Human Biomonitoring of and Determinants of Biomarker Levels for Contaminants and Nutrients in Old Crow, Yukon Territory

by

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Examining Committee Membership

The following served on the Examining Committee for this thesis. The decision of the Examining Committee is by majority vote.

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

I was the sole author for Chapters 1, and 5. Committee members provided editorial advice on these chapters.

This thesis consists, in part, of three manuscripts that I wrote for publication, in collaboration with co-authors. All three manuscripts results collected as part of the Old Crow Biomonitoring Project (The Project), which was initiated prior to the beginning of this doctoral thesis. Dr. Brian Laird and Dr. Kelly Skinner were the Principal Investigators on grants from the Northern Contaminants Program (NCP) and Global Water Futures, which supported The Project. Other investigators on the original NCP grant included Mary Gamberg (Gamberg Consulting), William Josie (VGG), Megan Williams (VGG), Dr. Brendan Hanley (Chief Medical Officer of Health, Yukon), Kim Hickman (Yukon Health and Social Services), Dr. Chris Furgal (Trent University), Dr. Amanda Boyd (Washington State University), and Dr. Michele Bouchard (Université de Montréal). Planning of the biomonitoring clinic was coordinated primarily by Dr. Mylene Ratelle, with support from other members of the research team, including myself. Surveys were piloted in the community by Victoria Leger and Mary Gamberg. Biomonitoring clinic implementation in Old Crow was conducted by a team including Frances Lord (the local coordinator from Old Crow), myself, Dr. Ratelle, Mary Gamberg, Sara Packull-McCormick (University of Waterloo), Connor Menzies-Judge (University of Waterloo), and Alyssa Sgro (Trent University). Biological samples were analyzed in the laboratories of: Dr. Michele Bouchard at the Université de Montréal (metals in whole blood and metals and creatinine in urine), Dr. Ken Stark at the University of Waterloo (omega-3 fatty acids in plasma), Dr. Alain Leblanc at Centre de Toxicology du Québec (POPs in plasma and mercury in urine), and Brian

Branfireun at Western University (mercury in hair). I returned the results to the community in person with Mary Gamberg, and Joshua Garcia-Barrios.

Research presented in Chapter 2:

Drysdale, M., Ratelle, M., Skinner, K., Garcia-Barrios, J., Gamberg, M., Williams, M., Majowicz, S. et al., Human biomonitoring results of contaminant and nutrient biomarkers in Old Crow, Yukon, Canada. Science of the Total Environment;760(15) (2021) (https://doi.org/10.1016/j.scitotenv.2020.143339).

As the first author on this paper, I conducted all data tabulation and analysis, and drafted the manuscript. I conducted all analyses of laboratory data included in this thesis, and reporting, including plain language community reports and peer review publication under the supervision of Dr. Laird, as part of this thesis. Co-authors on Chapter 2 provided editorial and technical advice on the manuscript. Individual results letters were compiled by Dr. Ratelle, Stephen Bell, and myself.

Research presented in Chapter 3:

Drysdale, M., Ratelle, M., Majowicz, S., Brammer, J., Gamberg, M., Skinner, K., Laird, B. Traditional food consumption and other determinants of blood and urinary lead, cobalt, manganese, and hexachlorobenzene in Northern Canada. Prepared for Arctic. (2022).

As the first author on this paper, I conducted all data tabulation and analysis, and drafted the manuscript. I conducted the statistical data analysis, with guidance from Dr. Laird and Dr. Shannon Majowicz. All co-authors on Chapter 3 (Dr. Mylene Ratelle, Dr. Shannon Majowicz,

Jeremy Brammer, Mary Gamberg, Dr. Kelly Skinner, and Dr. Brian Laird) provided editorial and technical advice on the manuscript.

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As the first author on this paper, I designed this study, conducted all data tabulation and analysis, and drafted the manuscript. Dr. Laird was the principal investigator for the traditional food sampling program in Old Crow, and other investigators include Mary Gamberg, Jeremy Brammer (VGG), and Megan Williams (VGG). Coordination of sample collection by local harvesters was conducted by Mallory Drysdale (remotely), Jeremy Brammer (in Old Crow) and Mary Gamberg (remotely). Sample processing and shipping was conducted by Jeremy Brammer and Mary Gamberg. Traditional food samples were analyzed at ALS Laboratories in Burlington, ON. I conducted the statistical data analysis, with guidance from Dr. Laird and Dr. Shannon Majowicz. Dr. Brian Laird, Dr. Kelly Skinner, Dr. Shannon Majowicz, Mary Gamberg, Jeremy Brammer, and Sara Packull-McCormick provided editorial and technical advice on the manuscript.

Abstract

Traditional food is an important part of the diet for many Arctic residents, particularly First Nations, and is associated with some improved health outcomes, nutrition, and food security. However, these foods can also pose potential risks via exposure to certain contaminants, including those which are found at higher levels in the Arctic. Several large-scale human biomonitoring projects have been conducted in Canada, however, prior to the one herein, none have recruited participants living in the Yukon. This thesis used the results of a human biomonitoring clinic conducted in Old Crow, Yukon, in 2019 to respond to community questions and concerns regarding human exposure levels of contaminants and nutrients in the community, and how these levels relate to traditional food consumption and other lifestyle and demographic determinants. The clinic included the collection of hair, blood, and urine samples for the analysis of contaminants and nutrients, and the administration of dietary and health messaging surveys. This thesis compared results of the clinic those from reference populations and health-based guidance values. Levels of most measured contaminants and nutrients, including most metals (e.g. mercury, cadmium), and persistent organic pollutants (POPs) (e.g. polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT)) were similar in Old Crow to those in the general Canadian population and were below available health-based guidance values. Some contaminants and nutrients, including the metal nutrients manganese and cobalt, the toxic metal lead, and the pesticide hexachlorobenzene (HCB), were elevated in Old Crow relative to the general Canadian population. These contaminants and nutrients were analyzed further to identify potential local determinants of urine and blood levels. Generalized linear models were run to identify significant associations between blood and urine levels of these substances, with factors including demographics, lifestyle risk factors, and traditional food consumption. Old Crow participants had higher levels of some key contaminants and nutrients if

they reported eating some traditional foods, including moose bones in soup or stew (86% higher urinary average manganese levels), caribou kidneys (22% higher average blood manganese levels and 58% higher average blood lead levels), and whitefish (28% higher average blood cobalt levels). Associations between moose and caribou organ consumption and levels of lead and HCB were also observed in reference populations in the Dehcho and Sahtú regions of the Northwest Territories, and a pooled population including those regions and Old Crow. However, no individual determinants were associated with HCB plasma levels Old Crow. In an effort to estimate dietary exposure to HCB in the community of Old Crow, a stochastic model was constructed based on dietary surveys and traditional food sampling conducted in the region. This model also estimated intake of healthy omega-3 fatty acids, including eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) from the same foods. Modeling showed that the majority (>60%) of estimated dietary HCB intake in Old Crow was from lipid-rich caribou organs, such as fat, bone marrow, ribs, and kidney. Estimated dietary intake of HCB was below relevant health-based guidance values for all participants. Traditional foods, particularly fish, were also identified as a significant source of healthy omega-3 fatty acids. The results of this thesis support the conclusion that the benefits of traditional food consumption generally outweigh the risks of contaminant exposure for this population.

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List of Abbreviations

AMAP: Arctic Monitoring and Assessment Programme

BE: Biomonitoring Equivalent

BW: Body weight

CDWQ: Canadian Drinking Water Quality

CHMS: Canadian Health Measures Survey

CI: Confidence interval

CRA: Community Research Agreement

DDE: dichlorodiphenyldichloroethylene

DDT: dichlorodiphenyltrichloroethane

DEW: Distant Early Warning

DHA: docosahexaenoic acid

EPA: eicosapentaenoic acid

FFQ: Food Frequency Questionnaire

FNBI: First Nations Biomonitoring Initiative

FNFNES: First Nations Food, Nutrition, and Environment Study

GM: Geometric mean

GWF: Global Water Futures

HCB: hexachlorobenzene

HCH: hexachlorocyclohexane

HMS: Health Messages Survey

HQ: Hazard Quotient

IPY-IHS: International Polar Year Inuit Health Survey

IR: Intake rate

ISR: Inuvialuit Settlement Region

LOD: Limit of detection

NCP: Northern Contaminants Program

NHANES: National Health and Nutrition Examination Survey

NNC: Nutrition North Canada

NOAEL: No Adverse Effect Level

NSERC: Natural Sciences and Engineering Research Council of Canada

NSTP: Northern Scientific Training Program

NWT: Northwest Territories

PBB: Polybrominated biphenyls

PBDE: Polybrominated diphenyl ethers

PCB: polychlorinated biphenyls

PFAS: perfluoroalkylated substances

PFOA: perfluorooctanoic acid

PFOS: perfluorooctane sulfonate

PUFA: Polyunsaturated fatty acid

POP: Persistent organic pollutant

RNFB: Revised Northern Food Basket

RV: Reference value

TDI: Tolerable Daily Intake

USEPA: United States Environmental Protection Agency

VGFN: Vuntut Gwitchin First Nation

VGG: Vuntut Gwitchin Government

WHO: World Health Organization

YT: Yukon Territory

List of Symbols

95P: 95th percentile

g: gram

L: litre

ng: nanogram

µg: micrograms

r: Correlation coefficient

X2: Chi-squared

Spearman ρ: Spearman rho

1 Introduction

1.1 Contaminant Burden in the Arctic

The Arctic is an area that is particularly vulnerable to environmental contamination from both nearby point sources and long distance sources from outside of the Arctic region (1). Contamination originating from the Arctic can be anthropogenic (human-created), such as increased arsenic concentrations in gold mine tailings ponds, or natural, such as increased lead in surface and groundwater due to contact with naturally enriched rock formations (2). Though these types of point sources can and do occur in non-Arctic regions, several factors lead to the particular vulnerability of the Arctic and sub-Arctic.

First, the polar regions are disproportionately affected by climate change in comparison to the more temperate regions closer to the equator (3). Current climate change models predict significant changes to the biogeochemical cycles and pathways in the region, which can result in the mobilization of metals and other contaminants that are currently immobile (4). For instance, in some Arctic mining regions, toxic heavy metals such as arsenic and cadmium have been found at elevated levels in permafrost when compared to surface soils and peat (5). Melting of permafrost in these regions mobilizes these point sources, resulting in increased exposure to local biota.

The Arctic is also an emerging “resource frontier”, due to increased access to the North as climate change opens waterways, and, unlike urban and rural zones, the mineral rights in remote northern regions are primarily held by governments rather than private entities (6, 7). An increase in resource extraction in the region leaves the area more vulnerable to contamination from these activities. Though resource extraction sites are some of the main pathways for point

source contamination in the Arctic, they are not the only sources. For instance, in Canada, the Arctic is the home of the Distant Early Warning (DEW) line sites, a series of abandoned military facilities that have left a legacy of hazardous waste sites across the Canada's North (8). Similar sites are also located in Sub-Arctic Canada, along the Mid Canada Line (8).

In addition to point sources originating from within the Arctic, another source of environmental contamination is through long-range transport. This process involves the emission of substances that are sufficiently volatile, such that they can remain airborne in warmer temperature environments and precipitate when transported to areas with cooler temperatures (9). Long-range transport can occur due a process called the "Grasshopper Effect", named due to the "hopping" of contaminants from temperate zones to colder polar regions (see Figure 1-1). Once particles have precipitated, cooler temperatures can also result in a decrease in rate of the natural decomposition processes that can transform these substances, which can result in lengthened environmental persistence (9). Common examples of contaminants whose accumulation in the Arctic is primarily driven by long-range transport include mercury, a toxic metal, as well as persistent organic pollutants (POPs), and perfluoroalkylated substances (PFAS), which are industrial chemicals (10). Other heavy metals, including lead, cadmium, and thallium, have also been found in Arctic ice core as a result of coal burning in more southern locations (11).

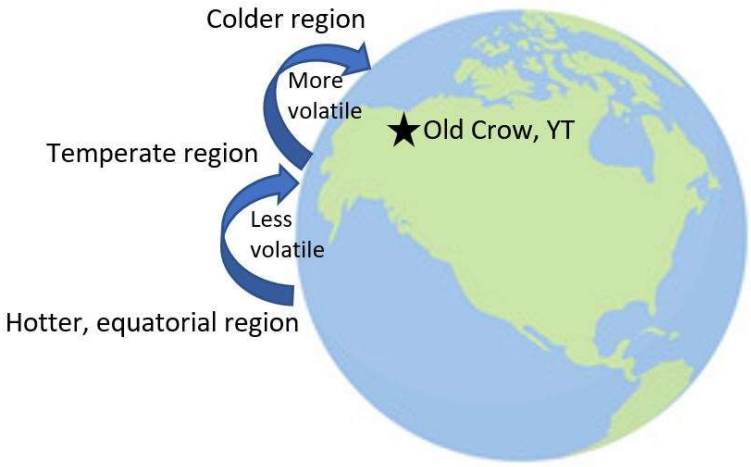

***Figure 1-1** – Contaminant Movement via the Grasshopper Effect*

Long-range transport of contaminants is challenging to manage at the local, regional, and even national level, as contaminants can travel thousands of kilometers from the original source, including across country borders (9). With the aim of decreasing contaminant emissions and exposures worldwide, including in the Arctic, the international community has formed several initiatives. These include the Stockholm Convention for POPs (12) and the Minamata Convention for mercury (13). Other programs, such as the Arctic Monitoring and Assessment Programme (AMAP), focus on monitoring the contaminant burden in circumpolar regions (14).

1.2 International Legislation and Monitoring Programs for Environmental Contamination

The Stockholm Convention was established in 2001, with the aim of eliminating or reducing the use of POPs internationally. This agreement was originally negotiated and signed by 152 countries in 2001, and put into effect in 2004. At its signing, the Stockholm Convention listed, twelve POPs across three Annexes, including pesticides (aldrin, chlordane, dieldrin, endrin, heptachlor, hexachlorobenzene [HCB], dichlorodiphenyltrichloroethane [DDT], mirex, and

toxaphene), industrial chemicals (polychlorinated biphenyls [PCBs], and by-products (dioxins and furans) (12). The agreement requires that participating countries eliminate the intentional production and eliminate or minimize the unintentional production of named POPs (12). Since 2001, 33 additional countries have agreed to join the Stockholm Convention, and 16 other POPs have been added to the list, including two perfluoroalkylated substances (PFAS): perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) (15).

Though many contaminants subject to long-range transport are organic, as are the case with POPs, some metals, such as mercury, can also volatilize and travel long distances through the atmosphere. To that end, the Minamata Convention is an international treaty that was designed to decrease the environmental and human health burden of mercury. The convention was opened for signature in 2013, and is currently approved by 137 countries (16). These countries have agreed to conditions including phasing out the use and production of certain products that contain mercury (e.g. dental amalgams, certain pesticides), and employing "best available" techniques and environmental practices for facilities that emit mercury (13). Criticisms of the Minamata Convention include that the measures are not sufficiently strict, due to unestablished standards for "best available" technologies and practices, as well as more lax restrictions for facilities that were operational prior to the convention (13). Both the Minamata and Stockholm Conventions are focused on source control and emissions, and therefore rely on the work of other organizations (e.g. AMAP) to conduct monitoring in vulnerable regions. These monitoring programs can provide valuable insight into the effectiveness of both of these international initiatives over time.

One of these initiatives is the AMAP, which is tasked with monitoring both the levels and effects of anthropogenic contaminants in Arctic regions (17). The AMAP is a working group within the

Arctic Council, which is an intergovernmental group consisting of the eight countries located above the Arctic Circle. The first AMAP report was released in 1998, and included longitudinal trends for metals, POPs, particulate matter, and radionuclides in the environment and biota based on 400 scientific studies (17). In recent years, AMAP has released reports focused on specific trends and subject areas, including, but not limited to: human health (18), POPs (19), and radioactivity (20). Unlike the Stockholm or Minamata Conventions, this work does not directly regulate contaminant emissions, however it is used to inform these agreements and others. The AMAP is an international example of many of the monitoring programs designed, in part, to evaluate the effectiveness of the initiatives of these conventions. Evaluation is being conducted using a variety of methods including monitoring of human health using biomonitoring, as well as environmental monitoring using water, plant, and wildlife sampling.

1.3 Contaminants in Northern Biota

Contaminant burden in Arctic and sub-Arctic environments, including in water, soil, air, and rocks, has the potential to reach local biota through direct uptake from these sources or through the food chain. This can lead to the contamination of biota, and thus contamination of water and traditional food sources harvested locally by the people living in the region. Though there are many nutritional benefits to eating traditional foods, these foods may also contribute to dietary contaminant exposure (21). Regional, national, and international organizations, such as AMAP, have been conducting or aggregating the results from monitoring programs to measure the levels of contaminants of concern in northern biota (17).

1.3.1 Persistent Organic Pollutants in Northern Biota

One of the primary focuses of contaminant monitoring in the Arctic include POPs. Persistent organic pollutants, such as PCBs, HCB, and DDT, can reach the Arctic through long-range transport, and can also remobilize at point sources due to environmental changes, including those caused by climate change. Due to their lipophilic nature and long-half life in most matrices, POPs accumulate in the fatty tissue of animals, where levels can increase over decades of exposure (22). The banning of most POPs as part of the Stockholm Convention has resulted in generally decreasing trends of many of these contaminants in biota in most Arctic regions over time. Some of the POPs that had generally decreased in Arctic plants and animals 15 years after their banning in 2001 include toxaphene, hexachlorocyclohexane (HCH), DDT, dichlorodiphenyldichloroethylene (DDE – a breakdown product of DDT), mirex, PCBs, and chlordane (23). Many of these, including HCH and PCBs, have since plateaued in Arctic regions (24). Other contaminants, including trans-Nonachlor, dioxins, as well as HCB and other chlorobenzenes, did not show as clear of a decreasing trend in biota during the same time period (23). The lack of decreasing trends in these POPs, despite their ban, has been attributed to factors including remobilization due to environmental factors such as climate change and the continued existence of primary and secondary exposure sources where these contaminants are a by-product (23). In addition to the increasing or decreasing trends of individual contaminants, the ratio of some of the by-products/breakdown products (e.g. DDE) of some POPs are increasing relative to concentrations of their parent compounds (e.g. DDT) in animal tissue, suggesting a lack of, or decrease in, new sources for these substances (25).

The initial exposure pathways for intake of POPs by plants and animals are through air, water, soil, and, sediment, where many POPs persist for long periods, (26). Though most POPs are

generally hydrophobic, and are therefore not highly water soluble, elevated concentrations of these substances can become trapped in their gaseous form in ice, and volatilized during melting periods (26). Some POPs, such as toxaphene and HCH, are more water-soluble, and can be found solubilized at higher levels in surface groundwaters (27). Due to the effects of climate change, the mobilization of POPs due to melting ice is expected to be an emerging exposure pathway for Arctic biota (26). Generally, levels of POPs in Arctic plants and soil are low in comparison to many southern regions (28). However, elevated concentrations of some POPs, including PCBs and DDT, have been observed in plants and soil in proximity to point sources, such as the abandoned DEW Line sites (28). The uptake and adsorption of POPs in plants is higher in plants that have higher lipid and wax content (e.g. conifer needles), and also higher in plants with higher surface area to volume ratios (e.g. lichen and moss) (29).

Once POPs are taken up by plants, soil, sediment, solubilized or frozen into water, they have the potential to enter animals through dietary intake. The levels of these contaminants in animals depends on factors including the animal's age, diet, position on the trophic web, fat composition, habitat, and toxicokinetic factors, such as rate of metabolism or excretion (30). For instance, observed levels of some dioxins were significantly higher in Finnish reindeer (*Rangifer tarandus tarandus*) than in moose (*Alces alces*) from the same region (31). The difference was hypothesized to be either diet-related, due to the lichen-heavy diet of reindeer in comparison to the twig and leaf-heavy diet of the moose, or related to the hypothesis that moose can more effectively metabolize dioxins than reindeer (31). Dietary intake is the primary driver of POP exposure for Arctic animals, and can be the driver of variable contaminant levels observed across a region when levels of these contaminants vary in local plants, soil, sediment, and water (28). For example, in Canada, several POPs, including PCBs, HCB, dioxins, and HCH showed a

generally increasing trend in terrestrial biota from west to east. This trend has been attributed to atmospheric transport to the eastern region of Canada from the more industrialized eastern North American coast in the south (28).

Once POPs have entered the food chain, they can be subject to biomagnification, and therefore, an animal's body burden of POPs is highly dependent on the body burden of the other animals and plants it eats. For example, biomagnification of POPs in the lichen-caribou (*rangifer tarandus groenlandicus*)-wolf (*canis lupus*) chain has been identified as a possible exposure pathway for caribou, wolves, and humans eating these animals (32). Similarly, a study from Greenland found that predatory animals at the top of the chain, including ringed seals (*Pusa hispida*) and polar bears (*Ursus maritimus*) had significantly higher levels of some POPs (PCBs and polybrominated diphenyl ethers [PBDEs]) than herbivorous animals in the region (33). POPs are also bioaccumulative due to their persistent nature in the environment and biota. Therefore, at exposure levels that exceed the slow metabolic rates of most of these contaminants, body burdens of POPs increase with the age of the animal (34).

In part because of the primarily hydrophobic nature of most POPs, these substances can be taken up by aquatic creatures either directly through water, in low concentrations, or after they have bound to sediment and plants. In one Arctic study, higher concentrations of most POPs, including PCB, DDT, HCB, and HCH, were observed in marine mammals than in terrestrial herbivores (35). In some cases, levels of these contaminants in fish are also higher in the Arctic than those observed in the south. For instance, toxaphene, HCB, and PCBs have been observed at elevated levels in the muscle tissue of some northern Canadian fish in comparison to fish in Canada's south (28). These contaminants can be found in the fatty portions of all fish tissue, but in particular, accumulate in fish livers (28). This process can result in higher overall

concentrations of these POPs in fish that have large livers proportional to their body size, such as burbot/loche (*Lota lota*). (28).

Though levels of POPs in local biota generally reflect regional levels of those contaminants, some animals have long migratory pathways, which may expose them to multiple point sources and regions with variable levels. Due to their long migratory pathways relative to many Arctic terrestrial animals, Arctic birds, in particular, have levels of POPs that may not fully reflect regional POP levels in northern regions. For instance, Arctic birds that migrate to the North from more heavily industrialized areas in the South have been observed to have higher levels of POPs including mirex and toxaphene than those that migrate through areas with less contamination (32). This variability is also diet-dependent. One studied showed that Arctic birds that eat fish had higher levels of POPs, including PCB, DDT, and, HCB, than birds that do not eat fish (36).

All of these trends with respect to POP levels in biota can be used to identify and prioritize specific animals, animal tissues, and plants for contaminant trend monitoring in the North. Specifically, an understanding of the toxicokinetic properties and environmental mobility of the contaminant of interest can inform environmental monitoring program design. This thesis discusses some key contaminants, including HCB, in more detail based on the results of analysis conducted in Chapter 2. More detailed reviews on the toxicokinetic properties and exposure sources of these specific contaminants was conducted after the analysis of Chapter 2, and these are included in Appendix A.

