunavik Nutrition and Health Committee (NNHC). The membership consists of the Nunavik Regional Board of Health and Social Services (NRBHSS), the Makivik Research Centre, the Kativik Regional Government, the two health centres in Nunavik (Inuulitsivik and Tulattavik), the Institut national de santé publique du Québec (INSPQ), the Nunavik IRA, representatives from ITK and Trent University, and an observer from the NCP.

In Nunavik, there is a strong link between the research institutes that conduct health research in the region and the regional government. This link allows good flow of information between researchers and the NNHC, which has led to several health advisories issued in the region, as described below.

4.5.2.1 Examples of contaminant communication in Nunavik

In Nunavik, elevated levels of contaminants have been observed in Inuit adults, newborns, children, and pregnant women as discussed and presented in Chapter 2. Risk communication experiences related to findings from specific studies in Nunavik have been described by Couture et al. (2012) for lead and by Dallaire et al. (2013, 2014) for PCBs and mercury.

In 1992, a cross-sectional health survey in Nunavik found that mean blood lead levels in Inuit adults were five times higher than levels found in the general population of the United States at the time (Pirkle et al., 1998; Dewailly et al., 2001). A study of Inuit newborns from 1992 to 1996 found that 7% of cord blood lead concentrations were equal to or greater than the blood lead intervention level of 0.48 umol/L (10 ug/dL) (Levesque et al., 2003) and were approximately double the concentration of blood lead levels in newborns from southern Québec (Plante et al., 1998; Dewailly et al., 1998; Rhainds et al., 1999). The elevated blood lead levels observed in these studies were likely attributed to exposures from lead shot used during hunting in Nunavik during these periods (Pirkle et al 1998; Couture et al, 2012; see also Chapter 2).

In response to these findings, in 1999 the Nunavik Regional Board of Health and Social Services, in cooperation with the Nunavik Hunting, Fishing and Trapping Association, the Kativik Regional Government, and the Makivik Corporation, acted to remove lead shot from use and to replace it with steel shot or other alternatives. The resulting Regional Coalition for the Banning of Lead Shot in Nunavik implemented a campaign to raise awareness for a program aimed at limiting exposure of the population to lead as a result of hunting activities, which included participation from municipal officials and merchants. Messages were distributed to the communities using local radio announcements, articles in various periodicals, and posters and brochures distributed in three languages (i.e. Inuktitut, French, and English).

Couture et al. (2012) reported that blood lead levels in Inuit from Nunavik had decreased significantly between 1992 and 2004, which is a period encompassing the lead shot intervention in 1999, but that blood lead levels still remained higher than for other populations in Canada and the United States (see also Chapter 2). It is unclear whether the decrease in lead levels was due to the intervention, a shift in diet away from hunted waterfowl, or a combination of both factors. The availability of lead shot has declined in many stores in Nunavik since the awareness campaign in 1999, but is still available in some. A survey of hunters in Inukjuak in 2004 and 2005 showed that only 31% of respondents were aware of the ban on the use of lead shot. While there is evidence that the intervention in 1999 may have initiated a positive result through the lowering of blood lead levels, the effectiveness of the messaging for hunters who may have switched to steel shot versus those who remove lead shot during meal preparation has not been assessed.

Discussed in Chapter 2, exposure to PCBs for Inuit in Nunavik is mainly due to consumption of marine mammal fat (especially beluga blubber), while beluga meat, ringed seal liver, and Lake Trout have presented very high concentrations of mercury in Nunavik (Lemire et al., 2015). The Nunavik Child Development Study (NCDS) has found that exposures to these contaminants are related to health and developmental effects observed in infants and children at different ages (see Chapter 3).

The communication of health results from the NCDS has led to risk communication messages in Nunavik that focus on specific groups. Public health messages have been developed for pregnant women and women of childbearing age and have focused on lowering exposures to mercury and lead while maintaining healthy intakes of omega-3 fatty acids. PCB exposures have declined significantly in pregnant Inuit women from Nunavik between 1994 and 2013 (see Chapter 2), which includes the time frame for recruitment of NCDS participants. No recommendations for reducing exposures to PCBs have been included during recent risk communications, in part because children born recently are expected to experience lower exposures to PCBs than children from the original NCDS cohort (Quinn et al., 2011).

In 2011, a public health message released in Nunavik (NRBHSS, 2011a) concerning mercury exposures described that:

"…the main source of mercury exposure is beluga meat. Therefore, until we have evidence of a decrease of the mercury content in this specific country food, pregnant women and those of childbearing age should decrease their consumption of beluga meat."

The campaign to communicate results from the NCDS was extensive and included study participants (parents and children), the general population in Nunavik, employees of the regional health and social services network, midwives, regional organizations, national and international Indigenous organizations (e.g. ITK, ICC Canada), RCCs and health officials from other northern regions of Canada, NCP representatives, Health Canada staff, and the general public. The communication of results was carefully planned to ensure that information went to the Nunavik population before it was presented at scientific meetings and in peer-reviewed scientific journals. More detailed information about the results of the study, in particular with regard to POPs, mercury, and lead (sources, trends and health impacts) and the nutritional benefits of omega-3 fatty acids, was also made available (NRBHSS, 2011b).

4.5.3 Nunavut

The RCC in Nunavut is the Nunavut Environmental Contaminants Committee (NECC). While the NECC membership includes government and non-governmental organizations, there is no set membership, and the NECC continues to evolve to include further representation from various organizations. The membership currently includes Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC), Fisheries and Oceans Canada (DFO), the Government of Nunavut (GN) Department of Health, GN Department of Environment, Nunavut Tunngavik Incorporated (NTI), the Nunavut Research Institute, the Nunavut Wildlife Management Board, Resolute Bay Hunters and Trappers Association, the Qikiqtaaluk Wildlife Board, the IRA in Nunavut, and ITK and NCP representation.

The NECC expects that researchers will report their results back to the NECC, particularly if human levels are approaching or exceeding guideline values for contaminants, or if contaminant levels are increasing. The annual NCP Synopsis of Research reports are shared by the NECC with their membership. The delivery of health messages related to environmental contaminants remains the mandate of the GN Department of Health in consultation with Inuit organizations.

4.5.3.1 Example of contaminant communication in Nunavut: The Nunavut Inuit Health Survey

A large and complex participatory health research survey was developed and undertaken in 25 communities in Nunavut in 2007 and 2008 (Egeland, 2010b; see also Chapter 2). The goal of the Nunavut Inuit Health Survey (NIHS) was to obtain an overview of the health status and living conditions of Inuit aged 18 and older in Nunavut. The NIHS included the measurement of contaminants in study participants. Interpretation of results from the NIHS led to the following key messages related to food and contaminants (Egeland, 2010b):

"Country foods provide many essential nutrients that can lower the risk of chronic diseases. Most Inuit adults in Nunavut need not be concerned about contaminant-related effects from country food consumption. Generally, the benefits of eating country foods outweigh the risks from contaminant exposure."

"Inuit women of child-bearing age who may become pregnant, are planning to get pregnant, or are pregnant should avoid eating ringed seal liver due to its high mercury content. Instead, ringed seal meat is a great and healthy alternative…"

Over the course of 2013 and 2014, the NIHS Steering Committee undertook a project aimed at reviewing the efficacy of NIHS contaminant communication. The project covered over 1,000 participants from three communities in Nunavut (i.e. Cambridge Bay, Arviat, and Iqaluit). Preliminary results (Furgal et al., 2014) showed that fewer than half of the people surveyed remembered hearing risk communication messages on avoiding certain country foods due to contaminants, while over 80% of participants reported hearing about the benefits of country food. One-third of participants stated that they had modified their eating habits after hearing about contaminants in country foods. The most popular sources of information were friends or family, radio, and television. The authors of the study found that responses differed between the three communities, and they concluded there is a need to conduct evaluations after risk communication activities, to ensure that messages were released and received as planned and expected.

4.5.4 Yukon

The RCC in Yukon is the Yukon Contaminants Committee (YCC). YCC members include CIRNAC, DFO, the Government of Yukon, the Council of Yukon First Nations (CYFN), Yukon College, the Yukon Conservation Society, and the NCP Secretariat. Data from research projects are reported to the YCC by researchers. As needed, the YCC in conjunction with Yukon Health and Social Services may contact Health Canada for toxicological advice. As well, Yukon Health and Social Services and the Yukon Chief Medical Officer of Health may work with the YCC to create appropriate communication messages. The Government of Yukon has prepared several publications that provide information to the general population about NCP monitoring activities and their results, including Hunting and Fishing Regulations summaries (Figures 2 and 3).

4.5.4.1 Examples of contaminant communication in Yukon

The NCP has been monitoring fish sampled from Kusawa Lake since 1996 and fish sampled from Lake Laberge since 1993. In general, mercury levels in these fish have not changed over time. For example, large, old Lake Trout (> 2 kg, 500 mm fork length, 15 years old in Laberge Lake; > 0.8 kg, 400 mm fork length, 12 years old in Kusawa Lake) have tended to contain mercury levels above the Health Canada guideline of 0.5 µg/g mercury in commercial fish (Health Canada, 2004). The remaining fish have generally showed mercury levels below this guideline, although mercury concentrations in fish from Lake Laberge have consistently been higher compared with fish from Kusawa Lake.

In response to elevated mercury levels in some fish, Yukon Health and Social Services has issued a health advisory that describes low levels of mercury in most fish, and provides safe fish consumption guidelines for women of childbearing age and children. In general, the health advisory that is included in the annual Yukon Fishing Regulations Summary (Figure 3) avoids using language that could discourage people from eating fish. The advisory was developed in partnership with Health Canada toxicologists, a University of Ottawa scientist, the Chief Medical Officer of Health, and the YCC.

This positive example grew out of previous experiences managing high levels of toxaphene measured in fish from Lake Laberge in 1990-1991. These findings for toxaphene were the subject of press releases and consumption advisories that were prepared in the absence of a previously planned communications strategy. Moreover, the advisories for toxaphene in fish were issued without consulting First Nations groups who were, in turn, informed by media reports. These media reports created concern in many First Nations communities.

In 2011, there was sufficient data for the Government of Yukon to confidently state that toxaphene levels were one-fifth of the higher levels measured in 1991, and that fish from Lake Laberge were safe to eat. Discussions followed between the YCC, First Nations communities, the Government of Yukon, and the Chief Medical Officer of Health on how best to communicate a ‘good news’ message on fish and toxaphene. The Government of Yukon shared a draft press release with two affected First Nations communities prior to proceeding into the media, which was an approach that was viewed as being very successful. Media coverage included a video of the Chief Medical Officer of Health removing a sign prohibiting fish consumption that was posted at the boat launch at Lake Laberge, in addition to an interview with the Chief Medical Officer of Health and the local Ta’an First Nation representative.

