Northern Contaminants Program

Canadian Arctic Contaminants and Health Assessment Report

HUMAN HEALTH 2009

Indian and Northern Affairs Canada
Affaires indiennes et du Nord Canada

Canada

Chukchi Sea
Arctic Ocean
Beaufort Sea
Sachs Harbour (Ikaahuk)
Old Crow
Tuktoyaktuk
Aklavik (Akłarvik)
Inuvik (Inuuvik)
Fort McPherson (Teetł’it Zheh)
Tsiigehtchic (Tsııgehtshık)
Paulatuk (Paulatuuq)
Holman (Uluqsaqtuuq)
Colville Lake (K’áhbamį́túé)
Fort Good Hope (Rádeyı̨lı̨kǫ́é)
Dawson
Keno Hill
Beaver Creek
Mayo
Pelly Crossing
Norman Wells (Tłegǫ́htı̨)
Kugluktuk (Coppermine)
Iqaluktuutiaq (Cambridge Bay)
Umingmaktuuq
Faro
Ross River
Carmacks
Déline (Délı̨ne)
Tulita (Tulít’a)
Qinguaq (Bathurst Inlet)
Haines Junction
Whitehorse
Wrigley (Pedzéh Kį)
Rae Lakes (Gametì)
Snare Lakes (Wekweètì)
Carcross
Teslin
Wha Ti (Wha Tı)
Rae-Edzo (Behchokǫ̀-Edzo)
Watson Lake
Fort Simpson (Łíídlı̨ Kų́ę́)
Jean Marie River (Tthek’éhdélı̨)
Yellowknife (Sǫ̀mbak’è)
Nahanni Butte (Tthenáágó)
Fort Liard
Fort Providence (Zhahtı Kų́ę́)
Lutselk’e (Łútsëlk’é)
Hay River (Xátł’odehchee)
Fort Resolution (Denínu Kų́ę́)
Fort Smith (Tthebacha)

Alert
Ausuittuq
(Grise Fiord)
Resolute
(Qausuittuq)
Ikpiarjuk/Tununirusiq
(Arctic Bay)
Mittimatalik
(Pond Inlet)
Kangiqtugaapik
(Clyde River)
Baffin Bay
Taloyoak
Igloolik
Sanirajak
(Hall Beach)
Qikiqtarjuaq
(Broughton Island)
Uqsuqtuuq
(Gjoa Haven)
Kugaaruk
(Pelly Bay)
Pangnirtung
Naujaat
(Repulse Bay)
Iqaluit
Kinngait
(Cape Dorset)
Qamanittuaq (Baker Lake)
Salliq
(Coral Harbour)
Kimmirut
(Lake Harbour)
Igluligaarjuk (Chesterfield Inlet)
Kangiqliniq (Rankin Inlet)
Tikirarjuaq (Whale Cove)
Ivujivik
Salluit
Kangiqsujuaq
Quaqtaq
Akulivik
Kangirsuk
Arviat
Puvirnituq
Aupaluk
Kangiqsualujjuaq
Tasiujaq
Nain
Kuujjuaq
Hudson Bay
Inukjuak
Hopedale
Makkovik
Postville
Rigolet
Umiujaq
Sanikiluaq
Happy Valley/Goose Bay
Kuujjuarapik

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HUMAN HEALTH

Contributors

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Executive Summary

The Northern Contaminants Program (NCP)[1] undertook this assessment to address concerns about possible adverse health effects for people exposed to persistent organic pollutants (POPs) and heavy metals through a diet of country (traditional) foods. These concerns are particularly relevant for Aboriginal peoples. Country food is an important part of their diet and there are significant cultural, social, economic, nutritional, spiritual, and psychological benefits.

The objective of this assessment was to build on the knowledge base of contaminants and human health developed in the first two phases of the program. This third assessment provides data from ongoing research on changes in human contaminant concentrations and exposure among Canadian Arctic people, discusses possible health effects, identifies new contaminants of concern, outlines risk characterization and communication about contaminants in country food, and identifies knowledge gaps.

Country food and northern diet

Many northern communities are facing economic, political, social, and environmental changes that are influencing human health and well-being. As a result, the need for timely, relevant information about food choices and safety has never been greater. This, in turn, calls for ongoing monitoring of food consumption behaviour, further understanding of food safety perspectives, and additional insight into determinants of food choice.

Country food contributes greatly to the overall quality of the diets of people living in Arctic Canada by increasing their intakes of protein and many vitamins and minerals. Country food, however, is also a significant source of exposure to environmental contaminants. Although country food use is culturally specific and varies widely throughout the Arctic, the overall trend shows that younger generations are consuming significantly less country food than their elders. Research suggests that the void has been replaced by high-carbohydrate, low-nutrient, market-based foods, which can contribute to increased risk of diabetes, micronutrient deficiencies, obesity, and chronic disease.

A detailed dietary analysis with corresponding contaminant data for the Inuvik region showed changing consumption patterns, which indicates that the risk-benefit message — "traditional food is good for you, especially during pregnancy, but if you are worried about contaminants, consume foods such as char, caribou, or moose" — is being heard. This analysis showed that fish consumption had increased markedly among the Inuvialuit and the Dene/Métis mothers. The Inuvialuit mothers also reported eating more caribou, bird, and seal meat and decreasing their intake of marine mammal fat (particularly beluga).

Human exposure and contaminant levels

Findings from this assessment show significant declines in most contaminants in maternal blood over the last 10 years for all Canadian Arctic regions. A number of maternal contaminant levels are now less than one-half the levels they were a decade ago. The one exception is cadmium, which showed increased levels in maternal blood samples from the Inuvik, Baffin, and Nunavik regions. This has been linked to increased smoking in this age group and is a significant public health issue for all regional health authorities. In order to confirm the decreasing levels seen over the past 10 years, ongoing monitoring of POPs and metals is imperative. This trend monitoring is also necessary for compliance with various national/international monitoring programs.

As noted in earlier assessments, Inuit have the highest levels of almost all POPs and metals — they have the highest levels of polychlorinated biphenyls (PCBs), mercury, and cadmium among the ethnic groups (Dene/Métis, Caucasian, Inuit) sampled. More than half of Inuit surveyed in Nunavik and almost one-quarter surveyed in Nunavut exceeded the Health Canada *Level of Concern* for PCBs, although the proportion of the

[1] For a complete list of acronyms, please refer to Appendix A.

mothers exceeding this guideline has decreased since the last assessment. None of the Dene/Métis or non-Aboriginal mothers exceeded this *Level of Concern*. These findings were consistent for mercury. One-third of Inuit mothers from Nunavut and Nunavik exceeded the *Increasing Risk Range*, while none of the other ethnic groups did. All groups were found to be below the *Intervention Level* that Health Canada has set for lead.

Additional research is required to monitor levels of organochlorines (OCs) and metals in country food in order to better understand how they are changing in the Arctic. Further work should be carried out to assess human dietary exposure to contaminants in a small representative cross-section of highly and moderately exposed regions, and to provide another time point with which to compare data from earlier phases of the program.

Policy makers require up-to-date information on new and emerging contaminants — such as polybrominated diphenyl ethers (PBDEs) and perfluorooctane sulfonate (PFOS) — to design appropriate control mechanisms. In some regions, concentrations of PBDEs (a group of chemicals used as flame retardant) and PFOS (a chemical used as a stain repellent) are increasing in Arctic wildlife, but there is insufficient data to assess trends in Arctic peoples. The level of PBDEs in Canada's Arctic population is similar among various ethnic groups, and is markedly lower than those of mothers from southern Quebec. The levels of PFOS found in Nunavik maternal blood samples has decreased, though this is based on very limited data. Given the amount of uncertainty in the Arctic today, recent changes in contaminant concentrations in the environment and humans will require verification through ongoing monitoring.

New analytical technologies and study methods now allow scientists to quantify human exposure to emerging POPs and POP metabolites and evaluate their health effects. New data should be available within the next few years.

Toxicology

Toxicology studies have shown that exposure to mixtures of chemicals found in country foods can modify tissue contaminant levels as well as the toxicity of individual contaminants. This affects body burden and dose-toxicity relationships, which means that single chemical toxicity studies are less applicable. Although epidemiological studies can identify exposures detrimental to human health, toxicological studies are needed to support the biological plausibility of associations and verify the mechanisms of action and precise dose-effect relationships. Therefore, additional research should focus on identifying and better understanding the health effects of mixtures of contaminants on highly exposed Arctic peoples.

While some experimental evidence shows interesting interactions between essential dietary nutrients and contaminants — trace elements, vitamins, and fatty acids are capable of attenuating to some degree the toxicity

Eric Loring

of some food-borne contaminants — confirmation in human studies tends to be equivocal. Additional studies are required to clarify the health benefits of consuming country foods.

Uncertainty exists regarding exposure to PBDEs and health effects for people in the Arctic. There is evidence that adverse health effects are not anticipated given current exposures to PBDEs, at least for the experimental effects involving thyroid hormones. However, adverse health effects could be plausible if human tissue levels continue to increase at the current rate. Therefore, future research is required to define more precisely the extent to which current dietary exposures or human residues are associated with a health risk.

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Epidemiology

Conducting epidemiological studies in the Canadian Arctic is challenging due to a variety of limiting factors: exposure to complex contaminant mixtures, small population size, contaminant-nutrient interactions, genetic factors, confounders, and health priorities. For this reason, epidemiological studies conducted in other parts of the world have been widely used for risk assessment. However, various unique factors may limit their external validity. Therefore, studies in the Canadian Arctic need to continue.

The multifaceted effects of contaminants on human health leave many research questions unanswered. New data suggest important beneficial effects on brain development for Inuit infants by country food nutrients such as omega-3 fatty acids. These effects are seen in different domains than those that are attributable to contaminants exposure. More research is needed to identify and characterize possible health effects such as thyroid hormone disruption or neurodevelopment problems in infants and children associated with prenatal exposure to contaminants. As well, the interactions between nutrients found in seafood and the effects of contaminants require further study.

Multiple studies related to the immune system function in Nunavik associated an increase in lower respiratory tract infections and acute otitis media during childhood with prenatal exposure to POPs. In addition, studies showing sub-optimal levels of vitamin A and altered vitamin A homeostasis from some POPs point to the need to understand the relationships between vitamin A, contaminant levels, and infectious disease incidence in Arctic populations.

Study results on human growth and PCB exposure are contradictory in general population studies where the exposure does not come from fish or sea mammal consumption, and are inconsistent when comparing data from highly exposed cohorts; however, the latter does not rule out the hypothesis of growth effects associated with in utero PCB exposure. Investigating the genetic specificity of studied populations would help further a more complete scientific understanding of the human growth and PCB exposure studies.

Studies looking at the role of methylmercury and POPs exposure in the development of the metabolic syndrome, cardiovascular diseases, and diabetes are only beginning. As such, they are still controversial. Methylmercury may suppress defence mechanisms against oxidative stress, decrease cardiac variability, and increase blood pressure. Further experimental and epidemiological work is needed in this area.

Risk communication

Risk communication is a continually evolving process. Over the past 16 years the NCP has learned that frequent information about contaminants may overwhelm communities, so the number and frequency of messages has decreased. It has also determined that communication may be more efficient and better heeded if it is built into existing public health messages and incorporates local perception and expertise. Studies show that northern residents want specific, practical information to help contextualize the risks associated with exposure to contaminants and support their decision-making processes. Evaluations of prior risk communications about contaminants would provide valuable knowledge as the NCP program continues to evolve.

In order to better assess scientific findings and assist with decision making, a common process to evaluate and compare all benefits and risks of country food (and its alternatives) needs to be developed. Many people living in the Arctic are cash-poor and their food choices largely depend on the type of food to which they have easy access, and on their social networks, which may include food sharing. The most successful health promotion strategies focus on changing the availability of nutritious foods, rather than on changing habits and behaviour. Research that advances the understanding of food choice determinants and evaluates food substitution and other management programs would be helpful in northern regions where exposure levels are a concern. Particular reference for evaluations and comparisons needs to be made with respect to the most highly exposed communities and vulnerable groups, including mothers, pregnant women, females of child-bearing age, the fetus, infants, and children. As well, more research is required to identify the specific regional sources and concentrations of contaminants in country foods.

A computer-based decision support tool has been recently developed in cooperation with the Nunavik Nutrition and Health Committee, with funding from the NCP and Health Canada. This tool could be beneficial to assist in analyzing the risks and benefits of consuming country foods for northern populations.

Both northern residents and public health professionals require more information and support in dealing with the contaminants issue. Although many gains have been made, increased knowledge about local risk perception would help to effectively reduce the confusion that still exists for some about the issue of contaminants and food choice.

Paul Vecsei

Résumé

Le Programme de lutte contre les contaminants dans le Nord (PLCN) a réalisé un examen dans le but de répondre aux préoccupations à l'égard des effets néfastes sur la santé qui pourraient découler d'une exposition aux polluants organiques persistants (POP) et aux métaux lourds par le biais de la consommation d'aliments traditionnels. Ces préoccupations sont particulièrement importantes dans le cas des peuples autochtones dont le régime alimentaire repose en grande partie sur des aliments traditionnels qui sont également associés à d'importants avantages culturels, sociaux, économiques, nutritionnels, spirituels et psychologiques.

L'examen poursuit le travail réalisé au cours des deux premières étapes du programme en vue d'améliorer la base de connaissances sur les contaminants et la santé humaine. Ce troisième examen nous informe sur les recherches en cours concernant les changements observés dans les concentrations de contaminants chez les habitants de l'Arctique canadien et leur exposition à ces contaminants; décrit les effets possibles sur la santé; identifie des nouveaux contaminants préoccupants; résume la caractérisation et la communication des risques liés aux contaminants dans les aliments traditionnels et fait état des lacunes dans les connaissances.

Les aliments traditionnels et le régime alimentaire des habitants du Nord

Puisqu'un grand nombre de collectivités du Nord vivent des bouleversements économiques, politiques, sociaux et environnementaux dont les effets se font sentir sur la santé humaine et le bien-être, le besoin d'obtenir rapidement de l'information pertinente sur les choix alimentaires et la sécurité n'a jamais été aussi pressant. Pour répondre à ce besoin, il est essentiel d'effectuer un suivi constant de la consommation alimentaire, d'améliorer la compréhension des enjeux relatifs à la sécurité alimentaire et de mieux comprendre les déterminants des choix alimentaires.

Les aliments traditionnels occupent une place importante dans la qualité générale de l'alimentation des habitants de l'Arctique canadien parce qu'ils sont une source de protéines, de vitamines et de minéraux. Par contre, les aliments traditionnels sont aussi une importante source d'exposition aux contaminants que l'on retrouve dans l'environnement. Même si la consommation des aliments traditionnels diffère selon les cultures que l'on retrouve en Arctique, la tendance générale montre que les nouvelles générations consomment beaucoup moins d'aliments traditionnels que les générations précédentes. Selon les recherches, ces aliments auraient été remplacés par des produits à forte teneur en glucides, peu nutritifs, disponibles dans les commerces et dont la consommation pourrait contribuer à l'augmentation du diabète, des carences en micronutriments, de l'obésité et des maladies chroniques.

Selon une analyse détaillée de l'alimentation et des données connexes sur les contaminants qui a été réalisée dans la région d'Inuvik, les habitudes de consommation sont en train de changer et le message concernant les risques et les avantages (« les aliments traditionnels sont bons pour vous, particulièrement pendant la grossesse, mais si les contaminants vous inquiètent, mangez de l'omble chevalier, du caribou ou de l'orignal ») est entendu. Cette étude montre que les mères inuvialuit, dénées et métisses ont augmenté leur consommation de poisson. Chez les Inuvialuit, on remarque que les mères mangent plus de caribou, d'oiseaux et de phoque et qu'elles consomment moins de graisse de mammifères marins (spécialement la graisse de béluga).

Exposition des personnes et niveaux de contaminants

Le présent examen montre que la plupart des contaminants que l'on retrouve dans le sang maternel ont diminué de façon importante au cours des 10 dernières années dans toutes les régions de l'Arctique canadien. Dans le cas de certains contaminants, les niveaux dans le sang maternel sont maintenant moins de la moitié de ce qu'ils étaient il y a 10 ans. L'exception à remarquer est le cadmium, qui est présent à des niveaux plus élevés dans les échantillons de sang maternel prélevés dans les régions d'Inuvik, de Baffin et du Nunavik. Cette situation

a été associée à l'usage croissant de la cigarette parmi les personnes faisant partie de ce groupe d'âge, et les responsables régionaux de la santé publique considèrent qu'il s'agit d'un enjeu important. Si nous voulons confirmer la diminution des niveaux de contaminants observée au cours des 10 dernières années, il est essentiel d'effectuer une surveillance continue des POP et des métaux. Cette surveillance de la tendance est également exigée par différents programmes nationaux et internationaux.

Les études précédentes avaient montré que les niveaux les plus élevés de presque tous les POP et les métaux se trouvaient chez les Inuits – parmi tous les groupes ethniques étudiés (Dénés/Métis, Blancs, Inuits), les Inuits avaient les niveaux les plus élevés de biphényles polychlorés (BPC), de mercure et de cadmium. Parmi la population examinée, plus de la moitié des Inuits du Nunavik et près du quart de ceux du Nunavut dépassaient le seuil préoccupant établi par Santé Canada pour les BPC, bien que la proportion des mères dépassant ce seuil ait diminuée depuis la dernière étude. Aucune mère dénée, métisse ou non autochtone ne dépassait le niveau préoccupant. Ces conclusions étaient les mêmes dans le cas du mercure. Le tiers des mères inuites du Nunavut et du Nunavik dépassait la plage de risque accru, tandis que ce niveau n'était pas dépassé dans les autres groupes ethniques. Dans le cas du plomb, les résultats de tous les groupes étaient inférieurs au niveau d'intervention établi par Santé Canada.

Des recherches supplémentaires sont requises pour surveiller les niveaux des organochlorés et des métaux dans les aliments traditionnels si nous voulons mieux comprendre leur évolution en Arctique. Il faudrait également poursuivre le travail qui permettrait d'étudier l'exposition des personnes aux contaminants par l'alimentation au sein d'un petit groupe représentatif vivant dans des régions ayant une exposition très élevée ou modérée, et d'obtenir une autre référence temporelle avec laquelle il serait possible de comparer les données recueillies au cours des étapes précédentes du programme.

Eric Loring

Pour être en mesure d'élaborer des mécanismes de contrôle appropriés, les décideurs doivent avoir accès aux données les plus récentes sur les nouveaux contaminants – tels que le polybromodiphényléthers (PBDE) et le sulfonate de perflurooctane (PFOS). Dans certaines régions, nous avons remarqué une croissance des concentrations des PBDE (un groupe de produits chimiques utilisés pour retarder la propagation des flammes) et des PFOS (des produits chimiques antitaches) dans la faune de l'Arctique, mais les données dont nous disposons sont insuffisantes pour étudier les tendances chez les habitants de la région. Le niveau des PBDE dans la population de l'Arctique canadien est semblable dans tous les groupes ethniques, tout en étant beaucoup plus bas que celui des mères du Sud du Québec. Les niveaux de PFOS dans les échantillons de sang maternel au Nunavik ont diminué, mais ce résultat repose sur des données très restreintes. Étant donné l'ampleur des incertitudes existant présentement en Arctique, les récents changements observés dans les concentrations de contaminants dans l'environnement et chez les personnes devront être vérifiés dans le cadre d'une surveillance continue.

Grâce à de nouvelles techniques d'analyse et méthodes d'étude, les scientifiques peuvent maintenant mesurer l'exposition des personnes aux POP émergeants et à leurs métabolites et d'en étudier les conséquences sur la santé. De nouvelles données devraient être disponibles d'ici quelques années.

Toxicologie

Des études sur la toxicologie ont montré que l'exposition à une combinaison de produits chimiques présents dans les aliments traditionnels est susceptible de modifier la toxicité individuelle des contaminants. Puisque cette situation a une incidence sur les relations entre la charge corporelle et la toxicité par dose, les études sur la toxicité individuelle d'un produit chimique sont moins pertinentes. Même si les études épidémiologiques permettent de fixer les niveaux d'exposition néfastes pour la santé humaine, des études toxicologiques sont nécessaires pour documenter la vraisemblance biologique des associations et pour vérifier les mécanismes d'action ainsi que la relation dose-effet précise. Par conséquent, des recherches supplémentaires devraient être réalisées pour identifier et mieux comprendre les effets des combinaisons de contaminants sur la santé des habitants de l'Arctique qui sont fortement exposés.

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Bien que certaines preuves expérimentales montrent qu'il existe des interactions intéressantes entre certains éléments nutritifs essentiels et les contaminants – les oligo-éléments, les vitamines et les acides gras sont capables d'atténuer un peu la toxicité de certains contaminants présents dans les aliments – la confirmation de ces interactions dans les recherches effectuées auprès des humains est plutôt équivoque. Il faudrait réaliser des études plus poussées pour éclaircir les avantages associés à la consommation d'aliments traditionnels.

Une incertitude persiste en ce qui a trait à l'exposition aux PBDE et à ses effets sur la santé des habitants de l'Arctique. Des preuves montrent que les niveaux actuels d'exposition aux PBDE ne devraient entraîner aucun effet néfaste sur la santé, au moins en ce qui concerne les effets expérimentaux sur les hormones thyroïdiennes. Par contre, des effets néfastes sur la santé pourraient être plausibles si les niveaux de concentration tissulaire continuent d'augmenter au rythme actuel. Des recherches devront être faites afin de définir plus précisément dans quelle mesure les expositions alimentaires actuelles ou les résidus sont associés à un risque à la santé.

Épidémiologie

Les études épidémiologiques dans l'Arctique canadien sont difficiles à réaliser en raison de nombreux facteurs limitatifs, notamment : l'exposition à des combinaisons complexes de contaminants, la faible population, les interactions entre les contaminants et les éléments nutritifs, les facteurs génétiques, les facteurs parasites et les priorités dans le domaine de la santé. Ces raisons expliquent pourquoi l'évaluation des risques repose en grande partie sur les études épidémiologiques réalisées dans d'autres pays. Cependant, étant donné qu'une variété de facteurs uniques peut limiter la validité externe de ces études, il est essentiel de poursuivre les études dans l'Arctique canadien.

Les multiples facettes des effets des contaminants sur la santé humaine laissent beaucoup de questions sans réponse. De nouvelles données suggèrent que des éléments nutritifs présents dans les aliments traditionnels, tels que les acides gras oméga-3, favorisent le développement du cerveau des nourrissons inuits. Ces effets positifs sont constatés dans des domaines qui diffèrent de ceux qui sont attribuables à l'exposition aux contaminants. Des recherches supplémentaires sont nécessaires pour identifier et caractériser les effets possibles sur la santé tels que la perturbation des hormones thyroïdiennes ou les problèmes neurologiques de développement chez les nourrissons et les enfants exposés aux contaminants pendant la grossesse. De plus, il faut également étudier plus en profondeur les interactions entre les éléments nutritifs que l'on retrouve dans les fruits de mer et les effets des contaminants.

Plusieurs études sur le système immunitaire des habitants du Nunavik ont associé la croissance du nombre d'infections de voies respiratoires inférieures et d'otites moyennes aiguës pendant l'enfance à une exposition aux POP pendant la grossesse. De plus, les études ayant relevé un niveau sous-optimal de vitamine A et une homéostasie altérée de la vitamine A en présence de certains POP nous confirment qu'il est essentiel de comprendre les relations entre la vitamine A, les niveaux de contaminants et l'incidence des maladies infectieuses chez les habitants de l'Arctique.

Les résultats des études sur la croissance humaine et l'exposition aux BPC se contredisent dans le cas des études sur la population générale dont l'exposition n'est pas imputable à la consommation de poisson ou de mammifères marins, et elles sont inconsistantes lorsqu'elles effectuent des comparaisons avec les données issues d'une cohorte dont l'exposition est très élevée. Par contre, cette dernière constatation ne réfute pas l'hypothèse qu'une exposition aux BPC pendant la grossesse entraîne des effets sur la croissance. En poursuivant la recherche sur les caractéristiques génétiques propres aux populations étudiées, nous arriverons à une compréhension scientifique plus complète des études sur la croissance humaine et l'exposition aux BPC.

Les études actuellement en cours sur le rôle de l'exposition au méthylmercure et aux POP dans l'apparition du syndrome métabolique, des maladies cardiovasculaires et du diabète viennent à peine de commencer. Par conséquent, ces études prêtent encore à controverse. Il est possible que le méthylmercure entrave les mécanismes de défense contre le stress oxydatif, qu'il diminue la variabilité de la fréquence cardiaque et qu'il augmente la tension artérielle. Des recherches expérimentales et épidémiologiques additionnelles sont requises dans ce domaine.

Communication des risques

La communication des risques est un processus qui évolue sans cesse. Au cours des 16 dernières années, le PLCN a constaté que la diffusion fréquente d'information sur les contaminants est susceptible de saturer les collectivités et, par conséquent, il a réduit le nombre et la fréquence des messages. Les responsables ont également constaté que la communication est plus efficace et mieux acceptée lorsqu'elle s'intègre aux messages actuels concernant la santé publique et qu'elle incorpore les perceptions et l'expertise locales. Des études ont démontré que les résidants du Nord veulent obtenir des renseignements précis et pratiques qui facilitent la mise en contexte des risques liés à l'exposition aux contaminants et qui soutiennent leurs processus décisionnels. L'évaluation des diverses communications des risques effectuées au cours des années précédentes permettrait au PLCN d'obtenir des renseignements qui lui seraient utiles pour la poursuite et l'amélioration de ses activités.

Si l'on veut mieux évaluer les découvertes scientifiques et aider la prise de décisions, nous devons élaborer un processus commun qui permettra d'évaluer et de comparer tous les avantages et les risques liés à l'alimentation traditionnelle (et à ses alternatives). Plusieurs habitants del'Arctique m'ant pas beacoup d'argent et leurs choix alimentaires reposent principalement sur la nourriture facilement accessible, mais aussi sur leurs réseaux sociaux, qui incluent parfois le partage de la nourriture. Les stratégies de promotion de la santé qui obtiennent les meilleurs résultats sont celles dont l'objectif est d'accroître la disponibilité des aliments nutritifs plutôt que de changer les habitudes et les comportements. Des recherches qui apporteraient de nouvelles connaissances sur les déterminants des choix alimentaires et qui feraient l'évaluation des substitutions alimentaires et des autres programmes de gestion seraient utiles pour les régions nordiques où les niveaux d'exposition sont préoccupants. Les évaluations et les comparaisons sont particulièrement importantes pour les collectivités ayant l'exposition la plus élevée et groupes vulnérables, notamment les mères, les femmes enceintes, les femmes en âge de procréer, les fœtus, les nourrissons et les enfants. Il faudrait également réaliser des recherches supplémentaires pour identifier les sources régionales particulières et les concentrations de contaminants dans les aliments traditionnels.

Un outil informatisé d'aide à la décision a été récemment créé en collaboration avec le Comité nutrition et santé du Nunavik, grâce au financement fourni par le PLCN et Santé Canada. Cet outil pourrait aider à analyser les risques et les avantages liés à l'alimentation traditionnelle chez les peuples nordiques.

Tant les habitants du Nord que les professionnels de la santé publique ont besoin d'obtenir plus d'information et de soutien pour aborder le problème des contaminants. Malgré les nombreux progrès accomplis, l'acquisition de connaissances sur la perception locale des risques pourrait nous aider à diminuer efficacement l'ambiguïté qui existe encore relativement à certains enjeux liés aux contaminants et aux choix alimentaires.

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Introduction

1.1 Introduction

The Northern Contaminants Program (NCP)[1] was created in 1991 to address the concerns about potential human health risks associated with exposure to environmental contaminants from a diet of country or traditional food (the two terms are used interchangeably in the North). These concerns are particularly relevant for Aboriginal peoples because of the high proportion of country food in their diet. The goal of the NCP is as follows:

> *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.*

The NCP takes innovative approaches to environmental, toxicological, and health research and monitoring as well as to communication activities in northern communities. Essential elements of the program include adaptability and flexibility, a non-hierarchical structure, decentralized and shared decision making, participation of local people, and ongoing two-way communication and capacity building. The research conducted under the NCP is reviewed to ensure that it is scientifically defensible, consistent with the objectives and priorities set out in the "blueprints" (i.e., NCP research priorities), and socially and culturally responsible in a northern context.

The NCP has conducted two previous human health assessments as part of the Canadian Arctic Contaminants Assessment Reports (CACAR-I in 1997, and CACAR-II in 2003). The current report extends the results of the two previous assessments by presenting the results of recent biomonitoring studies, human health research, and risk management and communication activities.

The Arctic was considered to be a pristine environment due to its remoteness from southern agricultural and industrial regions. However, a number of studies conducted in the mid-1980s and early 1990s found environmental contaminants, including heavy metals (e.g., mercury and lead) and organochlorines (e.g., lindane, chlordane, toxaphene, dichlorodiphenyltrichloroethane [DDT], polychlorinated biphenyl [PCBs]) in all components of the Arctic ecosystem (Wong, 1986; Barrie *et al.*, 1992; Lockhart *et al.*, 1992; Muir *et al.*, 1992; Thomas *et al.*, 1992). Many of these contaminants released to the environment in southern regions are transported to the Arctic via long-range atmospheric transport, waterways, and ocean currents.

Due to their chemical and physical properties, organochlorine contaminants tend to be highly lipophilic and resistant to biodegradation. Organochlorine (OC) contaminants bioaccumulate in biota and biomagnify in the food web. The highest levels of contaminants are often found in long-lived animals at higher trophic levels of the food web. Metals such as mercury are not lipophilic but the organic form of mercury does bioaccumulate in tissues. The levels of environmental contaminants are typically higher at the top of the marine food web compared with the top of the terrestrial food web in the Arctic because there are more steps in the marine food web.

Country food is a significant vector of exposure to environmental contaminants. Many people who live in the Arctic consume country food on a regular basis. Their exposure to organochlorines and heavy metals tends to be higher relative to many populations living in southern Canada.

The processes associated with harvesting and consuming country food are similar and are important for social, nutritional, spiritual, psychological, economic, and cultural reasons. These activities form a common thread that connects people of all cultural backgrounds, giving the Canadian Arctic a distinctive regional character. As stated by Sheila Watt-Cloutier (Watt-Cloutier, 2000):

> We have no alternative to traditional food. The environment is our supermarket and eating what we hunt lies at the core of our culture and economy. Traditional food is our staple diet. We won't abandon the land.

[1] For a complete list of acronyms, please refer to Appendix A.

It teaches skills needed even in modern society, and builds character—courage under stress, patience, and tenacity—skills we require as a people in these times of tumultuous social change.

Sheila Watt-Cloutier's statement reflects the perception of many living in the Canadian Arctic about the land and its renewable resources. The management of, and communication about, the possible risk associated with exposure to environmental contaminants from a regular diet of country food and the benefits of traditional foods is a difficult balance for public health professionals. For example, from a nutritional perspective, a shift in diet from country food to market food has potential health impacts (see Chapter 2 for details). Days when country food is not consumed are often associated with a corresponding increase in total fat, saturated fat, and sucrose consumption above recommended levels; a lower intake of vitamins A, D, E, B6, and riboflavin; and a decreased intake of important minerals such as iron, zinc, copper, magnesium, manganese, phosphorus, potassium, and selenium (Receveur and Kuhnlein, 2000). Lower consumption of country food also increases the risk of obesity, which is associated with increased risk of chronic disease (Kuhnlein *et al.*, 2004). Consequently, the contamination of country food raises very complex issues that cannot be resolved simply by the provision of dietary advice or food substitutions alone.

The first phase of the NCP (1991–1996) led to a much greater understanding of the spatial patterns, levels, and health implications of contaminants. This assessment provided evidence that the major sources of contaminants were human activities outside the Arctic (CACAR, 1997). The second phase of the program (1997–2002) built on the existing knowledge base and produced a large amount of data on contaminants in the Canadian Arctic and possible health effects (CACAR, 2003). The information gathered in the first

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and second phases of the NCP on the benefits and risks of country food consumption was integral to risk management and communication of potential human health risks.

Research ethics are an important consideration in any project — including medical or social science research — that involves people as research subjects. The NCP has invested considerable effort to ensure that its research meets the highest possible ethical standards. This has included the development of documents to guide research in the North, the establishment of committees to oversee the approval of research projects, and the continued improvement of processes such as obtaining informed consent and communicating research results.

1.2 Key Conclusions and Knowledge Gaps from NCP Phase I and II

1.2.1 Major conclusion of NCP Phase I (1991–1997)

The first phase of the NCP gathered information on the risks and benefits of country food consumption. A key objective of the human health assessment was to assess the impact of exposure to current levels of environmental contaminants in the Canadian Arctic (CACAR, 1997). Major findings of Phase I included the following:

- Country foods were an economic necessity for many Aboriginal northerners. One study estimated that the cost to purchase equivalent amounts of imported meat in local stores in the Northwest Territories (NWT) was well over $10,000 per household per year.
- Traditional foods were widely consumed in northern communities. The key food resources, depending on the regions (coastal or inland), were marine mammals and large ungulates (caribou and moose). Country food consumption varied seasonally and annually as well as regionally. It also varied according to income and access to urban centres, and as a factor of age and gender. Country food consumption in the communities studied ranged from 292 kg per year in Sanikiluaq to 27 kg per year in the Wood Buffalo Park area.
- The levels of OCs such as DDE, PCBs, mirex, toxaphene, and chlordane were found to be between twofold and tenfold higher in breast milk of Inuit women from Arctic Canada than of non-Aboriginal women from southern Canada.
- In the eastern Arctic, a large number of Inuit women (48% and 75%) in two of the communities studied exceeded the Tolerable Daily Intake (TDI) for chlordane based on dietary survey estimates. A number of

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these women also exceeded the TDI for toxaphene, hexachlorobenzene, hexachlorocychlohexane, dieldrin, and PCBs. A much smaller percentage of Dene and Métis (approximately 6%) exceeded the TDI for one or both of chlordane and toxaphene. Comparisons of human milk data clearly demonstrated that increasing concentrations of many OCs are associated with increasing consumption of traditional foods (mainly fish and marine mammals). Some individuals need to reduce their intake of the most contaminated food items to lower their exposure. These individuals should consume other traditional foods to maintain the benefits these foods bring.

- Two surveys of eastern Arctic Inuit indicated that on any given day 21% to 37% of women consuming traditional foods exceeded the World Health Organization (WHO) TDI for mercury and cadmium respectively. Other surveys have indicated that only smokers exceeded the TDI for cadmium.
- The risks of exposure to environmental contaminants must be considered along with the socio-cultural, nutritional, economic, and spiritual benefits.

1.2.2 Major knowledge gaps identified under NCP Phase I (1991–1997)

The assessment revealed significant insights about exposure to and effects of contaminated foods in Arctic communities. In addition, key areas requiring more data were identified specifically for the Human Health component of the NCP:

- Maternal/cord blood monitoring data are needed across the Canadian Arctic to allow an accurate assessment of human fetal exposures. This monitoring is underway in the NWT and northern Québec and must be initiated in the Yukon and Labrador.
- Food surveys should be conducted to obtain accurate food consumption information that could assist in the estimation of contaminant and nutrient intakes. This information is essential in a risk–benefit evaluation of country foods for specific communities. While western Arctic communities participated in food consumption surveys in the first phase of the NCP, there remains a need for these surveys in some eastern Arctic and Labrador Inuit communities.
- Since the major difficulty in the risk-determination process is the comparison of the risks and benefits of traditional food consumption, a good model or approach for comparing risks with benefits must be developed to remove the subjective aspects of risk determination and allow a more rigorous approach to weighing the risks and benefits of traditional food consumption.
- Information exists on the effect of contaminants in isolation; however, little is known about the effects of contaminants in the presence of common confounders such as poor nutrient intake and exposure of the fetus to alcohol or the products of maternal smoking. An important priority for research in this area is an evaluation of growth, disease, and resistance to infection in children related to the combined effects of these confounders and relatively high contaminant exposure.

1.2.3 Major conclusion of NCP Phase II (1998–2003)

The second phase of the program (1998–2003) built on the existing knowledge base gathered during Phase I, and new research produced a large amount of data on human health aspects of contaminants. The following is a selection of key conclusions on human health and risk management from this report:

- Persistent environmental contaminants such as PCBs, toxaphene, DDT, and mercury biomagnify and bioaccumulate in the food chain. Because Aboriginal peoples have a diet comprising substantial proportions of traditional food, they have a greater contaminant exposure than non-Aboriginal peoples or people in southern Canada.
- Traditional/country food use for women and men 20 to 40 years of age is highest in Inuit communities, followed by Dene and Métis of the NWT, and then First Nations people of the Yukon. Age and sex are factors influencing traditional food use, with men having higher average intakes than women and consumption increasing with age.
- There is some evidence that dietary nutrients such as polyunsaturated fatty acids, fish protein, and selenium may interact with methylmercury toxicity at least on the mechanistic level. It is suggested that these nutrients may be protective against methylmercury neurotoxicity; however, there is no conclusive evidence.
- Conducting epidemiological studies on contaminants in the Arctic is difficult due to a variety of limiting factors: exposure to complex contaminant mixtures, small population size, contaminant–nutrient interactions, genetic factors/confounders, and health priorities. For this reason, epidemiological studies conducted in other parts of the world (e.g., the Faroe Islands) on PCB- and methylmercury-induced neurotoxicity should be used as much as possible for risk assessment in Canada. The external validity of the studies may be restricted by differences in the limiting factors.
- Specific epidemiological findings included a study in Nunavik where *otitis media* (middle ear infection) during the first year was associated with prenatal exposure to para, para-1,1-dichloro-2,2-bis(p-chlorophenyl) ethane (*p,p'*-DDE), hexachlorobenzene (HCB) and dieldrin. Furthermore, the relative risk of recurrent *otitis media* increased with prenatal exposure to these compounds. The ongoing Nunavik study supported the hypothesis that the high incidence of infections (mostly respiratory) observed in Inuit children may be in part due to high prenatal exposure to persistent organic pollutants (POPs), although definitive conclusions can only be made after final adjustments for important possible confounders (e.g., parental smoking, vitamin A).
- In recent dietary surveys among five Inuit regions (Baffin, Inuvialuit, Kitikmeot, Kivalliq and Labrador), mean intakes by 20- to 40-year-old adults in Baffin,

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Kivalliq, and Inuvialuit communities exceeded the provisional Tolerable Daily Intakes (pTDIs) for chlordane and toxaphene. High consumers (95th percentile) of traditional/country foods were exceeding the pTDIs by many folds for toxaphene, chlordane, and PCBs. The Inuit populations that had the greatest exceedance of the pTDIs also had the greatest exceedance of the PCB maternal blood guideline. Inuit mothers exceeded the Level of Concern value of 5 microg/L plasma for PCBs but none exceeded the Action level of 100 microg/L.

- Mercury is the heavy metal of greatest concern in the Canadian Arctic. Dietary intakes of mercury were similar in the surveys conducted 1987–1988 and 1998–1999, indicating there was little change in dietary pattern and in mercury concentration in traditional/country foods.
- The nutritional benefits of traditional/county food and its contribution to the total diet are substantial. Research findings are consistent across the Canadian Arctic and confirm that decreasing the amount of traditional/country food in the diet is likely to have negative health consequences, in part through the corresponding increase in total fat, saturated fat, and sucrose above recommended levels. Traditional/country food also contributes significantly more protein, iron, and zinc to the diets of Inuit children than imported foods.
- In the Arctic, the benefits of continuing consumption of traditional/country foods outweigh the risks of contaminants.

1.2.4 Major knowledge gaps identified under NCP Phase II (1998–2003)

NCP Phase II identified knowledge gaps in relation to the multiple facets of human health, which were intended to guide further human health research initiatives:

- Continued monitoring and assessment of the frequency of consumption of traditional/country foods in a limited number of Dene and Métis, Yukon First Nations, and Inuit communities is needed to identify any significant changes in consumption pattern. Focus needs to be placed on communities with the highest exposure but must include an assessment of regional variations.
- The monitoring of organochlorines in human tissues does not have a long history in the Canadian Arctic, and continued monitoring of tissue levels is needed to determine contaminant trends. Special attention should be given to oxychlordane, trans-nonachlor, HCB, mirex, toxaphene, PCBs, and mercury, especially among the Inuit of Nunavut and Nunavik. There may be systematic differences among subgroups in these regions, and more data are needed.

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- It is clear that there is need for more studies designed specifically to address the role of nutrition in the metabolism and detoxification of methylmercury. It is also important to collect more detailed dietary information in future epidemiological studies of methylmercury exposure. A controlled human study on the effects of various nutrients such as the omega-3 fatty acids, selenium, and vitamin E on methylmercury toxic kinetics will be useful to confirm the results obtained from animal experiments.
- The Nunavik cohort study should allow differentiation between the specific deficits attributable to PCBs and those associated with mercury, since the cord blood PCB–mercury intercorrelation is low. With the establishment of prospective Arctic birth cohorts, there will be opportunities to look at other contaminants that may have neurodevelopment effects, as well as to study long-term effects that can only be documented at school age or later in the course of development.
- The only recent epidemiological study of contaminant effects conducted in the Canadian Arctic is the one in Nunavik. This study suggested an association between in utero exposure to POPs and susceptibility to infections during the first year of life. Although efforts have been made to also use effect biomarkers (vitamin A and cytokines), the low predictive ability of these markers limits their use. The usefulness of new markers (antibodies post immunization, complement system) needs to be assessed within the cohort study in Nunavik and elsewhere in the Arctic.

- The substantial nutritional benefits of traditional/country food and its contribution to the total diet have been documented; however, further research is needed on the negative health consequences of reduced consumption of traditional/country food.
- Research is also needed on ways that women of childbearing age use information to make decisions regarding the consumption of PCB and mercury-contaminated traditional/country food.

1.3 Phase III Assessment Objectives

The overall objective of the current assessment is to address concerns about possible adverse health effects in people who are exposed to POPs and heavy metals through a diet of country food. Northern Aboriginal people have particularly high exposure to these contaminants due to the high proportion of country foods in their diet, such as marine mammals, fish, and terrestrial wild game. This assessment acknowledges that this poses an immediate concern for Aboriginal people for whom the harvest and consumption of country food is integral to their cultural identity as well as to their nutrition, overall health, and economic well-being.

This assessment report has five objectives:

- Provide data on temporal trends of contaminant exposure among Canadian Arctic peoples.
- Present research results on human exposure and possible health effects of current levels of contaminants.
- Identify new contaminants of concern.
- Provide the current state of knowledge of risk characterization and communication about contaminants in country food.
- Identify knowledge gaps to be filled by future research and monitoring.

1.4 Organization of Assessment Report

This assessment report is organized into nine chapters. Following this introduction, Chapter 2 emphasizes the importance of understanding the extent of traditional food use and its contribution to peoples' health and well-being in the midst of potential threats from contamination, climate change, and a dietary transition toward market food. The chapter reviews dietary and other studies conducted in the Canadian Arctic. It also presents the benefits of country food and weighs their implications on the health of northerners.

Chapter 3 presents a set of health status indicators of disease burden of Canadian Arctic populations. This chapter puts the health concerns surrounding environmental contaminants into the broader health

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context by considering other health issues among northern populations.

Chapter 4 provides the results of follow-up biomonitoring studies (2002–2007) focusing on Inuit populations across the Canadian Arctic who consume marine mammals. This chapter presents biomonitoring studies related to northern contaminants exposure pathways. It provides insight into relationships between contaminants exposure, traditional food consumption, and other lifestyle factors. Recent information on emerging contaminants is also provided.

Chapter 5 describes the toxicological aspects of the key environmental contaminants of concern, provides a comparison of epidemiology and toxicology results on selected health end points, and describes the potential risks posed by complex chemical mixtures and nutrient–contaminant interactions.

Chapter 6 evaluates possible human health impacts of northern contaminants of concern. Health risk data are provided on infants, children, and adults for cardiovascular, neurobehavioral, endocrine, and immune system effects.

Chapter 7 describes the current state of knowledge of risk-benefit characterization and communication about contaminants in country food. It presents the process adopted by the NCP as well as the issues surrounding risk management.

Chapter 8 presents the key conclusions from each chapter and looks at their potential implications in assessing Arctic Canada's contaminant health issues.

Chapter 9 identifies areas of research for which further investigation is necessary to address specific knowledge gaps so as to better understand the issues at hand.

The many factors influencing human health and well-being need to be considered when evaluating the results of this assessment. Environmental contaminants may not play a major role in determining the overall health status of a person. Lifestyle choices, diet, socio-economic status, gender, and genetic predisposition and other health determinants need to be considered when assessing the risk associated with contaminant exposure due to a diet of country food.

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Food and Dietary Research

2.1 Introduction

This chapter provides a review of the benefits of country food (also known as traditional food), dietary studies, and the health implications of dietary change in Arctic Canada. The review focuses on studies that have been conducted in Arctic Canada as part of the Northern Contaminants Program (NCP) or independently at Canadian universities, in particular at the Centre for Indigenous Peoples' Nutrition and Environment (CINE) at McGill University. As in other circumpolar countries, research has found that the contemporary diet of people living in the Canadian Arctic tends to be one of mixed country and market foods, and there is a notable regional difference in the reliance upon country foods. In addition to its nutritional value, the harvesting, processing, and consumption of country food is associated with a more active lifestyle, food diversity, and participation in cultural activities (Receveur and Kuhnlein, 2000). Consumption of country food is also associated with greater food security (Lawn and Harvey, 2001; 2003).

2.2 Benefits of Traditional Food

Many Aboriginal peoples living in the Arctic have a holistic view of health and well-being. Definitions of health among those living in the Canadian Arctic, however, are very different. This section does not provide a detailed discussion about the many perspectives of health held by those living in the Canadian Arctic. Rather, it is intended to provide the reader with a general understanding of the important role of country food in health and well-being.

Country foods consist of locally derived plants, animals, and fish that are harvested from the land. Aboriginal peoples have stated that country foods provide the following health benefits (Receveur *et al.*, 1997; Berkes, 1999; Kuhnlein *et al.*, 2000; Receveur and Kuhnlein, 2000; Pelly, 2001; Krupnik and Jolly, 2002):

- Country food is a cultural anchor and its use is often important to their identity as Aboriginal peoples.
- The sharing of country food plays a role in the maintenance of social norms and expectations.
- Given the high cost of living in most Arctic communities, country food saves many families money.
- There are important spiritual aspects associated with country food use.
- Country foods provide substantial nutritional benefits.
- Physical health benefits are associated with harvesting country food.

The benefits associated with country food such as the ones listed above play an important role in the overall health and well-being of many people living in the Canadian Arctic. The following two subsections provide further detail about its nutritional and economic benefits.

2.2.1 Nutritional benefits of traditional food

Country food provides significant nutritional value and is an important contributor of key nutrients to the diet (Kuhnlein *et al.*, 2000). For example, across 18 Inuit communities in Canada, country food consumption led to increased intake of iron, zinc, vitamins A and E, and sometimes vitamin C (Kuhnlein *et al.*, 2000). Marine mammal blubber, a traditional food eaten by the Canadian Inuit, is a major source of omega (ω)-3 fatty acids (Kuhnlein *et al.*, 1991).

Fediuk *et al.* (2002) analyzed vitamin C in 37 types of country food consumed by Inuit of the Canadian Arctic. Rich sources of vitamin C included fish eggs, raw whale skin ("mattak"), caribou liver, ringed seal liver, and blueberries. Estimating the intake of this nutrient for women 20–40 years of age, researchers have determined that country food contributed approximately 20% to the total intake.

Kuhnlein *et al.* (2002) analyzed 236 samples of country foods and calculated energy content, minerals (calcium, iron, copper, zinc, phosphorus, magnesium, sodium, manganese, potassium, and selenium) and fatty acids (SFA [saturated fatty acids], MUFA [monounsaturated fatty acids], and n-3 and n-6 PUFA [polyunsaturated fatty acids]). The foods analyzed represented country foods frequently consumed across the Canadian Arctic.

This report was followed by analyses of 180 country food samples for vitamins A, D, and E (Kuhnlein *et al.*, 2006). Their research estimated the adequacy of these three vitamins in Canadian Arctic diets. Results suggested a high prevalence of inadequacy for vitamins A and D, particularly for Yukon First Nations and Dene/Métis, together with a largely inadequate intake of vitamin E overall. Vitamin A status varied by age and gender, with older Inuit men having the greatest adequacy as was previously reported (Egeland *et al.*, 2004).

Information on the dietary intakes across 44 communities of the Canadian Arctic, based on the most complete nutrient databases available, has now been published (Kuhnlein *et al.*, 2004; Kuhnlein *et al.*, 2007a). While fibre intakes are uniformly low, nutrients of concern, to various extents depending on the locality, age, and gender, are magnesium; folate; vitamins A, C, E, and D; n-6 fatty acids; and calcium (Kuhnlein *et al.*, 2007a). An increase in country food in the diet correlates with an increase in the intake of protein, vitamins D and E, riboflavin, vitamin B-6, iron, zinc, copper, magnesium, manganese, and potassium. Country food makes a significant contribution to the overall quality of the diet of the people living in the Canadian Arctic (Kuhnlein *et al.*, 2005; Kuhnlein *et al.*, 2007b).

2.2.2 Economic benefits of traditional food

The high cost of market food in remote northern communities is likely to affect food choices and ultimately food security. These factors are important to take into consideration when evaluating the economic benefits of traditional food. In a 2006 market food cost survey, 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 that were more accessible to food distribution networks. Within the Yukon, weekly food basket costs were as high as $388 in Old Crow compared with $163 in Whitehorse, and within most of the remote communities surveyed in the Northwest Territories, costs were over $300 per week compared to $159 in Yellowknife. Similarly, within Nunavut, costs ranged from $317 to $325 for Kitikmeot communities, $288 to $352 for Kivalliq communities and $297 to $299 for Baffin Region communities (Indian and Northern Affairs Canada, 2006). In contrast, costs for a weekly food basket were $173 in Edmonton, and $144 in Montréal. These differences in costs are even more pronounced when food costs are limited to perishable items only.

In Nunavut, 40% of middle-to-high-income residents reported that they did not have enough food to eat; this

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percentage was even greater (68%) for low to lower-mid income families (Ledrou and Gervais, 2005). In another Baffin community, approximately half of the 52 adults surveyed indicated that it was "true" or "sometimes true" that they "eat less or skip a meal because there isn't enough money to buy food" (Egeland *et al.*, in press). There may be significant and widespread food security issues in northern communities given that the prevalence of Inuit households identified to be "working poor" or on social assistance has been estimated to be as high as 80% (Indian and Northern Affairs Canada, 2003).

In a study involving focus groups in six communities in Nunavut in 2004, participants expressed their perception that people are having difficulty obtaining enough food every month and that a "lot of people are living near poverty" (Chan *et al.*, 2006). Prominent barriers to food security mentioned by focus group participants included the costs of hunting, the limited income available after bills were paid, inadequate government support and involvement, as well as the many societal and individual changes that have occurred in recent times (Chan *et al.*, 2006). Those that they considered to be most vulnerable to food insecurity included elders who often use their limited income to help support an extended family, people with gambling or substance abuse problems, and people living in households that have a low cash flow.

In a survey of Yukon First Nations, Dene/Métis, and Inuit women (n=1771) that evaluated access to country and market food in 44 communities across the three Canadian territories, some degree of food insecurity was reported. There was, however, considerable regional variability in the percent of respondents indicating that they could afford adequate amounts of food (Lambden *et al.*, 2006). Inuit women, regardless of age grouping, were less likely to respond that they could afford market food than Yukon First Nations or Dene/Métis women. To illustrate, only 40% of Inuit women 20–40 years of age reported being able to afford market food compared with 56% of Yukon First Nations and 70% of Dene/Métis women of similar age (Lambden *et al.*, 2006). Age and regional differences were also apparent with regard to affordability of, or access to, fishing or hunting equipment. Across all regions, those over the age of 61 years generally had limited access to hunting and fishing gear. The findings are compatible with previous surveys indicating that single, divorced, and widowed Inuit women had lower intakes of country food compared with other community members (Dewailly *et al.*, 2001; Duhaime *et al.*, 2002). The studies provide evidence of the vulnerability of Indigenous women to food insecurity and show that factors associated with the

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high costs of market food, lack of accessibility to hunting and fishing, and/or lack of a hunter in the family contribute to food insecurity.

2.3 Traditional Food Use and Dietary Change

A number of food use and dietary surveys have taken place in Arctic Canada. One study employed both food frequency questionnaires (FFQs) and 24-hour recalls to assess country food intake (Guyot *et al.*, 2006), while two studies used FFQs alone (Solomon, 2005; Nancarrow *et al.*, 2007) and two studies used 24-hour recalls alone (Nakano *et al.*, 2005a; 2005b). Sample sizes for the studies ranged from 12 to 222 individuals, and all studies took place among Aboriginal peoples of Canada, including Yukon and Dene/Métis First Nations and the Inuit. Each study involved an assessment of the extent of country food use and clarified the link between country food intake and contaminants, climate change, self-reported harvest data, risk-benefit assessment and nutrient contribution in adults and children.

2.3.1 Food use of Dene/Métis and Yukon children

Research conducted in 2000 and 2001 surveyed children from five communities including Fort McPherson, Tulita, and Fort Resolution in the Northwest Territories (NWT) and Old Crow and Carcross in the Yukon. Two publications based on this study detailed the extent of country

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food and market food use using 24-hour recalls (Nakano *et al.*, 2005a), anthropometrics (height and weight measurement) and nutrient intakes (Nakano *et al.*, 2005b). Participants reported eating twenty-eight country foods, although caribou, moose, and whitefish were most frequently consumed (comprising 95% of energy intake from country foods). Of the country foods consumed, 86% were land animals, 11% fish, 2% birds, and 1% berries. In children 10–12 years of age, country foods contributed from 4.3% to 4.7% of total energy (Nakano *et al.*, 2005a). Still, on days when children consumed country food, they had significantly more protein, iron, zinc, copper, magnesium, phosphorus, potassium, riboflavin, and vitamins E and B6. Children from northern communities consumed significantly more country food and had lower intakes of fat, saturated fat and sodium (Nakano *et al.*, 2005a). The children were deemed to be adequate in their nutrient intakes for vitamin B6 and C, riboflavin, zinc, iron, copper, selenium, manganese, carbohydrate, and protein, and had a probable inadequate intake of vitamins A, D, and E, phosphorus, magnesium, calcium, omega-6 fatty acids, and omega-3 fatty acids (Nakano *et al.*, 2005a). A similar study measured energy intake in Dene/Métis adults in 1997 (Receveur *et al.*, 1997). Country food contributed 11%–30% of energy intake in women and 16%–29% intake in men. Similar to the children, days with country food intake had significantly more protein, iron, zinc, copper, magnesium, and phosphorus than days with market food only. However, in 1997, the adult population was only inadequate in folate and fibre.

2.3.2 Climate change impacts on dietary nutrient status of Inuit in Nunavut

In 2005, a cross-sectional, participatory study used both qualitative and quantitative methods to characterize the nutritional implications of climate change related to the country food system of Inuit in Nunavut (Nancarrow *et al.*, 2007). The study used both a food frequency questionnaire and two-day focus groups in two communities to gather data. Ten individuals from Repulse Bay and seven from Kugaaruk were selected using purposeful sampling methods to participate in the focus groups. Climate change impacts on key country food items were discussed in depth. A qualitative analysis categorizing strategy was used to code the data, allowing for the emergence of themes and cross-community comparisons. To collect country food data, a previously validated FFQ, consisting of 111 food items from 12 country food species, was administered to a random sample of the adult population of Repulse Bay (n=103, approximately 25% of the community). Portion sizes were estimated by a sub-sample of participants. Median daily country food intake (g/day) for the total population was used to compare intake of 22 nutrients to Dietary Reference Intakes (DRIs) established by the U.S. National Academies (Institute of Medicine, 2000). The DRI of each nutrient is set as a guideline for optimum nutrition. They include Estimated Average Requirements (EAR), Recommended Dietary Allowance (RDA), Adequate Intake (AI) and the Tolerable Upper Intake Level (UL). Data were divided into age and gender categories for analysis.

The study confirmed that participants from both communities found that climate change was affecting the country food harvest in both positive and negative ways. Key nutrients that will potentially be affected were reported to be protein, iron, zinc, omega-3 fatty acids, selenium, and vitamins D and A. The results of the FFQ indicated that the median daily intake of country foods in the community of Repulse Bay was 386 g/day. Country food was reported to provide 100% of the Estimated Average Requirements for protein, vitamins A and B6, riboflavin, phosphorus, iron, copper, zinc and selenium, and of the Adequate Intake for omega-3 fatty acids. Caribou was found to be the most commonly consumed country food (by weight and frequency).

The authors concluded that climate change is affecting the availability of country food which is extremely important to maintain adequate dietary nutrient intakes. Some climate changes occurring in the communities were reported to increase access to country foods. The study postulated that if this translates to an increase in the country food harvest, nutrient intake may increase.

Conversely, climate changes that have the potential to reduce access to country foods may have serious consequences for nutrient intakes of Inuit.

2.3.3 Local observations of climate change and impacts on country food security in two northern Aboriginal communities

In 2004, 12 community members from Deh Gah Got'ie First Nation in Fort Providence, NWT, participated in a study that investigated the link between self-reported harvest data and estimated average daily intake of country food. Guyot and Chan (2006) used FFQ and focus groups to collect data. Focus groups determined the self-reported community harvest numbers for key species of country food in the 12 months prior to the meeting. The average available food intake per person per day was calculated for each species using the edible weight of each species, self-reported harvest data, and number of known country food consumers in the community. This was compared with the average daily intake of each species from a previous CINE diet study in the same region. The ratios of harvest data to consumption data were calculated.

Top country food species, in descending order of percent of the total harvest, included moose, barren-ground caribou, whitefish, snow goose, woodland caribou, and sucker fish. Land animals made up 63% of the total harvest, followed by fish (23%) and birds (14%). A ratio of one was interpreted by the authors to mean that intake of species and the amount of edible food available from the harvest are similar. Of all the country foods surveyed, moose and whitefish had ratios close to one. The authors concluded that since both are key country food species and were easily counted due to size and preparation method, recall accuracy was more likely. Ratios larger than one were interpreted as meaning that intake was greater than the amount available from the harvest. Species with the largest ratios tend to be smaller animals or fish, which the authors described as being typically under-reported in harvest data found in the literature. It was stated that the main species contributing to the harvest were similar to those reported in the 1990s. The authors concluded that a reasonable estimate of harvest data, but not nutritional assessment, can be obtained using semi-quantitative methods such as focus groups. They recommended that future studies include accurate and precise harvest surveys to improve estimates of food security using harvest data.

2.3.4 Managing the issue of mercury exposure in Nunavut

A participatory study between CINE and the communities of Repulse Bay and Igloolik, Nunavut, took place in spring 2004 (Solomon, 2005). The goal of

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this study was to characterize the risk of methylmercury exposure by exploring the link between dietary intake of mercury and levels found in hair. Researchers used a cross-sectional approach and collected data using FFQs, hair samples, and country food samples. A mix of volunteers and randomly selected community members participated in the study. The quantity of mercury in the diet was determined by comparing daily intake per food item (grams/person/day) to mean mercury concentrations found in meat samples or a database. Estimates of individual mercury body burden were calculated using the mean value of individual hair segments. Analysis of the meat samples revealed that narwhal muktuk, beluga muktuk, and walrus flesh had the highest mercury concentrations.

Forty people (16 were randomly selected and 24 volunteers) participated in the study in Igloolik. The most commonly consumed species in Igloolik were caribou, char, walrus, ringed seal, non-specified Arctic bird, and beluga. The top three items contributing to mercury exposure were walrus meat, caribou meat, and ringed seal meat. Average daily intake of country food in Igloolik was found to be 134, 783, and 303 g/person/day for women 18–40, women 41+, and men, respectively. Estimated average dietary mercury exposure for the general population was 23±14 microg/day (range 1.0–49 microg/day) and for women of CBA it was 6.0± 5.8 microg Hg/day (range 0.2–24 microg/day). After comparison with the World Health Organization Provisional Tolerable Weekly Intake (PTWI) at 1.6 microg/kg body weight/week (WHO, 2004), it was determined that three participants (25% of the sample population) in the general population and three participants (11% of the sample population) from the women of CBA group were above the minimal risk level. The mean hair mercury concentration in Igloolik for the general population was 6.2±4.6 mg/kg (range 0.1–13 mg/kg). For women of CBA, average mercury concentration was 2.1±1.7 mg/kg (range 0.2–7.0 mg/kg). Six participants in the general population as well as seven women of CBA exceeded the minimal risk level set for hair by Health Canada (6 mg/kg for the general population and 3 mg/kg for women of CBA).

A total of 52 community members (22 randomly selected and 30 volunteers) participated in Repulse Bay. The most frequently consumed country foods in Repulse Bay were caribou, char, narwhal, ringed seal, and walrus. The top contributors to mercury exposure were narwhal muktuk with blubber, caribou meat, and beluga muktuk. Daily country food intake by age group was 657, 2239,

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and 1358 g/person/day for women 18–40, women 41+, and men, respectively. Estimated average mercury dietary exposure for the general population was 44±46 microg/day (range 1.7–181 microg/day) and was 21±22 microg/day (range 0.3–79 microg/day) for women of CBA. Compared with the WHO PTWI, 12 people (55%) from the general population and 15 women of CBA (50%) were over the minimal risk level. Mean hair mercury concentration for the general population in Repulse Bay was 2.7±1.6 mg/kg (range 1.0–6.3 mg/kg) and for women of CBA was 2.1±1.4 mg/kg (range 0.5–6.0 mg/kg). Only one participant in the general population (5%) exceeded the minimal risk level set for hair by Health Canada, whereas four women of CBA (14%) exceeded the level. The difference between exposure estimate and body burden may be due to over reporting of traditional food consumption and/or over estimation of Hg concentrations in traditional foods in Repulse Bay.

The study is limited by small sample size and the volunteering participants may have skewed the data to over represent the heavy traditional consumers. In general, a strong correlation was found between country food intake and mercury hair concentrations. However, no individual concentrations in hair were above the "at risk" level of 30 mg/kg. Furthermore, the authors concluded that the most susceptible population, women of child-bearing age, had average hair mercury concentrations that were below the minimal risk. Mercury hair concentrations were found in 1976–1985 in Igloolik and in 1977 in Repulse Bay. This study shows that mercury hair concentration in both communities has declined, probably due to decreasing intake of country food. The authors conclude that the results indicate that communities are not at high risk of mercury toxicity with the current patterns of country food intake. Results from an accompanying socio-cultural questionnaire concluded that country food is an important part of the diet, that the population was aware of the benefits of consuming it, and that the population was unaware of or lacked concern for contaminant levels in country food.

2.3.5 Monitoring temporal trends of human environmental contaminants study in the Northwest Territories

A comprehensive survey conducted between 2005–2006 to study the country food intake and body burden of contaminants among women of child-bearing age was conducted in the Inuvik region, located in the Mackenzie Delta of the Northwest Territories (Armstrong *et al.*, 2007), as a Follow-up study to the Baseline survey conducted between 1998–1999. The surrounding communities, served by the Inuvik Hospital, are made up of Inuvialuit,

INAC

Gwich'in, Métis, and Dene people, as well as non-native individuals. The economy of the Inuvik region is based mainly on government and Aboriginal corporation services and oil and gas activity and is supplemented by hunting, trapping, fishing, and tourism.

The Follow-up study involved recruiting pregnant women, and then collecting maternal blood samples, hair samples, and information on lifestyle and diet. The project had three main objectives:

- to establish a trend of environmental contaminants in blood and hair of women living in the Inuvik region;
- to evaluate maternal exposure to contaminants from diet and selected lifestyle factors; and
- to contribute to international blood monitoring programs including the Global Monitoring Plan under the Stockholm Convention.