1.3.2 Metals in Northern Biota

Targeted studies on metal contaminant exposure of biota in northern ecosystems have generally focused on the toxic heavy metals, including mercury, lead, cadmium, and chromium, as well as

arsenic, a toxic metalloid (28). As with POPs, metal exposure in the food web can begin with the occurrence of metals in water, plants, soil, and sediment. Unlike most POPs, many metals can be highly water-soluble, depending on the geochemical conditions of the water and the form that the metal is in (37). For instance, a study evaluating the effects of acid mine drainage on metal uptake in Arctic plants found that concentrations of heavy metals such as zinc, aluminum, and nickel, were highest in water and plants during the spring thaw, when surface water pH values are more acidic and therefore most metals were more mobile (38). Elevated levels of metals in water and soil during periods of high metal mobility can also be reflected in local biota. For example, levels of heavy metals such as cadmium and lead in fish were found to be strongly associated with the seasonal mobilization of these metals in the waterbody (39). In one case study, levels of these cadmium and lead observed in Arctic char tissue were highest during the drop in surface water pH during snowmelt (39).

Though some metals, such as lead and mercury, can reach Arctic ecosystems through long-range transport, in many cases, elevated metal levels observed in plants, soil, and water are localized to point sources of contamination. These point sources can be anthropogenic, where, for instance, particularly high levels of heavy metals, such as lead, nickel, manganese, and mercury, have been observed in lichens and soils in proximity to northern mining sites in Russia (40). Similarly, arsenic was observed at elevated levels in berries (raspberries, gooseberries, cranberries) in proximity to gold mining sites near Yellowknife, NWT (32). In some cases, the primary source of exposure may not be local to the Arctic, but could be brought in through long-distance migration of animals. For instance, elevated lead levels have been observed in some birds that migrate through areas using leaded gasoline (41). These contaminants can then enter other Arctic biota through the food chain, or the Arctic environment through decomposition or fecal matter

(41). Though some metal contamination is localized to a point source, regional-scale contaminant concentration trends have been observed across the Arctic more broadly. Measurement of mercury levels in polar bears, ringed seals, and belugas (*Delphinapterus leucas*) found higher levels of mercury in the Western Canadian Arctic than those in the Eastern Arctic (27). However, the opposite trend was observed for cadmium and lead, where concentrations were higher in the Eastern Arctic than the West. These trends were generally attributed to regional differences in naturally occurring metal levels in water and soil (27). Unlike mercury, studies have shown that average lead levels in Arctic biota were generally lower than those observed in more industrialized areas in Canada's south, though elevated lead levels in biota due to point source contamination has been observed in Arctic regions as well (27, 40).

Some metals are found at elevated levels in Arctic biota when compared to similar biota in southern Canada. For instance, mercury levels in Arctic marine mammals, in particular, were elevated relative to marine mammals in the Canada's south (42). In some cases, these levels have been higher than commercial sales guidelines (28). However, some researchers recommend using caution when comparing contaminant levels in biota in the Arctic to those in the south (e.g. when using health-based thresholds for commercial sale or consumption). For instance, one study found that levels of metals, including cadmium and mercury, were significantly higher in some Arctic animals harvested for foods than in farmed animals from the south (43). However, the authors noted that Arctic animals harvested for food were often higher on the food chain than animals farmed for foods, and therefore levels of contaminants that undergo biomagnification are expected to be different (43). The same study found that metals which do not biomagnify to the same extent, including lead, were generally similar for northern and southern biota harvested or farmed for consumption (43).

Unlike POPs, some sources of metals in the North can be naturally occurring in the environment. One example of a naturally-occurring metal contaminant resulting in elevated metal levels in biota is the elevated cadmium levels that have been observed in Yukon moose in comparison to moose in other northern Canadian regions (32). The primary hypothesis for the difference is regional natural cadmium enrichment in Yukon soil, affecting cadmium levels in plants that readily take metals up (32, 44). These elevated levels are then reflected in the animals that feed on these plants, including moose. Arctic willow, in particular, has been observed to contain significantly higher concentrations (2 to 10 times higher) of specific divalent metals (including such as cadmium, zinc, and manganese) in comparison to other Arctic plants, such as mosses, heather, and lichen (44). These differences in plant uptake can result in different exposure levels for animals higher up the food chain, depending on diet.

The level of metals observed in biota also depends on the propensity of the metal for bioaccumulation in the organism and biomagnification up the food chain. For instance, manganese and cobalt, metal nutrients that can be toxic at high levels, are not highly bioaccumulative or biomagnificative in most animals, and therefore body burden generally represents recent exposure rather than being correlated with organism age or trophic position (45, 46). Some metals, like lead, can bioaccumulate in some species, but do not biomagnify to the same extent that highly biomagnificative metals, like mercury, do in the food chain (47). Like POPs, the levels of highly bioaccumulative metals observed in animals can change as the animal ages (32). For instance, studies on mercury levels in beluga whales showed a strong significant correlation between muscle, liver, and kidney mercury concentrations and the animal's age (27). Levels of bioaccumulative metals can also change as organisms grow, as well as affect the rate at

which organisms grow, though this relationship is complex, and can be affected by other environmental factors, including the occurrence of other nutrients (48).

Also similar to POPs, the levels of these metal contaminants in organisms are primarily driven by dietary consumption for most animals (32). For example, terrestrial animals that consume more fish, such as the Arctic fox (*Vulpes lagopus*), generally have higher body burdens of metals found at elevated levels in fish, such as mercury, than terrestrial animals that primarily consume other terrestrial animals (e.g. wolves) (32). Similarly, birds that consume more marine animals, such as the king eider (*Somateria spectabilis*), which eats mussels, had higher average mercury concentrations than common eiders, which eat a more varied diet (32). Smaller marine animals, not including mammals, can be one exception, where dietary intake may not be the primary exposure pathway. Aquatic species can be exposed to metals both via diet, by consuming plants and other animals contaminated with these metals, or directly from the water via gills or dermis (27). The relative impact of dietary intake of metals on total metal concentrations in aquatic species generally increases with size of organism (27). For biomagnificative metals, body burden of these metals can then increase up the food chain. This process highlights the importance of understanding possible exposure sources at all trophic levels.

Similar to POPs, metals can accumulate in certain animal tissues depending on the toxicokinetic properties of the metal in that organism. For example, in both the Yukon and the NWT, elevated cadmium levels have been observed in the kidneys and livers of terrestrial animals such as caribou and moose in comparison to levels observed in muscle tissue (28). These elevated levels have also been observed up the food chain in the kidneys and livers of wolves of the region (49). Other heavy metals, such as lead and manganese, have also been found at higher levels in the

kidneys, livers, and bone marrow of Arctic terrestrial animals such as moose and caribou, than in the muscle tissue of these animals. (50-52).

This thesis discusses some key contaminants, including the metals lead, cobalt, and manganese, in more detail based on the results of analysis conducted in Chapter 2. The toxicokinetic properties and exposure sources of these specific contaminants are discussed in Appendix A.

1.4 Traditional Foods – Risks and Benefits

Traditional northern foods, such as locally harvested berries, fish, seafood, wild plants, birds, and land animals, are both culturally important for many Indigenous Peoples, and critical to overall food security and sovereignty in Arctic communities (21). These foods can be important sources of many beneficial nutrients, including omega-3 fatty acids, proteins, vitamins, and metal nutrients such as iron, zinc, copper, magnesium, phosphorus, and potassium (21, 53-56). Previous work in Arctic communities reported that diets rich in traditional foods were more likely to meet dietary recommendations for fat intake than diets consisting of only market foods (21, 57). In addition to the health benefits of traditional food consumption, traditional food gathering has been associated with higher physical activity levels (58) and other benefits to general wellness, including increased spiritual connection and emotional healing (59). A review of the literature reported a potential positive link between higher traditional food access and consumption and improved mental health outcomes in circumpolar populations (60).

Traditional foods are a vital component of the food system in many northern Canadian communities. However, elevated levels of some metals and POPs in some of the Arctic biota that are harvested for food has resulted in concern about possible health risks from consuming these foods. For example, contaminants including mercury and cadmium are currently being analyzed regularly in local Yukon wildlife and in the environment, resulting in some animal and site-

specific consumption notices for communities (53, 61, 62). Similar consumption notices have been issued in the Northwest Territories (NWT) after elevated cadmium levels were observed in some moose organs (63). Elevated mercury levels in some fish have also been flagged as a potential health risk in the NWT, resulting in both territory-wide and site-specific consumption notices (64).

Generally, these notices specify tissues, such as land animal kidneys and livers, species, such as burbot/loche, or harvesting locations. These consumption notices can be useful tools for minimizing contaminant exposure in vulnerable populations (65). However, consumption notices have also been linked to social, lifestyle and economic disruption in some communities when community members replace harvesting and consumption of traditional foods with other less healthy behaviours and/or less nutrient-rich market foods (65). In these cases, a reduction in risk of adverse health effects due to contaminant exposure from the targeted traditional food may be replaced by an increased risk of adverse health effects due to the behavioural change.

A risk-benefit approach is essential when determining how to communicate information regarding contaminants in traditional foods, and whether consumption notices and/or recommendations are necessary or beneficial.

This approach is based on the ten principles for risk management adapted by Jardine et. al. (66), which demonstrate the complicated balance. These include the following: 1. “Do more good than harm”, 2. “Fair process of decision making”, 3. “Ensure an equitable distribution of risk”, 4. “Seek optimal use of limited risk management resources”, 5. “Promise no more risk management than can be delivered”, 6. “Impose no more risk than you would tolerate yourself”, 7. “Be cautious in the face of uncertainty”, 8. “Foster informed risk decision making for all stakeholders”, 9. “Risk management processes must be flexible and evolutionary to be open to

new knowledge and understanding", and 10. "The complete elimination of risk is not possible" (66, 67). Many of these principles are consistent with a precautionary approach to risk communication, focusing on "the Golden Rule" ("impose no more risk than you would tolerate yourself"), and using caution when faced with uncertainty of risk (66). When approaching these principles from a toxicological perspective alone, the recommendations may appear to favour an approach that minimizes contaminant exposure at the possible detriment of behavioural changes. However, risk communication researchers have indicated that a trans-disciplinary approach is essential when evaluating and communicating risks (68). This is emphasized by some of the other principles for risk management in Jardine et. al. (66), including "do more good than harm", and "the complete elimination of risk is not possible", which indicate that managing one risk may have unintended consequences and create new risks.

Generally, risk of contaminant exposure from dietary sources, such as traditional foods, is an estimated value based on a comparison between a health-based guidance value for contaminant intake and estimated intake of that contaminant from the food in a targeted population (66, 69). Risks can then be balanced against quantifiable benefits of traditional foods, such as nutrient intake (66, 69). This process is made complicated by the lack of inclusion of qualitative benefits from traditional foods, including both cultural and mental health and wellness benefits (70). In cases, including with traditional foods, where the risk is determined to be low, and benefits are known but cannot necessarily quantifiable, it may be appropriate to conduct a qualitative risk assessment (71). In an effort to minimize negative behavioural changes resulting from consumption notices and dietary change recommendations, this thesis employs a framework where the burden of proof is on contaminant risk before messaging changes from the status quo of "the benefits of traditional foods generally outweigh contaminant risks".

The quantification of risk is often completed through an estimation of contaminant intake based on both environmental monitoring and estimated consumption of foods. This method may not reflect the actual exposure levels to the contaminant in the population, as it is often estimated based on self-reported dietary data, and contaminant concentrations that may vary significantly in the food. Therefore, actions, such as the formulation of consumption notices or recommendations, may be taken in cases where a population is highly exposed based on the estimate, but not highly exposed in terms of body burden of the contaminant (72). It is for this reason, that other tools, such as human biomonitoring, can be used in combination with environmental monitoring and human health risk assessments, to develop a clearer picture of contaminant intake and body burden in a region, and inform future risk management and communications.

1.5 Human Biomonitoring

Human biomonitoring is a method used to quantify demographic, spatial, and temporal trends in human exposure to contaminants and nutrients. This method involves the analysis of a substance, its metabolites, or susceptibility factors in samples of human specimens or tissue (73). These measurements are called biomarkers, and can include biomarkers of exposure (a direct measurement of the targeted substance or its metabolite), biomarkers of effect (measurement of an alteration within an organism), and biomarkers of susceptibility (measurement of a factor that can make an organism more sensitive to exposure) (73). Human biomonitoring is used at the local, regional, national and international level to measure exposure to contaminants and nutrients, and its associated determinants. This method is a vital public health tool, which has been integral in the formation of exposure legislation and policies. One example of a policy that was informed by the results of biomonitoring is the restriction of lead usage for industrial and

household purposes after observed elevated blood lead levels in adults and children were linked to adverse developmental effects (73).

1.5.1 Interpreting Human Biomonitoring Data

The most common focuses of large-scale human biomonitoring programs are primarily biomarkers of exposure. Common examples of biomarkers included in national-scale programs are blood and urinary metal levels, blood levels of POPs, urinary levels of phthalate metabolites, and urinary levels of cotinine, a metabolite of nicotine (74-80). The interpretation of these biomarker levels can be challenging, particularly when returning individual results to participants of a biomonitoring study, as there may be limited information regarding individual contaminant levels in other populations, or with respect to the risks of health effects.

In some cases, a health-based guidance value for biomarker levels is available. For example, health-based guidance values have been established for lead and mercury in blood in Canada. These values were developed by Health Canada based on both animal and human epidemiological studies indicating that certain levels are associated with increased health risk at the individual and/or population level (81, 82). When returning results to participants, individual biomarker levels can be compared to these health-based guidance values to identify individuals and populations at higher risk of adverse health effects due to contaminant exposure.

When no health-based guidance value is available, other comparison values have been used to identify populations with elevated exposure to contaminants or nutrients. These comparisons do not characterize risk of adverse health effects, but can inform screenings of individual contaminants at the population level. One example of a comparison value used for biomonitoring studies is the Reference Value (RV). The RV is determined by a percentile in a comparison

population, where populations with biomarker levels above this value are more highly exposed than the comparison population (83). Typically, RVs are based on the 95th percentile of the values observed in the comparison population, however other percentiles have also been used (83). In Canada, RVs have been established based on the 95th percentile values for contaminants observed in blood and urine in the Canadian Health Measures Survey (CHMS), a national-scale program which is considered to be representative of the general Canadian population (84, 85).

Another value that can be used for comparison is the biomonitoring equivalent (BE). Such values are derived based on exposure guidelines from human (i.e., epidemiological) or animal (i.e., toxicological) studies, which are then converted to biomarker levels using toxicokinetic data (86). An example of an exposure guideline value in this case, could be a tolerable daily intake (TDI) value for humans, which is generally reported as a value of contaminant intake volume per time period per unit body weight (86). Similarly, occupational health guidance values may calculate intake rates using the same methods, but focused on specified time periods or assuming certain health and safety measures are in place (86). Biomonitoring equivalents can be derived from thresholds established in animal testing data, such as a No Adverse Effect Level (NOAEL), which is the highest level of exposure at which there is no increased risk of an adverse effect (87). These thresholds are then converted to BEs based on an understanding of, or assumptions about, the toxicokinetic properties of the substance. In the case of new and emerging contaminants, this information may be unknown, and therefore the establishment of a BE may require assumptions that diminish the reliability of the threshold (87). Like RVs, BEs are recommended for population-level comparisons. However, unlike RVs, BEs provide some health risk context for exposure. Though these values are not recommended for use as individual

health-based guidance values, they can be used to prioritize contaminants for future risk assessment (87, 88).

For the purposes of this thesis, levels of contaminants in human biomarkers were compared to health-based guidance values for assessing individual risk in human biomonitoring studies. This is consistent with the methods described by Ratelle *et. al.* for the work conducting community-partnered biomonitoring in the Northwest Territories (89). At the population level, results were compared to both RV95s and reference communities in Canada, including the general Canadian population for the purpose of identifying contaminants and nutrients for follow-up analysis (84, 85). This comparison was selected to identify regional differences between the study population and reference groups, for the identification of sources specific to the study setting, rather than selecting contaminants based on risk to the population, as would be the case with biomonitoring equivalents.

1.5.2 National Human Biomonitoring Projects in Canada

In Canada, human biomonitoring has been conducted at the national scale by Health Canada, the Public Health Agency of Canada, and Statistics Canada under the CHMS. The CHMS is a cycle-based program, similar to the National Health and Nutrition Examination Survey (NHANES) in the United States, occurring approximately every two years (74, 90). In the CHMS, a representative sample of approximately 5,000 to 6,000 participants is selected from urban centers across the ten provinces to represent the general Canadian population (74). These participants submit biological samples such as hair, blood, and urine, for analysis of contaminants and nutrients. Currently, the CHMS has collected 15 years of biological sampling data, providing information about exposure levels for key contaminants including, but not limited to toxic

metals, POPs, and PFAS (78). The recruitment process for the CHMS excludes some marginalized and minority groups, such as incarcerated individuals, or recent immigrants, and excludes those who do not live in urban areas, such as Indigenous groups living on reserve or in remote regions (91). There is increasing evidence that the census, which informs recruitment for the CHMS, is also under-counting the number of Indigenous Peoples living in urban areas (92).

It is for these reasons that another national-scale program was conducted to evaluate exposure in First Nations populations in Canada. This program is called the First Nations Biomonitoring Initiative (FNBI), and it was conducted once from 2011 – 2012 (93). Approximately 500 participants from 15 randomly selected First Nations communities located in the Canadian provinces submitted blood and urine samples for contaminant and nutrient analysis (79). Many of the contaminants and nutrients analyzed as part of the FNBI were the same as those analyzed in the early CHMS cycles, including POPs, PFAS, and metals (93). Though the aim of the FNBI was to establish baseline exposure levels for First Nations people on reserve, the study did not include any communities located within Canada's northern territories.

1.5.3 Human Biomonitoring in Canada's North

There is limited human biomonitoring data available in the Arctic and sub-Arctic. Human biomonitoring in northern Canada has been limited to smaller scale studies, the largest of which was the 2007 – 2008 International Polar Year Inuit Health Survey (IPY-IHS), where 2,500 adults in Nunavut, Nunatsiavut, and the Inuvialuit Settlement Region (ISR) participated (94, 95). Like both the FNBI and Cycle 2 of the CHMS, this study included the measurement of metals and POPs in blood samples (96). Levels of some contaminants, including cadmium, lead, and several POPs, such as DDT and chlordane, were higher in participating Arctic communities when

compared to the general Canadian population in the south, however, the majority of participants did not have contaminant levels above available health-based thresholds (96).

The Nunavik Inuit Health Survey was conducted across three cycles: in 1992, 2004, and 2017, involving the collection of blood samples for analysis of metals and POPs from more than 900 adult participants from 14 coastal villages in Nunavik (97). This work provided both baseline exposure levels, as well as trends in exposure for key contaminants over time. Overall, the results of this project showed that though some contaminants, such as lead, mercury, and cadmium, were elevated in the region in comparison to Canada's south, concentrations of these parameters were generally decreasing over time from both 1992 to 2004 and from 2004 to 2017 (97). In comparison to the IPY-IHS, blood mercury, cadmium, and lead levels observed in Nunavik in 2004 were higher than those observed in Nunavut, Nunatsiavut and the ISR in 2007 – 2008 (98, 99). Levels of all three of these contaminants in blood decreased in Nunavik between 2004 and 2017, though remained higher than those observed in the general Canadian population (98). Similarly, levels of all POPs, including chlordanes, DDT, PCBs, and toxaphenes, decreased in Nunavik from 2004 to 2017, but remained higher than those observed in the general Canadian population throughout (100). Levels of all POPs in Nunavik in 2004 were higher than those observed in Nunavut, Nunatsiavut and the ISR in 2007 – 2008 (96).

In addition to these studies, the Health Effects Monitoring Program (HEMP) was a prospective cohort study of 2,037 participants in the Yellowknife region that was conducted in 2017 and 2018 (101). The results of this work found that both Yellowknife children and adults in the study had significantly higher inorganic urinary arsenic concentrations than the general Canadian population (101). Other studies have targeted specific vulnerable groups. For instance, the Pregnancy Wellness with Country Foods (NQN) project focused on pregnant people in Nunavik.

This study involved the collection of biological samples from 97 participants in 2016 and 2017, with comparisons to previous monitoring of pregnant people in the region (102). This study found that levels of some contaminants, including methylmercury, and PFAS compounds such as perfluorononanoic acid (PFNA), were elevated with respect to the general Canadian population (102, 103).

Another biomonitoring project in the region was conducted in partnership with our research group at the University of Waterloo in the Dehcho and Sahtú regions of the Northwest Territories (80). In these regions, levels of some metals, including mercury and lead, and metabolites of polycyclic aromatic hydrocarbons, such as pyrene, fluorene, and naphthalene, were higher in the Dehcho and Sahtu regions than in the general Canadian population (104, 105).

Some projects have focused on sub-populations, including pregnant women in northern British Columbia (106) and children and pregnant women in Nunavik (94). These projects provide valuable insight into vulnerable groups, which may inform health messaging to these groups in the region. Prior to the Old Crow Biomonitoring Project (the Project), only one human biomonitoring project, involving the analysis of hair samples for methylmercury levels, had been conducted in the Yukon, leaving a significant data gap for biomonitoring in the territory, and more broadly in Canada's western Arctic (107).

1.6 Old Crow, Yukon Territory

The northernmost community in the Yukon is Old Crow, a fly-in community of approximately 220 people located above the Arctic Circle (108). The community is located on the traditional lands of the Gwich'in, which stretches from the Arctic Ocean to the north, Fort McPherson, NWT, to the east, Fort Yukon, Alaska to the west and nearly 200 km south of Old Crow (109). The traditional territory is also delineated by the migratory patterns of the Porcupine caribou

herd, which extends north to close to the Arctic Ocean in the summers for calving, and then disperses across the southern reaches of the region in the winter (109). The main waterbody in the region is the Porcupine River, which abuts the community of Old Crow on the south side. Old Crow is primarily accessible by plane, as it has an all-season airport. However, there is seasonal accessibility to Eagle Plains, which is on the Dempster Highway, either by ice road, which is constructed every few winters, depending on community construction projects, or in the summer by canoe along the Porcupine River. The ice road is not open to the general public, however, it can be used to ship supplies, including construction materials for large projects.

Though Old Crow is located above the Arctic Circle, with permafrost approximately one foot below the surface, it is not above the treeline. Houses in Old Crow are primarily constructed from logs, and electrical heating systems are combined with wood stoves for heating during the winter (109). Old Crow is the location of the offices of the Vuntut Gwitchin Government (VGG), which is the governing body for the Vuntut Gwitchin First Nation (VGFN) and Dagoo Gwich'in (110). Other Gwich'in communities, including, for instance, the Teetl'it Gwich'in in Fort McPherson, are governed by separate groups, such as the Gwich'in Tribal Council (111).

Like many northern remote communities, people in Old Crow rely on a combination of market foods shipped from the south by plane, and traditional foods harvested regionally or shared from other communities (112). The availability of store-bought foods relies on regular shipments from more southern cities, which are subject to weather and staffing delays and cancellations. Market foods are sold in the community's grocery store, or can be bought directly by consumers in the south and shipped privately as plane cargo, which requires the presence of a person shopping in a southern community. Like other Arctic and sub-Arctic remote communities, market food prices can be high in the community. A 2017 study found that the cost of the Revised Northern Food

Basket (RNFB; a nutritious weekly diet for a family of four) was nearly two times higher in Old Crow when compared to the same foods in Whitehorse (113). These cost differences are occurring despite subsidies for healthy foods in Old Crow under the Nutrition North Canada (NNC) program, of which Old Crow is the only qualifying community in the Yukon.