Figure 2 - NCP information and meat consumption health advisory from the Yukon Hunting Regulations Summary, 2015 – 2016 (Environment Yukon, 2015).

Northern Contaminants Program: Testing Yukon Wildlife

The Northern Contaminants Program currently monitors contaminant levels in the Porcupine caribou herd. It monitored Yukon moose and caribou from the early 1990s up until a few years ago. The major conclusions to date are:

- Mammals, birds and plants in Yukon are largely free from contamination.
- Some animals have elevated levels of cadmium in their organs.
- Cadmium levels in Yukon moose and caribou appear to be stable over time.
- Mercury fluctuates over time in caribou organs, but over the long term is remaining stable in the Porcupine caribou herd.
- Fallout from the nuclear accident in Fukushima, Japan, in 2012 did not affect the safety of meat harvested from Porcupine caribou.

Recommendations for Meat Consumption

These recommendations are based on eating these referenced amounts every year. If you do not eat any this year, you can eat twice as much next year and remain within the recommended limits.

- **Meat:** Caribou and moose meat is very nutritious, with no limit on the amount of meat (muscle) recommended for consumption.
- **Organs:** Health Canada has issued recommendations for consumption of organ meats based on concentrations of metals found in some Yukon wildlife. The recommendations vary with the type of animal and the herd. For caribou, the recommendation ranges from a maximum of 7-32 kidneys/person/year and 4-16 livers/person/year. The recommended limit for moose liver or kidney is 1/person/year.
- Tobacco contains much higher levels of cadmium than animal sources. Reducing or eliminating smoking is the most effective way of limiting cadmium intake.

For more information about contaminants in wildlife, contact the Yukon Contaminant Committee at 867-667-3283.

Figure 3 - Health advisory for mercury in fish from the Yukon Fishing Regulations Summary, 2016 – 2017 (Environment Yukon, 2016).

Mercury

Just like fish available in the grocery store, fish caught in Yukon may contain small amounts of mercury. In general, adults do not need to limit their intake of lake trout or burbot. However, because larger fish have higher concentrations of mercury, consuming smaller lake trout and burbot (i.e., less than 60 cm or 24" in length) would give an extra degree of safety in limiting mercury exposure.

Women of child-bearing age and children under the age of 12 should limit the number of large lake trout and burbot they eat (i.e., only 1 or 2 meals per week of fish greater than 60 cm or 24"). Small fish (less than 40 cm, or 2 lbs) do not pose a risk and can be consumed in any quantity.

All other commonly targeted species of fish, including grayling, pike, whitefish, inconnu, and salmon have very low levels of mercury that are well below the Health Canada guideline. All Yukoners can eat as much of these fish as desired.

4.5.5 Northwest Territories (NWT)

The NWT RCC membership includes CIRNAC (including the NCP Secretariat), Environment and Climate Change Canada, DFO, Health Canada, the Departments of Resources, Wildlife and Economic Development and Health and Social Services for the Government of the Northwest Territories (GNWT), the Aurora Research Institute, several Indigenous organizations (the Dene Nation, ITK, Inuvialuit Game Council, Inuvialuit Regional Corporation, Gwich'in Tribal Council, Sahtu Secretariat Inc., Deh Cho First Nations, North Slave Métis Alliance, Northwest Territory Métis Nation, Dogrib Treaty 11, Akaitcho Territory Government), and the IRA for the Inuvialuit Settlement Region.

In the NWT, it is expected that research findings are communicated to the NWT RCC so that they may assist the GNWT with the management and interpretation of northern research results for projects conducted in the Northwest Territories, with particular attention given to contaminant levels that might be of concern to people's health. The Government of the Northwest Territories works in partnership with Health Canada to assess health risks, as needed.

Monitoring studies conducted in the NWT have frequently observed high levels of mercury in fish. There are currently 14 health advisories from the Department of Health and Social Services concerning mercury in fish from specific lakes (e.g. DHSS, 2010, 2012) and also one advisory for cadmium in moose organs (DHSS, 2009). In the past, the GNWT has issued public advisories through media channels. However, the GNWT has shifted away from this approach after observing that media advisories have tended to create excess concern, and, consequently, northerners have sometimes avoided consuming traditional foods. As well, because contaminant levels often fluctuate from year to year, media advisories have been found to not be suitable for addressing periodic contaminant exposures from fish.

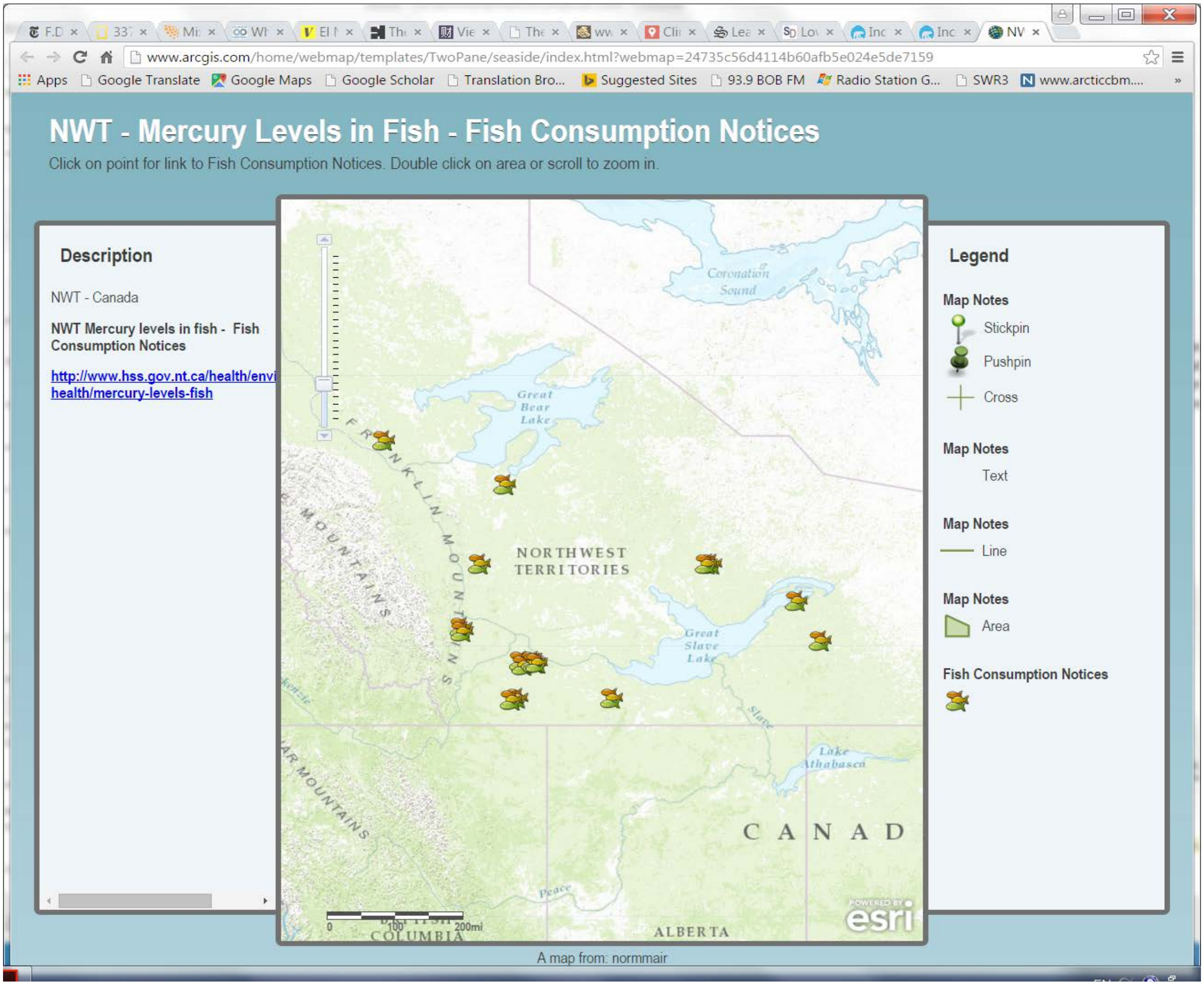
The GNWT has therefore developed a web-based fish consumption advice tool and generic guidelines to keep the general public informed about contaminants and fish (see Figure 4). Fish consumption notices are posted to a map on the internet (Figure 4), and users may locate a particular lake on the map to determine if there is existing fish consumption advice for that lake. Advice is directed to people consuming higher amounts of fish every week and to vulnerable groups such as pregnant and breastfeeding women and children aged 1 to 11 years. Generic fishing guidelines are also included in the annual NWT fishing guide.

During prior experiences in communicating northern research results, it was found that smaller communities in the NWT prefer face-to-face communication related to the assessment of risk from data collected in their communities. An example is given, below.

4.5.5.1 Examples of contaminant communication in NWT

The GNWT Office of the Chief Public Health Officer released a public health advisory in 2010 on limiting the consumption of Lake Trout from four lakes due to high methylmercury concentrations. In Tulita, one of five Dene communities in the Sahtu region, the publically posted notices raised concerns about the safety of eating fish from Kelly Lake (one of the four identified lakes), which is particularly valued for its large Lake Trout. Traditionally, fish is a staple food source that is culturally significant for the Dene. Regional and NCP staff met with the community and offered their support for addressing local concerns over contaminants and fish. A two-year collaborative study that involved fish consumers in Tulita was developed (see also Chapter 2). The study included a communication plan to communicate findings in meaningful ways within and beyond the community of Tulita (Delormier, 2012).

Figure 4 Northwest Territories mercury levels in fish public health advisories map (Source: http://www.arcgis.com/home/webmap/templates/TwoPane/seaside/index.html?webmap=24735c56d4114b60afb5e024e5de7159).



Throughout the implementation of the study, information was shared continuously and formally through presentations to the elders' council, to high school science students, over the local radio, during study participant recruitment, and with family services luncheon events. Information was also shared informally within the community; for example, at card tournaments, church socials, hockey tournaments, and community events. The priority, however, was to formally present findings as quickly as possible on levels of methylmercury in hair samples taken from Tulita study participants.