The methodology used was similar to a Baseline study conducted between 1997 and 2000 known as the *Inuvik Regional Human Contaminants Monitoring Program* (Butler-Walker *et al.*, 2003; 2006). This study also involved recruiting pregnant women and collecting maternal and umbilical cord blood samples, hair samples, and information on lifestyle and diet. One hundred and four pregnant women participated; the study collected 95 maternal and 90 cord blood samples, 73 hair samples, and 102 lifestyle surveys. The participation

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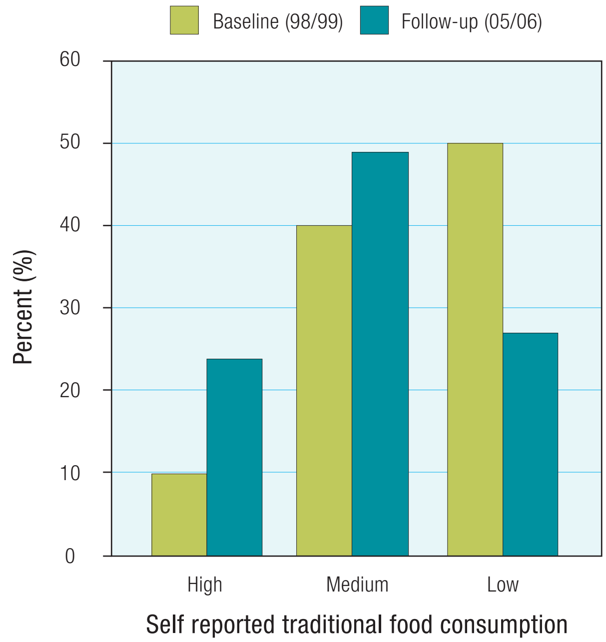

FIGURE 2.3.1

Self-report on country food consumption Baseline versus Follow-up study. (Armstrong *et al.*, 2007)

and demographic characteristics of the two studies are shown in Table 2.3.1. The objective of the study was to establish baseline data for specific heavy metal and organochlorines in the blood of women and their newborns, from communities in the Inuvik region.

TABLE 2.3.1 Participation and demographic comparisons between Baseline and Follow-up studies. (Armstrong *et al.*, 2007)

	Baseline Study (1998/1999) N (range or %)	Follow-up study (2005/2006) N (range or %)
Total participants	104	86
Surveys completed	104	79
Blood sample (maternal)	95	83
Blood samples (cord)	90	0
Hair samples	73	79
Age (mean years, min.–max.)	25.9 (15–45)	25.9 (16–40)
Inuvialuit	33 (32%)	54 (68%)
Dene/Métis	46 (44%)	18 (23%)
Other/Non-Aboriginal	25 (24%)	7 (9%)
First-time mothers	35 (34%)	28 (35%)
For parity >1, mothers who previously breastfed	54 (78%)	41 (80%)
Current smokers	54 (52%)	53 (67%)

Women in both studies were asked to rate themselves as high, medium, or low consumers of country foods. Women in the Follow-up study reported higher consumption of country foods compared with women in the Baseline study (Figure 2.3.1). It must be noted however, that the differences in communities surveyed and distribution of ethnicities may contribute to the differences in reporting.

The level of country food consumption was calculated for the two ethnic groups (Inuvialuit and Dene/Métis) in order to compare the two studies. The number of non-Aboriginal women was too small to make comparisons. It is important to consider the distinctions between eating habits of the groups, as Inuvik is a region representing different ethnic, historical, and cultural backgrounds. In addition, climatic conditions and country food diets vary throughout the region. Overall categories of country food consumption for the Inuvialuit and Dene/Métis are shown in Table 2.3.2 and 2.3.3, respectively.

In their interviews, the women in the Follow-up study confirmed that elders and family members had indeed shared with them the importance of eating country food, especially during their pregnancy. From the Baseline study to the Follow-up study, respondents reported increasing their country food consumption, although the amount and type varied considerably by

TABLE 2.3.2 Annual country food consumption (kg/person/year) for Inuvialuit in the Follow-up study versus the Baseline study. (Armstrong *et al.*, 2007)

Food Item	Inuvialuit Mothers	
	Baseline (n=33) 1998–99	Follow-Up (n=54) 2005–06
All Fish / Seafood	8.0[1] (8.1)[2] [0, 6.1, 36][3]	27[1] (35)[2] [0, 17, 225][3]
Terrestrial Mammal Meat	30[1] (22)[2] [0.3, 30, 75][3]	34[1] (25)[2] [0, 35, 114][3]
Marine Mammal Meat	1.4[1] (4.9)[2] [0, 0, 28][3]	5.2[1] (18)[2] [0, 0, 114][3]
Marine Mammal Fat	4.3[1] (10)[2] [0, 1.2, 50][3]	1.4[1] (2.4)[2] [0, 0, 14][3]
Birds Meat	3.5[1] (2.9)[2] [0, 0, 11][3]	15[1] (25)[2] [0, 4.7, 107][3]
All Plant	4.0[1] (6.1)[2] [0, 0, 31][3]	1.9[1] (2.5)[2] [0, 0, 10][3]

[1] mean
[2] (standard deviation)
[3] [minimum, median, maximum]

TABLE 2.3.3 Annual country food consumption (kg/person/year) for Dene/Métis in the Follow-up study versus the Baseline study. (Armstrong *et al.*, 2007)

Food Item	Dene/Métis Mothers	
	Baseline (n=45) 1998–99	Follow-Up (n=18) 2005–06
All Fish / Seafood	9.4[1] (12)[2] [0.2, 4.3, 50][3]	21[1] (32)[2] [0, 5.9, 1.3][3]
Terrestrial Mammal Meat	31[1] (28)[2] [0, 17, 95][3]	27[1] (32)[2] [1.4, 17, 75][3]
Marine Mammal Meat	0.0[1] (0.1)[2] [0, 0, 0.7][3]	0.1[1] (0.2)[2] [0, 0, 0.7][3]
Marine Mammal Fat	0.2[1] (0.4)[2] [0, 0, 1.2][3]	0.1[1] (0.3)[2] [0, 0, 1.2][3]
Birds Meat	7.9[1] (15)[2] [0, 3.0, 84][3]	8.1[1] (21)[2] [0, 2.4, 92][3]
All Plant	3.8[1] (4.4)[2] [0, 2.0, 18][3]	2.1[1] (2.2)[2] [0, 1.8, 7.2][3]

[1] mean
[2] (standard deviation)
[3] [minimum, median, maximum]

community and population. For the Dene/Métis, the amount of country food use in 2006 was similar to that of 2000, except for the amount of fish consumed, which doubled. Among Inuvialuit, fish consumption increased three fold between 2000 and 2006. The Inuvialuit also reported eating more seal meat, but the consumption of marine mammal fat (particularly beluga) decreased by a factor of three. This decrease could be a positive reflection of the message communicated by health professionals, which suggested decreasing intake because contaminants often build up in fat. (Armstrong *et al.*, 2007)

2.4 Health Implications Associated with Changes in Dietary Habits

The dietary shift away from nutrient-dense country food to energy-dense and nutrient-poor market food have nutritional health implications for micronutrient deficiencies and obesity, and for the development of obesity-related chronic diseases such as type 2 diabetes mellitus and cardiovascular disease. The occurrence of obesity and sub-optimal nutrient intakes have been noted to co-occur across the three Canadian territories (Kuhnlein *et al.*, 2004) in a similar pattern as that found in developing countries (Popkin, 2002). Dietary studies in the three Canadian territories show that on days when country food is not consumed, there is a lower intake of vitamins A, D, E, B6, and riboflavin, and a lower intake of the important minerals iron, zinc, copper, magnesium, manganese, phosphorus, potassium, and selenium when compared to days when country food is consumed (Kuhnlein *et al.*, 2004). Also, total fat, saturated fat, and sucrose consumption have been noted to be above recommended levels (Kuhnlein *et al.*, 2004).

2.4.1 Relationship between dietary change and obesity

The prevalence of overweight and obese people has risen throughout Canada as it has globally, and there is now evidence that the same trends are occurring in the Circumpolar North (Popkin, 2002; Anderson *et al.*, 2004; Kuhnlein *et al.*, 2004; Schnohr *et al.*, 2005; Shields, 2005). In Dene/Métis and Yukon First Nations' children, 32% were above the 85th percentile for body mass index (BMI) for age and gender (Nakano *et al.*, 2005a), which was similar to the prevalence of children at-risk for overweight observed in other Canadian Aboriginal populations (Bernard *et al.*, 1995; Potvin *et al.*, 1999; Hanley *et al.*, 2000).

The prevalence of obesity in adults living in the three territories exceeded Canadian rates for obesity based upon the standard definition of adult obesity (BMI

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greater than 30 kg/m^2) (Kuhnlein *et al.*, 2004). The prevalence of obesity may be overestimated, to some degree, among Inuit, given that BMI overestimates adiposity in individuals with a long torso relative to standing height (Charbonneau-Roberts *et al.*, 2005; Norgan, 1994). However, BMI does not capture the extent of visceral adiposity in a population. A high prevalence of central fat patterning was observed in a Baffin community survey and all measures of obesity were identified as strong predictors of insulin resistance (Charbonneau-Roberts *et al.*, 2007). The findings are noteworthy because they suggest that the emergence of obesity among Inuit is likely to have health consequences, although the health consequences of obesity may not be as pronounced among Inuit as among other populations (Young *et al.*, 2007). In analyses of data pooled from four Inuit study populations, Inuit had lower blood pressure and lipid levels at every level of BMI or waist circumference than did the European and southern Canadian comparison populations (Young *et al.*, 2007). For example, Inuit men with a BMI greater than 30 had a mean high density lipoprotein (HDL)-cholesterol level which was comparable to that observed among the Euro-Canadian men with a BMI under 25: the mean HDL-cholesterol was 1.2 mmol/L (95% CI: 1.2–1.3) and 1.2 mmol/L (95% CI: 1.1–1.3), respectively (Young, 2007).

In general, the evidence supports a high prevalence of overweight and obese adults and children at risk to become overweight and obese adults in the Circumpolar North, and adds to the cumulative evidence of a global shift in adiposity with significant health implications. While data suggest that adiposity may not have the same magnitude of association with metabolic syndrome risk factors for Inuit as Caucasians, adiposity is related to increased insulin resistance (Charbonneau-Roberts *et al.*, 2007) and to related metabolic syndrome risk factors among Inuit (Ludi, personal communication; Egeland, in press).

2.5 Conclusions and Recommendations

Country food use is culturally specific and varies widely over the many communities and regions in the Canadian Arctic. The results of the studies presented in this chapter suggest that meat and fat from game species, fish, marine mammals, dairy products, and edible plants and berries are consumed in different quantities depending on latitude, proximity to a major centre and water, age, and culture. The findings from eight studies reporting the contribution of country food to total dietary energy ranged from 4.3% to 89% with a median value of 18% of total energy.

As discussed in this chapter, country food consumption was associated with higher levels of nutrients in the diet, including vitamins A, D, E, B_6, and B_{12}, protein, iron, and omega-3 fatty acids. Those studies that compared present intake to past intake confirmed a decline in country food use, except for one study of pregnant women in the Inuvialuit region of Canada where an increase of fish consumption was reported while marine mammal fat consumption decreased. Three studies reported that younger generations consume significantly less country foods than older generations.

The current nutrient transition in the Canadian Arctic has led to observed changes in intake levels of vitamins A, C, D, and E as well as iron, calcium, folate, omega-3 fatty acids, and fibre. The level of nutrition transition is dependant on the ratio of market food to country food and the food items consumed. Research suggests that a decreased intake of country food and an increased intake of high-energy, low-nutrient market food will put Inuit communities at risk for micronutrient deficiencies (Kuhnlein *et al.*, 2004). Decreasing intake of country food also increases the risk of obesity, which is associated with increased risk of obesity-related chronic disease (Receveur and Kuhnlein, 2000).

Future research is required to study the diet in the Canadian Arctic in the context of overall heath and well-being, disease prevention, and health promotion. In particular, additional research is needed on the following:

- regionally specific sources of contaminants in country foods;
- the relationship between changes in risk of cardiovascular disease and changes in diet among Arctic Aboriginal populations; and
- the impacts of climate change on country food safety and availability and general food security.

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Chapter 3

Health Status of the Canadian Arctic Population

3.1 Introduction

The purpose of this chapter is to provide a short overview of selected health status indicators for northern populations of Canada. The overview focuses on the Northwest Territories (NWT), Yukon, Nunavut, and the region of Nunavik located in the north of the Province of Québec. Nunavik is predominantly populated by Inuit, and therefore could provide a basis for comparison with other Inuit regions across Canada's North. Unfortunately, not much data were available for Nunatsiavut region in northern Labrador.

This overview of several indicators of disease burden of Canadian Arctic populations is primarily based on disease outcomes and associated metrics, and does not attempt to address health status in a holistic way. Annual rates are often used to illustrate important regional/national differences and the reader is referred to other publications to see more in depth analyses of disease rates (NWT, 2005; INSPQ, 2007; Young, 2008). Measures of health system performance and health service utilization are not included as they are beyond the scope and purpose of this report.

Following in the steps of the Yukon Department of Health and Social Services (2003), it is fitting to quote here A. Einstein in his astute observation that "not everything that counts can be counted; not everything that is counted counts."

3.1.1 Data sources

Indigenous status has been associated with lower health outcomes in the past (Frohlich *et al.*, 2006); however, there is often a scarcity of data that would allow clear illustration of health disparities between Indigenous and non-Indigenous northern populations. Whenever this information was found, it was included in this overview. Primary sources of data included health status reports developed by the Yukon, NWT, and Nunavut governments between 2003 and 2005, as well as Statistics Canada publications. Information about the health status of Nunavik residents was drawn from a synthesis report developed for the First Nations and Inuit Health Branch of Health Canada by É. Counil, PhD, at the Institut national de santé publique du Québec (INSPQ, 2007). This report was based, to a large extent, on data from the *Portrait de santé du Québec et de ses regions* (2006) with numerous complementary data extracted from the *Nunavik Health Survey 2004, Qanuippitaa, how are we?* (INSPQ, 2007). Additional information was extracted from various peer-reviewed publications and unpublished sources that are referenced throughout the text.

3.2 Demographic Indicators Relevant for Health Status

Among the demographic attributes associated with health status and health behaviour are basic population characteristics such as size, distribution, and composition. The compositional factors of the population—age, sex and race/ethnicity—are not only linked to health behaviour, but are also excellent predictors of health status (Pol and Thomas, 2002).

Total population numbers for the Yukon and NWT appeared to be generally stable over the last decade, with a combined effect of deaths, births, and in/out migrations producing a slight positive increase from 1995 to 2005 of between 1.8% in Yukon to 3.8% in the NWT (Figure 3.2.1). During the same time period, there was a remarkable 20% increase in the population of Nunavut, mostly influenced by a very high birth rate (Statistics Canada, 2006a). With the exception of Alberta, the territories were the only regions of Canada posting rates of natural increase in 2004–2005 that were clearly above that of the national average (Statistics Canada, 2006a). At the same time, it is important to mention that migration was a notable source of population fluctuations in both Yukon and the NWT, primarily between 1994 and 2000.

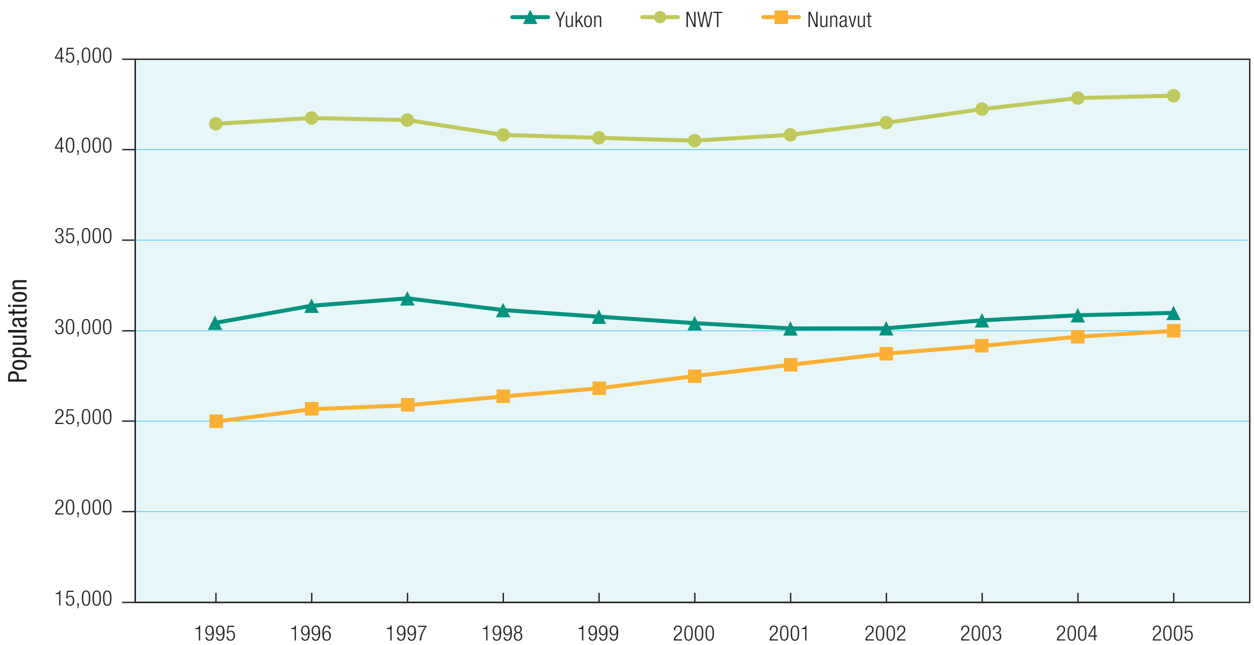

FIGURE 3.2.1

Annual population estimates for Yukon, Northwest Territories, and Nunavut (Statistics Canada, 2005).

The population of Canadian northern territories is characterized by an increasing proportion of Indigenous peoples as a part of the total population, particularly as one moves geographically west to the east (Figure 3.2.2).

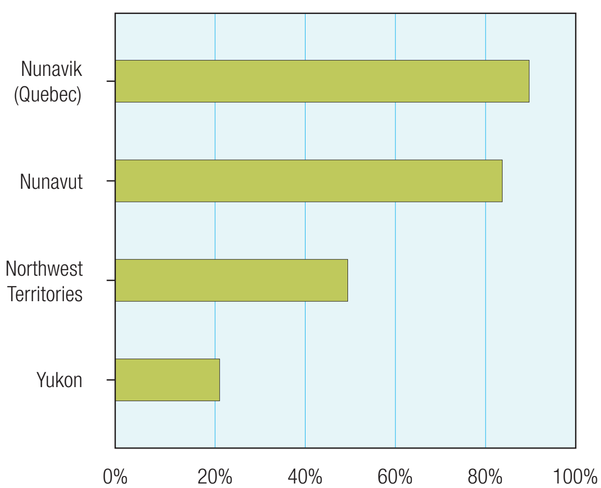

FIGURE 3.2.2

Percentage of total population who identify themselves as Aboriginal in three territories and the region of Nunavik (Québec) (Statistics Canada, 2001; Statistics Canada, 2003).

According to the demographic profile of the Aboriginal peoples of Canada,[1] in the 2001 census, the 22,720 Aboriginal people in Nunavut represent 85% of the territory's total population, one of the highest proportions in the country. Aboriginal people represent more than one-half (51%) of the population of the NWT, and almost one-quarter (23%) of the Yukon population. According to the 2001 census, 91% of people living in Nunavik self-identified as Inuit.

First Nations accounted for approximately 29% of the NWT's and 20% of Yukon's populations. Inuvialuit (Inuit), who live primarily in the six most northern communities of the NWT, comprise 11% of the total territorial population. Ten per cent of the total NWT population are Métis, living mostly in the communities of Yellowknife, Hay River, and Fort Smith (NWT, 2005).

In 1931, the Inuit population of Canada was around 5,000 people (Bjerregaard and Young, 1998). Seventy years later, in the 2001 census, about 5% of all self-identified Aboriginal populations, or 45,070, reported that they were Inuit. In comparison to five years earlier, this was a 12% increase. In contrast, the total non-Aboriginal population grew only 3.4% between 1996 and 2001 (Statistics Canada, 2003). Most of the growth

[1] According to Statistics Canada (2003), "incomplete enumeration and undercoverage account for most of the difference between the 2001 Census count of persons registered under the Indian Act (about 558,000) and that produced by the Indian Register maintained by the Department of Indian Affairs and Northern Development (about 681,000)."

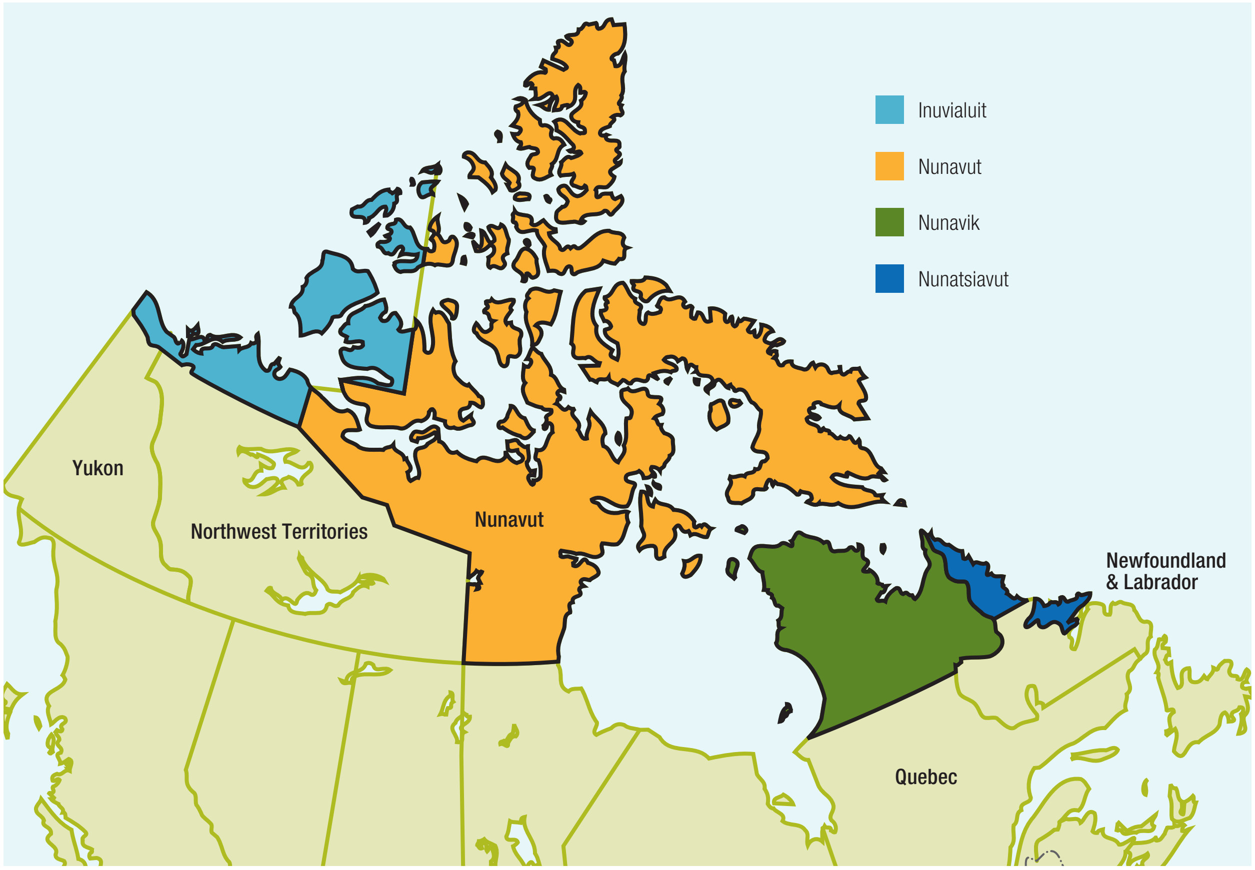

FIGURE 3.2.3

The Inuit Regions (ITK, 2007).

for the Aboriginal population is attributable to demographic factors—higher fertility rates and increasing life expectancy (Statistics Canada, 2003).

In 2001, the majority of Inuit (81%) were living in one of four Inuit regions of the Canadian Arctic (Figure 3.2.3) (Statistics Canada, 2006b; ITK, 2007):

- Nunatsiavut, the region of Labrador, with 5% of all Inuit;
- Nunavik, which lies mostly north of the 55th parallel in Québec, where 19% of Canada's Inuit population lives;
- The territory of Nunavut, home to about 50% of Inuit; and
- The Inuvialuit region of the NWT, with 7% of the Inuit (Inuvialuit).

The median age of Canada's Inuit population was only 20.6 years in 2001 compared with the median of 37.7 years for the non-Aboriginal population. Québec and Nunavut had the youngest Inuit populations, with respective median ages of 19.0 and 19.1 years. The 2001 census enumerated 17,460 Inuit children aged 14 and under, representing 39% of the total Inuit population. This was down from 41% five years earlier (Statistics Canada, 2003). As a result of higher fertility than in the rest of the country, Nunavut (22.9 years) stood out as the only region in Canada with a median age of the total population under 30 (Statistics Canada, 2006a).

At the same time, a slight trend toward aging in the Inuit population was noticed. This aging is in large part due to declining, although still high, fertility rate among the Inuit. Although the 1,405 Inuit seniors aged 65 and older accounted for just over 3% of the Inuit population (up slightly from five years earlier), their numbers grew by 38% between 1996 and 2001 (Statistics Canada, 2003).

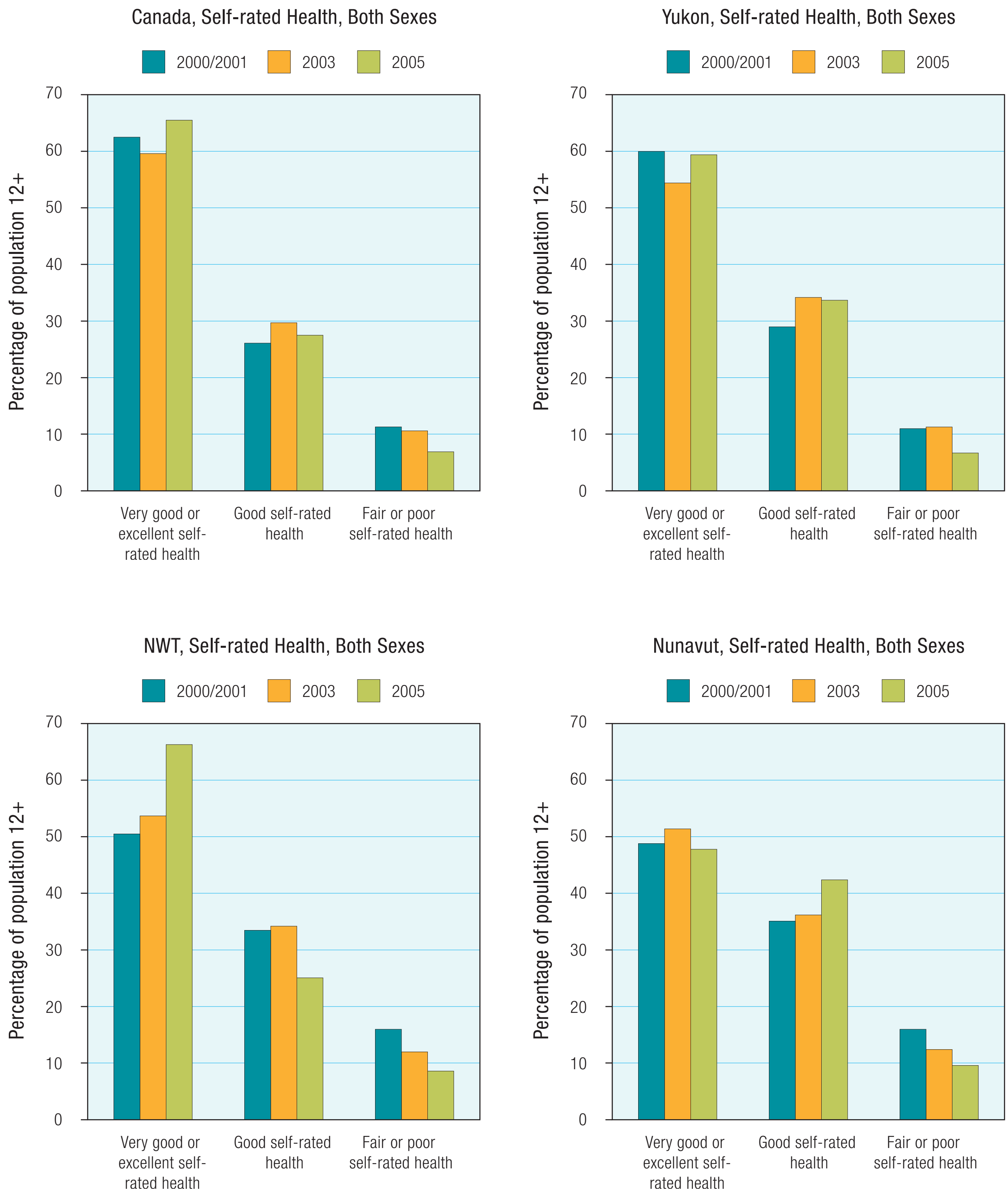

FIGURE 3.3.1

Self-rated health by the household population aged 12 and over for Canada and the territories (Statistics Canada, 2008a).

3.3 Health Status of the Canadian Arctic Population

3.3.1 Self-assessed health

Self-reported or self-assessed state of health as a global health indicator is both very direct and very subjective. On the one hand, it allows survey participants to identify their total health experience; on the other hand, respondents may use different values and frameworks in assessing their state of health increasing the potential for problems with the comparability of the outcomes (Larsen *et al.*, 1998).

Nevertheless, a reasonable correlation has been found between self-reported ratings of health status and more objectively derived indicators of health status (Pol and Thomas, 2002). There is some evidence that a relatively strong association exists when self-assessments are correlated with responses to a symptom checklist (Proctor *et al.*, 1998). In general, survey participants experiencing or reporting a large number of symptoms tend to rate their health status lower than those with few identified symptoms. Furthermore, self-reported health status has been shown to be a predictor of subsequent incidence of chronic disease, loss of ability to function, and ultimately, survival and mortality (McGee *et al.*, 1999; Health Canada, 2006). The main source of the self-rated health data nationally is the Canadian Community Health Survey, which replaced the National Population Health Survey in 2000. Additional information for Yukon is also available from the First Nations Regional Longitudinal Health Survey (CYFN, 2006).

In 2005, 66% of Canadians aged 12 years and older reported their health as *very good or excellent*, an increase from the 60% reported in 2003 (Health Canada, 2006) (Figure 3.3.1). Similar dynamics could be observed in both Yukon and the NWT. In Yukon, 59% of the population (95% CI=54-65) older than 12 reported their health to be *very good or excellent*, while in the NWT, 66% of the population (95% CI=60-73) reported their health in this category. The NWT Health Status Report (NWT, 2005) noted that in 2003, women were less likely than men to report their health as *good* or higher. In Nunavut, only 47.8% of the surveyed population (95% CI=42-54) reported their health as *very good or excellent*. Over the period of five years from 2000, this percentage remained relatively steady, while the age-standardized rate for population reporting their health as *good* increased from 35% in 2000/2001 (95% CI=33-38) to 42% in 2005 (95% CI=35-50).

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Yukon First Nations Longitudinal Health Survey (CYFN, 2006) investigated self-reported health among nine of fourteen First Nations and showed that only 43% of Yukon First Nations people rated their health as *very good or excellent*, and 22% reported *fair or poor* health. This is about twice the *fair or poor* health category numbers reported by all Yukoners over 12 years of age. It was also noted by Adelson, 2005 (in CYFN, 2006) that given the discrepancies between people's generally positive reflections on health and their reported conditions, "we need to ask what 'health' means for Aboriginal people…. Health status and meanings of health are not adequately developed."

According to the Nunavik Health Survey conducted in 2004 (Counil, 2007; INSPQ, 2007), only 22% of Inuit aged 15 years and over reported *very good or excellent* self-rated health with 33% of participants rating their health as *fair or poor*. When compared with the results from other northern territories, these numbers could indicate a rather poor level of health and well-being in Inuit communities of Nunavik. The incidence of suicide and violence-related mortality further supports this assumption (Counil, 2007).

3.3.2 Selected indicators

Evaluation of key indicators of health outcomes can provide a rough estimate of the overall health status of population groups. Life expectancy, data on causes of death in a given population and infant mortality rates are particularly useful. In respect to Inuit, infant mortality tells a story by itself. It is a story of dramatic change, a story of more than a 10-fold decrease in Inuit infant mortality in Arctic Canada and other Arctic jurisdictions over the past 60 years (Fig. 3.3.2). This is in contrast to infant mortality rates in the general population of the USA, Canada and Denmark where infant mortality rates have declined at a much slower rate, but these populations continue to have lower infant mortality than that seen in Inuit or other Aboriginal populations.

3.3.3 Life expectancy

Life expectancy, based on existing age-specific death rates, is an important indicator of current population health and conditions of mortality in a given population. Life expectancy at birth is defined as an average "number of years a newborn baby can be expected to live if current mortality trends continue" (Last, 2001).

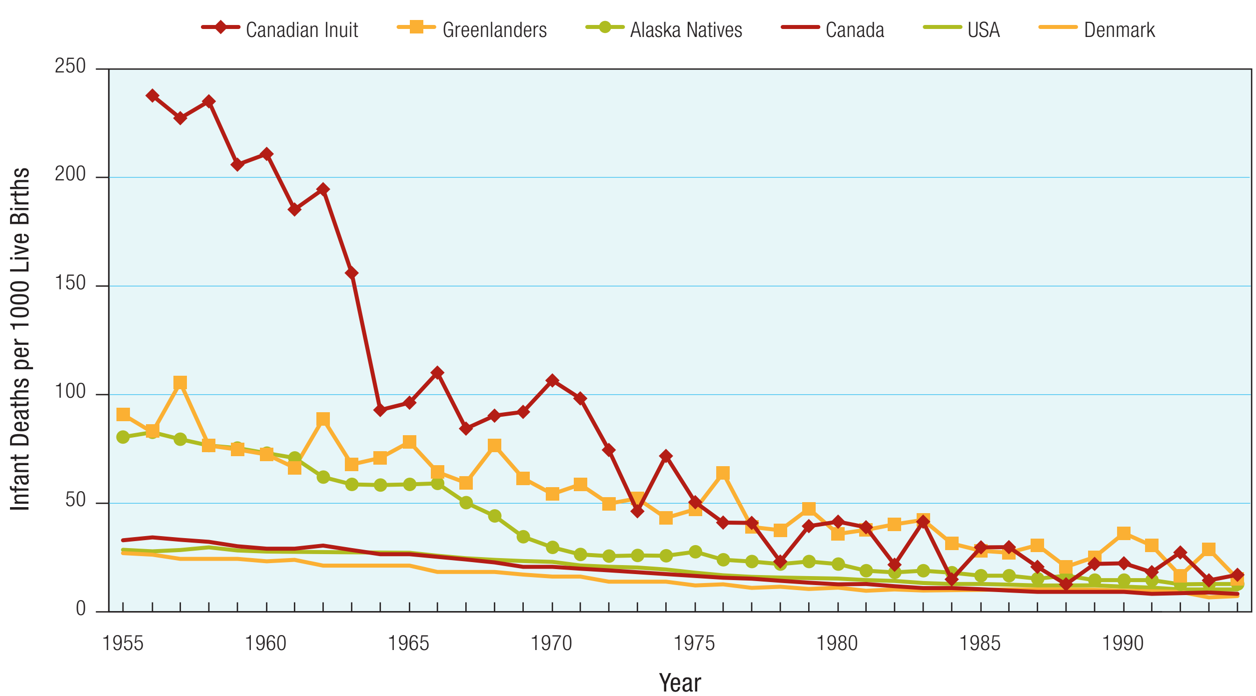

FIGURE 3.3.2

Trends in infant mortality rates among Inuit in different circumpolar regions in comparison with the general population of the respective countries (Adapted from Bjerregaard and Young, 1998).

This measure of health is affected by infant and child mortality in the first year of life and, therefore, is more of a reflection of the current state of health and health determinants.

As illustrated in Figure 3.3.3, female life expectancy is consistently higher than for males, although there appears to be a slight trend over the last decade toward narrowing this gap in the NWT and Yukon, as well as nationally. It has been shown by DesMeules *et al.* (2004) that "external preventable causes of death"[2] were responsible for a large portion of the gender gap in mortality and life expectancy in Canada. When excluding these causes from the calculations, the gender gap in life expectancies was reduced, decreasing nationally from approximately 5.5 years to approximately 2.2 years (DesMeules *et al.*, 2004).

Life expectancy at birth for residents of Nunavut is ten years lower than for the rest of Canada (NRCHI, 2004). The life expectancy indicator in Nunavik was 63 years in 2000–2003, lower than in the rest of Québec (79 years) (Counil, 2007). A recently published analysis (Wilkins *et al.*, 2008) suggested that from 1991 to 2001, life expectancy in the Inuit-inhabited areas did not increase, while during the same interval of time it grew by about two years for Canada as a whole. As a result, the gap widened to more than 12 years (Wilkins *et al.*, 2008).

As an indicator, life expectancy reflects social, economic, and lifestyle determinants of health affecting survival of infants and children in particular, as well as, to a certain extent, quality of health care people receive when they are ill (NRCHI, 2004).

Life expectancy measures from all three territories and the region of Nunavik have to be interpreted with caution because of the small underlying numbers, which can account for the overall variability of the measure.

3.3.4 Infant mortality

Infant mortality is one of the most frequently and universally used indicators of health status in a community. It is a measure of the yearly rate of death in children less than one year old, calculated per 1000 live births (Last, 2001).

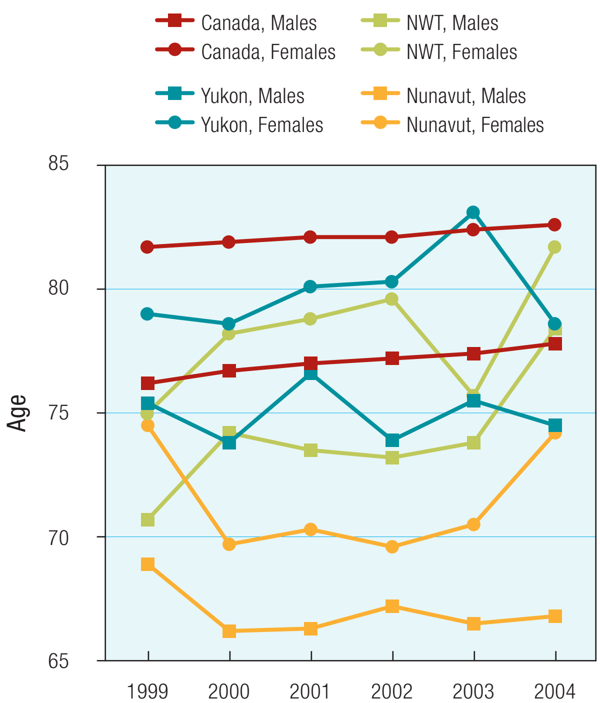

FIGURE 3.3.3

Life expectancy of the population in the Yukon, the NWT, and Nunavut in comparison to Canada (Statistics Canada, 2008b).

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[2] "External" causes of mortality included smoking-related deaths, HIV/AIDS, accidental deaths, and a proportion of colorectal cancer preventable through primary prevention (physical activity and diet). Smoking-related causes of death include coronary heart disease, cerebrovascular disease, cancer, and COPD" (DesMeules *et al.*, 2004).

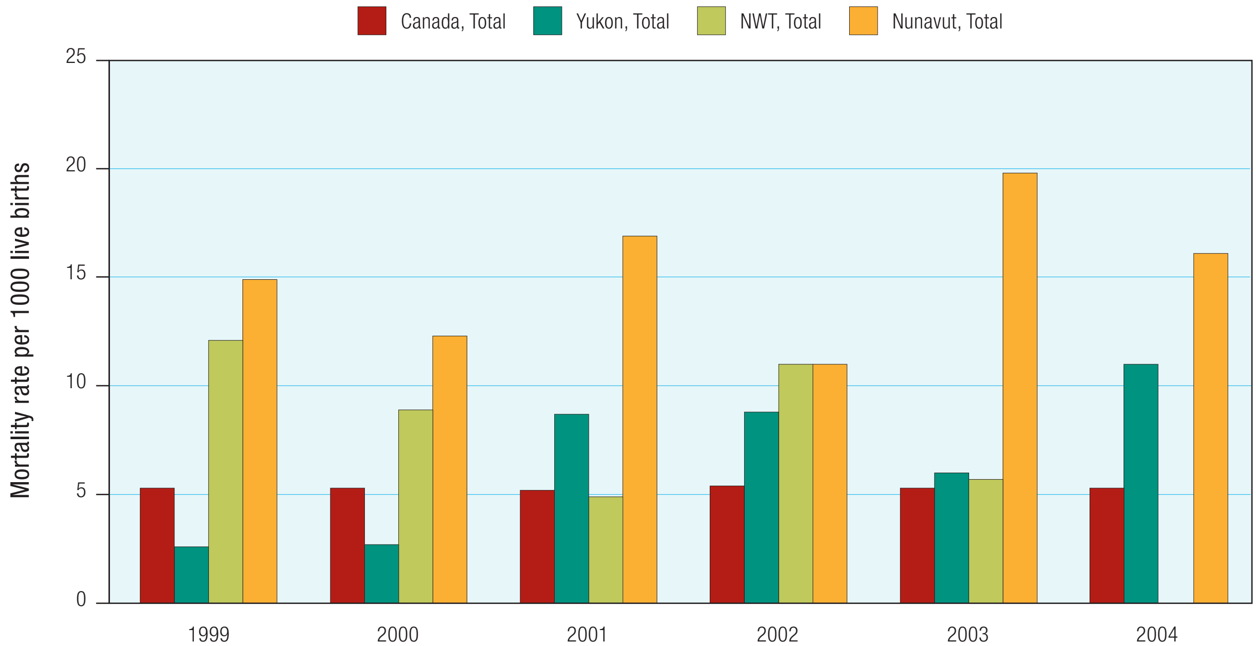

FIGURE 3.3.4

Infant mortality in Canada and the territories per 1000 live births, 1999–2004 (Statistics Canada, 2008c).

It is important to consider that the rates presented in Figure 3.3.4 are based on a relatively small number of births, where two or three deaths a year could significantly affect the rate. Therefore, caution is advised when interpreting these rates.

The importance of the infant mortality indicator lies in its ability to reflect several key aspects of the quality of preventative care in the community; the socio-economic conditions of women; attention the community pays to the health of pregnant women, new mothers, and their infants; public health practices; and access to appropriate health care (NWT, 2005).

Infant mortality can be separated into neonatal (deaths under 28 days of life) and post-neonatal (deaths from day 28 to 364). The causes of death generally would be different in these two categories; each would have implications for public health and primary care practice. While neonatal deaths are considered to be generally associated with the quality of prenatal and perinatal health care provided, the post-neonatal deaths are notably affected by socio-economic conditions (NWT, 2005).

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When we look at the components of infant mortality in Nunavut, we can see that they seem to be more affected by post-neonatal mortality (Figure 3.3.5), and may be related to social and economic conditions of nursing mothers in Nunavut. When averaged over the six years between 1999 and 2004, infant mortality in Nunavut was nearly three times higher than it was for Canada during the same period.

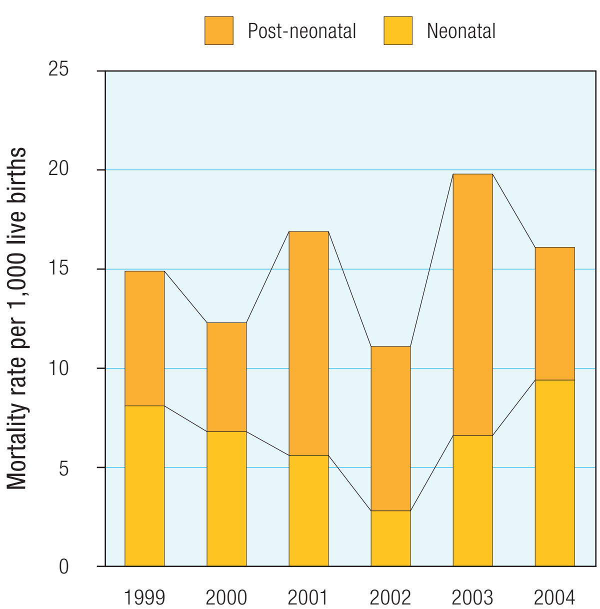

FIGURE 3.3.5

Infant mortality, neonatal mortality, and post-neonatal mortality in Nunavut (Statistics Canada, 2008c).

In the NWT, for the period from 1996 to 2002, neonatal deaths accounted for 61% and post-neonatal for 39% (NWT, 2005).

The NWT Health Status Report for 2005 (NWT, 2005) presented the leading causes of infant mortality in the territory for 1996 to 2002. According to this analysis, the leading cause (39%) was due to conditions that originated in the prenatal period and included disorders related to short gestation period, low birth weight, and respiratory distress. These were followed by congenital anomalies (25%), infections (11%), SIDS (9%) and injuries (9%).

The six-year means of infant mortality in Yukon and the NWT (1999–2004) are fairly close, around 7 per 1000 live births, with the mean value in the Yukon being slightly lower. Comparable data for Nunavut indicate that infant mortality rates are approximately double (15 per 1000 live births) those reported in Yukon and the NWT (Figure 3.3.4). At the same time, the mean post-neonatal mortality rate for the same period in Nunavut is about five times higher than comparable rates in Yukon and the NWT (data from Statistics Canada, 2008c).

Infant mortality in Nunavik decreased, compared with the 1985–1989 period, but still reached 17.7 deaths per 1,000 live births, compared with 4.6 in the rest of Québec in 2000–2003 (Counil, 2007).

3.3.5 Leading causes of death

Examination of the leading causes of death suggests which determinants of health (i.e., high-risk behaviours, dietary preferences, and personal choices) influence the likelihood of the onset of serious illness and mortality. Figure 3.3.6 demonstrates some of the key causes of death in 2000-2004, providing an illustration of their relative importance. A more in-depth analysis of leading causes of death is provided in the territorial health status reports. Some aspects of these analyses are highlighted below.

Between 2000 and 2002, the leading causes of death in the NWT were malignant neoplasms (cancers), cardiovascular diseases, injuries, and respiratory diseases such as chronic obstructive pulmonary disease. Together these causes were responsible for three out of four deaths (NWT, 2005). While these causes stayed the same for both males and females, their relative ranking was different. The leading cause of death for men was cardiovascular disease (26%), followed by injuries (23%), cancer (23%), and respiratory disease (11%). For women, cancers were the leading cause (28%), followed by cardiovascular disease (16%), injury (16%), and respiratory diseases (11%) (NWT, 2005).

When averaged over five years, cancers were the leading cause of death in northern Canada (the Territories), closely trailed by circulatory illnesses and then by accidental injuries and chronic lower respiratory diseases. In Nunavik in 2000–2004, chronic lower respiratory diseases were fewer than circulatory diseases, and were trailed by suicide and then accidental injuries (Fig. 3.3.6).

In Nunavik, between 2000 and 2003, the leading causes of death were, in descending order, cardiovascular disease, cancers, respiratory diseases, suicide, and accidental (unintentional) injuries (Counil, 2007). Leading causes

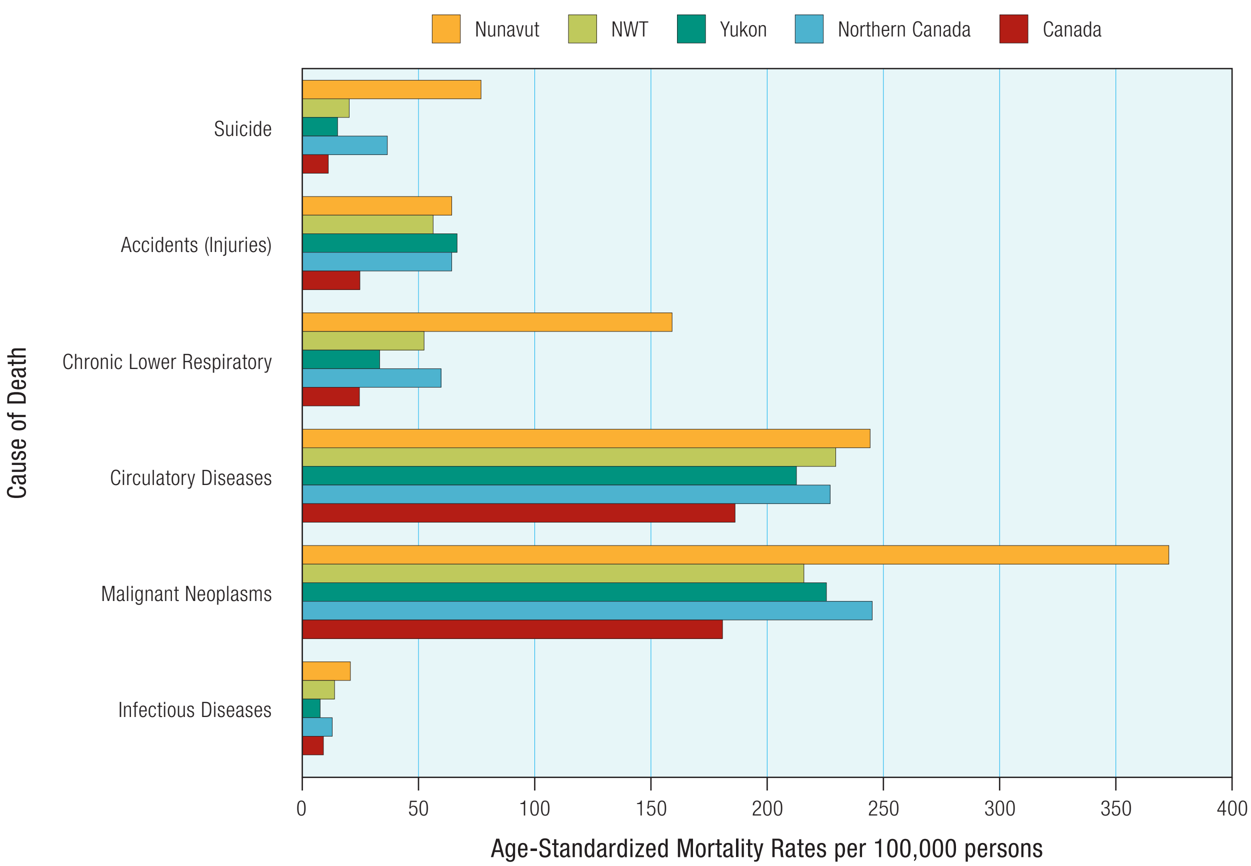

FIGURE 3.3.6

Causes of death in Canada (2000-2004), expressed as age-standardized mortality rates per 100,000 population. Standardised to European standard population. (Young TK., 2008).

of death were different for males (cancer, followed by respiratory and cardiovascular diseases, then suicide and unintentional injuries) and females (cardiovascular diseases, then malignancies, followed by respiratory diseases). Among women, suicide was a much farther removed cause of death in terms of relative ranking, and few unintentional injuries (accidents) were reported (Counil, 2007).

There appears to be certain similarity between Nunavik and Nunavut in the structure of the leading causes of death, and also a surprising emergence of major circulatory illnesses as a leading cause of death in both regions. This is noteworthy, because of a long-standing assertion that cardiovascular illnesses were less prevalent in the Inuit population, due to some genetic, cultural or dietary factors. In this context a number of publications referred to the protective effect of omega-3 fatty acids in the traditional foods of Inuit (Dewailly *et al.*, 2001; Counil, 2007). It is possible that nutritional transition together with associated decrease in physical activities and high smoking rates in Nunavut and Nunavik are some of the health determinants that may influence the increasing mortality rate from cardiovascular diseases. It is also remarkable to note that in both 2002 and 2003, mortality from cerebrovascular diseases was higher in Nunavut than in other territories. This is similar to the observation that mortality from stroke was higher in Greenland Inuit than in Denmark between 1965 and 1998 (Bjerregaard *et al.*, 2003).

Predominantly Inuit regions seem to carry a double burden of disease: the mortality rates are higher for most usual causes of death also prevalent in Canada, and some specific causes of death affect this population particularly in younger ages, mainly suicide and unintentional injury (Counil, 2007).

3.3.6 Premature mortality

Typical mortality statistics are dominated by deaths of elderly people. However, all northern regions are characterized by a high proportion of Aboriginal populations, which have high mortality rates for many diseases and conditions that tend to occur earlier in life (Allard *et al.*, 2004). Two indicators have been used in recent years by territorial health authorities to provide a glimpse into sources of mortality that are affecting younger populations but which can be expected to decrease as population health improves and lifespan is extended. The NWT Health Status Report (NWT, 2005) relied on the Premature Mortality Rate, which is a standardized rate of premature death. At the same time, the Yukon and Nunavut relied more on Potential Years of Life Lost (PYLL) indicator, which reflects the number of years of life “lost” when a person dies prematurely from any cause before the age of 75.

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The premature mortality rates have diminished significantly in the NWT in the last 20 years from 37 deaths per 10,000 population in 1980–1982, to 26 per 10,000 in 1990–1992, to 22 per 10,000 population in 2002–2003 (NWT, 2005). However, the NWT age-standardized premature mortality rate was significantly higher than the 2001 Canadian rate of about 16 per 10,000 population[3] (Statistics Canada, cited in NWT, 2005). Males in the NWT were much more likely to die prematurely (before age 75) than females; much of this difference could be attributed to higher injury mortality rates among males. Overall, for the NWT, cancers were responsible for 29% of all premature deaths between 2000 and 2002, followed by injury (27%) and cardiovascular diseases (15%). For males, injuries accounted for 33% of all premature deaths, followed by cancer

[3] As for several other indicators presented in the NWT Health Status Report, 2005 this rate was developed through age-standardization to 1991 NWT population.

(26%) and cardiovascular diseases (17%). Meanwhile cancer (35%) was the primary cause of premature death for females, followed by injury (16%) (NWT, 2005).

Between 1999 and 2003, overall mortality rate due to suicide in the NWT was more than twice the 2001 crude rate for Canada. The NWT rate was still two times higher when the rates were age-standardized (NWT, 2005). Youth between 15 and 24 years of age were at higher risk of suicide, followed by the 25–44 age group. Gender differences in suicide rates were found to be significant, with males being five times more likely than females to die due to suicide between 1999 and 2003 (NWT, 2005). Health Canada's Report on Mental Health Illness (2002) supported these findings. The report highlighted that although both males and females exhibit suicidal behaviour and attempt suicide, males are more likely to die as a result of these attempts because they use deadlier means (e.g., firearms and hanging). Females are more likely to be hospitalized due to self-inflicted injury (Health Canada, 2002; NWT, 2005). Between 2001/2002 and 2003/2004, the hospitalization rate due to self-inflicted injury was the highest for those in their late teens and early twenties (Fig. 3.3.7).

It is important to note that residents of smaller communities in NWT had significantly higher rates of suicide than residents of Yellowknife. This fact has been attributed to the possible contributing role of several socio-economic factors in the smaller communities such as poor housing conditions, low incomes, and easy access to firearms (Health Canada, 2002).

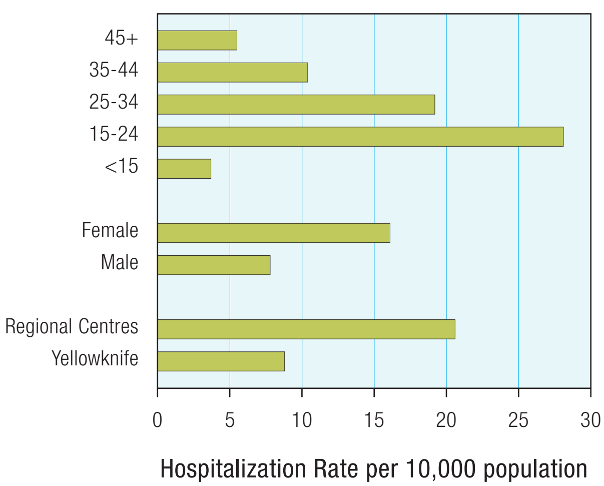

FIGURE 3.3.7

Hospitalization rate (per 10,000 population) due to self-inflicted injury by selected groups, NWT 2001/2002–2003/2004 (NWT, 2005).

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Deaths due to unintentional injuries form a very large component of the PYLL in Yukon (Yukon, 2003). Data presented in the 2003 Yukon Health Status Report show that the PYLL by Yukoners due to unintentional injuries is 2.5 times higher than for Canada. In addition, this pattern is consistent across genders (Yukon, 2003). The burden of PYLL due to suicide has also been consistently higher in the Yukon than in Canada as a whole. This implies that Yukoners are younger than Canadians in general when they commit suicide (Yukon, 2003). The aggregate data illustrates that males are more likely than females to take their own lives in Yukon; males make up 89% of the deaths by suicide. Suicide is not, however, limited to one or a few age categories, but occurs across the duration of life (Yukon, 2003). The Report of the Yukon First Nations Regional Health Survey also showed that suicidal experiences were not uncommon among different age groups, with 36% of First Nations adults having considered suicide at some time in their lifetime (CYFN, 2006).

Nunavut has a higher PYLL due to unintentional injuries than the rest of Canada. The PYLL is five times higher for males than for females, which is a significant difference (NRCHI, 2004). The rates of suicide in Nunavut are also much higher than in other provinces and territories and they appear to be increasing (Figure 3.3.8).

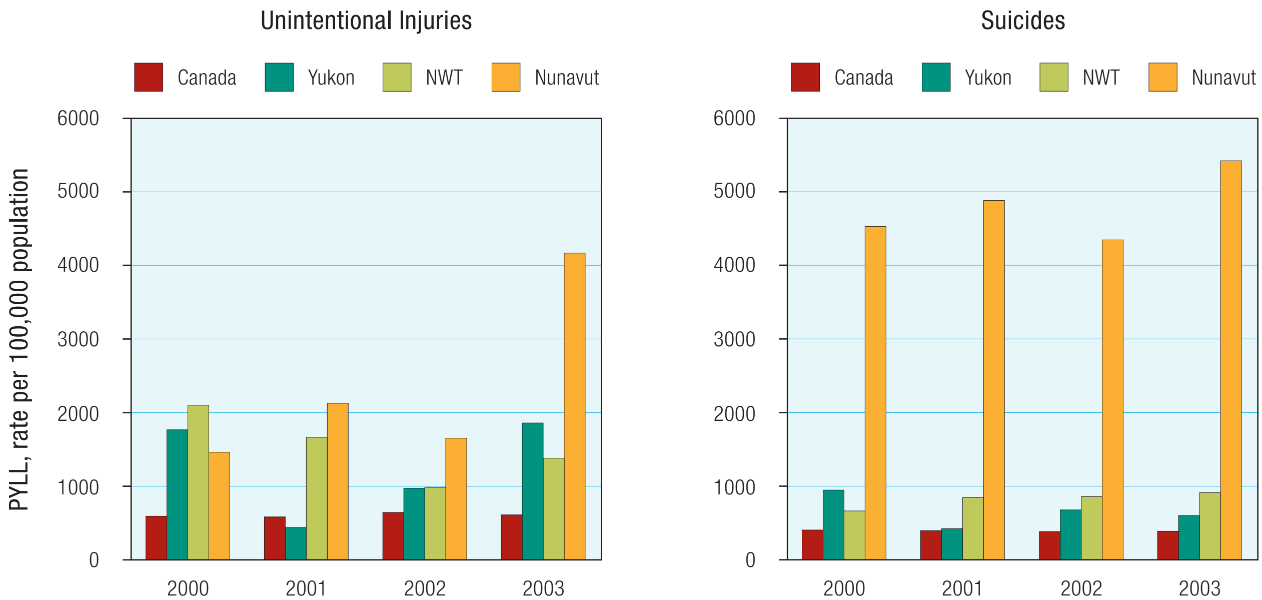


FIGURE 3.3.8

Potential years of life lost (PYLL) due to unintentional injuries and suicides in the population aged 0 to 74 in Canada and the territories from 2000 to 2003 (Statistics Canada, 2008d).

NOTE: For the territories, rates should be interpreted with caution due to low underlying counts

Deaths due to unintentional injuries were more than four times higher in Nunavik than in Québec between 2000 and 2003 and were dominated by male mortality. Transportation accidents were responsible for 46 deaths per 100,000 of the population and were predominantly related to accidents involving motorized vehicles. Counil (2007) suggested that the high rate of transportation accidents is likely related to a combination of more dangerous environments due to extreme weather conditions in the north and worsened transportation conditions due to deterioration of winter roads and quality of ice. Further, the frequency of driving under the influence of alcohol or drugs was also a very significant factor (Counil, 2007; INSPQ, 2007). Literature suggests that injury deaths, particularly among young people, may be related to substance abuse (Single *et al.*, 2000; Allard *et al.*, 2004).

The high rate of premature mortality due to motor vehicle accidents is not unique to Nunavik. In fact, this phenomenon has been observed in other regions of Canada with large Indigenous populations. Furthermore, there is a suggestion that some deaths classified as motor vehicle accidents may be intentional (Allard *et al.*, 2004).

Studies undertaken in the general population suggested that bouts of drinking to intoxication have a propensity to lead to violent assaults, road injuries, and drowning. (Single *et al.*, 2000; Chikritzhs *et al.*, 2001).

Suicide-related deaths were notably more frequent in Nunavik (20% of deaths in 2001–2005) than in the rest of Québec (2.2% of deaths). In 2001–2005, 50% of suicide-related deaths occurred among youth aged 10 to 19 and another 37% in the 20–29-year-old category, which demonstrated a trend toward earlier occurrence of suicide compared to 1996–2000 (Counil, 2007). It would appear that while suicide attempts were more common in women than in men in Nunavik (similar to other northern regions), suicide deaths for males have decreased since 1996–2000; meanwhile, suicide deaths for females have increased, a tendency that has to be further confirmed because the small population and the low overall number of deaths creates significant variability from year to year (Counil, 2007).

3.3.7 Selected morbidity indicators

It is difficult to develop a clear picture of morbidity because of a degree of uncertainty associated with various sources of data. Data provided here are based primarily on territorial health status reports and the Disease Surveillance On-Line system of the Public Health Agency of Canada. The Canadian Community Health Surveys provided information on certain chronic conditions to territorial governments, including an estimate of disease prevalence.

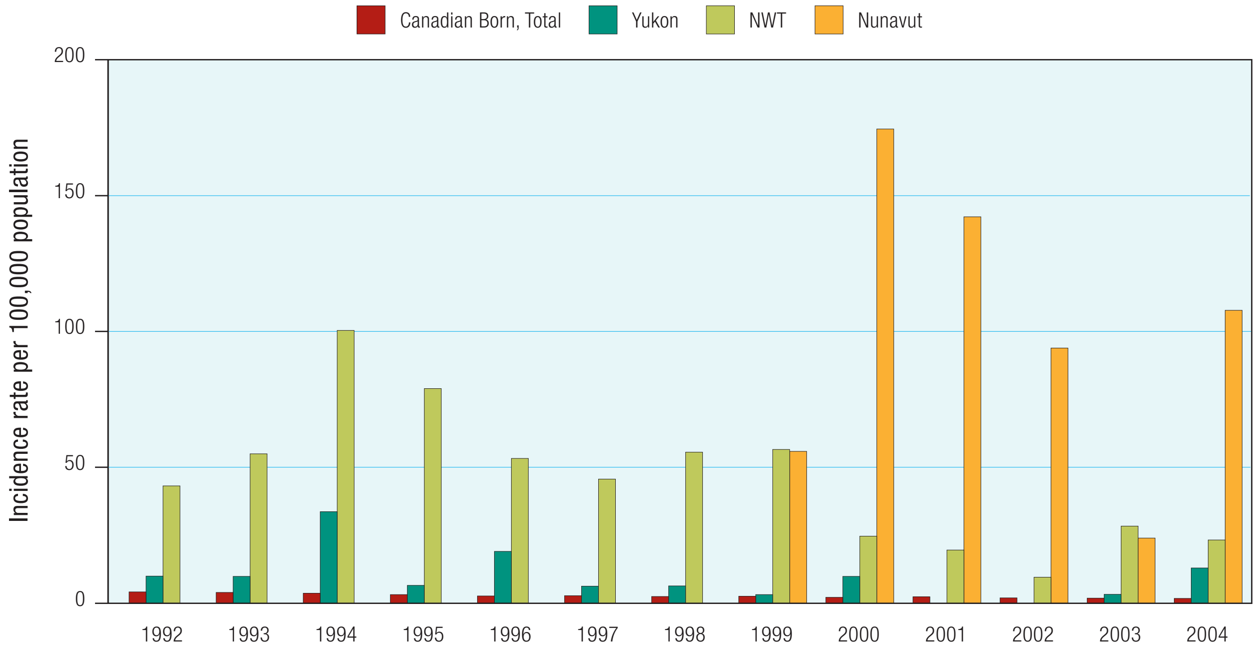


FIGURE 3.3.9

Tuberculosis-incidence rate per 100,000 by territory and for Canada, 1992–2004 (Health Canada, 2006).

Tuberculosis

The rate of tuberculosis has significantly decreased during the last decade of the twentieth century. However, as the incidence rate is influenced by outbreaks happening in one or two communities in the north (NWT, 2005), the rate fluctuates from year to year, also affected by the low underlying counts. Such fluctuations are particularly apparent in Fig. 3.3.9.