Though store-bought foods can be acquired in the community, the majority of the residents of Old Crow also consume wild game, including caribou and moose, fish, such as Chinook salmon and whitefish, birds, berries, and other wild plants (114). These foods are nutritionally important to the residents of Old Crow, and are a part of the staple diet of community members (55, 56). A 24-hour recall survey conducted in 1995 found that traditional foods fulfilled a significant proportion of the daily nutrient recommendations in average Old Crow diets, including, for example, 67% of protein, 61% of riboflavin, 100% of vitamin B12, 63% of iron, and 65% of zinc (115). Additionally, traditional food consumption and harvesting play an important cultural role in the community (55, 56). Old Crow community members have conveyed the significance of traditional food, particularly the Porcupine caribou, in Gwich'in culture, along with concern that cultural practices are being lost or forgotten to the community over time (116). Despite these concerns, traditional food consumption rates in Old Crow did not change significantly between 1995 and 2014 (117).

Some of the same factors affecting environmental contamination levels in the Arctic also play a role in traditional food availability in Old Crow. For instance, oil exploration in the Arctic National Wildlife Refuge in Alaska, and proposed extraction projects are predicted to result in lower birth rates and herd size for the Porcupine caribou herd (118). This herd is also vulnerable to the effects of climate change, with climate-based models predicting a decrease in habitat size of 21% by 2104 due to an increase in forest fires in their southern boreal habitat (119). Other

commonly eaten traditional foods, such as Chinook salmon, have seen decreased population sizes in the previous decade, leading to regional recommendations to limit harvesting these foods in recent years (120). These issues are of high importance to community members and government in Old Crow, who have participated and led multiple conservation, monitoring, and research programs with the aims of protecting local traditional food sources and minimizing the community's climate impacts.

Several of the monitoring programs initiated in partnership with the VGG, include a focus on contaminant exposure and the safety of traditional foods in the region (61, 116, 121). The remote location and high latitude of Old Crow, combined with high levels of traditional food consumption, highlight the possibility that the community may be particularly vulnerable to contaminant exposure from these foods. Based on the results of this work, there are currently two consumption advisories in the region. With the intention of limiting exposure to mercury, the community of Old Crow has issued recommendations for consumption of loche/burbot and inconnu of 1 to 2 servings per week for children and women of childbearing age (61). Additionally, the Government of the Yukon has issued a Health Advisory for Yukon Wildlife due to elevated levels of cadmium observed in kidneys and livers of land animals including caribou, moose, sheep (*Ovis dalli*), beaver (*Castor canadensis*), porcupine (*Erethizon dorsatum*) and snowshoe hare (*Lepus americanus*) (62).

These advisories were created with the intention of reducing exposure to contaminants that may cause health effects at elevated levels. However, the level of human exposure to these contaminants and other contaminants and nutrients in the community, is generally unknown. Prior to the Project, one human biomonitoring project had been conducted in Old Crow. The study was conducted in 2016, when 32 residents of the community, submitted hair samples for

methylmercury analysis as part of a larger study investigating the link between mercury exposure, *Helicobacter pylori (H. pylori)* and gastric cancer risk (107). Hair methylmercury levels in participating Old Crow community members were below the levels which may cause adverse health effects, however, the number of participants was low and there was still a significant knowledge gap regarding exposure to other contaminants of interest, including cadmium, in the region. This work identified a further need for investigation into contaminant exposure levels in the community, which can inform existing and future regional consumption recommendations (107).

1.7 Study Rationale and Objectives

This thesis was designed to address community concerns in Old Crow regarding contaminant exposure, after elevated levels of some contaminants were observed in local traditional foods. Using the results of a human biomonitoring project in the region, this thesis provided baseline exposure levels for a comprehensive list of both contaminants and nutrients in Old Crow community members. Additionally, this thesis fills a significant data gaps regarding contaminant exposure in the Yukon, the Western Arctic, and the broader Canadian North. Large-scale national biomonitoring projects do not generally include populations located within remote communities, particularly those located in the North, despite the particular vulnerabilities of these communities to contaminant exposure. By understanding how levels of contaminants and nutrients in these regions compare to regions in Canada's south, key contaminants and nutrients of interest can be identified for targeted sampling programs in local environments and traditional foods.

To that end, the overarching research questions for this thesis were:

What are the human exposure levels for contaminants and nutrients, including heavy metals, industrial chemicals, micronutrients and omega-3 fatty acids, in the community of Old Crow? How do these relate to traditional food consumption and other lifestyle and demographic determinants?

This thesis began with a broader research question asking about baseline levels of contaminant and nutrient exposure in the community, and narrowing into more specific follow-up questions based on the results of the first manuscript. These questions were addressed in three manuscripts, each with its own sub-question(s) described below.

Chapter 2: Do contaminant and nutrient biomarker levels in Old Crow differ from those observed in the general Canadian population and other First Nations communities? Are any contaminant levels greater than health-based guidance values in the general population or in vulnerable groups?

Chapter 3: What are some of the determinants of urinary and blood levels of key contaminants and trace metal nutrients identified as elevated in Old Crow in comparison to the general Canadian population?

Chapter 4: What are the primary sources of dietary exposure to HCB, a contaminant identified as elevated in Old Crow, and healthy omega-3 fatty acids for the community members in Old Crow? How do levels of these substances compare to health-based guidance values for dietary intake?

1.8 Old Crow Biomonitoring Project Description and Research Group

1.8.1 Community Partnership and Ethics

This thesis includes results collected as part of the biomonitoring project in Old Crow (the Project), as well as the subsequent follow-up monitoring program, both of which were conducted using community-based research methods. Community-based research does not include all research that is conducted in communities, but is differentiated in that it is conducted with communities as partners throughout the research process (122). Minkler (123) notes that well-conducted community-based research has many benefits, including a stronger and more informed consent process, increased recruitment and retention, and improved cultural sensitivity, which can lead to improvements in the reliability of tools used during the study and the applicability of study outputs. This method or framework involves active contribution and input from non-academic or government researchers, including members of the general public (122).

As part of the community-based research method employed for the Project, a Community Research Agreement (CRA) was drafted between the University of Waterloo and the VGG. The CRA was designed to incorporate the four components of OCAP®[1] (Ownership, Control, Access, and Possession), and principles for data sovereignty and governance designed for work within First Nations communities (124, 125). Community collaboration is outlined in detail in the CRA, including components designed for community engagement, capacity building, Indigenous knowledge integration and consistent communication (126). The 2018 CRA was used to inform all stages of this project, from design to final reporting, and was updated and renewed in 2021.

[1] OCAP® is a registered trademark of the First Nations Information Governance Centre (FNIGC)

One of the most important aspects of community-based research is the timely return of results back to the community. As per the CRA, all results are returned within one year of sampling (in the case of human biological samples and traditional food samples) or one year of analysis (in the case of biobanked samples, or statistical analysis of secondary data) (126). Publication of results in academic journals, media, or at conferences cannot be done without approval from the community (126). The return of results methods for the results of this thesis are discussed in more detail in each manuscript (Chapters 2 – 4), as well as in Chapter 5.

1.8.2 Project Summary and Timeline

This thesis includes data analysis collected as part of the Old Crow Biomonitoring Project. The Project was initiated in October 2016 after community consultations. Several preliminary components were conducted in support of the clinic and its components, including a pilot project to create and refine the Food Frequency Questionnaire (FFQ) (127) and Health Messages Survey (HMS) in October 2017, as well as the preliminary administration of these surveys to community members in February 2018. These phases were conducted prior to this Ph.D. in September 2018, and are not discussed in detail in this thesis (Figure 1-2).

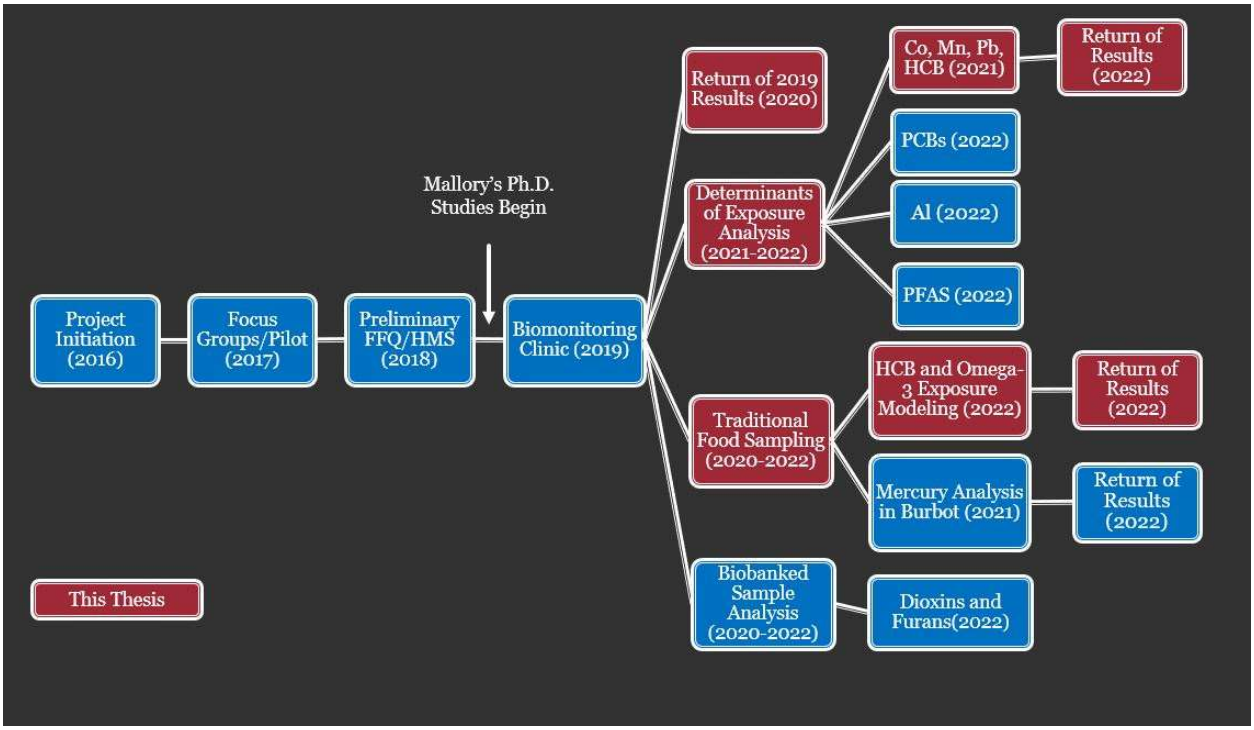

Figure 1-2 *– Old Crow Biomonitoring Project (the Project) Timeline with Thesis Components*

A community biomonitoring clinic was conducted in January and February, 2019, by members of Dr. Laird and Dr. Skinner's research groups, including myself. The clinic included the administration of the FFQ and HMS, as well as collection of three biological samples, including hair, blood, and urine, for analysis of contaminants and nutrients. Recruitment and consent form for this component are shown in Appendix B. During the initial analysis phase, hair was analyzed for mercury levels, whole blood and urine were analyzed for metals, plasma was analyzed for POPs and omega-3 fatty acids, and serum was analyzed for PFAS. The results of PFAS analysis are not included as part of this thesis. Additional samples were bio-banked, with participant consent, for analysis of contaminants and nutrients identified as priorities by the community during later consultations.

The recruitment and sampling methods described in Chapter 2 refer to the implementation of the Project, generally (see Figure 1-2). Chapters 2, 3, and 4 discuss the analysis and interpretation of biomonitoring clinic results (this thesis). Additional research involving the sampling and analysis of some traditional foods in the area was initiated by Jeremy Brammer (VGG), Brian Laird, Mary Gamberg, and myself in July 2020. I conducted the analysis of the traditional food sampling results, which are included in Chapter 4 of this thesis. Because the results of the traditional food sampling program are not fully shown in Chapter 4, Appendix C includes the community report I wrote for this thesis component.

The results of the Project have been returned to the community in several stages, within one year of sample collection or bio-banked sample analysis. These results were returned in person, when possible, including community-wide and individual meetings, as well as by plain language documents, media interviews, and methods requested by the community, such as the presentation of results during a local science symposium. I have returned all of the results of this thesis to the community in plain language documents, which are shown in Appendix D.

1.8.3 Research Group Structure and Other Projects

This thesis was conducted under the supervision of Dr. Brian Laird, who leads a research group focusing on contaminant exposure and nutrient intake, particularly in Northern regions. Dr. Laird's research group works in collaboration with the research group of Dr. Kelly Skinner to address broader questions about traditional food consumption and harvesting, including the risks and benefits of consuming these foods, as well as broader food security challenges in the North. The Project is one of several biomonitoring projects conducted by these research groups at the University of Waterloo, in partnership with individual participating communities, regions, and

territorial governments, as well as biologists and wildlife experts conducting community-based monitoring projects measuring contaminants in traditional foods.

Between 2016 and 2018, Drs. Laird and Skinner's research groups, in partnership with participating communities, held biomonitoring clinics in six communities in the Dehcho region of the NWT and three communities in the Sahtú region (80, 128). These biomonitoring programs were conducted prior to the beginning of this Ph.D thesis and some of the results of the biomonitoring projects in the NWT were used in this thesis for the purposes of comparison to Old Crow, and to create a larger dataset to identify determinants of biomarker levels in the broader North. More details about the use of this data is included in Chapter 3.

1.8.4 Impacts of the COVID-19 Pandemic

This Ph.D. began in fall 2018, prior to the COVID-19 pandemic, which began in March 2020. The majority of the field work, including the biomonitoring clinic, and the first return of results visit for that clinic, were conducted prior to travel restrictions. The community of Old Crow, like many northern communities, does not have a hospital and no doctor is permanently stationed there. Residents with emergency medical needs that cannot be addressed at the local nursing station must be flown to hospitals in Whitehorse, or other major cities, for care. This leaves the community especially vulnerable to the effects of COVID-19, resulting in strict limitations on travel within the region for nearly two years, between March 2020 and February 2022. There were several times that the project pivoted due to these restrictions, as many milestones fell during this time, including the implementation and return of results for the traditional food sampling program, and the return of results for Chapters 3 and 4. The traditional food sampling program was designed in spring 2020, as a project that could be conducted under the current

COVID-19 restrictions. Sampling in the community was led by Jeremy Brammer, a member of the research team from the VGG, who recruited local harvesters and processed samples for shipment to the laboratory. The inability to travel to the community was a challenge, in terms of logistics and the inability for members of the research team in the south to help to conduct quality control on the samples, but was also a capacity-building opportunity in the community. All the in-person work was coordinated or conducted by Jeremy Brammer, who trained several local harvesters in sample processing, and also led a moose harvesting trip with the local school where additional moose samples were collected and processed for this project. The inability to visit the community for the majority of this project has resulted in limited opportunities for in-person conversation with members of the general public in the community. Hearing from diverse voices at more points throughout this thesis work could have helped inform communication for the work described in Chapters 3 and 4. In response to this communication gap, some of the results of this thesis that have been returned to the community virtually, or through plain language reading materials will be returned to the community for a second time, in person, by a member of Dr. Laird and Dr. Skinner's research teams in early 2023.

2 Human Biomonitoring Results of Contaminant and Nutrient Biomarkers in Old Crow, Yukon, Canada

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2.1 Abstract

Several large-scale human biomonitoring projects have been conducted in Canada, including the Canadian Health Measures Survey (CHMS) and the First Nations Biomonitoring Initiative (FNBI). However, neither of these studies included participants living in the Yukon. To address this data gap, a human biomonitoring project was implemented in Old Crow, a fly-in Gwich'in community in the northern Yukon. The results of this project provide baseline levels of contaminant and nutrient biomarkers from Old Crow in 2019. Samples of hair, blood, and/or urine were collected from approximately 44% of community residents (77 of 175 adults). These samples were analyzed for contaminants (including heavy metals and persistent organic pollutants (POPs)), and nutrients (including trace elements and omega-3 fatty acids). Levels of these analytes were compared to health-based guidance values, when available, and results from other human biomonitoring projects in Canada. Levels of lead (GM 0.64 µg/g creatinine in urine/24 µg/L blood), cadmium (GM 0.32 µg/g creatinine in urine/0.85 µg/L blood), and mercury (GM <LOD in urine/0.76 µg/L blood/0.31 µg/g hair) were below select health-based guidance values for more than 95% of participants. However, compared to the general Canadian population, elevated levels of some contaminants, including lead (approximately 2x higher),

cobalt (approximately 1.5x higher), manganese (approximately 1.3x higher), and hexachlorobenzene (approximately 1.5x higher) were observed. In contrast, levels of other POPs, including insecticides such as dichlorodiphenyltrichloroethane (DDT), its metabolite, dichlorodiphenyldichloroethylene (DDE), and polychlorinated biphenyls (PCBs) were similar to, or lower than, those reported in the general Canadian population. This study can be used along with future biomonitoring programs to evaluate the effectiveness of international initiatives designed to reduce the contaminant burden in the Arctic, including the Stockholm Convention and the Minamata Convention. Regionally, this project complements environmental monitoring being conducted in the region, informing local and regional traditional food consumption advisories.

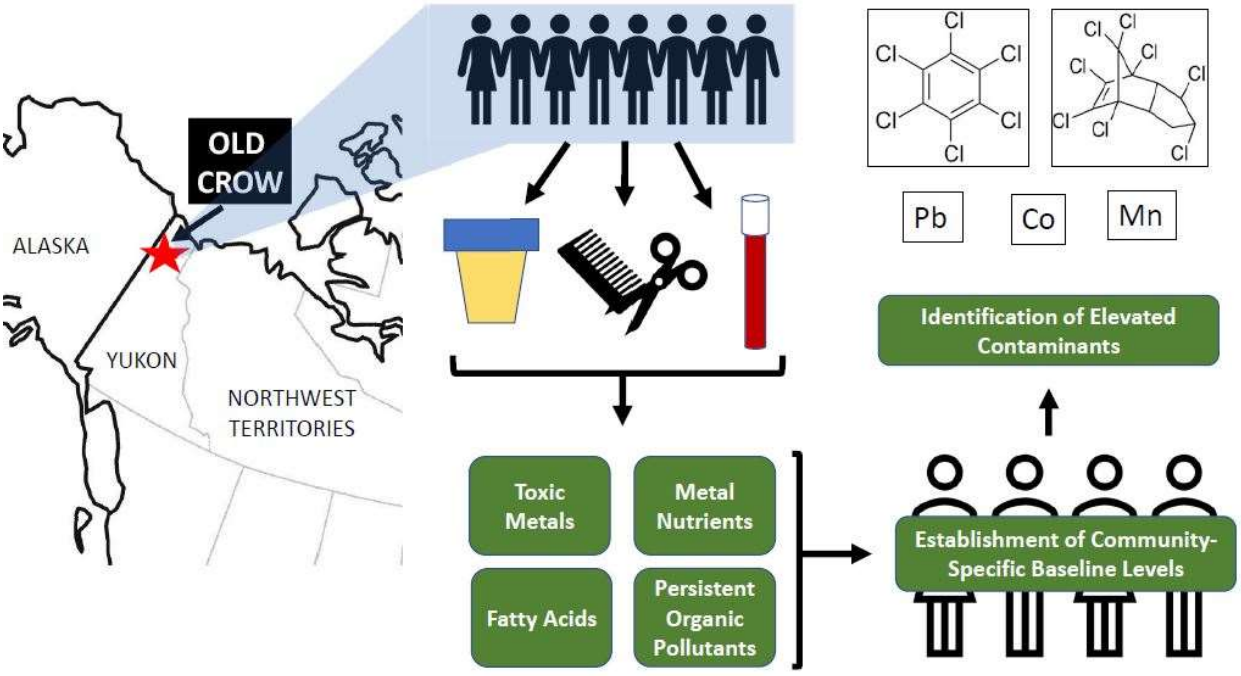

Figure 2-1 - *Graphical Abstract for Human Biomonitoring Results in Old Crow*

2.2 Introduction

Contaminants in the Arctic are a significant area of concern in Canada and internationally. To address this concern, the international community has come together to agree on several policies to reduce and monitor the contaminant burden in the north (129). Examples of these agreements and initiatives include the Stockholm Convention (12), which aims to ban or reduce the emissions of many Persistent Organic Pollutants (POPs), the Minamata Convention (13), which aims to reduce global emissions of mercury, and the Arctic Monitoring and Assessment Programme (14), which aims to monitor and assess contaminant burdens in the Arctic. Human biomonitoring is a method that can be used to describe spatial and temporal trends in human exposure, making it a key part of efforts to monitor the effectiveness of these programs (130). In Canada, several human biomonitoring programs have been conducted on a large scale, including the ongoing Canadian Health Measures Survey (CHMS), which includes a sample from the general population, and the 2011 First Nations Biomonitoring Initiative (FNBI), which recruited participants from 15 First Nations communities in the ten provinces (74-76, 78, 79, 131). Neither of these programs have recruited participants from communities in the northern territories (74-76, 78, 79, 131).

Though none of the national-scale human biomonitoring projects conducted in Canada have included participants outside of the ten provinces, several smaller scale human biomonitoring

programs have been conducted among Indigenous[2] and northern populations across the Canadian Arctic and subarctic. For example, the International Polar Year Inuit Health Survey (IPY-IHS) is a biomonitoring project that recruited more than 2,500 adults in Nunavut, Nunatsiavut, and the Inuvialuit Settlement Region (2007 – 2008) (94, 95). Human biomonitoring work was also conducted in 2016 and 2017 for 533 participants from nine communities in the Dehcho and Sahtu regions of the Northwest Territories (NWT), as well as for 29 pregnant women in British Columbia (80, 106, 128). Both the IPY-IHS and the more recent work in the NWT included the analysis of metals, and persistent organic pollutants (POPs), such as organochlorine pesticides and polychlorinated biphenyls (PCBs) (80, 94). Other human biomonitoring projects have been conducted in Canada's north, with focuses on specific subpopulations, including children and pregnant women in the Nunavik region (94). Though all of these studies have included Indigenous groups in Canada's north, only one had been conducted in the Yukon. This small project was conducted in Old Crow, a community located in the northern Yukon. In 2016, hair samples were collected from 32 Old Crow residents and analyzed for mercury by CANHelp (University of Alberta) as part of a study investigating interactions between dietary exposure to mercury, *H. pylori*, and risk of gastric cancer (107). Though this study provided valuable mercury exposure data in the region, no project including a comprehesive set of contaminants in people had been conducted in the Yukon prior to 2019.

[22] Section 35 (2) of the Constitution Act, 1982, defined "Aboriginal peoples in Canada" as including "the Indian, Inuit and Métis peoples of Canada." However, *Indian* is an offensive colonial term, and should not be used. It has been replaced by *First Nations*. Indigenous is the preferred term over Aboriginal and as the collective noun for **First Nations, Métis**, and **Inuit.** Acknowledging that First Nations are not homogenous and have many different languages, cultures, traditions, and spiritual beliefs, wherever possible the specific names of the Nations and communities should be used, especially if you are referring to territory and identity. Most of the Indigenous population in Old Crow, Yukon are Gwich'in, a First Nations peoples who belong to the Vuntut Gwitchin First Nation.