During a third visit to Tulita, the partners and a translator prepared a presentation and shared the hair sample findings. Of the 68 participants who provided hair samples for mercury exposure analysis, fewer than 5% of participants exceeded a screening value in hair that was considered acceptable for this study, and none exceeded a higher threshold that the investigators determined would warrant immediate intervention by a health care professional (Delormier, 2012). The findings were presented during a public meeting and meal attended by about 45 community members. In 2011, the partners also co-presented the work at the NCP Annual Results Workshop and provided a community perspective for this research.

Community members provided a variety of feedback on the presentation that was given in the community of Tulita. Feedback ranged from members indicating they appreciated the effort, while others expressed disappointment that there could be acceptable levels of contaminants in the environment and in people. As well, some criticisms were given about the scientific data and scientific language that was used to describe risk of exposure to mercury from fish, as the scientific language was difficult for some community members to understand. During a debriefing about feedback to the presentation, a decision was reached to develop a communication tool to make the findings of the study easier to understand and accessible past study completion.

A vinyl banner that was durable, portable, and easy to display was developed to translate the quantitative Tulita research findings graphically, with minimal text. Banners are permanently displayed in Tulita at the Tulita Renewable Resources Council and at the Sahtu Renewable Resources Board. Although not originally developed for this purpose, the banners are also being used in regional renewable resource activities and during other local meetings to describe and share the study approach, findings, and community concerns on the issue of environmental contamination.

This research was designed as a community-based project that valued the collaboration and participation of community stakeholders and the sharing of information with community members in the context of their everyday lives. This approach addressed the ethical expectations of Indigenous communities regarding research that affects their health concerns (Kaufert et al., 1999). An important part of this research was the creation of an on-going, collaborative communication strategy that was developed with the partners.

4.6 International chemicals management and communication

4.6.1 Stockholm Convention on Persistent Organic Pollutants and the POPs Review Committee

The Stockholm Convention is a global, legally binding treaty with the objective to protect human health and the environment from persistent organic pollutants (see also Chapter 1) (UNEP, 2009). The Stockholm Convention was adopted in 2001 and came into force in 2004. As of 2015, 179 countries have ratified the Stockholm Convention, making these countries Parties to the Convention.

The NCP is concerned with contaminants that reach the Arctic via long-range transport from source areas around the globe. These include a large number of POPs (and metals, particularly mercury). The measurement of POPs in the Arctic is a clear indication of the long-range environmental transport of these chemicals and their ability to bioaccumulate and biomagnify in the Arctic food web. The NCP provided key research information on contaminants in the Arctic for establishing the Stockholm Convention, and on-going work by the NCP continues to support the consideration of new POPs for listing under the Stockholm Convention and for measuring its effectiveness.

The Stockholm Convention has a technical body, the POPs Review Committee (POPRC), that is responsible for evaluating chemicals nominated for addition to its Annexes and meets annually. The POPRC membership includes 31 experts nominated by Parties from the five United Nations regional groups: African States (8 members), Asian and Pacific States (8 members), Central and Eastern European States (3 members), Latin American and Caribbean States (5 members), and Western European and other States (including Canada; 7 members). While the membership generally rotates between countries within the regional groups, to date Canada has always been a member of POPRC.

The POPRC was established at the first meeting of the Conference of the Parties (COP) of the Stockholm Convention in May 2005 to identify, scientifically review, and recommend additional POPs that could be listed under the Convention. Every two years, the COP meets to determine if additional chemicals should be listed to the Convention based on recommendations from the POPRC and if amendments need to be made to the Convention. POPRC and COP meetings may be attended by registered observers (e.g. from countries, non-governmental organizations, Indigenous groups, industry). The Inuit Circumpolar Council (ICC) has been funded by the NCP to participate in POPRC work and attend POPRC meetings as an observer since 2010. The ICC provides an Arctic Indigenous perspective to POPRC, and it facilitates the sharing of data and knowledge from northern research conducted in the Canadian Arctic (under the NCP) and in the circumpolar Arctic (under the Arctic Monitoring and Assessment Programme; AMAP) during international decision-making.

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AMAP is one of six working groups under the Arctic Council, and, like all Working Groups, its members include representatives of all eight circumpolar nations, Permanent Participants, and Observers. AMAP is responsible for monitoring and assessing the status of the circumpolar Arctic region with respect to pollution and climate change issues. These responsibilities include documenting levels and trends of contaminants, their pathways and processes, and the effects of contaminants on ecosystems and humans. AMAP also proposes actions to reduce associated threats for consideration by governments and produces sound science-based, policy-relevant assessments and public outreach products to inform policy and decision-making processes. AMAP work is dependent on ongoing national programs of member Arctic states, and the NCP is Canada's main contribution of high quality scientific information on contaminants to AMAP.

Northern research and monitoring conducted under the NCP and the AMAP fulfills (in part) Article 11 of the Stockholm Convention, which outlines responsibilities of the Parties, within their capabilities, to encourage or undertake research and monitoring on POPs, their alternatives, and other candidate POPs. In particular, Parties are asked to look at sources, levels, and trends for POPs, their environmental transport, fate, and transformation, effects on human health and the environment, and socio-economic and cultural impacts. Parties are also asked, within their capabilities, to support and further develop international programs, networks, and organizations engaged in data collection and monitoring, to strengthen national scientific and technical research capabilities, to promote access to and exchange of data, and to make the results of the research and monitoring activities accessible to the public.

There are three annexes under the Stockholm Convention where a chemical may be listed:

- Annex A – Elimination: Contains chemicals for which Parties must take measures to eliminate the production and use. Time-limited specific exemptions for use or production are listed in the Annex and apply only to Parties that register for them.
- Annex B – Restriction: Contains chemicals for which Parties must take measures to restrict the production and use. There can be acceptable purposes listed (for example, in the case of dichlorodiphenyltrichloroethane (DDT) used for disease vector control to combat malaria following World Health Organization (WHO) guidelines (UNEP, 2009)), or specific exemptions (for example, PFOS for a number of specific uses, such as metal plating). Parties may also register for time-limited specific exemptions and can request the COP to extend the expiry date and re-register for this purpose, unless the COP decides otherwise. The COP reviews the continued need for acceptable purposes regularly. To date, no acceptable purposes have been removed for the two listed chemicals under this Annex.
- Annex C - Unintentional Production: Contains chemicals for which Parties must take measures to reduce the unintentional releases with the goal of continuing minimization and, where feasible, ultimate elimination. These chemicals may be formed and released unintentionally from human-made sources, such as waste incinerators. The Stockholm Convention provides guidance on preventing or reducing unintentional releases of these chemicals.

Under the Stockholm Convention, the POPRC reviews nominated chemicals in three stages:

- Annex D – Screening Criteria: POPRC determines whether the nominated chemical fulfills POP screening criteria detailed in Annex D under the Stockholm Convention relating to its chemical identity, persistence, bioaccumulation, potential for long-range environmental transport (LRET), and evidence of adverse effects or toxicity to human health or to the environment. Once POPRC decides that Annex D criteria are fulfilled, the chemical moves to Annex E.

- Annex E - Risk Profile: Information can be submitted by Parties and observers in the form of comments, reports, and published studies. The risk profile is drafted during the intersessional period and is made available for comments to members, Parties, and observers. The risk profile undergoes several draft stages before it is presented to the POPRC for adoption and decision. Additional discussions and revisions may take place during the POPRC meeting in 'plenary' (i.e. with all POPRC members and all observers) and, if necessary, in smaller contact groups (which may be attended by all interested POPRC members and observers), or drafting groups (usually only open to POPRC members).

- In plenary, interventions by observers are permitted at the discretion of the POPRC chairperson, unless a decision is being made by POPRC members. Experts on chemicals may be invited to clarify or present additional information. POPRC members are required to base their decisions on their technical expertise. Article 8 of the Convention further states that "*lack of full scientific certainty shall not prevent the proposal from proceeding*", meaning that the precautionary approach should prevail over a lack of full scientific certainty. Once POPRC decides that a chemical is *"likely, as a result of its LRET, to lead to significant adverse human health and/or environmental effects and therefore warrants global action"*, it moves to Annex F.

- Annex F – Risk Management Evaluation: This stage includes an analysis of possible control measures, as well as economic considerations, alternative replacements, and whether there are unintentional sources. The chemical is then recommended for listing in Annex A, B, and/or C under the Stockholm Convention. The risk management evaluation (RME) is revised during the intersessional process and is then discussed at the next POPRC meeting. The POPRC also deliberates on possible specific exemptions or acceptable purposes for the chemical that is being considered. If POPRC makes a decision about the recommendation for listing of the chemical, the matter is referred to the next COP meeting.

- COP decision: Article 9 of the Stockholm Convention states that the COP should take into account POPRC recommendations, "*including any scientific uncertainty*" and "*shall decide, in a precautionary manner, whether to list the chemical [...] in Annexes A, B and/or C.*" Parties to the Convention may then register specific exemptions or acceptable purposes, if available. The Stockholm Convention has 'opt-in' Parties (including Canada), that is, these countries are required to ratify (or accept) each new chemical listed to the Convention. All other countries may 'opt-out' within a year of the decision, that is, they can request not to be bound by the new obligation to eliminate or manage a chemical before the amendment comes into force for those Parties. This means that not all chemicals that are listed as amendments in the annexes may be accepted by all Parties to the Convention at the same time.

4.6.2 International contaminant communication experiences related to the Arctic

Two Articles under the Stockholm Convention specify the requirements of Parties with regard to communication (Articles 9 and 10). These articles describe that information on POPs needs to be made available and that the public needs to be made aware of this information. For example, Parties shall, within their capabilities, *"promote and facilitate"* educational and public awareness programs on POPs, and the Parties may establish *"information centres at national and regional levels"*.

The NCP and AMAP have important roles in disseminating information about the risks posed by contaminants for Indigenous people in the Arctic. However, the sharing of specific health research findings and risk reduction messages can lead to ambiguous results. While some specific contaminant communication messages are intended for the protection of a local community or a regional population from potential adverse health effects related to contaminants found in parts of their diet, these same public health messages can spread to other communities, regions, or countries through the media and social media. Rapid dispersal of messages meant for one group or location can create concerns and confusion in other areas where the scientific information or the advisory does not apply, or is not intended (AMAP, 2015).

For example, an international conference in 2011 on Climate Change and Pollution included a presentation from Faroe Island researchers that examined an association between developmental PCB exposure and the efficacy of some vaccines (Heilmann et al., 2010). The researchers described that the findings of the research led to a health advisory in the Faroe Islands suggesting that local communities refrain from eating pilot whale (AMAP, 2015). Subsequent media reporting by an Arctic newspaper described that the same recommendation would be valid for the consumption of other toothed whales in other areas in the Arctic, including Canada, leading to concerns within Canadian Inuit organizations that the reports could discourage Canadian Inuit from eating traditional foods.