Although there has been progress in decreasing the incidence rate of tuberculosis in the north, the current rates in the NWT and Nunavut in particular, are dramatically higher than the national incidence rate of 5.2 per 100,000 (PHAC, 2005). Yukon saw no new cases between 2001 and 2002, but reported five new cases in 2003–2004. In Nunavik, the incidence rate of tuberculosis was also high, 52 per 100,000 population, compared with 3.6 per 100,000 in the rest of Québec (2000-2004) (Counil, 2007).

According to the NWT Health Status Report (NWT, 2005), while the risk of tuberculosis is much higher for older population groups, the actual number of cases is dispersed more evenly through the age groups. The risk of tuberculosis is higher in smaller communities of the NWT, with poor housing conditions and overcrowding potentially playing a role as contributing factors.

Tuberculosis, a persistent public health problem in Nunavut, is associated with issues of drug resistance and co-infection to HIV. Nunavut implemented school-based screening programs at kindergarten, Grade 6, and Grade 9 (NRCHI, 2004). Throughout the north, public health authorities continue sustained efforts to control the incidence of tuberculosis.

Chlamydia and Gonorrhea

Genital chlamydia is a sexually transmitted infection caused by *Chlamydia trachomatis*. Females are disproportionately affected by the complications of this infection. Untreated infection in females may lead to pelvic inflammatory disease, tubal infertility, and chronic pelvic pain (PHAC, 2007). Chlamydia and gonococcal infections are the two most common types of sexually transmitted infections (NWT, 2005). The incidence rate of both infections had been on the decline in the NWT, particularly for gonorrhea, until the end of the 1990s (Fig. 3.3.10); however, since then the rates for both infections have been increasing. The incidence of sexually transmitted infections is two times higher in the smaller communities of the NWT than in the regional centres and more than three times higher than the incidence rate for Yellowknife.

Chlamydia is Nunavut's most commonly reported communicable disease and is a sensitive indicator of both the extent of sexual risk-taking behaviours and the effectiveness of prevention initiatives (NRCHI, 2004). At the same time the incidence of gonococcal infections in Nunavut appeared to be on the decline between 2000 and 2003 (Fig. 3.3.10).

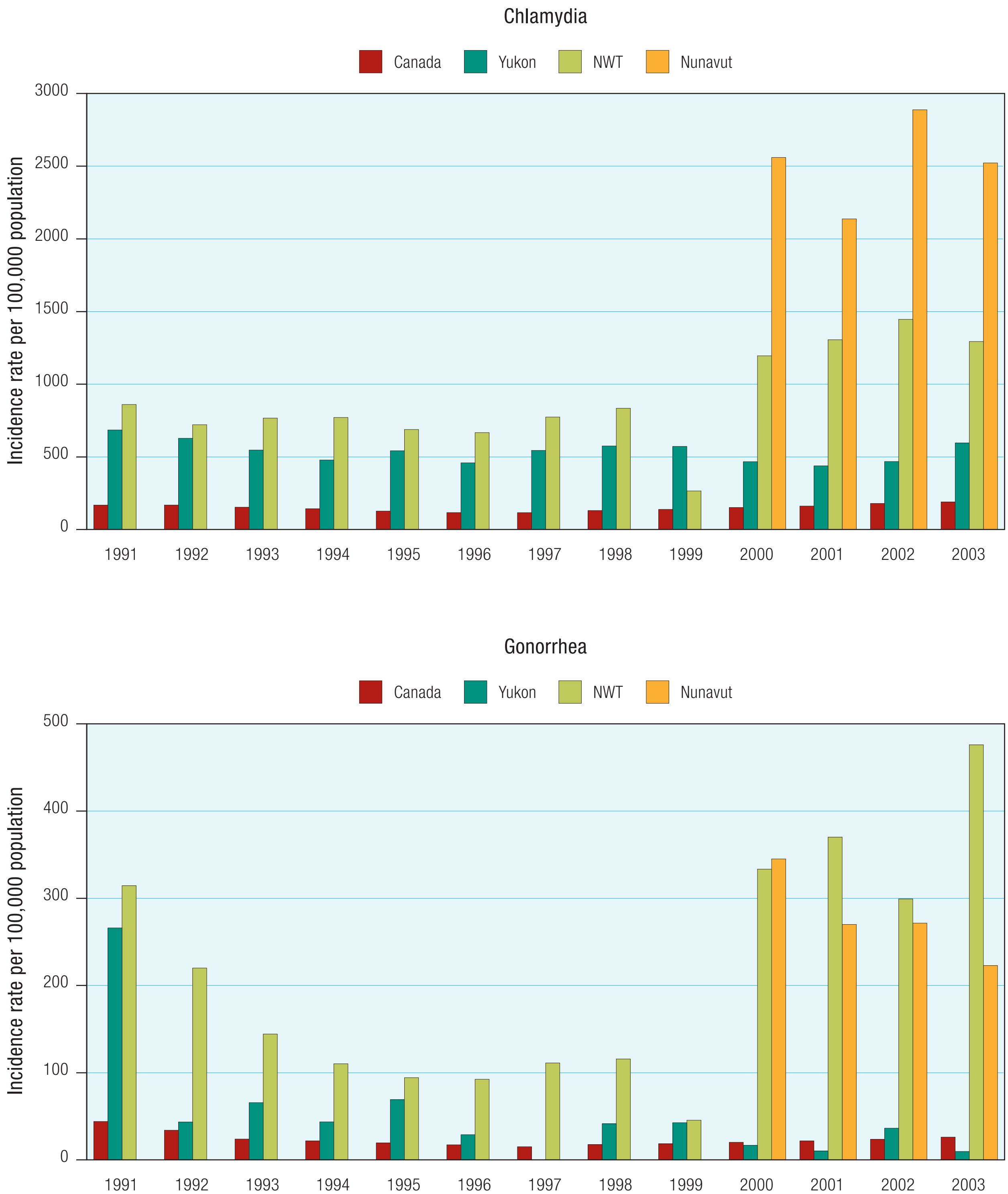


FIGURE 3.3.10

Incidence rate of chlamydia and gonorrhea for both genders from 1991–2003 (PHAC, 2005).

Eric Loring

Yukon's incidence rates for chlamydia are the lowest in Arctic Canada, but much higher than the national rates. The highest rates of this infection are among young adults and teenagers between 15 and 24 years of age (Yukon, 2003).

Between 2000 and 2004, chlamydiosis (chlamydia-caused infectious disease) occurred in Nunavik at a rate that was 21 times higher than in the rest of Québec (3,064 cases per 100,000 people) (Counil, 2007). This could be indicative of a low level of sex education and practice of protection during sexual intercourse, as well as the quality and/or accessibility of specialized medical treatment provided to the population.

Hepatitis C

Hepatitis C (HCV) is a viral infection of the liver. The virus is spread by direct exposure to the blood infected with HCV. People who inject drugs are particularly at risk of exposure to HCV. About 85% of people infected with HCV carry it for the rest of their lives and may develop cirrhosis of the liver and liver failure. An increase in testing for hepatitis C in recent years has resulted in a substantial increase in the number of hepatitis C cases reported to territorial and provincial public health authorities (PHAC, 2005).

Therefore, an increase in the number of cases of hepatitis C between 1994 and 2001 may be reflective primarily of the increased diagnosis of this illness, as rates appear to be stabilizing, although at a higher level for the Yukon than other northern territories (Fig. 3.3.11). In 2000, the highest rates of diagnosed hepatitis C in Yukon were among adults 30 to 59 years of age (Yukon, 2003).

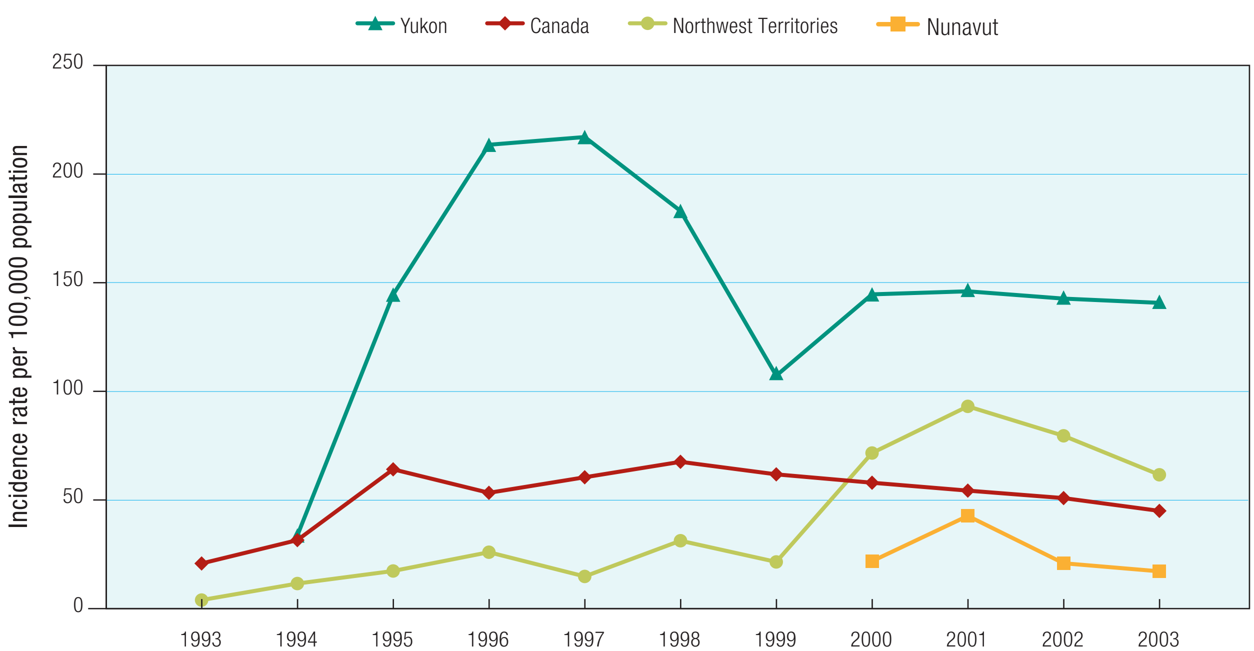


FIGURE 3.3.11

Incidence rate of hepatitis C for both genders for 1993–2003 (PHAC, 2005).

Paul Vecsei

Cancer

Cancer is a leading cause of death in the NWT (NWT, 2005; Fig. 3.3.6). On average, 75 new cases of cancer were diagnosed in the NWT every year from 1992 to 2002. The incidence rate did not change much during that time, growing from 16.6 per 10,000 population in 1992–1994 to 19.1 per 10,000 population in 2001–2002 (NWT, 2005). Analysis conducted by the NWT Health and Social Services demonstrated that this increase was not statistically significant and could be explained by population aging.

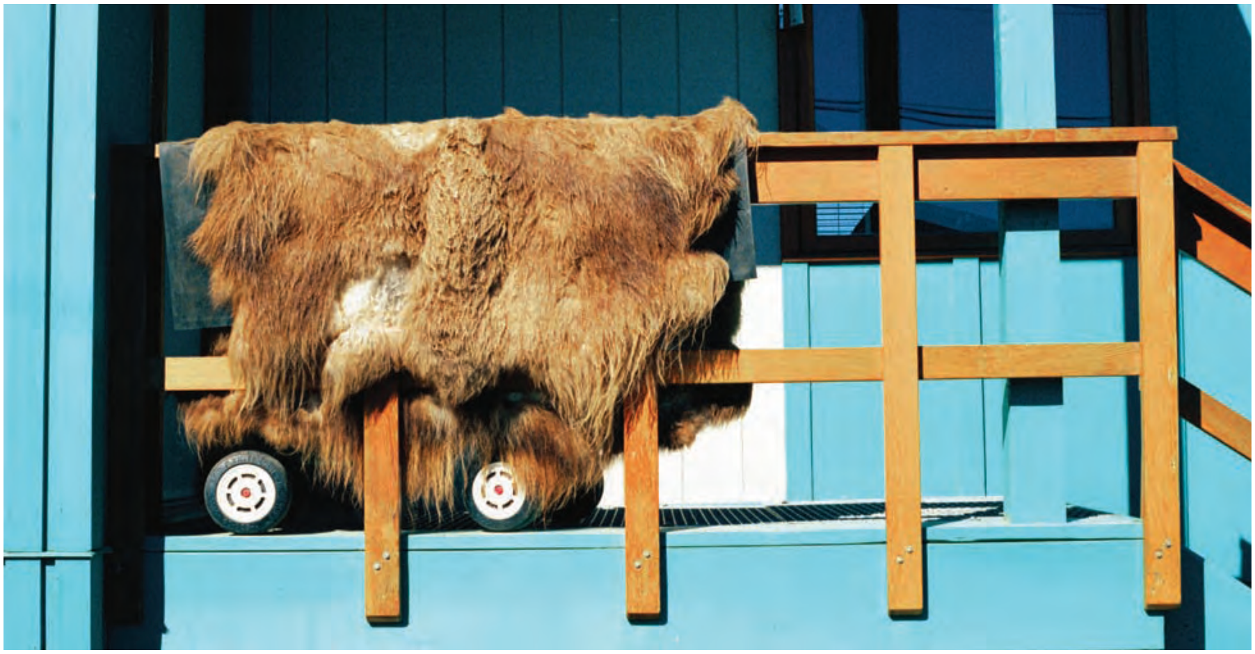
Nunavut's estimated 2006 age-standardized incidence rate for female breast cancer was the lowest in Canada at 49 per 100,000 population, followed by Yukon at 89 per 100,000 (Statistics Canada, 2006c). It has been suggested that breastfeeding might have some significance in effecting a lower incidence of breast cancer (Lipworth *et al.*, 2000) in pre-menopausal women.

However, certain other cancers are comparatively high in the Arctic. For example, Nunavut has the highest estimated 2006 incidence rate for lung cancer in Canada (231.7 per 100,000 for males and 235.1 per 100,000 for females),[4] which is more than triple the national rate for males and more than four times the national incidence rate of lung cancer for females. Nunavik incidence rates for bronchus and lung cancers are also very high (214 per 100,000 for males and 191 per 100,000 for females) (Counil, 2007).

Estimated 2006 age-standardized incidence rates for colorectal cancer among females in Nunavut (130.4 per 100,000) and among males in NWT (165 per 100,000) are also remarkably high in comparison with national estimates of 41 per 100,000 for females and 62 per 100,000 for males.[5]

4 Comparable Health Indicators 2006, Table 50b-HLT Lung cancer incidence (ICD-0-3 C34.0 to C34.9) by sex, Canada, provinces and territories, 2006 (estimates) (Statistics Canada, 2006c). Estimates produced by Health Canada through extrapolation (f) of cancer incidence data from the National Cancer Incidence Reporting System (NCIRS, 1969-1991) and the Canadian Cancer Registry. Details of the statistical methods used to produce the projections are described in Appendix II: Methods of the Canadian Cancer Statistics monograph produced by the Canadian Cancer Society, the National Cancer Institute of Canada Statistics Canada, the Provincial/Territorial Cancer Registries, and Health Canada. (CANSIM table 103-0204).

5 Comparable Health Indicators 2006, Table 53b-HLT Colorectal cancer incidence (ICD-0-3 C18.0 to C18.9, C20.9, C26.0), by sex, Canada, provinces and territories, 2006 (estimates) (Statistics Canada, 2006c).



Eric Loring

Diabetes

The National Diabetes Surveillance System (NDSS) was developed in 1996 to provide strategic information support for the Canadian Diabetes Strategy in respect to prevalence of diabetes in Canada. The NDSS counts a person as having diabetes if he or she received a hospital separation with a discharge diagnosis of diabetes or if two claims were submitted by a physician in a two-year period where the diagnosis was diabetes (Yukon, 2003).

In 2001–2002, the age standardized national prevalence rate was 5.3%, which meant that nearly 1.2 million Canadians over 20 were living with diabetes.

In 2001–2002, the crude prevalence rate of diabetes in the NWT was the highest among northern territories at 3.6% of the population. After age standardization, the rate increased to 4.8 per 100 persons age 20 and over. Although this rate was lower than the national rate, there has been an observable trend toward increasing prevalence of diabetes since 1997–1998. During the five-year period between 1997 and 2001, approximately 150 new cases of diabetes were diagnosed in the NWT every year (NWT, 2005). There was an observed increased prevalence of diabetes with age.

The 2001 crude prevalence rate for diabetes in Yukon was 3%, although the same prevalence growth trend as in the NWT could be observed. When age structure of the population was factored into the calculations and age standardization was applied, the prevalence rate of diabetes in Yukon in 2001–2002 was slightly higher than in NWT at 4.9 per 100 persons age 20 and over (Fig. 3.3.12).

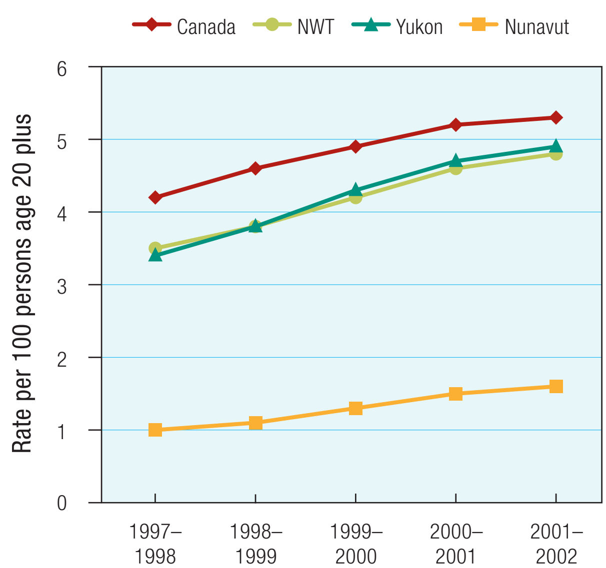


FIGURE 3.3.12

Age standardized[6] prevalence of diabetes, Canada and territories (PHAC, 2008).

[6] Standardized to the Canada 1991 population.

Paul Vecsei

The prevalence rate for diabetes in Nunavut remains the lowest in the country, although there is also a slight increasing trend, which may reflect both the increasing impact of the nutritional transition and the slight aging of Nunavut's population.

In Nunavik, the estimated prevalence of diabetes reached 4.8% in 2004 (INSPQ, 2007). Yet women showed a high prevalence of diabetes risk factors such as abdominal obesity and hyperinsulinemia, which contrasts with the overall improvement of glyceamia and insulinemia in the population as a whole since 1992 (INSPQ, 2007).

3.4 Conclusion

Our increasing concern with the health effects of chronic exposure to low levels of environmental contaminants is inextricably linked to the victories of public health measures in battling communicable diseases both nationally and globally. There is an increasing body of knowledge, which suggests that certain classes of environmental pollutants are implicated in the pathogenesis of chronic diseases and may also have impact on our susceptibility to infectious diseases by compromising the immune system. The overview of selected health outcome measures in the Canadian Arctic suggests that while the public health priority needs to focus on sources of premature mortality and morbidity of the northern populations, various avenues of contaminants exposure and their often subtle health effects should not be overlooked.

Joëlle Tessier Gagné

Human Exposure to Environmental Contaminants

4.1 Introduction

Previous studies in the Canadian Arctic have shown that Inuit people who consume marine mammals have higher levels of various persistent bioaccumulative contaminants such as polychlorinated biphenyls (PCBs) and mercury (CACAR, 2003). Exposure to environmental contaminants is a potential risk to human health, especially for the developing fetus and young children due to their physiological and anatomical immaturity and rapid development. For these reasons many of the Follow-up studies (2002–2007) funded by the Northern Contaminants Program (NCP) focused on the Inuit populations across the Canadian Arctic who consumed marine mammals. Other populations who lived in the same regions were included for comparative purposes.

The data presented in this chapter have been supplied by biomonitoring studies undertaken in the Inuvik Region of Northwest Territories, the Baffin Region of Nunavut and two studies in Nunavik (northern Quebec). The focus is on maternal blood levels of several persistent organic pollutants (POPs) and metals (i.e., mercury, cadmium, and lead); however, data for adults living in Nunavik are also provided.

These studies describe three key aspects of human tissue levels of environmental contaminants. First, they provide an update on the geographic pattern of human exposure to environmental contaminants in the Canadian Arctic. Second, they provide data to assess changes in human exposure over time, indicating whether or not contaminant levels are decreasing, remaining the same, or increasing. Finally, the data collected provide important information on dietary habits and important insights into the relationship between contaminant exposure, traditional food consumption, and other lifestyle factors. The comparison of data presented in CACAR-II (CACAR, 2003) and the new data presented in this chapter allow for a greater understanding of trends in human tissue levels of environmental contaminants and their ongoing causative factors related to exposure.

Comparable methods were used in all of the studies to ensure that conclusions about the spatial trends are not simply the result of methodological or analytical variability. The Quality Assurance/Quality Control (QA/QC) program in which the human health analytical laboratories participate is described in Section 4.7. This QA/QC program assures that data can be compared from one study to another and from one time period to another. For the POPs, the concentrations are expressed on a lipid weight basis (microg/kg lipid in plasma) because POPs accumulate in lipids and the percentage of lipid in plasma increases over pregnancy. For comparative purposes, the data for POPs are also presented on a wet weight basis (microg/L plasma) in Appendix B. Data on levels of various metals that do not accumulate in lipids are presented as microg/L in whole blood.

In the previous human environmental monitoring reports from the NCP a wide range of POPs were included. Data were reported for more than 12 pesticides (e.g., aldrin, dieldrin, toxaphene, mirex, oxychlordane, transnonachlor, cisnonachlor, dichlorodiphenyltrichloroethane [DDT], and its principal metabolite dichlorodiphenyldichloroethylene [DDE], hexachlorocychlohexane [HCH], etc). A number of POPs from industrial sources were also included in the initial human monitoring in the Arctic, e.g., hexachlorobenzene (HCB) plus 16 polychlorinated biphenyl congeners (PCBs 28, 138, 153, 170, 180, etc.). Several metals were also included in this baseline monitoring: cadmium, lead, mercury (both total and organic), nickel, and selenium (CACAR, 1997; 2003). This report focuses on changes in contaminant concentration for several POPs, some of which are found at the highest levels in the Arctic peoples (e.g., DDE), and others that have reached concentrations in food that lead to exceedances of human tolerable dietary intakes (e.g., chlordane derivatives oxychlordane and trans-nonachlor, as well as toxaphene and PCBs). These analyses will also be undertaken for metals such as mercury and lead, which are found at higher levels in Arctic populations than in southern populations (CACAR, 2003).

In Section 4.2, which reviews results from the Inuvik region monitoring, it will be possible to examine levels of contaminants in more depth, as data on contaminant levels in three different ethnic groups and dietary data are available to match the trend analyses undertaken for the various contaminants. In the Baffin region (Section 4.3) and in Nunavik (Section 4.4), the contaminant data have only recently become available. Comparisons of in-depth dietary intake and body burden for individuals in these regions will not be available for this report.

4.2 Exposure Assessment in the Inuvik Region of Northwest Territories

This section presents the results of a biomonitoring study that took place in the Inuvik region of Northwest Territories. This was a Follow-up study to assess temporal trends of human exposure to environmental contaminants using maternal blood and hair as biomarkers of exposure. The Baseline study was completed in 1999 and the Follow-up study in 2006. The Inuvik region was included in the Follow-up study as it had the lowest levels of contaminants among Inuit regions in the Baseline study and would be a useful comparison to follow-up in regions such as Baffin and Nunavik that had higher contaminant levels.

A total of 89 participants enrolled in this study with 75 contributing blood samples for follow-up. It included 52 Inuit women, 17 Dene/Métis women, and 6 non-Aboriginal women (Armstrong *et al.*, 2007). Samples were collected late in the third trimester of pregnancy or immediately after giving birth. These samples were analyzed for a similar range of POPs and metals to the Baseline study; vitamins and various nutrients were also measured. Dietary information for these mothers is also available and has been presented in Chapter 2 (see section 2.3.5). A brief overview of some health effects of these contaminants that are a priority for trend monitoring are included in this section as this information should be useful for the reader and applicable to later sections. The levels of contaminants in maternal blood will be examined by ethnic group, first related to diet (Section 4.2.2) followed by contaminant concentration changes over time (Section 4.2.3).

4.2.1 Tissue levels of environmental contaminants in the Inuvik region

Metals

Metals are elements that occur naturally in rock or soils. They can leach from rock and soil or be released during volcanic eruptions, and may be released into the environment through industrial activities.

Lead

Lead occurs naturally in the environment. However, anthropogenic activities such as some types of mining and smelting increase the release of lead. The use of leaded fuels was the primary source of lead in the atmosphere; however, the concentration of lead in the

Ed Struzik

air in Canada has declined significantly since the introduction of unleaded gasoline in 1975. Previous work has shown that Aboriginal mothers and children can have higher exposures to lead shot fragments found in the meat of hunted game birds (Dewailly *et al.*, 2000).

In the most recent 2005–2006 sampling period the minimum level of lead detected in mothers was 4.4 microg/L and the maximum was 56 microg/L. The Inuvialuit and Dene/Métis mothers had similar mean levels of lead (13 microg/L), which were almost double the non-Aboriginal mothers mean levels of 6.9 microg/L (Table 4.2.1).

Cadmium

Cadmium's major natural sources are weathering and erosion of rock and soil, forest fires and volcanic activity. Cadmium is also used commercially and is released from industrial and domestic waste. Tobacco smoke is also a significant source of exposure for humans.

In the most recent study (2005–2006) the minimum level of cadmium found in maternal blood was not detectable, and the maximum level was 7.2 microg/L (Table 4.2.1). The slightly higher levels of cadmium in Inuvialuit and Dene/Métis versus the non-Aboriginal mothers is likely due to the higher levels (1.4 vs. 0.7 microg/L) of smoking in the former groups.

TABLE 4.2.1 Contaminant concentrations found in Dene-Métis, Inuvialuit and Non-Aboriginal Mothers from the Inuvik region (Geometric mean (range), (microg/kg plasma lipid or metals microg/L whole blood)

Organochlorine contaminants	Dene/Métis			Inuvialuit			Non- Aboriginal		
	Baseline 1998–1999[1] 24 (18, 35)[3] (n = 41)[4]	Follow-up 2005–2006[2] 24 (16, 36)[3] (n = 17)[4]	SD[5]	Baseline 1998–1999[1] 23 (15, 37)[3] (n = 31)	Follow-up 2005–2006[2] 26 (17, 38)[3] (n = 52)	SD[5]	Baseline 1998–1999[1] 31 (19, 45)[3] (n = 21)	Follow-up 2005–2006[2] 32 (23, 40)[3] (n = 6)	SD[5]
Oxychlordane	4.4 (1.0-25)	1.6 (0.29-5.0)	SD[c]	18 (2.4-108)	8.7 (0.29-117)	SD[b]	4.1 (1.9-8.7)	1.3 (0.59-3.4)	SD[b]
Trans-nonachlor	6.2 (1.0-42)	2.2 (0.59-9.3)	SD[c]	33 (3.6-182)	14 (0.59-258)	SD[b]	5.3 (2.2-13)	1.3 (0.59-4.2)	SD[b]
p,p'-DDE	64 (23-222)	35 (13-141)	SD[a]	125 (44-491)	76 (5.3-867)	SD[b]	64 (26-189)	38 (18-111)	NS[6]
Toxaphene-Parlar 50	1.7 (0.96-7.9)	0.46 (0.29-2.2)	SD[c]	6.8 (0.77-53)	2.9 (0.29-75)	SD[b]	1.1 (0.83-1.4)	0.36 (0.29-1.1)	SD[b]
PCB 138	10 (2.5-61)	3.1 (0.59-13)	SD[c]	22 (5.1-83)	8.6 (0.59-98)	SD[c]	8.7 (2.9-22)	2.9 (1.4-6.8)	SD[b]
PCB 153	16 (3.2-130)	5.9 (0.59-34)	SD[b]	30 (6.5-105)	17 (0.59-152)	SD[b]	12 (3.5-32)	4.3 (2.0-9.0)	SD[b]
PCB 180	8.2 (2.0-76)	3.5 (0.59-40)	SD[a]	9.4 (2.0-31)	6.8 (0.59-52)	NS	7.5 (2.0-26)	2.4 (0.59-4.2)	SD[b]
Metals									
Total Hg	1.1 (0.1-6.0)	0.7 (0.1-4.4)	NS	2.1 (0.6-24)	1.1 (0.1-14)	SD[b]	0.6 (0.1-2.3)	0.22 (0.1-0.9)	SD[a]
Organic Hg	NA[7]	NA	NA	NA	NA	NA	NA	NA	NA
Pb	35 (5.0-112)	13 (4.8-35)	SD[c]	19 (2.1-101)	13 (4.4-56)	NS	13 (2.1-37)	6.9 (4.6-10)	SD[b]
Cd	0.56 (0.01-5.9)	1.4 (0.28-7.2)	SD[a]	1.0 (0.01-7.11)	1.5 (0.05-5.2)	NS	0.13 (0.01-3.6)	0.7 (0.2-2.8)	SD[a]
Se	108 (67-152)	NA	NA	118 (88-151)	NA	NA	116 (84-164)	NA	NA

1 Tofflemire, 2000
2 Armstrong *et al.*, 2007
3 Arithmetic mean age of group sampled (range)
4 1998-1999 (N= 41 for Metals and N=42 for organochlorines), 2005-2006 (N= 17 for organochlorines and N= 18 for metals)
5 SD= Significant difference (p<0.05)
SD[a] = significant difference, p= (<0.05- 0.01)
SD[b] = significant difference, p= (0.01-0.001)
SD[c] = significant difference, p= (0.001- <0.0001)
6 NS= not significant, p>0.05
7 NA= not available

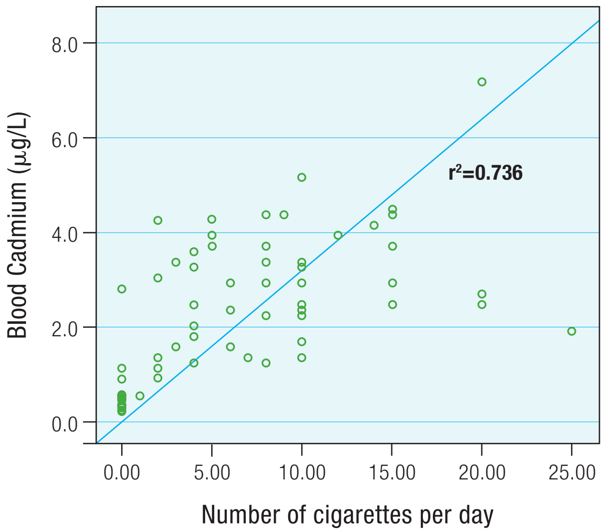


FIGURE 4.2.1

Cadmium levels by average number of cigarettes smoked in a day (N=73)

Figure 4.2.1 depicts the level of cadmium by average number of cigarettes smoked per day (non-smokers were entered as 0). The level of cadmium significantly increases as the number of cigarettes smoked per day increases, with a visible correlation of 0.74. This strong relationship between smoking and cadmium levels in maternal blood has been noted in the previous baseline studies completed in Northwest Territories (NWT) and Nunavut (Butler-Walker *et al.*, 2006).

Total Mercury

Mercury is present in air, water and soil from both natural sources and as a result of human activity. The minimum level of total mercury found in maternal blood was 0.10 and the maximum level was 14 microg/L whole blood in the mothers in the Inuvik region. The mercury levels of the Inuvialuit mothers are more than four times higher, and the Dene/Métis mothers almost three times higher, than the non-Aboriginal mothers (1.1, 0.7 and 0.2 microg/L, respectively) (Table 4.2.1, Figure 4.2.2).

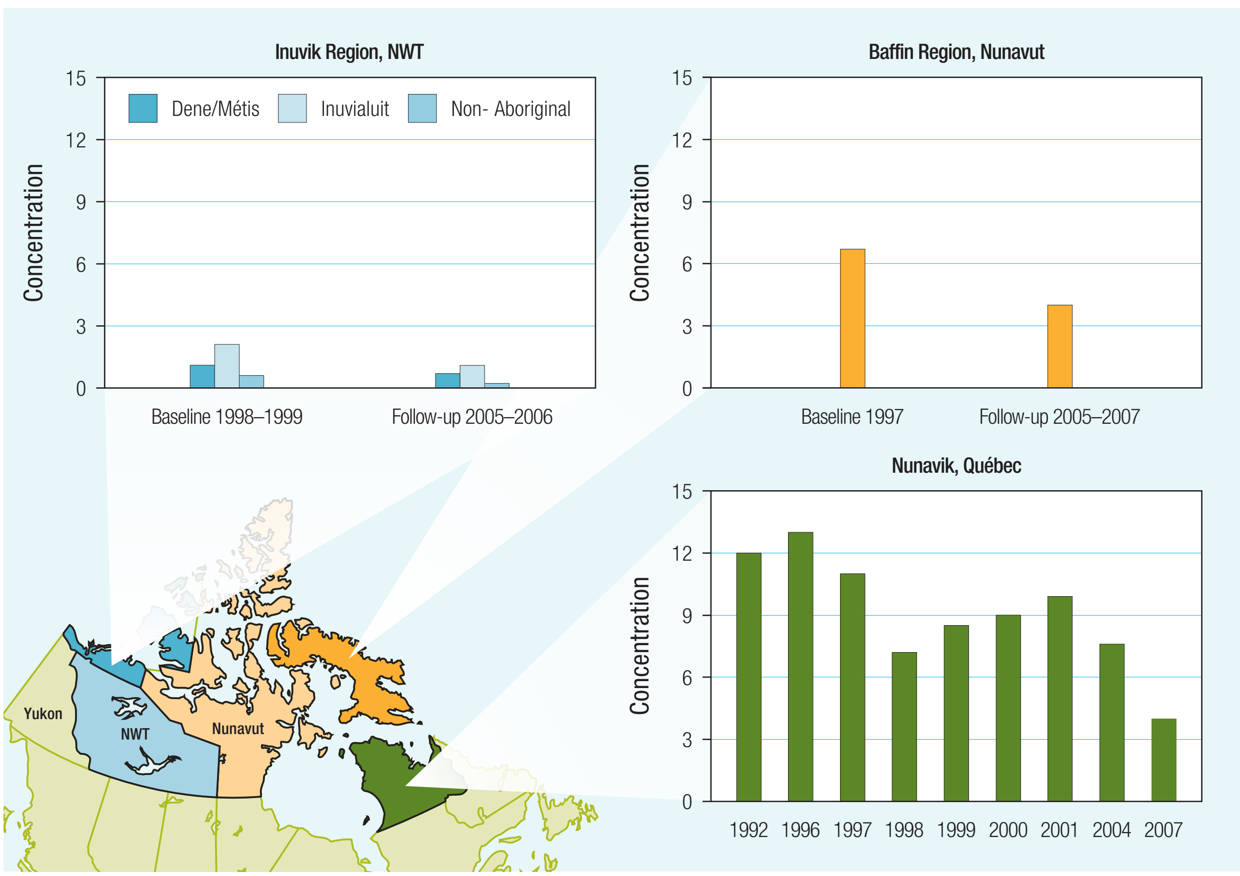


FIGURE 4.2.2

Changes in maternal contaminant concentrations in Arctic Canada: Total mercury (microg/L whole blood)

Persistent Organic Pollutants (POPs)

POPs

Almost all POPs are manufactured chemicals; they do not occur naturally. POPs do not easily break down and thus accumulate in the fatty tissue of animals. Their ability to biomagnify in the food chain makes them of greater concern in the Arctic due to their accumulation at high levels in seals, beluga whales, and polar bears. Some of the most common POPs in the Arctic wildlife are industrial chemicals (PCBs) and pesticides such as DDT, toxaphene, and chlordane derivatives (trans-nonachlor and oxychlordane).

PCBs

PCBs are a group of anthropogenic industrial organo-chlorine chemicals (there are 209 structurally similar compounds, which only differ in the number and placement of the chlorine atoms). Because they do not conduct electricity and can withstand high heat, PCBs were used in electrical transformers as insulators. Their oil-like properties also led to their use in a variety of other industrial and consumer applications since the 1930s (e.g., inks, plasticizers, etc). They also do not break down easily in the environment. The use of PCBs was banned in Canada in the 1970s.

Table 4.2.1 provides the levels of PCBs (congeners 138, 153 and 180) in the blood of mothers for each sample population (also see Figures 4.2.3 and 4.2.4). In this most recent Follow-up study (2005–2006), levels of the predominant PCB (PCB 153) are three to four times higher in Inuit mothers than levels seen in Dene/Métis or non-Aboriginal mothers (17, 5.9 and 4.3 microg/kg lipid in plasma, respectively). A similar pattern can be seen for the other PCB congeners 138 and 180 as well as for the total PCBs measured as Aroclor 1260 (data not displayed). It is useful to summarize the data as Aroclor 1260, as this allows comparisons to older studies where PCBs are quantified by packed column techniques and allows comparisons to the only PCB blood guidelines that are expressed on an Aroclor basis.

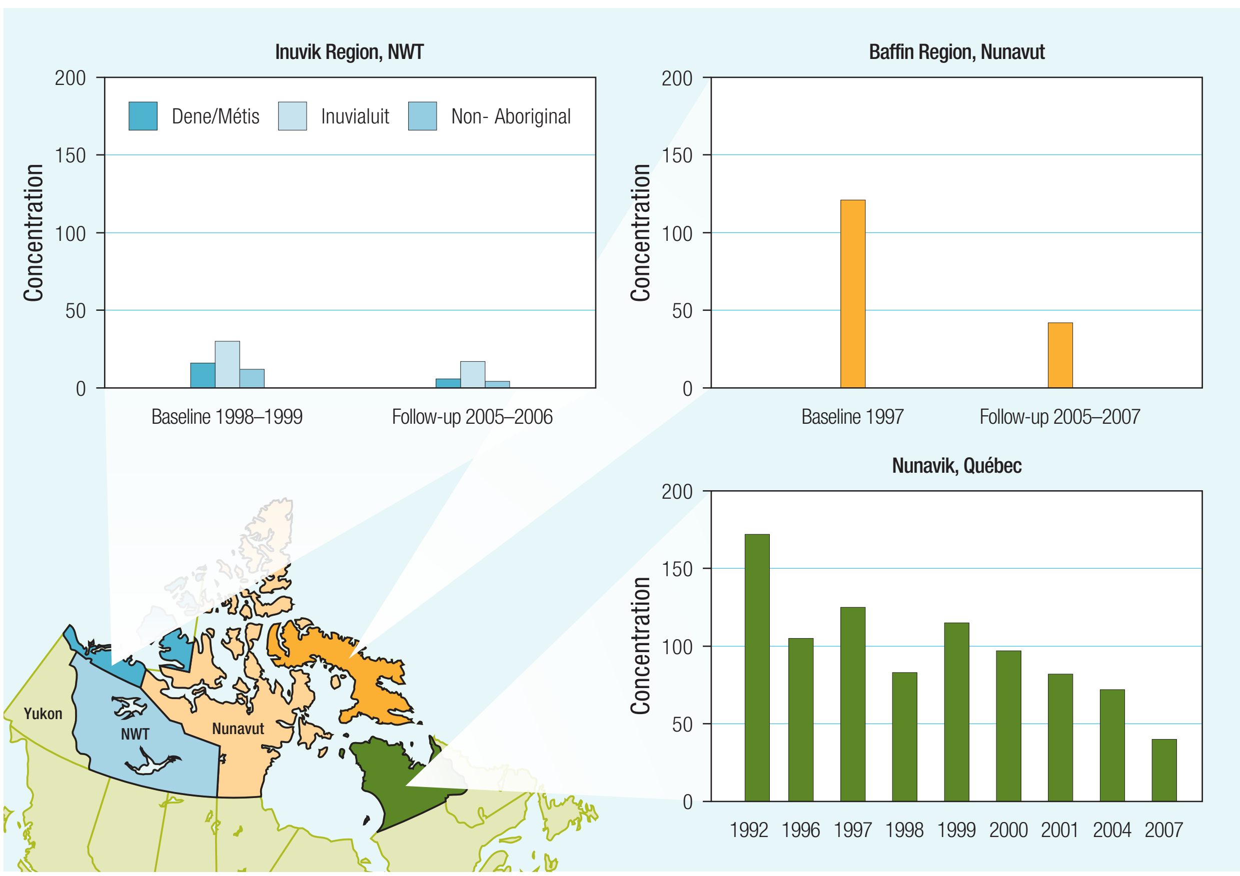


FIGURE 4.2.3

Changes in maternal contaminant concentrations in Arctic Canada: PCB 153 (microg/kg plasma lipid)

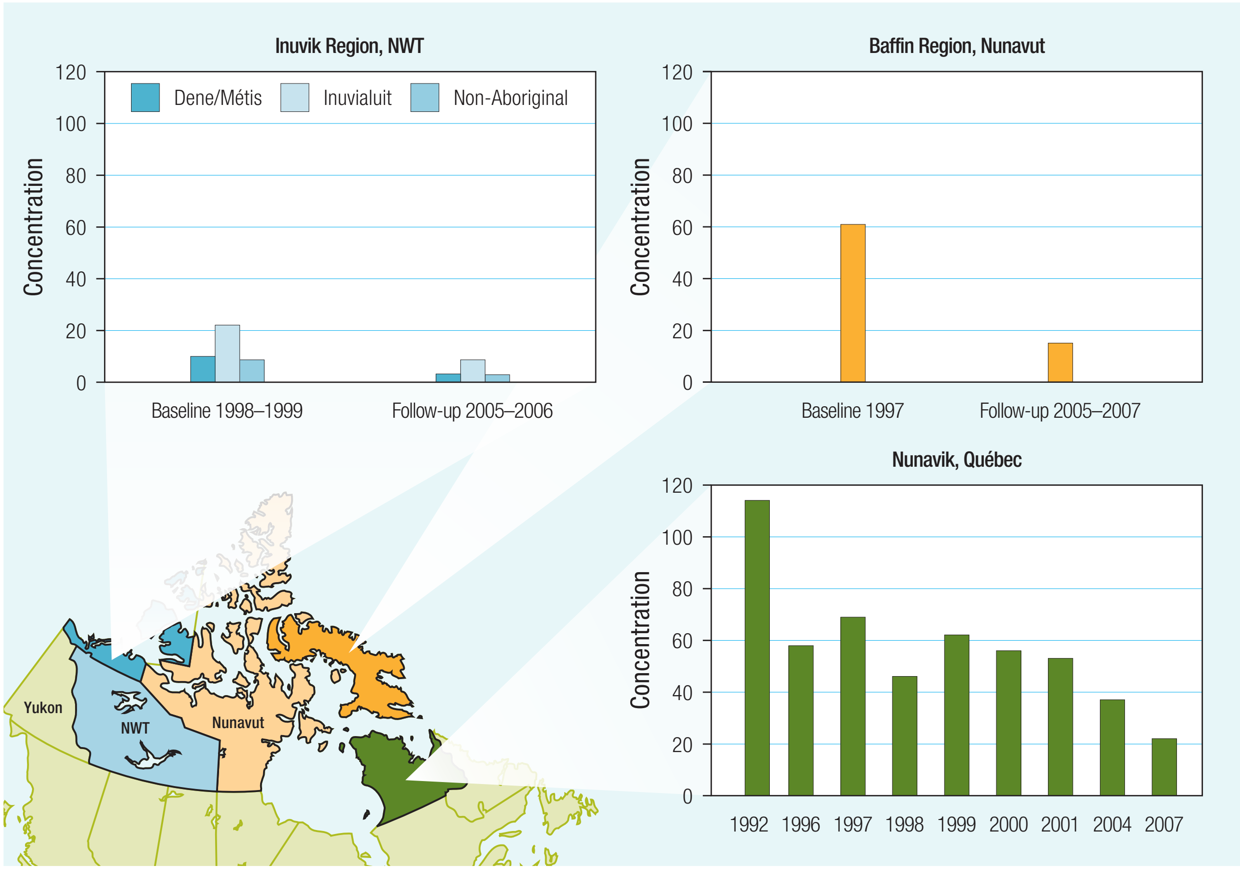


FIGURE 4.2.4

Changes in maternal contaminant concentrations in Arctic Canada: PCB 138 (microg/kg plasma lipid)

Eric Loring

Toxaphene

Toxaphene is a complex mixture of chlorinated camphenes and was historically used as a pesticide. In this Follow-up study, toxaphene parlars 26 and 50 were measured, with the results for parlar 50 presented in Table 4.2.1 and Figure 4.2.5. The geometric mean level of parlar 50 in maternal blood was six and eight times higher in Inuit mothers than Dene-Métis or non-Aboriginal mothers (2.9 vs. 0.46 and 0.36 microg/kg lipid in plasma, respectively).

Chlordane

Chlordane is a mixture of over 120 structurally related organochlorine compounds, and was introduced as a broad spectrum insecticide in the 1940s and widely used in North America. Although chlordane is no longer registered in either Canada or the United States, various chlordane-related contaminants, distinct from the original mixture, persist in the environment.

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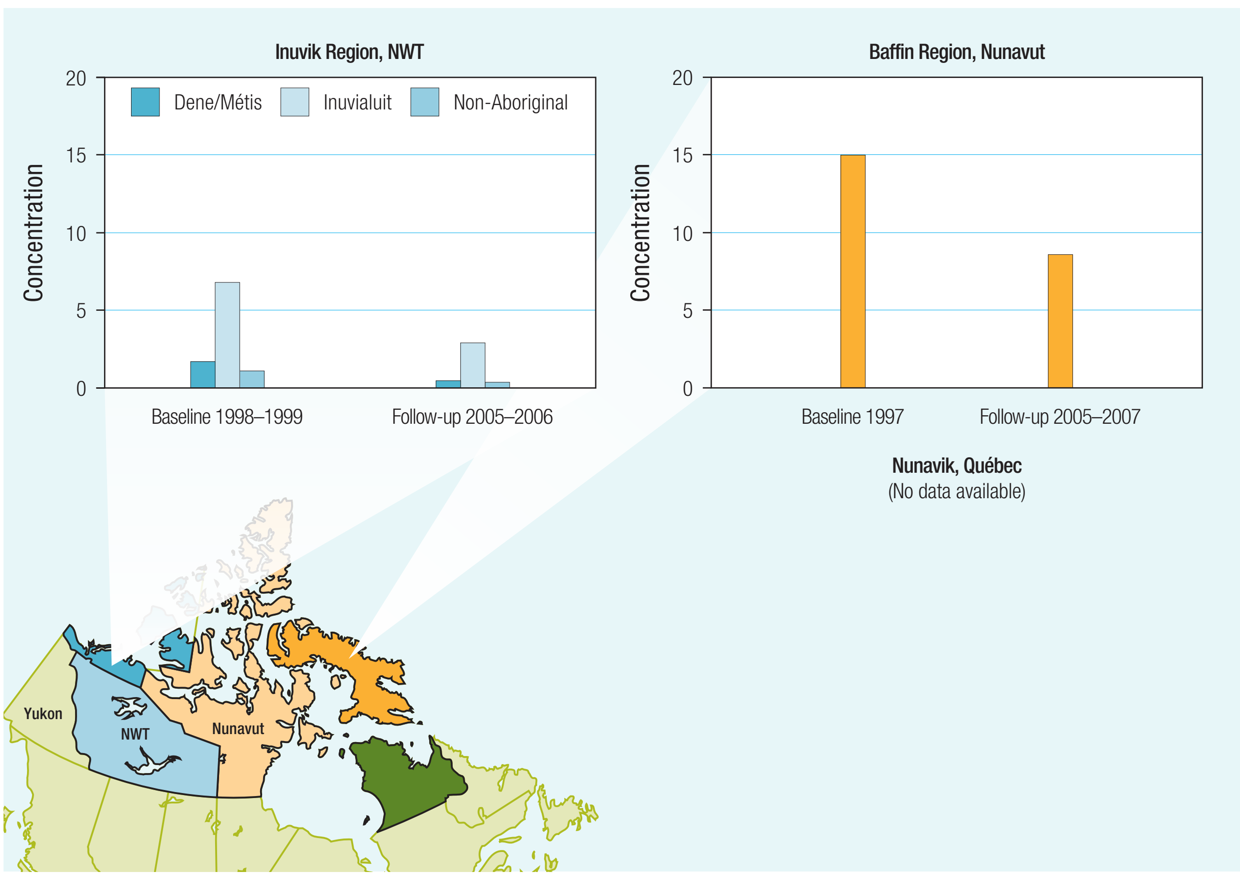

FIGURE 4.2.5

Changes in maternal contaminant concentrations in Arctic Canada: Toxaphene (microg/kg plasma lipid)

Together, trans-nonachlor and oxychlordane made up 76-78% of chlordane-related residues in ringed seal blubber samples collected from the NWT in 1991, and 83% of chlordane-related residues in walrus blubber samples collected from Greenland in 1989 (Addison and Smith, 1998; Muir *et al.*, 2000). The pattern of chlordane-related residue accumulation in humans parallels that seen in the highest levels of the Arctic marine food chain. Trans-nonachlor and oxychlordane make up more than 90% of the total chlordane contaminants measured in human breast milk from both northern and southern Canadians, with combined residues in the late 1990s more than four-fold higher in the milk of Arctic mothers (Newsome and Ryan, 1999).

In this Follow-up study, the geometric mean level of trans-nonachlor in maternal blood among Inuit mothers was six and seven times higher than Dene-Métis or non-Aboriginal mothers (14 vs. 2.2 vs. 1.3 microg/kg lipid, respectively, Table 4.2.1, Figure 4.2.6). A similar pattern is seen for oxychlordane though the levels are slightly lower (Figure 4.2.7).

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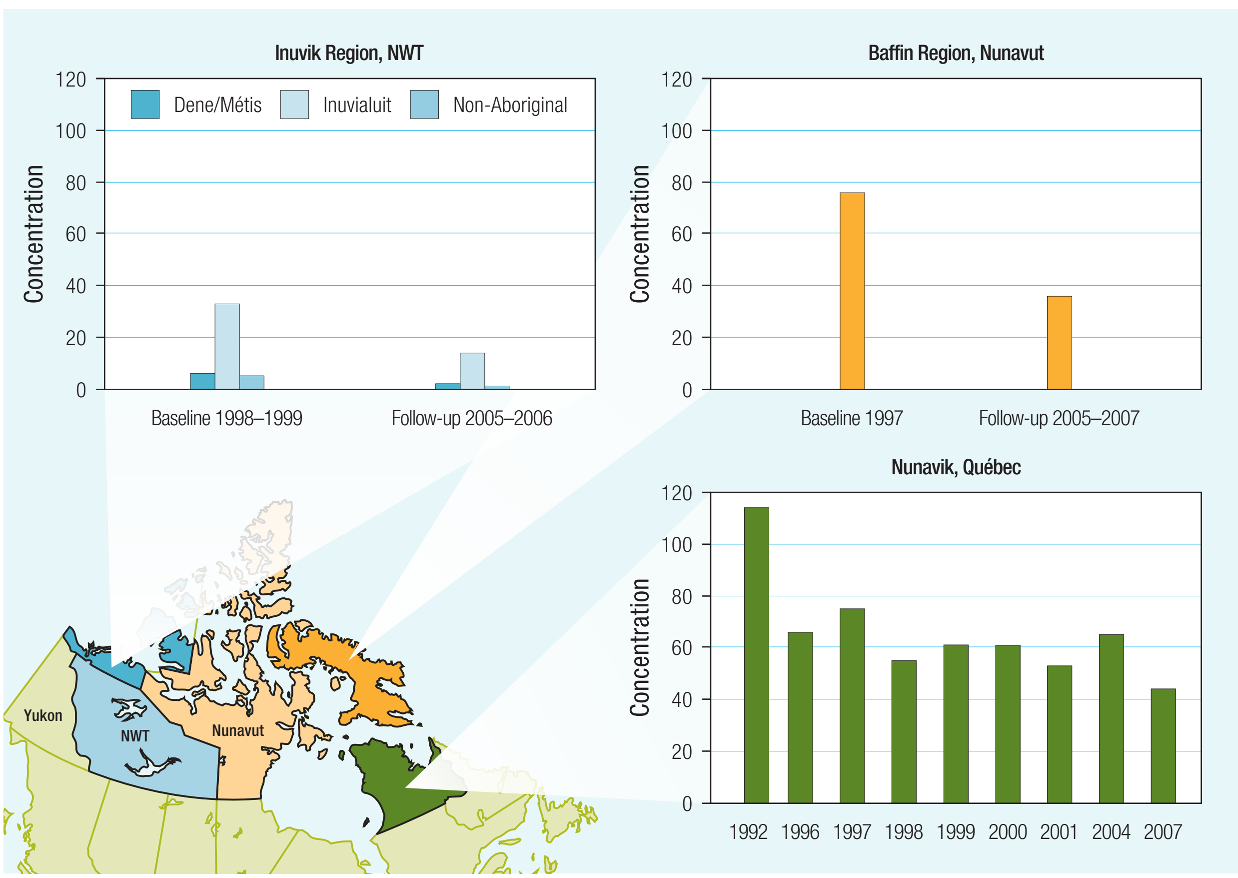

FIGURE 4.2.6

Changes in maternal contaminant concentrations in Arctic Canada: Trans-nonachlor (microg/kg plasma lipid)

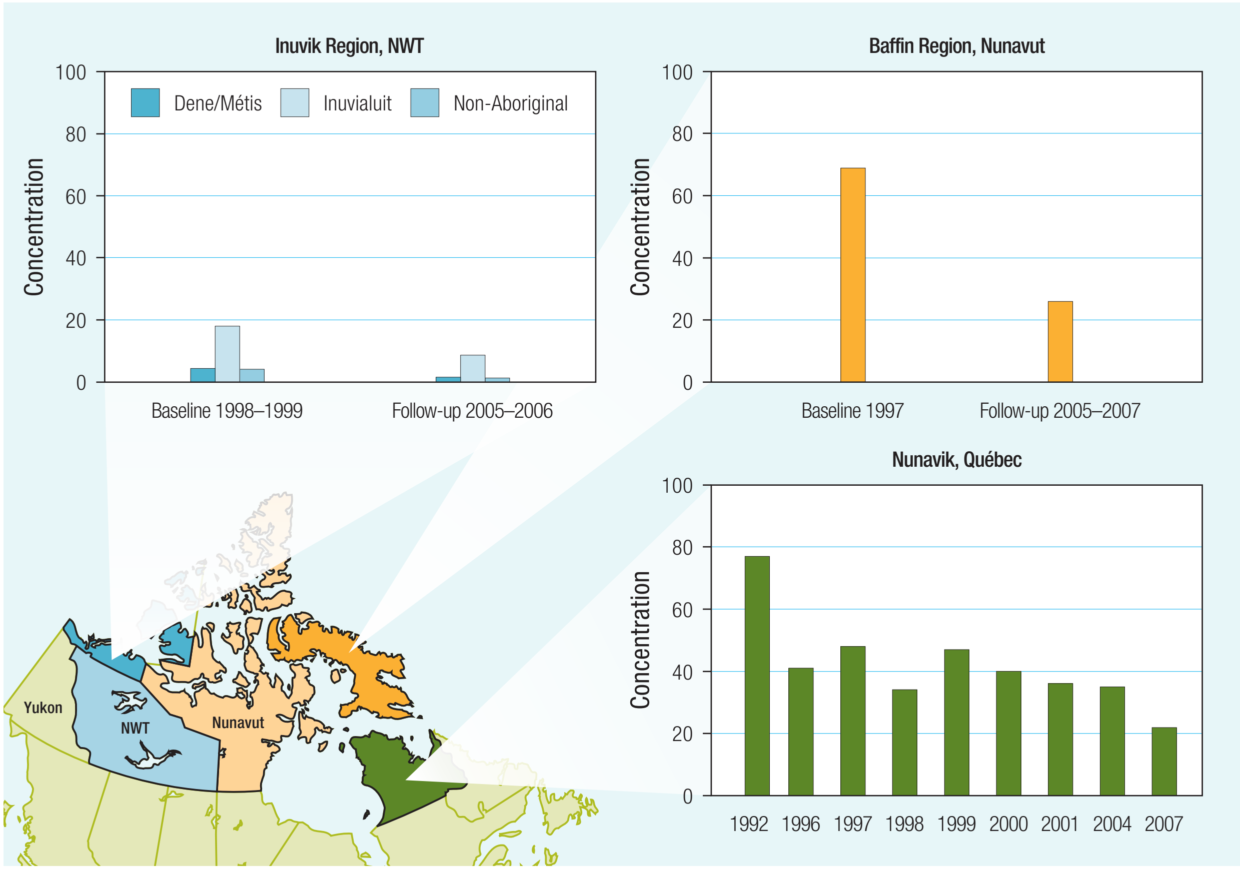

FIGURE 4.2.7

Changes in maternal contaminant concentrations in Arctic Canada: Oxychlordane (microg/kg plasma lipid)

DDE (dichlorodiphenyldichloroethylene)

DDE is the principal metabolite of DDT, which is an insecticide that has been heavily used worldwide for agricultural and disease vector control purposes. DDT was banned in Canada for most uses during the 1970s and Canada has been working for a global restriction on its use through the Stockholm Convention.

The concentration of DDE is the highest of all the POP concentrations presented in Table 4.2.1 and Figure 4.2.8. The geometric mean concentration of DDE in this Follow-up study (2005–2006) also had the highest concentrations in the Inuit (Inuvialuit) mothers, which were double the levels seen in the Dene/Métis or non-Aboriginal mothers (76 vs. 35 or 38 microg/kg lipid in plasma, respectively).

4.2.2 Dietary exposure to contaminants

The overall description of the dietary survey undertaken with this monitoring study is outlined in Chapter 2. Based on the amount of food consumed and the concentration of each contaminant in a food item an estimated intake level for selected contaminants can be calculated for all foods and expressed in micrograms per person per day. These intake levels were then correlated with maternal blood levels of contaminants and the results can be seen in Table 4.2.2 for Inuit and Dene/Métis mothers. The non-Aboriginal mothers were not included as there were too few enrolled and most ate only small amounts of country foods, if any. There were moderate to strong correlations between food intake and contaminant levels measured in the blood for a broad range of contaminants such as PCBs, DDE, toxaphenes, hexachlorocyclohexanes, chlordanes, lead, and mercury. The strongest correlation between body burden and dietary intake was for mercury (Spearman correlation coefficient = 0.76). Only for cadmium was the correlation between dietary intakes and maternal contaminant levels low and non-significant. This indicates that diet is not a significant source of cadmium in this study. Other studies in Arctic Canada have indicated that cigarette smoking is a much more significant source of cadmium (Butler-Walker *et al.*, 2006).

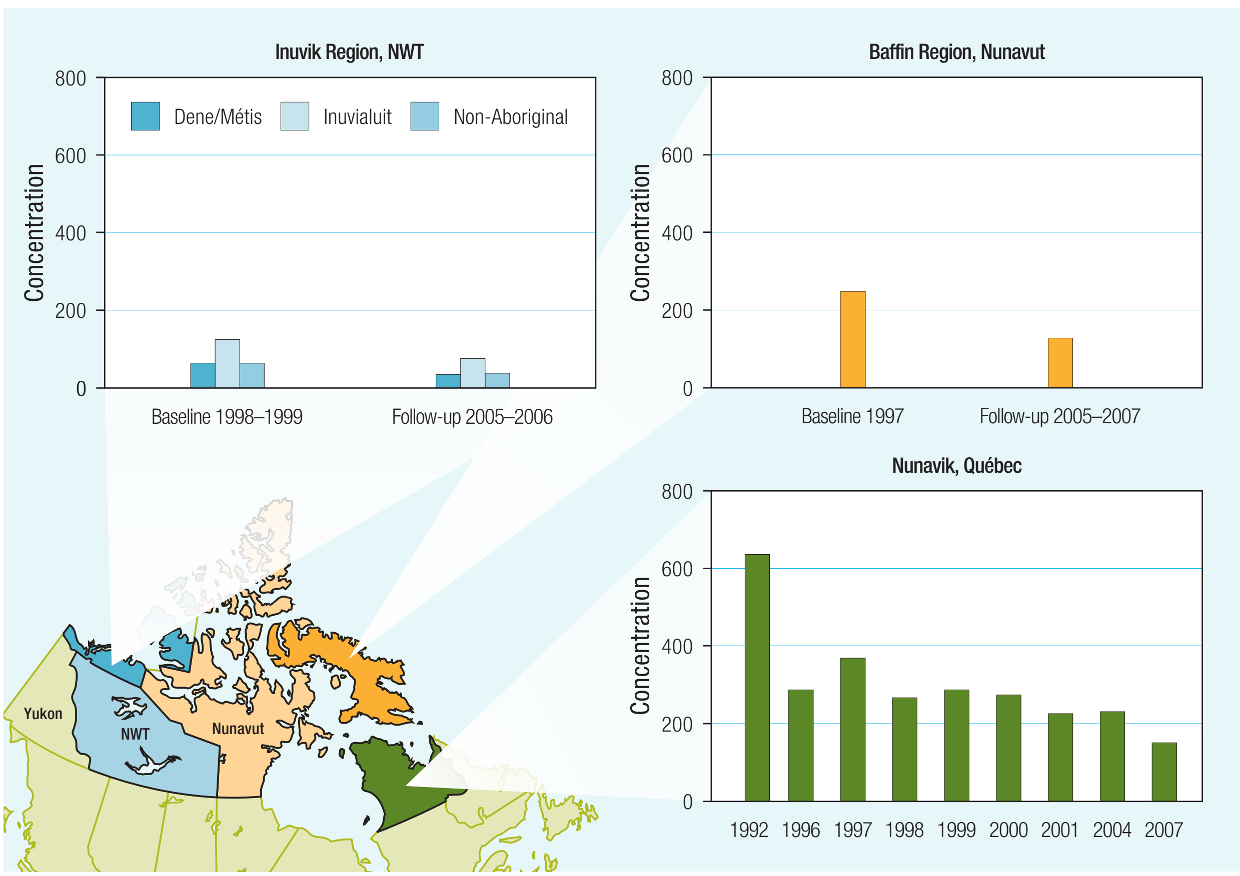

FIGURE 4.2.8

Changes in maternal contaminant concentrations in Arctic Canada: p,p'-DDE (microg/kg plasma lipid)

TABLE 4.2.2 Spearman correlation coefficients (p values) for associations between dietary exposure and body burden variables

Estimated Dietary Exposure	Measured Maternal Parameter	
Cadmium	0.03 (NS)	(n=75)
Lead	0.30 (0.008)	(n=76)
Mercury	0.55 (0.000)	(n=74)
Arsenic	0.35 (0.002)	(n=76)
Chlordane	0.49 (0.000)	(n=73)
Hexachlorobenzene	0.46 (0.000)	(n=75)
Mirex	0.41 (0.000)	(n=75)
Polychlorinated biphenyls (PCBs)	0.45 (0.000)	(n=75)
Toxaphenes	0.57 (0.000)	(n=75)
Dichlorodiphenyltrichloroethane	0.27 (0.02)	(n=75)
Hexachlorocyclohexanes	0.55 (0.000)	(n=75)
Hg blood: hair	0.76 (0.000)	(n=74)

Separate analyses indicated that dietary sources of lead were mostly from terrestrial mammal meat and bird meat. The main food sources for exposure to mercury, based on this survey, were fish and marine mammal fats. As would be expected, marine mammal fat supplied the greatest amount of exposure to contaminants such as PCBs (Armstrong *et al.*, 2007). It can be seen that the Inuvialuit mothers have decreased quite markedly their marine mammal fat consumption while increasing their fish and seafood (Table 4.2.3). Among the Dene/Métis mothers, the greatest change is seen in the increased fish consumption (Table 4.2.4). No comparisons were made for the non-Aboriginal mothers as the follow-up group was too small and their traditional food consumption was very low.