As part of the effort to address this data gap, this paper includes the results of a human biomonitoring project conducted in Old Crow, Yukon. Old Crow is a fly-in only Gwich'in community located in the northern Yukon on the Porcupine River (Figure 2-2). The community of Old Crow is located above the Arctic circle, a region that is especially vulnerable to the effects of climate change (10). Wild food is an important part of the diet for many Yukon residents, particularly for Gwich'in and other local First Nations, who harvest food from the land and water, including caribou, moose, fish, waterfowl, small game and many plants. Community members in Old Crow consume more traditional food than Yukon communities with road access, as well as more traditional food than is average for First Nations communities in Canada (56). The high latitude and remote location of the community within the Yukon, combined with high levels of traditional food consumption, result in a unique ecosystem which may be particularly vulnerable to contaminant exposure. Contaminants including mercury and cadmium are currently being analyzed in local wildlife and the environment, resulting in some consumption advisories for local communities (53, 61, 62). However, the level of exposure to these contaminants in nearby communities is unknown. Although there has been extensive research on contaminant levels in those wild foods (132) and some dietary surveys have been conducted in the past (117, 133), there is little to no human biomonitoring data of these contaminants available for Yukoners. This project was initiated at the request of the Vuntut Gwitchin Government (VGG) to investigate contaminant and nutrient levels in the residents of Old Crow, and to identify possible traditional food sources for these parameters. The aim of this project is to provide baseline levels of human exposure to many environmental contaminants of concern in Old Crow, including metals, such as mercury, lead, and cadmium, and legacy POPs. Additionally, the results of this study can be used as a tool to evaluate the universality of patterns observed in

national-scale biomonitoring projects in Canada, including the CHMS and FNBI, which do not include participants from northern communities.

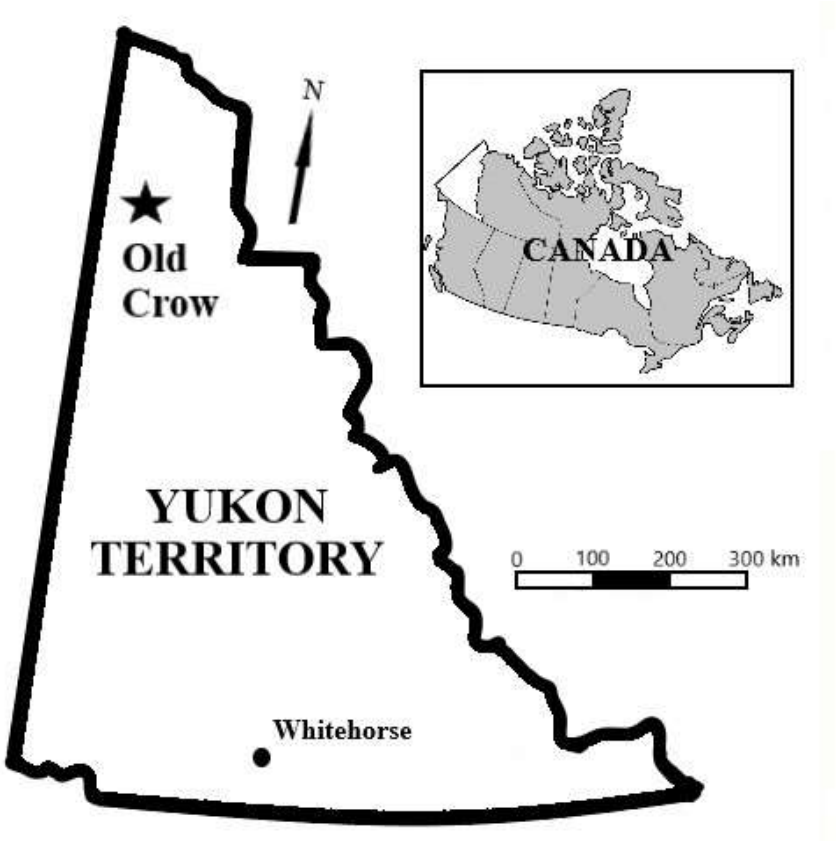

Figure 2-2 - *Location of Old Crow, YT*

2.3 Methods

The methods used for this project (including study design, questionnaires and surveys, consent forms, anthropometry measurement methods, biological sample collection, sample biobanking, and sample preservation and shipment) were consistent with those employed in the Dehcho and Sahtú Regions of the Northwest Territories, as described by Ratelle *et. al.* (80, 128). This description below provides a general overview of the methods with some of the details specific to Old Crow.

2.3.1 Community Partnership and Ethics

The results in this paper are being presented after individual and aggregate-level results were returned to participants, and aggregate-level results were returned to the community, in accordance with the agreement made with the VGG (126). In addition to the community research agreement with the VGG, this study was approved by the University of Waterloo Research Ethics Committee (#32076) and obtained a Scientists and Explorers Research License from the Yukon Government (12-27S&E).

2.3.2 Study Population

The study population for this project included all residents of Old Crow over the age of four regardless of sex, family status, or ethnicity. Children under the age of four and children and adults who were unable to provide free and informed consent, including those under the influence of drugs or alcohol, individuals with Alzheimer's disease, and minors who did not receive the consent of their parent or guardian, were unable to participate. Additionally, to be eligible to participate, individuals had to agree (via the informed consent process) to receive their personal results.

2.3.3 Recruitment

Recruitment was conducted using methods described by Ratelle *et. al.* (80, 128). Specifically, participants were recruited using both a random selection process by phone and passive recruitment by word of mouth, poster, and media interviews. Random recruitment was conducted by a local coordinator hired from the community. The coordinator used a list of phone numbers to call 40% of the residents with the aim of recruiting 10% of the 220 residents (134). During

these phone calls, the local coordinator explained the objectives of the study, and described the informed consent process. As per the community agreement with the VGG, individuals recruited using the passive techniques listed above, were eligible to participate to make the project as inclusive as possible.

2.3.4 Compensation

Participants who took part in any component of the study, including taking surveys and/or submitting any or all biological samples, received a gift card to the local grocery store or local airline. Participation in each component of the study was compensated with a raffle ticket, up to a maximum of five tickets for the five components, including the three biological samples and two surveys. The raffle tickets were entered into a draw for one of two gift cards for use at the grocery store or local airline.

2.3.5 Sampling and Chemical Analysis

Biological samples including hair, blood and urine were collected from participants. Sample collection methodologies were similar to those reported by Ratelle *et. al.* (80, 128), although an additional tube of serum (6 mL) was collected for long-term storage in a biorepository. Mercury was measured in hair samples for the 2-cm segment closest to the root. These values represent the cumulative exposure of the two months prior to the biomonitoring clinic (135, 136). The full suite of analytes is shown in Table 2-1. Analytical methods for metals and POPs in hair, blood, and urine were previously described in Ratelle *et. al.* (80). Fatty acids of plasma total lipids were extracted with 2:1 chloroform:methanol and transesterified with 14% boron trifluoride in methanol and then measured by gas chromatography with a DB-FFAP capillary column (Agilent

Technologies) with flame ionization detection (137). The methods employed for this project allow for the comparison of participant results to other Canadian biomonitoring programs, including the FNBI and the CHMS (74-76, 78, 79, 131).

2.3.6 Data Interpretation

Data interpretation was consistent with those reported in the aforementioned study in the Dehcho and Sahtú regions of the Northwest Territories (80). The GMs and 95Ps from this project are compared to those from nationally-representative biomonitoring projects, including the CHMS (representing the general Canadian population) and the FNBI (representing First Nations communities in the 10 provinces) (74-76, 78, 79, 131). In the case of the CHMS, the most recent cycle, including Cycles 1 -5, available for each parameter was used for comparison (74-76, 78, 131). These methods of comparison are indicators of the level of exposure in Old Crow relative to the reference populations, and do not specify level of toxicological risk.

For some toxicants (e.g., mercury and lead), Health Canada has developed guidance values that describe whether observed exposures are associated with increased risks at the individual and/or population level (81, 82). However, the majority of parameters do not have such federal guidance values. For the purposes of this project, additional guidance values (81, 82, 138-142) were selected, following the same process as a similar human biomonitoring project (80). The protocol for re-testing and consultation with participants who had biomarker concentrations above these values was described in Ratelle *et. al.* (80).

2.4 Results and Discussion

2.4.1 Data Analysis

Statistical analysis was performed using IBM SPSS Statistics Software Version 26 to calculate the 95% confidence intervals for the geometric means (GM) and 95th percentiles (95P) of the sample set using bootstrapping. Due to the small sample size, the 95th percentiles represent only a small fraction of the sample data. Therefore, the confidence intervals of this statistic are wide. For statistical analysis purposes, to remain consistent with the CHMS and FNBI, values below the laboratory limit of detection (LOD) were assigned values equal to half the LOD. If greater than 50% of samples in a group were below the LOD, the GM was described as below the LOD. Results of this study were compared to reference populations, including the FNBI and the CHMS. Descriptive statistics, including geometric mean and 95th percentile, are considered different when the confidence intervals do not overlap. In addition to the summary statistics, the strength of linear relationship between several biomarkers was analyzed using Spearman rank correlation coefficient (Spearman rho). Specific contaminants were selected based on their similar toxicokinetic behaviours, or synergistic effects. These contaminants included divalent metal cations, as well as POPs with greater than 60% of samples reporting values above the LOD. Participant demographics were compared using a Fisher's exact test. These analyses were conducted using SAS Software Version 9.4. Correlations were considered significant when $p<0.05$.

Table 2-1 - *List of Analytes and Biological Matrices for Old Crow Biomonitoring Project*

Class	Matrix	Parent Compounds	Biomarkers
Metals	Hair	Mercury	Total Mercury
	Whole Blood and Urine	Aluminium	Total Aluminum
		Arsenic	Total Arsenic
		Barium	Total Barium
		Beryllium	Total Beryllium
		Cadmium	Total Cadmium
		Cesium[a]	Total Cesium
		Chromium	Total Chromium
		Cobalt	Total Cobalt
		Copper	Total Copper
		Gallium	Total Gallium
		Iron[b]	Total Iron
		Lead	Total Lead
		Lithium	Total Lithium
		Manganese	Total Manganese
		Mercury	Total Mercury
		Nickel	Total Nickel
		Rubidium[a]	Total Rubidium
		Selenium	Total Selenium
		Strontium	Total Strontium
		Thallium	Total Thallium
		Uranium	Total Uranium
		Vanadium	Total Vanadium
		Zinc	Total Zinc

a: Only available in blood samples

Class	Matrix	Parent Compounds	Biomarkers
POPs - Flame retardants	Plasma	Polybrominated diphenyl ethers (PBDE)	PBDE , IUPAC # 15
			PBDE , IUPAC # 17
			PBDE , IUPAC # 25
			PBDE , IUPAC # 28
			PBDE , IUPAC # 33
			PBDE , IUPAC # 47
			PBDE , IUPAC # 99
			PBDE , IUPAC # 100
			PBDE , IUPAC # 153
	Plasma	Polybrominated biphenyls (PBB)	PBB , IUPAC # 153
POPs - Pesticides	Plasma	Aldrin	Aldrin
		Chlordane	gamma-Chlordane
			alpha-Chlordane
			Oxychlordane
			cis-Nonachlor
			trans-Nonachlor
		Lindane	gamma-HCH
			beta-HCH
		Hexachlorobenzene	Hexachlorobenzene
		Mirex	Mirex
		DDT	p,p'-DDE
			p,p'-DDT
		Toxaphene	Parlar no. 26
			Parlar no. 50

Class	Matrix	Parent Compounds	Biomarkers
POPs - Electrical and coolant fluids	Plasma	Polychlorinated biphenyls (PCB)	PCB , Aroclor 1260
			PCB , IUPAC # 28
			PCB , IUPAC # 52
			PCB , IUPAC # 66
			PCB , IUPAC # 74
			PCB , IUPAC # 99
			PCB , IUPAC # 101
			PCB , IUPAC # 105
			PCB , IUPAC # 118
			PCB , IUPAC # 128
			PCB , IUPAC # 138
			PCB , IUPAC # 146
			PCB , IUPAC # 153
			PCB , IUPAC # 156
			PCB , IUPAC # 163
			PCB , IUPAC # 167
			PCB , IUPAC # 170
			PCB , IUPAC # 178
			PCB , IUPAC # 180
			PCB , IUPAC # 183
			PCB , IUPAC # 187
			PCB , IUPAC # 194
			PCB , IUPAC # 201
			PCB , IUPAC # 203
			PCB , IUPAC # 206

Lipids	Plasma	Fatty acids	Omega-3 (EPA + DHA)	
			PUFAs	
			N-3, N-6	

b: Only available in urine samples

PUFA: Polyunsaturated fatty acid

EPA: Eicosapentaenoic acid

DHA: Docosahexaenoic acid

HCH: Hexachlorocyclohexane

DDT: Dichlorodiphenyltrichloroethane

DDE: Dichlorodiphenyldichloroethylene

*Other contaminants have been analyzed as part of this study, and are not included in this report. These include perfluoroalkylated substances (143) in serum, and dioxins and furans in plasma.

The full set of laboratory results was compiled for analysis for each biomarker, including hair and blood. However, three urine samples were omitted from the statistical analysis due to low creatinine levels (< 0.3 g/L), indicating dilute urine, which may impair the detection of some contaminants (144). Urine samples have been adjusted for creatinine levels to account for differences in hydration status among participants (145). Additionally, POP concentrations have been normalized to plasma lipid levels to account for interindividual variation of lipid levels in blood in blood lipid levels (145). Calculation of total PCBs was reported using two methods, including Aroclor 1260 (74) and two times the sum of PCB 138, PCB 153, and PCB 180 (85).

2.4.2 Participation and Demographics

The demographics of participants are shown in Table 2-2. About 44% of the eligible residents (77 of 175 adults) of Old Crow took part in at least one of the components. During the four-day sampling period, 178 biological samples were collected, including 56 blood samples, 73 hair samples and 49 urine samples. Women between the ages of 18 and 50 represented 32% of participants. All participants but two were 18 years or older. Results for the two minors were not included in this paper to preserve participant confidentiality. The proportion of adult participants under 40 years of age in the study (36/77; 47%) was higher than the proportion of adults under 40 in Old Crow observed in the 2016 census (43%) based on a Fisher's exact test ($p>0.05$) (134). More participants were female (43/77; 56%) than male (34/77; 44%). The proportion of female participants in the study was significantly higher than the proportion of adult females in Old Crow observed in the 2016 census (47%) based on a Fisher's exact test ($p>0.05$) (134).

Table 2-2 - *Demographics of Adult Participants and Types of Samples from Old Crow Biomonitoring Project*

Demographic		Hair		Blood		Urine	
Sex		**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
Total		31	40	26	28	22	25
Age Group	**18 - 39**	13	19	11	15	8	14
	40 - 59	11	11	10	8	9	7
	60+	7	10	5	5	5	4
Women of Childbearing Age (18 - 50)		-	23	-	17	-	16

2.4.3 Hair Mercury

Table 2-3 presents the levels of mercury measured in hair. All participants' exposure levels fell below the selected health guidance values for mercury (Table 2-4). Hair mercury concentrations in Old Crow were generally similar to those reported in the general Canadian population and to First Nations communities in British Columbia as part of the First Nations Food, Nutrition, and Environment Study (FNFNES) (78, 146). In addition to a comparison to the CHMS and FNFNES, hair mercury concentrations in Old Crow were compared to results from a previous study in the area. This previous study was conducted in 2017 in several Canadian Arctic communities and included 32 participants in Old Crow who provided hair for mercury analysis. The study reported a mean value of 0.54 μg/g mercury in hair (107). Mercury concentrations in the 2017 study were below 2 μg/g hair for all participants in Old Crow, which is consistent with the results reported in this study (107).

Table 2-3 - *Summary Statistics and 95% Confidence Intervals of Hair Mercury Concentrations in Adults from the Old Crow Population in this Study, Compared to Reference Populations*

Mercury Concentrations (µg/g)									
Old Crow (this study)				Canadian Health Measures Survey (CHMS)[a]		First Nations Food, Nutrition, and Environment Study (FNFNES)[b]		2017 Canadian Arctic Study (CAS)[c]	
n=71				n=1201		n = 487		n=32	
Limit of Detection (LOD)	% of Samples <LOD	Geometric Mean (GM)	95th Percentile (95P)	GM	95P	GM	95P	GM	95P
0.08	0	0.31 (0.25 - 0.36)	1.3 (0.74 - 1.6)	0.19 (0.14 - 0.25)	1.4 (0.81 - 1.9)	0.37 (0.26 - 0.53)	1.6 (1.2 - 3.6)	0.54	NR

a - Canadian Health Measures Survey (CHMS) Cycle 5 (147)

b – First Nations Food, Nutrition, and Environment Study – Results for British Columbia (146)

c - Canadian Arctic Study (107)

NR - Parameter was analyzed but statistic could not be reported

Table 2-4 - *Percentage of Participants (n=77) in Old Crow Exceeding Selected Health-Based Guidance Values*

Demographic		Men (>18)	Women of child-bearing age (18 – 49)	Women (>50)
Blood		n=26	n=17	n=11
Mercury	% > 8.0 µg/L whole blood for women of child-bearing age and 20 µg/L whole blood for men >18 and women >50[a]	0	0	0
Lead	% > 50 µg/L whole blood for women of child-bearing age[b] and 100 µg/L whole blood for men >18 and women >50[c]	3.8	5.9	9.1
Cadmium	% > 5 µg/L whole blood[b,d,e]	3.8	0	0
Urine				
Sample Size (n)		21	15	8
Mercury	% > 25 µg/L urine[f]	0	0	0
Lead	% > 7 µg/L urine[e]	0	0	0
Cadmium	% > 7.3 µg/L urine[e]	0	0	0
Hair				
Sample Size (n)		31	23	17
Mercury	% > 2 µg/g hair for women of child-bearing age and 5 µg/g hair for men >18 and women >50[g]	0	0	0

a - (72), b - (124), c - (131), d - (125), e - (126), f - (127), g - (128)

2.4.4 Urine Metals

Concentrations of metals in urine samples and creatinine-adjusted values are shown in Table 5. Urine cadmium, lead, and mercury levels for all participants were below individual follow-up guidance values (7.3 µg/L cadmium, 7 µg/L lead, and 25 µg/L mercury), as shown in Table 2-4 (140, 141).

Levels of most toxic metals (including cadmium, uranium, and mercury) in urine were similar or lower to those in the CHMS and FNBI, with several exceptions, including: lead, arsenic, manganese, cobalt, and vanadium. At the upper end of exposure (e.g., 95P), higher levels of lead were found in the urine samples of participants from Old Crow than in the general Canadian population. However, the 95P is representative of a small number of participants, due to the low sample size. The geometric mean of samples from Old Crow were within the range reported in the CHMS. Creatinine-adjusted levels of some essential trace elements (including selenium, nickel, thallium, and zinc) in Old Crow participant urine samples were similar to or lower than those observed in the CHMS and FNBI. Elements that were lower in creatinine-adjusted urine in Old Crow than those observed in the CHMS and FNBI included copper, mercury, nickel, thallium, and cadmium.

Table 2-5 - *Summary Statistics and 95% Confidence Intervals of Metal Concentrations in Urine in Adults from the Old Crow Population in This Study, Compared to Reference Populations*

	Concentrations (µg/L)								Creatinine-Adjusted (µg/g)					
	Old Crow (this study)				Canadian Health Measures Survey (CHMS)[a]		First Nations Biomonitoring Initiative (FNBI)[b]		Old Crow (this study)		CHMS		FNBI	
	n = 44[c]				n = 2715 - 6311[abc]		n = 495							
	Limit of Detection (LOD)	% of Samples <LOD	Geometric Mean (GM)	95th Percentile (95P)	GM	95P	GM	95P	GM	95P	GM	95P	GM	95P
Aluminium	1.4	0.0	11 (9.4 – 14)	30 (24 – 150)	NA	NA	NA	NA	11 (8.9 – 13)	32 (21 – 100)	NA	NA	NA	NA
Arsenic[a]	0.057	0.0	13 (11 – 16)	46 (27 – 95)	9.2 (7.7 – 11)	77 (58 – 96)	4.5 (3.4 - 5.9)	39 (31 – 47)	12 (10 – 15)	74 (18 – 110)	8.6 (7.2 – 10)	71 (55 – 87)	5.0 (3.9 - 6.4)	38 (24 – 52)
Barium[a]	0.021	0.0	1.7 (1.4 - 2.0)	6.6 (3.3 - 7.3)	NA	NA	NA	NA	1.6 (1.2 - 2.0)	8.8 (3.1 – 13)	NA	NA	NA	NA
Beryllium	0.02	75	<LOD	0.042 (0.035 - 0.065)	NA	NA	NA	NA	<LOD	0.11 (0.035 - 0.12)	NA	NA	NA	NA
Cadmium[c]	0.022	0.0	0.33 (0.26 - 0.43)	1.3 (0.87 - 2.3)	NR	1.4 (1.0 - 1.8)	0.54 (0.47 - 0.63)	2.1 (1.8 - 2.3)	0.32 (0.25 - 0.40)	1.2 (0.93 - 1.3)	NR	1.2 (0.88 - 1.5)	0.61 (0.55 - 0.69)	1.6 (1.2 - 2.0)
Chromium	0.043	4.5	0.19 (0.15 - 0.24)	0.52 (0.45 - 0.73)	NA	NA	NA	NA	0.18 (0.15 - 0.22)	0.67 (0.38 - 0.87)	NA	NA	NA	NA
Cobalt[a]	0.018	0.0	0.37 (0.30 - 0.47)	1.7 (0.69 - 3.6)	0.23 (0.21 - 0.26)	0.97 (0.86 - 1.1)	NA	NA	0.35 (0.30 - 0.43)	1.8 (0.56 - 3.3)	0.22 (0.20 - 0.25)	0.88 (0.79 - 0.97	NA	NA
Copper[a]	0.048	0.0	6.8 (5.7 - 8.1)	16 (14 – 16)	11 (10 – 11)	28 (26 – 29)	12 (11 – 13)	43 (29 – 58)	6.5 (5.7 - 7.3)	14 (11 – 14)	10 (9.9 – 10)	19 (18 – 20)	13 (11 – 15)	33 (25 – 41)
Gallium	0.022	0.0	0.11 (0.089 - 0.13)	0.38 (0.20 - 0.48)	NA	NA	NA	NA	0.10 (0.083 - 0.13)	0.41 (0.20 - 0.69)	NA	NA	NA	NA
Iron	0.28	0.0	11 (9.2 – 15)	30 (25 – 280)	NA	NA	NA	NA	11 (8.8 – 14)	55 (19 – 420)	NA	NA	NA	NA
Lead[a]	0.017	0.0	0.68 (0.49 - 0.91)	3.9 (2.1 - 4.1)	0.52 (0.49 - 0.55)	1.9 (1.7 - 2.0)	0.51 (0.43 - 0.60)	2.3 (1.5 - 3.1)	0.64 (0.47 - 0.87)	3.1 (2.3 – 17)	0.48 (0.46 - 0.51)	1.6 (1.4 - 1.8)	0.56 (0.48 - 0.66)	2.2 (1.6 - 2.8)
Lithium	0.77	0.0	28 (23 – 33)	67 (43 – 200)	NA	NA	NA	NA	26 (23 – 29)	51 (41 – 89)	NA	NA	NA	NA
Manganese[a]	0.032	2.3	0.14 (0.11 - 0.18)	1.5 (0.25 - 2.5)	<LOD	0.36 (0.32 - 0.4)	<LOD	0.59 (0.27 - 0.92)	0.13 (0.96 - 0.17)	1.7 (0.37 - 2.8)	<LOD	0.61 (0.51 - 0.7)	<LOD	0.89 (0.66 - 1.1)
Mercury[b]	0.2	65	<LOD	0.76 (0.60 - 1.1)	<LOD	2.2 (1.7 - 2.7)	0.26 (0.19 - 0.36)	2.0 (1.6 - 2.4)	<LOD	0.61 (0.44 - 0.81)	<LOD	1.5 (1.2 - 1.8)	0.30 (0.22 - 0.39)	1.8 (1.2 - 2.4)
Nickel[a]	0.24	0.0	0.80 (0.62 - 1.0)	2.9 (1.8 - 3.3)	1.3 (1.3 - 1.4)	4.8 (4.2 - 5.4)	1.2 (1.1 - 1.4)	4.6 (3.9 - 5.2)	0.75 (0.62 - 0.94)	2.8 (1.7 - 3.4)	1.2 (1.2 - 1.3)	4.0 (3.5 - 4.4)	1.4 (1.3 - 1.5)	3.8 (3.2 - 4.4)
Selenium[a]	0.52	0.0	57 (45 – 72)	170 (130 – 180)	51 (49 – 53)	130 (130 – 140)	51 (44 – 59)	160 (140 – 180)	54 (49 – 60)	100 (79 – 140)	48 (46 – 50)	96 (88 – 100)	57 (51 – 64)	130 (100 – 170)
Strontium	0.39	0.0	130 (100 – 150)	310 (250 – 310)	NA	NA	NA	NA	120 (100 – 140)	300 (260 – 460)	NA	NA	NA	NA