The Faroe Island example underlines an inherent obstacle in sharing risk communication messages in international fora: news about research results and risk reduction strategies may be extrapolated to other regions, regardless of the relevance or validity of the advice. This can be a challenge for the development of trustworthy contaminant communication messages in other regions and for specific groups in specific locations where contaminant levels and food intakes have been measured and evaluated, but have not been found to pose a similar risk.

The ICC has reported similar experiences during negotiations for legally-binding instruments for implementing global action on POPs and mercury under the Stockholm Convention for POPs and the Minamata Convention on Mercury, respectively. The Minamata Convention on Mercury is a global treaty to protect human health and the environment from the adverse effects of anthropogenic mercury emissions and releases that was adopted in 2013 and may now be ratified by signatory countries (UNEP, 2015). In total, 128 countries took a first step to sign the treaty, and, as of June 2016, it has been ratified by 28 countries. The Minamata Convention on Mercury will enter into force 90 days after 50 countries have ratified the treaty.

Both Conventions contain preambular texts that reference Indigenous communities and the vulnerability of Indigenous people.

The final Preamble to the Stockholm Convention text acknowledges that …"*the Arctic ecosystems and indigenous communities are particularly at risk because of the biomagnification of persistent organic pollutants and that contamination of their traditional foods is a public health issue.*"

The preamble in the Minamata Convention notes … "*the particular vulnerabilities of Arctic ecosystems and indigenous communities because of the biomagnification of mercury and contamination of traditional foods*" and concern about … "*indigenous communities more generally with respect to the effects of mercury…*"

For the POPs negotiations from 1998 to 2001, several Canadian Indigenous partners formed the *Canadian Arctic Indigenous Peoples Against POPs* (CAIPAP), a coalition that advocates for consensus and urgency in addressing the risks presented by POPs (Downie and Fenge, 2003). CAIPAP was seen as a valuable source of relevant scientific information in the negotiations and also a human face to the problem of contaminants that have reached the Arctic. However, international messages created during the POPs negotiations reached Canada and the northern regions through international media, and seemed to contradict messages developed for northern communities in Canada (Myers and Furgal, 2006). Examples are illustrated in Figure 6.

Inuit Circumpolar Council (ICC) participation in the mercury negotiations between 2010 and 2013 was able to draw from the experience during the POPs negotiations. During the mercury negotiations, ICC tried to avoid contradicting messages by referencing regional consumption advisories in Canada to highlight impacts of atmospheric mercury emissions on Inuit in northern Canada, such as the beluga meat consumption advisory in Nunavik in 2011 (NRBHSS, 2011a). The ICC was very careful in the wording it used in its international communications; however, subsequent reporting by local media misstated the international message in some cases.

Figure 5 - International versus community messaging on persistent organic pollutants. Comparison of messages communicated in 1998 - 2001 during the Stockholm Convention negotiations by the ICC Vice-Chair with messages given locally in Canadian Inuit regions (AMAP, 2016).

For example, after the fifth negotiation session in January 2013, the ICC press release stated:

"*After a week with long negotiations that lasted throughout several nights, ICC participants were pleased to see the adoption of a global mercury treaty* [...]. [...] *the mercury treaty is expected to result in the reduction of mercury levels in the environment globally, however many years will pass before the first measures have to be implemented.* [...] *Nevertheless, the fact that over 140 countries were able to agree on measures to reduce mercury in the environment has to be viewed as a success.*"

It also included a quote from the ICC Canada President:

"*Several Inuit regions currently have consumption advisories in effect due to high mercury levels in some traditional food items, and the mercury in our foods is largely due to global mercury emissions, for example from coal-fired power plants in Asia. Consumption advisories are not an acceptable way for us to avoid health effects from mercury. Our environment needs to be healthy in order for us to be healthy.*"

One media outlet subsequently reported:

"*The Inuit Circumpolar Council says it is pleased with progress made in efforts to reduce global mercury levels. Early this week, more than 140 countries adopted a global mercury treaty at the United Nations Environment Programme meetings in Geneva, Switzerland. The treaty includes legally binding and voluntary measures to regulate mercury emissions, the related health aspects and other concerns. Mercury is a poison released into the air, water and land from small-scale artisanal gold mining, coal-powered plants, and from discarded electronic or consumer products such as thermostats, batteries and paints. Because mercury concentrates and accumulates in fish and goes up the food chain, it poses the greatest risk of nerve damage to pregnant women, women of childbearing age and young children.*

"Over the years in the Arctic, mercury levels have been rising. Inuit consume mercury when they eat country food like beluga and ringed seal. The council has been pushing for tougher regulations in countries where mercury is coming from."

While ICC referred to food advisories created due to high mercury levels in '*some*' traditional food items, a media outlet took a broad-brush approach by reporting that "*Inuit consume mercury when they eat country food*". Based on previous experience, such generalized messages may cause anxiety and uncertainty in northern regions, where the overall dietary advice given by health officials is that country food is healthy and should be consumed (e.g. Donaldson et al., 2010).

Overall, ICC experiences with risk communication on the international scale shows that it may not be advisable for one source to use messages with significantly different content for different audiences, since this message can reach a non-target audience through global media and social media sources. At the same time, it is likely that different messages are transmitted by different (global) sources and reach local non-target audiences, which can cause confusion in local populations. Therefore, continuous communication is required to reinforce the validity of messages to a local audience and prevent confusion through non-local information sources that may not be valid for a specific audience (AMAP, 2015).

References for Chapter 4

AMAP. AMAP Assessment 2015: Human Health in the Arctic. Oslo: Arctic Monitoring and Assessment Programme (AMAP); 2015.

Arbuckle TE, Fraser WD, Fisher M, Davis K, Liang CL, Lupien N, et al. Cohort profile: The Maternal-Infant Research on Environmental Chemicals research platform. Paediatr Perinat Epidemiol. 2013;27(4):415-25.

Assembly of First Nations. First Nations Biomonitoring Initiative: National Results (2011). Ottawa: Assembly of First Nations; 2013: Available: http://www.afn.ca/uploads/files/afn_fnbi_en_-_2013-06-26.pdf.

Couture A, Levesque B, Dewailly É, Muckle G, Déry S, Proulx J-. Lead exposure in Nunavik: From research to action. Int J Circumpol Health. 2012;71(1).

Dallaire R, Dewailly É, Ayotte P, Forget-Dubois N, Jacobson SW, Jacobson JL, et al. Exposure to organochlorines and mercury through fish and marine mammal consumption: associations with growth and duration of gestation among Inuit newborns. Environ Int. 2013;54:85-91.

Dallaire R, Dewailly É, Ayotte P, Forget-Dubois N, Jacobson SW, Jacobson JL, et al. Growth in Inuit children exposed to polychlorinated biphenyls and lead during fetal development and childhood. Environ Res. 2014;134:17-23.

Delormier T. Examining benefits and risks of traditional and market food: Hair mercury analysis and communicating research results in the community of Tulita, NWT. In: Synopsis of Research Conducted under the 2011-2012 Northern Contaminants Program. Ottawa: Aboriginal Affairs and Northern Development Canada; 2012.

Department of Health and Social Services (DHSS). Limit consumption of moose organs from the southern Mackenzie Mountains in the Dehcho, due to high cadmium levels. Yellowknife: Government of the Northwest Territories; 2009. Available: http://www.hss.gov.nt.ca/advisory/limit-consumption-moose-organs-southern-mackenzie-mountains-dehcho-due-high-cadmium-levels.

Department of Health and Social Services (DHSS). Increase in mercury levels in Trout Lake, Cli Lake, Ste. Therese and Kelly Lake. Yellowknife: Government of the Northwest Territories; 2010. Available: http://www.hss.gov.nt.ca/advisory/increase-mercury-levels-trout-lake-cli-lake-ste-therese-and-kelly-lake.

Department of Health and Social Services (DHSS). Mercury levels in fish. Yellowknife: Government of the Northwest Territories; 2012. Available: http://www.hss.gov.nt.ca/health/environment-and-your-health/mercury-levels-fish.

Dewailly É, Nantel A, Weber J-, Meyer F. High levels of PCBs in breast milk of Inuit women from Arctic Quebec. Bull Environ Contam Toxicol. 1989;43(5):641-6.

Dewailly É, Bruneau S, Ayotte P, Lebel G, Muckle G, Rhainds M. Évaluation de l'exposition Prénatale aux Organochlorés et aux Métaux Lourds chez les Nouveaux-nés du Nunavik, 1993-1996. Beauport: Centre de santé publique de Québec, Centre de toxicologie du Québec et Departement of Nutritional Sciences Guelph University; 1998.

Dewailly É, Ayotte P, Bruneau S, Lebel G, Levallois P, Weber JP. Exposure of the Inuit population of Nunavik (Arctic Québec) to lead and mercury. Arch Environ Health. 2001;56(4):350-7.

Donaldson SG, Van Oostdam J, Tikhonov C, Feeley M, Armstrong B, Ayotte P, et al. Environmental contaminants and human health in the Canadian Arctic. Sci Total Environ. 2010;408(22):5165-234.

Downie DL, Fenge T (Eds). Northern Lights against POPs: Combatting Toxic Threats in the Arctic. Montreal/Kingston: McGill-Queens University Press; 2003.

Egeland, GM. Inuit Health Survey 2007-2008: Nunatsiavut. Ste-Anne-de-Bellevue: Centre for Indigenous Peoples' Nutrition and Environment; 2010a. Available: http://www.mcgill.ca/cine/files/cine/adult_report_-_nunatsiavut.pdf.

Egeland, GM. Inuit Health Survey 2007-2008: Nunavut. Ste-Anne-de-Bellevue: Centre for Indigenous Peoples' Nutrition and Environment; 2010b. Available: http://www.mcgill.ca/cine/files/cine/adult_report_nunavut.pdf.

Environment and Climate Change Canada. A Guide to Understanding the Canadian Environmental Protection Act, 1999. Ottawa: Environment and Climate Change Canada; 2004. Available: http://www.ec.gc.ca/lcpe-cepa/E00B5BD8-13BC-4FBF-9B74-1013AD5FFC05/Guide04_e.pdf.