4.2.3 Trend comparisons between the Baseline and the Follow-up study (1998/99 versus 2005/06)

Great care must be taken when assessing changes in contaminant concentration between the results of the 1998–1999 Baseline survey and the 2005–2006 Follow-up study. These are not random population samples; all expectant mothers from a region were able to volunteer for this study due to the limited birth rate in the North. The age of the mothers and parity are similar between the two studies but the different ethnic proportions in the two studies indicate that results can only be interpreted on an ethnic-specific basis. The proportion of mothers from each community also varied between the two studies but could not be adjusted for due to small numbers. It should also be

TABLE 4.2.3 Annual traditional food consumption for Inuvialuit mothers (kg/person/year) (Armstrong *et al.*, 2007)

Food Item	Inuvialuit Mothers	
	Baseline (n=33) 1998–99	Follow-Up (n=54) 2005–06
All Fish / Seafood	8.0[1] (8.1)[2] [0, 6.1, 36][3]	27[1] (35)[2] [0, 17, 225][3]
Terrestrial Mammal Meat	30[1] (22)[2] [0.3, 30, 75][3]	34[1] (25)[2] [0, 35, 114][3]
Marine Mammal Meat	1.4[1] (4.9)[2] [0, 0, 28][3]	5.2[1] (18)[2] [0, 0, 114][3]
Marine Mammal Fat	4.3[1] (10)[2] [0, 1.2, 50][3]	1.4[1] (2.4)[2] [0, 0, 14][3]
Birds Meat	3.5[1] (2.9)[2] [0, 0, 11][3]	15[1] (25)[2] [0, 4.7, 107][3]
All Plant	4.0[1] (6.1)[2] [0, 0, 31][3]	1.9[1] (2.5)[2] [0, 0, 10][3]

[1] mean
[2] (standard deviation)
[3] [minimum, median, maximum]

TABLE 4.2.4 Annual traditional food consumption for Dene/Métis mothers (kg/person/year) (Armstrong *et al.*, 2007)

Food Item	Dene/Métis Mothers	
	Baseline (n=45) 1998–99	Follow-Up (n=18) 2005–06
All Fish / Seafood	9.4[1] (12)[2] [0.2, 4.3, 50][3]	21[1] (32)[2] [0, 5.9, 1.3][3]
Terrestrial Mammal Meat	31[1] (28)[2] [0, 17, 95][3]	27[1] (32)[2] [1.4,17, 75][3]
Marine Mammal Meat	0.0[1] (0.1)[2] [0, 0, 0.7][3]	0.1[1] (0.2)[2] [0, 0, 0.7][3]
Marine Mammal Fat	0.2[1] (0.4)[2] [0, 0, 1.2][3]	0.1[1] (0.3)[2] [0, 0, 1.2][3]
Birds Meat	7.9[1] (15)[2] [0, 3.0, 84][3]	8.1[1] (21)[2] [0, 2.4, 92][3]
All Plant	3.8[1] (4.4)[2] [0, 2.0, 18][3]	2.1[1] (2.2)[2] [0,1.8, 7.2][3]

[1] mean
[2] (standard deviation)
[3] [minimum, median, maximum]

noted that the number of women who smoked actually increased over the seven years (52 to 67%) (Armstrong *et al.*, 2007).

4.2.4 Changes in dietary exposure to contaminants

Initial dietary analyses enabled some general comments on exposure in this report but more detailed analyses are warranted. Estimated exposure levels for selected contaminants were expressed in micrograms per person per day for the two ethnic groups in relation to specific foods (separate analyses, data not presented). In general, these analyses showed that cadmium intake from the diet was very similar between the two studies. Lead consumption was actually higher in the Follow-up study due to an increase in the consumption of birds (lead shot fragments). Mercury intake was higher in the Follow-up study in both Inuvialuit and Dene/Métis populations, primarily because of the increase in fish consumption. In contrast, the intake of various POPs was similar in the two surveys for the Dene/Métis while the Inuvialuit had a marked decrease in POPs intake mostly related to a decrease in consumption of marine mammal fat (Armstrong *et al.*, 2007).

It is important not to over-interpret these data as the levels of contaminants were not actually measured in the dietary survey and average values from other regions were often used. As was indicated previously, it was not possible to perfectly match the communities in the two surveys. It will be important to interpret these levels in concert with actual body burden level in mothers.

4.2.5 Contaminant trends in the Inuvik region and dietary implications

Data on levels of a number of contaminants in maternal blood for the Baseline study (1998–1999) and the Follow-up study (2005–2006) can be seen in Table 4.2.1. Changes in contaminant and the significant differences between these two time points are indicated ($p<0.05$). Care must be taken when interpreting these data as these are reasonably small numbers of mothers who could not be randomly selected.

Among the organochlorine contaminants it can be seen that all contaminants have decreased among all ethnic groups over this time period (1998–2006). The Inuvialuit have the greatest absolute decrease for pesticides such as *p,p'*-DDE and trans-nonachlor (125 to 76, and 33 to 14 microg/kg lipid, respectively) and there is a significant decrease in many of the organochlorine contaminants. The absolute change in contaminants levels such as *p,p'*-DDE was less among Dene/Métis and non-Aboriginal mothers (64 to 35 and 64 to 38 microg/kg lipid, respectively) but the decrease was significant for the Dene/Métis and Inuvialuit and non-significant for the non-Aboriginal mothers. PCBs tend to be decreasing significantly, especially among Inuvialuit mothers with the most marked decrease in PCBs 138 and 153.

Among the metals, lead had the greatest change over the period 1998 to 2006 and the greatest decrease can be seen among Dene/Métis mothers (35 to 13 microg/L), representing a significant decrease over the seven years. The Inuvialuit and non-Aboriginals also showed a decrease over this time period. In other regions where hunting traditional foods is common, researchers have been able to use lead isotope signatures to link a decline in maternal body burdens to reduced use of lead shot (Dewailly *et al.*, 2000). Though this decrease in maternal blood lead levels in the Inuvik region may be related to less use of lead shot in hunting of game birds and waterfowl, there are no data to validate this conclusion for this region. Mercury has also decreased significantly over this period of time among all ethnic groups, and the greatest magnitude of change was among Inuvialuit mothers (2.1 to 1.1 microg/L whole blood). Cadmium showed the opposite trend with increasing maternal blood levels and the greatest increase among Dene/Métis mothers (0.56 to 1.4 microg/L whole blood). As previously noted elevated cadmium exposure has not been linked to traditional food consumption and in fact is much more strongly related to cigarette smoking. It is disappointing from a public health perspective to see that smoking rates among mothers have increased in this population and this increase in cadmium levels is a validation of this finding.

The decrease in the maternal blood levels of various organochlorines is supported by dietary information that indicates the Inuvialuit mothers are consuming fewer marine mammals while other less contaminated foods such as fish and caribou/moose are being consumed more. This is encouraging because much of the risk communication information released after the last assessment in 2003 indicated that mothers should continue to eat their traditional foods and if they were concerned about contaminants they should consume traditional foods with lower contaminant levels. For other contaminants, the trend data in maternal blood are not totally supported by the available dietary contaminant exposure information from this region as previously noted. The dietary exposure information indicates that the exposure to mercury and lead has actually increased while blood contaminant levels in these mothers have significantly decreased. Armstrong *et al.* (2007) have indicated that this may be due to not actually measuring the contaminant levels in the diets as consumed and having to rely on regional averages for contaminant levels in various species. This is a challenge that all dietary/contaminant studies face (i.e., limited budgets, a large number of contaminants, and a wide range of food items).

4.3 Qikiqtaaluk (Baffin) Region of Nunavut

4.3.1 Monitoring temporal trends of human environmental contaminants in Nunavut: Baffin region

The Qikiqtaaluk (Baffin) region in Nunavut recently completed a multi-year study that assessed changes in contaminant levels in human body burdens of selected environmental contaminants using maternal blood and hair as biomarkers. It was conducted as a follow-up study to one which took place in 1997. The region was identified as a monitoring priority due to the historically high levels of many contaminants compared to other regions of Arctic Canada that conducted baseline assessments during 1994–1999.

The current project in the Baffin Region aimed to 1) update geographic patterns of maternal exposure; 2) provide data to assess changes in maternal exposure over time (i.e., whether levels of different classes of contaminants are increasing, decreasing or remaining unchanged); and 3) collect information on maternal dietary habits and describe relationships between contaminant exposure, frequency of consumption of country foods and select lifestyle factors. Inuit women in their ninth month of pregnancy were invited to participate. They were asked a series of dietary and lifestyle questions. Blood and hair samples were collected and analyzed.

The study population consisted of 100 pregnant Inuit women recruited between December 2005 and January 2007. Blood samples were analyzed for persistent organic pollutants, polybrominated diphenyl ethers (PBDEs, a group of flame retardant chemicals with widespread use in foams and plastics), metals, vitamins and nutrients (selenium and fatty acids). Mercury exposure was also measured per trimester from hair samples. Information on country food consumption patterns, demographics and lifestyle characteristics were also collected. At the present time only the initial demographic and contaminant levels data set is available for this assessment (Table 4.3.1) and more in-depth analyses will have to await the availability of the full data set and the dietary data. It is encouraging to see that the mean age and range of the mothers at the two time points are very similar.

As was seen in the mothers from the Inuvik region, the levels of all organochlorines (OCs) have decreased significantly between 1997 and 2007 among Inuit mothers from the Baffin region of Nunavut (Table 4.3.1, Figures 4.2.3-4.2.8). The greatest decrease in organochlorine pesticide levels is seen for *p,p'*-DDE and oxychlordane (248 to 128 and 69 to 26 microg/kg lipid). PCB levels have also decreased significantly over this time period with the greatest decrease seen for the predominant congener PCB 153.

Among the metals included in this monitoring program, mercury and lead have decreased markedly between 1997 and 2007 (Table 4.3.1, Figure 4.2.2). The greatest

TABLE 4.3.1 Contaminant concentrations in Inuit mothers from Nunavut-Baffin Region (geometric mean (range), POPs microg/kg plasma lipid and metals microg/L whole blood)

Organochlorines Contaminants	Baseline 1997[1a, b] 24 (15-39)[3] n=30[4]	Follow-up 2005–2007[2] 24 (15-39)[3] n=99[4]	SD[5]
Oxychlordane	69 (12-264)	26 (4.8-216)	<0.0001
Trans-nonachlor	76 (21-275)	36 (4.3-262)	<0.0001
p,p'-DDE	248 (70-719)	128 (17-672)	<0.0001
Toxaphene – Parlar 50	15 (3.9-73)	8.6 (0.93-97)	0.0008
PCB 138	61 (16-177)	15 (3.5-77)	<0.0001
PCB 153	121 (33-355)	42 (6.2-276)	<0.0001
PCB 180	48 (9.5-158)	18 (1.9-158)	<0.0001
Aroclor 1260	950 (252-2700)	301 (52-1710)	<0.0001
Metals			
Total Hg	6.7 (0.10-34)	4.0 (0.52-28)	0.0152
Organic Hg	6.0 (0.8-29)	2.4 (0.20-23)	<0.0001
Pb	42 (5.0-120)	14 (4.1-71)	<0.0001
Cd	1.6 (0.03-6.2)	2.0 (0.27-7.3)	NS[6]
Se	118 (99-152)	NA	NA

1 a) Butler-Walker, 2003,
b) Butler-Walker, 2006
2 Potyrala, 2008, personal communication
3 Age of group sampled (arithmetic mean, range)
4 Number of individuals sampled
5 SD = significant difference ($p<0.05$)
6 NS = Not significant

absolute change is seen for lead, which significantly decreased from 42 to 14 microg/L whole blood. Both total mercury and organic mercury have decreased significantly, with the greatest change seen in organic mercury levels (6.0 to 2.4 microg/L whole blood). This decrease is particularly encouraging as the organic form of mercury is most toxic to humans and animals. The maternal blood levels of cadmium have increased over this time period but this change did not attain statistical significance. Questionnaire data from this study has found that mothers are smoking more in this region also, and this is supported by this increasing cadmium level (Potyrala, unpublished data).

4.4 Nunavik region of Québec

4.4.1 Temporal trends of POPs and metals in mothers from Nunavik

Over the past fifteen years, several studies in Nunavik have monitored the exposure of Inuit mothers to persistent organic pollutants and heavy metals. The objectives of this study were to compare current exposure levels to POPs with past levels and to assess exposure to emerging environmental POPs. Maternal blood levels of contaminants have been followed due to the concern about possible effects on infant and newborn development.

A series of nine studies have focused on contaminants in mothers from Nunavik and are outlined in Table 4.4.1.

TABLE 4.4.1 Summary of studies used in the database integration

Years	Study ID	Population studied	Region	Age (range)
1992	Enquête Santé – Québec Inuit 1992	Pregnant women	Nunavik	24 (18-35)
1996	Infant development study	Pregnant women	Nunavik	24 (17-34)
1997				25 (15-41)
1998				25 (15-37)
1999				26 (17-36)
2000				26 (17-39)
2001				27 (17-39)
2004	Qanuippitaa	Pregnant women	Nunavik	26 (19-37)
	Time trends (this project)	Pregnant women	Nunavik	32 (18-42)
	All			27 (18-42)
2007	Time trends (this project)	Pregnant women	Nunavik	24 (18-37)

These studies ranged from pregnant women in the 1992 Quebec Inuit Health Survey to Infant Development Studies led by Muckle *et al.* (2001a; 2001b) to more recent surveys that focused on time trend monitoring in Nunavik mothers (2004–2007). These studies recruited between 11 and 53 mothers each year and the average age varied from 24 to 32 years.

Measurements of the conventional POPs, emerging POPs, and heavy metals (which include 14 PCB congeners, 11 chlorinated pesticides, methyl mercury, lead, and selenium) were carried out on all samples collected in this project. Exposure assessment data from past and current studies were integrated into a functional database for this assessment. The dietary data are not available for this report.

Table 4.4.2 outlines the results for the time trend data for the conventional POPs and the metals over the period 1992–2007 (also see Figures 4.2.2-4.2.8). A temporal trend analysis of plasma concentration of organochlorines (OC) in pregnant women was performed using multiple regression modelling with the contaminant concentrations (log values) as dependant variables, and year of sampling as the main independent variable. The data were adjusted for age and region of sampling (Hudson vs. Ungava) as there were significant effects of these two parameters. All three models used explained between 16% and 30% of the variance observed in concentrations of contaminants.

The concentration of lead in maternal blood in Nunavik decreased over the period (1992 to 2007) from 41 to 16 microg/L. This decrease was statistically significant though the maximum level of 56 microg/L was in 1997. The concentration of total mercury also decreased significantly over this same time period from a maximum of 12 microg/L in 1992 to 4.0 microg/L in 2007. Cadmium in maternal blood also appears to have decreased from 3.2 to 1.9 microg/L, but this difference was not statistically significant. Cadmium measurements were only made in 1992, 2004 and 2007.

The levels of all three PCBs decreased significantly in maternal blood in Nunavik over the period 1992–2007, with PCB 153 the predominant congener showing the greatest change from 172 to 40 microg/kg lipid (Table 4.4.2). The chlordane derivatives trans-nonachlor and oxychlordane also both significantly decreased over this same time period. Trans-nonachlor showed the greatest change from a maximum of 114 in 1992 to a minimum of 44 microg/kg lipid in 2007. In 1992 *p,p'*-DDE had the highest concentration of all the POPs (636 microg/kg lipid) and decreased to 150 microg/kg lipid (which was a statistically significant decrease).

TABLE 4.4.2 Time Trends of Contaminants in Inuit pregnant women from Nunavik (Québec) (geometric mean (range). POPs microg/kg plasma lipid and metals microg/L whole blood)

Organochlorines Contaminants	1992[1] 24 (18-35)[6] (n=11)	1996[2] 24 (17-34)[6] (n= 25)	1997[2] 25 (15-41)[6] (n= 53)	1998[2] 25 (15-37)[6] (n= 46)	1999[2] 26 (17-36)[6] (n= 26)	2000[2] 26 (17-39)[6] (n= 36	2001[2] 27(17-39)[6] n=20	2004[3] 27 (18-42)[6] n=29	2007[9] 24 (18-37)[6] n=39	SD[4, 5]
Oxychlordane	77 (32-244)	41 (6.1-177)	48 (8.6-390)	34 (7.0-342)	47 (15-138)	40 (7.5-207)	36 (8.2-130)	35 (7.1-230)	22 (ND–182)	<0.0001
Trans-nonachlor	114 (50-322)	66 (15-246)	75 (14-332)	55 (12-578)	61 (21-169)	61 (13-304)	53 (12-204)	65 (14-412)	44 (2.5-255)	<0.0001
p,p'-DDE	636 (292-1567)	287 (71-1022)	369 (59-1444)	266 (67-2269)	287 (142-901)	274 (64-1328)	226 (54-1685)	231 (55-933)	150 (30-718)	<0.0001
Toxaphene- Parlar 50	NA[7]	NA	NA	NA	NA	NA	NA	NA	NA	NA
PCB 138	114 (45-218)	58 (10-211)	69 (12-317)	46 (13-387)	62 (17-216)	56 (10-297)	53 (11-165)	37 (8.6-118)	22 (16-30)	<0.0001
PCB 153	172 (71-287)	105 (19-409)	125 (23-612)	83 (27-709)	115 (29-473)	97 (15-499)	82 (16-417)	72 (16-253)	40 (5-218)	<0.0001
PCB 180	90 (34-146)	44 (7.6-189)	51 (11-216)	35 (12-278)	53 (14-384)	42 (5.0-263)	44 (7.5-240)	31 (4.9-125)	16 (12-22)	<0.0001
Metals	**n= 11**	**n= 25**	**n=53**	**n= 27**	**n= 16**	**n=29**	**n=19**	**n=31**	**n=42**	
Total Hg	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)	<0.0001
Organic Hg	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pb	41 (8.3-172)	48 (17-141)	56 (10-259)	54 (27-131)	53 (19-112)	44 (10-137)	33 (5.2-129)	19 (5.8-85)	16 (6.6-77)	<0.0001
Cd	3. 2 (0.36-7.6)	NA	NA	NA	NA	NA	NA	2.7 (.34-8.0)	1.9 (0.2-7.6)	NS[8]
Se	NA	37 (19-62)	32 (19-98)	30 (19-47)	30 (15-58)	34 (19-123)	26 (19-39)	27 (13-70)	26 (13-71)	0.0002

1 Santé Québec, 1994.
2 Dallaire *et al.*, 2003
3 Dewailly *et al.*, 2007 a and b
4 Special Analysis – Pereg, in press
5 SD = Significant difference (p<0.05), using ANOVA adjusted for age and region (Hudson or Ungava), regression adjusted for age and region (Hudson or Ungava) and smoking status (smoker, ex-smoker, non-smoker)
6 Age of group sampled (arithmetic mean, range)
7 NA = Not Available
8 NS = Not Significant
9 Pereg *et al.*, 2008

4.4.2 Changes in concentration of conventional POPs and metals in adults from Nunavik

Some of the environmental contaminant and dietary data results were previously reported in CACAR-I (CACAR, 1997) and CACAR-II (CACAR, 2003). A major follow-up health survey was undertaken in Nunavik in 2004 to again assess health status and identify risk factors of chronic disease. The concentrations of contaminants in blood samples were measured and levels of country food consumption were established for the population. The initial results for conventional and emerging POPs and metals can be seen in Dewailly *et al.* (2007a,b) but detailed dietary analyses are not available for this report.

Analysis of contaminants was conducted at the Laboratoire de toxicology of the Institut national de santé publique du Québec utilizing a new method known as the Automated Solid Phase Extraction (ASPE). This method allows measurement of 86 contaminants in a single analysis. The conventional POPs and a wide range of emerging POPs were then able to be measured on a single sample. In this section only conventional POPs will be reported but the data on emerging POPs will be reported in Section 4.5. In 2004, blood samples were obtained from 917 men and women 18 years of age and older with a participation rate of 69% (Dewailly *et al.*, 2007a,b). Special analyses were undertaken for this report (Dewailly *et al.*, 2007a) and the results are presented in Table 4.4.3 and Table 4.4.4. In total, 498 women and 408 men agreed to contribute blood samples for the 2004 follow-up monitoring program. It is encouraging to see the very similar age ranges in both sampling periods (18 to 73 or 74 years) and the similar mean ages (35, 36 or 37 years) in all four groups (Table 4.4.3 and Table 4.4.4). In-depth analyses of this data set have shown the expected age dependent increase in POPs levels in both men and women (Dewailly *et al.*, 2007 a, b).

As seen in Tables 4.4.3 and 4.4.4, the levels of POPs in Nunavik adults declined significantly from 1992 to 2004 (also see Figures 4.4.1 - 4.4.3). Previous monitoring in the Arctic and elsewhere have found that PCBs 138, 153 and 180 were the most abundant congeners in blood and all three congeners have declined over the 1992 to 2004 time period. PCB 138 declined at the fastest rate for men and women. The concentrations of *p,p'*-DDE had the greatest absolute decrease from 1195 to 461 for men and 1001 to 467 microg/kg lipid for women. The two chlordane metabolites/components oxychlordane and trans-nonachlor also declined significantly.

It is interesting to note that in adults from Nunavik levels of conventional POPs were much higher (10 to 20%) in men than women in 1992. This has changed in 2004 where oxychlordane, trans-nonachlor, *p,p'*-DDE, and PCB 138 are similar between men and women and only PCBs 153 and 180 are still 10 to 20% higher in men. At present, the diet survey information is not available for the most recent survey so no firm conclusions can be made.

TABLE 4.4.3 Contaminant concentrations in Inuit Men from Nunavik in 1992[1] and 2004[2] (geometric mean, range, POPs microg/kg plasma lipid and metals microg/L whole blood)

Organochlorines Contaminants	Inuit Men Nunavik 1992[1] 36 (18-74)[3] (n=210)	Inuit Men Nunavik 2004[2] 37 (18-74)[3] (n=408)	SD[4]
Oxychlordane	138 (1.9-2849)	66 (0.93-1608)	<0.0001
Trans-nonachlor	202 (7.7-2442)	116 (1.5-3942)	<0.0001
p,p'-DDE	1195 (115-11330)	461 (13-8306)	<0.0001
Toxaphene – Parlar 50	NA[5]	NA	NA
PCB 138	212 (9.7-1960)	77 (3.0-1388)	<0.0001
PCB 153	340 (14-2865)	189 (6.3-3428)	<0.0001
PCB 180	208 (7.7-3094)	111 (6.2-1851)	<0.0001
Metals			
Total Hg	14 (0.8-97)	9.2 (0.08-241)	<0.0001
Organic Hg	NA	NA	NA
Pb	96 (17-346)	46 (9.1-497)	<0.0001
Cd	5.1 (0.34-15)	4.1 (0.24-12)	<0.0001
Se	NA	NA	NA

1 Santé Québec, 1994
2 Dewailly *et al.*, 2007 a and b
3 Age of group sampled (arithmetic mean, range)
4 SD = significant difference (p <0.05), Dewailly 2007a
5 NA = not available

TABLE 4.4.4 Contaminant concentrations in Inuit Women from Nunavik in 1992 and 2004 (geometric mean, range, POPs microg/kg plasma lipid and metals microg/L whole blood)

Organochlorines Contaminants	Inuit Women Nunavik 1992[1] 35 (18-73)[3] (n =282)	Inuit Women Nunavik 2004[2] 37 (18-74)[3] (n = 498)	SD[4]
Oxychlordane	115 (5.0-1957)	66 (2.3-2692)	<0.0001
Trans-nonachlor	164 (13-1425)	117 (4.7-3702)	<0.0001
p,p'-DDE	1001 (97-14597)	467 (27-8306)	<0.0001
Toxaphene – Parlar 50	NA[5]	NA	NA
PCB 138	172 (17-1616)	73 (3.7-2549)	<0.0001
PCB 153	263 (27-2452)	158 (5.7-5805)	<0.0001
PCB 180	144 (10-2203)	75 (3.3-3510)	<0.0001
Metals			
Total Hg	16 (2.0-112)	12 (0.20-164)	<0.0001
Organic Hg	NA	NA	NA
Pb	78 (8.3-472)	34 (5.8-311)	NA
Cd	5.0 (0.29-22)	4.1 (0.16-15)	<0.0001
Se	NA	NA	NA

1 Santé Québec, 1994
2 Dewailly *et al.*, 2007 a and b
3 Age of group sampled (arithmetic mean, range)
4 SD = significant difference (p <0.05), Dewailly 2007a
5 NA = not available

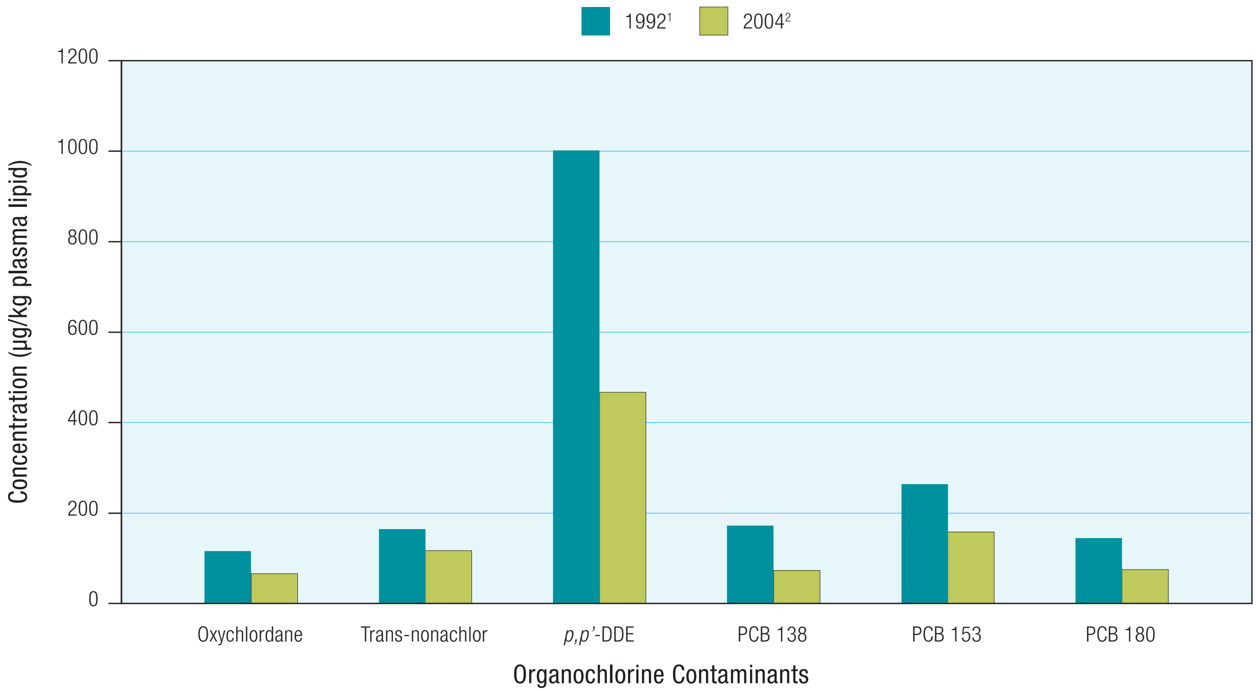

FIGURE 4.4.1

Organochlorine concentrations in Inuit women from Nunavik in 1992 and 2004 (microg/kg plasma lipid)

1 Santé Québec, 1994

2 Dewailly *et al.*, 2007 a and b

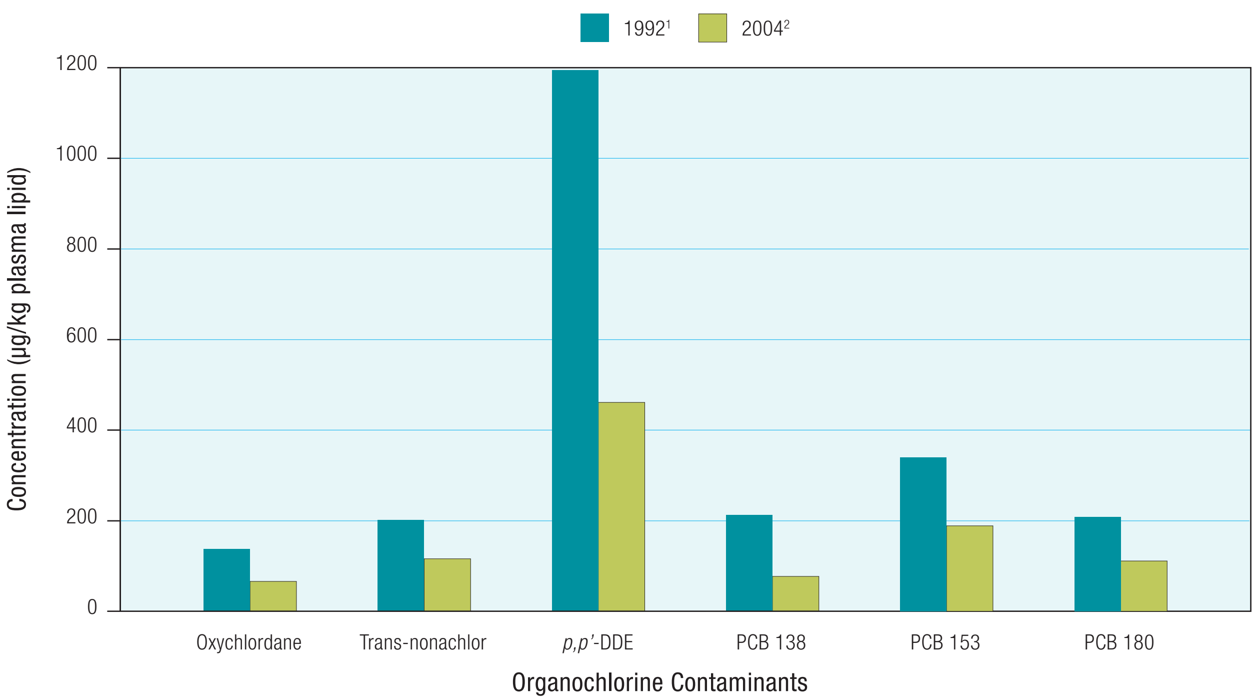

FIGURE 4.4.2

Organochlorine concentrations in Inuit men from Nunavik in 1992 and 2004 (microg/kg plasma lipid).

1 Santé Québec, 1994

2 Dewailly *et al.*, 2007 a and b

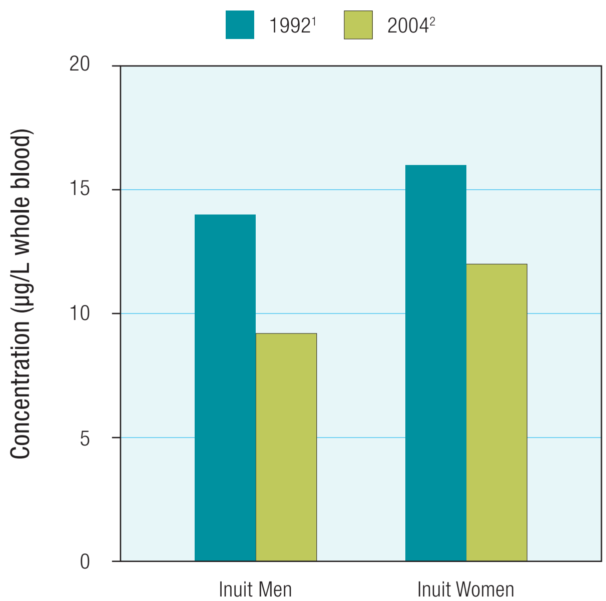

FIGURE 4.4.3

Total mercury concentrations in Inuit men and women from Nunavik in 1992 and 2004 (microg/L whole blood).

[1] Santé Québec, 1994

[2] Dewailly *et al.*, 2007 a and b

In Nunavik adults it appears that all metal levels have declined over the period 1992 to 2004. The greatest change is seen for lead where levels decreased from 96 to 46 microg/L for men and 78 to 34 microg/L whole blood for women. Mercury has also declined significantly in both men and women. Cadmium levels in men and women have also declined significantly. Age group analyses for this data set by Fontaine *et al.* (2006) have shown that in fact cadmium levels in adults aged 18 to 24 were found to be at the highest level in 2004.

4.5 Emerging Contaminants

At the same time as many legacy POPs such as DDT and PCBs are decreasing in Arctic marine wildlife, new contaminants are emerging. PBDEs are now being found in wildlife species that are the traditional foods of Arctic Canadians (Braune *et al.*, 2005). Braune *et al.* (2005) have reported that PBDEs increased 4- to 9-fold between 1975 and 1998 in some bird species but there is insufficient information to assess inter-species differences and spatial or temporal trends. A second group of chemicals, the perflorinated compounds (PFCs), which have been widely used as stain repellents and in the manufacture of non-stick surfaces, are also being seen in the Arctic. The PFCs have been very difficult to measure and new analytic procedures were only developed in the last ten years. A large amount of wildlife and human data have now become available. One of the major PFCs, perfluorooctane sulphonate (PFOS), is the predominant halogen in the liver of polar bears from eastern Hudson Bay, exceeding the concentrations of PCB congeners and DDE (Braune *et al.*, 2005). As was indicated for PBDEs, there has been insufficient monitoring for PFCs to assess inter-species differences and spatial or temporal trends. This chapter will review some of the initial data for the levels of these PBDEs and PFCs in human tissues and discuss their relevance to future monitoring.

4.5.1 Levels of emerging contaminants

PBDEs

All four of the studies described in the trend monitoring of the legacy POPs and metals outlined in Sections 4.2, 4.3, and 4.4 have measured some of the emerging POPs. A limited number of PBDEs (47, 99, 100, 153) were measured in these four studies and the initial results are summarized in Tables 4.5.1 and 4.5.2. The concentration of four PBDE congeners in mothers from the three ethnic groups from Inuvik and Inuit from the Baffin region are presented in Table 4.5.1. PBDE 47 is found at the highest mean concentration in the non-Aboriginal mothers (11 vs. 6.9 to 6.3 microg/kg plasma lipid) compared to the Dene/Métis or Inuit mothers though the maximal values were seen among the Inuit mothers (Armstrong *et al.*, 2007; Potyrala, 2008, personal communication). It needs to be noted that for the Baffin region, which has the higher levels of PCBs, the level of PCB 153 is almost seven-fold higher than PBDE 47 (Tables 4.4.2, 4.5.1 and 4.5.2). Unfortunately, dietary assessments are not available for these contaminants from the Inuvik or Baffin regional studies. An earlier study that used composite samples from the baseline monitoring program in the NWT and Nunavut did not find any difference in PBDE levels in Inuit, Dene/Métis and Caucasian mothers and the levels were similar to the levels seen in the follow-up studies in 2006–2007 (Ryan and Van Oostdam, 2004).

In Table 4.5.2 the concentrations of PBDEs 47, 99, 100, and 153 are presented for Nunavik Inuit men, women and women of child-bearing age on a lipid weight basis. The concentration of PBDE 47 is also the predominant congener in the men, women, and women of child-bearing age from Nunavik. The Inuit men, women, and women of child-bearing age have very similar levels to those seen among Inuit, Dene/Métis, and Caucasians from Inuvik and Baffin regions. Initial analyses of the Nunavik data indicate that PBDEs do not increase with age among men and women and only PBDE 47 was weakly associated with marine mammal consumption (Dewailly *et al.*, 2007). In

TABLE 4.5.1 Concentrations of Polybrominated Diphenyl Ethers (PBDEs) in Dene-Métis, Inuit and Non-Aboriginal Mothers in the Inuvik and Baffin regions. (geometric mean (range), microg/kg plasma lipid)

Emerging Contaminants	Non-Aboriginal	Dene-Métis	Inuit	
	Inuvik[1] (2005-2006) 32 (23-40)[3] (n=6)	Inuvik[1] (2005-2006) 25 (16-36)[3] (n=17)	Inuvik[1] (2005-2006) 26 (17-38)[3] (n=52)	Baffin[2] (2007) 24 (15-39)[3] (n=99)
PBDE 47	11 (3.6-102)	6.9 (1.8-30)	6.7 (1.8-468)	6.3 (1.1-174)
PBDE 99	2.2 (1.2-14)	1.6 (1.2-6.8)	2.2 (1.2-152)	1.9 (0.74-145)
PBDE 100	2.1 (1.2-12)	1.4 (1.2-4.2)	1.9 (1.2-90)	1.7 (0.74-30)
PBDE 153	1.3 (0.59-5.3)	1.8 (0.59-4.3)	2.5 (0.59-68)	2.1 (0.47-22)

1 Armstrong *et al.*, 2007 (special analysis for this report)
2 Potyrala, 2008, personal communication
3 Age of group sampled (arithmetic mean, range)

TABLE 4.5.2 Plasma concentrations of emerging contaminants in Nunavik (geometric mean (range), PFOS[1] microg/L plasma, PBDE[2] microg/kg plasma lipid)

		Nunavik		
		Men (18-74)[3] n=402	Women (18-74)[3] n=494	WCBA[4] (18-39)[3] n=301
PFOS[5] (microg/L)		21 (2.8-470)	16 (0.5-200)	13 (2.3-97)
PBDE[5] (microg/kg)	47	6.0 (<ND[6]-101)	6.0 (<ND[6]-344)	6.7 (<ND[6]-344)
	99	<ND[6] (<ND[6]-97)	<ND[6] (<ND[6]-82)	<ND[6] (<ND[6]-82)
	100	<ND[6] (<ND[6]-78)	<ND[6] (<ND[6]-83)	<ND[6] (<ND[6]-83)
	153	4.0 (<ND[6]-135)	2.1 (<ND[6]-58)	4.0 (<ND[6]-58)

1 Perfluorooctane sulfonate (PFOS)
2 Polybrominated Diphenyl ethers (PBDEs)
3 Age of group sampled
4 Women of child bearing age
5 Dewailly *et al.*, 2007
6 Not Detected (ND)

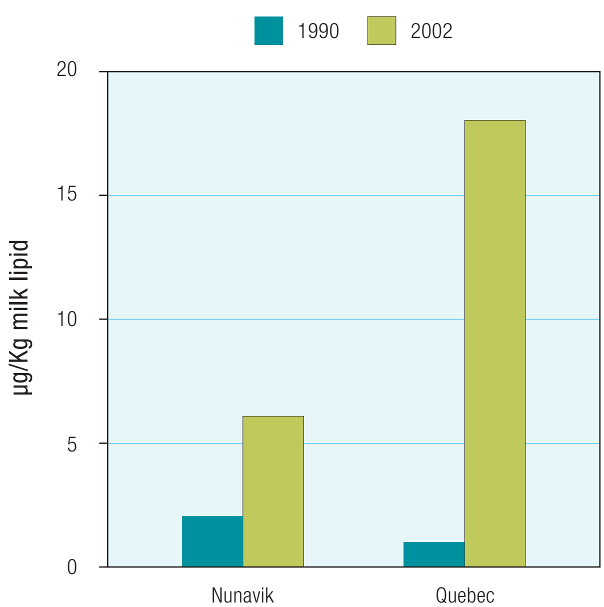

FIGURE 4.5.1
Change in concentrations of sum of PBDEs in two Quebec populations (Pereg *et al.*, 2003)

Nunavik and southern Quebec, breast-milk samples collected in 1990 were archived and newer samples collected in 2002 (Pereg *et al.*, 2003). All samples were analyzed at the same laboratory in 2003 and in the same laboratory that conducted the other PBDE analyses presented here. The sum of PBDE congeners in breast milk for these two populations is increasing over this time period but to a much greater extent in the southern Quebec population (Figure 4.5.1).

Comparative levels of PBDEs, expressed on a lipid weight basis in adults from other countries, are presented in Table 4.5.3; it can be seen that the predominant congener is PBDE 47. The concentration of PBDE 47 is higher in the United States but lower in the United Kingdom and similar in southern Quebec, Korea, and New Zealand compared to the concentrations seen in mothers from Inuvik and Baffin regions. These comparisons must be viewed with great caution as many of these groups

TABLE 4.5.3 Concentrations of Polybrominated Diphenyl Ethers (PBDEs) in blood of adult men and women from various countries

Region	Population	Period of Sampling	Lipid Weight (microg/kg plasma/serum lipid)			
			PBDE-47	PBDE-99	PBDE-100	PBDE-153
Canada, Quebec[1]	Women Postmenopausal N=110 58(48-76)[6]	2003-2004	8.1[7a] (0.81-1780)	1.4 (<0.40-716)	1.1 (<0.40-366)	1.4 (<0.40-198)
US[2]	Men and Women N=93 (NA)[8]	2001-2003	13[7a] (0.71-1389)	3.2 (0.33-545)	2.7 (0.30-280)	3.2 (0.39-165)
Korea[3]	Men N=10 (NA)[8]	2001	5.7[7b] (2.2-12)	2.68 (1.5-5.4)	1.4 (0.45-2.5)	4.7 (2.8-7.7)
	Women N=12 (NA)[8]	2001	4.5[7b] (1.8-7.7)	2.3 (1.1-4.9)	0.99 (0.33-1.9)	3.0 (1.6-7.5)
New Zealand[4]	Men and Women N=23 NA[8] (20-64)[6]	2001	3.5[7b] NA[8]	0.91 NA[8]	0.86 NA[8]	1.2 NA[8]
UK[5]	Men and Women N=154 (NA)[8]	2003	0.82[7c] (<0.30-180)	<0.16 (<0.16-150)	0.76 (<0.17-390)	1.7 (<0.26-87)

1 Sandanger *et al.*, 2007
2 Morland *et al.*, 2005
3 Kim *et al.*, 2005
4 Harrad and Porter, 2006
5 Thomas *et al.*, 2006
6 Mean Age of group sampled (Range)
7a Geometric Mean
7b Arithmetic Mean
7c Median
8 Data not available (NA)

are not age or gender matched with the mothers from Inuvik and Baffin. These mothers will most likely be significantly younger than the adult populations cited.

PFCs

The PFCs were only measured in a few studies conducted in Arctic Canada. In Table 4.5.2 it can be seen that men have higher concentrations of perfluorooctane sulfonate (PFOS) than women. Women of child-bearing age have the lowest levels (Dewailly *et al.*, 2007). Recently, data have become available that compares the concentrations of PFOS in mothers and women of child-bearing age from Nunavik in 1992 and 2004 (Figure 4.5.2). These data show that levels of this contaminant have decreased significantly over this time period (Pereg, 2007). The concentrations of PFOS in Nunavik Inuit in 2004 (Table 4.5.2) can be compared to the levels in adults from other countries in Table 4.5.4. It will be noted that many of the values for concentrations of PFOS from the USA, southern Canada, Denmark, Germany, and Japan are similar or slightly higher than the levels seen in Nunavik adults but the

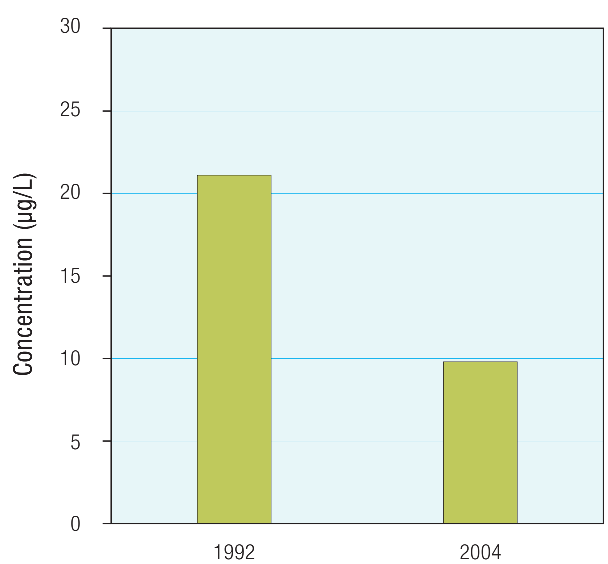

FIGURE 4.5.2
PFOS concentrations in women of child bearing age and pregnant women (Pereg, 2007) (1992 n= 49; 2004 n=31)

TABLE 4.5.4 Concentrations of perfluorooctane sulfonate (PFOS) in blood serum or plasma of adult men and women in various countries.

Region		Population	Period of Sampling	Wet Weight (microg/L) PFOS
US[1]		Men n=2094[7] (12–60+)[8]	2003–2004	23[9a] (21-26)
			1999–2000	33[9a] (30-38)
		Women n=2094[7] (12–60+)[8]	2003–2004	18[9a] (17-20)
			1999–2000	28[9a] (25-32)
US[2]		Men n=332 (20-69)[8]	2000–2001	38[9a] (<4.3-1656)
		Women n=313 (20-69)[8]		32[9a] (6.0-226)
Ottawa/Gatineau, Canada[3]		Men n=35 NA[10]	2002	28[9b] (3.7-65)
		Women n=21 NA[10]		30[9b] (9.5-62)
Denmark[4]		Women[11] n=1400 NA[10]	1996–2002	35[9b] NA[10]
Germany[5]		Men and Women[11] n=105 NA[10]	2003–2004	22[9c] (6.2-131)
Japan[6]	Kyoto	Men n=28 37[8]	2003	28[9a] NA[10]
		Women n=26 37[8]		14[9a] NA[10]
	Miyagi	Men n=32 40[8]		5.7[9a] NA[10]
		Women n=23 42[8]		3.5[9a] NA[10]

1 Calafat *et al.*, 2007
2 Kubwabo *et al.*, 2004
3 Olsen *et al.*, 2003
4 Fei *et al.*, 2007
5 Midasch, *et al.*, 2006
6 Harada K. *et al.*, 2004
7 Number of participants is men and women combined
8 Mean Age of group sampled, or range.
9a Geometric Mean
9b Arithmetic Mean
9c Median
10 Data Not Available (NA)
11 Plasma samples, all other samples are serum

levels are quite variable. An earlier study that used composite samples from the baseline monitoring program in the NWT and Nunavut did not find any difference in PFOS and other PFCs in Inuit, Dene/Métis, and Caucasian mothers and the levels were 50% higher than the levels seen in the follow-up studies in 2006–2007 presented here (Tittlemier *et al.*, 2004). Initial analysis of PFCs in traditional foods of Arctic Canadians has not indicated that consumption of marine or terrestrial mammals will lead to high contaminant exposures (Tittlemier *et al.*, 2006).

Recently human tissue levels of various PCB metabolites such as hydroxyl-PCBs and methyl sulfone PCBs have become available for adults in Nunavik. There is little comparative data in the literature or in Arctic populations and the reader is referred to Dewailly *et al.* (2007) for further information.

4.6 Contaminant Tissue Levels and Guidelines

Criteria for acceptable levels of contaminants in humans have been established for a number of contaminants. This section compares tissue levels of PCBs (as Aroclor 1260), mercury, cadmium, and lead in various northern ethnic groups to the established guidelines presented in Table 4.6.1.

4.6.1 PCB tissue levels and guidelines

The Health Canada (1986) guideline for PCBs lists a Level of Concern when concentrations are greater than 5 microg/L in blood and an Action Level when concentrations are greater than 100 microg/L in blood. Table 4.6.1 summarizes the blood guideline exceedances for PCBs (as Aroclor 1260) in mothers from the Inuvik region (NWT), Nunavut, and the Nunavik region (northern Quebec). The recent results of biomonitoring studies (i.e., since 2003) conducted in the Inuvik region indicate that 7.4% of the blood samples from Inuvialuit exceeded the 5 microg/L Level of Concern and none of the blood samples from Dene/Métis and non-Aboriginal groups exceeded this value. The corresponding results from Inuit mothers in Nunavut indicate that 25% of the blood samples exceeded the 5 microg/L Level of Concern, while the results from mothers in Nunavik indicate that 52% of the blood samples exceeded the 5 microg/L Level of Concern (none of the blood samples exceeded the 100 microg/L Action Level). The percentages of Inuit that exceeded the 5 microg/L PCB guideline from Nunavut and Nunavik are the highest compared to other groups because they have the highest mean levels of PCBs.

TABLE 4.6.1 Guidelines for selected contaminants, women of childbearing age

Contaminant	Level of Concern (LoC)	Level of Action (LoA)
Cadmium[1]	5 microg/L	Not available
Lead[2]	Not available	100 microg/L (Level of Intervention)
Mercury (blood, US)[3]	5.8 microg/L	
Mercury (blood)[4]	20 microg/L (Increasing Risk Range)	100 microg/L (At risk range)
Mercury (hair)[4]	6 microg/g (Increasing Risk Range)	30 microg/g (At risk range)
PCBs (as Aroclor 1260)[5]	5 microg/L	100 microg/L

1 OSHA, 1992
2 Health Canada, 1994
3 Based on the US 1999 re-evaluation which derived a mercury Benchmark Dose Level (58 µg/L) and advised a ten-fold safety factor, allowing the development of a maternal blood guideline of 5.8 µg/L.
4 Health Canada, 1984
5 Health Canada, 1986

Biomonitoring studies have taken place over a number of years. By comparing the levels of PCBs from the recent biomonitoring studies to the older biomonitoring studies, insight into trends can be gained. Table 4.6.2 indicates that the percent of samples exceeding the Level of Concern for PCBs for Inuvialuit and Dene/Métis in the Inuvik region are decreasing between the late 1990s and 2006–2007. There has also been a notable decrease among Inuit from Nunavut (i.e., 73% of samples exceeding the 5 microg/L guideline in 1997 compared to 25% of samples exceeding 5 microg/L in the 2005-07 biomonitoring study) and an overall decrease among Inuit from Nunavik (i.e., 91% of samples exceeding >5 microg/L guideline in 1992 compared to 52% of samples exceeding >5 microg/L in the 2004 study). Overall, these results indicate that there is a decreasing proportion of mothers exceeding the 5 microg/L Level of Concern for PCBs and the results support the overall decreasing levels of PCBs among these mothers (Section 4.6.2).

TABLE 4.6.2 Blood guideline exceedances for mercury (total), lead, cadmium and PCBs (as Aroclor 1260) in women of reproductive age by region and ethnicity (%)

Country Region/Ethnicity	N	Year	Mercury (total)		Lead	Cadmium	PCBs as Aroclor 1260	
			% of samples exceeding 5.8 microg/L	% of samples exceeding 20 microg/L	% of samples exceeding 100 microg/L	% of samples exceeding 5 microg/L	% of samples exceeding >5 microg/L	% of Samples ≥ Action Level (100 microg/L)
Canada (mothers)								
Nunavut/ Inuit	31	1997	68	9.7	9.7	13	73	0
	100	2005–2007	32	2.0	0	9.1	25	0
Inuvik/ Inuvialuit	31	1998–1999	16	3.2	3.2	6.4	13	0
	52	2005–2006	5.6	0	0	1.9	7.4	0
Inuvik/ Dene/Métis	42	1998–1999	2.4	0	4.8	4.8	2.4	0
	17	2005–2006	0	0	0	5.3	0	0
Inuvik/ Non-Aboriginal	21	1998–1999	0	0	0	0	0	0
	6	2005–2006	0	0	0	0	0	0
Nunavik/ Inuit								
	11	1992	55	36	9.1	NA	91	0
	25	1996	76	20	8	NA	68	0
	53	1997	72	19	13	NA	72	0
	27	1998	52	3.7	19	NA	44	0
	16	1999	56	13	13	NA	58	0
	29	2000	59	17	10	NA	57	0
	19	2001	47	26	5.3	NA	55	0
	31	2004	61	6.5	0	NA	52	0
	42	2007	31	2.1	0	NA	NA	NA

4.6.2 Metal tissue levels and guidelines

This section compares blood guideline exceedances for mercury (total), lead, and cadmium in women of reproductive age.

Mercury

Health Canada has developed blood guidelines for mercury (Health Canada, 1984). Mercury levels that are below 20 microg/L in human blood are considered by Health Canada to be within an acceptable range. When mercury levels are found to be between 20 and 100 microg/L, individuals are considered to be at "increasing risk" and when mercury levels exceed 100 microg/L in blood, individuals are considered to be "at risk." The United States has re-assessed its mercury dietary guidelines. This assessment developed a Bench Mark Dose Level (BMDL) of 58 microg/L for mercury and suggested that a ten-fold safety factor be applied in developing a dietary intake value (NRC, 2000). From this BMDL, an informal blood guideline for mercury in women of reproductive age of 5.8 microg/L has been developed.

Table 4.6.2 shows that among mothers from the Inuvik region, Nunavut, and Nunavik, only 2% of Inuit mothers from Nunavut and 2.1% (2007) of Inuit mothers from Nunavik exceeded the Health Canada 20 microg/L guideline. None of Inuvialuit, Dene/Métis or non-Aboriginal mothers from the Inuvik region exceeded this guideline.

The percentage of mothers that exceeded the 5.8 microg/L U.S. guideline value for mercury was 32% for Inuit from Nunavut, 31% (2007) for Inuit from Nunavik, and 5.6% for Inuvialuit from the Inuvik region.

The proportion of Inuit mothers from the recent biomonitoring studies that exceeded the Health Canada 20 microg/L "increasing risk" guideline and the U.S. 5.8 microg/L acceptable value has decreased markedly from earlier biomonitoring studies. There have been the following decreases in the percent of samples exceeding the 20 microg/L Health Canada guideline: from 3.2% in a 1998–1999 biomonitoring study to 0% in a 2005–2006 biomonitoring study among Inuvialuit living in the Inuvik region; from 9.7% in a 1997 biomonitoring study to 2.0% in the 2005–2007 biomonitoring study among Inuit living in Nunavut; and from 36% in the 1992 biomonitoring study to 2.1% in the 2007 biomonitoring study among Inuit living in Nunavik. A similar trend can be observed for the percent of samples exceeding the 5.8 microg/L U.S. value for the same regions and ethnic groups (See Table 4.6.2).

Lead

The Canadian blood guideline of 100 microg/L is the Intervention Level for lead (Health Canada, 1994). As presented in Table 4.6.2, none of the mothers from the Inuvik region, Nunavut, or Nunavik exceeded the 100 microg/L guideline. The results of previous biomonitoring studies (1998–1999) indicate that Inuvialuit and Dene/Métis mothers from the Inuvik region exceeded the lead 100 microg/L guideline by 3.2 and 4.8%, respectively. Among Inuit mothers from Nunavut and Nunavik, the exceedances of the 100 microg/L lead guideline in previous biomonitoring studies (1992–2001) were 5.3 and 19%, respectively.

The gradual decline in the percent of samples exceeding the lead blood guideline could be the result of public health efforts. For example, in Nunavik public health officials have made an effort to reduce human exposure to lead by actively informing the population about the potential health impacts of lead shot fragments in food on children's health (Levesque *et al.*, 2003).

Cadmium

The blood guideline used in this report for cadmium is 5 microg/L, an occupational guideline (Occupational Safety and Health Administration, 1992). Data from a recent biomonitoring study are available for the Inuvik region by ethnicity (Table 4.6.2). In the Inuvik region, 1.9% of the Inuvialuit mothers and 5.3% of the Dene/Métis mothers exceeded the 5 microg/L cadmium blood guideline. None of the non-Aboriginal group in the Inuvik region exceeds the 5 microg/L cadmium guideline.

By comparing the results of the recent biomonitoring studies to older biomonitoring studies (see Table 4.6.2), it is evident that levels of cadmium are increasing in mothers from some regions (Inuvik, Baffin) but declining among other groups (Nunavik mothers, adults). The percent of samples exceeding the 5 microg/L cadmium guideline has decreased from 6.4 (1998–1999) to 1.9% (2005–2006) among Inuvialuit mothers from the Inuvik region and from 13 (1997) to 9.1% (2005–2007) among Inuit mothers from Baffin region. This decline in the percent exceeding the guideline is in opposition to the increasing cadmium levels seen in some of these groups, which is likely due to fewer mothers smoking but those who do smoke are smoking more (Potyrala, 2008, personal communication). The increasing levels of cadmium can be seen in the higher percent of samples exceeding the 5 microg/L cadmium guideline among Dene/Métis mothers from the Inuvik region (4.8% in 1998-99; 5.3% in 2005–2006).

4.7 Quality Assurance/Quality Control

The NCP is committed to generating results that are of high quality to properly assess and interpret temporal and spatial trends of chemical contaminants. To ensure the consistent quality of the results, QA/QC measures have been implemented and reviewed during each phase of the program. The NCP requires an ongoing QA program that demonstrates to NCP managers and scientists the quality, reliability and comparability of measured results from biomonitoring studies. This section discusses quality assurance and quality control aspects of the NCP human health studies (for details, please see Chapter 6 in CACAR, 2003).

The Centre de Toxicologie du Quebec (CTQ), of the Institut national de santé publique du Québec as well as laboratories at Health Canada and the Centre for Indigenous Peoples Nutrition and Environment have analyzed the human tissue and food samples reported in this human health assessment.

The CTQ has provided the analysis of trend data for the NCP. The CTQ is a laboratory accredited by the Standards Council of Canada (SCC, 2006) under ISO/IEC 17025 (certificate of accreditation available at http://palcan.scc.ca/specs/pdf/304_e.pdf) and participates in the Arctic Monitoring and Assessment Program (AMAP) Ring Test program, as well as other international external quality assurance schemes. This laboratory provides expertise in the areas of clinical, industrial, and environmental toxicology. Evaluation of the levels of PCBs and other organochlorinated compounds and heavy metals in Aboriginal populations in Arctic Canada and other circumpolar countries is one of CTQ's areas of expertise.

There are a number of intercomparison programs (external quality assessment schemes) available from the CTQ, which is accredited as a Proficiency Testing Provider (SCC, 2007). The CTQ initially established an Interlaboratory Comparison Program for laboratories conducting measurements of heavy metals in blood and urine in 1979. This program supports its internal quality control needs and provides a way to compare the quality of results with other international toxicology laboratories. The check samples are typically prepared from human biological fluids spiked with the analytes of interest. These samples meet the requirement for matrix matching that cannot be optimally achieved with most commercial reference materials that are often freeze-dried.

In 1996, the CTQ inaugurated a program called the Quebec MultiElement Assessment Scheme (QMEQAS), formerly known as the ICP-MS Comparison Program with the objective of enabling laboratories performing simultaneous multi-element determinations in clinical specimens to compare results and improve performance. Over 200 laboratories participate in these programs for one or more metals. Since 2002, the CTQ has provided interlaboratory comparison for the AMAP. Weber (2002) has termed this program the "AMAP Ring Test." This is a mandatory program for laboratories providing analytical results for PCBs, organochlorine pesticides and other POPs (e.g., polybrominated flame retardants, PFOS) to AMAP. The laboratories that participate in the AMAP Ring Test are provided with frozen human blood plasma samples spiked with various levels of the analytes. At the end of each of the three annual rounds, they receive a summary report with their laboratory's performance.

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The CTQ provides quality data to the NCP. Their procedures are well documented and adequately address the data quality measures that are required (Rhainds, 1999; SCC, 2006; Sandanger, 2007).

In addition to its own programs, the CTQ participates successfully in a number of internationally recognized external quality assurance schemes for inorganic and organic contaminants, including from the following:

- *The Centers for Disease Control and Prevention, Atlanta, GA*
- *The College of American Pathologists, Chicago, IL*
- *Quasimeme, Wageningen, Netherlands*
- *State of New York Department of Health, Albany, NY*
- *Finland Institute of Occupational Health, Helsinki, Finland*
- *The Northern Contaminants Program Interlaboratory Study (Ottawa)*

- *The German Society of Occupational and Environmental Medicine, University of Erlangen-Nuremberg. Germany*

4.7.1 Comparability of data obtained by different methods or over time

The issue of method comparability does not only affect the CTQ laboratory and the team in human health, but it affects every single researcher working on spatial and temporal trends or on longitudinal studies who uses and compares data obtained with different methods or the same method at different times.

At the outset, it is important to point out that laboratory methods are not static but evolve constantly as laboratories strive to achieve better performance, aspects of which include accuracy, precision, selectivity, and sensitivity. This is made possible notably by the improvement in analytical technology.

In earlier studies, laboratories using vintage instruments and techniques in the case of PCBs and OCs would have used packed columns with electron-capture detectors, and reporting aggregates (such as the fictional Aroclor 1260) rather than individual congener data.

The CTQ has been active in the monitoring of POPs in northern Canadian populations for the past two decades. During this period, the analytical methods have of necessity improved due to new knowledge and better analytical equipment. Two major developments are the switch from the electron capture detector to the mass spectrometer (1990s), allowing more specific identification of individual congeners, and the recent (2006) implementation of a solid phase extraction technique (Sandau *et al.*, 2003) to replace the traditional liquid-liquid extraction. In both instances, there was potential for systematic bias between the new and the old method.

Changes in technology may affect comparability of contemporary and historical data. For instance, improvement in separation efficiency through better chromatographic columns will reduce the incidence of co-eluting compounds. A specific example is that of PCB 138, which until recently co-eluted with PCB 163 on most chromatographic columns. Currently, these two congeners can be separated, with the consequence that results for 138 will be lower than they would have been using older methods.

An exhaustive evaluation of the old and new methods was conducted to determine whether significant biases were present. The resulting report (CTQ, 2006) was submitted to NCP. Statistical analysis of data showed that bias present was generally below the acceptable criterion of 10%. Examples for two compounds are shown in Figure 4.7.1 below.

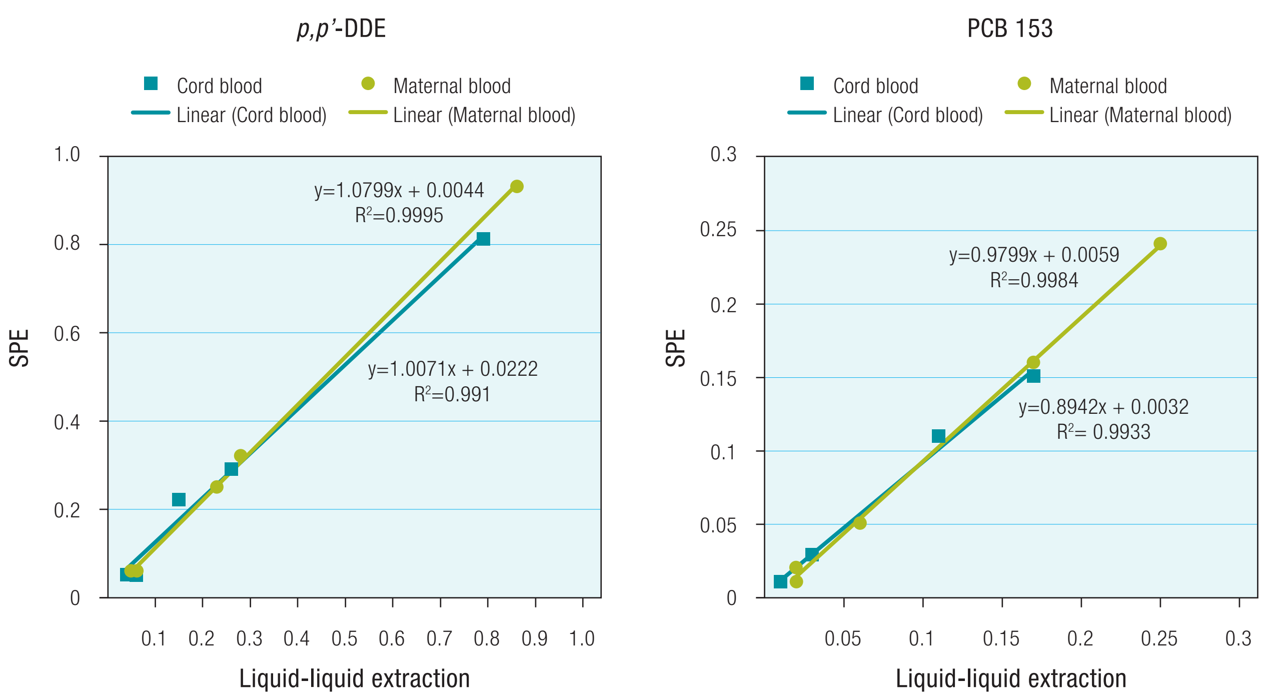

FIGURE 4.7.1

Comparison of results obtained with the liquid-liquid and the solid-phase extraction (SPE) for *p,p'*-DDE and PCB-153

In a few cases, biases were identified and correction factors were determined in order to enhance comparability of data between the old and the new methods.

4.8 Concluding Remarks

Many of the previous conclusions on contaminant levels distributions in regional populations are very similar to that seen in the late 1990s (Van Oostdam *et al.*, 2005). Among the Inuit, Dene/Métis, and non-Aboriginal groups, the Inuit have the highest levels of almost all POPs and metals. This is well illustrated in the Inuvik region maternal blood contaminant study (Section 4.2.1) though the number of non-Aboriginal participants was small. The east-to-west geographical gradient of increasing levels of mercury and POPs in Inuit can also be seen in these new data. This pattern is seen by the increasing concentrations of total mercury in 2004–2006 from 1.1 microg/L in the western Inuvik region of the NWT, to 4.0 microg/L in the Baffin region of Nunavut, to 7.6 microg/L in Nunavik, in Arctic Quebec. The highest levels of total mercury in maternal blood during the late 1990s were also in Nunavik (Van Oostdam *et al.*, 2005). In the late 1990s, the highest levels of various POPs such as PCBs were found in mothers from the Baffin region. In the more recent data available here, the highest levels of almost all POPs are now seen in Nunavik as exemplified by *p,p'*-DDE (76, 128 and 231 microg/kg) and trans-nonachlor (14, 36 and 65 microg/kg) for Inuvik, Baffin, and Nunavik, respectively (Tables 4.2.1, 4.3.1, 4.4.2).

The new data set on levels of contaminants in adult men and women in Nunavik is interesting because Dewailly *et al.* (2007a, b) have again shown the age-dependent increase for contaminants such as POPs, lead, and mercury. This age-dependent increase can be clearly seen in the 2004 data from Nunavik where the levels of contaminants in the adult women are almost double the levels of contaminants seen in mothers from the same region (Tables 4.4.2, and 4.4.4) (e.g., *p,p'*-DDE in 2004 for mothers and older women is 226 and 467 microg/kg plasma lipid, respectively).