Tsble 2-5 Continued	Concentrations (µg/L)								Creatinine-Adjusted (µg/g)					
	Old Crow (this study)				Canadian Health Measures Survey (CHMS)[a]		First Nations Biomonitoring Initiative (FNBI)[b]		Old Crow (this study)		CHMS		FNBI	
	n = 44[e]				n = 2715 - 6311[abc]		n = 495							
	Limit of Detection (LOD)	% of Samples <LOD	Geometric Mean (GM)	95th Percentile (95P)	GM	95P	GM	95P	GM	95P	GM	95P	GM	95P
Thallium[a]	0.026	2.3	0.13 (0.11 - 0.16)	0.28 (0.27 - 0.38)	0.23 (0.21 - 0.24)	0.62 (0.55 - 0.7)	NA	NA	0.12 (0.11 - 0.14)	0.21 (0.19 - 0.24)	0.22 (0.20 - 0.23)	0.55 (0.49 - 0.61)	NA	NA
Uranium[a]	0.014	73	<LOD	0.030 (0.021 - 0.032)	<LOD	0.020 (0.018 - 0.023)	<LOD	NR	<LOD	0.058 (0.018 - 0.066)	<LOD	0.024 (0.021 - 0.028)	<LOD	NR
Vanadium[a]	0.013	0.0	0.12 (0.10 - 0.14)	0.25 (0.21 - 0.28)	<LOD	0.13 (0.10 - 0.15)	<LOD	0.19 (0.13 - 0.26)	0.11 (0.097 - 0.13)	0.30 (0.19 - 0.32)	<LOD	0.24 (0.21 - 0.26)	<LOD	0.35 (0.25 - 0.45)
Zinc[a]	0.96	0.0	320 (260 – 390)	760 (730 – 780)	320 (300 – 340)	1200 (1100 – 1300)	370 (330 – 420)	1400 (1200 – 1600)	310 (250 – 370)	800 (510 – 1000)	300 (280 – 310)	770 (730 – 810)	420 (370 – 460)	1200 (1000 – 1400)

a - Canadian Health Measures Survey (CHMS) Cycle 2 n=6311 (148)

b - Canadian Health Measures Survey (CHMS) Cycle 4 n=5595 (149)

c - Canadian Health Measures Survey (CHMS) Cycle 5 n = 2715 (147)

d - First Nations Biomonitoring Initiative (79)

e - Sample set is n=47, three samples were omitted due to low creatinine levels (<0.3 g/L)

NA - Parameter was not analyzed

NR - Parameter was analyzed but statistic could not be reported

Some Old Crow participants had relatively high levels of manganese, and cobalt in the creatinine-adjusted urine samples compared to the reference populations. There are no standard thresholds for health effects for these metals in urine. Generally, urinary manganese is not a reliable indicator of manganese status, with the exception of short-term acute and elevated exposure (74). Cobalt is readily excreted in urine, and both blood and urinary cobalt are used as biomarkers for recent cobalt exposure (150).

Associations among urinary concentrations of divalent metal cations, including cadmium, cobalt, copper, iron, lead, manganese, nickel, and zinc, were assessed using Spearman rank correlation coefficients. Correlation coefficients for creatinine-adjusted concentrations in urine are shown in Table 2-6. The majority of the divalent cations in urine had significant positive (0.30 – 0.76) associations. The strongest associations between creatinine-adjusted urinary metals were between cadmium and copper (0.67, $p<0.01$), and manganese with cobalt (0.76, $p<0.01$) and iron (0.58, $p<0.01$). Associations between manganese, cobalt, and iron levels have been noted in the literature (151, 152), however, urinary iron levels are not considered a reliable biomarker for iron status (153). An association between cadmium and copper levels in urine has been attributed to factors including similar exposure pathways, as well as the possible renal effects of cadmium exposure, resulting in increased copper excretion (154, 155).

Table 2-6 - *Spearman Correlation Coefficients (r) of Metals in Urine and Whole Blood in the Old Crow Biomonitoring Project*

		Metals in Whole Blood							Creatinine-Adjusted Metals in Urine							
		Cd	Co	Cu	Pb	Mn	Ni	Zn	Cd	Co	Cu	Fe	Pb	Mn	Ni	Zn
Metals in Whole Blood	Cd	1														
	Co	-0.045	1													
	Cu	0.17	0.065	1												
	Pb	0.27*	-0.047	-0.091	1											
	Mn	0.089	0.18	0.20	0.26	1										
	Ni	-0.016	0.13	0.15	-0.059	0.056	1									
	Zn	0.084	-0.053	-0.14	0.030	-0.12	-0.054	1								
Creatinine-Adjusted Metals in Urine	Cd	0.67**	-0.39*	0.16	0.50**	0.22	-0.073	0.11	1							
	Co	-0.017	0.32*	0.16	-0.015	0.39*	-0.16	-0.52**	-0.12	1						
	Cu	0.21	-0.26	0.057	0.39*	0.29	-0.16	0.14	0.67**	0.080	1					
	Fe	0.18	-0.10	0.10	0.19	0.20	-0.063	-0.44	0.43**	0.37*	0.45**	1				
	Pb	0.19	-0.25	-0.048	0.74**	0.18	-0.19	-0.10	0.40**	0.20	0.36*	0.31*	1			
	Mn	0.078	0.071	0.22	0.13	0.35*	-0.22	-0.30	0.19	0.76**	0.34*	0.58**	0.31*	1		
	Ni	0.14	0.23	0.14	0.082	0.12	0.11	-0.32*	0.12	0.47**	0.19	0.32*	0.25	0.46**	1	
	Zn	0.17	0.053	-0.095	0.35*	0.26	0.073	0.10	0.36*	-0.44	0.37**	-0.011	0.20	-0.10	-0.056	1

*p<0.05

** p<0.01

2.4.5 Blood Metals

Table 2-7 presents levels of metals in whole blood samples with comparisons to reference populations including the CHMS and the FNBI. The percentage of participants with blood metal concentrations exceeding the selected health-based guidance values are shown in Table 4. Blood mercury concentrations for all participants were below the selected health-based guidance values of 8 µg/L (for women under 50 years of age and children) and 20 µg/L (for adult men and women 50 years and older) (82). Cadmium levels in blood were also below the screening guideline of 5 µg/L in 98% of adult participants (140). Lead levels in 95% of participants were below the available health-based guidance values of 100 µg/L (for women 50 and older and men) and 50 µg/L (for children and women of child-bearing age) (81). All participants had blood lead levels below the early notification value of 200 µg/L applied in other biomonitoring studies (138,

140). Uranium does not have a health-based guidance value for blood concentrations, however, concentrations were below the detection limit for all participants.

Blood concentrations of cadmium, mercury, arsenic, and uranium, were similar or lower than those observed in the reference populations. However, both the GM and 95P of blood lead levels in Old Crow were more than two times higher than those observed in the CHMS and FNBI. Elevated blood lead levels compared to those observed in the south have been reported in some northern populations in previous studies, including those conducted in Nunavik in 2004, and the Inuvialuit Settlement Region and Nunavut in 2007-2008 (94, 97, 156). At the time, elevated blood lead levels in these communities were partially attributed to the use of lead shot for hunting, which may result in lead contamination in some traditional foods (97). The levels reported in the 2004 and 2007-2008 studies may not represent current lead levels in these areas, as they may have followed the decreasing trend of blood lead levels observed in southern Canada during this time period (78). Notably, blood lead concentrations for adults in Nunavik decreased significantly between 1994 and 2004 (97, 156). Future studies can use the baseline data gathered in this report to assess whether a similar downward trend is present in Old Crow.

Similar to with urine, both the geometric mean and 95th percentile of some nutrients, including cobalt and manganese, were higher in Old Crow participants than in the general Canadian population. Further, manganese levels were higher than in southern First Nations communities (cobalt was not analyzed as part of the FNBI). There is no health-based guidance value for manganese or cobalt in blood for non-occupational exposed individuals. Copper, another metal nutrient, had a higher geometric mean in Old Crow than in the CHMS. However, copper levels in Old Crow were within the range reported in the FNBI. Other metal nutrients, including zinc, and selenium, in participants from Old Crow were within the range of those reported in the

general Canadian population. Nickel concentrations were lower in Old Crow than in both the CHMS and the FNBI.

The Spearman rank correlation coefficients for divalent metal cation concentrations in blood are shown in Table 2-6. The only divalent metal cations with a significant association in blood are cadmium and lead (0.27, $p<0.05$). Associations between these contaminants may indicate a shared exposure pathway, such as smoking (157). Table 6 also shows the Spearman rank correlation coefficients between blood and urine divalent metal cations. The majority of blood metal concentrations were associated with the same metal in urine, including cadmium (0.67, $p<0.01$), cobalt (0.32, $p<0.05$), lead (0.74, $p<0.01$), and manganese (0.35, $p<0.05$).

Some nutrient concentrations may be associated with lead levels in blood. For instance, elevated blood lead levels have been associated with an increase in blood copper levels, and a decrease in blood zinc levels (151). Blood lead levels in Old Crow were not significantly associated with either blood zinc or copper levels, however, weak to moderate (0.30 – 0.40) positive significant associations were observed between blood lead levels and urinary copper and zinc. Notably, blood copper and zinc are considered more reliable than urine as exposure biomarkers for these metals in the general population (153).

Table 2-7 - *Summary Statistics and 95% Confidence Intervals of Metal Concentrations in Whole Blood (µg/L) from the Old Crow Population in this Study, Compared to Reference Populations*

		Old Crow (this study)			CHMS[abc]		FNBI[d]	
		n = 54			n = 4517-6070[abc]		n = 473	
	LOD	% of Samples <LOD	Geometric Mean (GM)	95th Percentile (95P)	GM	95P	GM	95P
Aluminium	0.76	22	19 (10 – 36)	539 (170 – 820)	NA	NA	NA	NA
Arsenic[b]	0.0087	0.0	0.54 (0.43 - 0.68)	3.4 (1.4 - 7.5)	0.89 (0.74 - 1.1)	4.1 (2.9 - 5.2)	0.49 (0.39 - 0.62)	3.3 (1.7 - 5.0)
Barium	0.16	11	0.44 (0.34 - 0.56)	2.9 (1.4 - 3.9)	NA	NA	NA	NA
Beryllium	0.011	5.6	0.043 (0.034 - 0.053)	0.12 (0.10 - 0.13)	NA	NA	NA	NA
Cadmium[c]	0.0059	0.0	0.85 (0.62 - 1.2)	4.0 (3.1 - 5.2)	0.28 (0.25 - 0.30)	2.9 (2.4 - 3.3)	0.96 (0.84 - 1.1)	4.7 (4.0 - 5.3)
Cesium	0.012	0.0	3.1 (2.7 - 3.6)	6.4 (5.0 – 15)	NA	NA	NA	NA
Chromium	0.021	30	0.075 (0.048 - 0.12)	1.2 (0.67 - 1.3)	NA	NA	NA	NA
Cobalt[a]	0.15	0.0	0.31 (0.28 - 0.33)	0.61 (0.51 - 0.84)	0.23 (0.21 - 0.24)	0.40 (0.36 - 0.43)	NA	NA
Copper[a]	0.57	0.0	970 (950 – 1000)	1200 (1100 – 1500)	900 (890 – 910)	1200 (1200 – 1300)	930 (900 – 960)	1200 (1100 – 1200)
Gallium	0.00058	78	<LOD	0.094 (0.056 - 0.14)	NA	NA	NA	NA
Lead[c]	0.042	0.0	24 (19 – 30)	98 (75 – 140)	9.3 (5.5 – 10)	25 (21 – 29)	12 (11 – 13)	33 (21 – 45)
Lithium	0.086	94	<LOD	2.5 (<LOD - 3.2)	NA	NA	NA	NA
Manganese[a]	0.082	0.0	12 (11 – 13)	22 (19 – 24)	9.8 (9.5 – 10)	15 (14 – 16)	12 (12 – 13)	21 (20 – 22)
Mercury[c]	0.031	5.6	0.76 (0.52 - 1.1)	4.3 (2.7 - 6.9)	0.64 (0.54 - 0.75)	3.8 (2.9 - 4.8)	0.95 (0.51 - 1.8)	9.3 (5.4 – 13)
Nickel[a]	0.21	61	<LOD	0.40 (0.36 - 0.51)	0.48 (0.45 - 0.51)	1.1 (1.1 - 1.2)	0.44 (0.37 - 0.52)	1.1 (0.79 - 1.5)
Rubidium	0.48	0.0	2600 (2500 – 2700)	3200 (3100 – 3600)	NA	NA	NA	NA
Selenium[c]	4.0	0.0	170 (170 – 180)	240 (200 – 280)	170 (170 – 170)	210 (200 – 210)	190 (180 – 200)	230 (220 – 250)
Strontium	0.0038	0.0	16 (15 – 17)	25 (21 – 31)	NA	NA	NA	NA
Thallium	0.10	100	<LOD	<LOD	NA	NA	NA	NA
Uranium[a]	0.0057	100	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Vanadium	0.12	93	<LOD	0.17 (<LOD - 0.38)	NA	NA	NA	NA
Zinc[a]	2.9	0.0	5700 (5500 – 5900)	7100 (6600 – 7500)	6000 (5900 – 6100)	7300 (7100 – 7600)	5700 (5600 – 5900)	6900 (6600 – 7200)

a - Canadian Health Measures Survey (CHMS) Cycle 2 n=6070 (148)

b - Canadian Health Measures Survey (CHMS) Cycle 1 n=5319 (158)

c - Canadian Health Measures Survey (CHMS) Cycle 5 n=4517 (147)

d - First Nations Biomonitoring Initiative n=473 (79)

NA - Parameter was not analyzed

There is no evidence of a correlation between zinc, copper, and lead status in Old Crow. Both blood manganese and cobalt levels had significant positive association with urinary cobalt (0.39, and 0.32, respectively, $p<0.05$). The elevated levels of these metals may be related to factors similar to those affecting lead concentrations, such as iron status. Higher blood iron status can be associated with a decrease in blood lead concentrations, and the same trend has been observed for both cobalt and manganese (151, 152, 159). However, blood iron status was not analyzed as part of this project.

Due to the elevated levels of these parameters, cobalt, manganese, and lead are priority substances for future work to determine possible determinants of u in Old Crow. Additionally, analysis of blood iron levels using biobanked samples is recommended to determine the relationship between iron and priority substances, as well as to indicate the level of anemia risk in the community.

2.4.6 Omega-3 Fatty Acids

Blood plasma samples were submitted for fatty acid composition analysis. Omega-3 polyunsaturated fatty acid status was assessed using the sum of the percentage of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) as a total percentage of fatty acid concentrations in the plasma (160). The geometric mean level of EPA+DHA in the plasma of the 54 adult participants from Old Crow was 75 mg/L (95%CI: 69 – 82 mg/L) with a 95th percentile of 130 mg/L (95%CI: 110 – 140 mg/L). The geometric mean of the percentage of EPA+DHA as a total of fatty acids is 1.9% (95%CI: 1.8 – 2.1%) with a 95th percentile of 2.9% (95%CI: 2.7 – 3.8%). The CHMS does not have reference ranges for plasma fatty acids at this date. Though the percentage of EPA+DHA in erythrocytes has been reported as part of Cycle 3 of the CHMS, it

does not include residents of the three territories, and First Nations communities and remote regions (161). However, the results in Old Crow are similar to those from recent summary of studies in Canada listing an average range of 1.5 - 2.4% EPA+DHA as a total of plasma fatty acids (160).

2.4.7 Persistent Organic Pollutants

Table 2-8 shows the levels of POPs, including several pesticides and industrial chemicals and their break-down products (i.e. metabolites), in the blood plasma of participants in Old Crow. The Spearman rank correlation coefficients were calculated for all lipid-normalized POPs with greater than 60% of samples reporting values greater than the LOD. These results are shown in Table 2-9. All of the lipid-normalized POPs with more than 60% of values above the LOD, including PCB 138, PCB 153, PCB 180, Trans-nonachlor, hexachlorobenzene, oxychlordane, and DDE had positive significant correlations greater than 0.65 ($p<0.01$). The association between these parameters may indicate a possible shared exposure pathway.

Generally, lipid-adjusted POP levels were similar to, or below, the values seen in the general Canadian population. For example, lipid-adjusted levels of insecticides such as dichlorodiphenyltrichloroethane (DDT), its metabolite, dichlorodiphenyldichloroethylene (DDE), toxaphene, and all PCBs had concentrations below those observed in the CHMS and FNBI. These similarities suggest the residents of Old Crow are generally not exposed to these contaminants at elevated levels in comparison to populations in Canada's south. However, several POPs appeared to be at levels higher than observed in the comparison populations. Both the lipid-adjusted GM and 95P of hexachlorobenzene, an organochlorine fungicide, levels in Old Crow were elevated with respect to the comparison groups. Additionally, γ-Chlordane levels

were higher at the upper end of exposure (95P) than those observed in both the CHMS and FNBI. However, due to the small sample size, the 95P is not representative of a large number of samples. Notably, more than 90% of samples were below the LOD for γ-Chlordane, and therefore the elevated levels observed at the 95th percentile may not be indicative of elevated exposure at the population level. There are no health-based guidance values for either hexachlorobenzene or γ-Chlordane.

Though hexachlorobenzene concentrations in Old Crow were higher than those observed in the southern comparison populations, mean levels were lower than observed in communities in Nunavut, Nunatsiavut, and the Inuvialuit Settlement Region in the 2007-2008 IPY Inuit Health Survey (94). POPs can travel very long distances through the atmosphere and, because they are persistent, can be detected many years after their release in the environment. Hexachlorobenzene will be a priority substance for future work to determine possible determinants of biomarker levels in Old Crow due to the elevated levels observed relative to the reference groups. The majority of the POPs analyzed as part of this project have not been used or produced in North America for decades and many were banned globally as part of the Stockholm Convention in 2001 (12, 15). The site-specific baseline levels reported in this project will enable future studies to monitor the extent to which POP exposures decrease over time as a result of the Stockholm Convention.

Table 2-8 - *Summary Statistics and 95% Confidence Intervals of POP Concentrations in Plasma in Adults from the Old Crow Population in this Study Compared to Reference Populations*

	Concentrations (µg/L)								Lipid-Adjusted (µg/kg)					
	Old Crow (this study)				CHMS[a]		FNBI[b]		Old Crow (this study)		CHMS		FNBI	
	n = 54				n = 1665		n = 471							
	Limit of Detection (LOD)	% of Samples <LOD	Geometric Mean (GM)	95th Percentile (95P)	GM	95P	GM	95P	GM	95P	GM	95P	GM	95P
Total PCBs (Aroclor 1260)	0.1	11	0.36 (0.27 - 0.49)	2.4 (1.3 - 3.1)	0.90 (0.79 - 1.0)	4.2 (3.3 - 5.0)	0.64 (0.43 - 0.96)	6.3 (3.2 - 9.4)	51 (39 – 67)	360 (160 – 550)	150 (130 – 170)	680 (550 – 810)	100 (67 – 150)	1000 (610 – 1400)
Total PCBs (2x(PCB 138 + PCB 153 + PCB 180))	0.03	7.4	0.20 (0.15 - 0.27)	1.3 (0.80 - 1.5)	NA	NA	NA	NA	29 (21 – 38)	170 (110 – 200)	NA	NA	NA	NA
PCB 28	0.2 - 0.3	100	<LOD	<LOD	NR	<LOD	<LOD	<LOD	<LOD	<LOD	NR	<LOD	<LOD	<LOD
PCB 52	0.9 - 2.0	100	<LOD	<LOD	NR	<LOD	<LOD	<LOD	<LOD	<LOD	NR	<LOD	<LOD	<LOD
PCB 66	0.09 - 0.10	100	<LOD	<LOD	NR	<LOD	<LOD	<LOD	<LOD	<LOD	NR	<LOD	<LOD	<LOD
PCB 74	0.09 - 0.1	100	<LOD	<LOD	NR	0.10 (0.09 - 0.12)	<LOD	0.09 (0.07 - 0.11)	<LOD	<LOD	NR	16 (13 – 19)	<LOD	15 (9.4 – 21)
PCB 99	0.03	95	<LOD	<LOD	NR	0.07 (0.06 - 0.09)	<LOD	0.07 (0.04 - 0.11)	<LOD	<LOD	NR	11 (9.1 – 14)	<LOD	14 (8.1 – 20)
PCB 101	0.09 - 0.10	100	<LOD	<LOD	NR	<LOD	<LOD	<LOD	<LOD	<LOD	NR	<LOD	<LOD	<LOD
PCB 105	0.01	93	<LOD	0.017 (<LOD - 0.024)	NR	0.02 (0.02 - 0.03)	<LOD	0.04 (0.02 - 0.06)	<LOD	2.5 (0.96 - 4.0)	NR	3.6 (2.6 - 4.5)	<LOD	4.9 (1.8 - 8.0)
PCB 118	0.01	50	<LOD	0.087 (0.033 - 0.11)	0.03 (0.02 - 0.03)	0.12 (0.10 - 0.14)	0.02 (0.01 - 0.03)	0.19 (0.10 - 0.28)	<LOD	12 (4.3 – 18)	4.4 (3.8 - 5.2)	20 (15 – 25)	2.8 (2.0 - 4.0)	NR
PCB 128	0.01	100	<LOD	<LOD	NR	<LOD	<LOD	<LOD	<LOD	<LOD	NR	<LOD	<LOD	<LOD
PCB 138	0.01	22	0.022 (0.017 - 0.030)	0.16 (0.078 - 0.23)	0.06 (0.05 - 0.07)	0.28 (0.23 - 0.32)	0.04 (0.03 - 0.06)	0.37 (0.18 - 0.59)	3.2 (2.4 - 4.2)	26 (8.9 – 38)	10 (8.9 – 12)	45 (40 – 49)	6.4 (4.5 - 9.2)	62 (39 – 85)
PCB 146	0.01	72	<LOD	0.046 (0.021 - 0.062)	0.01 (0.01 - 0.01)	0.06 (0.04 - 0.08)	<LOD	0.13 (0.06 - 0.20)	<LOD	6.1 (3.0 – 10)	2.0 (1.8 - 2.3)	9.2 (6.3 – 12)	<LOD	22 (11 – 33)
PCB 153	0.01	9.3	0.045 (0.033 - 0.061)	0.32 (0.18 - 0.37)	0.11 (0.09 - 0.13)	0.54 (0.42 - 0.66)	0.08 (0.05 - 0.12)	0.81 (0.40 - 1.2)	6.4 (4.7 - 8.4)	42 (21 – 68)	18 (16 – 21)	86 (68 – 100)	13 (8.4 – 19)	140 (82 – 200)