Environment and Climate Change Canada. Planning for a Sustainable Future: A Federal Sustainable Development Strategy for Canada. Ottawa: Environment and Climate Change Canada; 2010. Available: http://ec.gc.ca/dd-sd/default.asp?lang=En&n=06E31414-1.

Environment and Climate Change Canada. Chemicals Management Plan Progress Report, Issue 4, Spring 2015. Ottawa: Environment and Climate Change Canada; 2015. Available: http://www.ec.gc.ca/ese-ees/default.asp?lang=En&n=102CC1EE-1\.

Environment Yukon. Yukon Hunting Regulations. Whitehorse: Government of Yukon; 2015. Available: http://www.env.gov.yk.ca/hunting-fishing-trapping/huntingregulations.php.

Environment Yukon. Yukon Fishing Regulations. Whitehorse: Government of Yukon; 2016. Available: http://www.env.gov.yk.ca/hunting-fishing-trapping/fishingregulations.php.

Furgal C, Boyd A, Chan LHM, Osborne G, Baikie M, Edmunds-Potvin S. Assessment of contaminant and dietary nutrient interactions in the Inuit Health Survey: Nunavut, Nunatsiavut and Inuvialuit - Part 1: Risk Perception and Message Evaluation Study. In: Synopsis of research conducted under the 2013-2014 Northern Contaminants Program. Ottawa: Aboriginal Affairs and Northern Development Canada; 2014.

Global Affairs Canada. CANADA: National Reporting to CSD-18/19. Thematic Profile on Chemicals. Geneva: United Nations; 2009. Available: http://www.un.org/esa/dsd/dsd_aofw_ni/ni_pdfs/NationalReports/canada/Chemicals.pdf.

Government of Canada. Pest Control Products Act. Ottawa: Minister of Justice; 2006. Available: http://laws-lois.justice.gc.ca/PDF/P-9.01.pdf.

Government of Canada. Canada Gazette, Vol. 145, No. 41; 2011. Available: http://www.gazette.gc.ca/rp-pr/p1/2011/2011-10-08/pdf/g1-14541.pdf.

Government of Canada. Prohibition of Certain Toxic Substances Regulations, 2012. Ottawa: Minister of Justice; 2012. Available: http://laws.justice.gc.ca/PDF/SOR-2012-285.pdf.

Government of Canada. Canadian Environmental Protection Act, 1999. Ottawa: Minister of Justice; 2015a. Available: http://laws-lois.justice.gc.ca/PDF/C-15.31.pdf.

Government of Canada. Canada Gazette, Vol. 149, No. 14; 2015b. Available: http://www.gazette.gc.ca/rp-pr/p1/2015/2015-04-04/pdf/g1-14914.pdf.

Government of Canada. Risk Management Scope for Selenium and its Compounds under the Selenium-containing Substance Grouping. Ottawa: Environment Canada and Health Canada; 2015c. Available: http://www.ec.gc.ca/ese-ees/12443637-B973-49EC-B4C7-142D9E895C89/RM%20Scope_Selenium_EN.pdf.

Haines DA, Murray J. Human biomonitoring of environmental chemicals-early results of the 2007-2009 Canadian Health Measures Survey for males and females. Int J Hyg Environ Health. 2012;215(2):133-7.

Health Canada. Mercury: Your Health and the Environment. A Resource Tool. Ottawa: Health Canada; 2004. Available: http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/mercur/index-eng.php.

Health Canada. Lindane Risk Assessment: Re-evaluation Note REV2009-08. Ottawa: Pest Management Regulatory Agency; 2009. Available: http://publications.gc.ca/collections/collection_2010/arla-pmra/H113-5-2009-8-eng.pdf.

Health Canada. Report on human biomonitoring of environmental chemicals in Canada: Results of the Canadian Health Measures Survey Cycle 1 (2007–2009). Ottawa: Health Canada; 2010.

Health Canada. Discontinuation of Endosulfan: Re-evaluation Note REV2011-01. Ottawa: Pest Management Regulatory Agency; 2011. Available: http://www.hc-sc.gc.ca/cps-spc/pubs/pest/_decisions/rev2011-01/index-eng.php.

Health Canada. Second report on human biomonitoring of environmental chemicals in Canada: Results of the Canadian Health Measures Survey Cycle 2 (2009–2011). Ottawa: Health Canada; 2013.

Health Canada. Third report on human biomonitoring of environmental chemicals in Canada: Results of the Canadian Health Measures Survey Cycle 3 (2012–2013). Ottawa: Health Canada; 2015.

Heilmann C, Budtz-Jorgensen E, Nielsen F, Heinzow B, Weihe P, Grandjean P. Serum concentrations of antibodies against vaccine toxoids in children exposed perinatally to immunotoxicants. Environ Health Perspect. 2010;118(10):1434-38.

Kaufert J, Commanda L, Elias B, Grey R, KueYoung T, Masuzumi B. Evolving participation of aboriginal communities in health research ethics review: The impact of the Inuvik workshop. Int J Circumpolar Health. 1999;58(2):134-44.

Kinloch D, Kuhnlein H. Assessment of PCBs in Arctic foods and diets. A pilot study in Broughton Island, Northwest Territories, Canada. Arctic Med Res. 1988;47 Suppl 1:159-62.

Kinloch D, Kuhnlein H, Muir DCG. Inuit foods and diet: A preliminary assessment of benefits and risks. Sci Total Environ. 1992;122(1-2):247-78.

Kuhnlein HV, Receveur O, Chan HM. Traditional food systems research with Canadian indigenous peoples. Int J Circumpolar Health. 2001;60(2):112-22.

Lemire M, Kwan M, Laouan-Sidi AE, Muckle G, Pirkle C, Ayotte P, et al. Local country food sources of methylmercury, selenium and omega-3 fatty acids in Nunavik, Northern Quebec. Sci Total Environ. 2015;509-510:248-59.

Lévesque B, Duchesne J-, Gariépy C, Rhainds M, Dumas P, Scheuhammer AM, et al. Monitoring of umbilical cord blood lead levels and sources assessment among the Inuit. Occup Environ Med. 2003;60(9):693-5.

Myers H, Furgal C. Long-range transport of information: Are Arctic residents getting the message about contaminants? Arctic. 2006;59(1):47-60.

NRBHSS. Results from the Nunavik Child Development Study (NCDS): Public Health Implications. Kuujjuaq: Nunavik Regional Board of Health and Social Services (NRBHSS); 2011a. Available: http://inuit.org/fileadmin/user_upload/File/2012/Consultation_statements/Public_health_implications_Version_oct_2011_English_final.pdf.

NRBHSS. Nunavik Child Development Study (NCDS): Summary of Results. Kuujjuaq: Nunavik Regional Board of Health and Social Services (NRBHSS); 2011b. Available: http://inuit.org/fileadmin/user_upload/File/2012/Consultation_statements/NNHC_Summary_of_study_results_Version_oct_2011_English_final.pdf.

Pirkle JL, Kaufmann RB, Brody DJ, Hickman T, Gunter EW, Paschal DC. Exposure of the US population to lead, 1991-1994. Environ Health Perspect. 1998;106(11):745-50.

Plante R, Benedetti JL, Carrier G, Deshaies P, Gaudreault P, Kosatsky T, et al. Monographie. Définition nosologique d'une maladie à declaration obligatoire ou d'une intoxication et d'une exposition significative: le plomb. Direction des risques biologiques, environnementaux et occupationnels. Quebec: Institut national de santé publique du Québec (INSPQ); 1998.

Quinn CL, Wania F, Czub G, Breivik K. Investigating intergenerational differences in human PCB exposure due to variable emissions and reproductive behaviors. Environ Health Perspect. 2011;119(5):641-6.

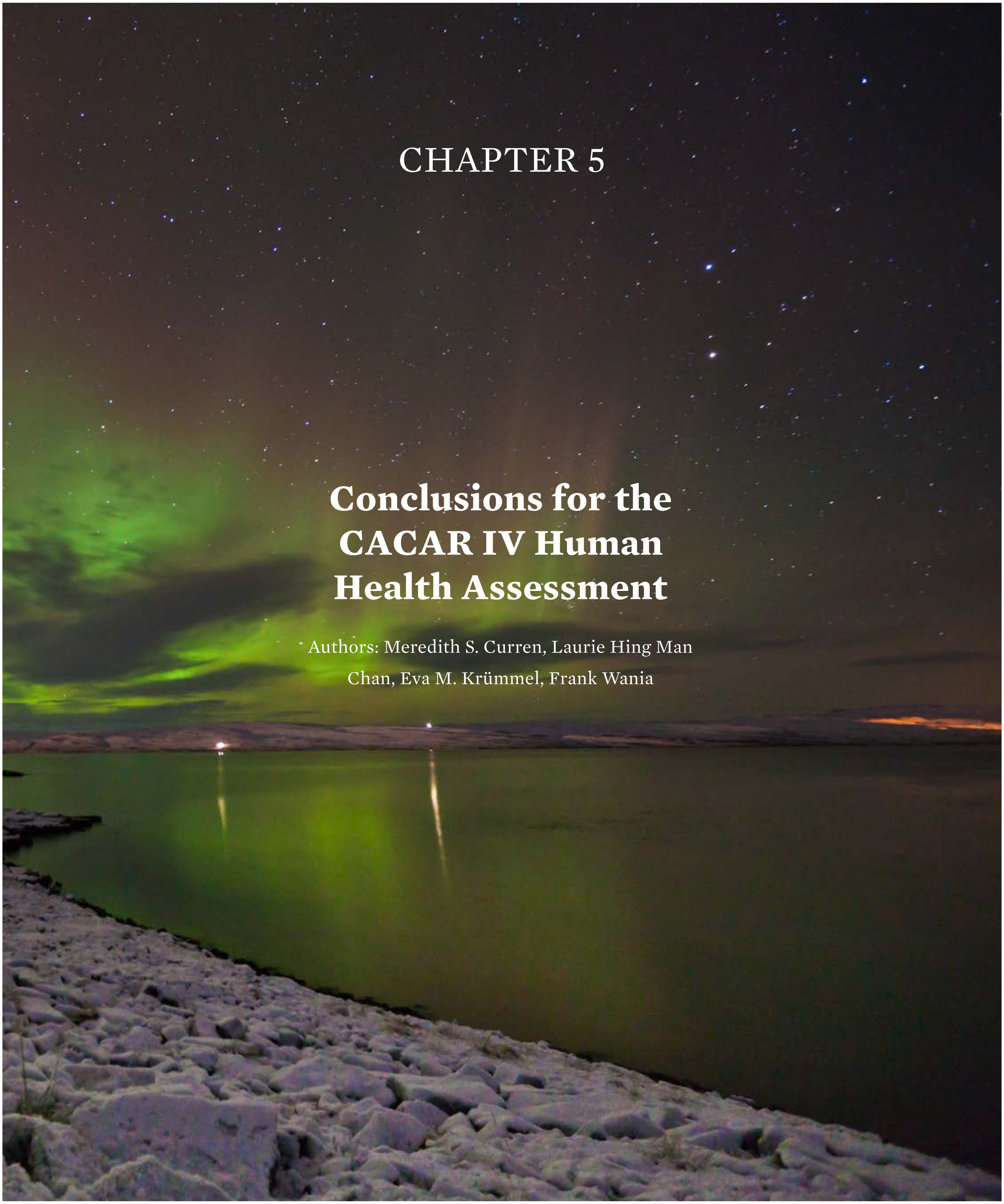
Rhainds M, Levallois P, Dewailly É, Ayotte P. Lead, mercury, and organochlorine compound levels in cord blood in Quebec, Canada. Arch Environ Health. 1999;54(1):40-7.