It is encouraging to see significant declines in almost all contaminants (e.g., PCBs 138, 153, 180, oxychlordane, transnonachlor, *p,p'*-DDE), in maternal blood over the time period 1992–1996 to 2004–2006 for all Canadian Arctic regions studied (NWT, Nunavut, Nunavik). A number of maternal contaminant levels are now less than one-half the levels they were less than 10 years ago. A true trend analysis for contaminant levels in blood is only possible for maternal blood in Nunavik as there were nine sampling points over the fifteen years (1992–2007)

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for these mothers. It is very encouraging to see the same decreasing levels in the other regions and populations (Inuvik, Baffin, Nunavik general population) where only two sampling points were available.

The levels of lead in mothers and adults have declined in all regions and both genders. In only one region is research available that addresses the possible cause. Lead isotope research in Nunavik by Dewailly *et al.* (2000) found that the source of elevated lead in mothers was likely to be lead shot fragments. Following this discovery, the public health authorities in Nunavik implemented a ban on the use of lead shot. In Nunavik, the decline in body burdens of lead can logically be linked to the banning of lead shot and it would be very interesting to survey the use of lead shot in other regions.

The levels of cadmium have not decreased and in fact have increased in the Inuvik, Baffin, and Nunavik regions among young women and mothers. This has been linked to increased smoking in this age group and is a significant public health issue for all regional health authorities.

In only one of the regional contaminant studies is a detailed dietary analysis available with corresponding contaminant data. The women in the Follow-up study in Inuvik discussed in their interviews that elders and family members had indeed shared with them the importance of using traditional food, especially during their pregnancy. Mothers in the Follow-up study reported increasing their traditional food consumption more than the mothers in the Baseline study, although the communities and population involved did vary. For the Dene/Métis, the amount of traditional food use in 2006 was similar to that of 2000 except for fish, which doubled. The increase of fish consumption was three-fold among the Inuvialuit. The Inuvialuit also reported eating more seal meat but had decreased the amount of marine mammal fat by a factor of three, particularly beluga. This decrease in consumption of marine mammal fat could be a positive reflection of the message by health professionals “that traditional food is good for you but if you are worried about contaminants you should consume foods lower in contaminants such as char or caribou/moose.”


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Toxicology

5.1 Introduction

Toxicology is the science that investigates "the adverse effects of chemical, physical or biological agents on living organisms and the ecosystem, including the prevention and amelioration of such adverse effects" (Society of Toxicology, 2005). Laboratory animals are used to test compounds under controlled conditions, such that only the treatment with the test chemical differs between experimental groups. In contrast, epidemiology is observational in nature and aims to identify factors that are associated with a specific disease in carefully selected groups of human subjects. Important differences between toxicology and epidemiology exist with regard to dose characterization. Ritter and Arbuckle (2007) have recently argued that these differences, which are summarized in Table 5.1.1, could be responsible for most of the inconsistencies that exist between epidemiological and toxicological studies regarding the deleterious effects of exposure to environmental contaminants.

Experimental toxicology is important for the safety assessment of a variety of chemicals that can be found in foods either as a result of direct addition or use (food additives, packaging materials, preservatives, flavours, pesticides) or through environmental sources (contaminants, natural toxins, radionuclides). It remains one of the main mechanisms for identifying potential toxic effects for humans and determining doses that are not expected to be associated with adverse effects over a lifetime of exposure.

5.2 Contaminants of Concern

Based on reviews of dietary surveys and human tissues, contaminants of concern for Arctic Canada country food consumers continue to be various persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs) and organochlorine (OC) pesticides, and three toxic metals (cadmium, lead, mercury). New global contaminants of interest that have gained worldwide

TABLE 5.1.1 Characteristics of the exposure assessment in toxicological and epidemiological studies (from Ritter and Arbuckle, 2007)

Characteristic	Toxicology	Epidemiology
Study agent(s)	Known and controlled source, vehicle, route	Can be multiple sources, routes and vehicles, not in control of investigator
Timing and duration of exposure	Known, constant and controlled; less likelihood of measurement error	Not controlled, may be of longer duration and even multi-generational and variable over observation period; higher likelihood of measurement error
Magnitude of exposure	Dose often exceeds range relevant to humans	Reflects actual range of human exposure
Exposure categorization	Dose is selected *a priori*, fixed, limited number of doses administered to groups of animals by investigator; usually one compound at a time	Estimated: commonly based on a one-time environmental (i.e., *ad libitum* exposure to contaminated air, drinking water, food) or biological (e.g., blood, urine) sampling; may or may not be categorized; evaluates mixtures to which people are exposed (although exact nature of mixture may not be well characterized)
Study groups	Homogenous (e.g., genetic, nutritional, environmental factors) both within dosing groups and between groups, except for the exposure under study	Efforts made to make the groups as homogenous as possible (within and between groups) using selection and restriction criteria for study population and/or data analysis
Relevance to humans	Species and strain selected may have metabolic pathways not representative of humans	Directly relevant if no selection biases present
Statistical analysis	Straightforward; a few select and fixed ordinal doses with a set number of animals exposed to each dose; if dose is selected appropriately, lends itself well to dose-response curves and threshold determinations (if applicable)	Complicated; concentrations are continuous variables, therefore can be issues such as a) data are not normally distributed; b) may have high proportions of non-detectable concentrations; c) choice of cut-points to categorize data; difficult to identify sufficient numbers of truly non-exposed; choice of statistical model for dose-response curves.

media attention and for which there are anticipated to be Arctic-related exposures include brominated flame retardants (polybrominated diphenylethers, PBDEs; hexabromocyclododecane, HBCD) and the perfluorochemicals perfluorooctane sulphate (PFOS) and perfluorooctanoic acid (PFOA). These new or emerging pollutants share many of the chemical properties of the traditional or legacy POPs in that they are extremely persistent in the environment, resist degradation, can be subject to long-range transportation processes, and bioaccumulate in biota, including humans.

5.2.1 Polybrominated diphenylethers (PBDEs)

PBDEs are structurally similar to PCBs and have been used worldwide as flame retardants in various consumer products (polyurethane furniture foam, plastics for consumer electronics, coatings for draperies and upholstery) since the 1960s (Alaee *et al.*, 2003). PBDEs are primarily used as additive flame retardants, specific to applications as defined by their physical-chemical properties, with total production in 2001 estimated at 70,000 tonnes (Gill *et al.*, 2004). From a regional perspective, the main commercial mixture generally used in North America was the penta formulation, with the major congeners found in the mixture also being the major congeners that are found in environmental and human samples (BDE-47, BDE-99, BDE-100, BDE-153) (Hites, 2004). The main sources of PBDE into the environment include emissions from manufacturing facilities and releases from the degradation, recycling, and disposal of consumer products treated with PBDEs. It has been estimated that up to 43 tonnes of PentaBDE per year are released to the environment in Europe by volatilization from polyurethane foam used in a variety of consumer products (Prevedouros *et al.*, 2004).

Early indications that PBDEs were capable of being transported to Arctic locations came from biota monitoring studies in Svalbard conducted during the 1980s (Jansson *et al.*, 1987). Analysis of air samples collected from various Arctic locations confirmed that a number of PBDEs were being transported to higher latitude locations. Subsequent trend analysis of archived samples of sea birds, beluga, and ringed seal collected from Canadian Arctic locations indicated positive increases from the early 1980s to the present (de Wit *et al.*, 2006). For example, analysis of ringed seal blubber samples collected from Holman Island illustrated exponential increases in PBDEs 1981–2000, which were consistent with global production figures for the penta commercial PBDE mixture (Ikonomou *et al.*, 2002). A similar positive time trend has been seen with blubber samples collected from St. Lawrence estuary beluga whales but at PBDE concentrations almost 100-fold higher (Lebeuf *et al.*, 2004). In contrast, temporal trend analysis of ringed seal blubber samples collected from Eastern Greenland (1986–2004) did not reveal any significant increase in total PBDE levels (Riget *et al.*, 2006).

Research in some Arctic communities has shown that people are exposed to PBDEs (see Chapter 4 for details). Canadian market basket surveys have shown average dietary exposure to PBDEs is approximately 30–40 ng/person/day, or almost five-fold lower than exposure

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to PCBs. In addition, human milk samples collected in Nunavik have shown increases in PBDE levels of approximately 3-fold from 1990 to 2002 (mean PBDE concentration of 6 ng/g lipid in 2001). In comparison, human residue levels of PBDEs in southern Canadian populations tend to be higher (mean human milk concentration of 64 ng/g lipid), probably from a combination of dietary exposure, indoor air/dust, and direct exposure from consumer products (Ryan *et al.*, 2002). Based on a combination of measured and estimated PBDE concentrations in air, soil dust, and foods, it has been suggested that inadvertent ingestion of indoor house dust represents the major contributor to daily exposure for southern Canadian urban dwellers (Jones-Otazo *et al.*, 2005). Confirming these results is a recent U.S. study that suggests up to 82% of daily exposure to PBDEs comes from indoor house dust (Lorber, 2008).

From the perspective of potential health risks posed by PBDEs, there are limited to no definitive human data to suggest that either current dietary exposures or human residues are associated with a health risk. Based on the paucity of human data, a number of experimental toxicology studies have been conducted with both PBDE commercial mixtures and major PBDE congeners usually detected in food and humans. The main effects seen to date include endocrine disruption (thyroid hormone perturbation), neurobehavioural effects (spontaneous behaviour, learning, and memory processing), liver toxicity, and possible reproductive effects (fertility). While continued uncertainty exists between the relevance of certain end points to humans, a recent summary suggests that at least for the experimental effects involving thyroid hormones, there appears be a fairly large margin of safety when based on internal dose metrics (Darnerud *et al.*, 2007). However, if human tissue levels continue to increase at the current rate, they could conceivably reach similar levels associated with adverse effects in experimental animals.

5.2.2 Perfluorinated chemicals

Perfluoroalkyl acids (PFAAs) are a family of fluorinated chemicals that consist of a backbone, typically four to fourteen carbons in length, and a charged functional moiety (primarily carboxylate, sulfonate or phosphonate). The two most widely known PFAAs contain an eight-carbon backbone and include PFOS and PFOA.

Due to their chemical resistance and surfactant properties, perfluorinated chemicals have been used in a wide variety of industrial and consumer applications including adhesives, cosmetics, cleaning products, firefighting foams, and water, stain, and oil repellent coatings for fabrics and paper (e.g., Teflon and Scotchgard) for the

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last 50 years. However, North American production of PFOS was phased out in 2002 with global production dropping to 175 metric tons by 2003. In contrast, the global production of PFOA escalated to 1,200 metric tons per year by 2004 from an estimated 500 metric tons in 2000 and is now considered as one of the more predominant PFAAs in commerce (Lau *et al.*, 2007).

The widespread use of these compounds has resulted in their detection in environmental media all over the world. Consequently, there are various potential sources of human exposure to perfluorocarbons (PFCs), such as water, food, dust, and treated fabrics. Dietary surveys conducted with market basket food samples collected in southern Canada suggest average dietary exposures to perfluorinated acids are in the range of approximately 250 ng/day, with only low ng/g levels being detected in a limited number of food items (Tittlemier *et al.*, 2007).

PFOS, PFOA, and a variety of additional perfluorinated chemicals have also been found in wide range of Canadian Arctic biota. As with commercial foods,

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the predominant PFAA tends to be PFOS; in biota, the liver contains the highest concentrations (Martin *et al.*, 2004). PFOS was also the perfluorinated chemical occurring in the highest concentration in ringed seal liver samples collected in Greenland, with an apparent positive trend (estimated annual increase of 8.2% from 1986 to 2003) (Bossi *et al.*, 2005). While analysis of ringed seal liver samples collected from Resolute Bay and Arviat also confirm a temporal increase in PFOS up to 2000, recent analysis suggests that for both locations, concentrations have begun to decrease with disappearance half-lives ranging from 3.2 to 4.6 years (Butt *et al.*, 2007). This is hypothesized to be due to the phase-out of production and use implemented for PFOS.

PFCs, PFOS, and PFOA have been detected in serum and plasma samples from populations in North America, South America, Europe, Asia, and Australia, providing evidence that humans are exposed to PFCs throughout the world. Olsen *et al.* (2007) have reported concentrations of PFOS and PFOA in American Red Cross blood donors from Minneapolis-St. Paul, Minnesota. Among the 100 serum samples analyzed for PFOS, the geometric mean was 33 ng/mL (95% CI 30–37) in 2000 compared with 15 ng/mL (95% CI 13–17) in 2005 for the 40 donor plasma samples. The geometric mean concentration for PFOA was 4.5 ng/mL (95% CI 4.1–5.0) in 2000 compared with 2.2 ng/mL (95% CI 1.9–2.6) in 2005. In most cases, workers occupationally exposed have serum levels of both PFOA and PFOS approximately one order of magnitude higher than those reported in the general population. Other PFAAs detected in human tissue at lower concentrations include perfluorooctane sulfonamide, 2-(N-methyl-perfluorooctane sulfonamido) acetic acid, 2-(N-ethyl-perfluorooctane sulfonamido) acetic acid, perfluoroheptanoic acid, perfluorononanoate, perfluorodecanoic acid, perfluoroundecanoic acid, perfluorododecanoic acid, perfluoropentanoic acid and perfluorohexanoic acid. While only limited blood samples have been analyzed from the Canadian Arctic, PFOS levels range from 13-21 ng/mL (geometric mean).

The majority of experimental studies to date have focused on the two main PFCs detected in humans, PFOS and PFOA. Research has indicated that they are both well absorbed orally, but poorly eliminated and not extensively metabolized. Both compounds are distributed mainly to the serum, kidney, and liver, with liver concentrations being several times higher than serum concentrations. Major effects that have been observed in experimental animals include histopathological changes in the liver and thyroid, thyroid hormone alterations, and changes in serum chemistry parameters, which can occur at dietary intakes as low as 30 microg/kg bw/day (Covance Laboratories, Inc., 2002a, b). There is some evidence to suggest that chronic exposure to PFOS may be associated with an increased liver cancer risk. However, statistically significant increases in tumour incidence were observed only at doses greater than doses associated with the development of non-neoplastic effects. In an unpublished study conducted by Health Canada, rats exposed to concentrations of PFOS ranging from 2 to 100 mg/kg in the diet for 28 days did not exhibit symptoms of immunosuppression. Toxic effects similar to those reported for PFOS have been observed in experimental animals following exposure to PFOA, but usually require higher doses. For example, exposure of male rats to 0.6 mg/kg bw/day of PFOA has been associated with liver effects (Butenhoff *et al.*, 2004).

In general, the available epidemiological information has not found a consistent association between serum perfluorochemical levels and adverse health effects in humans. Although thyroid hormone imbalance has been reported in laboratory animal studies, corresponding findings have not been consistently reported in humans. A significantly elevated risk of bladder cancer has been observed for one group of workers exposed to PFOS; however, the available epidemiological studies of workers occupationally exposed to PFOS are considered inadequate to assess the potential of this substance to induce cancer in humans. In a recent study, Apelberg *et al.* (2007) examined the relationship between cord serum concentrations of PFOS and PFOA in a population of newborns in the U.S., and gestational age, birth weight, and measures of birth size, including head circumference, length, and ponderal index (a measure of body mass at birth). Although the results showed negative associations between PFOS and PFOA concentrations and birth weight, ponderal index, and head circumference, after adjusting for potential confounders, it is possible that other unmeasured factors in this study—such as diet—may be influencing the observed relationships.

Although based on limited surveillance data, it appears that the levels of some PFCs, in particular PFOS, detected in the blood of Arctic inhabitants do not substantially differ from those found in people from industrialized countries. This would serve to illustrate the global nature of these emerging contaminants.

5.3 Contaminant Mixtures Studies

Humans are generally exposed to variable mixtures of chemicals found in food that can differ in composition based not only on geographic location but also by food commodity. A number of factors have to be considered when attempting to estimate the potential risk posed by complex chemical mixtures, including the actual chemicals present in the mixture and whether toxicological interactions might be expected between the mixture components (Teuschler, 2007). There is widespread recognition that risk assessments based on animal toxicology studies using single chemicals may not adequately characterize the toxicity in humans exposed to a set of chemical pollutants (Yang *et al.*, 1989; Mumtaz *et al.*, 1994; Simmons, 1995; Carpenter *et al.*, 1998; Feron and Groten, 2002; Hertzberg and Teuschler, 2002; De Rosa *et al.*, 2004; Cory-Slechta, 2005).

The Northern Contaminants Program (NCP) has funded a number of experimental toxicology studies to examine the toxicity of complex chemical mixtures. A number of strategies have been used to generate chemical mixtures based on different parameters: maternal blood levels in Inuit populations, estimated intake from contaminated foods, and specific sources of food for northern populations.

As a follow-up to studies where pigs were fed a complex mixture of organochlorine contaminants resembling that found in ringed seal blubber and then assessed for reproductive and immunology capacity (review in Van Oostdam *et al.*, 2005), the development and reproductive function of male rats was assessed after perinatal exposure to the same mixture (Anas *et al.*, 2005) (also see Table 5.3.1). Pregnant female rats were gavaged with either corn oil or variable doses of the organochlorine mixture for five weeks before mating and throughout gestation. Developmental effects were monitored in the male offspring from postnatal day (PND) 2 until PND 90. The highest dose of the mixture (exposure to major OC components, e.g., chlordane, dichlorodiphenyltrichloroethane [DDT], and toxaphene, in the range of 0.1-3 mg/kg bw/day) decreased litter size, number of live offspring, and pup weight. Measures of preputial separation (an androgen-dependent developmental event) indicated that the mixture also delayed the onset of puberty, although no reduction in circulating levels of testosterone was noted. While the medium dose increased testes weights on PND 21, ventral prostate weights were reduced in the medium-dose group on PND 60. At PND 90 the medium dose reduced weights of the epididymis, ventral prostate, and seminal vesicle. In addition, sperm motility, assessed by computer-assisted sperm analysis, was reduced in the low- and medium-dose groups at PND 90 but not PND 60. The highest dose severely altered testicular and epididymal morphology at PND 90. No treatment affected the levels of serum luteinizing hormone (LH), follicle-stimulating hormone (FSH), prolactin, and total thyroxine. The authors concluded that exposure to this OC mixture during gestation and lactation affects the reproductive system of male rats and that this combination of chemicals may be a reproductive health hazard for humans and other species (Anas *et al.*, 2005). It was thought that these effects may be mediated by antiandrogenic compounds present in the mixture although, as noted, no significant effects on circulating testosterone levels were seen from PND 21 to 90 (Anas *et al.*, 2005).

TABLE 5.3.1 Composition of the organochlorine mixture (Bilrha *et al.*, 2004)

Compound	CAS number	% weight
PCB mixture[a]		33
Technical chlordane	57-74-9	21
p,p'-DDE	72-55-9	19
p,p'-DDT	50-29-3	6.8
Technical toxaphene	8001-35-2	6.5
α-HCH	319-84-6	6.2
Aldrin	309-00-2	2.5
Dieldrin	60-57-1	2.1
1,2,4,5-Tetrachlorobenzene	95-94-3	0.86
p,p'-DDD	72-54-8	0.49
β-HCH	319-85-7	0.46
Hexachlorobenzene	118-74-1	0.35
Mirex	2385-85-5	0.23
γ-HCH	58-89-9	0.20
Pentachlorobenzene	608-93-5	0.18

[a] Mixture containing 2,4,4'-trichlorobiphenyl (320 mg), 2,2',4,4'-tetrachlorobiphenyl (256 mg), 3,3',4,4'-tetrachlorobiphenyl (1.4 mg), 3,3',4,4',5-pentachlorobiphenyl (6.7 mg), Aroclor 1254 (12.8 g), and Aroclor 1260 (19.2 g).

Endocrine-disrupting properties of this complex organochlorine mixture were also investigated using reporter gene cell bioassays to evaluate activation of the estrogen receptor, the androgen receptor, and the aryl hydrocarbon receptor (Ayotte, 2008, pers. comm). Estrogenic activity was detected at micromolar concentrations for aldrin, dieldrin, DDT/DDE (dichlorodiphenyldichloroethylene), B-hexachlorocyclohexane and toxaphene when tested individually. Concentration-dependent estrogenic effects were also found for the mixture, most likely related to the presence of several weak xenoestrogens in the mixture. PCBs and DDT compounds produced strong anti-androgenic activities with submicromolar IC50 values while the mixture induced a concentration-dependant inhibition of the androgen-signalling pathway. This is probably due to the p,p'-DDE content of the mixture. Dioxin-like activity was detected for the PCBs, and the mixture produced a concentration-dependant dioxin-like response that paralleled the response produced by PCBs. However, at the highest concentration tested, the mixture produced a lower response than the PCBs alone. These results indicate that this complex organochlorine mixture can perturb a number of hormone-signalling pathways and is particularly potent in blocking that of the androgen receptor.

Additional studies with complex mixtures have been conducted, with the contaminant concentrations based on the body burden in Inuit maternal blood. Initial studies were designed to assess the validity of the mixture and dosing regime to replicate tissue levels in rodent mothers and offspring that are comparable to blood levels in Inuit maternal blood. These compared the relative concentrations of 25 contaminants in pregnant rodents and their offspring after perinatal exposure to the chemical mixture.

Table 5.3.2 lists the concentrations of all components in the chemical mixture based on Inuit maternal blood concentrations. Female Sprague-Dawley rats were bred and assigned to one of three doses of the chemical mixture (0.05, 0.5, 5.0 mg/kg bw/day) and dosed from gestation day 1 until weaning and PND 21. Offspring were dosed only indirectly (*in utero* and via breast milk).

To determine the comparability of the exposure profile in rodents to the exposure in Inuit mothers, tissue samples were collected from rodent mothers after exposure (collected at PND 21) as well as from blood, liver, and brain samples in offspring. Analysis of the contaminant profile (relative concentrations) of the organochlorine chemicals in the mixture are shown in Figure 5.3.1

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TABLE 5.3.2 Concentrations of all components in the chemical mixture[a] used to dose rats.

PCB Congener	Mg	Organochlorines	mg
28	0.01	Aldrin	0.01
52	0.02	ß-HCH	0.08
99	0.09	cis -Nonachlor	0.05
101	0.02	p,p'-DDE	0.92
105	0.02	p,p'-DDT	0.06
118	0.07	Dieldrin	0.02
128	0.01	Hexachlorobenzene	0.29
138	0.21	Heptachlor epoxide	0.02
153	0.32	Mirex	0.03
156	0.03	Oxychlordane	0.14
170	0.06	Toxaphene	0.07
180	0.15	trans-Nonachlor	0.22
183	0.02	Methylmercury chloride	2.00
187	0.08		
Sum PCB	**1.09**	**Sum Non-PCB**	**3.90**
Total Dose			**5.00**

[a] Chemical constituents of PCB congeners, methylmercury and OC pesticides in the highest dose group mixture. Values represent actual quantities per 5 mg of the Mixture/1 mL corn oil solution. All of the test chemicals were found to be between 85 and 124% of the nominal concentrations with the exception of aldrin (78%), oxychlordane (67%), toxaphene (65%) and mirex (67%).

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for maternal blood for the high dose of the mixture (5.0 mg/kg bw/day). There is a close match between rodent maternal blood and the relative concentration in the dosing mixture indicating that the chemical profile in rodent maternal blood is comparable to the blood profile in Inuit maternal blood. Analysis of the blood contaminant profile in offspring was similar, as were results for relative contaminant levels for brains of offspring. These results indicate that this chemical mixture produces tissue-contaminant profiles in exposed rodents that closely mimic the exposure profiles in Inuit mothers.

Concentrations of key contaminants in rodent maternal blood are shown in Table 5.3.1. Blood concentrations of key contaminants are comparable to human maternal blood levels at the lowest dose used (0.05 mg/kg bw/day) but are 50–100 times higher at the highest dose used. Rodent maternal blood mercury concentrations are the exception. The highest dose of the mixture produced very high maternal blood mercury levels (approximately 46 ppm), which is well above recorded blood mercury levels in humans. Similarly, the lowest dose mixture also produced relatively high maternal blood mercury levels (approximately 0.51 ppm). In offspring, however, the lowest mixture dose produced blood mercury levels at weaning (when dosing ceased) that were close to reported human umbilical cord levels (about 18 ppb, see Muckle *et al.*, 2001). The highest dose produced offspring blood mercury levels about 100 times higher than the lowest dose (about 200–240 ppb), consistent with the fact that the highest mixture dose is 100 times higher than the lowest mixture dose. Also, offspring blood mercury levels drop by about 90% between PND 4 and 21 (when weaning occurred and dosing ceased). While the maternal blood levels are considerably higher than human maternal blood mercury levels at all doses of the mixture, offspring blood mercury levels are close to human offspring blood levels.

TABLE 5.3.3 Rodent maternal blood concentrations of key chemicals in the mixture. Numbers in italics after maternal mercury levels indicate offspring blood mercury levels at postnatal day (PND) 21. Units are microg/L.

Dose	PCB 118	PCB 138	PCB153	PCB180	HCB	p,p'-DDE	Total Hg *(offspring)*
Vehicle	0.06	0.35	0.36	0.15	0.10	0.58	31 *(9.4)*
0.05 Mix	0.83	0.78	1.1	0.40	0.37	1.4	511 *(13)*
0.5 Mix	1.1	2.9	5.1	2.2	2.1	6.3	5820 *(37)*
5.0 Mix	4.6	28	50	22	30	80	46,370 *(249)*

It is interesting to note that in humans, maternal mercury blood levels tend to be lower than umbilical cord levels while in rodents, the maternal blood levels are higher than offspring blood levels at all ages assessed, as has been reported by others (Beyrouty and Chan, 2006). Overall, there is good concordance between relative concentrations of the organochlorine compounds in the mixture and the relative concentrations found in human maternal blood. While there is poorer concordance for mercury in maternal blood, this is less problematic for offspring blood mercury levels, particularly since effects on offspring were the primary concern for this work.

Toxicological effects

Exposure to the chemical mixture had no effect on reproduction in exposed mothers. There were no effects on litter size, gestational weight gain, or number of live offspring. To provide a complete characterization of mixture effects, neurochemical, genomic, thyroid, and systemic effects were also evaluated. Exposure to the highest dose of the mixture decreased weight gain in mothers during lactation and produced decreases in offspring weight gain that persisted into adulthood. In addition, the highest dose of the mixture increased mortality rates (about 17%) in young animals up to weaning, but not after weaning. While weight gain data are consistent with results reported for similar doses of methylmercury, mortality rates in mixture-exposed offspring were considerably lower than mortality rates reported by others using lower doses of only methylmercury (Beyrouty and Chan, 2006).

The highest dose of the mixture decreased pre-weaning neuromuscular development (grip strength) and produced hyperactivity in offspring at PND 16. Alteration in motor activity patterns appeared to be transient as mixture-treated animals recovered by PND 48. Results also indicated that the highest mixture dose affected learning and memory in adults as measured in the Morris water maze. Assessment in the holeboard apparatus revealed that all mixture doses altered motor performance or decreased reactivity to a novel environment. Because existing literature suggests that PCBs can alter brain dopamine function (Morse *et al.*, 1996; Seegal, R. F. 1998), researchers also evaluated amphetamine-induced motor activity in animal offspring at adulthood. There was no indication that exposure to the mixture affected amphetamine-induced activity, suggesting that the mixture does not alter sensitivity of the dopaminergic system in adulthood. Interestingly, exposure to the

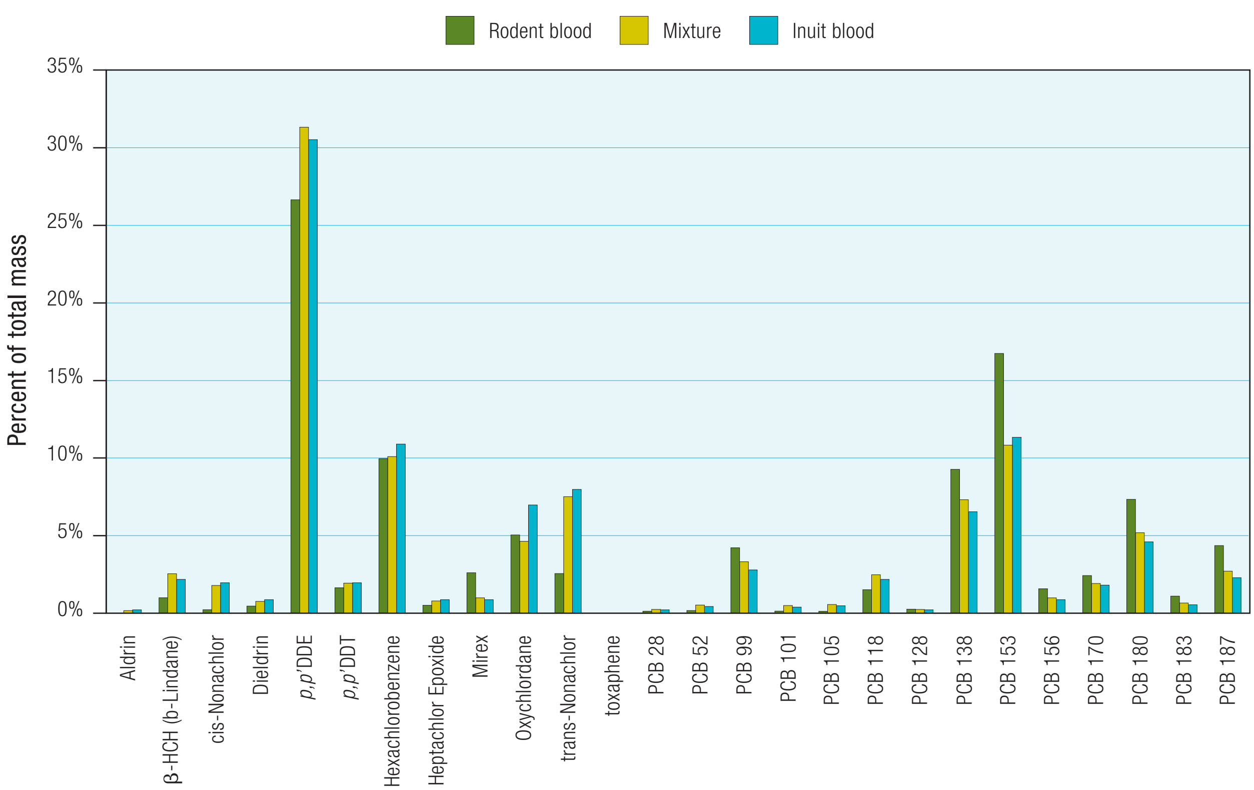

FIG. 5.3.1

Comparison of rodent maternal blood contaminant profile, the contaminant profile in the dosing mixture, and Inuit maternal blood.

highest mixture dose produced dose-dependent changes in the levels of the neurochemicals dopamine and serotonin in brains of PND 35 offspring. This could reflect that altered DA function is transient with recovery in early adulthood.

In addition to neurobehavioural disturbances, mixture-treated animals exhibited a range of systemic effects including modest weight and pathological changes in liver, spleen, thyroid, and thymus (Chu *et al.*, 2007). These results demonstrate that exposure to a mixture of chemicals that mimic exposure in offspring of northern populations produces a range of neurobehavioural impairments and systemic toxicity.

Ongoing work is evaluating the impact of the mixture on retinoid levels in dosed mothers and offspring (Stern *et al.*, 2004). Preliminary results indicate that hepatic vitamin A levels are decreased in dosed dams and in offspring exposed to the highest mixture dose at PND 35, 75, and 350. Dams, as well as offspring at 350 days of age also showed reduced levels of renal vitamin A at the intermediate dose (0.5 mg/kg bw/day). Assessment of bone structure and morphology also indicated that the highest mixture dose decreased femur length in both male and female offspring as measured at PND 35. In addition, bone cortical area and bone mineral content and bone strength were decreased in male and female pups exposed to the high dose of the mixture. In contrast, the lowest mixture dose increased bone (femur) length and bone cortical thickness as measured in PND 35 offspring but did not appear to influence bone strength. These data indicate that the mixture, even at the lowest dose, affects the development of skeletal structures. Whether this persists into adulthood is currently being evaluated.

A second series of mixture studies conducted by Health Canada researchers examined the potential impact of individual components of the chemical mixture described above (PCBs, OC pesticides, mercury). Pregnant Sprague-Dawley rats were exposed to either the full chemical mixture described above (Table 5.3.2) or to the major components of this mixture. The components selected were a) only the PCB component of the mixture, b) the organochlorine pesticide component of the mixture, or c) the methylmercury component of the mixture. It is important to note that the dose of each of these separate components was identical to the dose of the component contained in the full mixture. As in earlier studies, animals were dosed during gestation and lactation, and offspring were dosed only indirectly (see Table 5.3.3). This work provides a direct replication

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of the earlier mixture study and provides data to evaluate the contribution of the selected components of the mixture to the toxic effects of the full mixture.

Analysis of maternal blood, and offspring blood and brain data confirmed residue results from the earlier study with the contaminant profile for the groups exposed to only PCBs and organochlorine pesticides matching the chemical profile in the dosing mixture. Similarly, blood concentrations for animals exposed to the full mixture were comparable to results from the previous mixture study. As in the case of the earlier study, blood contaminants profiles in both rodent mothers and offspring were comparable to the contaminant profile in the dosing mixture.

Results for weight gain in mothers and offspring and mortality rates in animals exposed to the full mixture were also comparable to results from the earlier mixture study. The highest mixture dose decreased maternal weight gain only during lactation. Offspring weight gain data also confirmed results from the previous mixture study with offspring weight gain decreases persisting into adulthood. In addition, the full mixture had no impact on reproduction and no effects on litter size. Mortality rates were comparable to results from the earlier mixture study.

Comparison of the toxicity of the full mixture to components of the mixture indicated that the methylmercury component of the mixture produced the same decrease in maternal weight gain as the full mixture. Similarly, early (up to weaning) offspring mortality rates were comparable between the mixture- and methylmercury-only-dosed offspring. The PCB or OC pesticide components had no impact on maternal or offspring weight gains. While increased mortality in mixture-exposed offspring was detected, these mortality rates were much lower than those reported using a similar dose of methylmercury alone (Beyrouty and Chan, 2006), especially in the post-weaning period. Because the full mixture contains chemicals in addition to methylmercury, one possibility is that mortality caused by methylmercury may be altered when methylmercury dosing occurs in combination with exposure to the other chemicals in the full mixture. This was supported by the results. For instance, while the highest doses of both the full mixture and methylmercury alone produced 15–18% mortality rates in pre-weaning offspring, the full mixture produced no mortality after weaning at PND 21 while methylmercury alone significantly increased mortality after weaning. Indeed, methylmercury continued to increase offspring mortality into adulthood. Interestingly, 75% of these post–weaning mortalities occurred in male offspring.

Like the full mixture, methylmercury alone decreased offspring weight gain into adulthood. As with post-weaning mortality, there were gender differences in the long-term effects of methylmercury alone. While the full mixture caused a decrease in offspring weight gain that persisted into adulthood (PND 75) in both males and females, methylmercury alone produced persistent decreases in weight gain into adulthood in the male offspring only. The impact of methylmercury on female offspring weight gain was no longer evident by adulthood. Exposure to only the PCB or OC pesticide components of the mixture had little effect on maternal or offspring weight gains or mortality rates.

Comparisons of the toxicity of the full mixture against specific components of the mixture indicated that most of the early developmental effects (neuromuscular development and motor activity) of the full mixture could be attributed to the methylmercury in the mixture. The full mixture produced decreases in pre-weaning grip strength and increases in PND 16 motor activity comparable to effects found in the earlier mixture study. These early neurobehavioural changes appear to be mediated primarily by the methylmercury component of the mixture as methylmercury alone produced almost identical changes in grip strength and motor activity. The PCB-only component of the mixture produced small decreases in motor activity and grip strength while the OC pesticide component had no impact.

Measures of learning and memory in offspring were tested at adulthood using the Morris water maze and revealed that the high dose of the full mixture impaired performance. This impact of the mixture appears to reflect the additive effects of the methylmercury and PCB components of the mixture as both methylmercury- and PCB-treated animals also exhibited impaired performance but to a lesser degree. Measures of reactivity (acoustic startle) showed that the highest mixture dose increased the startle response magnitude, which is suggestive of increased reactivity. None of the separate mixture components produced any significant change in startle response.

The cerebellum of PND 14 animals exposed to the full mixture or separate mixture components were examined for changes in expression of genes involved in nerve cell differentiation, migration, myelination, and synaptic transmission. While PCB, methylmercury, and the OC pesticide components all altered expression of a number of genes, the full mixture produced minimal changes in gene expression. In a subset of genes assessed with the polymerase chain reaction technique (PCR), six of the eight genes affected by PCBs, methylmercury, and OC pesticides were not affected in animals exposed to the full mixture (Padhi *et al.*, 2007). The gene expression data suggest that for brain gene expression, combined exposures to the chemicals in this mixture cannot be easily predicted from the effects of the separate components of the mixture. Indeed, the full mixture produced fewer alterations in gene expression than any of the individual mixture components used.

Comparisons of contaminant tissue levels between animals exposed to the full mixture and animals exposed to the separate mixture components were also conducted. Animals exposed to the full mixture and to the same doses of separate components of the mixture revealed that tissue contaminant levels were affected by co-exposure to the chemicals in the mixture. For example, some PCB congener concentrations in blood of offspring exposed to the full mixture were 50–300% higher than PCB concentrations in the offspring exposed to only the PCB component (Figure 5.3.2). While not complete, preliminary data indicate that similar differences were present in the brains of offspring. Although these differences were evident in offspring blood at all ages evaluated, differences were greatest in the youngest animals. Similar to the PCB residue results, blood methylmercury levels also differed between animals exposed to methylmercury only versus animals exposed to the same methylmercury dose as part of the full mixture. In contrast to PCBs, however, blood methylmercury levels *decreased* by about 50% in animals exposed to the full mixture compared with animals exposed to the methylmercury-only component of the mixture.

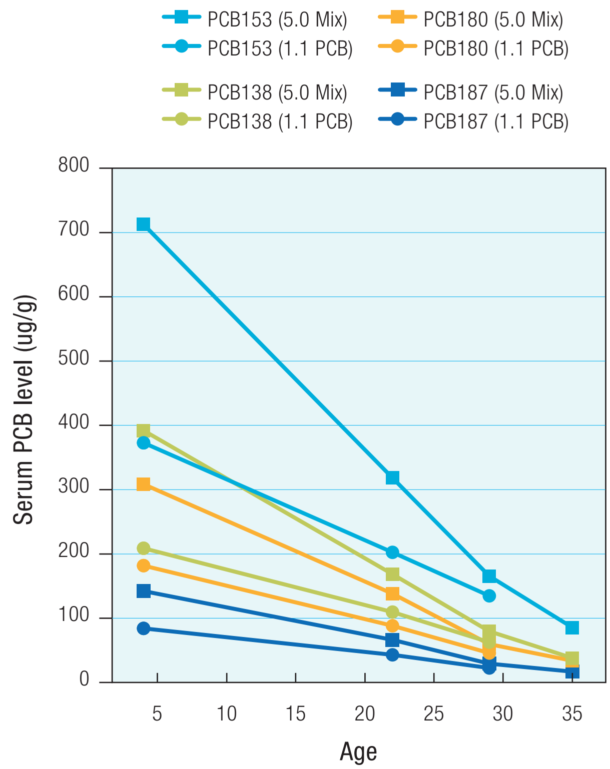


FIGURE 5.3.2

Comparison of blood PCB concentrations for selected PCB congeners in offspring exposed to PCBs only (1.1 PCB) or the same PCB dose as part of the chemical mixture (5.0 Mix).

Because of small samples sizes, however, the results for methylmercury should be interpreted with caution.

Current ongoing work has confirmed the relative differences in effects of methylmercury alone versus the full mixture on early mortality, maternal and offspring weight gain, and pre-weaning motor activity. The reduced mortality rates in mixture-treated animals relative to methylmercury-only treated animals may reflect the fact that methylmercury-only treated animals have higher blood methylmercury levels than mixture-treated animals. Effectively, animals dosed with methylmercury alone are receiving a higher internal dose than mixture-treated animals that received the same dose of methylmercury. Differences in tissue levels may also explain gender differences in toxicity between offspring exposed to the full mixture and to methylmercury alone. It is not yet clear whether differences in toxicity of the mixture compared with methylmercury are attributable solely to differences in tissue levels or whether combined exposure to all chemicals in the mixture also modifies the toxicity of chemical components.

Variations in tissue residue levels as reported here are likely to play a role in the toxicity of chemical mixtures. Data indicate that co-exposure to a mixture of chemicals appears to modify not only tissue contaminant levels but also the toxicity of at least some contaminants. The data suggest that single-chemical studies may generate inaccurate estimates of both tissue levels and toxicity in human studies as co-exposure to chemicals (the normal human exposure scenario) can affect both body burden and dose-toxicity relationships. Further, it is interesting to speculate that some of the apparently discrepant results of epidemiological studies (e.g., Faroe versus Seychelles) may be related to the overall exposure profile that may alter the estimated toxicity of single chemicals such as methylmercury or PCBs.

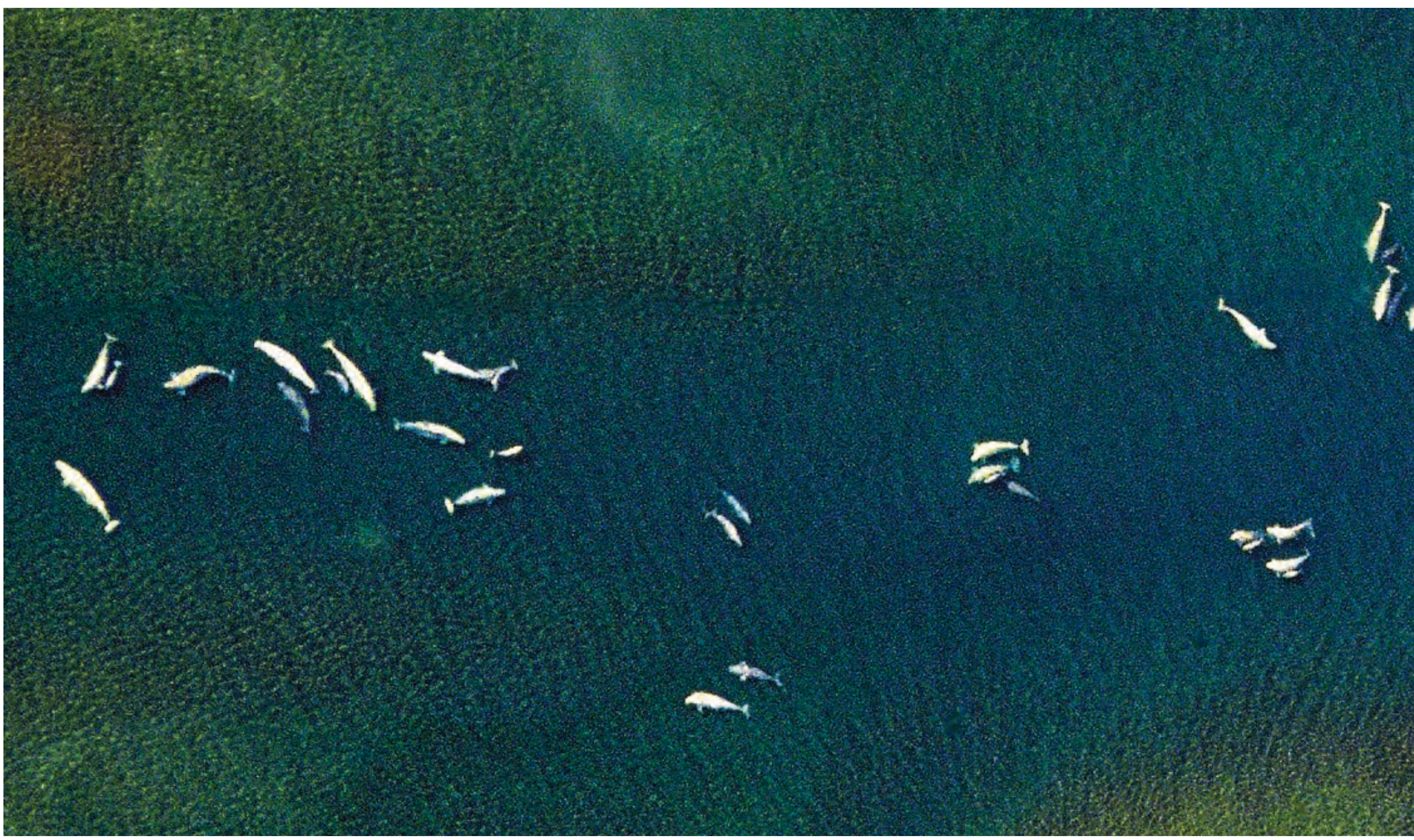
5.4 Nutrient – Contaminant Interactions

5.4.1 Dietary modulation of mercury toxicity: evidence from rat models

Mercury (Hg) is an environmental contaminant of concern, particularly for First Nation Peoples and Inuit whose traditional diet consists of fish and/or marine mammals, which have higher levels of methylmercury.

There is evidence in the literature that certain nutrients in the diet, such as selenium, vitamin E, fibre, and polyunsaturated fatty acids, may alter the toxicity of mercury. The NCP has funded a number of animal feeding experiments to test the hypothesis that co-consumption with these nutrients can modulate the kinetics and toxicity of mercury and the results are described below.

Increased selenium dose increases methylmercury concentrations in the liver, kidney, and frontal lobe of the brain, while increased vitamin E dose increases methylmercury in the kidney but lowers methylmercury in the liver (Beyrouty and Chan, 2006). Increased phytate dose resulted in a significant increase in methylmercury in the frontal lobe. However, none of the diet treatments (selenium, vitamin E, phytate) demonstrated clear protection in neurotoxicity in adult rats. A two-generation study showed that exposure to methylmercury (1.25 mg/kg bw/day) caused adverse effects both on reproduction of the dams and decreased progeny survival. However, the dams showed significant improvement in body weight gain during lactation and average auditory startle response times when the diet was enriched with both selenium (1 ppm) and vitamin E (225 IU/kg)



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(Beyrouty and Chan, 2006). The combination of both vitamin E and selenium also resulted in a statistically significant increase in postnatal survival of the offspring. For example, for the PND 4–21 period, only 50% of offspring born to dams treated with methylmercury alone survived compared with approximately 90% of offspring in the combination treatment group of methylmercury, vitamin E, and selenium. These results suggest that antioxidant nutrients in the diet may alter methylmercury reproductive and developmental toxicity. Dietary fat was also found to be a significant factor. Rats fed a diet in which the fat was supplied as lard (mainly saturated fat and mono-unsaturated fatty acids) had significantly increased relative spleen weights following exposure to 3 mg/kg bw/day methylmercury (14-day dosing) whereas those fed diets with fish oil, soy oil, or seal oil did not (Jin *et al.*, 2007). There is also some evidence that the diet supplemented with seal oil may protect against the toxic effects of methylmercury on the immune system, as illustrated by enhanced production of serum immunoglobulins.

Additional experimental evidence suggests that selenium may also be protective against renal toxicity associated with cadmium exposure. Significant decreases in antioxidant enzyme activity and increases in lipid peroxidation end products were noted in rat kidney tissue following short-term exposure to cadmium chloride (intraperitoneal injection for 10 days to 2 mg/kg bw/day) (El-Sharaky *et al.*, 2007). Pre-treatment of the same animals with sodium selenite (2 mg/kg bw/day) prior to the daily cadmium exposure resulted in restoration of antioxidant enzymes to control activity levels. While these doses would be considered far in excess of normal cadmium and selenium dietary intakes seen with consumers of country foods, the results do suggest that selenium is capable of interfering with one of the principal mechanisms of cadmium-induced toxicity, oxidative stress.

Exposure of rats to oral doses of cadmium (1.8 mg/kg bw/day) for 30 days resulted in significant bioaccumulation of cadmium with the highest levels found in plasma, followed by liver and then kidney (Borges *et al.*, 2008). Various clinical indicators of hepatic damage (aspartate aminotransferase, gamma-glutamyl transferase, alanine aminotransferase) were also increased, along with histopathological alterations, following the cadmium exposure period. When the cadmium dosing was followed by

equivalent exposure to diphenyl diselenide (an organoselenium compound being considered for potential therapeutic applications), a significant decrease in cadmium bioaccumulation was noted (approximately 50–85% in kidney and liver). A reduction in cadmium-induced liver cell damage was also observed in the rats co-treated with both cadmium and selenium. Besides functioning as an antioxidant, it was also suggested that selenium was capable of complexing with cadmium, thereby reducing its toxicity.

Oxidative stress is also one of the mechanisms hypothesized to be associated with methylmercury neurotoxicity. Exposure of pregnant mice to oral doses of methylmercury (0.63–6.3 mg/kg bw/day) through gestation and lactation periods resulted in a dose-dependent inhibition in the usual postnatal development of the glutathione antioxidant system in the brains of offspring (Stringari *et al.*, 2007). Even following the reduction of cerebral mercury concentrations to control levels by PND 21, antioxidant enzyme activities continued to be suppressed while indices of oxidative lipid damage (F2-isoprostanes) were elevated.

While experimental evidence exists that various dietary constituents such as essential trace elements, vitamins, and fatty acids are capable of attenuating the toxicity of food-borne contaminants, confirmation in human studies tends to be equivocal. For example, when methylmercury-induced neurobehavioural dysfunctions observed in the Faroese birth cohorts were assessed against varying concentrations of cord blood selenium, no clear evidence of a protective effect was seen, even when selenium was present at a 10-fold greater molar excess compared with methylmercury (Choi *et al.*, 2007). However, experimental toxicology remains an effective tool in the investigation of nutrient: contaminant interactions of potential benefit and relevance to human health.

5.5 Toxicology and Epidemiology: Comparison of Findings

5.5.1 Introduction

Research projects funded by the NCP include both basic experimental toxicological studies and epidemiological studies conducted in human populations living in the Arctic. On the one hand, toxicologists have tested a variety of compounds singly or in combination in animal models to identify their potential to decrease immune-system function, modify endocrine pathways, and induce adverse reproductive and developmental effects. On the other hand, epidemiologists have examined relations between exposure to more or less the same compounds and end points that are also similar to those studied experimentally in laboratory animals. This section of the toxicology chapter compares results that have been obtained by researchers in both fields of investigations in order to gain a better understanding of the impacts of contaminants exposure in Arctic populations.

5.5.2 Comparison between toxicology and epidemiology on selected health end points

5.5.2.1 Immune system function

The high incidence of infectious diseases—particularly meningitis, broncopulmonary infections, and middle ear infections—in young children from Nunavik has been known for many years (Duval and Thérien, 1982; Dufour, 1988; Proulx, 1988). *Otitis media* and the damage it can cause to hearing is a major problem for Inuit children and adults. In fact, Inuit in Nunavik report hearing loss as their most common chronic health problem (Santé Québec, 1994). In 1984, 78% of Inuit schoolchildren in Kuujjuarapik were found to have had current or previous ear infections and 23% of the children had a significant hearing loss in one or both ears (Julien *et al.*, 1987). The prevalence of hearing loss among 74 students tested in Inukjuak in 1988 was 24% (Proulx, 1988). In 1995–1996, screenings performed on the coast of Ungava found a 28% rate of hearing loss in students (Proulx, pers. comm.). The majority of hearing losses in Inuit children are due to *otitis media* (Ayukawa *et al.*, 2004).

In view of the immunotoxic properties displayed by some OCs, in particular following perinatal exposure, it has been hypothesized that part of the high infection incidence among Inuit infants could be related to the relatively high maternal body burden of these contaminants, and its partial transfer to the newborns during breastfeeding. To test this hypothesis, three different epidemiological studies have been conducted during the last 15 years in Arctic Quebec to investigate the relationship between pre- or postnatal OC exposure, the immune status, and the occurrence of infectious diseases among Inuit infants. In addition, a toxicological study of pigs involving developmental exposure to a complex mixture of contaminants was undertaken to investigate this issue and other end points (see below).

5.5.2.1.1 Epidemiological investigations

In the first study (Dewailly *et al.*, 2000), the researchers compiled the number of infectious disease episodes in 98 breastfed and 73 bottle-fed infants during the first year of life. Concentrations of organochlorines were measured in breast milk and immune-system parameters were determined in venous blood samples collected from infants at 3, 7, and 12 months of age. Cumulative exposure to organochlorines through breastfeeding was estimated by multiplying the breast milk concentration by the breastfeeding duration. The risk of *otitis media* among breastfed infants appeared lower than in bottle-fed infants during the first trimester but not thereafter. During the second and third follow-up periods (4–8 and 8–12 months post partum, respectively), the risk of *otitis media* increased with cumulative exposure to 1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene (*p,p'*-DDE) through breastfeeding (relative risk for 9- to 12-month-old infants in the highest tertile of exposure as compared with infants in the lowest (Odds Ratio 2.4; 95% confidence interval, range 1.1 to 5.3). Furthermore, a negative association was found between the helper T cell (CD4)/cytotoxic T cell (CD8) lymphocyte subset ratio and either cumulative polychlorinated biphenyl exposure (Spearman r = 0.27; p<0.05) or breastfeeding duration during the second follow-up period (Spearman r = 0.29; p<0.05). It was concluded that organochlorine exposure through breastfeeding can modulate the immune-system function and may be a risk factor for acute *otitis media* in Inuit infants (Dewailly *et al.*, 2000).

The hypothesis of a link between prenatal OC exposure and infectious diseases in Inuit infants was subsequently studied in the context of the Infant Development Study in Nunavik. The medical charts of a cohort of 199 Inuit infants during the first 12 months of life were reviewed and evaluated to determine the incidence rates of upper and lower respiratory tract infections (URTI and LRTIs, respectively), *otitis media*, and gastrointestinal infections. Maternal plasma during delivery and infant plasma at 7 months of age were sampled and assayed for PCBs and dichlorodiphenyldichloro-ethylene (DDE). Compared to rates for infants in the first quartile of exposure to PCBs (least exposed), adjusted rate ratios for infants in higher quartiles ranged between 1.1 and 1.3 for URTIs, 1.0 and 1.4 for *otitis media*, 1.5 and 1.9 for gastrointestinal infections, and 1.2 and 1.7 for LRTIs during the first 6 months of follow-up. For all infections combined, the rate ratios ranged from 1.2 to 1.3. The effect size was similar for DDE exposure but was lower for the full 12-month follow-up. Globally, most rate ratios were greater than 1.0, but few were statistically significant (p<0.05). No association was found when postnatal exposure was considered. These results show a possible

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association between prenatal exposure to OCs and acute infections early in life in this Inuit population (Dallaire *et al.*, 2004).

The third study (Dallaire *et al.*, 2006) set out to assess whether environmental prenatal exposure to PCBs is associated with incidence of acute respiratory infections in preschool Inuit children. The medical charts of 343 children from 0 to 5 years of age were reviewed and evaluated for associations between PCB-153 concentration in umbilical cord plasma and the incidence rates of acute *otitis media*, URTIs, and LRTIs. The researchers noted that the incidence rates of acute *otitis media* and LRTIs were positively associated with prenatal exposure to PCBs. Compared with children in the first quartile of exposure (least exposed), children in the fourth quartile (most exposed) had rate ratios of 1.3 ($p<0.001$) and 1.4 ($p<0.001$) for acute *otitis media* and LRTIs, respectively. There was no association between prenatal PCB exposure and incidence rates of URTIs or hospitalization. It was concluded that prenatal exposure to PCBs could be responsible for a significant portion of respiratory infections in children of this population (Dallaire *et al.*, 2006).

5.5.2.1.2 Toxicological studies

Recognizing that environmental contaminants such as organochlorines in traditional diets occur as complex mixtures, with possible interactions between compounds that may result in antagonism, additivity, or synergism, one conclusion of the first Canadian Arctic Contaminants Assessment Report (CACAR, 1997) was that further animal studies should be carried out to explore possible interactive effects of contaminants. As previously stated, in most toxicological studies that investigated possible adverse health effects from exposure to POPs, single compounds or technical/commercial mixtures were administered to laboratory animals (Giesy and Kannan, 1998). Only a few toxicological studies have been conducted on mixtures of food-chain contaminants relevant to the Arctic environment.

Bilrha *et al.* (2004) investigated the immunotoxic potential of a complex mixture of POPs that bear environmental relevance to that present in the Arctic aquatic food chain. They monitored immune parameters in male piglets exposed *in utero* and through lactation to an organochlorine mixture composed of 16 compounds including PCBs and DDT (dichlorodiphenyltrichloroethane) compounds as main constituents. Prepubertal sows were orally administered either corn oil (control group) or the OC mixture in increasing doses (low, medium, and high) from 4 months of age until puberty. The sows were inseminated with the semen from an untreated boar and OC treatment was continued throughout gestation (112–115 days) and lactation (21 days). Blood was collected from the sows at delivery and monthly from piglets until 8 months of age for the determination of plasma OC concentrations and parameters of innate, cellular, and humoral immunity. All piglets were weaned at 21 days to standardize the dosing period and avoid effects of different maternal milk feeding. Treatment with the OC mixture had no

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dose-dependent effect on the proportion of CD4+ and CD8+ T-cell subsets, and did not modulate the functional activity of the complement component C2. The proportion of CD4+CD8+ cells, CD8+DR+ cells, and the mitogenic lymphoproliferative response increased in OC-treated, 4-month-old piglets. At 6 months, the lymphoproliferative response to mitogen and the proportion of CD4+CD8+ cells were still elevated in the OC-treated piglets, but the proportion of CD8+DR+ cells was decreased as compared to the controls. Animals in the high-dose group also exhibited a slight increase in polymorphonuclear leukocyte phagocytic activity at 8 months of age. Furthermore, the high dose decreased the antibody response to *Mycoplasma hyopneumoniae*. These results indicated that developmental exposure to an environmentally relevant OC mixture can alter the immune function in swine.

5.5.2.1.3 Differences and similarities between both approaches

Results from epidemiological studies conducted in three different groups of Inuit children indicated that prenatal exposure to OCs increases the susceptibility to infectious diseases, and in particular to *otitis media* (Dewailly *et al.*, 2000; Dallaire *et al.*, 2004; 2006). Although potential confounding factors were considered in the statistical analyses, residual confounding is still a possibility. Hence, to verify the plausibility of this association, a toxicological study was performed using the pig model and a relevant OC mixture. It was observed that several aspects of immune-system function were altered by developmental exposure to the complex OC mixture (Bilrha *et al.*, 2004). The decrease in the secondary vaccinal response noted in the high-dose group in the study indicates that the OC mixture affected the production of antibodies by B cells and the memory response. This result increases the biological plausibility of associations noted in epidemiological studies between OC exposure during the developmental period and decreased humoral immunity. The efficacy of vaccination programs in Inuit infants should be examined in relation to their OC exposure to further support the hypothesis that OCs decrease humoral immunity.

Plasma concentrations of OCs in piglets were comparable to those observed in human populations exposed to the same compounds in Quebec. Indeed, Muckle *et al.* (2001) reported in Inuit women giving birth in Nunavik, a mean concentration of PCBs (sum of 14 congeners) in plasma lipids of 397 microg/kg, with values ranging from 72 to 1951 microg/kg. In the Bilrha *et al.* (2004) study, mean plasma lipid PCB concentrations in sows at delivery were 153, 1425, and 11485 microg/kg for the low-, medium-, and high-dose groups, respectively. The mean plasma lipid concentration of *p,p'*-DDE in Inuit women was 386 microg/kg (range, 60 to 2260 microg/kg). Mean *p,p'*-DDE concentrations in plasma lipids from sows at delivery were 152, 1538, and 13756 microg/kg. Mean concentrations of these major OCs in sows in the high-dose group are only five to six times higher than maximal concentrations recently reported in Inuit women giving birth in Nunavik. Therefore, body burdens of OCs achieved in the Bilrha *et al.* (2004) study are relevant to the Inuit population of Nunavik.

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5.5.2.2 Bone density and osteoporosis

Osteoporosis is commonly defined as a decrease in bone mineral density (BMD) and the microarchitectural deterioration of bone tissue (Genant *et al.*, 1999). This multifactorial chronic disease may progress silently for decades until characteristic fractures occur late in life.

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Risk factors for osteoporosis in women include advanced age, small body size, cigarette smoking, hormone deficiency, genetics, low physical activity, low intake of calcium and vitamin D, menopausal status, the use of certain drugs (e.g., glucocorticoids) as well as several medical disorders (Lane, 2006; NAMS, 2006). Exposure to environmental chemicals that are able to disrupt the hormonal equilibrium might represent another risk factor for this disease (Holmes *et al.*, 2004). More specifically, in view of the important role of estrogen deficiency in the osteoporotic process (Deroo and Korach, 2006), compounds that can interact with estrogen receptors or alter estrogen metabolism could be involved in the pathogenesis. Certain OCs can modulate the estrogen-signalling pathway, namely PCBs (DeCastro *et al.*, 2006), β-hexachlorocyclohexane (Steinmetz *et al.*, 1996) and 2,3,7,8-tetrachlorodibenzo-p-dioxin and structurally-related compounds (Krishnan and Safe, 1993; Kharat and Saatcioglu, 1996; Abdelrahim *et al.*, 2006). Results from two studies suggest a possible relation between osteoporosis and exposure to OCs (Beard *et al.*, 2000; Alveblom *et al.*, 2003).

In view of the unusually high exposure to OCs in Greenland, a study was initiated to examine the associations between OC plasma concentrations and ultrasound bone measurements among peri- and postmenopausal Greenlandic Inuit women.

5.5.2.2.1 Epidemiological investigations

The associations between plasma concentrations of OCs and ultrasound bone measurements were examined among peri- and postmenopausal Greenlandic Inuit women (Côté *et al.*, 2006). Measurements of quantitative ultrasound (QUS) parameters at the right calcaneum were taken for 153 peri- and postmenopausal Inuit women (49–64 years old) from Nuuk, Greenland, and the relation between these parameters and plasma organochlorine concentrations was investigated. High-resolution gas chromatography with electron capture detection was used to analyze plasma samples for 14 PCB congeners and 11 chlorinated pesticides and metabolites. Morning urine samples were analyzed for cadmium (a potential confounder) by atomic absorption spectrometry. A validated questionnaire was used to document dietary and lifestyle habits as well as reproductive and medical histories.

Concentrations of PCB 153, a surrogate of exposure to most organochlorines present in plasma samples, were inversely correlated to QUS parameters in univariate analyses ($p<0.001$). However, PCB 153 concentrations were not associated with QUS values in multivariate analyses that comprised potential confounding factors such as age, body weight, former oral contraceptive use, and current hormone replacement therapy (HRT) use; all are significant predictors of bone stiffness (total

R-square = 0.39; $p<0.001$). Overall there was little evidence that organochlorine exposure is related to osteoporosis in Greenlandic Inuit women. However, additional exploratory analyses revealed statistically significant associations ($p<0.05$) between QUS bone measurements and PCB 156 concentrations, a congener with dioxin-like properties. This would suggest that dioxin-like compounds may decrease bone density and increase the risk of osteoporosis in Greenlandic women.

5.5.2.2.2 Toxicological studies

Finnish researchers have reported that long-term exposure to 2,3,7,8-tetrachloro-*p*-dioxin interferes in a dose-dependent fashion with bone growth, modelling (where bone is being continuously reabsorbed and replaced by new bone), and mechanical strength in two rat strains with different aryl hydrocarbon receptor structures (Jämsä *et al.*, 2001). Decreased tibial growth was associated with altered bone geometry, as indicated by decreased cross-sectional and medullary areas at the diaphysis. Cortical BMD was not affected, but the three-point bending test indicated decreased bending breaking force and stiffness of the tibial diaphysis. These changes were observed at exposure levels that were not much higher than current average human dioxin exposures. Interestingly, a dioxin-resistant rat strain with mutated aryl hydrocarbon receptor (AhR) was more resistant to these effects than the rat strain with normal AhR structure and high dioxin sensitivity. This further supports the theory that an AhR-mediated mechanism contributes to these bone alterations. Animal studies have also shown that dioxin-like PCBs may impair normal bone metabolism and result in increased bone fragility (Lind *et al.*, 1999, 2000). PCB 126, a non-ortho coplanar PCB congener, impaired the mineralization process of tibiae in rats (Lind *et al.*, 1999) and also reduced the collagen content and serum osteocalcin concentrations, resulting in impaired maximum torque and stiffness of the rat humerus (Lind *et al.*, 2000).

5.5.2.2.3 Similarities and differences between both approaches

In an epidemiological investigation, exploratory analyses indicated that PCB 156, a congener with limited dioxin-like activity, might decrease QUS parameters in Greenlandic Inuit women (Côté *et al.*, 2006). Relations were stronger for the stiffness index, which reflects the rigidity of the bone structure. Toxicological evaluations have indicated that bone stiffness of the rat humerus is impaired following exposure to dioxin-like contaminants. Although biologically plausible, the association noted between PCBs and QUS parameters in Inuit women may be due to chance and needs to be replicated in another study in which all dioxin-like OCs are measured and considered in statistical analyses. The relation between OC exposure and QUS measurements is currently being examined in Inuit women from Nunavik. The concentration of all dioxin-like compounds in plasma of participants will be measured by the dioxin-receptor chemical-activated luciferase expression assay. Women will be followed prospectively in order to accurately define the onset and the rate of bone loss.