Table 2-8 Continued	Concentrations (µg/L)								Lipid-Adjusted (µg/kg)					
	Old Crow (this study) n = 54				CHMS[a] n = 1665		FNBI[b] n = 471		Old Crow (this study)		CHMS		FNBI	
	Limit of Detection (LOD)	% of Samples <LOD	Geometric Mean (GM)	95th Percentile (95P)	GM	95P	GM	95P	GM	95P	GM	95P	GM	95P
PCB 156	0.01	72	<LOD	0.025 (0.021 - 0.032)	0.02 (0.01 - 0.02)	0.07 (0.06 - 0.09)	<LOD	0.10 (0.05 - 0.15)	<LOD	4.0 (2.5 - 5.7)	2.6 (2.4 - 2.9)	11 (8.4 – 14)	<LOD	13 (7.3 – 19)
PCB 163	0.01	61	<LOD	0.055 (0.033 - 0.084)	0.02 (0.02 - 0.02)	0.10 (0.07 - 0.12)	0.02 (0.01 - 0.02)	0.12 (0.05 - 0.20)	<LOD	7.3 (4.4 – 14)	3.2 (2.9 - 3.7)	16 (12 – 21)	2.5 (1.8 - 3.5)	22 (14 – 20)
PCB 167	0.01	98	<LOD	<LOD	<LOD	0.02 (0.01 - 0.02)	<LOD	0.04 (0.02 - 0.06)	<LOD	<LOD	<LOD	3.4 (2.5 - 4.3)	<LOD	5.9 (3.2 - 8.6)
PCB 170	0.01	46	0.011 (<LOD - 0.017)	0.054 (0.044 - 0.059)	0.03 (0.02 - 0.03)	0.14 (0.11 - 0.17)	0.03 (0.02 - 0.04)	0.14 (0.11 - 0.17)	1.6 (<LOD- 2.3)	7.9 (6.0 - 9.8)	4.6 (4.1 - 5.2)	23 (17 – 29)	4.0 (2.8 - 5.7)	39 (24 – 54)
PCB 178	0.01	87	<LOD	0.021 (0.013 - 0.029)	<LOD	0.03 (0.02 - 0.04)	<LOD	0.06 (0.03 - 0.09)	<LOD	2.9 (1.3 - 4.8)	<LOD	4.6 (3.1 - 6.2)	<LOD	8.0 (5.2 – 11)
PCB 180	0.01	20	0.031 (0.023 - 0.043)	0.18 (0.14 - 0.20)	0.09 (0.08 - 0.10)	0.49 (0.38 - 0.60)	0.07 (0.04 - 0.10)	0.86 (0.45 - 1.3)	4.4 (3.3 - 5.9)	24 (19 – 34)	15 (14 – 17)	77 (59 – 96)	10 (6.8 – 16)	120 (69 – 180)
PCB 183	0.01	82	<LOD	0.019 (0.011 - 0.026)	<LOD	0.04 (0.03 - 0.05)	<LOD	0.09 (0.05 - 0.13)	<LOD	2.8 (1.4 - 4.9)	<LOD	6.6 (5.4 - 7.7)	<LOD	13 (7.1 – 19)
PCB 187	0.01	43	0.012 (<LOD - 0.017)	0.089 (0.055 - 0.10)	0.02 (0.02 - 0.03)	0.13 (0.10 - 0.16)	0.03 (0.02 - 0.04)	0.29 (0.11 - 0.46)	1.7 (<LOD - 2.4)	11 (7.0 – 19)	3.7 (3.2 - 4.3)	20 (13 – 27)	3.9 (2.6 - 5.9)	49 (29 – 70)
PCB 194	0.01	57	<LOD	0.039 (0.030 - 0.048)	0.02 (0.02 - 0.02)	0.10 (0.08 - 0.13)	0.02 (0.01 - 0.03)	0.20 (0.09 - 0.31)	<LOD	5.3 (4.0 - 6.2)	2.9 (2.6 - 3.3)	16 (12 – 20)	2.8 (2.0 - 4.0)	28 (15 – 41)
PCB 201	0.01	57	<LOD	0.046 (0.033 - 0.055)	0.02 (0.01 - 0.02)	0.09 (0.06 - 0.11)	0.02 (0.01 - 0.03)	0.22 (0.09 - 0.34)	<LOD	6.3 (4.6 - 8.1)	2.6 (2.3 - 2.9)	14 (10 – 19)	3.0 (2.1 - 4.3)	32 (17 – 48)
PCB 203	0.01	70	<LOD	0.024 (0.018 - 0.027)	0.01 (0.01 - 0.01)	0.07 (0.05 - 0.09)	<LOD	0.15 (0.07 - 0.23)	<LOD	3.2 (2.4 - 4.3)	2.3 (2.0 - 2.5)	11 (8.4 – 14)	<LOD	22 (12 – 32)
PCB 206	0.01	82	<LOD	0.014 (0.011 - 0.016)	<LOD	0.03 (0.03 - 0.04)	<LOD	0.08 (0.05 - 0.12)	<LOD	2.0 (1.5 - 2.3)	<LOD	5.5 (4.4 - 6.5)	<LOD	14 (7.2 – 20)

Table 2-8 Continued	Concentrations (µg/L)								Lipid-Adjusted (µg/kg)					
	Old Crow (this study)				CHMS[a]		FNBI[b]		Old Crow (this study)		CHMS		FNBI	
	n = 54				n = 1665		n = 471							
	Limit of Detection (LOD)	% of Samples <LOD	Geometric Mean (GM)	95th Percentile (95P)	GM	95P	GM	95P	GM	95P	GM	95P	GM	95P
PBDE 15	0.09 - 0.20	100	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PBDE 17	0.09 - 0.20	100	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PBDE 25	0.09 - 0.20	100	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PBDE 28	0.09 - 0.20	100	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PBDE 33	0.09 - 0.20	100	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PBDE 47	0.03	50	<LOD	0.19 (0.098 - 0.45)	0.06 (0.05 - 0.07)	0.41 (0.33 - 0.49)	0.04 (0.03 - 0.05)	0.25 (0.15 - 0.34)	<LOD	24 (14 – 74)	10 (9.1 – 11)	67 (51 – 83)	6.4 (5.4 - 7.6)	32 (20 – 44)
PBDE 99	0.02	74	<LOD	0.072 (0.032 - 0.23)	<LOD	0.08 (0.07 - 0.09)	<LOD	0.05 (0.04 - 0.07)	<LOD	9.4 (5.5 – 38)	<LOD	13 (11 – 14)	<LOD	8.1 (4.6 – 12)
PBDE 100	0.02	83	<LOD	0.066 (0.030 - 0.12)	<LOD	0.09 (0.06 - 0.12)	<LOD	0.05 (0.03 - 0.07)	<LOD	8.1 (3.9 – 17)	<LOD	15 (12 – 19)	<LOD	6.7 (5.0 - 8.5)
PBDE 153	0.03	41	0.036 (<LOD - 0.045)	0.20 (0.10 - 0.33)	<LOD	0.22 (0.14 - 0.29)	<LOD	0.15 (0.07 - 0.16)	5.0 (<LOD - 6.4)	30 (13 – 47)	<LOD	35 (22 – 48)	<LOD	20 (13 – 28)
PBB 153	0.09 - 0.20	100	<LOD	<LOD	<LOD	<LOD	<LOD	NR	<LOD	<LOD	<LOD	<LOD	<LOD	2.9 (1.8 - 4.1)
Aldrin	0.01	100	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
γ-Chlordane	0.005	91	<LOD	0.0055 (<0.005 - 0.007)	<LOD	<LOD	<LOD	<LOD	<LOD	0.77 (<LOD - 1.2)	<LOD	<LOD	<LOD	<LOD
α-Chlordane	0.005	100	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
cis-Nonachlor	0.005	50	<LOD	0.061 (0.018 - 0.10)	NR	0.02 (0.01 - 0.02)	<LOD	0.03 (0.02 - 0.04)	<LOD	9.0 (2.0 – 17)	NR	3.1 (2.2 - 4.1)	<LOD	5.1 (4.2 - 6.0)
trans-Nonachlor	0.01	20	0.027 (0.020 - 0.039)	0.44 (0.11 - 0.75)	0.04 (0.03 - 0.04)	0.14 (0.12 - 0.16)	0.03 (0.02 - 0.03)	0.19 (0.16 - 0.21)	3.9 (2.9 - 5.4)	66 (13 – 130)	6.0 (5.3 - 6.8)	23 (19 – 26)	4.1 (3.8 - 4.5)	25 (21 – 29)
γ-HCH	0.01	100	<LOD	<LOD	NR	<LOD	<LOD	<LOD	<LOD	<LOD	NR	<LOD	<LOD	<LOD

Table 2-8 Continued	Concentrations (µg/L)								Lipid-Adjusted (µg/kg)					
	Old Crow (this study)				CHMS[a]		FNBI[b]		Old Crow (this study)		CHMS		FNBI	
	n = 54				n = 1665		n = 471							
	Limit of Detection (LOD)	% of Samples <LOD	Geometric Mean (GM)	95th Percentile (95P)	GM	95P	GM	95P	GM	95P	GM	95P	GM	95P
β-HCH	0.01	59	<LOD	0.085 (0.026 - 0.12)	0.04 (0.03 - 0.05)	0.54 (0.07 - 1.01)	0.01 (0.01 - 0.01)	0.06 (0.05 - 0.07)	<LOD	13 (3.6 – 20)	6.4 (4.8 - 8.6)	90 (9.2 – 170)	1.8 (1.7 - 2.0)	9.3 (8.3 – 10)
HCB	0.04	0.0	0.10 (0.080 - 0.12)	0.43 (0.31 - 0.66)	0.05 (0.05 - 0.06)	0.17 (0.14 - 0.20)	<LOD	0.14 (0.11 - 0.16)	14 (12 – 17)	71 (40 – 76)	9.1 (8.0 – 10)	27 (20 – 33)	<LOD	18 (13 – 24)
Mirex	0.01	44	<LOD	0.051 (0.037 - 0.086)	NR	0.05 (0.04 - 0.06)	<LOD	0.21 (0.11 - 0.31)	<LOD	8.3 (5.2 – 11)	NR	9.1 (6.5 – 12)	<LOD	28 (16 – 39)
Oxychlordane	0.005	15	0.015 (0.011 - 0.021)	0.19 (0.053 - 0.33)	0.03 (0.02 - 0.03)	0.09 (0.08 - 0.10)	0.02 (0.01 - 0.02)	0.10 (0.08 - 0.13)	2.1 (1.6 - 2.9)	28 (7.0 – 55)	4.2 (3.8 - 4.7)	14 (12 – 16)	2.5 (2.2 - 2.7)	14 (10 – 18)
p,p'-DDE	0.04	0.0	0.30 (0.23 - 0.38)	1.6 (1.0 - 2.0)	0.91 (0.76 - 1.1)	6.5 (4.4 - 8.7)	0.50 (0.47 - 0.53)	4.2 (3.5 - 4.9)	42 (34 – 53)	230 (210 – 320)	150 (130 – 180)	1100 (690 – 1500)	77 (70 – 85)	690 (500 – 870)
p,p'-DDT	0.2	100	<LOD	<LOD	NR	0.09 (<LOD-0.15)	<LOD	<LOD	<LOD	<LOD	NR	16 (<LOD – 26)	<LOD	<LOD
Toxaphene , Parlar 26	0.005	72	<LOD	0.063 (0.016 - 0.069)	NR	0.01 (0.01 - 0.01)	<LOD	0.01 (0.01 - 0.01)	<LOD	9.1 (1.8 – 12)	NR	1.6 (1.2 - 2.0)	<LOD	1.5 (1.0 - 1.9)
Toxaphene , Parlar 50	0.005	50	<LOD	0.081 (0.021 - 0.085)	NR	0.01 (0.01 - 0.02)	<LOD	0.01 (0.01 - 0.02)	<LOD	12 (2.2 – 39)	NR	2.4 (1.8 - 3.0)	<LOD	2.2 (1.3 - 3.0)

a - Canadian Health Measures Survey (CHMS) Cycle 1 (158)

b - First Nations Biomonitoring Initiative (79)

NR - Parameter was analyzed but statistic could not be reported

NA - Parameter was not analyzed

Table 2-9 - *Spearman Correlation Coefficients (r) of Select Lipid-Adjusted POPs in Plasma in Old Crow Biomonitoring Project*

	PCB 138	PCB 153	PCB 180	Trans-Nonachlor	HCB	Oxychlordane	DDE
PCB 138	1						
PCB 153	0.97**	1					
PCB 180	0.92**	0.96**	1				
Trans-Nonachlor	0.93**	0.91**	0.88**	1			
HCB	0.75**	0.77**	0.73**	0.82**	1		
Oxychlordane	0.95**	0.95**	0.91**	0.96**	0.82**	1	
DDE	0.87**	0.90**	0.85**	0.79**	0.65**	0.86**	1

* $p<0.05$
** $p<0.01$

2.4.8 Chemical Exposure and Traditional Food Advisories

This project was initiated based on community concerns about contaminant exposure due to the consumption of certain traditional foods. Traditional foods provide important nutritional, economic, social and cultural benefits to the people of Old Crow (116, 117, 162). One of the primary goals of this project is to support the investigation of risks and benefits of eating traditional foods, including both the risk from contaminant exposure and the benefits from nutrients eaten when consuming foods from the land. The Government of the Yukon has issued a Health Advisory for Yukon Wildlife, recommending a maximum annual number of land animal kidneys and livers per year for consumption (62). This advisory includes some traditional foods consumed in Old Crow such as caribou, moose, sheep, beaver, porcupine and snowshoe hare. The land animal consumption advisory was created to limit cadmium exposure after elevated cadmium levels were observed in these animal organs. Additionally, the Yukon Government has also issued recommendations for consumption of burbot (loche) and lake trout of 1 to 2 servings per week for children and women of childbearing age to limit exposure to mercury (163). To complement this recommendation, the community of Old Crow has issued an interim advisory for consumption of loche and inconnu of 1 to 2 servings per week for children and women of childbearing age to limit exposure to mercury (61). The biomonitoring levels of mercury were

below the selected health-based screening values for all participants in Old Crow, and the levels of cadmium were below the screening values for 98% of Old Crow participants. Overall, the results of this study have shown that, despite elevated concentrations of mercury and cadmium in some local traditional foods, exposure levels for community members in Old Crow have remained low.

In addition to the potential risks of contaminant exposure, one of the nutritional benefits of some traditional food includes high levels of healthy omega-3 fatty acids, particularly in fish (164). Many commonly-consumed fish in the community, including Chinook salmon, and whitefish, are high in omega-3 fatty acids and low in mercury (165). Average levels of omega-3 fatty acids in Old Crow were similar to those observed in previous studies in Canada (160), in contrast to some other northern Indigenous populations in North America and Russia have higher EPA + DHA blood status in comparison to the general population (160). However, the biomonitoring clinic was conducted in the winter, and blood omega-3 results may not represent omega-3 levels when fish consumption is highest in the summer months.

2.5 Conclusions

The results of this project fill an important data gap related to chemical exposures in Canada, and specifically, the Yukon. In particular, the results of this project speak to the generalizability of the two national-scale human biomonitoring projects in Canada, the CHMS and the FNBI. In Old Crow, the majority of nutrient biomarkers, contaminant biomarkers, including toxic metals such as cadmium, uranium, and mercury, as well as POPs, such as PCBs, and organochlorine pesticides, were similar to those observed in the general population of Canada and other First Nations communities. Key exceptions include lead, cobalt, manganese, and hexachlorobenzene, which were observed at elevated levels. These parameters have been identified as priority substances for future work to identify possible sources of exposure in the community. The results

of this project add to the growing body of human biomonitoring research in circumpolar regions, allowing for the long-term evaluation of international initiatives (e.g., Stockholm Convention and the Minamata Convention) designed in part to decrease the contaminant burden in the Arctic.

The majority of the contaminants measured in this project do not have guidelines to assess health risk. However, all participants' exposure levels were below the biomonitoring guidance values for mercury, and most participants levels were below the guidance values for cadmium and lead. Generally, the results of the biomonitoring work in Old Crow support the conclusion that the benefits of consuming traditional foods, such as wild-harvested fish, and wild game outweigh the risk of contaminant exposure for this community.

3 Traditional Food Consumption and Other Determinants of Blood and Urinary Lead, Cobalt, Manganese, and Hexachlorobenzene in Northern Canada

Drysdale, M., Ratelle, M., Majowicz, S., Brammer, J., Gamberg, M., Skinner, K., Laird, B. Traditional food consumption and other determinants of blood and urinary lead, cobalt, manganese, and hexachlorobenzene in Northern Canada. Submitted to Arctic. (2022).

3.1 Abstract

The results of a 2019 human biomonitoring study indicated that several parameters, including lead, cobalt, manganese, and hexachlorobenzene, were elevated in blood and urine samples in Old Crow, Yukon, in comparison to the general Canadian population. This study aims to identify possible determinants of blood and urinary levels of these parameters, including consumption of locally harvested traditional foods, lifestyle factors, and demographics, for these parameters in Old Crow and two other northern populations for comparison: communities in the Dehcho and Sahtú regions of the Northwest Territories. Generalized linear models were run to identify possible associations between dietary and risk factors and key biomarkers, adjusting for age and sex. In Old Crow, several variables were associated with elevated exposure levels of these biomarkers, including drinking untreated river water (29% higher blood manganese levels and 120% higher blood lead levels), eating caribou kidneys (22% higher blood manganese levels and 58% higher blood lead levels), and eating whitefish (28% higher blood cobalt levels). Additionally, relationships between consumption of moose and caribou organs, and lead and hexachlorobenzene levels were observed in the reference populations and pooled population groups. Though levels of particular contaminants may be elevated in some traditional foods, these foods remain an important source of nutrients for members in these communities, as well

as providing other benefits, including increased physical activity through harvesting, mental health improvements, and spiritual wellness.

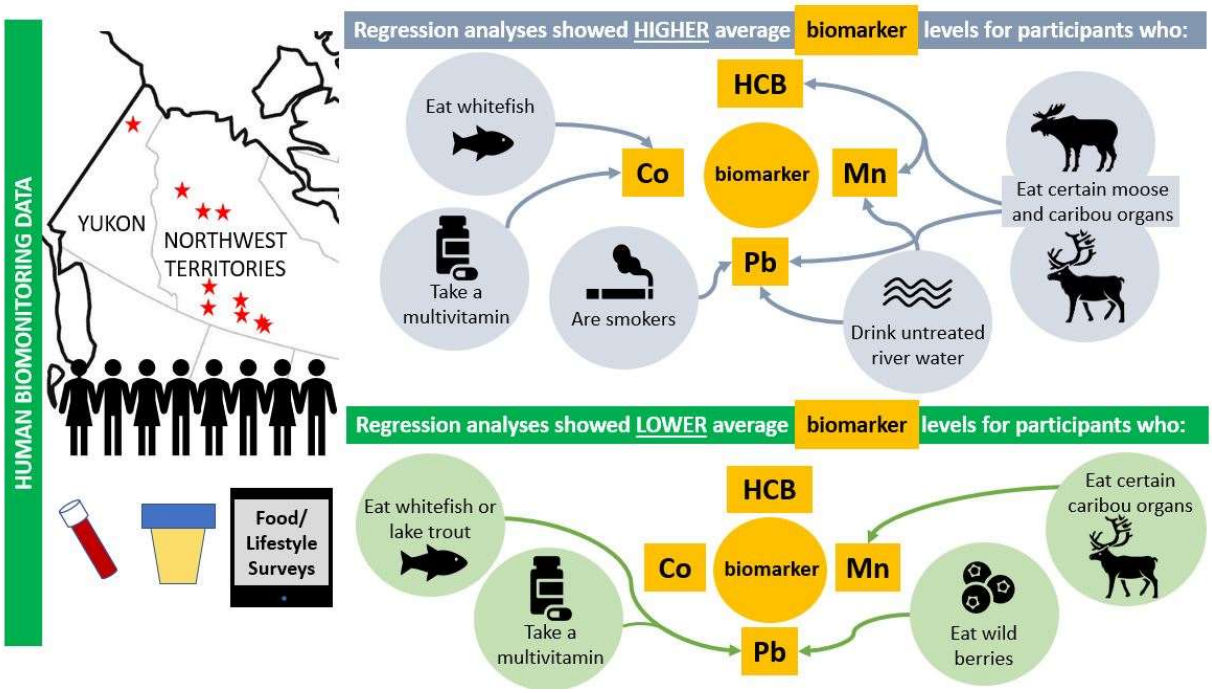

Figure 3-1 - *Graphical Abstract - Traditional Food Consumption and Other Determinants of Urinary and Blood Lead, Cobalt, Manganese, and Hexachlorobenzene in Northern Canada*

3.2 Introduction

In 2019, a human biomonitoring project was conducted in collaboration with the Vuntut Gwitchin Government (VGG) in the community of Old Crow. Old Crow is a fly-in only Gwich'in community located above the Arctic Circle in the northern Yukon, Canada. The biomonitoring project was initiated in response to community concerns regarding elevated concentrations of some toxic metals and persistent organic pollutants (POPs) in traditional foods harvested locally (61, 62). These traditional foods, such as wild game, fish, birds, berries and wild plants, are both nutritionally and culturally important to the residents of Old Crow, and are a part of the staple diet of community members (55, 56, 114). Based on the human biomonitoring study results, some parameters, including lead, cobalt, manganese, and hexachlorobenzene (HCB

- an organochlorine pesticide), were elevated in comparison to the general Canadian population and other First Nations communities located outside of the northern territories (166).

Elevated exposure to contaminants including lead and HCB can cause harmful health effects, including damage to liver and thyroid function, and impairment of neurological development (167, 168). Though cobalt and manganese are essential metal nutrients, required for necessary processes such as red blood cell formation with cobalt-bearing vitamin B-12, they can also cause adverse health effects at elevated levels (169, 170). No health-based guidance values for biomarkers of HCB, cobalt, or manganese have been validated, however lead levels in Old Crow were below available health-based guidance values in both blood and urine for the majority (>95%) of participants (166).

The aim of this study was to identify possible determinants of urinary and blood levels of key contaminants and trace nutrients found at elevated levels in Old Crow with data collected during a biomonitoring clinic, including biological sampling results, dietary and lifestyle surveys, and demographics. Similar analyses were also completed in two sub-Arctic reference populations: Dene communities in the Dehcho and Sahtú regions of the Northwest Territories (NWT). In this study, we evaluated possible associations between parameters found at elevated levels in Old Crow and other northern communities in Canada with traditional food consumption as well as potential risk factors for exposure. Understanding the most significant potential sources of exposure for contaminants and potential drivers of nutrient status can help to inform consumption notices and health promotion materials that are tailored to the community. On a broader scale, this study can be used to complement and guide other biomonitoring and environmental monitoring programs aimed at evaluating the impact of initiatives designed to reduce the contaminant burden in the sub-Arctic and Arctic.