UNEP. The Stockholm Convention on POPs. Geneva: United Nations Environment Programme (UNEP); 2009. Available: http://chm.pops.int/Portals/0/download.aspx?d=UNEP-POPS-COP-CONVTEXT-2009.En.pdf.

UNEP. The Minimata Convention on Mercury. Geneva: United Nations Environment Programme (UNEP); 2015. Available: www.mercuryconvention.org.

United Nations. Report of the United Nations Conference on Environment and Development. Geneva: United Nations, 1999. Available: http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm.

Usher P, Baikie M, Demmer M, Nakashima D, Stevenson MG, Stiles M. Communicating about contaminants in country food: The experience in aboriginal communities. Ottawa: Inuit Tapiriit Kanatami /Inuit Tapirisat of Canada; 1995.



CHAPTER 5

Conclusions for the CACAR IV Human Health Assessment

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Chapter 5: Conclusions for the CACAR IV human health assessment

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This chapter presents conclusions for each of the previous chapters and the potential implications in assessing issues concerning contaminants and health in northern Canada.

5.1 Conclusions for Chapter 2

5.1.1 Key findings

Traditional food consumption

- Traditional foods are nutritious dietary choices for children and adults living in northern Canada. One-quarter to one-third of total calories consumed by Inuit in northern Canada is nowadays coming from high sugar foods and drinks. Including traditional food in the diet of Inuit children has been shown to reduce excessive energy and carbohydrate intake and to increase intake of protein, omega-3 fatty acids, and other important nutrients.

- The consumption of some traditional foods disproportionately increases mercury intake relative to nutrient intake. Substituting traditional foods high in mercury for others lower in mercury is one way to lower mercury intake, while still promoting consumption of healthy levels of important nutrients like selenium and omega-3 fatty acids in traditional food. It is critical that dietary substitutions and intervention strategies are designed at the regional level to make sure they are relevant to the different contaminant exposure sources, dietary preferences, and food availability scenarios for people across northern Canada.

- The importance of regionally specific dietary advice was reinforced during a mechanistic modelling study focusing on PCBs that found that the impact of changing marine mammal intake for women of childbearing age greatly depended on pre-existing rates of consumption and PCB body burdens. Because of the very long elimination half-life of PCBs from the human body, temporary reductions in the consumption of marine mammals may be largely ineffective in lowering blood concentrations of these POPs. On the other hand, large increases in marine mammal intake can very rapidly result in higher PCB exposure concentrations. However, for those who generally eat little traditional food from marine mammals, supplementing the diet with modest amounts of marine mammals can be nutritionally beneficial without necessarily causing undue risk from contaminant exposure.

Exposure to contaminants

- Geometric mean blood concentrations of nearly all measured POPs and metals were higher in Inuit women of childbearing age from Nunavik (2004) and Nunavut (2007-2008) than for women from the Inuvialuit Settlement Region (ISR) and Nunatsiavut (2007-2008). In Nunavut and Nunavik, where higher amounts of selenium-rich marine mammals are consumed, geometric mean selenium concentrations were also marginally higher and levels varied widely among study participants.

- Body burdens of POPs, metals, and selenium were most often higher in Inuit men who participated in the Inuit Health Survey (2007-2008) compared with Inuit women, often by as much as two- or three-fold; however, blood concentrations for Inuit men and women who participated in the Nunavik Inuit Health Survey (2004) were often quite similar, although mercury was higher among women. Cadmium was an exception, where Inuit men and women had similar concentrations within each of the four northern Inuit regions.

- Smoking, a major source of cadmium exposure, was highly prevalent amongst participants from the Inuit Health Survey (2007-2008) and the Nunavik Inuit Health Survey (2004), with about 70% of people smoking. Blood cadmium levels among non-smoking study participants from the Inuit Health Survey were about 3 to 10 times less than for than for the general Inuit population sampled during the Inuit Health Survey.

- Blood concentration data for total PCBs, toxaphene, chlordane, the sum of p,p'-DDT and p,p'-DDE, and lead increased with age for both male and female participants from the Inuit Health Survey (2007-2008). Inuit men who participated in the Inuit Health Survey ate larger portions of traditional foods and ate these foods more frequently than women. In addition, older adults (more than 40 years old) ate more traditional food than younger adults (less than 40 years old).

- Mechanistic modelling studies have observed that higher PCB levels in older individuals are due to the body's slow depuration of PCBs accumulated during time periods of high exposure in the past, and the main determinant of the body burden age relationship is the length of time elapsed since the peak in PCB exposure. Among Arctic populations this age trend is even more pronounced, as older generations tend to have a higher dietary intake of traditional food than younger generations, implying a higher intake of PCBs throughout life.

- Routes of exposure to PBDEs appear to vary across the Arctic. Blood concentrations for PBDEs tended to be lower in Inuit adults who participated in the Nunavik Inuit Health Survey (2004) compared to Inuit Health Survey (2007-2008) participants from the other three northern Inuit regions, and were otherwise generally similar between men and women from the ISR, Nunavut, and Nunatsiavut. These results suggest there were PBDE exposure sources that were not related to the consumption of traditional food, particularly to the consumption of marine mammals. PBDE-209, which has been shown to bioaccumulate in the eastern and western Arctic foodwebs, was the congener with the highest mean concentration in Inuit from the ISR, Nunavut, and Nunatsiavut.

Trends in exposure

- Levels of POPs have declined by about 80% across the 20 years (1992–2013) that biomonitoring has been used to evaluate contaminants exposure in pregnant Inuit women from Nunavik. Blood concentrations for total mercury have decreased by nearly 60% in these pregnant women. In contrast, selenium concentrations have decreased by less than 20% across 20 years. This observation may suggest a dietary transition towards traditional food items lower in mercury, but this remains to be confirmed. Some traditional foods are significant dietary sources of mercury, namely predatory fish and specific parts of marine mammals, but many traditional foods are also rich sources for selenium.

- Blood data for pregnant Inuit women from Nunavik showed declines of approximately two-fold for toxaphene, PBDE-47, pentachlorophenol, PFOS, and PFOA from 2004 to 2011-2012 or 2013 (toxaphene only). The exception was PBDE-153, which increased in mothers from Nunavik between 2004 and 2011-2012.

- Between 1992 and 2013, blood lead concentrations decreased by over 60% in pregnant women from Nunavik, likely related (in part) to the 1999-2000 multiple Nunavik stakeholder intervention to ban lead shot ammunition in Nunavik after the Government of Canada regulated the use of lead shot for hunting in 1999.

- A follow-up study in Nunavut in 2012 found that dust was a likely source for lead in households with the highest blood lead levels from the Inuit Health Survey (2007-2008). Lead isotope ratios found in the environment, when compared with those in the blood of participants, suggested that lead from paint and ammunition could be contributing to the lead burden in house dust. Exposure to lead from traditional food was relatively low in this follow-up study.

- Concentrations of several POPs declined by more than 40% in the blood of Inuit children from Nunavik as these children aged from an average of 5 years old to 11 years old. This decrease was likely influenced by several factors, including the lowering of environmental levels for some of these POPs and the duration of breastfeeding. POP levels are expected to decrease as children age because their rate of growth will likely exceed the rate of contaminant uptake from food over time.

Blood guideline exceedances

- When blood concentrations for total mercury in Inuit women of childbearing age from the Inuit Health Survey (2007-2008) were compared against the provisional interim blood guidance value for methylmercury of 8 µg/L in whole blood (for pregnant women, women of childbearing age, and children of both sexes), 42.5% of Inuit women from Nunavut exceeded this blood guideline in 2007-2008. While a marginally lower proportion of pregnant Inuit women from Nunavik exceeded this blood guideline in both 2011-2012 (36%) and 2013 (37.9%), the proportion of Inuit pregnant women and Inuit women of childbearing age from Nunavik exceeding the methylmercury blood guidance value has been decreasing overall since 1992.

- The proportion of pregnant Inuit women and Inuit women of childbearing age exceeding the blood lead intervention level of 100 µg/L in whole blood, as well as the guideline of 50 µg/L for lead in whole blood of pregnant women, has been decreasing steadily over time in Nunavik, with exceedances approaching zero since 2004.

- A higher proportion of Inuit men and women from Nunavut exceeded the guidance value for methylmercury of 20 µg/L in whole blood (for older women and adult men) compared to Inuit men and women from the ISR and Nunatsiavut. While the percentage of Inuit women exceeding the blood lead intervention level of 100 µg/L was highest in Nunavut, the percentage of Inuit men exceeding this blood lead intervention level was marginally higher in the ISR compared with Inuit men from Nunavut or Nunatsiavut.

Exposures in northern and southern Canada

- Levels for oxychlordane, PCB-153, PCB-180, mercury, lead, and selenium were generally between two- and eleven-fold higher among Inuit men and women from the four northern Inuit regions in Canada (2007-2008, and 2004 for Nunavik) compared to the general Canadian population in southern Canada (2007-2009). However, PBDE-47 concentrations were higher in men and women from the general Canadian population in southern Canada than for Inuit adults living in the four northern Inuit regions.

- The observation of higher levels of many POPs in people from northern versus southern Canada is consistent with findings from some mechanistic modelling studies that have observed that Inuit living in northern Canada may have potentially greater POP exposure due to the presence of some marine mammals in their diet.