5.6 Concluding Remarks

Emerging contaminants of increasing concern in Arctic Canada include contaminants such as PBDEs and PFCs; however, few data currently exist on the toxicological effects of these contaminants on human health, especially in relation to existing contaminants such as PCBs and mercury. While continued uncertainty exists concerning the relevance of certain experimental end points to humans, a recent summary suggests that, at least for the effects involving thyroid hormones and PBDEs, there appears be a fairly large margin of safety between current exposures based on internal dose metrics and effects. It is thought that if human tissue contaminant concentrations continue to increase at the current rate, there is the potential to reach similar concentrations associated with adverse effects in experimental animals.

Experimental data also indicate that co-exposure to a mixture of chemicals appears to modify not only some tissue contaminant levels, but also the toxicity of at least some contaminants such as methylmercury and PCBs. Single chemical toxicity studies may generate less applicable estimates of both tissue levels and toxicity for risk assessment, as co-exposure to food-borne chemical contaminants has been shown to affect both body burden and dose-toxicity relationships. Nutrients may also alter the toxicity of contaminants; however, the effects of nutrient-contaminant interactions in humans remain unclear.

While in theory epidemiological studies are the most relevant to identify exposures that are detrimental to human health, toxicological studies are needed to support the biological plausibility of associations and to gain knowledge of the mechanisms of action. Ritter and Arbuckle (2007) concluded that research efforts should focus on including biomonitoring in both animal and human studies to facilitate comparisons between animal and human models and to improve exposure assessment in epidemiological studies. If animal and human studies measure similar biomarkers, this will facilitate human health risk assessment.


INAC

Epidemiology of Human Health Effects Related to the Presence of Contaminants in the Canadian Arctic

6.1 Introduction

Over the past decades most research efforts in Arctic Canada focused on the characterization of the exposure of northerners. In the early 1990s, epidemiological studies started to evaluate possible health impacts of contaminant exposure on the health of northerners.

The second Canadian Arctic Contaminants Assessment Report (CACAR, 2003) made specific recommendations for epidemiological work:

- To continue the Nunavik child development cohort study on the long-term effects of PCBs, mercury, and other contaminants;
- To complete epidemiological studies on immunotoxic effects and test new biomarkers of the immune system;
- To implement long-term circumpolar studies to assess the role of contaminant exposure on the emergence of chronic diseases such as cancer and cardiovascular diseases; and
- To restrict epidemiological studies to conditions and diseases that have high incidence rates, have gradients of severity (from normality to overt abnormalities), and are easy to diagnose.

Similar to the last CACAR report (CACAR, 2003), this chapter focuses on metals and persistent organic pollutants (POPs). Most health risk uncertainty related to the presence of contaminants in the Arctic food chain is due to methylmercury and POPs. Much of this chapter is devoted to prenatal exposure to these substances and their adverse effects on early development (i.e., altered immune and nervous system function). However, cardiovascular outcomes related to mercury exposure are now under investigation in children and adults. Blood pressure and cardiac variability are possibly associated with mercury exposure. Considering endocrinology, some new data now suggest that exposure to POPs might have effects on the hormonal system. For example, steroid hormone disruption might be associated with osteoporosis and male fertility abnormalities. Preliminary experimental data on emergent POPs toxicity suggest that thyroid hormone modulation may also be a result. No epidemiological study was conducted on health effects related to new emerging POPs such as brominated and fluorinated compounds.

Since Inuit constitute the group that is most exposed in the Canadian Arctic, this assessment is also oriented to this subset of Arctic Canadians. Reference to other relevant epidemiological work conducted in the Arctic is restricted to Greenland, the Faroe Islands, and Alaska.

Conducting epidemiological studies in the Arctic is difficult and should take into account some specific considerations. Multi-chemical interactions of ecologically relevant mixtures (at relevant concentrations) can have an effect different from the sum of the effects of each component of the mixture. The exact extent of how important these differences are is not known. The polychlorinated biphenyl (PCB) congener profile found in human tissues in the Arctic is similar to that found in southern Canada. Some new emerging contaminants such as perfluorooctane sulphate (PFOS) or polybrominated diphenyl ethers (PBDEs) (a group of flame retardants) are now found in Arctic biota and humans (see Chapter 4) due to both increasing concentrations and improved analytical capabilities. The contaminants have different pathways of exposure and different half-lives. Some are highly correlated with legacy POPs such as PCBs, while others are not. Body burdens for some new POPs are sometimes higher but for others sometimes lower in Inuit compared with Caucasians (see Chapter 4). Using new complex matrices of exposure raises methodological challenges for ongoing and future epidemiological studies. Effects of mixtures need to be better understood to properly evaluate individual and population risks. Chapter 5 of this report discusses the effects of mixtures of POPs and mercury on laboratory species and the similarities between the concentrations found in the tissues of exposed animals and naturally exposed Arctic populations.

The possibility that nutrients present in seafood could modify or counteract the toxicity of contaminants is highly probable and specific to fish-eating populations. These interactions need to be better understood. Epidemiological studies looking at health outcomes associated with mercury or POPs exposure are particularly at high risk of being biased by confounding variables related to local food consumption. Marine food diets are known to be the major source of key nutrients such as polyunsaturated fatty acids (PUFAs), iodine, and selenium.

Another difficulty is associated with the size of the populations living in the Arctic. The number of disease cases is small and case control studies are extremely difficult to conduct. Therefore, only cross-sectional and cohort designs are possible. Health outcomes most amenable to epidemiological research in the Arctic are those with a range of stages from normal to abnormal that can be measured in all individuals and are not based on having the disease. Canada is actively involved in large prospective circumpolar cohort studies in adults and children, which may be one method of avoiding the limitation of sample size.

It is also important to recognize that genetic variability may influence the susceptibility of individuals or populations to the effects of pollutants. Gene-environment interactions could also explain why some populations or individuals are more susceptible than others. Given that Aboriginal peoples have unique genetic backgrounds, the impact of genetic polymorphisms that are involved in xenobiotic metabolism and toxicity in the Arctic should be evaluated.

Finally, many health end points, such as child neurodevelopment or cardiovascular diseases, have multifactorial causes and environmental stressors that can contribute in varying degrees to the etiology of these diseases. Compared to the large roles that lifestyle and genetics play in the etiology of many diseases, contaminants likely play a modest role. However, risk factors associated with contaminants are often highly preventable by local, regional, or international interventions.

6.2 Immune System Function and Infections

In Nunavik, an epidemiological study investigated whether organochlorine exposure was associated with the incidence of infectious diseases and immune dysfunction in Inuit infants (Dewailly *et al.*, 2000). Concentrations of organochlorines were measured in breast-milk samples within a few weeks of childbirth and were used as surrogates for prenatal exposure levels. Acute *otitis media*

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(middle ear infection) was the most frequent infectious disease reported, with 80% of infants experiencing at least one episode during the first year of life. During the second follow-up period, the risk of acute *otitis media* increased with prenatal exposure to *p,p'*-DDE (dichlorodiphenyl dichloroethylene), HCB (hexachlorobenzene), and dieldrin. Furthermore, the relative risk of recurrent acute *otitis media* (more than three episodes) increased with prenatal exposure to these compounds. No clinically relevant differences were noted between breastfed and bottle-fed infants with regard to biomarkers of immune function, and prenatal organochlorine exposure was not associated with these biomarkers. In this study, the potential confounders (i.e., omega-3 fatty acids, vitamin A, and smoking) were not fully controlled. For this reason, further studies were designed and initiated to address these issues (Dewailly *et al.*, 2000).

Inuit children from Nunavik have high rates of acute *otitis media* and lower respiratory tract infections (LRTI). Such rates were higher than for that of other non-native North American populations previously published. Hospital admissions for LRTI were up to 10 times more frequent in Nunavik compared with other Canadian populations (Dallaire *et al.*, 2006b).

Two other studies were conducted on the effects of POPs on immune function and infectious disease incidence. The first was a component of the Child Cohort Study, where infectious diseases are monitored during the first year of life (Dallaire, 2004). Results showed that prenatal exposure to PCBs and DDE was associated with a higher incidence rate of acute infections during the first six months of life. Although the associations were not always statistically significant because of limited statistical power, infants in the highest quartiles of PCBs and DDE exposure systematically had more episodes of infections than their counterparts in the first quartile of exposure. This was mostly observed during the first six months of life, and the association was much weaker when infections during the first 12 months of life were considered. This study supported the hypothesis that the high incidence of infections observed in Inuit children (mostly respiratory infections) is due in part to high prenatal exposure to POPs (Dallaire *et al.*, 2004; 2006a; 2006b).

The second study reviewed all the medical files of 343 preschool children who participated in the Nunavik umbilical-cord blood-monitoring program 1993–1996 (Dallaire, 2006a). Results showed that during the first five years of life, children in the higher quartiles of PCB prenatal exposure had a significantly higher incidence rate of outpatient visits for acute *otitis media* and LRTIs, but not for upper respiratory tract infections (URTIs).

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The association between PCB exposure and acute *otitis media* adopted a clear dose-response pattern. This study confirms the associations previously observed in the same population. Furthermore, it shows that the relation between organochlorines and respiratory infection seems to persist past the first few months of life.

6.2.1 Antibody response following vaccination

A study conducted in the Faroe Islands assessed whether prenatal and postnatal exposure to PCBs affects antibody response to childhood immunizations. Results suggested that perinatal exposure to PCBs may have an adverse impact on immune responses to childhood vaccinations (Heilmann *et al.*, 2006).

6.2.2 Immune biological markers

In the course of a 1990 cohort study conducted in Nunavik, biomarkers of immune system function (lymphocyte subsets, plasma immunoglobulins) were determined in venous blood samples collected from breastfed and bottle-fed infants at 3, 7, and 12 months

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of age. Results showed that at age 3 months, concentrations of white blood cells (lymphocytes, more specifically those of the CD4 subtype) were lower ($p<0.05$) in blood samples from breastfed babies when compared with those in the bottle-fed group. At 7 and 12 months of age, immunoglobulin A (IgA) concentrations were lower ($p<0.05$) in breastfed infants than in bottle-fed infants. This also appeared to be the case for CD4/CD8 lymphocyte ratios, although differences were not statistically significant. None of the immunological parameters was associated with prenatal organochlorine exposure (Dewailly *et al.*, 2000).

Vitamin A deficiency could increase the frequency, severity, and duration of infections. Higher incidence of respiratory disease has been associated with vitamin A deficiency in many cross-sectional clinical and population-based studies. Also, acute *otitis media* was among the first infections to be associated with vitamin A deficiency in humans (West *et al.*, 1989).

Previously vitamin A clinical deficiency has never been documented in Canadian Arctic populations; however, numerous studies have documented inadequate intakes of vitamin A (Receveur and Kuhnlein, 1998). A more recent report suggests that only 24% of the Nunavik population meet the Vitamin A Dietary Reference Intake recommendation of Health Canada (Gouvernement du Canada, 2005; Blanchet *et al.*, 2008). Furthermore, persistent organic pollutants such as organochlorines have been shown to alter vitamin A *homeostasis* in many species, including primates (Novak *et al.*, 2008). Therefore, it is important to gain a better understanding of the relationships between vitamin A, organochlorine levels, and infectious disease incidence in Arctic populations.

In a recent study, plasma concentrations of retinol were measured in cord blood samples to assess the vitamin A status of 135 Inuit newborns from Arctic Quebec and 22 newborns from the general population of southern Quebec. Mean retinol concentrations were 148 ng/mL and 242 ng/mL, respectively. Vitamin A levels in excess of 200 ng/mL have been considered as normal vitamin A status, those between 100 and 200 ng/mL as low, and those lower than 100 ng/mL as deficient. The difficulty of using vitamin A as an effect biomarker of PCB exposure is related to the variability of vitamin A intake among individuals and to the unsystematic supplementation programs in infants (Dallaire *et al.*, 2003).

Vitamin A concentration in umbilical cord blood has been associated with incidence and severity of respiratory infections in preschool Inuit children from Nunavik, following a review of medical charts of 305 children from birth to 5 years of age. Compared to children with a vitamin A concentration greater than 200 ng/mL, adjusted rate ratios for children below 200 ng/mL ranged from 1.1 to 1.6 for acute *otitis media*, 1.1 to 1.3 for LRTIs, and 1.1 to 1.4 for hospitalization for LRTIs. Most rate ratios were statistically significant for acute *otitis media* and LRTIs, but not for hospitalization for LRTIs. It was concluded that neonatal vitamin A deficiency appeared to be a significant risk factor for acute *otitis media* and LRTIs in this population (Cameron *et al.*, 2008).

6.3 Neurodevelopment

There is widespread concern about potentially adverse health effects of environmental chemicals on children. Infants exposed *in utero* and during the early neonatal period are particularly vulnerable because of their rapid growth, cell differentiation, immaturity of metabolic pathways, and development of vital organ systems, including the Central Nervous System (CNS).

6.3.1 Lead (Pb)

Although 100 to 150 microg/L has long been considered the lower bound threshold for lead neurotoxicity in children (Centers for Disease Control and Prevention, 2003), improvements in study design have provided empirical evidence that there may be no safe level of lead exposure (Finkelstein *et al.*, 1998; Wigg, 2001; Chiodo *et al.*, 2004). Results from prospective cohort studies have provided evidence that low-level *in utero* lead exposure can impair infant growth and development. Cord blood lead levels below 100 microg/L have been associated with decreased birth weight (Dietrich *et al.*, 1989), weight gain (Sanin *et al.*, 2001) and decreased body mass index (Odland *et al.*, 1999).

Fewer studies have examined infant and child behaviour in relation to prenatal exposure to lead, other than the work of Tang *et al.* (1999) who reported neurotoxic effects on the developing serotonergic system in infants. Studies with preschool and school-aged children did not report any behavioural effects associated with prenatal exposure (Padich *et al.*, 1985; Wasserman *et al.*, 1998). By contrast, the effects of postnatal lead exposure were documented for various aspects of child behaviour, including activity, attention, anxiety, sleep disturbances, and conduct disorders (Padich *et al.*, 1985; Hansen *et al.*, 1989; Sciarillo *et al.*, 1992; Wasserman *et al.*, 1998; Wasserman *et al.*, 2001; Chiodo *et al.*, 2004; Davis *et al.*, 2004). However, most of these studies did not control for prenatal exposure or for exposure during early infancy.

Recently, results from one cohort study conducted with preschool Inuit children from Nunavik have indicated that blood lead levels at 5 years of age were associated with changes in neuromotor performance (i.e., reaction time, sway oscillations, alternating arm movements, and action tremor) (Despres *et al.*, 2005). Behavioural effects (increased impulsivity and activity during neuropsychological testing) were also observed and rated by child testers (Fraser *et al.*, 2006). These effects were correlated with blood lead levels determined at the time testing took place, but not with cord blood lead concentrations. However, a recent analysis of data from another Nunavik cohort study involving infants followed up at 11 months of age has shown that cord blood lead concentrations were related to direct observational measures of inattention (Plusquellec *et al.*, 2007). This association remained significant even after removing the data of children

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whose cord lead concentration was above 100 microg/L. This result emphasizes that behavioural effects of prenatal low lead exposure are likely to be observed when testing protocols include sensitive measures of behaviour.

6.3.2 Polychlorinated biphenyls (PCBs)

Several prospective longitudinal studies have been conducted since the mid-1980s to study the effects of prenatal exposure to background levels of PCBs and other organochlorine compounds from environmental sources. The first generation of studies included the North Carolina (Rogan *et al.*, 1986) general population cohort, the Michigan (Jacobson and Jacobson, 1993), German (Winneke *et al.*, 1998), and Oswego (Stewart *et al.*, 1999) cohorts of fish consumers, and the Netherlands cohort where POPs exposure was related to consumption of dairy products (Koopman-Esseboom *et al.*, 1994). Comparisons of PCB exposure between these cohorts have been published by Longnecker *et al.* (2003) to situate exposure of cohorts.

Other, more contemporary cohort studies of fish consumers have been conducted in the Faroe Islands (Grandjean *et al.*, 2001a), Nunavik (Muckle *et al.*, 2001a, b), Western Greenland (Bjerregaard and Hansen, 2000), and Hokkaido, Japan (Nakajima *et al.*, 2006).

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In addition, several studies have been conducted with general populations from the United States (i.e., the National Collaborative Perinatal Project [NCPP]) (Daniels *et al.*, 2003), the New York City Children's Environmental Health Study (Wolff *et al.*, 2007) and the Child Health and Development Study conducted in the San Francisco Bay Area (Hertz-Picciotto *et al.*, 2005). Overall, the Hokkaido, Oswego, and North Carolina studies report data for the least PCB-exposed cohorts, whereas the Faroe Islands study reports data for the highest exposed cohort. Cohort exposures in the German, NCPP, Michigan, Nunavik and Netherlands studies were in the mid range.

Fetal and neonatal growth have been evaluated in several of the exposed cohorts mentioned above. In Michigan, higher cord plasma PCB concentrations were associated with lower birth weight, smaller newborn head circumference and shorter gestation (Fein *et al.*, 1984; Jacobson *et al.*, 1990). In the Netherlands, *in utero* PCB exposure was associated with smaller birth weight and growth until 3 months of age (Patandin *et al.*, 1998). In contrast, fetal growth and duration of gestation were not affected by prenatal exposure to PCBs in the two highest PCB-exposed cohort studies conducted in the Faroe Islands and Western Greenland (Grandjean *et al.*, 2001a). However, in the Nunavik cohort (which had PCB exposures similar to those found in the Michigan and Netherlands studies but exposures two to three times lower than those found in the Greenland and the Faroe Islands studies), cord plasma PCB concentrations were associated with reduced physical growth at birth and shorter duration of pregnancy (Muckle *et al.*, 2004).

As expected due to low exposures to PCBs, most of the general population studies conducted in the U.S. did not report an association between prenatal PCB exposure, and fetal and infant growth and duration of gestation (see Gladen *et al.*, 2000, 2003, and Rogan *et al.*, 1986, for the North Carolina studies; Stewart *et al.*, 1999, for the Oswego study; and Wolff *et al.*, 2007, for the New York Children's Environmental Health Study).

Nine prospective PCB cohort studies provided empirical data on neurobehavioural function during infancy and childhood. Three studies out of six, those from North Carolina (Gladen *et al.*, 1988; Gladen and Rogan, 1991), the Netherlands (Koopman-Esseboom *et al.*, 1996), and Germany (Winneke *et al.*, 1998; Walkowiak *et al.*, 2001), suggested effects of prenatal PCB exposure on general development (mental or psychomotor) during infancy. Negative effects of PCBs on fine and gross motor development were not observed in children from three highly exposed fish-eating cohorts (i.e., in Michigan [Jacobson *et al.*, 1990], Nunavik [Despres *et al.*, 2005], and the Faroe Islands [Grandjean *et al.*, 2001b]), but were reported in the Netherlands where exposure was related to consumption of dairy products and meat (Vreugdenhil *et al.*, 2002).

Several components of human memory have been assessed at multiple ages and using different test methods in these PCB cohort studies, which make comparisons of study results difficult. Although it appears that consistent effects were found on visual recognition memory tasks during infancy in the Oswego (Darvill *et al.*, 2000), Nunavik (Jacobson *et al.*, 2008), and Michigan (Jacobson *et al.*, 1985) cohorts, similar effects were not found in the highly exposed German cohort (Winneke *et al.*, 1998). When visual recognition memory was assessed at 4 years of age in the Michigan study, negative effects of prenatal PCB exposure were found, suggesting long-lasting effects on this component of cognition (Jacobson *et al.*, 1992).

A conceptual hypothesis to understand the neurobehavioral effects associated with *in utero* exposure to POPs is that these effects are mediated through the disruption of the thyroid system during brain development. First, in the Netherlands study involving 418 mother-infant pairs, thyroid hormone levels were in the normal range, but higher dioxin and PCB-TEQ levels in human milk were significantly correlated with lower triiodothyronine (T3) and thyroxine (T4) levels and with higher levels of thyroid stimulating hormone (TSH) in the infants' plasma at 2 weeks and 3 months of age. However, differences in thyroid hormone levels detected in this study were not directly associated with neurological dysfunction (Koopman-Esseboom *et al.*, 1994). Sandau *et al.* (2002) examined chlorinated phenolic compounds in umbilical cord plasma of newborns in three populations with different PCB exposures, including the Inuit population of Nunavik. Retinol and thyroid hormone status (T3, T4, TSH, and thyroxin-binding globulin) were determined in most samples. An inverse association was found ($r=-0.47$; $p=0.01$) between log-normalized free thyroxine and log-normalized total phenolic compounds (sum PCP and OH-PCBs). Total chlorinated phenolic compounds were also negatively associated with T3 ($r=-0.48$, $p=0.03$). Finally, in 182 singleton term births in the Faroe Islands, maternal serum, hair, milk and newborn umbilical cord blood were analyzed for contaminants. Levels of essential fatty acids, selenium, and thyroid hormones were determined in cord blood. Thyroid function was normal and not associated with PCB exposure levels in this cohort (Steuerwald *et al.*, 2000).

In conclusion, study results related to human fetal and infant growth and PCB exposure are contradictory in general population studies where the exposure does not come from fish or sea mammal consumption. When data from more highly exposed cohorts with PCB exposure from fish and marine mammal consumption are compared, study results are also inconsistent but the hypothesis that growth effects are associated with *in utero* PCB exposure cannot be ruled out. Recent results from Wolff *et al.* (2007) suggest that individual susceptibility due to the presence or absence of specific genetic polymorphisms in studied populations may explain discrepancies between study results and emphasize that genetic specificity of studied populations should be taking into account in future studies.

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6.3.3 Methylmercury (MeHg)

Growth and developmental effects of prenatal methylmercury exposure have been studied since the 1970s in nine large birth-cohort and retrospective studies. Neurobehavioural effects related to mercury exposure have also been studied in three well-designed, prospective, longitudinal studies of children. Sources of exposure to mercury were from fish and pilot whale consumption in the Faroe Islands (Grandjean *et al.*, 1992), deep-sea and reef fish consumption in the Seychelles (Myers *et al.*, 1995b), and fish consumption in New Zealand (Kjellstrom *et al.*, 1982). Other cohort studies were conducted in Michigan, Madeira, Brazil, French Guyana,

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the Philippines, Greenland, and also in Cree Indians and Inuit from northern Québec. Mercury-contaminated fish were also the main source of exposure in these cohorts.

In the Seychelles study, maternal hair mercury concentration was related to increased birth weight, but this association was only significant for males (Myers *et al.*, 2000a). In the Faroe Islands study, cord blood mercury levels were not associated with birth weight (Grandjean *et al.*, 2001a); however, a doubling of the cord blood mercury concentration was associated with lower infant weight at 18 months and this delay was persistent at 42 months of age (Grandjean *et al.*, 2003). In the Philippines, where methylmercury exposures were two times higher than in the Faroe Islands study, prenatal mercury exposure was not associated with birth weight but was related to smaller head circumference at birth (Ramirez *et al.*, 2000). In Michigan, where maternal hair mercury level was half that reported for the Seychelles cohorts, exposure to mercury was related to increased incidence of preterm delivery (i.e., less than 35 weeks [Xue *et al.*, 2007]). In Greenlanders, a negative association has previously been shown between blood mercury concentrations and birth weight (Foldspang and Hansen, 1990); however, in a reanalysis with a completed dataset, this initial result was rejected. Finally, in Nunavik, birth weight was not associated with cord blood mercury concentrations in the first study conducted 1993–1996 (Lucas *et al.*, 2004) and corroborated in another study conducted with this population (Muckle *et al.*, 2004).

In the Faroe Islands, several associations have been observed between hair mercury or cord blood mercury concentrations and neurobehavioral outcomes. These outcomes include a decreased neurological optimality score in newborns; decreased performance in domains of language, attention, and memory; and decreased auditory and visual brain processing in 7-year-olds (Grandjean *et al.*, 1997; Grandjean *et al.*, 1998; Murata *et al.*, 1999a, b), which persisted at 14 years of age (Murata *et al.*, 2004; Debes *et al.*, 2006). Similar neurobehavioral effects were observed at 6–7 years of age in the New Zealand study (Crump *et al.*, 1998). On the other hand, prenatal mercury exposure in the Seychelles studies was not related to development during infancy and childhood, although a broad range of neurobehavioral end points (i.e., neurocognitive, language, memory, motor, perceptual-motor, and behaviour) were documented from 6 months to 9 years of age (Davidson *et al.*, 1995; Myers *et al.*, 1995a, b; Myers *et al.*, 1997; Davidson *et al.*, 1998; Axtell *et al.*, 2000; Davidson *et al.*, 2000; Myers *et al.*, 2000b). The authors of the Faroe Islands cohort pointed out the possibility that methylmercury neurotoxicity might be potentiated by simultaneous PCB exposure, which was about 3–4 fold higher in their population than in most other cohorts studied (Grandjean *et al.*, 2001b). Furthermore, when study results are scrutinized by neurobehavioural domains of effect, key outcomes identified in at least two cohorts were verbal function (the Seychelles-pilot study [Myers *et al.*, 1995a]; the New Zealand study [Kjellstrom *et al.*, 1982; Crump *et al.*, 1998]; the Faroe Islands study [Grandjean *et al.*, 1997; Debes *et al.*, 2006]), visuo-motor integration (the Faroe Islands study [Grandjean *et al.*, 1997]; the Brazil study [Grandjean *et al.*, 1999]; the French Guyana study [Cordier *et al.*, 2002]), and verbal memory and attention (the Faroe Islands study [Grandjean *et al.*, 1997; Debes *et al.*, 2006]; the Brazil study [Grandjean *et al.*, 1999]). The conflicting results suggest that differences in maternal diet during pregnancy may have an impact on the fetal susceptibility to methylmercury exposure and that potential neurobehavioural effects of methylmercury exposure could be found in the domains of verbal function, visuo-motor integration and attention.

Altered brainstem auditory-evoked potentials have been consistently reported as a detrimental effect of prenatal methylmercury exposure (Murata *et al.*, 2007). This neurophysiological measure of auditory processing was examined in children in Madeira, Spain (Murata *et al.*, 1999b), in the Faroe Islands at 7 and 14 years (Grandjean *et al.*, 1997; Murata *et al.*, 2004) and in Greenland (Weihe *et al.*, 2002). Both the Faroe Island and Madeiran studies found a positive association between methylmercury exposure and latencies of brainstem auditory-evoked potentials. Results from the Greenland cohort somewhat corroborate these findings despite their lack of statistical power due to small sample size. These results are also in accordance with those obtained in Ecuador with school-age children of gold miners exposed to elemental mercury vapours and methylmercury in food (Counter, 2003). Although it appears that the most consistent marker of prenatal methylmercury exposure is delayed auditory processing assessed from brainstem auditory-event potentials, it is still important to clarify uncertainties. As a result, there is a need for other well-conducted prospective studies to elucidate the specific growth and neurobehavioural effects of methylmercury.

6.3.4 Nutrients affecting environmental contaminants neurotoxicity

6.3.4.1 Selenium (Se)

It has been suggested during the last decade that the neurotoxicity of environmental contaminants might be partially or totally attenuated by some nutrients and antioxidants that co-occur with seafood consumption, but this hypothesis has not been adequately tested empirically in humans.

In order to address this hypothesis in the Nunavik preschool cohort, Saint-Amour *et al.* (2006) included child blood mercury and child blood selenium in a multivariate analysis. These interaction variables were not associated with latencies and amplitudes of visual-evoked potentials (VEP). In contrast, high intake of selenium during childhood from maternal seafood consumption had a negative impact on the visual system instead of being beneficial or protective against mercury neurotoxicity. Although such associations with selenium were unexpected, it is known that very high intake of essential elements may have adverse effects for brain development, as was recently demonstrated for vitamin E (Miller *et al.*, 2005). Selenium toxicity is documented in adults (Yang and Xia, 1995; Hansen *et al.*, 2004), but there is a lack of reliable scientific information regarding toxicity thresholds for infants and children. The Food and Nutrition Board of the National Research Council (USA) recommends a "Tolerable Upper Intake Level" of selenium of 150 microg/day for children 4 to 8 years old, which corresponds to an average blood concentration of 2.8 micromol/L (National Academy of Sciences, 2000). The average blood selenium concentration observed in Nunavik was approximately twice that limit (i.e., 5.6 micromol/L). Moreover, close to 20% of the children tested had blood selenium concentrations exceeding the maximum safe level recommended for adults, which ranges from 8 to 10 micromol/L. It is therefore likely that the VEP protocol was sensitive enough in the Nunavik cohort to reveal sub-clinical effects of high selenium intake. Further research is needed to address the issue of the threshold for selenium toxicity in pediatric populations. Furthermore, these results support the possibility that nutritional factors may account for study result differences between the two major mercury studies (i.e., the Seychelles Child Development and Faroe Island studies).

6.3.4.2 Polyunsaturated fatty acids (PUFAs)

A growing body of research data indicates that imbalances or deficiencies of certain PUFAs of the omega-3 and omega-6 series may contribute to shorter duration of pregnancy and a wide range of childhood difficulties including ADHD (attention deficit hyperactivity disorder) or related symptoms, disruptive behaviours, and learning difficulties (Richardson, 2003; Hibbeln *et al.*, 2006; Richardson, 2006). Two PUFAs, arachidonic acid (AA) and docosahexaenoic acid (DHA), play a major structural role in the brain and the visual system, making up 20% of the dry weight of the brain and more than 30% of the retina (Helland *et al.*, 2001; Innis, 2004). Two others PUFAs, dihomogamma-linolenic acid (DGLA) and eicosapentaenoic acid (EPA), play a more

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minor structural role but are crucial for normal brain function (Marszalek and Lodish, 2005). These PUFAs are synthesized from essential fatty acids (EFAs) via processes of desaturation and elongation (Richardson, 2003). EFAs from the omega-6 and omega-3 series are linoleic acid (LA) and alpha-linolenic acid (ALA), respectively. PUFA cannot be synthesized *de novo* by mammals; they (or their precursors, EFAs) must be ingested from dietary sources and transported to the brain (Marszalek *et al.*, 2005). As DHA synthesis from dietary ALA is limited in humans (Gerster, 1998; Pawlosky *et al.*, 2001; Burdge and Calder, 2005), preformed DHA and EPA must be obtained primarily from the diet (Gerster, 1998; Burdge and Calder, 2005; McNamara and Carlson, 2006). In modern diets, vegetable oils, nuts, seeds, and grains are the main sources of LA intake, while leafy green vegetables, seaweed, and some nuts and seeds (such as flax and walnut) are the dietary sources of ALA. Consumption of meat and dairy products provides additional PUFAs (DGLA and AA) from the omega-6 series, while fish and seafood are dietary sources of PUFAs (EPA and DHA) from the omega-3 series (Richardson, 2003; McNamara and Carlson, 2006). Prenatal PUFAs are thus of interest in circumpolar populations as they may act as protective factors against the neurotoxicity of environmental contaminants. Their source, as is that of environmental contaminants, is mainly through fish and seafood consumption.

In the Faroe Islands, despite methylmercury exposure, increased weight and length at birth was related to a higher frequency of seafood meals consumed during pregnancy (Olsen *et al.*, 1993). On the other hand, the plasma n-3/n-6 ratio, as a marker of high dietary intake of local marine mammals, was not related to the weight of Greenlandic newborns (Deutch *et al.*, 2007). In the cord blood monitoring program conducted in Nunavik between 1993 and 1996, n-3 PUFAs were associated with increased duration of gestation and birth weight (Lucas *et al.*, 2004). The significant beneficial effects of omega-3 fatty acid on growth and duration of gestation was corroborated in another cohort of Nunavik newborns but the negative effects of prenatal PCB exposure on human growth and gestation remained significant despite these beneficial effects (Muckle *et al.*, 2004). A recent cohort of Seychelles children has been established to help document whether nutrients (e.g., DHA, iodine, iron) derived from fish can explain the absence of association between *in utero* exposure to methylmercury and neurobehavioural development (Clarkson and Strain, 2003); however, results are not yet available. In Nunavik, higher cord plasma DHA concentration was associated with longer gestation, better visual acuity, and recognition memory at 6 months, as well as better Bayley Scale mental and psychomotor performance at 11 months (Jacobson *et al.*, 2008). By contrast, DHA from breastfeeding was not related to any indicator of these parameters. In preschool-aged children from Nunavik, n-3 PUFA concentrations were related to faster processing of information in the visual system (Saint-Amour *et al.*, 2006). On the other hand, Saint-Amour *et al.* (2006) reported no significant interactions between nutrients and contaminants, which does not provide support for the hypothesis that these nutrients could afford protection against environmental neurotoxicants. These results with selenium and PUFAs highlighted the importance of taking into account nutrients that may co-occur with environmental contaminants when attempting to study the complex associations between pollutants and human growth and development in fish-eating populations.

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6.4 Sex Hormone Disruption

The development and maintenance of reproductive tissues are to a large extent controlled by steroid hormones. Some environmental chemicals mimic, while others antagonize, natural hormone activity when tested in *in vitro* assays or in whole animal models. Studies dating back to the late 1960s identified *o,p'*-DDT (dichlorodiphenyltrichloroethane), a minor constituent of technical DDT, as a weak estrogenic compound capable of causing an increase in rat uterine weight in the classic immature female rat model (Bitman and Cecil, 1970). This compound and others sharing estrogenic properties have been implicated in abnormal sexual development in birds and in feminized responses in male fish.

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Certain male reproductive tract disorders (e.g., cryptorchidism, hypospadias, testicular cancer) have been reported to be increasing in parallel with the introduction of xenoestrogens such as DDT into the environment. Reduced semen quality was also reported in certain regions of the world during the last half of the twentieth century, though there have been inconsistent findings on the influence of contaminants on semen quality in humans (Bonde *et al.*, 2008). Although these alterations are thought to be mediated by the estrogen receptor, they are also consistent with inhibition of androgen receptor-mediated events. Kelce *et al.* (1995) identified the major and persistent DDT metabolite, *p,p'*-DDE, as a potent anti-androgenic agent in male rats. In addition to inhibiting androgen binding to the androgen receptor, this compound, when administered to pregnant dams, also induced characteristic anti-androgenic effects in male pups (i.e., reduced ano-genital distance, presence of thoracic nipples). Treatment with *p,p'*-DDE at weaning delayed the onset of puberty, while treatment of adult rats resulted in reduced weight of the seminal vesicle and ventral prostate.

Another organochlorine that has been shown to alter sexual development in male rats is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD). Decreases in epididymis and caudal epididymis weights, and in daily sperm production and the number of caudal epididymal sperm were observed at day 120 and at most earlier times when a dose as little as 64 ng/kg was administered to dams on day 15 of gestation. A number of compounds structurally related to TCDD, including other 2,3,7,8-chloro-substituted dibenzo-*p*-dioxins, and dibenzofurans, as well as non-*ortho* and mono-*ortho* substituted PCB congeners, bind to the Ah receptor and display similar toxicological properties.

Typical organochlorine mixtures found in highly exposed human populations contain a large variety of organochlorine compounds, including substances with estrogenic, anti-estrogenic, or anti-androgenic capacities. It may therefore be hypothesized that complex real life mixtures, composed of numerous compounds that can interact with different receptors involved in cell differentiation and growth, could affect reproduction and development and be involved in the pathogenesis of hormonally responsive cancers.

6.4.1 Clinical outcomes

6.4.1.1 Sexual maturation of newborn males

Normal development of male genitalia in mammals depends on androgen action. Recently, Longnecker *et al.* (2002) used stored serum samples to examine the relationship between maternal DDE levels during pregnancy and adjusted odds of cryptorchidism (n=219), hypospadias (n=199), and polythelia (extra nipples) (n=167) among male offspring, using a nested case-control design with one control group (n=552). Subjects were selected from a United States birth cohort study 1959–1966, when DDE levels were much higher than they are at present. Compared with boys whose mothers' recovery-adjusted serum DDE level was less than 21 microg/L, boys born to mothers with recovery-adjusted serum DDE levels greater than or equal to 86 microg/L had adjusted odds ratios of 1.3 (95% confidence interval [CI] 0.7, 2.4) for cryptorchidism, 1.2 (95% CI 0.6, 2.4) for hypospadias, and 1.9 (95% CI 0.9, 4.0) for polythelia. For cryptorchidism and polythelia, the results were consistent with a modest-to-moderate association, but in no instance was the estimate very precise. The results were inconclusive. In this cohort, DDE concentrations in umbilical cord serum were much higher than in Nunavik.

Sexual maturation of newborn males is being examined within the ongoing cohort study conducted in Nunavik and ano-genital distance and penis length are being recorded. In adults, no study on hormone-associated diseases (breast cancer, endometriosis, male fertility) has been conducted in the Canadian Arctic.

6.4.1.2 Environmental risk factors for osteoporosis

POPs have recently been associated with an increased risk of osteoporosis in humans. The relationship between DDE and bone mineral density was recently examined in 68 sedentary Australian women who reported adequate dietary intake of calcium. Reduced bone mineral density was correlated significantly with age (r=-0.36, p=0.004), as well as with increases in the log of DDE levels in serum (r=-0.27, p=0.03). The authors also used multiple-regression analysis to examine the influence of other predictor variables on the relationship between log DDE and bone mineral density. The strongest model (p=0.002) included log DDE (p=0.02), age (p=0.002), and years on hormone replacement therapy (HRT) (p=0.10) as predictor variables. This model afforded a prediction of 21% of bone mineral density variation. These results suggest that past community exposures to DDT may be associated with reduced bone mineral density in women. As a potent androgen receptor antagonist, DDE may reduce the inhibitory effect on cytokines and result in the inappropriate turnover of osteoclasts or inadequate production of osteoblasts within bone marrow, thus leading to reduced bone density. These are interesting results, but they must not be over-interpreted, as this was a small study in which two important determinants of osteoporosis— menopausal status and time since menopause—were not included in the analyses.

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A study was conducted in Nuuk, Greenland, in 2000 to evaluate the prevalence of risk factors for osteoporosis fracture and, more particularly, environmental factors and their association with bone mass in menopausal women. The risk of osteoporosis fracture was assessed using an ultrasound bone densitometer. All three ultrasound parameters were lower in this Inuit population compared with the women of southern Québec when adjusted for age (Côté *et al.*, 2006).

The study found that 19% of the Inuit women had a high risk of osteoporosis fracture compared with 7.2% for the women of southern Québec. To identify which risk factors were associated with ultrasound parameters, a multiple linear regression model involving the stepwise removal of non-significant independent variables was used. Concentrations of PCB 153, a surrogate of exposure to most organochlorines present in plasma samples, were inversely correlated to quantitative ultrasound (QUS) parameters in univariate analyses (p<0.001). However, PCB 153 concentrations were not associated with QUS values in multivariate analyses that comprised potential confounding factors such as age, body weight, former oral contraceptive use, and current HRT use, which were all significant predictors of bone stiffness (total R2=0.39; p<0.001). Overall, little evidence was found that organochlorine exposure is related to osteoporosis in Greenlandic Inuit women, but the hypothesis that exposure to dioxin-like compounds might be linked to decreased bone quality and osteoporosis deserves further attention (Côté *et al.*, 2006).

The 2004 Qanuippitaa survey included bone density measurements performed among 207 peri-menopausal women. Regression analyses are ongoing to see if dioxin-like compound exposure (as measured by the Chemically Activated Luciferase Expression [CALUX] assay) is a risk factor for osteoporosis as found among Greenlandic women.

6.4.1.3 Male fertility in Greenland and environmental contaminants

A number of papers have been published since the CACAR-II report (CACAR, 2003) on male fertility parameters. A major study of these parameters included the following European populations: 178 Swedish fishermen, 141 men from Warsaw (Poland), 195 men from Kharkiv (Ukraine), and 193 Greenlanders. In most of the papers from this study, two proxy exposure markers, DDE and PCB-153, were used. The main findings from this international epidemiological study on the impact of POPs on human reproductive function include a database with interview and biological data from 2,269 women and their spouses and 18 published core papers. The study did not provide direct evidence of hormone-like activity of the PCB congener CB-153 and the main DDT metabolite *p,p'*-DDE since serum concentrations of these compounds were not consistently related to either endogenous or exogenous hormone activity in serum. Nevertheless, several links between POPs exposure and biomarkers of male reproductive function were identified. First, an association between high PCB-153 serum levels and low sperm counts was detected within a subgroup of men with short androgen receptor repeat length. Second, a relationship between increased PCB-153 serum concentrations and decreased sperm motility was seen in all four regions studied, and indications of reduced neutral-alpha glucosidase (NAG) activity (a marker of epididymal function in seminal plasma) suggest a post-testicular effect. Third, damage of sperm chromatin integrity was considerably less frequent in Greenlandic Inuit compared with European groups and only in the latter was impairment of sperm chromatin integrity related to POPs. In spite of these effects, the fertility in terms of time taken to conceive was not related to POPs except in Inuit. A likely explanation of the latter was not identified, although POPs may interfere with male reproductive function without any major impact on fertility. However, the data do not provide direct evidence for endocrine disruption, and other mechanisms should also be considered (Bonde *et al.*, 2008).

6.5 Oxidative Stress

Studies of Inuit in Nunavik suggest that consumption of marine products, a major source of n-3 polyunsaturated fatty acids (n-3 PUFA), is beneficial to cardiovascular health. Dewailly *et al.* (2001) concluded that the traditional Inuit diet was likely responsible for the low mortality rate from ischemic heart disease in this population. However, fish and sea mammals consumed by the Inuit are also highly contaminated by methylmercury (Wagemann *et al.*, 1996) and other potentially pro-oxidant contaminants such as PCBs (Dewailly *et al.*,

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1993; Muckle *et al.*, 2001a). Both methylmercury (LeBel *et al.*, 1990; Sarafian and Verity, 1991; Lund *et al.*, 1993; Yee and Choi, 1994) and PCBs (Slim *et al.*, 1999; Slim *et al.*, 2000; Ryu *et al.*, 2003) are documented sources of oxidative stress. For example, PCB-153, the main PCB congener found in Inuit, was reported to induce concentration-dependent formation of reactive oxygen species (ROS) and death of cerebellar granule cells (Mariussen *et al.*, 2002). The mean concentrations of PCB, methylmercury, and selenium in Inuit of Salluit were respectively 16–18-fold, 10–14 fold, and 8–15 fold higher than reported for reference Caucasian populations consuming little amounts of fish (Bélanger *et al.*, 2006). The low risk of cardiovascular disease observed in an Inuit population highly exposed to methylmercury stands in sharp contrast with the increased risk of cardiovascular disease and acute myocardial infarction found to be associated with mercury exposure in Finnish men (Salonen *et al.*, 1995; Virtanen *et al.*, 2005). The potentially deleterious effects of methylmercury on cardiovascular health have been the focus of vigorous debates (Salonen *et al.*, 2000; Guallar *et al.*, 2002; Yoshizawa *et al.*, 2002; Seppanen *et al.*, 2004; Virtanen *et al.*, 2005), and it would be of particular interest to find out which factors may account for the contrasting results obtained in different populations.

The Inuit are heavily exposed to potentially pro-oxidant contaminants such as methylmercury and PCBs through their traditional diet. This diet is also an abundant source of n-3 PUFA, selenium, and antioxidants, which might reduce cardiovascular risk. Although Inuit from Nunavik have low concentrations of plasma oxidized low density lipoprotein (OxLDL) and elevated glutathione-related antioxidant defences, the variance in OxLDL was predicted by PCB and blood glutathione, leaving the issue of contaminant-associated oxidative stress unresolved (Belanger *et al.*, 2006).

In Nunavik, no evidence of alterations in plasmatic concentrations and redox states of α-tocopherol (α-TOH) and coenzyme Q10 (CoQ10) were found to be associated with methylmercury exposure. Oxidative stress was assessed by measuring the plasma concentrations and redox states of α-TOH and CoQ10, two sensitive biomarkers of oxidative stress, in relation to exposure. Ubiquinol-10, ubiquinone-10, and ubiquinone-10/CoQ10 ratio were elevated as compared with Caucasian populations but showed no associations with PCB, methylmercury, or n-3 PUFA. Ubiquinol-10 (β=0.23, p=0.007) and CoQ10 (β=0.27, p=0.009) were predicted by blood selenium, and α-tocopherol by PCB (β=4.1, p=0.0002), n-3 PUFA (β=9.2, p=0.02) and OxLDL (β=3.0, p=0.05). Unexpectedly, the α-tocopheryl quinone/α-tocopherol ratio, in the normal range, was negatively predicted by PCB (β=-0.41, p=0.02). Using sensitive biomarkers of redox alterations, no evidence of oxidative stress associated with methylmercury or PCB exposure was found in these Inuit. However, despite robust blood antioxidant defences, the unusually elevated ratio of ubiquinone-10 to CoQ10 (0.21±0.11) suggests some form of oxidative stress of unknown origin (Belanger *et al.*, 2008).

In addition to intrinsic genetic background, susceptibility to methylmercury toxicity is likely to depend on many environmental factors including diet. The traditional Inuit diet is unusually rich in selenium (Blanchet *et al.*, 2000), CoQ10 (Bliznakov, 1976), and vitamin E (Blanchet *et al.*, 2000), all of which might be beneficial for cardiovascular health. An inverse relationship between serum selenium concentrations and risk of coronary heart disease or myocardial infarction was found in the Finnish men (Salonen *et al.*, 1982), a population featuring relatively low selenium status. Selenium is essential to human health (Rayman, 2000); it is a key component of several antioxidant proteins including selenoprotein P, and glutathione peroxidase (GSHPx) and thioredoxin reductase enzyme families, which harbour a critical seleno-cysteine bond at their active sites. Blood GSHPx activity was found to be elevated in Inuit of Nunavik (Bélanger *et al.*, 2006) in the range that was associated with lower risk of cardiovascular disease in Caucasians (Blankenberg *et al.*, 2003). These Inuit also showed favourable lipid profiles and

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low levels of OxLDL (Bélanger *et al.*, 2006), a factor implicated in the pathophysiology of atherogenesis (Stocker and Keaney, 2004).

That both mercury and selenium can modulate cardiovascular disease risk is also suggested by observations of fish-eating coastal populations such as Inuit living in Arctic regions. Inuit consume large amounts of fish and marine mammals, and consequently receive large doses of mercury. However, contrary to the situation in eastern Finland, the mortality rate from cardiovascular disease in Inuit is low. Although it was reported that omega-3 fatty acids are strong protective factors for cardiovascular diseases among Inuit (Dewailly *et al.*, 2001), the protection could also result from a high intake of selenium (Bélanger *et al.*, 2003) through the consumption of traditional/country food such as muktuk (beluga and narwhal skin) and sea mammal liver, both of which are rich in selenium.

Methylmercury is a highly toxic environmental neurotoxin that can cause irreparable damage to the central nervous system. Although the underlying biochemical and molecular mechanisms that lead to impaired cell function and nerve cell degeneration are not well understood, there is abundant evidence supporting the hypothesis that a major mechanism of methylmercury neurotoxicity involves oxidative stress (Sarafian and Verity, 1991). Mercury increases production of reactive oxygen species via deregulation of mitochondrial electron transport, as well as through glutathione (GSH) depletion (Lund *et al.*, 1993). The oxidative stress hypothesis is clearly supported by the finding that methylmercury neurotoxicity can be inhibited by various antioxidants, including selenium (Park, 1996) and N-acetyl-L-cysteine, a precursor of GSH.

Glutathione peroxidase (GSHPx) and glutathione reductase (GSHRd) activities were measured in blood samples from 142 residents of Salluit, Nunavik (Dewailly, 2001). Activities of enzymes involved in detoxification of free radicals were measured to investigate the relationships between mercury, selenium and oxidative stress. Mercury was found to be negatively correlated with GSHRd activity, an NADPH (nicotinamide adenine dinucleotide phosphate)-dependent enzyme that regenerates glutathione from glutathione disulfide. In contrast, plasma selenium concentration was positively correlated to GSHPx activity, a selenoenzyme that catalyzes the conversion of hydrogen peroxide to water. Mercury exposure may, therefore, diminish defence mechanisms against oxidative stress by limiting the availability of glutathione, while selenium may afford protection by favouring the destruction of hydrogen peroxide.

The biochemical assessment of the oxidative stress in adult residents of Nunavik should continue. The level of plasmatic LDL oxidation has been measured during the Qanuippitaa survey as a potential marker of oxidative stress. Preliminary results indicate that OxLDL was significantly lower (1.6 times, $p<0.0001$) in Inuit subjects than the Caucasian population, supporting the previous observation that omega-3 fatty acids and selenium could be strong protective factors for cardiovascular diseases among Inuit (Bélanger *et al.*, 2003).

6.5.1 Blood pressure

Intake of mercury from consuming sea mammals and fish has a possible involvement in cardiovascular disease, but the relationship between mercury in blood and 24-hour ambulatory blood pressure has never been studied. In Greenland, mercury was measured in blood and 24-hour blood pressure in four groups of healthy subjects: Group 1, Danes living in Denmark consuming European food; Group 2, Greenlanders living in Denmark consuming European food; Group 3, Greenlanders living in Greenland consuming European food; and Group 4, Greenlanders living in Greenland consuming mainly traditional Greenlandic food. Mercury in blood was highest in Greenlanders and increased when they lived in Greenland and consumed traditional

Greenlandic food (Group 1, 2.2 microg/L [median]; Group 2, 4.8 microg/L; Group 3, 11 microg/L; and Group 4, 25 microg/L). The 24-hour blood pressure was the same in all three groups of Greenlanders. However, 24-hour diastolic blood pressure was lower among Greenlanders than Danes (71 versus 76 mmHg, $p < 0.001$) and 24-hour pulse pressure was higher (54 versus 50 mmHg, $p<0.001$). Mercury in blood was significantly and positively correlated to pulse pressure ($r=0.27$, $p<0.01$). Pulse pressure was higher and diastolic blood pressure was lower in Greenlanders than Danes. Pulse pressure increased with higher mercury content in the blood. Although genetic factors must be responsible to some extent for the difference in pulse pressure between Greenlanders and Danes, the present results lend some support to the hypothesis that mercury intake from maritime food is involved in cardiovascular disease (Pedersen *et al.*, 2005).

Blood pressure in childhood is an important determinant of hypertension risk later in life, and methylmercury exposure is a potential environmental risk factor. A birth cohort of 1,000 children from the Faroe Islands was examined for prenatal exposure to methylmercury, and at age 7 years blood pressure, heart rate, and heart rate variability were determined (Sorensen *et al.*, 1999). After adjustment for body weight, diastolic and systolic blood pressure increased by 14 mmHg (95% confidence limits [CL]=7.4, 20) and 15 mmHg (95% CL=8.3, 21), respectively, when cord blood mercury concentrations increased from 1 to 10 microg/L. Above this level, which corresponds to a current exposure limit, no further increase was seen. Birth weight acted as a modifier, with the mercury effect being stronger in children with lower birth weights. These findings suggested that prenatal exposure to methylmercury might affect the development of cardiovascular *homeostasis*.

In Nunavik, the impact of mercury levels on blood pressure was recently studied among Nunavik Inuit adults taking into account potential confounding factors. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured during a clinical visit and pulse pressure (PP) was calculated. Pearson correlation was used to study simple relations between mercury and blood pressure parameters, while multiple regressions were carried out to control for confounders. Mercury was correlated with SBP ($r=0.15$; $p< 0.0001$) and PP ($r=0.17$; $p< 0.0001$) while the correlation with DBP did not reach statistical significance. After adjusting for confounders, the association with SBP ($b=2.4$; $p=0.0004$) and PP ($b=1.2$; $p=0.02$) remained statistically significant while the association with DBP became significant ($b=1.0$; $p=0.04$). The results of this study suggest a negative impact of mercury on blood pressure after controlling for confounding factors (Valera *et al.*, 2008).

Health end points related to contaminant exposure and cardiovascular disease could be of greater relevance for public health than those related to, for example, neurotoxicity at current exposure levels. For example,

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the low incidence of cardiovascular disease in Greenland Inuit is possibly due to the fatty acid composition of their diet could be attenuated by high mercury exposure since recent studies indicate that mercury can have a negative effect on the cardiovascular system. The reason is still unknown, but mercury may inhibit important antioxidative mechanisms in humans and could promote the peroxidation of unsaturated fatty acids such as DHA and EPA. Regarding cardiovascular toxicity at low-level methylmercury exposures, the first Faroe Islands cohort showed that blood pressure tended to increase and the heart rate variability tended to decrease when prenatal mercury exposures increased in the low-dose range (Sorensen *et al.*, 1999). Alkyl-mercury poisoning is associated with increased blood pressure and children with mercury poisoning often have increased heart rate and blood pressure. Experimental evidence shows that methylmercury toxicity results in irreversible hypertension that remains many months after cessation of exposure. Although insufficient for risk assessment purposes, this evidence suggests that the cardiovascular system should be considered a potential target for methylmercury. Even a slight negative impact on the cardiovascular system could be of greater public health relevance than a slight impact on the central nervous system.

6.5.2 Mercury and heart rate variability

Methylmercury is well known for its toxic activity on the central nervous system, but recently it has been suggested that it can also interfere with the normal functioning of the cardiovascular system (Sorensen *et al.*, 1999; Guallar *et al.*, 2002; Oka *et al.*, 2002; Grandjean *et al.*, 2004; Pedersen *et al.*, 2005). Some studies have reported an association between mercury and myocardial infarction (Guallar *et al.*, 2002), elevated blood pressure (Sorensen *et al.*, 1999; Pedersen *et al.*, 2005), and reduced heart rate variability (Sorensen *et al.*, 1999; Oka *et al.*, 2002; Grandjean *et al.*, 2004). This latter effect reflects the cardiac parasympathetic and sympathetic activities of the autonomic nervous system, but information concerning the influence of methylmercury on heart rate variability is sparse. Reduced heart rate variability can cause ventricular fibrillation, which can lead to sudden cardiac death (Galinier *et al.*, 2000; Makikallio *et al.*, 2001; Kruger *et al.*, 2002; La Rovere *et al.*, 2003; Kataoka *et al.*, 2004;). The diminution of heart rate variability has also been associated with cardiac mortality and all-cause mortality (Tsuji *et al.*, 1996; Tsuji *et al.*, 1994; Seccareccia *et al.*, 2001).

The effect of methylmercury on heart rate variability has only been studied in subjects exposed *in utero* (Sorensen *et al.*, 1999; Oka *et al.*, 2002; Grandjean *et al.*, 2004). In a cohort study of 7-year-old children

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from the Faroe Islands, heart rate variability decreased with increasing mercury exposures, particularly when cord blood concentrations increased from 1 to 10 microg/L, at which the variability was reduced by 47% (95% CL=14%, 68%). This was depicted as an indication of parasympathetic nervous dysfunction in children exposed to low doses of methylmercury during the prenatal period (Sorensen *et al.*, 1999). At age 14, this cohort demonstrated a diminution of the coefficient of variation of heart rate of 2.7% as well as a diminution in parasympathetic and sympathetic activity of 6.7% (Grandjean *et al.*, 2004).

On the other hand, Oka *et al.* (2002) conducted a case-control study to assess the chronic effect of exposure to high doses of methylmercury on heart rate variability in subjects suffering from fetal minamata disease (FMD). Some of the heart rate variability indices such as the rate ratio interval and high frequency of variability were lower in FMD patients. The standard deviation of all normal RR intervals tended to be lower in the FMD group, but this difference did not reach statistical significance.

Until recently, the influence of background mercury levels on the heart rate variability of adults who have been environmentally exposed had not been studied. Valera *et al.* (2008) conducted a study to assess the impact of methylmercury levels on heart rate variability in an adult population of Nunavik, taking into account the influence of possible confounding factors such as n-3 fatty acids, age, gender, cholesterol, diabetes, obesity, smoking, and alcohol consumption. Several indices of heart rate variability from the time and the frequency domains were derived from a 2-hour Portable Holter monitoring assessment. Simple linear regression was used to analyze the relation between mercury levels and Holter parameters while multiple regressions were carried out to control for confounders. Methylmercury was weakly associated with low frequency of heart rate variability in simple correlation but these associations became non-significant after adjusting for confounders. The results of this study suggest a deleterious effect of methylmercury on blood pressure and heart rate variability of adults. Systolic and pulse blood pressure increased with blood mercury concentrations while heart rate variability decreased with blood mercury concentration.

6.6 Conclusions

1. Conducting epidemiological studies in the Canadian Arctic is a challenge due to a variety of limiting factors: exposure to complex contaminant mixtures, small population size, contaminant-nutrient interactions, genetic factors, social and lifestyle confounders, and health priorities. For this reason, epidemiological studies conducted in other parts of the world on PCB, lead, and methylmercury-induced neurotoxicity should be used as much as possible for risk assessment. However, different factors may limit their external validity, and studies in the Canadian Arctic need to continue.
2. Ongoing work in child and adult cohorts in Nunavik will provide valuable information for residents of the Canadian Arctic in the near future.
3. Studies conducted in the Arctic suggest that prenatal exposure to methylmercury, lead, and PCBs have distinct effects on child brain development. These effects are in accordance to those found in other part of the world.
4. Thyroid hormone disruption is considered to be a possible mechanism of action of POPs on brain development. This hypothesis will have to be further studied for legacy POPs and extended to their metabolites and to emergent POPs.
5. New data also support the important beneficial effects of traditional food nutrients, particularly omega-3 fatty acids, on brain development. These effects are seen in different domains than those attributable to contaminants exposure.
6. The health benefits of omega-3 fatty acids on child development highlight the importance of testing interactions and emphasize the need for further study of the complex association between nutrients and contaminants in fish-eating populations.
7. In Nunavik, three successive studies reported that lower respiratory tract infections and acute *otitis*

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media during childhood were associated with prenatal exposure to POPs. This is also supported by data from the Faroe Islands reporting immunization deficiency linked to POPs exposure. Vitamin A deficiency, which is also linked to POPs exposure, is another risk factor for these infections.

8. Typical organochlorine mixtures found in the Arctic contain a large variety of POPs, including substances with estrogenic, anti-estrogenic, or anti-androgenic capacities. These organochlorine compounds can interact with different receptors involved in cell differentiation and growth, could affect reproduction and development, and could be involved in the pathogenesis of hormonally responsive cancers. Few studies to date have looked at cancer rates and contaminants in the Arctic due to small populations in this region.

9. Investigations on the role of methylmercury and POPs exposure in the development of the metabolic syndrome, cardiovascular diseases, and diabetes are only beginning. They are still controversial. Methylmercury may suppress defence mechanisms against oxidative stress (and ultimately promote atherosclerosis), decrease cardiac variability, and increase blood pressure. POPs exposure may also be involved as a risk factor for the metabolic syndrome and diabetes. Further experimental and epidemiological work is needed in this area.

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Risk-Benefit Characterization and Communication

7.1 Introduction

The bioaccumulation of environmental contaminants in country food and the lack of affordable, accessible, and culturally acceptable substitutes for country food in Arctic Canada raise complex issues for the public health field. Northern public health professionals and others involved must have access to the best available information in order to provide easily understood and effective messages for the public. However, they face a significant challenge. Many uncertainties associated with the data on the risk and benefits of country food exist. Contaminant mixtures and diets of those under study may also differ. In addition, different approaches to study methodology and types of study disciplines (animal studies, human population studies, food and tissue analyses, etc.) are used to derive data and the results are expressed using different units and forms of measurement. Understanding and balancing the risks and benefits of a regular diet of country food in the subsequent development of effective dietary advice is difficult.

Despite these challenges, significant progress has been made on strengthening the Northern Contaminants Program (NCP) risk characterization and communication process. This chapter describes the state of knowledge of risk characterization and communication. The chapter begins with a summary of the processes that have been developed to assess, manage, and communicate the benefits and risks of consuming country food. Also discussed are risk perception, a case study of risk-benefit characterization, and a software package that has been recently developed to assist with the risk characterization and communication process.

7.2 The Risk Characterization Process

The process for developing health advice requires input and cooperation from all the stakeholders and the leadership of local health authorities. A detailed description of the risk assessment and risk management process under the NCP has been previously reported (CACAR, 1997; CACAR, 2003; Furgal *et al.*, 2003) and is not repeated here.

7.3 Risk Communication

The process of communicating the risks and benefits associated with country food is a central aspect of risk management strategies. Communication that focuses solely on risks is unlikely to have the intended result and instead may be damaging to individuals and communities. In fact, one of the key lessons learned in the Canadian Arctic is that some risk communication can create unnecessary fear, anxiety, and confusion. As Loring (2007a) describes, there are a number of potential negative impacts of poor contaminants communication:

- adverse impact on health and behaviour (physical, mental, and social);
- increased anxiety and stress;
- decreased hunting and fishing activity;
- decreased consumption of country foods;
- socio-economic impact of changes in consumption patterns; and
- increased exposure to new risks.

Country foods are a crucial cultural anchor and play a vital nutritional role in Aboriginal peoples' health and well-being (see Chapter 2 for further details). To further complicate the issue, food substitutes may not be readily available and there is no guarantee that they would be culturally acceptable, or affordable. The issues surrounding human exposure to environmental contaminants from country food in Arctic Canada (i.e., its role in health, culture, society, and the economy) need to be considered in order to construct messages that inform residents but minimize potentially negative impacts on northern lifestyles and social well-being. Risk communication should situate the message within the broader public health context in a way that is culturally appropriate (Furgal *et al.*, 2003; Loring, 2007b).

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Under the NCP, risk communication about contaminants involves considering the quantitative results of risk calculations and the qualitative benefits of country food use and how risk is perceived among the public.

Typically, the focus of communication efforts in the Canadian Arctic has been to answer basic public questions such as "Is my food safe to eat?" An effective answer to this question is formulated by putting the technical information about the risks of contaminants into a message that is understood by the targeted group (Loring, 2007a). Communication strategies should be adaptable and reflect the uniqueness of each target group. As such, effective risk communication messages tend to be those tailored for the specific cultural groups present in the North.

Risk communication is a process that continually evolves (Powell and Leiss, 1997). In view of that, a number of important changes have taken place since within the NCP. The amount of communication material and the number of messages sent to northern communities has, in general, decreased. This is an important step because frequent information about contaminants may overwhelm communities. Communication about the issue may be more efficient if it is built into existing public health messages. Another notable change is that there has been a shift from a concentration strictly on contaminants to a focus on situating the concern about the contaminant within a broader public health context (Furgal *et al.*, 2003).

The NCP, its Regional Contaminants Committees, and partner institutions such as the Inuit Tapiriit Kanatami (ITK), the Inuit Circumpolar Council (ICC), the Dene Nation, the Council of Yukon First Nations (CYFN), and the Nasivvik Centre at Laval University are making significant efforts to enhance capacity among northerners to understand, make decisions, and take action on the contaminants issue. These efforts have focused on equipping health and environment representatives in the Canadian Arctic with the understanding, skills, and access to information, knowledge, and training about contaminants, which enables them to effectively conduct risk management and communication activities. Education and training of frontline workers will continue to build capacity in the North. Specific activities promoted by the NCP to date include courses for Regional Contaminants Coordinators, training courses for frontline workers, community tours, elder–scientist retreats and the production of educational materials for the elementary and high school curriculum. Since 1997, there have been four retreats where elders, scientists, and youth were able to build relationships. In addition, school curriculum materials have been developed and used in elementary and high schools in the Northwest Territories (NWT) and Yukon. These efforts are making significant progress toward involving northerners in risk communication activities in a meaningful way (Furgal *et al.*, 2003).

Risk communication about contaminants and health in the Canadian Arctic must evolve in several important directions. In order for risk communication to mature within the NCP, the program should evaluate prior risk communications about contaminants in collaboration with appropriate public health authorities to assess what factors influenced their success and effectiveness, and to determine the appropriate context for their delivery. Further, a forward-looking strategy should be developed that fosters and expands communication strategies that have been proven to have been successful. This would support communicators and regional health promotion professionals in their efforts to develop culturally appropriate messages and ensure effective delivery in the future. Efforts to enhance capacity may be the best strategy for improving future communication and health promotion efforts with the community rather than simply developing more educational material (Loring, 1997b). The NCP has the important role of fostering relationships and encouraging researchers to build capacity development initiatives into their research. The development of local capacity will be essential in the future, not only to address contaminant challenges, but also to equip communities with resources when facing increasing research activity and continued environmental, social, political, and economic change.

7.4 Ethical Research and the NCP

The NCP has invested considerable effort to ensure that research that takes place under the program respects the highest possible ethical standards. This has included the development of documents to guide research in the North, the establishment of committees to oversee the approval of research projects, and the continued improvement of processes such as obtaining informed consent and communicating research results.