3.3 Materials and Methods

3.3.1 Community Biomonitoring Projects

This study used data from biomonitoring clinics which have been documented in other publications (80, 127, 128, 166). These clinics were conducted between 2016 and 2018 in partnership with Old Crow, in the Yukon, as well as six communities from the Dehcho region of the NWT and three communities in the Sahtú region, to respond to community questions regarding contaminant exposure and nutrient intake in these regions. The methods used in these clinics, including study design, surveys, consent forms, biological sample collection, and sample preservation and shipment, have been described elsewhere (80, 128, 166). Participant recruitment was conducted by local coordinators hired from the community and by the research team using methods including random selection by phone and passive recruitment by word of mouth, poster, and media interviews (80, 128, 166). The minimum age for participants in these clinics varied between communities, from four to six years, depending on factors such as community preference and available equipment. However this study includes the results for adult participants (18+ years) only. Data collected in all communities included biological samples, including metals in whole blood and urine, and POPs in plasma, a food frequency questionnaire (FFQ) for traditional foods, and some risk factor and demographic data, including smoking status, sex, and age (80, 127, 128, 166). Other risk factors, including self-reported use of lead ammunition, vitamin consumption, and drinking water source were only assessed in Old Crow and not the Dehcho and Sahtú regions.

The results for this study were returned to participants and communities, in accordance with agreements made with each community. In addition to the community research agreements, this study was granted approval and licensure by the University of Waterloo Research Ethics

Committee, the Yukon Government Scientists and Explorers, the Stanton Territorial Health Authority for Human Research, and the Aurora Research Institute (80, 126, 128, 166).

3.3.2 Identification of Parameters of Interest

Parameters of interest were identified as part of the Old Crow biomonitoring project conducted in 2019 (166). Parameters were selected for further analysis when the 95% confidence intervals of both the geometric mean and 95th percentile of a reliable biomarker for the parameter were elevated relative to at least one of the Canadian Health Measures Survey (CHMS) and the First Nations Biomonitoring Initiative (FNBI) (74-76, 78, 79, 131). Parameters that were elevated in Old Crow included HCB in plasma, as well as lead, cobalt, and manganese, analyzed in whole blood and creatinine-adjusted urine (166). Both whole blood and urine are considered reliable biomarkers of lead and cobalt exposure (169, 171), however, the reliability of urinary manganese as a biomarker has been debated in the literature (172, 173).

3.3.3 Reference Populations

Due to the small population of Old Crow (n = approximately 175 adults) (112), and subsequently small sample size for the biomonitoring study (n=77 adults), potential relationships between contaminants and nutrients in biological samples and consumption of traditional food and other risk factors were challenging to evaluate with sufficient power. As part of the effort to mitigate this issue, two additional reference populations from northern Canada were included in this study. As noted above, these reference populations include six communities from the Dehcho region of the NWT (n=231 adults) and three communities in the Sahtú region (n=217 adults) (80, 127, 128). Using reference populations can support associations observed in Old Crow, as well as differentiate trends specific to Old Crow from those in other northern communities. These communities were integrated with Old Crow to create a pooled dataset, and were also evaluated

separately for comparison purposes. Results are compared between regions due to the cultural, dietary, and location differences among the three groups.

3.3.4 Key Determinants of Blood and Urinary Biomarkers

Key determinants of blood and urinary biomarkers were selected as independent variables for the purposes of modeling based on three criteria: (1) commonly eaten traditional foods or food categories in Old Crow, including caribou, moose, Chinook salmon, whitefish, game birds, and berries, (2) a focus on the organs/parts of these foods that are eaten by more than 15% of the population and have been shown in the literature to have elevated concentrations of some or all of the key parameters, and (3) risk factors that have been shown in the literature to potentially increase exposure to some or all of the key parameters.

The biomonitoring clinics in Old Crow and the reference population included the administration of FFQs to identify the type, source, serving size, and frequency of consumption of traditional foods, as described by Ratelle and colleagues (127). The reference populations do not necessarily have the same commonly eaten foods (e.g. no Chinook salmon), but do include some of the commonly eaten foods in Old Crow (e.g. moose, whitefish, berries). When a food was eaten in Old Crow, but not the reference populations, the analysis was conducted for Old Crow only. Foods were only included if they were eaten by 15% or more of the participants in each region to maintain numbers greater than n=10 for analysis. Frequency of consumption is not included in this study, as the majority of participants (>85%) reported eating all of these foods once or less per week (174).

In addition to the FFQ, a survey was administered in Old Crow to identify possible risk factors for contaminant exposure. These included questions regarding drinking water sources, the use of

lead ammunition for hunting, vitamin consumption, and smoking status. The risk factors survey was not administered in the reference populations in the Northwest Territories.

The rationales for each potential determinant of biomarker levels selected for these analyses including demographics, traditional foods, and risk factors are summarized in Supplemental Table 3-1 (end of Chapter 3).

3.3.5 Statistical Analysis

The majority of the independent variables included in modeling, including traditional food consumption, sex, and risk factors for exposure, were treated as binary variables and age was treated as a continuous variable. When a participant reported that they did not know or could not remember, that data point was excluded from the analysis of that question. Concentrations of biomarkers that were below the limit of detection (LOD) were assigned values equal to half the LOD to remain consistent with the CHMS and FNBI. Urine samples have been adjusted for creatinine levels to account for differences in hydration status among participants (145). Additionally, POP concentrations were normalized to plasma lipid levels to account for interindividual variation of lipid levels in blood (145).

The strength of associations between non-log-transformed biomarkers analyzing the same parameter (e.g. blood vs. urinary manganese) were analyzed using Spearman rank correlation coefficient (Spearman rho). Geometric mean biomarker concentrations were compared between males and females using 95% confidence intervals. In addition to comparisons using means, generalized linear models were run to identify possible correlations between the independent variables including sex, age, traditional food consumption and risk factors, and the dependent outcome biomarker levels. Biological sample results of key parameters were log-transformed to normalize their distributions for modeling. Separate models were run for each participant group,

including Old Crow, the two reference populations, and the pooled dataset for all three groups. Due to the log-transformation of the dependent variable, regression coefficients were converted to percent change for the non-log transformed outcome. In cases where there were multiple independent variables significantly associated with the dependent variable, Chi-square testing was used to assess associations between independent variables. In many of these cases, some category combinations included zero or only one participant, and therefore models include only sex, age, and one other independent variable (e.g. traditional food consumption, risk factor) each. Analysis was conducted using SAS Software Version 9.4. Residuals were checked after each analysis to confirm the assumptions of linearity and homoscedasticity.

3.4 Results and Discussion

3.4.1 Study Population

The participating adult population for this study is summarized in Table 3-1. Old Crow and the two reference populations had between 45 and 52% female participants. Old Crow had the lowest participation levels for participants over 60 years old (19-20% of participants who submitted biological samples) compared to the Dehcho (23-27%) and Sahtú (26-32%). Additionally, Old Crow had the highest participation levels for adult participants under 40 years (45-48%) compared to the Dehcho (25-30%) and Sahtú (29-38%) despite similar age distributions between the three regions (112, 175, 176).

Table 3-1 - *Number of Participants and Demographics by Type of Sample*

	Old Crow		Reference Populations			
			Dehcho		Sahtú	
Demographics and Participation in Surveys by Sample Type						
	Blood (n=54)	Urine (n=44)	Blood (n=122)	Urine (n=78)	Blood (n=123)	Urine (n=100)
Sex						
Female	28 (52%)	23 (52%)	61 (50%)	35 (45%)	60 (49%)	52 (52%)
Male	26 (48%)	21 (48%)	61 (50%)	43 (55%)	63 (51%)	48 (48%)
Age (Years)						
20-39	26 (48%)	20 (45%)	35 (29%)	19 (24%)	46 (37%)	29 (29%)
40 – 59	18 (33%)	15 (34%)	54 (44%)	36 (46%)	43 (35%)	39 (39%)
60+	10 (19%)	9 (20%)	27 (22%)	21 (27%)	31 (25%)	32 (32%)
Surveys						
Food Frequency Questionnaire	48 (89%)	40 (91%)	76 (62%)	53 (68%)	51 (41%)	42 (42%)
Risk Factors Survey	44 (81%)	36 (82%)	-	-	-	-
Responses to Risk Factor Questions by Sample Type						
	Blood (n=44)	Urine (n=36)	Blood (n=122)	Urine (n=78)	Blood (n=123)	Urine (n=100)
Smoking Status (has smoked in the previous 24 hours)						
Yes	22 (50%)	18 (50%)	49 (40%)	52 (67%)	66 (54%)	45 (45%)
No	21 (47%)	17 (47%)	73 (60%)	26 (33%)	59 (48%)	55 (55%)
Vitamin Usage (has taken a vitamin in the previous 24 hours)						
Yes	32 (73%)	25 (69%)	-	-	-	-
No	12 (27%)	11 (31%)	-	-	-	-
Drinking Water (drinks untreated water sometimes or often)						
Yes	37 (84%)	29 (81%)	-	-	-	-
No	7 (16%)	7 (19%)	-	-	-	-
Lead Ammunition Usage (eats game hunted with lead shot sometimes or often)						
Yes	24 (54%)	19 (53%)	-	-	-	-
No	7 (16%)	4 (11%)	-	-	-	-
Don't know/Prefer not to say	13 (30%)	13 (36%)	-	-	-	-

– Not available: Risk factors survey not conducted in reference populations

3.4.2 Survey Results

Table 3-1 includes risk factors for exposure that have been included as independent variables in the analysis. Two thirds of participants who submitted urine samples in the Dehcho reported smoking in the previous 24 hours, however between 40 and 52% of participants submitting all other sample types in all regions were smokers. These smoking proportions are higher than those observed in the general Canadian population (10 to 15%), and similar to the proportions observed in other First Nations populations (40 to 54%) (177). The numbers for risk factors, including drinking water source and use of lead ammunition were small (n<10 out of 44) for some response options. Nearly one third (n=13 out of 44) participants reported they did not know what kind of ammunition was used for the game meat they consumed.

The proportions of respondents consuming traditional foods are shown in Table 3-2 for all foods selected for analysis. Generally, a higher percentage of Old Crow participants consumed caribou organs and wild berries compared to the two reference populations. Consumption of some foods in Old Crow, including some moose organs, and whitefish, were within 5% of those observed in the reference populations, with the exception of moose bone marrow and liver in the Dehcho region (17 and 15% higher, respectively) and moose liver in the Sahtú region (8% higher). Consumption of game birds was also lower in Old Crow (56%) when compared to both reference populations (73%). The most commonly eaten birds include Canada goose (34%), white-winged scoter (32%), and ptarmigan (20%) in Old Crow, Canada goose (55%), mallard (51%) and spruce grouse (31%) in the Dehcho region, and Canada goose (63%), ptarmigan (35%) and black duck (35% - includes multiple species as the terms ‘black duck’ and ‘black scoter’ are used interchangeably in some communities (178) in the Sahtú region.

Table 3-2 - *Proportion of Adult Respondents in a Food Frequency Questionnaire who Reported Consuming Selected Traditional Foods in the Previous Year*

			Old Crow n=69 (%)	Reference Populations		Pooled Dataset n=268 (%)
				Dehcho n=128 (%)	Sahtú n=71 (%)	
Game Birds			58	71	73	68
Berries			84	67	55	68
Moose		*Bones in Soup/Stew*	43	30	41	36
		Fat	43	37	38	39
		Kidneys	35	37	27	34
		Bone Marrow	35	46	38	41
		Liver	16	29	18	23
Caribou	*Barren-ground/Porcupine*	*Bones in Soup/Stew*	62	2*	24	23
		Fat	65	2*	15	23
		Kidneys	51	2*	14*	18
		Bone Marrow	71	3*	20	25
		Liver	30	3*	11*	12
	Woodland	*Bones in Soup/Stew*	-	12*	37	21
		Fat	-	11*	30	18
		Kidneys	-	13*	25	18
		Bone Marrow	-	16	28	21
		Liver	-	15	13*	14
Fish		*Chinook*	90	-	-	-
		Whitefish	83	92	80	87
		Lake Trout	14*	57	79	51

*foods eaten by less than 15% of the population within a region were excluded in the analysis for this region

– food was not eaten/included in Food Frequency Questionnaire (FFQ) for this region as these foods are not harvested in the region

3.4.3 Baseline Key Parameter Results

The concentrations of key parameters, including lead, cobalt, manganese, and HCB, in Old Crow and both reference populations are shown in Table 3-3, that also compares results to two national studies, the Canadian Health Measures Survey (CHMS) and the First Nations Biomonitoring Initiative (FNBI) (74-76, 78, 79, 131). Generally, blood lead levels did not differ significantly (overlapping 95% confidence intervals of the geometric mean and 95th percentile) among the three regions, though blood lead levels were lower in the Dehcho region than in the Sahtú region

and in Old Crow. Mean urinary lead levels in all three regions were not significantly different from those observed in the general Canadian population (CHMS) and other First Nations communities (FNBI). All three populations had higher blood lead levels than those observed in the general Canadian population (CHMS). Blood lead levels in Old Crow and the Sahtú reference populations were also higher than those observed in other First Nations communities (FNBI). However, the majority of adult participants in Old Crow, the Dehcho, and Sahtú regions (>95%) had lead levels below health-based guidance values of 100 µg/L (for women 50 and older and men) and 50 µg/L (for children and women of child-bearing age) in blood and 7 µg/L in urine (81, 140). Blood lead levels above this threshold have been associated with adverse health effects including cognitive impairment and hypertension (179, 180). However, adverse health effects, including cognitive impairment in both children and adults, have been observed at blood lead levels below the health-based guidance values (180, 181).

The majority of samples (95%) were below the analytical detection limit for blood cobalt (0.15 µg/L) in the reference populations. Therefore, only urinary cobalt levels were reported for these groups. Generally, urinary cobalt levels were similar or lower in both the Dehcho and Sahtú compared to Old Crow, and mean urinary cobalt levels were elevated in both Old Crow and the Dehcho region in comparison to the general Canadian population. The majority of participants in all three regions (>95%) had cobalt levels below values reflecting excessive exposure (1 µg/L in blood, 1.7 µg/g creatine in urine) (166, 182). There is no health-based guidance value for cobalt, however, a review of the epidemiological literature and biokinetic modeling found that blood cobalt levels below 300 µg/L have not been associated with adverse health effects in humans (183). Similarly, a clinical study involving cobalt supplementation found that no adverse health effects were detected at blood cobalt levels up to the maximum detected value of 117 µg/L (184).

Table 3-3 - *Levels of Key Biomarkers in Old Crow, Dehcho and Sahtú Populations (>18 Years)*

			Old Crow (166)		Sahtú Region (174)		Dehcho Region (174)		CHMS (General Canadian Population)[a]		FNBI (First Nations Biomonitoring Initiative) (79)	
			GM[b]	95P[c]	GM[b]	95P[c]	GM[b]	95P[c]	GM[b]	95P[c]	GM[b]	95P[c]
Whole blood	n		54		123		122		4596-6070[a]		473	
	Co	µg/L	0.31 (0.28 - 0.33)	0.61 (0.51 - 0.84)	<LOD	<LOD	<LOD	<LOD	0.23 (0.21 - 0.24)	0.40 (0.36 - 0.43)	NA	NA
	Mn	µg/L	12 (11 – 13)	22 (19 – 24)	9.6 (9.1 - 10)	16 (15 - 21)	11 (10 - 12)	22 (18 - 32)	9.8 (9.5 – 10)	15 (14 – 16)	12 (12 – 13)	21 (20 – 22)
	Pb	µg/L	24 (19 – 30)	98 (75 – 140)	26 (23- 29)	85 (73 - 130)	12 (10 - 14)	47 (32 - 76)	8.1 (7.7 – 8.5)	24 (21 – 28)	12 (11 – 13)	33 (21 – 45)
Plasma	n		54		123		122		1665[a]		471	
	HCB	µg/L	0.10 (0.080 - 0.12)	0.43 (0.31 - 0.66)	0.097 (0.086 - 0.11)	0.37 (0.31 - 0.59)	0.053 (0.048 - 0.059)	0.13 (0.12 - 0.29)	0.05 (0.05 - 0.06)	0.17 (0.14 - 0.20)	<LOD	0.14 (0.11 - 0.16)
	HCB	µg/g lipids	14 (12 – 17)	71 (40 – 76)	15 (14 - 17)	54 (47 - 78)	8.7 (8.0 - 9.6)	24 (20 - 48)	9.1 (8.0 – 10)	27 (20 – 33)	<LOD	18 (13 – 24)
Urine	n		44		100		78		6311		495	
	Co	µg/L	0.37 (0.30 - 0.47)	1.7 (0.69 - 3.6)	0.30 (0.25 - 0.35)	1.1 (0.76 - 2.7)	0.37 (0.32 - 0.43)	1.5 (0.91 - 2.0)	0.23 (0.21 - 0.26)	0.97 (0.86 - 1.1)	NA	NA
	Mn	µg/L	0.14 (0.11 - 0.18)	1.5 (0.25 - 2.5)	0.16 (0.13 - 0.17)	0.46 (0.35 - 0.79)	0.35 (0.31 - 0.40)	1.2 (0.62 - 12)	<LOD	0.36 (0.32 - 0.4)	<LOD	0.59 (0.27 - 0.92)
	Pb	µg/L	0.68 (0.49 - 0.91)	3.9 (2.1 - 4.1)	0.68 (0.51 - 0.90)	4.5 (3.1 - 7.0)	0.51 (0.42 - 0.64)	2.0 (1.7 - 11)	0.52 (0.49 - 0.55)	1.9 (1.7 - 2.0)	0.51 (0.43 - 0.60)	2.3 (1.5 - 3.1)
	Co	µg/g creatinine	0.35 (0.30 - 0.43)	1.8 (0.56 - 3.3)	0.33 (0.32 - 0.42)	1.1 (0.87 - 20)	0.41 (0.35 - 0.48)	1.5 (0.93 - 2.3)	0.22 (0.20 - 0.25)	0.88 (0.79 - 0.97)	NA	NA
	Mn	µg/g creatinine	0.13 (0.096 - 0.17)	1.7 (0.37 - 2.8)	0.17 (0.14 - 0.21)	0.77 (0.50 - 4.2)	0.39 (0.32 - 0.48)	1.2 (1.2 - 5.8)	<LOD	0.61 (0.51 - 0.7)	<LOD	0.89 (0.66 - 1.1)
	Pb	µg/g creatinine	0.64 (0.47 - 0.87)	3.1 (2.3 – 17)	0.83 (0.66 - 1.1)	5.7 (3.3 - 21)	0.57 (0.48 - 0.68)	2.4 (1.7 - 3.6)	0.48 (0.46 - 0.51)	1.6 (1.4 - 1.8)	0.56 (0.48 - 0.66)	2.2 (1.6 - 2.8)

a – Results for blood and urinary cobalt and manganese, and urinary blood, cobalt, and lead are from Cycle 2 of the CHMS (n=6070) (75). Lead results are from Cycle 6 of the CHMS (n=4596) (185). Plasma HCB results are from Cycle 1 of the CHMS (n=1665) (74).

b – GM = Geometric mean

c – 95P = 95th percentile

Urinary and blood manganese levels were similar among the three regions (Old Crow, Dehcho, and Sahtú), with the exception of elevated mean manganese concentrations in urine observed in the Dehcho region (Table 3-3). Manganese is an essential nutrient, however psychomotor development impairment has been observed in children born from mothers with manganese concentrations > 30 µg/L in blood (186). No women of child-bearing age in any of the three regions had manganese levels above this effect threshold (Table 3-3). However, the threshold for manganese sufficiency vs. toxicity has not been consistently described in the literature. Some adverse health effects, including impairment to motor function, have been observed at blood manganese levels above the median observed level of 15 µg/L in blood, with more visible effects, including tremors, observed above 25 µg/L in blood (187). However, a study of infants found that cognitive development indices peaked at blood manganese levels of approximately 24 µg/L, decreasing when biomarker levels were lower or higher than this level (188).

Similar to Old Crow, HCB levels were elevated in the Sahtú relative to the general Canadian population and other First Nations populations. Both of these groups also had elevated HCB levels compared to the Dehcho region. There is no health-based guidance value for HCB, however, reference values and biomonitoring equivalents can indicate elevated exposure levels compared to the Canadian population. A reference value, represented by the 95th percentile value for the general Canadian population, of 23 µg HCB/kg lipids in plasma was calculated using Canadian biomonitoring data collected in 2011 (85). This value represents the upper margin of exposure for the population, but does not indicate the level of health risk as it is not based on toxicological data. Similarly, Health Canada has developed a biomonitoring equivalent for HCB of 25 µg HCB/kg lipids based on neoplastic effects to the liver (189). The majority of participants in Old Crow (>80%), Dehcho (>95%), and Sahtú (>75%) had HCB levels below

these values. In epidemiological studies, HCB levels exceeding 1.0 to 1.5 µg/L in children and pregnant mothers have been associated with decreased behavioural competence and increased BMI in children, however, all participants had HCB levels below this threshold (190, 191).

3.4.4 Manganese

Blood and urinary manganese were positively correlated in Old Crow (Spearman $\rho=0.44$, $p<0.01$), however, no significant association between the two was observed in the two reference populations or the pooled dataset. Mean blood manganese levels were not significantly different between females and males in Old Crow or in the reference populations (Table 3-4). However, mean urinary manganese levels were higher in females than in males in all three groups. Higher manganese levels in women have been observed in the CHMS in Canada and National Health and Nutrition Examination Survey (NHANES) in the United States, attributed to sex-related differences in manganese metabolism (75, 192). No association was observed between blood or urinary manganese levels and age in Old Crow ($p=0.95$ and 0.55, respectively), however, urinary levels increased with age in the Dehcho reference population (Spearman $\rho=0.31$, $p<0.001$) and the pooled dataset (Spearman $\rho=0.20$, $p=0.002$).

For each independent variable, excluding sex and age, Tables 3-5 – 3-8 show the percent difference in manganese levels between groups, adjusting for age and sex. A positive value indicates that the participants who ate the specified food, smoked, took a vitamin, or drank untreated water, as indicated, had higher average biomarker levels by the percentage indicated, than those who did not. A negative value indicates that the participant who ate the specified food, smoked, took a vitamin, or drank untreated water, as indicated, had lower average biomarker levels by the percentage indicated, than those who did not. In Old Crow, traditional foods

Table 3-4 - *Concentrations of Key Biomarkers for Males and Females*

	Geometric Mean Concentration (95% CI)						
	Blood (µg/L)			Urine (µg/g creatinine)			Plasma (µg/kg lipids)
Old Crow	Mn	Co	Pb	Mn	Co	Pb	HCB
	n=54			**n=44**			**n=54**
Female	13 (12-16)	0.32 (0.29-0.35)	19 (16-24)	0.26 (0.17-0.31)	0.51 (0.37-0.62)	0.26 (0.11-0.40)	12 (10-15)
Male	11 (10-12)	0.29 (0.26-0.33)	31 (26-35)	0.067 (0.055-0.08)	0.26 (0.22-0.31)	0.75 (0.63-0.83)	18 (15-21)
Dehcho	**n=122**			**n=78**			**n=122**
Female	13 (12-14)	<0.075	9.4 (7.8-11)	0.53 (0.39-0.72)	0.58 (0.47-0.71)	0.57 (0.46-0.69)	8.5 (7.4-9.8)
Male	9.4 (8.7-10)	<0.075	15 (13-18)	0.30 (0.23-0.39)	0.31 (0.26-0.37)	0.57 (0.44-0.74)	9.0 (7.9-10)
Sahtú	**n=123**			**n=100**			**n=123**
Female	10 (9.8-12)	<0.075	24 (20-29)	0.21 (0.16-0.28)	0.48 (0.40-0.61)	0.90 (0.56-1.4)	16 (14-20)
Male	9.2 (8.5-9.9)	<0.075	28 (23-33)	0.14 (0.11-0.17)	0.28 (0.24-0.32)	0.81 (0.63-1.1)	15 (12-18)

associated with increased manganese biomarker concentrations while adjusting for age and sex included eating caribou kidneys (22% higher average blood manganese levels), and eating soup/broth made from moose bones (86% higher average creatinine-adjusted urinary manganese levels). None of these associations were observed in the reference populations (Tables 3-6 and 3-7). However, in the pooled dataset, participants who ate caribou fat had urinary manganese levels that were 38% lower, on average, than those who did not eat caribou fat, and participants who ate broth made from caribou bones had urinary manganese levels that were 31% lower, on average, compared to those who did not eat caribou bones in broth (Table 3-8). As noted above, urinary manganese levels may not reliably reflect manganese exposure, and therefore these trends may not represent manganese exposure levels for participants. The association between increased blood manganese and the consumption of caribou kidneys in Old Crow is supported by literature documenting the accumulation of manganese in bones, kidneys, and livers of mammals (193, 194).