- When data for women of childbearing age from the general Canadian population (2007-2009) are examined by country of birth, it appears that women born outside of Canada experienced higher exposures to several POPs than women born in Canada. These foreign-born women had contaminant body burdens that were often similar to Inuit women of childbearing age from the ISR and Nunatsiavut (2007-2008). As well, p,p'-DDE levels in foreign-born women of childbearing age from the general Canadian population appeared to be two- to ten-fold higher than for Canadian-born women of childbearing age from the general Canadian population and for Inuit women of childbearing age living in the four northern Inuit regions.

- Results from the Nunavik Child Development Study suggest that Inuit children from Nunavik experienced higher exposures to mercury and lead than children from the general Canadian population during the period 2000 to 2009.

5.1.2 Knowledge gaps and future directions

Biomonitoring for specific populations

- Northern studies have observed that the developing fetus is sensitive to some contaminant exposures. Time trends for contaminants have been determined for pregnant Inuit women from Nunavik through continued sampling of maternal blood; however, additional studies are required to ascertain contaminant trends for women of childbearing age and pregnant women from the other three Inuit regions. Recognizing that Inuit children living in northern Canada appear to show relatively high concentrations of some contaminants compared with children from the general Canadian population, but that there are also some chemicals at higher concentrations in the general Canadian population relative to northern Inuit (e.g. PBDE-47), it is important that women of childbearing age and children are considered during future biomonitoring studies in both northern and southern Canada.

- The factors driving the observed decreases for mercury and selenium in Inuit from Nunavik are not well understood, and it is also unclear whether these factors might be relevant for other northern regions. Both increasing and decreasing mercury concentrations have been observed in northern biota (Braune et al., 2005; Rigét et al., 2011), while levels in northern people show a general decline. The decrease in blood mercury concentrations in people might be related to lower consumption of traditional foods high in mercury (or readily absorbed mercury), a decrease in mercury deposition, bioaccumulation, biomagnification, or rate of methylation in the Arctic environment, a shift in the consumption of different traditional foods, or several of these variables occurring simultaneously.

- The extent of site-specific variations of mercury concentrations in fish and other traditional food, as well as the importance of consuming specific traditional foods that may contain high concentrations of mercury, remains a knowledge gap. On-going consideration of the interests of northern communities during future studies that examine contaminants in traditional food will ensure these specific exposures are being investigated within the context of the regional exposure issue. As well, this approach would ensure that any important health, dietary, or contaminant issues that may arise will be addressed with the communities in the most appropriate cultural health context.

- Biomonitoring studies that examine older adults (45 years and older) specifically are warranted because contaminant concentrations have, in general, been shown to be higher in the adult Inuit population in northern Canada, particularly in older men, due in part to higher historical or current consumption of traditional food. It is known that high body burdens of contaminants of concern are sometimes related to health effects during adulthood. Older men and women may require specific dietary advisories or information to make dietary choices for their own health.

- The co-location of biomonitoring studies in people and wildlife is encouraged, as this would permit researchers to create direct links between current exposures and measured body burdens. It is expected that levels of POPs and metals will continue to vary in both people and wildlife across time.

- The contribution of dietary and non-dietary sources for PBDE exposures in northern Canada is not well understood and warrants further investigation. The extent of exposure from traditional food compared to other sources, such as dust in the home, still remains largely unclear.

- House dust may also be an important source of exposure to lead in older homes or in households that handle ammunition and firearms for hunting. The contribution of house dust as a source of exposure to lead under these circumstances is a knowledge gap.

New and emerging chemicals

- The identification and measurement of new chemicals in commerce that might be transported to the Arctic and bioaccumulate in wildlife and northern people is a current knowledge gap. For example, a mechanistic modelling study has estimated that a small number of chemicals included in the third phase of Canada's Chemicals Management Plan (see Chapter 4) may be reasonably persistent in the environment and undergo only very limited metabolism in higher organisms. These chemicals almost all contain highly fluorinated alkyl-chains.

- The inclusion of new chemicals in northern biomonitoring studies will likely require the development of novel laboratory methods for identifying and measuring these chemicals in human samples. The development of new methods is oftentimes a resource- and time-intensive process. Recognizing the varying requirements of ethics approval committees, storing samples for longer periods of time in biobanks would help facilitate the development of new methods and, eventually, the measurement of long-term trends of new contaminants of concern.

New methods and screening tools

- Continuing to develop innovative tools (e.g. mechanistic models, biomonitoring equivalents) would support public health authorities during the interpretation of biomonitoring results and with the management of risk of exposure to contaminants. The development of such models and screening tools may also help account for changing environmental levels, along with the impact of dietary transitions.

- Metal bioaccessibility studies (the fraction of metal solubilized by the body after oral exposure) may also be used to adjust exposure estimates and to inform risk mitigation strategies.
- Exposure characterization in future epidemiological studies may benefit from mechanistic modelling of longitudinal contaminant concentrations in individuals, including the reconstruction of cumulative exposure as well as exposure during age brackets of susceptibility. This would require reliable information on dietary composition and weight gain or loss, in addition to the parameters typically collected for epidemiological studies (e.g. age, weight, height, reproductive characteristics).
- Novel methods should be developed and applied to complement dietary recall and food frequency questionnaires to determine reliable rates or types of traditional food consumption during human biomonitoring studies. These methods could rely on chemical tracers and improved recording of dietary intake and composition.

5.2 Conclusions for Chapter 3

5.2.1 General conclusion

- There are many challenges associated with the design, implementation, and interpretation of studies that examine health outcomes related to contaminants in the Arctic. Northern studies must address exposure to complex contaminant mixtures, small population sizes, contaminant-nutrient interactions, genetic factors, other confounding factors, and regionally-specific health priorities. Nonetheless, significant progress has been made since the last CACAR report in 2009. Two decades of work with children and adults in Nunavik have provided information regarding the long-term effects of exposure to lead, mercury, and PCBs, along with empirical support for national and international regulations and for regional public health interventions. As well, the Inuit Health Survey (2007-2008) has expanded the coverage of cross-sectional studies for adults beyond Nunavik to the other three Inuit regions (i.e. the Inuvialuit Settlement Region, Nunatsiavut, and Nunavut). Knowledge gaps still exist that provide opportunities for further research to inform and support public health activities on contaminants-related health issues in northern Canada.

5.2.2 Knowledge gaps and future directions

Effects of lower dose and long-term effects on health

- During the past several years, effects associated with methylmercury exposure have been documented in humans at lower exposures than ever before (Karagas et al., 2012). This may be attributable to the use of better study designs, larger groups of participants, more sensitive methods, or better control of confounding factors that may influence the study outcomes. From the evidence available, it is clear that the developing brain is the most vulnerable organ system. Given the complexity of brain development and the difficulties in determining detailed functions, especially in developing children, it is likely that future studies will continue to identify effects at lower methylmercury exposures than those considered safe today. This is an important area requiring more research.

Interactions of nutrients and contaminants

- There is increasing evidence showing beneficial interactions between some nutrients and contaminants. For example, polyunsaturated fatty acids appear to protect against mercury neurotoxicity in children, while selenium may protect against the effects of mercury and POPs on oxidative stress. The contaminant concentration and nutrient composition of many traditional food items need to be identified (or updated), and additional studies on the potential beneficial effects of readily available foods in the North are warranted. A detailed contaminant concentration and nutrient composition database with data collected at the regional level will help public health professionals to recommend specific dietary approaches to lower the risk associated with the intake of contaminants and to maximize the benefits of nutrients.

PCB time trends and composition of congeners

- The results from the Nunavik Child Development Study suggest that the composition of PCB congeners found in people in northern Canada may have less toxicity than those in southern populations. With the implementation of the Stockholm Convention (see Chapters 1 and 4), environmental PCB concentrations are expected to be in decline. The combined effects of these two factors may change the concern of PCB exposure on the health of Inuit populations in the future. Health studies that examine on-going and future PCB exposures for Indigenous people in northern Canada could provide confirmation of these assumptions.

Long-term effects of cadmium exposure

- Elevated cadmium concentrations continue to be observed among Inuit in northern Canada. Smoking rates remain high, particularly among women of childbearing age. Sustained efforts on anti-smoking campaign are needed. Moreover, potential long-term effects of cadmium exposure on bone and kidney health of Indigenous people in northern Canada should be studied.

Health effects for emerging contaminants

- Some new and emerging contaminants, such as PFOS and PBDEs, are now found in Arctic biota and humans. There is preliminary evidence that indicates both groups of chemicals have potential effects on the thyroid and the endocrine system. More data on exposure to and potential health outcomes related to new or less studied environmental contaminants at exposure levels relevant to Indigenous people in northern Canada are needed to inform risk evaluation and risk management decisions.

Effects of mercury on adults

- The exposure levels of mercury among some Inuit adults in northern Canada were found to be at levels that in other populations were sufficiently high to cause effects on motor functions and vision. However, to date, potential effects of mercury on the neurological performance of Inuit adults have not been studied. A well designed study focusing on adults with high mercury exposures is warranted.

Effects of selenium

- Although selenium is an essential nutrient for human health, it can be toxic at elevated exposures, leading to selenosis. Inuit who consume marine mammal based diets have been identified as having the potential for elevated selenium exposure. Some Inuit in northern Canada have shown high blood selenium levels, and selenium levels have also varied widely among northern Inuit (see Chapter 2). In some cases, selenium has been found to be a beneficial cofactor for mercury and POP effects on risk of cardiovascular disease. However, while there has been no reported case of selenosis among the Inuit, selenosis has not been specifically monitored in Canadian Inuit populations. The benefits and potential risks of elevated selenium consumption from a traditional diet warrant further investigation.

- There is increasing evidence that some organic chemical forms of selenium (i.e. found in traditional food with naturally high concentrations of selenium) may be of lower toxicity than other organic or inorganic chemical forms of selenium (e.g. found in some selenium dietary supplements, in drinking water, or in an occupational setting). More research on the chemical forms of selenium present in selenium-rich traditional northern diets and on the associated health effects of those selenium forms are also areas of potential research focus.

Contaminants and risk of chronic diseases

- New data related to the role of mercury and POPs on cardiovascular disease risk factors (e.g. oxidative stress, cardiac variability, and blood pressure) collected from three cross-sectional studies conducted in Greenland (Nielsen et al., 2012; Valera et al., 2013), Nunavik, and the three Inuit regions from the Inuit Health Survey have been inconsistent. These inconsistencies may be due to the relatively small number of samples for each study. Since the design of the three studies is similar, the combining of these datasets should be considered. Analysis of the combined data may provide more power to elucidate potential effects of contaminants on health. As well, circumpolar studies outside of Canada have examined associations between Type 2 diabetes and POP exposures. It is recommended that the Canadian studies also examine this association.