Many aspects must be considered in assessing the ethics of human research. While these can be complex in any research project, there is an added dimension of complexity—and also of necessity—when working in and with northern or Aboriginal communities.

For example, a fundamental aspect of ethical research is informed consent. Any participant in a project, whether providing a blood sample or responding to a questionnaire, must understand what is required of him or her before he or she consents to participate. This participation must also be voluntary, meaning that the participant cannot feel threatened or coerced into participating. When there are cultural or language barriers between researchers and communities, as is often the case for Arctic research, the possibility for miscommunication increases. Extra time, attention and innovative approaches are necessary to ensure that participants have as complete an understanding as possible of the expectations involved in participation.

Another significant ethical issue that must be considered is that of the potential harm and benefit of research, with any possible harm to the individual participants or their communities being minimized to the greatest extent possible. More weight should be placed on the risks to cultural values than on the potential contributions of the research to knowledge. The overall balance of harm and benefit of the research must be positive for the individual, community, and researcher, but the distribution of benefit is also critical. Any benefits that result must be shared rather than accrue only to the researcher. If a researcher obtains data from a community but does not relay the findings back to the community adequately, the benefits of the research are not being appropriately shared.

The NCP uses several strategies (some of which are listed below) in order to ensure that these and other ethical requirements are met.

- In order to be sure that northerners' views and concerns are considered in the overall **program management**, the NCP includes representatives of several northern Aboriginal organizations on its management committee. This management committee is not an advisory body; it is responsible for establishing NCP policy and research priorities and for final decisions on the allocation of resources.

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- **Five Regional Contaminants Committees** covering the territories and northern Québec were established to ensure the flow of information between the management committee, the researchers, and the individual communities. Each of these committees has Aboriginal partners as co-chairs, following the philosophy shown by the management committee of involving Aboriginal people in key decision-making bodies.
- These committees help ensure that communities receive the appropriate information and that scientists are apprised of the needs and issues of the communities. They also participate in the socio-cultural review of research projects in their jurisdictions. **Regional Contaminants Coordinators** (RCC) are front-line workers in the communities who are trained to liaise with the researchers and the communities, and provide information on contaminants to the community members.
- The NCP has made its proposal review process **open and transparent**. External peer reviewers evaluate the proposals, with assistance from technical review teams, to ensure scientific rigor. The same proposals undergo a socio-cultural review by the Regional Contaminant Committees to consider ethical issues from the community perspective.
- The NCP has developed several **documents and activities to promote appropriate communication** with communities, and to increase communities' capacity to make informed decisions about their health, food consumption, and wildlife with regard to contaminants:
  - ***NCP summary of projects*** funded through the program. This plain language booklet, which describes the projects and provides contact information, is a valuable tool for communities.
  - ***NCP Guidelines for Responsible Research*** with accompanying consultation requirements. The guidelines provide direction and set a framework for communities and researchers to agree upon mutual obligations and foster an equitable and beneficial relationship. Consultation requirements ensure that communities are fully aware and approve of the research to be conducted in or close to their community on a case-by-case basis. Together, and with the input of a NCP Social/Cultural Review, these guidelines and consultation requirements are used to effectively involve northern communities as partners in research activities right from the stage of project design, and to integrate communication in all stages of the research. Guidelines for responsible research can be found on the NCP website at http://www.ainc-inac.gc.ca/ncp/index_e.html.
  - NCP Training Course for Front-line Community Professionals for their Role as Contaminants Communicators and Research Liaison Professionals. The northern frontline training course is designed for capacity building at the community level. Course participants acquire the knowledge to answer or access information on the questions and concerns of local residents about contaminants. This document is a well-designed and tested curriculum package for a three-day contaminants course.
  - ***Contaminants Communication in Inuit Communities—Communicating about Contaminants in Traditional/Country Food: The Experience in Aboriginal Communities:*** The work undertaken through this project constitutes a crucial step in realizing key, long-term objectives for contaminants communications in Inuit communities. These are two-fold:
    - to have relevant, complete, up-to-date and accessible information for Inuit to increase their control over contaminants-related issues and problems, and to assist them in making their own, informed lifestyle decisions. These may include, for example, exerting more pressure on government and industry from the "grassroots"

for preventing the generation of contaminants at their sources, making choices about preparing and eating traditional/country food in certain ways, and educating others about contaminants; and

– to develop the capacity among front-line communicators in Inuit communities to answer questions and serve as sources of knowledge and wisdom on contaminant-related matters.

› ***A Guide to Making Presentations in Northern Aboriginal Communities for the Northern Contaminants Program:*** This guide was written for environmental scientists and health professionals who, in the course of their work on contaminants, are called upon to present information to groups of Aboriginal peoples from northern communities.

Dialogue between the managers, researchers, community members, and organizations will continue to ensure that the fundamentals of research ethics continue to be respected and improved whenever necessary or possible.

7.5 Risk Perception

The differences in perception of risks between members of the public and scientific or other technical experts has been extensively studied (Rowe and Wright, 2001; Sjoberg, 2002; Verbekea *et al.*, 2005). Often, for a given risk, there is disagreement even among the experts about the threat it poses to individuals or communities (Sjoberg, 2002). Risk perception has been shown to be influenced by a variety of factors including age, gender, education, occupation, language, world view, and culture (Slovic and Peters, 1995; Jardine and Furgal, 2006; Myers and Furgal, 2006). However, not only do an individual's characteristics influence perception, a number of factors related to the hazard itself are important to consider. These include the voluntary or involuntary nature of the exposure, uncertainty about probabilities or consequences of exposure, lack of personal experience with the risk (fear of the unknown, lack of acceptance of the significance of the risk), effects of exposure delayed in time, genetic effects (effects on the next generation), accidents related to human activity (anthropogenic, not "natural" causes), unequal distribution of risks and benefits, and the ease of perception of the associated benefits. Risk perception is a combination of personal and collective factors that influence the way in which one understands issues, and to which one reacts and takes action at the individual level (i.e., personal behaviours).

The understanding and perception of risk among people are much richer and more complex than originally thought, and they reflect legitimate concerns that are often omitted from formal risk assessment processes. Assessments of the response to risk communication (e.g., health advisories) indicate that individuals who adapt and respond to environmental or other health advisories within the context of limited socio-economic resources demonstrate more passive strategies or are less inclined to comply with advice (Vaughan, 1995). Diana *et al.* (1993) indicated that compliance with fishing advisories in the Great Lakes region is often negatively correlated with the traditions of fishing (Diana, 1993; Burger, 2000; Burger *et al.*, 2005). This is likely very important in the context of compliance or reaction to advisories or advice on contaminants in country foods in the Arctic where limited resources or alternatives to minimize risk sometimes exist. Therefore, it is important to not only understand individual or population perceptions of contaminant risks in the North but also their relationship to attitudes about country foods and a number of socio-demographic factors that may influence the ability of community members to respond or take action (Burger, 2004). For these reasons, the perceptions of those involved and affected by a hazard must be considered as they directly influence the effectiveness of any risk management decisions and actions (including communications) taken to minimize risks and maximize the benefits of, in this case, consuming country foods in the North.

7.5.1 Risk perception and contaminants in the North

The Canadian Arctic Contaminants Assessment Report I and II (CACAR, 1997; 2003) detailed the efforts made in assessing and collecting both qualitative and quantitative data on the perceptions of environmental contaminants among northern residents and related to activities during Phases I and II of the NCP (1992–2003). The discussion presented here refers to and builds upon this information, presenting further knowledge gained in this area since 2003 or not previously reviewed. Prior to Phase II of the NCP, little work on assessing risk perception had been conducted under the program. During Phase II, some projects (Bruneau *et al.*, 2001; Furgal *et al.*, 2001) conducted basic assessment surveys of perception of country food risks, knowledge of contaminants, and awareness of basic messages that had been regularly released via the research and education initiatives under the program. Furgal *et al.* (2005) provided a review and analysis of these efforts and offered recommendations as to where research and action should lead this topic in the future.

In some studies, surveys conducted during earlier phases of the program have been revisited to assess risk perception data collected but not initially analyzed. For example, in a detailed analysis of the Santé Québec Regional

Health Survey conducted in 1992 among the Inuit of Nunavik (Nunavimmiut), Furgal *et al.* (2001) found evidence that further supports some of the previously assumed hypotheses regarding the relationship between perception of country food risks, socio-demographic factors and the consumption of certain country food items (Vaughan, 1995; Burger *et al.*, 1999). The results suggest that communication about environmental contaminants in the region had only moderately affected the perception of food quality among Nunavimmiut. Considering that 69% of Inuit were aware of country food contamination and only 22% of Inuit mentioned having changed their living habits following the announcement of contaminants, Furgal *et al.* (2001) argued that the knowledge of country food contamination did not significantly decrease or negatively influence the perception of country foods among most Nunavimmiut. In fact, they reported that 62% of Nunavimmiut still had a very favourable perception of country foods. As stated earlier, human perceptions of risk and their responses to these risks are complex.

In their extensive review of 13 case studies, Usher *et al.* (1995) concluded that political, economic, cultural, and psychological factors all shape perception among northern Aboriginal communities to the issue of environmental contaminants. Hence, the high social, economic, cultural, and symbolic value of country foods may explain why most Inuit still had a very favourable perception of country foods in Nunavik (i.e., that country foods were safe and contributed to good health) at the time of the regional Inuit health survey even though most were also aware of contamination in the environment and country food chain. This reanalysis of the Santé Québec database showed that older Inuit had a more positive perception of country foods, which may explain, in part, the continued greater use of country foods primarily by older Inuit in communities today. In an anthropological study conducted in Inuit communities of Baffin Island, Borré (1991) reported certain comments of older Inuit revealing that those who grow up eating traditional foods believed they must continue to do so regularly to survive. Furthermore, the Santé Québec Health Survey revealed that younger Inuit were less aware than the elders of the relationship between country food consumption and health (Furgal *et al.*, 2001).

Furgal *et al.* (2001) did not find significant differences in the levels of perception associated with gender, location of residence, or formal education levels of participants. However, perception of country foods did vary according to occupation, in that Inuit who declared housework as their occupation had a less favourable perception of country food safety compared with others. The perception

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of country foods also appeared to be related to marital status and the number of persons living in the house. The most favourable perception was observed among Inuit living in couples, followed by divorced and widowed, and single Inuit. Another study conducted by the same authors revealed that Inuit living in couples were more likely to consume country foods more often, suggesting that single, separated, or widowed Inuit may have less access to county food or the resources (equipment, etc.) to attain these foods (Furgal *et al.*, 2002).

Duhaime *et al.* (2004) reported that the presence of a male as the head of a household and, to a lesser extent, access to a wage income, significantly raised the proportion of country foods in the total diet among Nunavik women. Wein and Sabry (1998) and Wein *et al.* (1991) also reported that the availability of country foods depended greatly upon having a hunter in the family who was equipped with adequate resources (including means of transportation) and skills. A more recent study conducted among Nunavik women of child-bearing age revealed that frequent fish eaters were likely to be less educated, to share their house with more adults, and to live in conditions that were more traditional (Muckle *et al.*, 2001). The authors attributed these associations to the fact that fish, which is usually caught by a family member and is available at no cost in a community freezer, is less expensive than many market foods. Hence, taking into account the above-mentioned observations, one could argue that the easier the physical access to country foods, the more favourably they are regarded.

In the 1992 Nunavik Inuit Health Survey (Sante Quebec, 1994), nearly 70% of Nunavummiut had heard about the presence of contaminants in the food chain and most (87%) declared their desire to receive more information on the subject. The findings of Usher *et al.* (1995), Furgal and Rochette (2007), and Furgal (in press) substantiate this earlier finding. According to Usher *et al.* (1995) and Furgal *et al.* (2005), northern residents want specific information of a directly practical nature (source, effects, safe levels of consumption, etc.) to help contextualize the risks associated with exposure to contaminants and support them in making their own judgments about the importance of this issue. Furgal *et al.*'s (2001) results also revealed that most of those who had changed their living habits following the announcement of polychlorinated biphenyls (PCBs) in breast milk were similarly distributed according to socio-demographic factors. A greater proportion of Inuit women appeared to have made changes in their living habits and this observation appeared to be consistent with the type of communication disseminated in Nunavik (e.g., the announcement of PCBs in the breast milk of Inuit women).

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Finally, Furgal *et al.* (2005) examined the association between contaminant exposures (intakes and blood concentrations) and individuals' perception and knowledge of country food contamination, modifications of food habits or level of participation in land-based activities (i.e., hunting and fishing). The results showed that no difference in contaminant exposure existed among those who had a more or less positive attitude or perception of country foods. Similarly, no differences in contaminant exposure existed among those who had or had not heard about contaminants in the regional country food chain. In contrast, actual blood concentrations of some contaminants varied significantly according to these variables. Concentrations of PCBs (measured as Aroclor 1260) and lead were higher among those having a less-favourable perception of country food safety whereas mercury concentration was higher among those having a more-favourable perception. These differences may be explained by the source of contaminants consumed. Moreover, it is possible that the use of 24-hour dietary recall questionnaires presents some limitations when comparing intakes (via dietary recall assessment) and blood concentrations of contaminants as was done in this study (i.e., the recalled diet behaviours may not be the most indicative of actual contaminant exposure based on diet at other times of the year). Finally, and perhaps most importantly, the results of this study showed no difference in the blood levels of contaminants between individuals who stated that they had changed their health habits after hearing about contaminants in their regional food chain, and those who had not. This potentially indicates a short-term impact of contaminant messages on diet and other health behaviours, or it may identify limitations of survey tools to directly assess the impacts of communication on these topics in northern populations. To date, little comparable work of this nature has been conducted in the rest of the Canadian Arctic.

Twelve years later, as part of the repeat of the Nunavik Regional Inuit Health Survey, the status of health risk perceptions and concerns and activities regarding country foods were reassessed (Furgal and Rochette, 2007). The survey found that country foods and the activities of hunting and fishing were still important aspects of everyday life in Nunavik communities today. Despite the social, cultural, economic, and political changes that have taken place in Nunavik, and the apparent concern over contaminants in the food chain, hunting, fishing, and gathering of wild resources and sharing them in the community are still regularly practised. Nearly half (45%) of the Nunavik population goes hunting frequently throughout the year; one-third (33%) goes fishing regularly once a week or more in at least two seasons; half (48%) participate in berry collecting at least once a month during berry-picking season; and more than half (57%) regularly share their catch with other members of the community. As well, nearly one-third of the population (28%) reported still using some traditional/country food items for their medicinal properties. Similar to the results reported in 1992, most (62%) people reported that they had heard about contaminants in the environment in the 2004 questionnaire (Furgal and Rochette, 2007). Familiarity with specific contaminants (mercury, PCBs, and lead) was reported (by 57%, 47%, and 38% of participants respectively) and was lowest among young females. Since hearing about chemical contaminants in country foods, one-quarter (25%) of the population reported having changed some aspect of their diet; however, only a very small number said they had stopped eating any country food items altogether (Furgal and Rochette, 2007). Less than one-quarter (23%) of hunters said they had rejected or thrown away something they have caught in the previous 12 months for safety reasons. However, rejection was more closely associated with the presence of visible anomalies such as parasites rather than concerns related to chemical contaminants in wildlife. These responses are often related to knowledge of visible anomalies in wildlife and personal experience with such things as parasites in country foods (e.g., trichinella worm in walrus) that can be transmitted to humans and make them sick (Bruneau *et al.*, 2001; Proulx *et al.*, 2002). This update highlights the continued importance of country food resources in the region and potentially, the limited impact of concern over contaminants on hunting and fishing activities and food consumption among Nunavummiut (Furgal and Rochette, 2007).

Myers and Furgal (2006) conducted a survey in two Nunavut and two Labrador communities to evaluate the degree to which residents had received and comprehended information about contaminants in country food. Additionally, the survey served as a tool through which to assess residents' perception of country food and contaminants issues. On average, 69% of participants across the four communities had heard of the term *contaminants*. However, when asked, over 40% included substances other than chemical or natural compounds in their definition of a contaminant and 15% could not identify what they thought a contaminant was. This highlights a possible problem with the comprehension of messages previously disseminated in these and perhaps other regions. Local sources (e.g., garbage, old military sites, oil drums, etc) were the most commonly identified causes of contamination in the country food chain in the regions and significant percentages of the populations responded that they were not sure there were contaminants in country foods in their area. This uncertainty was higher among respondents in the Nunavut communities than in the Labrador communities and in general, the greatest uncertainty on this issue was expressed among elders and female participants. The majority of participants (61%) in the Myers and Furgal (2006) survey said they did not have any concerns about the safety of their country foods; however, among those that did, more hunters (55%) than women (30%) reported concerns. Among those that expressed concern, such things as wildlife health, physical abnormalities, and contaminants were identified as the primary issues. Responses indicated that individuals are primarily relying on visual cues to discern whether or not there are contaminants in country foods and whether or not these foods are safe for consumption. Finally, the predominant perception was that individuals themselves had not been exposed to contaminants (73%). The majority of Nunavut respondents (65%) said that they would never change their diet because of concern about contaminants while the majority of Labrador participants (60%) said they would.

Despite a strong belief in the health and safety of country foods, concern has been raised in many regions about the presence and potential effects of contaminants on animal and human health. Previous studies conducted by O'Neil *et al.* (1997) and others (Furgal, 1999; Myers and Furgal, 2006) are further supported by findings of Furgal and Rochette (2007) and Furgal (in press) in more recent surveys throughout the North. In regional surveys conducted in 2003 in Yukon, Inuvialuit

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Settlement Region, Nunavut, and Labrador involving over 700 participants in total, more concerns were expressed among Yukon residents about health and wildlife (66%) than among Inuit residents (44% for all Inuit regions combined). However, in all regions, the most commonly cited concerns were associated with chronic diseases in people, general food quality, garbage on the land, and water quality. Approximately 10% (or less in some regions) of respondents identified environmental contaminants in country foods as one of these concerns. However, among those expressing concerns about country foods, "contaminants and industrial pollution" was the top concern in each region, followed by "abnormalities and animal health." All regions showed a high level of awareness of the basic contaminants messages that had been delivered previously under the NCP. The lowest level of recall and awareness for these messages was reported by women of child-bearing age in nearly all regions. Many participants' understanding of "environmental contaminants" reflected the same confusion between chemical phenomena and visible wildlife anomalies reflected by other studies (see above). These results further support Furgal *et al.*'s (2005) and Myers and Furgal's (2006) argument that the invisible phenomenon of chemical contamination in the country food chain is a significant challenge to traditional knowledge systems and understandings of food safety, which have historically been based on observation and personal experience of illness. These results show that although northerners identify contaminants and industrial pollution in the country food chain as an issue when prompted, it falls relatively further down the list of all environment and health concerns than expected.

Further supporting this argument are the results of another general health and environment perception survey conducted among Dene of the Yellowknife area and Inuit of two Nunatsiavut (Labrador Inuit) communities by Jardine and Furgal (2006). Their investigation used both a survey and qualitative research technique known as "photovoice" in which residents took photos of components of their environment they felt were risks to their health, and discussed these in an interview setting. This approach looked at the understanding and awareness of known and theoretical or potential environmental risks to health in northern Aboriginal communities. The two data collection methods showed the importance of socio-cultural variables and place in the identification of risks of concern to residents in the communities. Many of the health concerns reported by individuals related to aspects of their social environment and personal behaviours more so than their physical environment.

In a risk-ranking activity done as part of this study, contaminants and the threat of contamination in the environment ranked very low among all risks recognized by the participants. The most important concerns or health risks identified through responses to various questions included activities involving alcohol, drugs, and smoking (Jardine and Furgal, 2006). However, participants did express concern about contamination of their land from anthropogenic sources, although to a lesser extent than lifestyle-related risks. Understanding of these risks varied. In general, participants understood and recognized visible changes in their local environment but had difficulties reporting clear understanding of more invisible phenomena, such as arsenic and PCB contamination of the land, water, and animals. According to Jardine and Furgal (2006), residents in the four communities involved in the study appeared to understand the nature and magnitude of the risks to their health associated with lifestyle and basic physical and environmental risks. They showed indication of having received, understood, and accepted information on these risks, yet they did not modify their behaviours as often as one might expect to minimize the risks to their health. Jardine and Furgal argue that this may be related to the strength of the social norms in these communities, which still consider some of these risky behaviours as acceptable, or to the perceived (or in many cases, actual) lack of options available to minimize exposure (e.g., changing the kind of country foods eaten to minimize contaminant exposure). In addition, it may be related to the lack of acceptance of the current message strategies.

7.6 Food Choice Research

For decades, researchers have been documenting changes in consumption of traditional country food among Inuit populations. A trend among Inuit and other Arctic residents of replacing and/or supplementing their traditional diet with some nutrient-poor imported market foods has been identified (CACAR, 2003). An improved understanding of the factors influencing diet choice helps northern health professionals and decision makers better understand diet trends and support their activities in protecting and promoting nutritional health and well-being in the face of concerns about environmental contamination of the country food chain.

Although economic, contaminant-related, and some social factors have been identified to explain associated changes in the consumption of traditional country foods, few studies prior to 2003 had looked at nutritional knowledge, food preferences, and factors influencing individual food choices in the North. Some studies do mention social and cultural factors related to changes in country food consumption (in particular food availability, harvesting time, costs of equipment for hunting/fishing, etc.). However, to date, relatively little work has been done to assess the actual impact these factors have on individual consumption-related behaviour and the relative importance that modernity, contaminant information, or social and individual preferences of food choice have in this diet transition.

In the context of the Canadian Arctic, food consumption is a particularly complex behaviour in that the population lives in a unique environment where socio-cultural (social value of country foods for example) and environmental constraints related to country food access must be considered in the study of food choices. It is necessary to approach the identification of personal determinants of food choices quite broadly by looking at an array of potential factors. To this end, several theories might apply to the context of northern Aboriginal food choice behaviour (see Box 1).

To date, there has been a few food choice studies conducted in the Canadian Arctic. For example, Kuhnlein *et al.* (2003) explored the factors that influence food choices among women and children in three Dene and Métis communities (Fort McPherson, Tulita, Fort Resolution) and two Yukon First Nations communities (Old Crow and Carcross). They found that the most important factors that influenced family food choices were costs associated with market food and the availability of country food. Furgal *et al.* (2001; 2003) conducted food choice research in Nunavik and Labrador. They found that the perceived ease or difficulty of obtaining county food, beliefs about the consequences of eating country food, and personal values were the strongest determinants influencing the intent to consume country foods. Similar results were found for factors influencing market food consumption behaviour as well. Most recently, Donaldson *et al.* (2006) found that the most influential determinants of country food consumption among Inuit living in Cape Dorset were accessibility, personal preferences, and personal values. The results on intent to consume market food show that the most influential determinants are accessibility, convenience, and personal values.

Environmental factors may influence food choice in the Arctic (Newton *et al.*, 2005; Nuttall *et al.*, 2005; Van Oostdam *et al.*, 2005). Furgal *et al.* (2003) found that contaminants were not a significant factor when making choices about country food in Nunavik and Labrador. Meanwhile, Donaldson *et al.* (2006) found that environmental contaminants were only an indirect influence on food choice in Cape Dorset, Nunavut. In their study, many of the hunters who raised concerns

Theories of Food Choice Behaviour (adapted from Bernier, 2003)

The Theory of Planned Behaviour (TPB) is one of the dominant models used to understand health-related intentions and behaviours (e.g., Armitage and Conner, 2001). The TPB considers how different forces work on an individual to determine the decision to perform a particular behaviour. The theory is an extension of the Theory of Reasoned Action (TRA) (Fishbein and Ajzen, 1975; Ajzen and Fishbein, 1980). The TPB argues that the most immediate determinant of a person's behaviour is one's intent. According to the model, **intention** is a function of attitude, subjective norms, and perceived behavioural control. **Attitudes** are seen as personal evaluations of the action. **Subjective norms** are seen as social pressures to perform the behaviour. **Perceived behavioural control** (PBC) can contribute to the prediction of behaviour when individuals have limited control over adoption of the specific behaviour in question. According to Armitage and Conner (2001) and others (e.g., Godin and Kok, 1996; Sheeran and Taylor, 1999) perceived behavioural control contributes between 5% and 13% of the variance seen in intention after the variables included in the TRA model are taken into account.

Notwithstanding the power of this theory in helping understand diet or other health-related behaviours, other constructs external to the TPB have been shown to add to the explained variance in behavioural intent (Godin and Kok, 1996; Armitage and Conner, 2000). In particular, variables from Triandis' theory (Triandis, 1980), such as personal normative belief (moral norm) and role beliefs have been shown to significantly increase the variance in intent, and thus explain this phenomenon better than can be explained by any one model of health behaviour (Godin and Kok, 1996). Triandis (1980) describes intention as being influenced by the cognitive dimension of attitude, affect, social determinants, and finally, personal normative beliefs.

In Triandis' model the cognitive component of attitude is similarly seen as the result of a personal and subjective analysis of the advantages and disadvantages that would result from performing a particular behaviour. The second determinant in Triandis' model, i.e., affect, represents the emotional response of an individual to the thought of performing a specific behaviour (i.e., the feelings that the behaviour evokes in the individual). Social factors are the third element influencing intention according to Triandis. Two determinants that have been used in the widest range of studies have been normative beliefs and belief in the existence of specific social roles. Normative beliefs are the individual's perception about the significance of a given behaviour within a reference group. Belief in the existence of specific social roles refers to the perception of individuals concerning the accepted behaviour of people who hold certain positions in society. The personal normative belief (PNB) or moral norm is the last factor thought to influence behavioural intent. The PNB of an individual is formed via an evaluation of the significance of a behaviour to one's self—in other words, how obligated the individual feels when faced with the decision of whether or not to perform the behaviour in question (e.g., to eat country foods, or not). Moral norms differ from social norms in the sense that the individual's final choice (i.e., the intent to perform the act or not) does not depend on the opinions of others.

A few examples of the application of these theories can be found in the literature on behaviours related to exercise (Godin *et al.*, 1989), mammograms (Montano and Taplin, 1991; Baumann *et al.*, 1993), influenza vaccination (Montano, 1986), workplace smoking (Boissonneault and Godin, 1990), condom use (Boyd and Wandersman, 1991; Godin *et al.*, 1996), and use of hormone replacement therapy (Légaré *et al.*, 2000). To date, only one project has applied these theoretical constructs to the investigation of the factors influencing food choice in northern populations (Furgal *et al.*, 2001 and 2003).

about the safety of the Arctic food chain relied on Inuit knowledge to assess whether an animal was safe for human consumption. If a hunter assessed an animal and considered it to be contaminated, it was not eaten:

> We can tell if an animal is sick from pollution. Usually there are green spots on the liver. Also, sometimes, there are patches of hair missing from their coat. When I find an animal that is sick I leave it on the land or I take it to the Hunters and Trappers Association. We do not eat these animals. We make decisions like this on a case-by-case basis. Each animal is inspected.
>
> *Anonymous Participant*
> *(Donaldson* et al.*, 2006)*

The direct and indirect influences of contaminants on country food choice raise concerns because of the known nutritional (Kuhnlein and Dickson, 2001; Kuhnlein *et al.*, 2001; 2004), social, economic, and cultural benefits of country food use (Wenzel, 1995; Collings *et al.*, 1998; Donaldson *et al.*, 2003; Donaldson *et al.*, 2005; Myers *et al.*, 2005; Van Oostdam *et al.*, 2005).

The results of food choice research in the Arctic highlight that access, perceived or real, is a primary determinant of country food and market food choice. To date, research suggests that store and country food choice is strongly associated with its availability (i.e., what the participants can obtain) within the participants' social network and the extent to which store food and country food was shared. In these cases, dietary intakes commonly reflected the type of food chosen by other people in their social network.

Considering that many people living in the Arctic are cash-poor and their food choices largely depend on the types of food to which they have access, health promotion strategies designed to reduce exposure to environmental contaminants found in some traditional foods and that focus on changing people's choices (i.e., by altering beliefs, providing knowledge or changing habits) stand little chance of success. Rather, strategies that focus on changing the availability of food choices are more likely to succeed. As Furgal *et al.* (2003) state:

> *The provision of health information alone would have little chance in changing behaviour if this traditional/wild food was available for free through sharing networks or other sources in the community (i.e., people do not choose their food solely on the basis of its value to health).*

The likelihood of successfully reducing exposure to environmental contaminants from a traditional diet would be significantly increased if culturally acceptable dietary alternatives were made available at the same time that dietary advice was provided. This knowledge of access as a limiting factor and the need to provide viable, culturally appropriate alternatives was considered in the initial development of a risk management strategy in Nunavik. The Nunavik Regional Board of Health and Social Services proposed providing free access to Arctic char for pregnant women while encouraging these individuals to reduce contaminant exposure by decreasing their consumption of country foods that are high in contaminants (e.g., marine mammal fats) and increasing their consumption of country foods that are low in contaminants and high in nutrients (e.g., Arctic char, caribou).

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7.7 Case Studies in Communication and Balancing Benefits and Risks

As knowledge of the benefits and risks of consuming country foods increases, the development of clear, easy-to-understand messages becomes more complex. Take for example the evolution in public messages released during the last 12 years. In 1995, the public messages released by the Inuit Tapirisat of Canada (now ITK) was "*…So far as we are aware, the risks to public health from continuing to eat beluga and seal blubber are very small and are outweighed by the benefits*" (Usher, 1995). Eight years later, in the 2003 response to the release of the Inuit infant cohort results in Nunavik, the Nunavik Nutrition and Health Committee released the following message:

> *…the study results are interesting and very valuable to understanding the impact contaminants may be having on infant development in Nunavik, but more importantly, we must put these results in a greater public health context with the other things we know influence the health of young mothers and their babies.*
>
> *The Public Health Department suggests that women of childbearing age (13–45) must first ensure to eat a variety of nutritious foods in an adequate amount. Whenever possible, we suggest that women select country foods that are rich in fatty acids and less contaminated with PCBs (Arctic char, misiraq made from seal blubber instead of beluga).*

The Committee goes on to state:

> *The NNHC and the PHD (Public Health Director) strongly believe that country food is generally the best food for Nunavummiut. Country foods are nutritious, bind communities together and reduce the risk for several diseases such as heart disease and diabetes. So yes, of course, they are still safe to eat.*
>
> (Nunavik Nutrition and Health Committee, 2003)

The result is a message that is getting increasingly complex as more information is obtained about the specificity of the risks and benefits and their potential interactions associated with country food consumption. Yet, accurate, accessible, and easy-to-use information and advice must be given to northerners related to diet behaviour, which is inclusive of this multitude of components. Currently, no calculations or methods exist that can be applied to provide the right 'risk-benefit' answer in the context of the Canadian north (CACAR, 1997; 2003). However, lessons learned elsewhere may be helpful in supporting northern decision makers as they face these challenges.

Formal literature on comparative risk and benefit methodology has been accumulating over the past few decades. Methodology development is continually being updated and expanded including the most recent issues of the journal *Risk Analysis*. Much of the methodology developed to date has been directed toward risk-based regulatory reform in the United States, focusing on the mandate of the U.S. Environmental Protection Agency (US EPA). While there is a diverse literature on comparative risk assessment (or risk ranking) techniques and issues, relatively few papers have addressed a common framework for considering diverse negative and positive health outcomes across an entire diet. A relevant attempt was carried out for the risks and benefits of fish consumption (Anderson *et al.*, 2002). These developments provide a sufficient basis to proceed with policy-relevant comparative risk and benefit decision-support tools.

Until recently, little evaluation had been carried out on the risk communication information available, the methods used, and the successes and challenges of information delivery. Surveys in northern regions have revealed gaps in information and in people's understanding of contaminants, yet few have investigated why these deficiencies exist. A recent project by Furgal (in press) conducted four regionally based case studies of past risk communication events to identify best practices and lessons learned throughout the North. Further work is ongoing to expand these case studies to look at factors that influence both the processes of risk assessment and the communication surrounding country food and contaminant risks in the Circumpolar north. The Canadian component of this study has reviewed one risk communication event in each participating region (Nunatsiavut [northern Labrador], Nunavik, Nunavut, and the Inuvialuit Settlement Region) related to contaminants in country foods to identify the key factors influencing the process and impact of communication strategies and efforts. In each case, the study reviewed material from key-informant interviews and documents, and in some instances, conducted a small population-based survey.

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Among the Canadian cases, the project has reviewed the release of a public health advisory to reduce consumption of certain country foods near an abandoned radar site in Nunatsiavut in 2003; the release of the child development study results by the Nunavik Regional Board of Health and Social Services, also in 2003; the community tour and public health messages released in the Baffin community of Iqaluit later that year; and the initial NWT maternal blood monitoring survey conducted in 1998, which was released to public health professionals (Furgal *et al.*, 2006).

Preliminary findings of the case studies indicate that the most successful risk communication processes draw on and involve a variety of regional experts and the public in the formal communication process. Members of the public are involved in the risk assessment and communication process from the beginning of the risk identification phase, including explicit consideration of local perception and qualitative benefits and risks in the deliberation of risk optimization strategies and message development, and formally and proactively planning the communication process. The four case studies also identified a number of common challenges in communicating risks related to contaminants, country foods, and

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health. These include the fact that messages are rarely pre-tested despite evidence showing that pre-testing significantly minimizes overreactions or negative reactions to messages disseminated; the fact that messages are rarely tailored specifically to the target audience, as seen by the limited number of messages directly designed and delivered for women of child-bearing age (a segment of the population most in need of this information); and the fact that communication successes (meeting identified goals of delivery, reception, and response) are rarely evaluated in a formal way. This formal evaluation can provide an opportunity to correct misconceptions of initial messages and increase reception, understanding, and compliance to advice. Although these findings are preliminary, they confirm the value of conducting formal evaluations of past and current cases to develop a body of knowledge for circumpolar health risk communication, best practices, and common challenges. They illustrate both the unique regional approach required and the common strengths and weaknesses of communication efforts throughout the North on these issues.

Many of the common challenges and ongoing needs to best support regions in developing and delivering this information have also been identified in other consultation processes held in the Canadian north with environment and health professionals. A workshop bringing together northern health professionals and Department of Health and Social Service representatives and other researchers identified key issues for the process of benefit risk assessment, management, and communication in relation to environmental contaminants, country foods, and health in the Canadian Arctic (Roach, 2007). This workshop, held in 2006, identified the following key issues:

- the need for further clarification regarding roles and responsibilities in the assessment, management, and communication process;
- liability and legal obligations to release results of studies (and how) that may not provide conclusive support for clear health advice on the topic;
- the need for greater clarity and understanding of the guidelines and terms used in technical risk assessments (e.g., Tolerable Daily Intake, Acceptable Daily Intake, Recommended Weekly Minimum Intake, Level of Concern, Level of Action);
- whether or not adequate data (spatially and temporally) exist upon which to assess risks and benefits at the local level and give clear health advice;
- the need to continue to monitor and track consumption behaviours in northern populations as the processes of social, economic, and cultural change and influence exposure to food borne risks and benefits;
- the need to better understand the complexities involved in the assessment process (e.g., contaminant-contaminant and contaminant-nutrient interactions, confounding factors) and how to use this in the balancing process;

- the need and utility for small evaluation exercises to review the applicability of existing data and understandings of these issues;
- the status of past advisories and their lasting impact on current and future advice on food safety and consumption habits; and
- the need for further emphasis on northern training and capacity building (including the provision of decision and communication support tools and materials) on this topic.

In combination with results from case studies and surveys, the perspectives of northern health professionals and researchers can support northern health departments, hunters and trappers organizations, and others as they direct or participate in these assessment processes, lead effective communication strategies, and support informed decision making among their populations.

7.8 New Risk-Benefit Characterization and Communication Tools

A multitude of factors must be considered when managing and communicating the risks and benefits associated with the consumption of country foods. Health and environmental managers and health professionals face the challenging task of making and communicating decisions about this issue. It is crucial that the most recent and pertinent information about country foods is easily accessible so that northern health decision makers and community residents are able to make informed decisions about food consumption. A decision support tool that could aid the decision-making process and policy development would be of great benefit to northern residents and health professionals. A computer-based decision support tool, which was recently developed in cooperation with the Nunavik Nutrition and Health Committee (NNHC) and funded by the NCP and Health Canada, was described in the Synopsis of Research conducted under the 2005–2006 Northern Contaminant Program and is presented in detail in Hartnett *et al.* (2008). Health Canada, the NNHC, and other agencies have conducted expert technical and health professional reviews of the model.

7.8.1 Model description

The decision-support tool is intended to assist northern health professionals and others during the review and decision-making processes surrounding the issue of country food consumption. This computer simulation model adopts a complete diet approach and the common metric of Disability Adjusted Life Years (DALYs) to assess the health benefits and risks associated with dietary options. It enables a comparative assessment of the benefits and risks associated with country food and market food consumption through the combination of data and information on food consumption, nutrient and mineral intakes, and contaminant exposure. The use of DALYs as the metric upon which to balance the risks from competing health effects has been used previously (see for example Havelaar *et al.*, 2000; Crettaz *et al.*, 2002a; Crettaz *et al.*, 2002b). However, the use of DALYs specifically in the context of considering the benefits of changes in diets is relatively new, but is increasing (see for example by Stein *et al.*, 2007).

Disability Adjusted Life Years (DALYs)

The DALY measure was developed to enable an assessment of the burden of disease around the world by comparing the vast spectrum of diseases and conditions that cause ill health (Murray and Lopez, 1996; Ezzatti *et al.*, 2002). A key attribute of the DALY measure is that it provides the ability to quantify the impact of different health endpoints in a standardized manner on a single scale according to their respective severities. This is achieved by considering the years of “healthy” life lost in states of less than full health as a result of the particular condition, broadly termed *disability*. To do this, disability weights are defined and used to weight years of life lived with disabilities resulting from a specific cause where disability is defined as the inability to perform the everyday duties of life. These disability weights are selected on a range of 0 to 1, with 0 representing perfect health and 1 representing a health status equal to death; therefore the effect of both morbidity and premature mortality can be measured in common units. The total burden of a disease is the sum of “years of life lost” (YLL) due to cause-specific mortality and the weighted “years lived with disability” (YLD). That is, burden of disease = DALYs = YLL + YLD. One DALY represents the loss of one year of equivalent full health. To estimate the DALYs, a 3% time discounting is applied to each year of life lost, and life lived with disability. Time discounting gives less weight to years lived at older (and younger) ages. This is in line with the World Health Organization approach to estimation of the burden of disease worldwide (for a full discussion on DALYs, see Murray and Lopez, 1996).

7.8.2 Estimating risk

The risk estimation process focuses on the estimation of the burden of disease by considering exposure to contaminants and nutritional adequacy/excess as a result of the total dietary intake. For each contaminant/vitamin/mineral explicitly considered in the model, the probable intake per day is estimated based upon the combination of the level at which each contaminant/vitamin/mineral would be expected to be present in each food item and the total dietary intake of each food item per day. These intake (or exposure) levels are then used to estimate the risk of adverse health outcomes occurring, and subsequently the burden of disease. Note that the impact of dietary supplementation (for example, vitamin and/or mineral supplements) is not included in the assessment. To enable the estimation of the burden of disease, specific health conditions must be identified and defined in terms of the associated DALYs per case. For each contaminant/vitamin/mineral explicitly considered, a health indicator condition is selected based on the condition that the DALYs are estimating. For example, inadequate calcium intake is associated with an increased risk of osteoporosis. Osteoporosis has an associated DALY of approximately 0.2 years per case. Therefore each case of calcium inadequacy predicted by the model is assigned a DALY of 0.2 years. For each indicator condition the risk of the adverse health outcome occurring is estimated and translated into the number of expected cases in the Inuit population. This is in turn translated into the number of DALYs in the population and is summed across all indicator conditions to give an estimate of the dietary burden of disease from the selected contaminants and vitamins/minerals and their associated selected indicator conditions. The contaminants and vitamins/minerals specified in the tool and the associated selected indicator conditions are presented in Table 7.8.1. Many of the contaminant/vitamin/minerals have multiple possible health end points. While it is ideal to specify all possible end points and their relative likelihood of occurrence, the aim here is to illustrate the power the tool has to provide information to support risk-based policy. Therefore, the exhaustive assessment of all possible health end points is not necessary for this purpose. However, users of the tool can extend the list of end points to meet their specific needs.

INAC

Underpinning the model is the definition of the diet of the Inuit population. The current (or baseline) diet is the one to which comparisons of dietary changes will be made. The model is designed such that the decision maker can readily enter the most relevant and up-to-date information into the model. To illustrate the use of the tool, the baseline diet specified here uses available data on the current dietary options of the Inuit population from the Food Mail Survey (Lawn and Harvey, 2004). The diet is summarized in terms of 92 food items or categories including both country and market foods, for example beluga meat, seal meat, milk, cheese, beef, fries, pizza, and fizzy drinks (pop). For each food item the average daily intake is entered in the model. This provides the basis for the estimate, or baseline diet, which is the foundation of the comparative analyses. Provisions can be made for changes to dietary intake that may occur, for example, as a result of a particular advisory or a social shift in dietary pattern, defined in relation to the baseline diet in terms of the change in DALYs.

The model also requires the level of contaminants, vitamins, and minerals in the food components that make up the diet. The level of contaminants in the food animals sourced for country food by the Inuit are taken from CACAR (2003). Table 7.8.2 presents the contaminants/food category combinations used in the diet. The vitamin/mineral levels for all 92 dietary components specified are obtained from the Canadian Nutrient File (CNF, 2007).

A summary of the mathematical approach adopted to estimate the risk given the dietary information is as follows. Full mathematical details are provided elsewhere (e.g., Hartnett *et al.*, 2008).

TABLE 7.8.1 Indicator conditions selected to estimate the burden of disease from each health end point.

Contaminants	Non-cancer Indicator condition	Cancer Indicator Condition
PCBs	Reduced birth weight and learning deficits	Hepatocellular carcinoma
DDT	Liver lesions	Liver tumors
Toxaphene	Impaired kidney function	Hepatocellular carcinoma
Chlordane	Hepatic necrosis	Hepatocellular carcinoma
HCHs	Impaired kidney function	Hepatocellular carcinoma
Mercury	Impaired kidney function	Not considered carcinogenic
Methylmercury	Developmental neuropsychological impairment	Not considered carcinogenic
Cadmium	Significant proteinuria	Not considered carcinogenic
Lead	lead poisoning	Hepatocellular carcinoma
Arsenic	Hyperpigmentation & keratosis	Hepatocellular carcinoma
Dieldrin	Liver lesions	Hepatocellular carcinoma
Mirex	Liver cytomegaly	Not considered carcinogenic
Vitamin/Nutrient	**Inadequacy Indicator Condition**	**Toxicity Indicator Condition**
Calcium	Osteoporosis	Impaired kidney function
Iron	Iron deficiency aneamia	NA
Zinc	Diarrhoea (case)	NA
Sodium	Fatigue, muscle weakness	hypertensive heart disease
Potassium	Potassium deficiency (hypokalemia)	NA
Vit A	Xeropthalmia	increased risk of birth defects
Vit C	Bleeding gums & fatigue	diarrhoea (case)
Vit B6	Dermatitis	NA
Folate	Preterm delivery and low birth weight	NA
Thiamin	Thiamin deficiency	NA
Riboflavin	Riboflavin deficiency	NA
Niacin	Pellagra	NA

NA – Although Tolerable Upper Intake Levels ULs have been defined for many of the nutrients/minerals, adverse health outcomes from excess consumption have not been observed from food, and have to date only been associated with dietary supplementation (IOM, 1998; IOM, 2000a; IOM, 2000b).

TABLE 7.8.2 Contaminant-dietary component combinations included in the model. The primary source of the contaminant information and data used in the model is CACAR (2003).

Contaminant	Dietary Component								
	Beluga (meat and muktuk)	Seal meat/ blubber/liver	Caribou meat/liver	Char	Other fish	Marine bird meat	Marine bird eggs	Walrus meat	Polar bear meat
PCB	✔	✔		✔	✔	✔			✔
DDT	✔	✔		✔	✔	✔			✔
Toxaphene	✔	✔		✔	✔	✔			
Chlordane	✔	✔		✔	✔	✔			✔
HCH		✔		✔	✔	✔			✔
Mercury		✔	✔	✔	✔	✔	✔	✔	
Methylmercury		✔	✔	✔	✔	✔	✔	✔	
Cadmium		✔	✔			✔		✔	
Lead		✔	✔	✔		✔		✔	
Arsenic		✔		✔	✔	✔		✔	
Dieldrin		✔		✔	✔	✔			
Mirex		✔		✔	✔	✔			

TABLE 7.8.3 The data used in the estimation of the risk of adverse health outcomes and the associated DALYs for intake levels of the nutrients/minerals in the diet.

Vitamin/ Nutrient	EAR	UL	Units	Inadequacy				Toxicity					
				Severity weight	Duration (years)	Discounted Duration (years, morbidity)	DALY (per case)	Severity weight	Duration (years)	Discounted Duration (years, morbidity)	Mortality rate	Discounted Duration (years, death)	DALY (per case)
Calcium	200***	2500	mg	0.01	40	23	0.21	0.29	1	0.99	0	0	0.29
Iron	8.1	45	mg	0.08	1	0.99	0.08	NA*	NA*	NA*	NA*	NA*	0
Zinc	6.8	40	mg	0.09	0.01	0.008	7.1E-04	NA*	NA*	NA*	NA*	NA*	0
Sodium	1500**	2300	mg	0.01	0.02	0.02	2.1E-04	0.35	2	1.9	0.71	23	17
Potassium	4700**	ND	mg	0.01	0.02	0.02	2.1E-04	NA*	NA*	NA*	NA*	NA*	0
Vit A	500	3000	microgram	0.001	1	0.99	0.001	NA*	NA*	NA*	NA*	NA*	0
Vit C	60	2000	mg	0.001	0.01	0.01	1.4E-05	0.09	0.01	0.01	0	0	0.001
Vit B6	1.1	100	mg	0.01	0.3	0.29	0.003	0.33	2	1.9	0	0	0.64
Folate	320	1000	microgram	0.15	70	29	4.4	NA*	NA*	NA*	NA*	NA*	0
Thiamin	0.9	ND	mg	0.08	1	0.99	0.08	NA*	NA*	NA*	NA*	NA*	0
Riboflavin	0.9	ND	mg	0.08	1	0.99	0.08	NA*	NA*	NA*	NA*	NA*	0
Niacin	11	35	mg/NE	0.08	1	0.99	0.08	NA*	NA*	NA*	NA*	NA*	0

References: IOM (1997, 1998, 2000a, 2000b, 2004); Dieticians of Canada (2001); WHO Global Burden of Disease; Victorian Government Department of Human Services (1999)

ND – not defined

NA* Not available: although ULs have been defined for many of the nutrients/minerals, adverse health outcomes from excess consumption have not been observed from food, and have to date only been associated with dietary supplementation (IOM 1997, 1998, 2000a, 2000b, 2004).

** This is an Adequate Intake level (AI). No Estimated Average Requirement EAR is currently defined.

*** For calcium this value is a reduction from the AI level of 1000 mg (as no EAR is set). The AI is reduced based upon Sellers et al. (2003) suggesting genetic adaptation to low dietary calcium.

TABLE 7.8.4 The data used in the estimation of the risk of adverse health outcomes and the associated DALYs for exposure to contaminants in the diet.

Contaminants	TDI (mg/kg)	CSF (mg/kg)	Non-cancer				Cancer			
			Severity	Duration (years)	Discounted Duration (years, morbidity)	DALY* (per case)	YLD** (per case)	Mortality rate	Discounted Duration (years, death)	DALY (per case)
PCBs	0.001	1	0.15	70	29	4.4	1.0	0.75	23	18
DDT	0.02	0.34	0.29	1	0.99	0.29	1.0	0.75	23	18
Toxaphene	0.0002	1.1	0.29	1	0.99	0.29	1.0	0.75	23	18
Chlordane	0.00005	0.35	0.29	1	0.99	0.29	1.0	0.75	23	18
HCHs	0.0003	6.3	0.29	1	0.99	0.29	1.0	0.75	23	18
Mercury	0.0007	'NA'	0.29	1	0.99	0.29	0	0	0	0
Methylmercury	1.0E-04	'NA'	0.15	70	29	4.4	0	0	0	0
Cadmium	1.0E-03	'NA'	0.29	1	0.99	0.29	0	0	0	0
Lead	3.6E-03	0.11	0.29	1	0.99	0.29	1.0	0.75	23	18
Arsenic	0.002	1.5	0.01	0.3	0.30	0.00	1.0	0.75	23	18
Dieldrin	5.0E-05	16	0.29	1	0.99	0.29	1.0	0.75	23	18
Mirex	2.0E-04	'NA'	0.29	1	0.99	0.29	0	0	0	0

* Rounded to two decimal places, calculation is DALY=Severity x Duration, where duration is discounted using [1-exp(0.03 x duration)] / 0.03.

** YLD – years lived with disability, for cancer this is estimated as in Victorian Government Department of Human Services (1999) taking account of time during treatment for cancer, and time post treatment for survivors.

References: CACAR (2003); EPA (2007); Murray & Lopez (1996); Victorian Government Department of Human Services (1999).

7.8.2.1 Estimating the risk from contaminants

To consider the risks from the exposure to chemical contaminants, health end points are categorized into two distinct categories, specifically cancer and non-cancer health end points. To estimate the risk of cancer end points, traditional cancer risk assessment techniques are adopted, specifically, the calculation of the excess cancer lifetime risk (see for example US EPA, 1996) The cancer slope factors (CSF) are taken from publicly available sources (US EPA, 2007).

Risk assessment of non-cancer end points has historically examined the intake level in comparison to the dose that is deemed to represent an absolute threshold point below which there is considered to be negligible (zero) risk, and above which there is some (undefined) level of risk of an adverse health outcome. This threshold is the Tolerable Daily Intake (TDI), defined as the total intake by ingestion to which it is believed that a person can be exposed to daily over a lifetime without deleterious effect. Expressed on the basis of body weight (e.g., mg/kg bw/day), it is specifically for non-carcinogenic effects. While this approach provides an indication of which contaminants may pose a risk of some adverse outcome, it does not directly indicate the level of risk associated with the occurrence of adverse outcomes at different intake levels. To be able to compare the competing risks/benefits to changes in the Inuit diet, it is necessary to consider the likelihood of non-carcinogenic health impacts occurring such that the associated DALYs can be estimated. Therefore, a linear dose response model is adopted to assess the risk of adverse outcomes for the daily intake. The approach uses the risk at the No Observed Adverse Effect Level (NOAEL) and TDI for each contaminant to define the linear dose-response model.

7.8.2.2 Estimating the risk from nutrients

To consider the health impacts of nutritional adequacy or excess, the measures of choice are the Estimated Average Requirement (EAR) and the Tolerable Upper Intake Level (UL). The EAR is defined as “the average daily nutrient intake level estimated to meet the requirement of half the healthy individuals in a particular life stage and gender group.” The UL is defined as “the highest average daily nutrient intake level that is likely to pose no risk of adverse health effects to almost all individuals in the general population. As intake increases above the UL, the potential risk of adverse effects may increase” (Institute Of Medicine, 2005). The EAR and UL may be used to assess the nutrient quality of a group of individuals participating in a dietary survey (Institute Of Medicine, 2000b). Therefore, using the predicted dietary intake as entered in the model and the EAR and UL, the risk of consuming levels that could be considered inadequate or in excess (i.e., toxic) was assessed for 12 nutrients and minerals required for women of child-bearing age; these are presented in Table 7.8.3. Note that in some cases an EAR has yet to be defined. In these cases an Adequate Intake (AI) measure is adopted as a surrogate. While this is not the intended purpose of an AI measure, it is the only option where there is currently no EAR. The risk associated with consuming inadequate or toxic levels of the vitamins or minerals is defined in terms of the risk of developing selected indicator conditions associated with each vitamin/mineral. The risk is defined by comparing the predicted intake and the actual requirements. For inadequacy, a probability approach is adopted comparing the predicted intake to the intake requirements assuming a normal model with a coefficient of variation of 10% (Renwick *et al.*, 2004). For toxicity, a linear model is adopted in the same manner as the exploration of non-cancer health effects.

The CSF, TDI, EAR, and UL have been taken using current information and guidelines. However, these aspects of the model can be readily updated in the tool should other values be preferred, or if current values are refined in the future.

7.8.2.3 Estimating the burden of disease

To translate the intake level (exposure level) into a measure of DALYs, indicator conditions are identified for each contaminant/vitamin/mineral and the categories of health effects that apply, that is cancer, non-cancer, nutritional inadequacy, or nutritional toxicity (Table 7.8.1). The incidence of each indicator condition is estimated as the product of the risk of the occurrence of each indicator condition and the population size, where the population size is set to 4778 female Inuit in Nunavik, as taken from Indian and Northern Affairs Canada (2002). The DALYs are then calculated using the combination of the severity weights and duration. This is in turn translated into the total number of DALYs in the population by summing all indicator conditions to provide an estimate of the dietary burden of disease from the selected contaminants and vitamins/minerals and their associated selected indicator conditions. The components used in the estimation of the risk and the burden of disease are presented in Table 7.8.3 for nutrients/minerals, and Table 7.8.4 for contaminants. Note that the data currently used in the model for the DALY calculations are not specific to the Inuit population. Many of the components can reasonably be applied across generic populations. For example, the severity weights from the Global Burden of Disease (GBD) study (initiated by WHO in 1990) are applied globally, and were intended for such use. Other components such as mortality rates for particular indicator conditions could, in the future, be specified for the population of interest should such information be available.

7.8.3 Scenario analysis

To demonstrate the use of the tool to explore dietary options, two sets of scenarios were defined in terms of changes to the diet based upon alterations to the diet's makeup that are aimed at avoiding the exposure to contaminants recognized in country foods. The first set of scenarios is based upon the manipulation of the components of the diet that may be classified as country foods. These are referred to here as Country Food Scenarios. Country Food Scenarios assume no change in the consumption level of market foods. The second set of scenarios is based upon a balanced diet manipulation, referred to here as Balanced Diet Scenarios, in which the avoidance of one food leads to the increased consumption of another food that is not in the group classified as country foods. The scenarios are presented in Table 7.8.5. The scenarios presented here are not intended to represent the most appropriate or most realistic replacement scenarios that may be selected. Rather, they are intended to demonstrate the types of information that the tool can provide to support risk-based decision making for the dietary options and to explore if the complete avoidance of foods associated with contaminants results in the absence of adverse health effects.

Figure 7.8.1 presents the results for the scenarios in terms of the DALYs saved/lost under each dietary scenario. In this figure, DALYs saved are presented as positive numbers and DALYs lost are negative numbers. Each DALY saved is a benefit of a dietary change indicating a reduced burden of disease compared to the baseline diet. Conversely, DALYs lost indicate a diet associated with an increased burden of disease in the population as a result of the diet change compared to the baseline diet. Results show that the scenarios Extreme Overreaction and Selective Extreme Reaction A result in an increased burden of disease in the population, whereas the remaining scenarios result in reduced disease burden from diet (that is DALYs saved compared to the baseline).

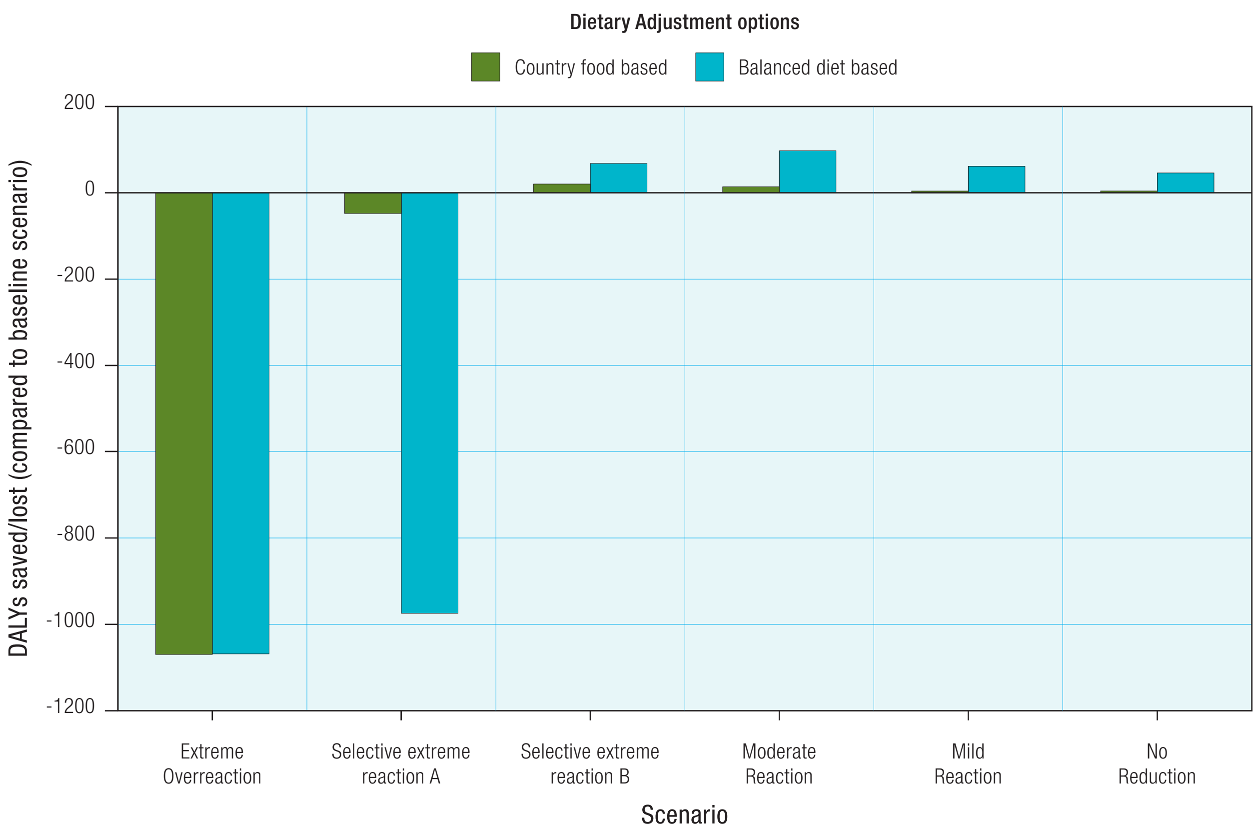

FIGURE 7.8.1

DALYs saved/lost compared to the baseline diet for each of the dietary scenarios considered. Note that a positive value indicates DALYs that are saved (and therefore an improvement over the baseline diet) and a negative value indicates DALYs that are lost to ill-health states.

TABLE 7.8.5 Changes in the amount of each food category consumed under the two sets of scenarios named Country Food scenarios and Balanced Diet scenarios. The changes presented in this table are multipliers on the amount of each food item applied for the scenario to the amount consumed under the baseline diet. Therefore, a multiplier of 1 indicates no change to the baseline diet. Changes are presented as [change for Country Food scenarios]/[change for Balanced Diet scenarios]. For example, 0.75/0.5 is presented for muktuk under the scenario Mild Reaction. This indicates that for the Country Food scenarios, the baseline amount is multiplied by 0.75, and for the Balanced Diet scenario the Baseline consumption amount is multiplied by 0.5 (that is, half the amount of muktuk is eaten under the scenario). Note that components of the diet not included in the table are unchanged from the baseline by the scenarios. This includes 43 different food items/categories.

Dietary Component	Scenario						
	Baseline	Extreme Overreaction	Selective extreme reaction A	Selective extreme reaction B	Moderate Reaction	Mild Reaction	No Reduction
Caribou, fresh/frozen/aged	1/1	0/0	1/0	1/1	1/1	1/1	1/1
Caribou dried	1/1	0/0	1/0	1/1	1/1	1/1	1/1
Muskox	1/1	0/0	1/0	1/1	1/1	1/1	1/1
Polar bear	1/1	0/0	0/0	1/0	1/1	1/1	1/1
Rabbit	1/1	0/0	1/0	1/1	1/1	1/1	1/1
Seal meat, fresh/frozen/aged	1/1	0/0	0/0	1/0	1/1	1/1	1/1
Seal meat, dried	1/1	0/0	0/0	1/0	1/1	1/1	1/1
Walrus meat, fresh/aged	1/1	0/0	0/0	1/0	1/1	1/1	1/1
Muktuk, total	1/1	0/0	0/0	0/0	0.5/0	0.75/0.5	1/0.9
Ptarmigan	1/1	0/0	1/0	1/1	1/1	1/1	1/1
Geese, dried	1/1	0/0	1/0	1/1	1/1	1/1	1/1
Geese/Ducks, fresh/smoked	1/1	0/0	1/0	1/1	1/1	1/1	1/1
Arctic char, fresh/frozen/aged	1/1	0/0	1/0	1/1	1.3/1	1.1/1	1.1/1
Arctic char, dried	1/1	0/0	1/0	1/1	1.3/1	1.1/1	1.1/1
CF Halibut	1/1	0/0	1/0	1/1	1/1	1/1	1/1
CF Trout, fresh/smoked	1/1	0/0	1/0	1/1	1/1	1/1	1/1
CF Whitefish	1/1	0/0	1/0	1/1	1/1	1/1	1/1
Eyes (caribou, seal,fish)	1/1	0/0	1/0	1/1	1/1	1/1	1/1
Beluga liver	1/1	0/0	0/0	1/0	1/1	1/1	1/1
Caribou liver	1/1	0/0	1/0	1/1	1/1	1/1	1/1
Seal liver	1/1	0/0	0/0	1/0	1/1	1/1	1/1
Walrus liver	1/1	0/0	0/0	1/0	1/1	1/1	1/1
Beluga fat/blubber	1/1	0/0	0/0	0/0	0.5/0	0.75/0.5	1/0.9
Caribou fat	1/1	0/0	1/0	0/1	0.5/0	0.75/0.5	1/0.9
Misirak	1/1	0/0	0/0	0/0	0.5/0	0.75/0.5	1/0.9
Narwhal fat/blubber, aged	1/1	0/0	0/0	0/0	0.5/0	0.75/0.5	1/0.9
Polar bear fat	1/1	0/0	0/0	0/0	0.5/0	0.75/0.5	1/0.9
Seal fat/blubber	1/1	0/0	0/0	0/0	0.5/0	0.75/0.5	1/0.9
Walrus fat	1/1	0/0	0/0	0/0	0.5/0	0.75/0.5	1/0.9
Chicken/turkey	1/1	1/1	1/1.3	1/1.2	1/1.1	1/1.1	1/1.1
Beef, ground or frozen beef patties	1/1	1/1	1/1.3	1/1.2	1/1.1	1/1.1	1/1.1
Beef, chuck/rump/cross-rib	1/1	1/1	1/1.3	1/1.2	1/1.1	1/1.1	1/1.1
T-bone steak	1/1	1/1	1/1.3	1/1.2	1/1.1	1/1.1	1/1.1
Pork chops	1/1	1/1	1/1.3	1/1.2	1/1.1	1/1.1	1/1.1
Spareribs	1/1	1/1	1/1.3	1/1.2	1/1.1	1/1.1	1/1.1
Wieners	1/1	1/1	1/1.3	1/1.2	1/1.1	1/1.1	1/1.1
Packaged luncheon meat	1/1	1/1	1/1.3	1/1.2	1/1.1	1/1.1	1/1.1
Fish sticks, frozen	1/1	1/1	1/1.3	1/1.2	1/1.1	1/1.1	1/1.1
Frozen, fried breaded chicken	1/1	1/1	1/1.3	1/1.2	1/1.1	1/1.1	1/1.1
Canned fish	1/1	1/1	1/1.3	1/1.2	1/1.1	1/1.1	1/1.1
Canned luncheon meat	1/1	1/1	1/1.3	1/1.2	1/1.1	1/1.1	1/1.1

To understand how the diet is contributing to the burden of disease, Figure 7.8.2 presents the total DALYs for each scenario broken out by the health end point categories. The results show that the main drivers of the risk are the health outcomes in the cancer and nutritional inadequacy categories, with nutritional inadequacy dominating the risk under the scenarios Extreme Overreaction and Selective Extreme Reaction A (where the scenarios are as presented in Table 7.8.5), accounting for an additional loss of DALYs in excess of 1,000 DALYs above the baseline diet in the population. In the remaining scenario nutritional status is improved, resulting in an overall gain in DALYs compared with the baseline. Figure 7.8.3 presents the breakdown of the risk estimate for each of the dietary scenarios by percentage contribution of each of the contaminants to the overall estimate of risk. In the case of cancer risk estimates the key drivers are lead and arsenic. For non-cancer health end points they are methylmercury and cadmium.

Figure 7.8.4 presents the percentage contribution of each nutrient to the total estimated DALYs attributed to nutrients for each dietary scenario. The results presented for the Balanced Diet set of scenarios show that the greatest driver of risk is the inadequate intake of folate. The findings are similar for the Country Food based scenarios and result from the combination of inadequate folate in the diet (compared with the intake requirements predicted from the EAR) and the high disease burden (that is DALY per case) associated with the indicator condition selected for folate inadequacy, which in this case is birth defects. While the outcome is related to the children of the population being considered, folate inadequacy was included in the burden of disease estimation process to ensure that inadequacy for this important nutrient was considered, and the indicator condition is essentially applied to the adult population as a surrogate for the future population burden that could be imposed by folate inadequacy

Simon Smith

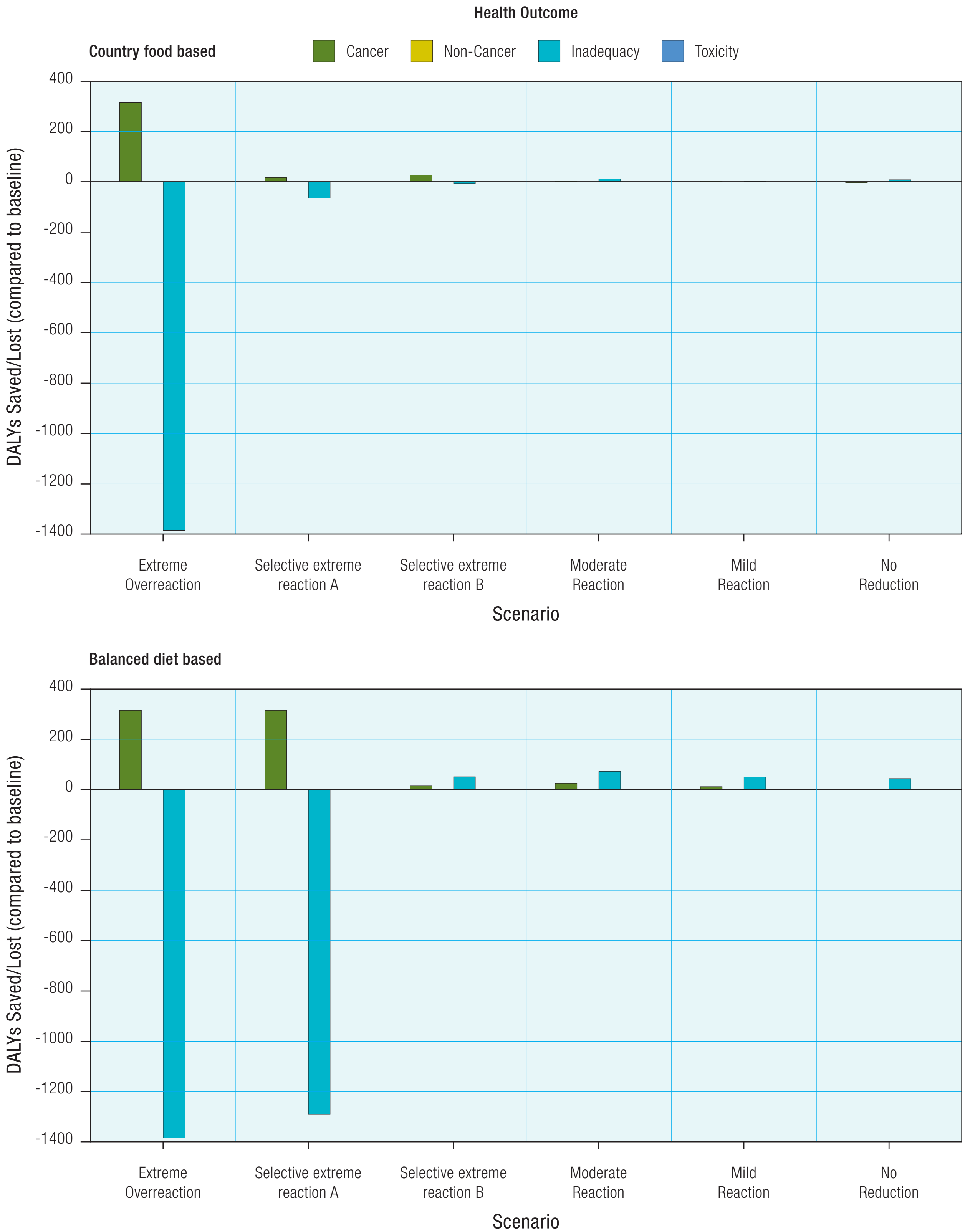

FIGURE 7.8.2

Breakdown of DALYs saved/lost by contributing factors. Note that a positive value indicates DALYs that are saved (and therefore an improvement over the baseline diet) and a negative value indicates DALYs that are lost to ill-health states. (a) country food based, (b) balanced diet based.

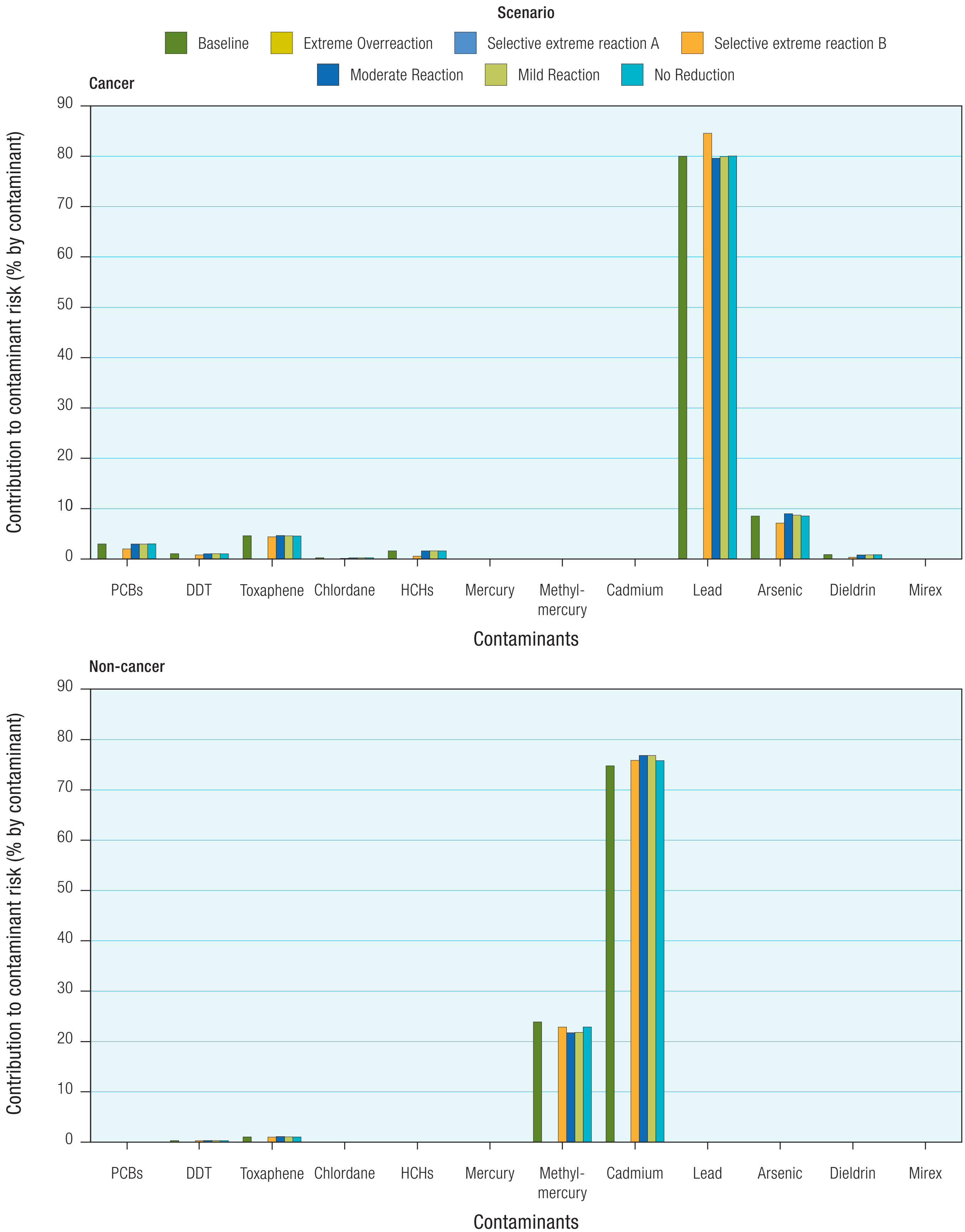

FIGURE 7.8.3

The contribution, by percentage, of each contaminant to the estimated burden of disease under each dietary scenario for the balanced diet set of scenarios for cancer (top) and non-cancer (bottom) health end points.

in women of child-bearing age. Compared with other nutritional outcomes the DALYs per case folate inadequacy are high. Therefore, a high incidence of folate inadequacy will dominate the risk. Considering the dominance of inadequacy in the overall burden of disease estimates for the scenarios Extreme Overreaction and Selective Extreme Reaction A, and to further examine the impact of folate inadequacy on model results, the disease burden from folate inadequacy was set to zero (essentially assuming no contribution to the overall disease burden from folate inadequacy). This would represent a situation where folate supplementation was advised to ensure adequate intakes. The results are presented in Figure 7.8.5. The overall pattern of the impact of dietary options remains the same because the contribution of folate to the disease burden is removed from all scenarios including the baseline. This indicates that in the absence of burden from folate inadequacy in the calculations, the risk for Extreme Overreaction (for both sets of scenarios) and Selective Extreme Reaction A (for the Balanced Diet scenarios) is still dominated by vitamin/mineral inadequacy. However the total or all scenarios are reduced from the estimated 20,000+ for the DALYs including consideration of folate inadequacy to less than 5,000 DALYs when folate inadequacy is no longer considered to contribute to the disease burden. This indicates that under current model assumptions the risks posed by inadequate intakes of folate dominate the overall dietary risk estimates. When folate is removed, the risks from vitamin B6 deficiency are the greatest contributor to nutritional-based risk but the overall estimated burden of disease is greatly reduced. With or without the inclusion of folate inadequacy in disease burden estimates, the scenarios Selective Extreme Reaction B, Moderate Reaction, Mild Reaction, and No Reduction result in DALYs saved compared to the baseline diet.

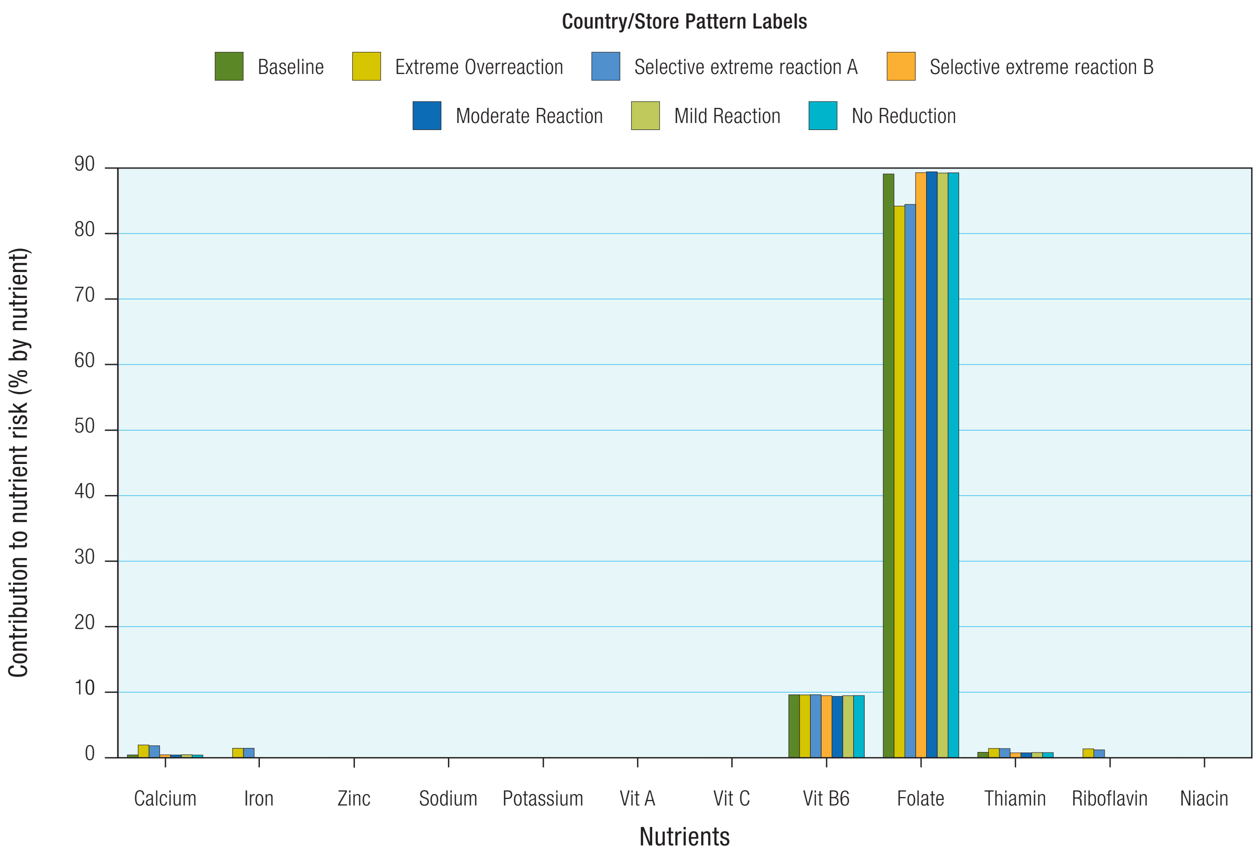

FIGURE 7.8.4

The contribution, by percentage, of each nutrient to the estimated burden of disease under each dietary scenario for the balanced diet set of scenarios.

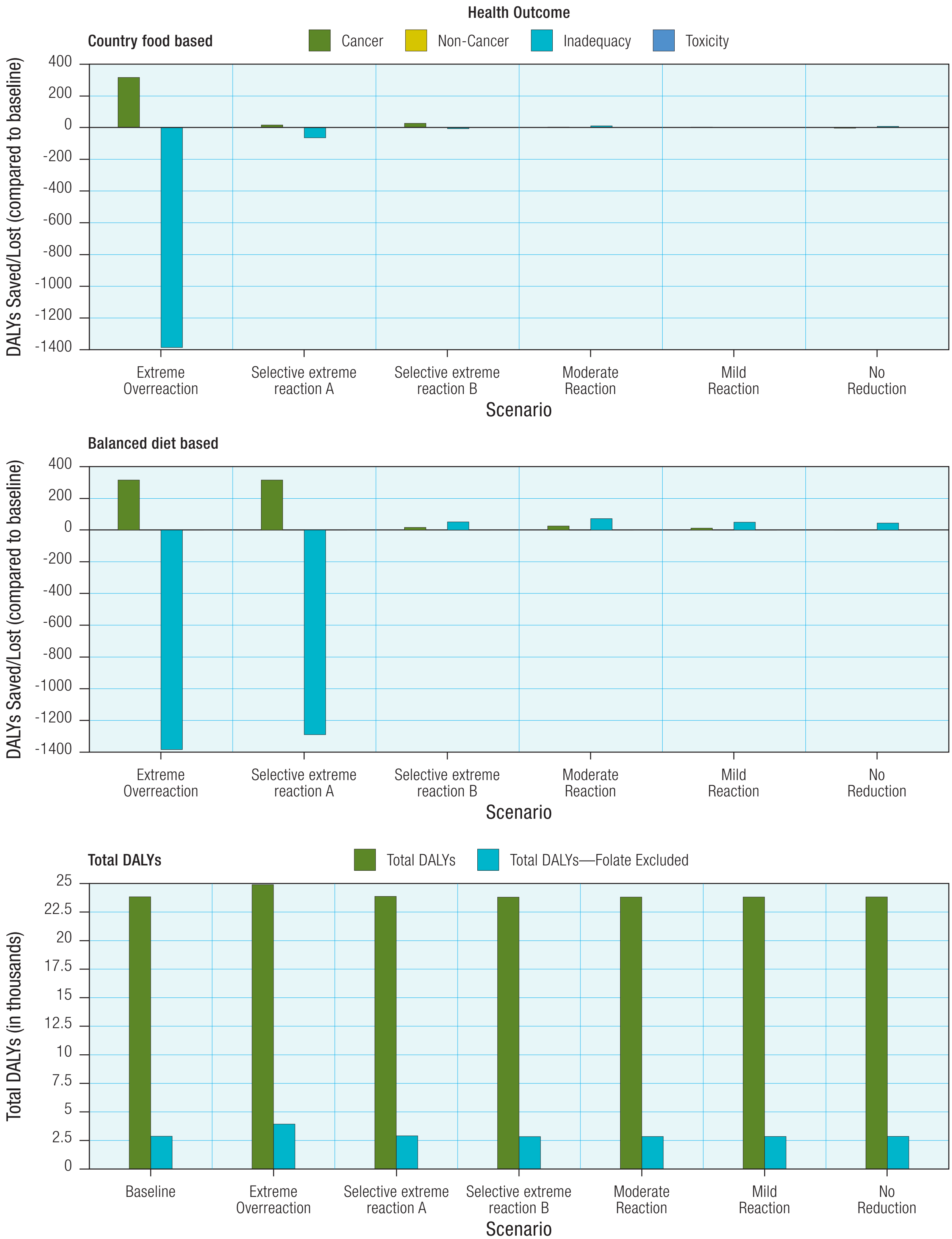

FIGURE 7.8.5

The impact of removing disease burden associated with folate from model estimates for the Country Food Based scenario (top left), Balanced Diet set of scenarios (top right) and the change in total DALYs (bottom).

7.8.4 Utility of the model

The results presented here show both risks and benefits associated with dietary options. The scenarios Extreme Overreaction and Selective Extreme Reaction A result in an increased burden of disease in the population (indicated by a loss in DALYs compared with the baseline diet), where as the scenarios Selective Extreme Reaction B, Moderate Reaction, Mild Reaction, and No Reduction all resulted in an improved level of population health based upon the comparison of DALYs to the baseline diet. This clearly illustrates that dietary options aimed at avoidance of contaminants can have both beneficial and detrimental impacts on the population health.

The model framework was created using Nunavik-specific data for country and market food consumption, nutrient and mineral intakes, and contaminant exposure. While this analysis provides detailed information on the impact of dietary components that has previously been absent, this analysis is still not a complete picture of the impact of dietary changes on the health of the Inuit population. The relationship between dietary choices and the health and welfare of a community is complex. For example, two key components are currently absent from the analysis presented here. First is an analysis of the impact of dietary options on the macronutrient intake levels (calories, fat, protein, etc.). There are many health links between increased intake of fat and excess calories, for example the increase in fat intake and rates of heart disease, and the increase in BMI resulting from excess caloric intake that leads to a number of adverse health effects such as heart disease, stroke, diabetes, etc. (e.g., Law and Wald, 2002). Dietary choices will impact the risks of developing health end points such as diabetes, stroke, and ischemic heart disease, the incidence of which are associated with appreciable morbidity and hence population burden of disease. A second key component that is not currently included in the tool is consideration of the socio-cultural impacts of dietary changes. There are many ways in which dietary changes can impact the socio-cultural health of the population, for example by leading to changes in cultural links between diet and community. These factors should not be excluded when considering the benefits and risks of dietary options. To date, the model has focused on quantitative assessment of contaminant and nutrient intakes. The other aspects of the support tool are still in the development stage. The final model will allow individuals to view possible outcomes of a recommended diet, incorporating both quantitative information (e.g., real contaminant exposure levels) and more qualitative parameters (e.g., user-defined consumption levels or changes in levels of certain health outcomes in the population). The output measure of health burden can be compared across possible dietary options.

Several applications for the model have been identified. These range from policy and case review, research planning, and prioritizing, to use in the decision processes related to the development and provision of health advisories on contaminants and country foods. Another potential application is to use past health advisory decisions as a basis for incorporating wildlife populations or economic modules into the model, which will be transferable to other populations because of its generic approach to the analytical components. The tool will likely be a valuable asset in decisions that involve balancing the risks and benefits of the consumption of country foods for northern and other Aboriginal populations.

7.9 Discussion and Conclusions

Knowledge about exposure to environmental contaminants (Chapter 4) and associated potential health effects (Chapters 5 and 6) has significantly increased since the previous assessment. Conducting epidemiological studies in the Canadian Arctic is a challenge due to a variety of limiting factors: exposure to complex contaminant mixtures, small population size, contaminant-nutrient interactions, genetic factors, confounders, and health priorities (see discussion in Chapter 6). In light of these factors, epidemiological studies conducted in other parts of the world on PCBs, lead, and methylmercury should be used as much as possible for risk assessment. However, different factors may limit their external validity, and studies in the Canadian Arctic need to continue.

When evaluating the impacts of contaminants on health and well-being of northerners, it is necessary to consider the broader health determinants. Environmental contaminants are just one factor that determines the health status of an individual. As discussed in Chapter 3, many health determinants such as physical well-being, education, gender, social support networks, and access to health services influence the health and well-being of northerners. Considering the many factors that influence health status, determining the potential adverse human health effects of contaminant exposure from a diet of country food is difficult.

Nutrition is a key determinant of health. Dietary choices have changed significantly over time in the Canadian Arctic (see Chapter 2). The amount of store-bought food in the diet of northerners has changed. Nevertheless, country food is still an important part of the overall diet. In almost all studies, country food consumption was associated with higher levels of nutrients in the diet, including vitamins A, D, E, B6, and B12, protein, iron, and omega-3 fatty acids. Those studies that compared present intake to past intake confirmed a decline in country food use, except for one study of pregnant women in the Inuvialuit region of Canada where an increase of fish consumption was reported while marine mammal fat consumption decreased. Three studies reported that younger generations consume significantly less country foods than older generations (Chapter 2).

The current nutrient transition in the Canadian Arctic has led to observed changes in intake levels of vitamins A, C, D, and E as well as iron, calcium, folate, omega-3 fatty acids, and fibre. The level of nutrition transition is dependant on the ratio of market food to country food and the food items consumed. Research suggests that a decreased intake of country food and an increased intake of high-energy (carbohydrate based), low-nutrient market food can contribute to a risk for Inuit communities of micronutrient deficiencies (Kuhnlein *et al.*, 2004) and diabetes. Decreasing intake of country food also increases the risk of obesity, which is associated with increased risk of chronic disease (Receveur and Kuhnlein, 2000).

Biomonitoring programs have provided key information about the levels and trends of contaminants in mothers and their infants. The contaminant trend and blood guideline exceedance data from mothers in the Inuvik region, Nunavut, and Nunavik presented in Chapter 4 suggests that levels of key environmental contaminants are declining in most cases. There has been a significant decrease in mercury levels in mothers from all regions. However, there are still cases where some mothers exceed the Health Canada 20 microg/L "increasing risk" range and a larger percentage that exceed the U.S. "reference dose" value of 5.8 microg/L. These results suggest that health intervention strategies should continue (e.g., that promote the consumption of less contaminated fish species), especially for women that are pregnant or that are of child-bearing age.

None of the samples from mothers in the Inuvik region, Nunavut, or Nunavik exceeded the 100 microg/L blood lead guideline. The ban of lead shot has reduced human exposure to lead and possible health effects (especially in children). Even though the levels of cadmium are relatively low in most groups, public health efforts to

reduce smoking could reduce cadmium exposure further and at the same time prevent health risks such as certain types of cancer and cardiovascular disease.

Considering that many people living in the Arctic are cash-poor and their food choices largely depend on what type of food they have access to, health promotion strategies to reduce exposure to environmental contaminants from a traditional diet that focus on changing people (i.e., beliefs, knowledge, habits) stand little chance of success. As discussed in section 7.6 of this chapter, strategies that focus on changing the availability of food choices stand the best chance of success.

The following risk management and communication conclusions can be drawn from this chapter:

- The inclusion, in some form, of the benefits of country food consumption along with the results of technical risk assessments to support the provision of information that will help residents in these regions make informed decisions about food and health has become critical to successful risk communication processes.
- The inclusion of various perspectives, including those of the population being exposed to the risks and benefits of country food consumption, has been shown to be one of the most important aspects of successful risk management strategies for this issue.
- Risk perception research has been valuable in showing the local perspectives and understandings of the issue; surveys and other qualitative assessments have shown that while the majority of the population has heard of contaminants, some confusion about the "chemical only" nature of the term by the research community exists and may create some barriers to message comprehension.
- In the Canadian Arctic, it appears as though the population that may be most at risk for contaminant exposure because of the sensitivity to contaminants or to nutritional deficiencies of the developing fetus is women of child-bearing age.
- Research conducted in the Canadian north indicates that contaminants are not a direct determinant influencing food choice among northern residents.
- Both northern residents and public health professionals require and request more information and support in dealing with the contaminant issue. Northern health professionals request more information support to interpret the implications of such things as technical risk assessment guidelines, viable risk optimization strategies, risk communication processes, and emerging issues in environmental health and toxicological research.
- New computer-based tools are being developed to support decision making for these issues. They are proving valuable in helping to summarize and synthesize an integrated view on both benefits and risks, but much work is required to further their utility by northern health professionals and other health and environment workers.
- Due to the rapid change going on in many northern communities (economic, political, social) and their influence on risk-benefit exposure via diet, regular monitoring of food consumption behaviour, food safety perspectives, and concerns and determinants of food choice would continue to support the development and provision of information that aids in informed decision making by northern residents.


INAC

Conclusions

This chapter presents the key conclusions from each chapter and their potential implications in assessing Arctic Canada's contaminant health issues.

8.1 Introduction

- There are many benefits associated with a diet of country food. There are numerous cultural, social, economic, nutritional, spiritual and psychological benefits associated with harvesting, processing and consuming country food for people living in the Canadian Arctic.
- At the same time, country food is a significant source of exposure to environmental contaminants. Many people who live in the Arctic consume country food on a regular basis. Their exposure to organochlorines and heavy metals is higher relative to many populations living in southern Canada.
- As a result, the risk management of and communication issues associated with exposure to environmental contaminants from a country food diet and the benefits of country foods is a difficult balance for public health professionals. This issue cannot be resolved simply by the provision of dietary advice or food substitutions alone.

8.2 Food and Dietary Research

Country food use and dietary change

- Country food makes a significant contribution to the overall quality of the diet of the people living in the Canadian Arctic. However, country food use is culturally specific and its consumption and diversity depends on many factors such as geographic location, the age of an individual, socio-economic status, and culture.
- Information on the dietary intakes across 44 communities of the Canadian Arctic, based on the most complete nutrient databases available, has now been published. An increase in country food in the diet correlates with an increase in the intake of protein, vitamins D and E, riboflavin, vitamin B6, iron, zinc, copper, magnesium, manganese, and potassium.
- In a 2006 market food survey, the weekly cost of a food basket for northerners in remote communities was significantly higher relative to southern Canadian cities or northern communities that were more accessible. Within the Yukon, weekly food basket costs were as high as $388 in the remote village of Old Crow compared with $163 in Whitehorse, and within the Northwest Territories (NWT) and Nunavut, costs were over $300 per week in most of the remote communities surveyed. In contrast, costs for a weekly food basket were $173 in Edmonton, $159 in Yellowknife, and $144 in Montreal. Thus, food costs in more remote communities are easily double that of the costs in accessible southern Canadian cities.
- Country food use studies that compared present intake to past intake confirmed a decline in country food use, except for one study among pregnant women in the Inuvialuit region of the Northwest Territories where an increase in fish consumption was reported, while marine mammal fat consumption decreased. Three studies reported that younger generations consume significantly less country food than older generations.
- A number of recent food use and dietary surveys have taken place in Arctic Canada. Each study involved an assessment of the extent of country food use and clarified the link between country food intake and contaminants, climate change, self-reported harvest data, risk-benefit assessment, and nutrient contribution in adults and children. Country food use is culturally specific and varies widely over the many communities and regions in the Canadian Arctic. Its diversity depends on many factors. Game meat and fat, fish, marine mammals, and edible plants and berries were consumed in different quantities depending on age, culture, latitude, and proximity to a major centre and water. The findings from eight studies reporting the contribution of country food to total dietary energy ranged from 4.3% to 89%, with a median value of 18% of total energy.

Health implications associated with changes in dietary habits

- The current dietary transition in the Canadian Arctic from a traditional to a market based diet has led to decreases in intake levels of vitamins A, C, D and E as well as iron, calcium, folate, omega- 3 fatty acids, and fibre. Research suggests that a decreased intake of country food and increased intake of high-energy (high carbohydrate), low nutrient market foods can contribute to a risk for Aboriginal communities of diabetes and micronutrient deficiencies. Decreasing intake of country food also increases the risk of obesity, which is associated with increased risk of chronic disease.

8.3 Human Exposure to Environmental Contaminants

General conclusions

- Many of the previous conclusions on the distributions of contaminant levels in regional populations are very similar to those seen in the late 1990s. Among the Inuit, Dene/Métis, and non-Aboriginal groups, the Inuit have the highest levels of almost all persistent organic pollutants (POPs) and metals.
- There are significant declines in almost all contaminants in maternal blood over the last 10 years (comparisons of samples collected between 1992–1996 to samples collected between 2004–2006) for all Canadian Arctic regions studied (NWT, Nunavut, Nunavik). A number of maternal contaminant levels are now less than one-half the levels they were less than 10 years ago.
- The levels of cadmium have not decreased and, in fact, have increased in the Inuvik, Baffin and Nunavik regions among young women and mothers. This has been linked to increased smoking in this age group and is a significant public health issue for all regional health authorities.

Contaminant tissue levels and guidelines

Polychlorinated biphenyls (PCBs)

- Comparing Health Canada guidelines to recent results from biomonitoring studies, 52% of Inuit from Nunavik and 25% of Inuit from Nunavut exceed the >5 microg/L PCB (measured as Aroclor 1260) *Level of Concern*; of these samples, none exceeded the >100 microg/L PCB *Action Level*. None of Dene/Métis or non-Aboriginal mothers exceed the >5 microg/L *Level of Concern*.
- Consistent with the overall decreasing levels of PCBs in maternal blood biomonitoring studies in Inuvik, Baffin and Nunavut, fewer mothers are exceeding the Health Canada *Level of Concern*.

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Mercury

- Only Inuit mothers from Nunavut and Nunavik exceeded the Health Canada guideline of 20 microg/L, (i.e., *Increasing Risk Range*) and 32 % of the mothers from Nunavut and 31% of the mothers from Nunavik exceeded the more recent US guideline of 5.8 microg/L.
- Mercury levels are decreasing in mothers from the Inuvik and Baffin regions and Nunavik, and the percent of mothers exceeding various blood guidelines are decreasing.

Lead

- There is an overall decrease in lead levels of mothers from the Inuvik region, Nunavut and Nunavik.
- The results of recent biomonitoring studies indicate that all of the mothers are below the 100 microg/L *Intervention Level* for lead set by Health Canada.

Cadmium

- The percent of mothers exceeding the 5 microg/L blood guideline for cadmium is relatively low. The highest exceedances are among Inuit from Nunavut.
- The percent of samples exceeding an occupational guideline of 5 microg/L cadmium has decreased from 6.4% (1998–1999) to 1.9% (2005–2006) among Inuvialuit mothers from the Inuvik region, and from 13% (1997) to 9.1% (2005–2007) among Inuit mothers from Baffin region. This decline in the percent of mothers exceeding the guideline is in opposition to the increasing levels seen in some of these groups. Since smoking is the primary source of cadmium, this is likely due to fewer mothers smoking but those who do smoke are smoking more.

Emerging contaminants

- The Inuit men, women and women of child-bearing age from Nunavik have very similar levels of polybrominated diphenylethers (PBDEs) to those seen among Inuit, Dene-Métis and Caucasians from Inuvik and Baffin regions but markedly lower levels than those seen in mothers from southern Quebec. Initial analyses on the Nunavik data indicate that PBDEs do not increase with age among men and women, and only PBDE 47 was weakly associated with marine mammal consumption. Concentrations of PBDE 47 in Inuit mothers from Inuvik and Baffin regions or Nunavik are lower than levels seen in the United States but higher than comparable groups in the United Kingdom.
- Comparisons of the concentrations of perfluorooctane sulfonate (PFOS) in the blood of mothers and women of child-bearing age from Nunavik collected in 1992 and 2004 show significant decreases over this time period. An initial analysis of PFCs in traditional foods of Arctic Canadians has not indicated that marine or terrestrial mammals will lead to high contaminant exposures

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- The Centre de Toxicologie du Quebec (CTQ) produces data that meet the Standards Council of Canada (SCC) requirements under the ISO/IEC 17025 standard. Internal quality control procedures ensure that data produced are reproducible over the long term (many years).
- For most comparisons of QA data using older and more recent technology, there was no significant bias that would affect the interpretation of samples analyzed in the past. In the few instances where this was not the case, correction factors were determined to allow comparison of contemporary and historical data.

8.4 Toxicology

Contaminants of concern

Polybrominated diphenylethers

- While continued uncertainty exists concerning the relevance of certain end points to humans, a recent summary suggests that, at least for the experimental effects involving thyroid hormones, there appears be a fairly large margin of safety between current exposures based on internal dose metrics and effects. However, if human tissue levels continue to increase at the current rate, they could conceivably reach similar levels associated with adverse effects in experimental animals.

Contaminant mixtures studies

- Data indicate that co-exposure to a mixture of chemicals appears to modify not only some tissue contaminant levels, but also appears to modify the toxicity of at least some contaminants such as methylmercury and PCBs.
- As co-exposure to chemicals that humans are frequently exposed to can affect both body burden and dose-toxicity relationships, single chemical toxicity studies may generate less applicable estimates of both tissue levels and toxicity for risk assessment.
- It is possible that some of the apparently discrepant results of epidemiological studies (e.g., Faroe versus Seychelles) may be related to the overall exposure profile that may alter the estimated toxicity of single chemicals like methylmercury or PCBs.

Nutrient–contaminant interactions

- Experimental evidence suggests that selenium may provide some protection against renal toxicity associated with cadmium exposure by blocking oxidative stress and by binding with cadmium and reducing its availability.

Toxicology and epidemiology: comparison of findings

- While, in theory, epidemiological studies are the most relevant to identify exposures that are detrimental to human health, toxicological studies are needed to support the biological plausibility of associations and to gain knowledge on the mechanisms of action and precise dose-effect relationships.
- Recent literature reviews indicate that research efforts should focus on improving the feasibility of including biomonitoring in both animal and human studies to facilitate comparisons between animal models and human studies. Animal and human studies should measure similar biomarkers where possible to facilitate human health risk assessment.
- Results from two animal studies suggest that some POPs with capacity to act as hormone mimics may be able to exacerbate *osteoporosis*. Studies with Greenlandic Inuit women revealed statistically significant associations ($p<0.05$) between bone strength measurements and PCB 156 concentrations, a congener with dioxin-like properties. This would suggest that dioxin-like compounds may decrease bone density and increase the risk of osteoporosis in Greenlandic women.

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8.5 Epidemiology

- Conducting epidemiological studies in the Canadian Arctic is a challenge due to a variety of limiting factors: exposure to complex contaminant mixtures; small population size; contaminant-nutrient interactions; genetic factors; confounders; and health priorities. For this reason, epidemiological studies conducted in other parts of the world on PCB, lead, and methylmercury-induced neurotoxicity have been used as much as possible for risk assessment. However, various unique factors may limit their external validity, and studies in the Canadian Arctic need to continue.
- New analytical technologies and study methods have been developed that now allow scientists to quantify human exposure to emerging POPs and POP metabolites and evaluate their health effects. Research is ongoing with child and adult cohorts in Nunavik, and data will be available in Nunavut, NWT, and Nunatsiavut in the next few years.

Immune system function

- In Nunavik, three successive studies reported that an increase in lower respiratory tract infections and *otitis media* during childhood were associated with prenatal exposure to POPs. These findings are also supported by data from the Faroe Islands that link immunization deficiency to increased contaminant exposure.

Neurodevelopment

- Studies conducted in the Arctic suggest that prenatal exposure to methylmercury, lead, and PCBs has distinct effects on child brain development. These effects are in accordance to those found in other parts of the world.
- Thyroid hormone disruption is still considered to be a possible mechanism of action of POPs on brain development. This hypothesis will have to be studied for legacy POPs and extended to their metabolites and to emerging POPs.

Polyunsaturated fatty acids (PUFAs)

- New data suggest important beneficial effects on brain development for Inuit infants by country food nutrients such as omega-3 fatty acids. These effects are seen in different domains than those that are attributable to contaminants exposure.

Sex hormone disruption

- Typical OC mixtures found in the Arctic contain a large variety of POPs, including substances with estrogenic, anti-estrogenic or anti-androgenic capacities. These OC compounds can interact with different receptors involved in cell differentiation and growth, and could affect reproduction and development, and be involved in the pathogenesis of hormonally responsive cancers.

Oxidative stress

- Investigations into the role of methylmercury and POPs exposure in the development of the metabolic syndrome, cardiovascular diseases, and diabetes are only beginning; therefore, the results are still preliminary and equivocal. Methylmercury may suppress defence mechanisms against oxidative stress (and ultimately promote atherosclerosis), decrease cardiac variability and increase blood pressure. POPs exposure may also be involved as a risk factor for the metabolic syndrome and diabetes.

8.6 Risk-Benefit Characterization and Communication

The risk characterization process

- The process for developing and delivering health advice requires input, cooperation and leadership from local health authorities and a number of stakeholders. As a result, the Northern Contaminants Program (NCP) uses a multi-stakeholder decision-making process. This includes collaborating with the various groups such as community groups, and Aboriginal organizations that would be affected by any risk management decision.

Risk communication

- Risk communication is a process that is continually evolving. A number of important changes have taken

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place within the NCP risk communication process over the past 16 years. In general, the volume of communication material and the frequency of messages sent to northern communities have decreased. This is an important step because frequent information about contaminants may overwhelm communities. Communication about the issue may be more efficient if it is built into existing public health messages. Another notable change is that there has been a shift from messages strictly on contaminants to situating the concern about contaminants within a broader public health context.

Ethical research and the NCP

- Research ethics are an important consideration in any project that involves people as research subjects, including medical or social science research. The NCP has invested considerable effort to ensure that research that takes place under the program respects the highest possible ethical standards. This has included the development of documents to guide research in the North, the establishment of committees to oversee the approval of research projects, and the continued improvement of processes such as obtaining informed consent and communicating research results.

Risk perception

- A number of risk perception studies have been conducted. In the 1992 Nunavik Inuit Health Survey, nearly 70% of Nunavummiut had heard about the presence of contaminants in the food chain, and most (87%) declared their desire to receive more information on the subject. Other authors have found that northern residents want specific information of a directly practical nature (e.g., sources of contaminants and their effects, safe levels of consumption) to help contextualize the risks associated with exposure to contaminants and support them in making their own judgements about the importance of this issue.

Food choice research

- The results of food choice research in the Arctic highlight that access to food items is a primary determinant of country food and market food choice. To date, research suggests that food access is commonly strongly associated with its availability (i.e., what the participants can obtain) within the participants' social network and the extent to which it was shared. In these cases, dietary intakes commonly reflected the type of food chosen by other people in their social network.

- Many people living in the Arctic are cash-poor and their food choices largely depend on the type of food to which they have easy access to. Health promotion strategies to reduce exposure to environmental contaminants from a country food diet that focus on changing people (i.e., their beliefs, knowledge, habits) stand little chance of success. Rather, strategies that focus on changing the availability of nutritious foods stand the best chance of success.

Risk management and communication case studies

- Preliminary findings of some Arctic case studies indicate that the most successful risk communication processes draw on and involve a variety of regional experts and the public in the formal communication process. Members of the public are involved in the risk assessment and communication process from the beginning of the risk identification phase. Explicit consideration of local perception and qualitative benefits and risks in the deliberation of the risk optimization strategies and message development are provided by local and Aboriginal experts in the risk communication process.

Risk management software

- A computer-based decision support tool has been recently developed in cooperation with the Nunavik Nutrition and Health Committee (NNHC), with funding from the NCP and Health Canada. The tool will be a valuable asset in decisions that involve balancing the risks and benefits of the consumption of country foods for northern and other Aboriginal populations. Several applications for this tool have been identified. These include policy and case review, research planning and prioritizing, and use in the decision processes related to the development and provision of health advisories on contaminants and country foods.

Ed Struzik

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Knowledge Gaps

9.1 Food and Dietary Research

Country food use and dietary change

- Research on country food availability, food safety, and food security should be completed. For risk management activities, it is important to continue this research.
- More research is required to identify the specific regional sources of contaminants in country foods.
- Future research in this area should consider the impacts of climate change and socio-economic change on country food safety and availability and general food security.

Health implications associated with changes in dietary habits

- Further analysis of dietary change in Arctic populations needs to be completed to access and explore any correlations and relationships between rising levels of chronic diseases (such as cardiovascular disease) and diet change. Also, research on current country food availability needs to be completed to explore relationships with current diet composition and risk of chronic diseases.

9.2 Human Exposure to Environmental Contaminants

- Further analyses of dietary data and recent human biomonitoring projects in Inuit regions of Arctic Canada need to be undertaken in order to better understand how the changing diet is impacting the levels of contaminants in northern peoples.
- More research is required to monitor levels of organochlorines (OCs) and metals in country food in order to better understand how levels of these contaminants are changing in the Canadian Arctic. This information is important to understand human tissue levels and the effectiveness of international contaminant control protocols.
- Further work should be carried out to assess human dietary exposure to contaminants in a small representative cross-section of highly and moderately exposed regions. This assessment will provide another time point with which to compare data from earlier phases of the program. The results will help provide an update of geographic patterns of exposure, and provide additional data to support temporal trend studies of contaminants in various northern populations. Consideration should be given to biological sampling of a subset of dietary survey participants as part of a verification process linking dietary intakes to concentrations found in blood, milk and other tissue.
- The traditional suite of contaminants (persistent organic pollutants [POPs] and metals) should continue to be monitored to ensure trend monitoring is available to confirm the decreasing levels seen over the last 10 years and for use in various national/international monitoring programs. Annual or biannual monitoring in select populations may need to be considered for more definitive trend assessments.
- New and emerging contaminants (e.g., polybrominated diphenylethers [PBDEs], perfluorooctane sulfonate [PFOS]) will need continued monitoring in Arctic peoples and their diet as some are increasing in Arctic wildlife. To date, any trends seen in Arctic peoples are very uncertain. Information on these emerging chemicals is also critical for policy makers who must decide if controls on these substances using various international and domestic instruments are warranted.

QA/QC

- External quality assessment schemes should ensure the comparability of contaminant levels obtained over long time periods, and in results generated by several laboratories. It is imperative that all laboratories contributing data to any long-term study be enrolled and participate actively in the appropriate scheme.

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9.3 Toxicology

- More research is required that focuses on identifying and better understanding the health effects of mixtures of contaminants that mimic the exposure profile of highly exposed Arctic peoples. The exposure profile used should be either that of maternal or cord blood (for infant and child development), or typical of a marine mammal diet (for other studies), and should be consistent with other Northern Contaminant Program (NCP)-funded toxicological studies using contaminant mixtures.

Polybrominated diphenylethers

- Results from ongoing human biomonitoring studies examining PBDEs in the Arctic should be compared to more recent toxicology findings to define more precisely the extent to which current dietary exposures or human residues are associated with a health risk.

Nutrient–contaminant interactions

- While experimental evidence exists that various dietary constituents, such as essential trace elements, vitamins and fatty acids, are capable of attenuating the toxicity of some food-borne contaminants, confirmation in human studies tends to be equivocal. Additional mechanism-of-interaction studies utilizing applicable dosing for both contaminants and a variety of dietary nutrients are required to further elucidate the health benefits of consuming country foods.

Epidemiology and toxicology findings

- The efficacy of vaccination programs in Inuit infants should be examined in relation to their OC exposure to further define the hypothesis that OCs decrease humoral immunity.
- The association noted between polychlorinated biphenyls (PCBs) and bone strength parameters in Inuit women is unclear. Future research could focus on improving this understanding by including all dioxin-like OCs. Research should also consider the possible effects of dioxin-like contaminants on tooth development and mineralization.

9.4 Epidemiology

- More research on identifying and characterizing the possible health effects in infants and children that are associated with prenatal exposure to contaminants should be carried out in northern regions characterized by exposure levels of concern to public health authorities.

- The possibility that nutrients present in seafood could modify or counteract the toxicity of contaminants is highly probable and specific to fish-eating populations. The interactions between nutrients present in seafood and the effects of contaminants need to be further studied.

Immune system function

- Vitamin A clinical deficiency has never been documented in Canadian Arctic populations. However, numerous studies have documented inadequate intakes of vitamin A. A more recent report suggests that the daily vitamin A intake in Nunavik falls below the recommended intake. Furthermore, some persistent organic pollutants have been shown to alter vitamin A *homeostasis* in many species, including primates. It is important, therefore, to gain a better understanding of the relationships between vitamin A, contaminant levels, and infectious disease incidence in Arctic populations.

Neurodevelopment

PCBs

- The study results on human growth and PCB exposure are contradictory in general population studies where the exposure does not come from fish or sea mammal consumption. When data from more highly exposed cohorts with PCB exposure due to fish and marine mammal consumption are compared, study results are also inconsistent but do not rule out the hypothesis of growth effects associated with *in utero* PCB exposure. Recent results underlined that individual susceptibility due to the presence/absence of specific genetic polymorphisms in studied populations may explain discrepancies between study results and emphasizes that genetic specificity of studied populations should be taken into account in future studies. Further investigation of genetic specificity of studied populations is needed to help bring forth a more complete scientific understanding of the human growth and PCB exposure studies.

- Investigations on the role of methylmercury and POPs exposure in the development of the metabolic syndrome, cardiovascular diseases and diabetes are only beginning and are still controversial. Methylmercury may suppress defence mechanisms against oxidative stress (and ultimately promote atherosclerosis), decrease cardiac variability, and increase blood pressure. POPs exposure may also be involved as a risk factor for the metabolic syndrome and diabetes. Further experimental and epidemiological work is needed in this area.

Omega-3 fatty acids

- The results on omega-3 fatty acids and child development highlight the importance of testing interactions when attempting to study the complex association between exposure to environmental contaminants and child development in fish/marine mammal-eating populations. This emphasizes the need to further study the complex association between nutrients and contaminants in these populations.

9.5 Risk-Benefit Characterization and Communication

Risk management process

- The framework for risk management has continued to evolve under the NCP; however, a common process that integrates all benefits and risks needs to be developed in order to assess scientific findings and assist decision making.

- Methods to evaluate and then compare the benefits and risks of traditional/country foods (and their alternatives) using a common denominator should be improved to provide better information to the health authorities making decisions.

Eric Loring

- Methods should be developed to assess risk-risk comparisons, so that the comparative risks of various courses of action can be compared.
- Risk-benefit evaluations and comparisons should be made with special reference to the most highly exposed communities and vulnerable groups (e.g., the fetus, infants, and children).

Communication

- Evaluations of prior risk communications about contaminants would provide knowledge necessary for the NCP program to continue to evolve. It 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.
- Both northern residents and public health professionals require/request more information and support in dealing with the contaminants issue. Northern health professionals request more support in the interpretation of the implications of technical risk assessment guidelines, viable risk optimization strategies, and risk communication processes and emerging issues in environmental health and toxicological research.

Risk perception

- Risk perception research has been valuable in showing the local perspectives and understandings of the issue. Surveys and other qualitative assessments have shown that while the majority of the population have heard of the issue of "contaminants", some confusion still exists that creates barriers to message comprehension. Increased knowledge about local risk perception is necessary to determine an effective way of decreasing barriers to message comprehension.

Food choice

- More research is needed to improve our understanding of what determines people's food choices in those northern regions where exposure levels are of concern to public health authorities, and to what extent contaminants are a factor in these choices. Particular reference needs to be made to mothers, pregnant women, other women of child-bearing age and children.
- Research is needed to evaluate food substitution and other management programs that reduce contaminant exposure in high exposure regions but still encourage consumption of highly valued traditional/country foods and other nutritional food sources.

Isabelle Dubois/ArcticNet

Risk-benefit characterization and communication tools

- Further development of decision-making software designed to summarize and integrate both benefits and risks is required to increase its relevance, accessibility, and ease of use by northern health professionals and other health and environment workers.

Monitoring of risk-benefit exposure and informed decision making

- The rapid changes occurring in many northern communities (economic, political, social, and environmental) and their influence on risk-benefit exposure through diet create the necessity for regular monitoring of food consumption behaviour, further understanding of food safety perspectives, as well as additional insight into determinants of food choice. These efforts would continue to support the development and provision of information that aids in informed decision making by northern residents.

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Appendix A: List of Acronyms

AA
Arachidonic acid

ADHD
Attention deficit hyperactivity disorder

AhR
Aryl hydrocarbon receptor

AI
Adequate intake

ALA
Alpha-linolenic acid

AMAP
Arctic Monitoring and Assessment Program

BMD
Bone mineral density

BMDL
Bench mark dose level

BMI
Body mass index

CACAR
Canadian Arctic Contaminants Assessment Report

CALUX
Chemically Activated Luciferase Expression

CANSIM
Canadian Socio-economic Information Management System

CBA
Child-bearing age

Cd
Cadmium

CI
Confidence interval

CINE
Centre for Indigenous Peoples' Nutrition and Environment

CNF
Canadian Nutrient File

CNS
Central nervous system

CoQ10
Coenzyme Q10

CSF
Cancer slope factor

CTQ
Centre de Toxicologie du Québec

CYFN
Council of Yukon First Nations

DALY
Disability adjusted life years

DBP
Diastolic blood pressure

DDE
Dichloro-diphenyldichloro-ethylene

DDT
Dichloro-diphenyl-trichloroethane

DGLA
Dihomogamma-linolenic acid

DHA
Docosahexaenoic acid

DRI
Dietary reference intakes

EAR
Estimated Average Requirement

EFA
Essential fatty acids

EPA
Eicosapentaenoic acid

FFQ
Food frequency questionnaires

FMD
Fetal minamata disease

FSH
Follicle-stimulating hormone

GBD
Global Burden of Disease

GSH
Glutathione

GSHPx
Glutathione peroxidise

GSHRd
Glutathione reductase

HBCD
Hexabromocyclododecane

HCB
Hexachlorobenzene

HCH
Hexachlorocychlohexane

HDL
High density lipoprotein

Hg
Mercury

HRT
Hormone replacement therapy

ICC
Inuit Circumpolar Council

INSPQ
Institut national de santé publique du Québec

ITK
Inuit Tapiriit Kanatami

LA
Linoleic acid

LDL
Low density lipoprotein

LH
Luteinizing hormone

LRTI
Lower respiratory tract infection

MeHg
Methylmercury

NAG
Neutral-alpha glucosidase

NADPH
Nicotinamide adenine dinucleotide phosphate

NCP
Northern Contaminants Program

NDSS
National Diabetes Surveillance System

NNHC
Nunavik Nutrition and Health Committee

NOAEL
No observed adverse effect level

NRCHI
Nunavut Report on Comparable Health Indicators

NWT
Northwest Territories

OC
Organochlorine

OxLDL
Oxidized low density lipoprotein

Pb
Lead

PBC
Perceived behavioural control

PBDE
Polychlorinated diphenyl ether

PCB
Polychlorinated biphenyl

PFAA
Perfluoroalkyl acid

PFC
Perfluorochemical

PFOA
Perfluorooctanoic acid

PFOS
perfluorooctane sulphate

PHAC
Public Health Agency of Canada

PHD
Public health director

PNB
Personal normative belief

PND
Postnatal day

POP
Persistent organic pollutant

PP
Pulse pressure

PTWI
Provisional Tolerable Weekly Intake

PUFA
Polyunsaturated fatty acid

PYLL
Potential years of life lost

QA/QC
Quality assurance/quality control

QMEQAS
Quebec MultiElement Assessment Scheme

QUS
Quantitative ultrasound

RCC
Regional contaminants coordinators

RDA
Recommended dietary allowance

SBP
Systolic blood pressure

SCC
Standards Council of Canada

Se
Selenium

SPE
Solid-phase extraction

T3
Triiodothyronine

T4
Thyroxine

TCDD
Tetrachlorodibenzo-*p*-dioxin

TDI
Tolerable daily intake

TOH
Tocopherol

TPB
Theory of planned behaviour

TRA
Theory of reasoned action

TSH
Thyroid stimulating hormone

UL
Tolerable upper intake level

URTI
Upper respiratory tract infection

VEP
Visual-evoked potentials

YLD
Years lived with disability

YLL
Years of life lost

WHO
World Health Organization

Appendix B: Blood Contaminant Concentrations, Wet Weight Data (microg/L plasma)

TABLE B 4.2.1 Contaminant concentrations found in Dene/Métis, Inuvialuit and Non-Aboriginal Mothers from the Inuvik region (Geometric mean (range), POPs microg/L plasma)

Organochlorine contaminants	Dene/Métis			Inuvialuit			Non-Aboriginal		
	Baseline 1998–1999[1] 24 (18, 35)[3] (n=41)[4]	Follow-up 2005–2006[2] 24 (16, 36)[3] (n=17)[4]	SD[5]	Baseline 1998[1] 23 (15, 37)[3] (n=31)	Follow-up 2005[2] 26 (17, 38)[3] (n=52)	SD[5]	Baseline 1998[1] 31 (19, 45)[3] (n=21)	Follow-up 2005[2] 32 (23, 40)[3] (n=6)	SD[5]
Oxychlordane	0.04 (0.01-0.22)	0.01 (0.00-0.04)	SD[c]	0.15 (0.03-1.06)	0.07 (0.00-1.0)	SD[b]	0.04 (0.02-0.07)	0.01 (0.01-0.03)	SD[b]
Trans nonachlor	0.05 (0.01-0.37)	0.02 (0.01-0.08)	SD[c]	0.28 (0.05-1.8)	0.12 (0-2.2)	SD[b]	0.05 (0.02-0.11)	0.01 (0.01-0.04)	SD[b]
p,p'-DDE	0.51 (0.17-1.8)	0.30 (0.11-1.2)	SD[a]	1.1 (0.4-3.8)	0.65 (0.05-7.4)	SD[b]	0.57 (0.22-2.1)	0.33 (0.15-0.95)	NS[6]
Toxaphene-Parlar 50	NA[7]	NA	SD[c]	NA	NA	SD[b]	NA	NA	SD[b]
PCB 138	0.08 (0.02-0.5)	0.03 (0.01-0.1)	SD[c]	0.19 (0.05-0.6)	0.07 (0.00-0.8)	SD[c]	0.08 (0.03-0.2)	0.02 (0.01-0.06)	SD[b]
PCB 153	0.12 (0.02-1.1)	0.05 (0.01-0.29)	SD[b]	0.26 (0.06-0.88)	0.14 (0.00-1.3)	SD[b]	0.11 (0.03-0.27)	0.04 (0.02-0.08)	SD[b]
PCB 180	0.07 0.02-0.63	0.03 0.01-0.34	SD[a]	0.08 (0.02-0.3)	0.06 (0.0-0.44)	NS	0.65 (0.1-2.3)	0.22 (0.1-0.9)	SD[b]

1 Tofflemire, 2000
2 Armstrong *et al.*, 2007
3 Age of group sampled (arithmetic mean, range)
4 1998-1999 (N=41 for Metals and N=42 for organochlorines), 2005-2006 (N=17 for organochlorines and N=18 for metals)
5 SD = Significant difference (p<0.05)
SD[a] = significant difference, p=(<0.05-0.01)
SD[b] = significant difference, p=(0.01-0.001)
SD[c] = significant difference, p=(0.001-<0.0001)
6 NS = not significant
7 NA = not available

TABLE B 4.3.1 Contaminant concentrations in Inuit mothers from Nunavut-Baffin region (geometric mean (range), POPs microg/L)

Organochlorines Contaminants	Baseline 1997[1 a, b] 24 (15-39)[3] (n=30)[4]	Follow-up 2005–2007[2] 24 (15-39)[3] (n=100)[4]	SD[5]
Oxychlordane	0.58 (0.09-2.4)	0.23 (0.04-1.9)	<0.0001
Trans nonachlor	0.64 (0.16-2.5)	0.32 (0.03-2.3)	<0.0001
p,p'-DDE	2.1 (0.55-6.0)	1.1 (0.13-5.9)	<0.0001
Toxaphene – Parlar 50	0.13 (0.03-0.66)	0.08 (0.007-1.0)	0.0008
PCB 138	0.51 (0.12-1.5)	0.14 (0.032-0.72)	<0.0001
PCB 153	1.0 (0.25-3.9)	0.37 (0.08-2.2)	<0.0001
PCB 180	0.4 (0.07-1.8)	0.16 (0.03-1.2)	<0.0001

1 a) Butler-Walker, 2003,
b) Butler-Walker, 2006
2 Potyrala, M., 2008, personal communication
3 Age of group sampled (arithmetic mean, range)
4 Number of individuals sampled
5 SD = significant difference (p<0.05)

TABLE B 4.4.2 Time trends of contaminants in Inuit pregnant women from Nunavik (Québec) (geometric mean (range). POPs microg/L plasma)

Organochlorines Contaminants	1992[1] 24 (18-35)[6] (n=11)	1996[2] 24 (17-34)[6] (n=25)	1997[2] 25 (15-41)[6] (n=53)	1998[2] 25 (15-37)[6] (n=46)	1999[2] 26 (17-36)[6] (n=26)	2000[2] 26 (17-39)[6] (n=36)	2001[2] 27(17-39)[6] n=20	2004[3] 27 (18-42)[6] n=29	2007[8] 24 (18-37)[6] n=39	SD[4, 5] (p<0.05)
Oxychlordane	0.57 (0.21-2.8)	0.34 (0.05-1.7)	0.36 (0.08-3.9)	0.26 (0.05-2.7)	0.32 (0.07-1.5)	0.27 (0.04-2.3)	0.24 (0.04-1.2)	0.27 (0.06-1.9)	NA	0.004
Trans-nonachlor	0.84 (0.35-3.7)	0.55 (0.11-2.4)	0.56 (0.12-3.3)	0.41 (0.07-4.6)	0.42 (0.10-1.8)	0.41 (0.08-3.4)	0.36 (0.07-1.6)	0.5 (0.11-3.4)	NA)	0.0006
p,p'-DDE	4.7 (1.9-18)	2.4 (0.5-9.7)	2.8 (0.54-14)	2.0 (0.34-18)	2.0 (0.63-9.9)	1.9 (0.37-15)	1.6 (0.38-13)	1.8 (0.43-7.7)	NA	<0.0001
Toxaphene-Parlar 50	NA[7]	NA	NA	NA	NA	NA	NA	NA	NA	NA
PCB 138	0.84 (0.29-2.5)	0.48 (0.08-2.0)	0.52 (0.11-3.1)	0.35 (0.06-3.1)	0.43 (0.08-1.4)	0.37 (0.06-3.0)	0.36 (0.06-1.5)	0.28 (0.06-1.0)	NA	<0.0001
PCB 153	1.27 (0.46-3.3)	0.87 (0.15-3.9)	0.95 (0.21-6.1)	0.63 (0.14-5.6)	0.79 (0.15-3.0)	0.65 (0.08-5.2)	0.56 (0.08-3.8)	0.55 (0.12-2.0)	NA	<0.0001
PCB 180	0.66 (0.22-1.3)	0.36 (0.06-1.8)	0.38 (0.08-2.2)	0.27 (0.06-2.2)	0.36 (0.08-2.0)	0.28 (0.03-2.3)	0.30 (0.04-2.2)	0.24 (0.05-1.3)	NA	<0.0001

1 Santé Québec, 1994.
2 Muckle *et al.*, 2003
3 Dewailly *et al.*, 2007a and b
4 Special Analysis–Pereg, 2007
5 SD = Significant difference (p<0.05), using ANOVA adjusted for age and region (Hudson or Ungava), regression adjusted for age and region (Hudson or Ungava) and smoking status (smoker. ex-smoker. non-smoker)
6 Age of group sampled (arithmetic mean, range)
7 NA = Not available
8 Pereg *et al.*, 2008

TABLE B 4.4.3 Contaminant concentrations in Inuit men from Nunavik in 1992 and 2004 (geometric mean and range), (POPs microg/L plasma)

Organochlorines Contaminants	Inuit Men Nunavik 1992[1] 36 (18-74)[3] (n=210)	Inuit Men Nunavik 2004[2] 37 (18-74)[3] (n=408)	SD[4]
Oxychlordane	0.87 (0.01-21)	0.40 (0.005-9.3)	<0.0001
Trans-nonachlor	1.3 (0.04-18)	0.71 (0.008-22)	<0.0001
p,p'-DDE	7.5 (0.76-96)	2.8 (0.076-49)	<0.0001
Toxaphene – Parlar 50	NA[5]	NA	NA
PCB 138	1.3 (0.05-13)	0.47 (0.03-8.1)	<0.0001
PCB 153	2.1 (0.07-19)	1.2 (0.051-20)	<0.0001
PCB 180	1.3 (0.04-18)	0.68 (0.039-11)	<0.0001

1 Santé Québec, 1994
2 Dewailly *et al.*, 2007 a and b
3 Age of group sampled (arithmetic mean, range)
4 SD = significant difference (p <0.05), Dewailly 2007a
5 NA = not available

TABLE B 4.4.4 Contaminant concentrations in Inuit women from Nunavik in 1992 and 2004 (geometric mean (range), POPs microg/L plasma)

Organochlorines Contaminants	Inuit Women Nunavik 1992 35 (18-73)[3] (n=282)	Inuit Women Nunavik 2004 37 (18-74) (n=498)	SD[4]
Oxychlordane	0.72 (0.02-11)	0.41 (0.01-16)	<0.0001
Trans-nonachlor	1.0 (0.05-12)	0.73 (0.02-22)	<0.0001
p,p'-DDE	6.2 (0.42-74)	2.9 (0.19-54)	<0.0001
Toxaphene – Parlar 50	NA[5]	NA	NA
PCB 138	1.1 (0.07-11)	0.46 (0.03-19)	<0.0001
PCB 153	1.6 (0.11-16)	0.98 (0.04-41)	<0.0001
PCB 180	0.9 (0.04-15)	0.47 (0.02-23)	<0.0001

1 Santé Québec, 1994
2 Dewailly *et al.*, 2007 a and b
3 Age of group sampled (arithmetic mean, range)
4 SD = significant difference (p <0.05), Dewailly 2007a
5 NA = not available

TABLE B 4.5.1 Concentrations of polybrominated diphenyl ethers (PBDEs) in Dene-Métis, Inuit and Non-Aboriginal mothers in the Inuvik and Baffin regions. (geometric mean (range), microg/L plasma)

	Non-Aboriginal	Dene-Métis	Inuit	
Emerging Contaminants	Inuvik[1] (2005–2006) 32 (23-40)[3] (n=6)	Inuvik[1] (2005–2006) 25 (16-36)[3] (n=17)	Inuvik[1] (2005–2006) 26 (17-38)[3] (n=52)	Baffin[2] (2007) 24 (15-39)[3] (n=99)
PBDE 47	0.10 (0.03-0.9)	0.06 (0.02-0.3)	0.10 (0.02-4)	0.04 (0-1.0)
PBDE 99	0.02 (0.01-0.1)	0.01 (0.01-0.06)	0.02 (0.01-1.3)	0.01 (0-1.0)
PBDE 100	0.02 (0.01-0.1)	0.01 (0.01-0.04)	0.02 (0.01-0.8)	0.01 (0-0.2)
PBDE 153	0.01 (0.005-0.05)	0.02 (0.005-0.04)	0.02 (0.005-0.6)	0.02 (0-0.1)

1 Armstrong *et al.*, 2007 (special analysis for this report)
2 Potyrala, 2008, personal communication
3 Age of group sampled (arithmetic mean, range)

TABLE B 4.5.2 Plasma concentrations of emerging contaminants in Nunavik (geometric mean (range), PFOS[1] microg/L and PBDE[2] ng/L plasma)

		Nunavik		
		Men (18-74)[3] n=402	**Women (18-74)[3] n=494**	**WCBA[4] (18-39)[3] n=301**
PFOS[5] (microg/L)		21 (2.8-470)	16 (0.5-200)	13 (2.3-97)
PBDE[5] (ng/kg)	47	36 (<ND[6]-610)	37 (<ND[6]-2400)	40 (<ND[6]-2400)
	99	<ND[6] (<ND[6]-440)	<ND[6] (<ND[6]-575)	<ND[6] (<ND[6]-575)
	100	<ND[6] (<ND[6]-360)	<ND[6] (<ND[6]-580)	<ND[6] (<ND[6]-580)
	153	24 (<ND[6]-620)	13 (<ND[6]-406)	11 (<ND[6]-406)

1 Perfluorooctane sulfonate (PFOS)
2 Polybrominated Diphenyl ethers (PBDEs)
3 Age of group sampled
4 Women of child bearing age
5 Dewailly *et al.*, 2007
6 Not Detected (ND)