Effects of genetic polymorphisms and epigenetics

- There is an increasing understanding of the role of genetic determinants on contaminant metabolism and accumulation. For example, significant associations between POP levels and certain genetic polymorphisms were observed among Greenlandic Inuit (Ghisari et al., 2013). Another study showed an association between plasma POP concentrations and the percentage of global DNA methylation among Greenlandic Inuit (Rusiecki et al., 2008). Given the unique genetic backgrounds of Indigenous people, the impact of genetic polymorphisms that are involved in xenobiotic metabolism and toxicity in the Arctic is an area that warrants further research.

- Moreover, a number of studies support that the Inuit have specific genotypes that affect lipid metabolism (for example, Dubé et al., 2014). Gene-diet interactions can play an important role in modifying plasma lipid levels and risk factors for cardiovascular disease. Therefore, the role of genetic determinants should be taken into consideration in future studies evaluating the susceptibility of the Inuit to environmental contaminants and the relationship between body burden of contaminants and risk factors for chronic diseases.

Roles of the gut flora

- There is increasing evidence that the diet can modify the community composition of the gut flora (or microbiome), which in turn has been associated with health outcomes, including gut health, allergies, and cancer (O'Keefe et al., 2015). Studies have demonstrated that bacteria play an important role in the methylation of mercury and can alter its bioavailability. However, further research is needed to elucidate the relationship between diet, exposure to contaminants, and the impact of the microbiome among Inuit. The unique marine-based diet of the Inuit and the relatively high exposure to environmental contaminants provide a rationale for research on the roles of microbiome on their health, taking into consideration the dietary transitions to market foods that might be taking place in northern Canada.

5.3 Conclusions for Chapter 4

5.3.1 Key findings

Chemical management and communication at national and regional levels

- *The Canadian Environmental Protection Act*, 1999 (CEPA) is the cornerstone of federal environmental legislation for assessing and managing chemicals in Canada. The Government of Canada launched the Chemicals Management Plan (CMP) in 2006 to protect human health and the environment by assessing substances of concern and taking action to manage those substances found to be harmful. CMP activities are conducted under the authority of CEPA. The CMP set a 2020 goal for completing the assessments of the 4,300 chemicals identified through the Domestic Substances List (DSL) categorization process as priorities for further assessment.

- Human biomonitoring for the general population in Canada differs from biomonitoring done through the NCP with regard to the chemicals covered, the make-up of study participants, and the communication plans or products. The CHMS has measured a broad range of contaminants (including POPs and metals) in the Canadian population aged 3 to 79 years living in the ten provinces, which covers approximately 96% of Canada's population. The CHMS does not include persons living in the three territories, on reserves and other Indigenous settlements in the provinces, or residents of certain remote regions. To fill some of these gaps, Health Canada provides funding to the NCP to enhance northern biomonitoring. Currently, the mandate of the NCP covers contaminants that undergo long-range environmental transport and persist in the northern environment.

- Expansion of northern biomonitoring to include chemicals that are studied under other national programs (e.g. in southern Canada under the Chemicals Management Plan) would support public health efforts of territorial, regional, and federal risk management groups, potentially permit the examination of chemical exposures from local sources, and provide a better understanding of the full chemical exposure profile of northern populations.

- The Stakeholder Advisory Council (SAC) has provided a mechanism for national Indigenous organizations to contribute input to the chemical review and communication processes under the CMP. While northern regional organizations and territorial governments have not been directly engaged in the CMP through the SAC, there have been recent activities that have involved the NCP network of northern Indigenous partners, research scientists, and territorial and regional health authorities; for example, during preparation of the draft Screening Assessment Report and Risk Management Scope documents for selenium and its compounds under the Substance Groupings Initiative of the Chemicals Management Plan. Plain-language documents are communication tools that are used to facilitate engagement with stakeholders and the public. For those chemicals identified as having particular relevance for Indigenous populations (e.g. selenium), tailored information pieces may be developed for Indigenous organizations and their respective networks.

- The NCP is a best practice program model that supports capacity building, and it ensures participation of northern Indigenous people in program management, research, and information dissemination. Since the early years of the NCP, benefit-risk communication has been undertaken by Indigenous partners and territorial and regional health authorities.

- Health messages created from NCP-funded projects have focused on the amount and types of traditional food consumed, as well as the benefits of traditional food consumption. However, the communication of research results and advisories to northern communities remains a challenging task due to the complexity of balancing the social, cultural, economic, spiritual, and nutritional benefits of consuming traditional foods with the potential health risks associated with contaminants in some traditional foods.

- Chemical management and contaminant communication follow similar processes in each of the Canadian northern regions, and these activities are guided by the NCP management structure. Each region has a Regional Contaminants Committee (RCC), whose membership differs from region to region. The RCCs provide a connection between the NCP, northern researchers, territorial and regional health authorities, and communities. The Inuit regions additionally have Inuit Research Advisors (IRAs) that form part of the RCCs. The RCCs are integral to assist in the development of communication plans for research results or health advisories to communities.

- Positive experiences in communicating research results in the North have been found when studies are designed and completed through a partnership approach between researchers and northern communities. Northern research studies that have engaged community members early-on and throughout the study have been shown to address the interests and concerns of community members.

Chemical management and communication at the international level

- The NCP has provided key research information on contaminants in the Arctic for establishing the Stockholm Convention, and on-going work by the NCP continues to support the consideration of new POPs for listing under the Stockholm Convention and for measuring its effectiveness. NCP studies that include new and emerging contaminants will permit the NCP to assess whether the next generation of chemicals may become a health concern in the North.

- Local health advisories in northern regions are important interim measures to address contaminant exposures until concentrations in traditional food sources decline to safe levels.

- Information on the Stockholm Convention process can be shared using existing federal government communications and activities, as well as via non-governmental and Indigenous organizations (such as the Inuit Circumpolar Council) that are registered observers to the Stockholm Convention, who participate in this process, and who are also NCP partners.

- The NCP has a key role in disseminating information about the risks posed by contaminants for Indigenous people in northern Canada and internationally. Findings from NCP studies on contaminants in Arctic biota may lead to the publication of regional consumption advisories for certain traditional food items and for specific populations that may be at a greater health risk. Rapid dispersal of messages meant for one group or location can create anxiety and confusion in other areas where the scientific information or the advisory does not apply, or is not intended. The information can be misconstrued if this language is changed during subsequent reporting through the media and social media.

5.3.2 Knowledge gaps and future directions

Chemical management and communication at national and regional levels

- A regular process in which the CMP engages the NCP Secretariat would permit the creation of a conduit for sharing of information between the CMP and northern stakeholders, potentially leading to improved northern engagement and progress toward protection of the Arctic ecosystem and of northern Indigenous people who rely on this ecosystem.

- Currently there is no single multi-stakeholder or partnership approach for contaminant communications within the NCP, and research funding is often disconnected from the risk communication process. Regionally appropriate risk communication processes should be integral within any research related to contaminants monitoring in the North, and agreement should be obtained between research partners on the different roles and responsibilities.

- Northern research funds should be specifically assigned to a communication plan, and all research stakeholders should participate in the preparation of risk communication messages. However, public health advisories should continue to fall within the role of the appropriate regional public health official. An integrated multi-stakeholder risk communication group that includes federal subject matter experts, toxicologists, researchers, community representatives, public health officials, and staff from the northern regions would be a good solution to balance the varying perspectives.

- There is a need to conduct evaluations after risk communication activities, to ensure that messages derived from northern research were released and received as planned and expected.

- Communication tools that contain complex scientific language are sometimes difficult for community members to understand. Effective northern communication tools include those that permit easy understanding of research results and make results accessible past study completion, and may include the creation of visual banners or signs posted in public locations that are frequented by community members.

- An additional improvement may be the creation of tools that can help researchers to develop their communication plans, such as through the creation of best practice communication examples that are made available through the internet or similar accessible media.

Chemical management and communication at the international level

- Communication strategies that solicit agreement between international research partners, including Indigenous organizations, for using the same language from local or regional advisories as at the international scale might help to avoid conflicting information delivered through a variety of communication outlets, including the international media and the internet.

- Continuous communication is required locally to reinforce the validity of messages to a specific audience and prevent confusion through non-local information sources that may not be valid for the region or community to which the information was intended.

References for Chapter 5

Braune BM, Outridge PM, Fisk AT, Muir DCG, Helm PA, Hobbs K, et al. Persistent organic pollutants and mercury in marine biota of the Canadian Arctic: An overview of spatial and temporal trends. Sci Total Environ. 2005;351-352:4-56.

Dubé JB, Wang J, Cao H, McIntyre AD, Johansen CT, Hopkins SE, et al. Common low-density lipoprotein receptor p.G116S variant has a large effect on plasma low-density lipoprotein cholesterol in circumpolar Inuit populations. Circ Cardiovasc Genet. 2015;8(1):100-5.

Ghisari M, Long M, Bonefeld-Jørgensen EC. Genetic polymorphisms in CYP1A1, CYP1B1 and COMT genes in Greenlandic Inuit and Europeans. Int J Circumpolar Health. 2013;72:21113.

Karagas MR, Choi AL, Oken E, Horvat M, Schoeny R, Kamai E, et al. Evidence on the human health effects of low-level methylmercury exposure. Environ Health Perspect. 2012;120(6):799-806.

Nielsen AB, Davidsen M, Bjerregaard P. The association between blood pressure and whole blood methylmercury in a cross-sectional study among Inuit in Greenland. Environ Health. 2012;11:44.

O'Keefe SJD, Li JV, Lahti L, Ou J, Carbonero F, Mohammed K, et al. Fat, fibre and cancer risk in African Americans and rural Africans. Nat Commun. 2015;6.

Rigét F, Braune B, Bignert A, Wilson S, Aars J, Born E, et al. Temporal trends of Hg in Arctic biota, an update. Sci Total Environ. 2011;409(18):3520-6.

Rusiecki JA, Baccarelli A, Bollati V, Tarantini L, Moore LE, Bonefeld-Jorgensen EC. Global DNA hypomethylation is associated with high serum-persistent organic pollutants in Greenlandic Inuit. Environ Health Perspect. 2008;116(11):1547-52.

Valera B, Jørgensen ME, Jeppesen C, Bjerregaard P. Exposure to persistent organic pollutants and risk of hypertension among Inuit from Greenland. Environ Res. 2013;122:65-73.