Table 3-5 - Percent Difference[1] in Biomarker Concentrations for Determinants of Blood and Urinary Biomarkers, Adjusting for Age and Sex in Old Crow (n=36 - 48)[2]

Determinant of Biomarker Levels		**Blood Mn**	**Urinary Mn[3]**	**Blood Co**	**Urinary Co[3]**	**Blood Pb**	**Urinary Pb[3]**	**Plasma HCB[4]**
Smokers (smoked cigarettes within last 24 hours)		-0.048	-6.7	-6.0	-35	29	18	32
Consumed a vitamin within last 24 hours		-13	-0.48	**29***	29	-32	**-56***	-0.41
Consumes untreated water sometimes to often		**29***	7.9	-8.4	2.6	**120****	110	5.7
Consumes food hunted using lead ammunition		12	1.4	-14	21	45	78	22
Consumers of the following traditional foods:								
Birds		-6.9	29	-47	-5.4	16	38	0.97
Berries		9.6	91	16	82	4.5	-10	5.9
Moose	*Bones in soup/stew*	1.8	**86***	15	25	14	38	35
	Fat	-0.25	55	7.4	7.9	14	15	-6.5
	Kidneys	-3.4	32	6.4	-8.6	35	86	35
	Bone Marrow	3.8	-2.7	5.2	6.7	35	62	8.4
	Liver	-7.5	26	16	28	26	91	-3.2
Caribou Porcupine	*Bones in soup/stew*	7.2	45	12	16	35	9.6	26
	Fat	18	35	2.8	4.5	9.4	-16	9.1
	Kidneys	**22***	5.7	9.6	-2.5	**58***	29	29
	Bone Marrow	11	51	5.2	19	13	-11	38
	Liver	6.9	-5.4	14	5.9	7.9	-38	-0.32
Fish	*Whitefish*	-17	-4.9	**28***	14	**-51***	**-79****	2
	Chinook	2	44	9.4	17	51	22	-4.1

*** p<0.05 and ** p<0.01**

– food was eaten by <15% or item not included in community surveys

1 – A positive value indicates that the participants who ate the specified food, smoked, took a vitamin, or drank untreated water, as indicated, had higher average biomarker levels in the percentage indicated, than those who did not. A negative value indicates that the participant who ate the specified food, smoked, took a vitamin, or drank untreated water, as indicated, had lower average biomarker levels in the percentage indicated, than those who did not.

2 – see Table 3-1

3 – Creatinine-adjusted

4 – Lipid-adjusted

Table 3-6 - *Percent Difference[1] in Biomarker Concentrations for Determinants of Blood and Urinary Biomarkers, Adjusting for Age and Sex in the Dehcho Region (n=53 - 122)[2]*

Determinant of Biomarker Levels		**Blood Mn**	**Urinary Mn[3]**	**Urinary Co[3]**	**Blood Pb**	**Urinary Pb[3]**	**Plasma HCB[4]**
Smokers (smoked cigarettes within last 24 hours)		0.46	-32	-19	**48****	21	5.9
Consumers of the following traditional foods:							
Birds		-3.2	7.6	32	12	-6.2	19
Berries		-3.6	24	0.21	-1.8	-32	0.69
Moose	*Bones in soup/stew*	-3.4	32	-0.73	-32	12	11
	Fat	9.4	20	6.2	7.6	11	-2.9
	Kidneys	6.2	22	-15	19	32	**32***
	Bone Marrow	4	9.4	-5.6	12	23	4.2
	Liver	-3.2	-16	-11	3.5	9.6	9.4
Caribou Woodland	*Bone Marrow*	5.4	55	11	-16	14	17
	Liver	-15	55	22	-28	25	35
Fish	*Whitefish*	1.3	11	25	10	-49	-12
	Lake Trout	-5.8	-16	-22	-7.5	**-34***	6.7

*** p<0.05 and ** p<0.01**

– food was eaten by <15% or item not included in community surveys

1 – A positive value indicates that the participants who ate the specified food, smoked, took a vitamin, or drank untreated water, as indicated, had higher average biomarker levels in the percentage indicated, than those who did not. A negative value indicates that the participant who ate the specified food, smoked, took a vitamin, or drank untreated water, as indicated, had lower average biomarker levels in the percentage indicated, than those who did not.

2 – see Table 3-1

3 – Creatinine-adjusted

4 – Lipid-adjusted

Table 3-7 - *Percent Difference[1] in Biomarker Concentrations for Determinants of Blood and Urinary Biomarkers, Adjusting for Age and Sex in the Sahtú Region (n=42-123)[2]*

Determinant of Biomarker Levels			Blood Mn	Urinary Mn[3]	Urinary Co[3]	Blood Pb	Urinary Pb[3]	Plasma HCB[4]
Smokers (smoked cigarettes within last 24 hours)			1.4	9.5	11	15	**110****	14
Consumers of the following traditional foods:								
Birds			-15	-2.7	-24	62	32	**48***
Berries			-0.03	-42	-28	-6.7	**-59***	19
Moose		*Bones in soup/stew*	12	-12	29	32	134	4.5
		Fat	8.4	0.58	11	18	91	8.4
		Kidneys	13	-10	21	20	86	7.2
		Bone Marrow	13	-15	41	26	66	15
		Liver	16	-38	-28	45	51	-4.7
Caribou	*Barren-Ground*	*Bones in soup/stew*	4.0	-41	-1.1	55	41	16
		Fat	-1.4	**-53***	-15	41	26	16
		Bone Marrow	-5.6	4.7	32	13	62	9.6
	Woodland	*Bones in soup/stew*	-7.3	-32	-1.3	38	58	29
		Fat	-9.4	-28	-2.0	35	58	**45***
		Kidneys	6.7	-0.89	29	51	220	22
		Bone Marrow	2.0	29	48	48	**230***	**48****
Fish		*Whitefish*	-15	14	-8.6	58	-25	-10
		Lake Trout	-6.9	38	25	14	130	17

*** p<0.05 and ** p<0.01**

– food was eaten by <15% or item not included in community surveys

1 – A positive value indicates that the participants who ate the specified food, smoked, took a vitamin, or drank untreated water, as indicated, had higher average biomarker levels in the percentage indicated, than those who did not. A negative value indicates that the participant who ate the specified food, smoked, took a vitamin, or drank untreated water, as indicated, had lower average biomarker levels in the percentage indicated, than those who did not.

2 – see Table 3-1

3 – Creatinine-adjusted

4 – Lipid-adjusted

Table 3-8 - *Percent Difference[1] in Biomarker Concentrations for Determinants of Blood and Urinary Biomarkers, Adjusting for Age and Sex in Pooled Participating Communities (n=131-229)[2]*

Determinant of Biomarker Levels			**Blood Mn**	**Urinary Mn[3]**	**Urinary Co[3]**	**Blood Pb**	**Urinary Pb[3]**	**Plasma HCB[4]**
Smokers (smoked cigarettes within last 24 hours)			5.0	16	3.5	**22***	**51****	11
Consumers of the following traditional foods:								
Birds			3.0	24	-1.8	9.7	18	12
Berries			8.4	-5.8	-9.0	-2.3	**-41***	3.5
Moose		*Bones in soup/stew*	1.5	26	14	**35***	45	**23***
		Fat	5.9	35	7.9	11	26	-0.39
		Kidneys	7.2	23	-2.5	14	**55***	16
		Bone Marrow	5.9	26	7.9	8.1	38	0.51
		Liver	0.74	11	-8.0	1.5	25	-8.6
Caribou	*Barren-Ground*	*Bones in soup/stew*	5.9	**-31***	-2.5	**74****	18	**51****
		Fat	13	**-38****	-8.6	**58****	6.9	**38****
		Bone Marrow	7.9	-22	2.2	**51****	14	**51****
	Woodland	*Bones in soup/stew*	-12	-17	7.1	**38***	35	**55****
		Fat	-13	-28	7.4	29	23	**58****
		Kidneys	-10	-8.6	17	29	70	**32***
		Bone Marrow	-3.0	38	26	26	**91***	**45****
Fish		*Whitefish*	-9.2	32	-0.89	-9.6	**-52***	-13
		Lake Trout	2.0	-2.1	17	51	22	-4.3

*** p<0.05 and ** p<0.01**

– food was eaten by <15% or item not included in community surveys

1 – A positive value indicates that the participants who ate the specified food, smoked, took a vitamin, or drank untreated water, as indicated, had higher average biomarker levels in the percentage indicated, than those who did not. A negative value indicates that the participant who ate the specified food, smoked, took a vitamin, or drank untreated water, as indicated, had lower average biomarker levels in the percentage indicated, than those who did not.

2 – see Table 3-1

3 – Creatinine-adjusted

4 – Lipid-adjusted

In addition to caribou kidney consumption, Old Crow participants who drank untreated water often or sometimes in the past year had blood manganese levels that were 29% higher, on average, than those who drank untreated water rarely or never, adjusting for age and sex. Old Crow community drinking water is sourced from a local well, where it is treated using both: i) disinfectant, and ii) removal of iron and manganese (due to elevated levels of these metals in the local groundwater). However, the majority of community members (81 – 84%) drank untreated surface water sometimes or often, generally in the form of ice collected from the nearby Porcupine River. The proportion of community members drinking untreated water sometimes to often in Old Crow was higher than the proportion drinking untreated water rarely to often in the Sahtú region (195). Untreated groundwater analysis during well installation in Old Crow reported manganese levels exceeding the Canadian Drinking Water Quality Guideline of 0.12 mg/L in all samples, indicating possible manganese enrichment in local soil (196). The majority (90%) of surface water samples collected from the nearby Porcupine River in the five years previous to the biomonitoring clinic (2014 – 2019) had manganese levels below the guideline (0.12 mg/L), however, exceedances were observed during the spring sampling events during this time period (197).

Though significant associations were observed between blood manganese levels and both the consumption of caribou kidneys and drinking untreated river water, all of the participants who reported drinking untreated river water also reported eating caribou kidneys. Due to the near-perfect correlation, further environmental sampling and surveying is necessary to determine whether manganese levels are truly associated with one or both of these independent variables. As well, due to the small number of participants, it is not possible to adjust for both of these variables in a generalized linear model.

3.4.5 Cobalt

Blood and urinary cobalt were positively correlated in Old Crow (Spearman $\rho=0.35$, $p<0.05$), but not in reference populations or the pooled dataset. No blood cobalt results were used for analysis in the Dehcho and Sahtú reference populations or the pooled dataset, as most values were below the analytical detection limit (0.075 µg/L).

In Old Crow, mean blood cobalt levels were similar between females and males, however, mean urinary cobalt levels were higher in females than in males in all three regions (Table 3-4). High urinary cobalt concentrations in women, such as those observed in this study, have been observed in the CHMS (75). These differences have been hypothesized to be linked to lower baseline iron levels or higher levels of iron loss in women (198), though iron status was not analyzed in Old Crow or the reference populations. No association was observed between mean blood or urinary cobalt levels and age in Old Crow ($p=0.32$ and 0.22, respectively) or urinary cobalt and age in the reference populations ($p=0.55$ the Dehcho and $p=0.41$ in the Sahtú) or the pooled dataset ($p = 0.15$).

For each independent variable, with the exception of age and sex, Tables 3-5 – 3-8 show the percent difference in cobalt levels between groups, adjusting for age and sex. No significant associations between urinary cobalt levels and eating any traditional foods were observed in Old Crow or the reference populations. In Old Crow, the only traditional food associated with increased cobalt biomarker concentrations after adjusting for age and sex was eating whitefish (those who ate whitefish had blood cobalt levels that were 28% higher, on average). This was not observed in the reference populations or the pooled dataset. A study of the diets of Indigenous Peoples from the Nenets Autonomous Region in north eastern Russia showed mean cobalt levels

in whitefish more than two times higher than other fish types that are eaten in both Russia and Old Crow, including inconnu, salmon, and northern pike (199). In areas where cobalt levels are elevated in the environment, dietary consumption of locally harvested foods, including primarily vegetables, grains, and fish, can result in elevated cobalt levels in the population (169) This association can be further examined in the future through the analysis of local whitefish samples for cobalt levels.

In addition to the consumption of whitefish, Old Crow participants who reported taking a vitamin in the previous 24 hours had blood cobalt levels that were 29% higher, on average, than those who did not take any vitamins, adjusting for age and sex. No association was observed between vitamin consumption and the consumption of whitefish (X^2 $p>0.05$). The association between vitamin intake and cobalt status may be related to the inclusion of vitamin B12, a cobalt-bearing compound, in many multi-vitamins. Consumption of multivitamins containing B12 has been found to affect blood cobalt levels (200). In Old Crow, 27% of respondents who provided blood samples took a vitamin that day. This is within the range of 23 to 33% observed in national-scale North American biomonitoring studies, including the CHMS and NHANES, and therefore may not explain elevated cobalt levels in Old Crow compared to the general Canadian population (201, 202).

3.4.6 Lead

Blood and urinary lead were positively correlated in Old Crow (Spearman $\rho=0.77$, $p<0.001$), both the Dehcho (Spearman $\rho=0.56$, $p<0.001$) and Sahtú (Spearman $\rho=0.70$, $p<0.001$) reference populations, and in the pooled dataset (Spearman $\rho=0.67$, $p<0.001$).

Mean concentrations of blood lead were lower in females than males in Old Crow, but not in either the Dehcho or Sahtú (Table 3-4). Higher urinary and blood lead levels in men, such as those observed in this study, have been observed in large, national-scale biomonitoring studies, including the NHANES (203). Some hypotheses for this trend include the biological, such as sex-specific differences in blood erythrocyte volume resulting in additional lead-bonding sites in males, or the social, including possible population-level lifestyle-based differences between genders, including occupational exposure (204). Mean lead levels in biomarkers increased with age in Old Crow, the reference populations and the pooled dataset for both blood lead (Spearman $\rho=0.41 – 0.49$, $p<0.001$) and urinary lead (Spearman $\rho=0.39 – 0.47$, $p<0.001$). An increase in lead with age in adults has been observed in the American population as part of NHANES, attributed to lead retention over a lifetime of exposure (203).

For each independent variable, with the exception of age and sex, Tables 3-5 – 3-8 show the percent difference in lead levels between groups, adjusting for age and sex. After adjusting for age and sex, average blood lead levels were higher for Old Crow participants who ate Porcupine caribou kidney in Old Crow (blood lead levels that were 58% higher, on average) than those who did not. In the Dehcho, no association was observed between lead levels in blood and urine and consumption of moose or caribou organs. In the Sahtú, participants who ate woodland caribou bone marrow had 230% higher urinary lead levels, on average, compared to those who did not, while accounting for age and sex. In the pooled dataset, participants who ate organs including caribou bones, fat, and bone marrow had 38 – 74% higher blood lead levels, on average, than those who did not, and participants who ate moose kidneys and caribou bone marrow had 55 – 91% higher urinary lead levels, on average, than those who did not. Lead accumulates in bones and can be found in high levels in organs such as the kidneys or liver (205). This observation has

been supported when comparing lead concentrations in the bones, kidneys, liver, and muscles of lead-exposed caribou in Alaska, where the highest lead concentrations were generally found in the caribou bones, or rumen, followed by liver, kidney, and muscle (206).

No association between smoking and lead levels was identified in Old Crow (Table 3-5), however, smokers in both of the reference populations and the pooled dataset had higher lead levels, on average, than non-smokers, adjusting for age and sex (Tables 3-6 to 3-8). The lack of significant association may be due to small numbers in Old Crow in comparison to the other groups, particularly the pooled dataset. Several large- and small-scale biomonitoring studies have observed elevated lead levels in current and former smokers, as lead can be found in tobacco smoke (207-209). As part of the return of results process for all biomonitoring clinics, health promotion materials included recommendations for reducing exposure to tobacco smoke to reduce exposure to some contaminants.

Though the majority of participants in the biomonitoring study (>75% of participants who knew the type of ammunition used in their traditional foods) ate food that had been hunted using lead ammunition, no significant association between consumption of these foods and lead exposure levels was identified. However, approximately one third of the participants in Old Crow did not know what type of ammunition was used for the game meat they consumed (Table 3-1). The number of participants who knew they did not consume game meat or fowl hunted using lead ammunition was small (n=4 - 7), and was not sufficient to identify trends in exposure patterns in this case. Previous studies evaluating the relationship between blood lead levels and ammunition found differences in the isotopic footprint of lead in the blood of consumers of food hunted using lead shot and bullets, concluding that the use of lead ammunition can be a source of lead exposure (210). The small number of participants who did not consume any meat hunted using

lead ammunition in Old Crow may be indicative of widespread use of lead-bearing shot and/or bullets for hunting in the community, resulting in elevated lead levels in the population.

Old Crow participants who drank untreated water often or sometimes had average blood lead levels 120% higher than those who drank untreated water rarely or never, adjusting for age and sex. In previous studies, elevated lead values relative to the CDWQ (0.005 mg/L) have been observed in surface water samples from the nearby Porcupine River during spring sampling events between 2014 – 2019 (197). The Porcupine River may not be the only river community members are sourcing for untreated drinking water, and further evaluation of drinking water, including source identification, water quality analysis, and intake calculation is recommended. As is discussed in the manganese section, significant associations were observed between blood lead levels and both the consumption of caribou kidneys and drinking untreated river water and all of the participants who reported drinking untreated river water also reported eating caribou kidneys. Due to small numbers, it was not possible to adjust for both of these variables in a generalized linear model.

This paper primarily aims to identify variables with positive associations with key parameters, however, it is noteworthy that consumption of some traditional foods were negatively associated with lead exposure, adjusting for age and sex, including the consumption of whitefish in Old Crow (consumers had blood lead levels that were 51% lower, on average), lake trout in the Dehcho reference population (consumers had creatinine-adjusted urinary lead levels that were 34% lower, on average), and berries in the Sahtu reference population (consumers had creatinine-adjusted urinary lead levels that were 59% lower, on average). In the pooled dataset, consumers who ate berries had creatinine-adjusted urinary lead levels that were 41% lower, on average, and consumers who ate whitefish had blood lead levels that were 52% lower, on

average. Negative associations may be relevant when identifying possible protective factors for exposure. These traditional foods are high in nutrients, including vitamin C (in the case of berries), and zinc (in the case of whitefish), which act as antioxidant defense mechanisms to reduce oxidative stress following lead exposure (211-214). Both vitamin C and zinc have also been found to reduce lead absorption following exposure (215, 216). In addition to traditional foods, Old Crow participants who reported taking a vitamin in the previous 24 hours had creatinine-adjusted urinary lead levels that were 56% lower, on average, than those who did not, adjusting for age and sex. This result is consistent with the literature, where it is noted that some vitamins, including vitamin C, vitamin E, calcium, and zinc, have been identified as both decreasing lead absorption following exposure, as well as possibly having protective properties on the adverse health effects of lead following exposure (213-216). Additionally, it is possible that broader behavioural differences, such as the replacement of higher contaminant level foods with whitefish or berries, may account for these differences in biomarker levels.

3.4.7 Hexachlorobenzene

Mean concentrations of lipid-normalized HCB were lower in females than males in Old Crow, but not in either the Dehcho or Sahtú (Table 3-4). Generally, lipid-normalized HCB levels increased with age in Old Crow, both reference populations, and the pooled dataset (Spearman ρ=0.63 – 0.76, $p<0.001$).

For each independent variable, with the exception of age and sex, Tables 3-5 – 3-8 show the percent difference in lipid-adjusted HCB levels between the two groups, adjusting for age and sex. Hexachlorobenzene is a lipophilic contaminant, and is most likely to be found in the fatty tissues of long-lived biota (217). Some associations were observed between HCB levels and

consumption of key traditional foods, particularly those high in fat, in several of the population groups. However, in Old Crow, none of the selected independent variables had significant associations with HCB levels. This may suggest the presence of multiple local exposure sources contributing to elevated average levels, or low enough effect sizes that they were not significant due to the small sample size. In the reference groups, higher average HCB levels were observed in Dehcho participants who ate moose kidneys, and in the Sahtú, higher average HCB levels were observed for those who ate birds, and woodland caribou fat and bone marrow. In particular, most association between traditional food consumption and HCB were observed in the pooled dataset. The higher sample size of the pooled dataset allows for the identification of significant trends with smaller effect sizes, which may be the case with HCB. In the pooled dataset, participants who ate organs including moose bones, caribou bones, fat, kidneys, and bone marrow had 23 – 58% higher blood HCB levels, on average, than those who did not. In all regions, the consumption of most moose and caribou organs were positively associated (X^2 $p<0.001$) with each other. Due to these near-perfect correlations, future studies should focus on HCB analysis and intake estimation for these foods. Previous work evaluating the HCB content of some traditional foods in northern British Columbia found elevated HCB concentrations in some of the types of fish eaten in Old Crow, including whitefish and chinook salmon, as well as in some game birds (52, 218). Generally, concentrations of HCB are low in caribou muscle tissue, but have been found in higher concentrations in kidneys, liver, and fat (28, 52, 219, 220).

No association between smoking status and HCB levels was observed in Old Crow (Table 3-5) or the reference populations. Several large- and small-scale biomonitoring studies have observed elevated HCB and lead levels in current and former smokers, as both contaminants can be found in tobacco smoke (207-209, 221).

3.4.8 Health Promotion

In Old Crow, and the reference populations, the consumption of some traditional foods, including caribou and moose organs, was associated with elevated levels of some of the key parameters of this study. Though concentrations of these parameters may be elevated in some traditional foods, these foods are an important source of nutrients for members in all three regions, and provide other important health and wellness benefits including increased physical activity during harvesting, cultural benefits, and improvements in mental health (133). During the return of results process for the biomonitoring studies, the importance and benefits of traditional foods were emphasized to community members. The message that the health benefits of eating traditional foods continue to outweigh the risks was communicated during community presentations, individual meetings, media outreach, posters, brochures, and written reports (89, 166). Additionally, other health promotional materials related to contaminant exposure were created in collaboration with community partners. In particular, recommendations were made to reduce the use of lead-bearing ammunition while hunting, as well as reducing exposure to tobacco smoke.

3.4.9 Study Limitations

This study uses the results from small biomonitoring programs administered in northern communities. Although the study participants represented 44% of the population of Old Crow, and 12 to 40% of the populations of the reference populations, the numbers are not sufficient to allow analytic adjustment for all possible factors that may impact results. Small sample numbers also increase the change of false discovery rate between dependent variables with independent variables that are highly correlated to each other, as is the case with traditional food

consumption. These intercorrelations unfortunately cannot be accounted for, and therefore further traditional food sampling and risk analysis is necessary to identify specific sources of contaminat exposure. Additionally, due to the nature of the recruitment process in small community-focused biomonitoring projects, a random sample is often not possible (80). Therefore, study recruitment might not reach certain members of the population, including those without phones, or those who work seasonally outside the community. These results are intended to guide and refine future research in the North in an effort to identify determinants of contaminant biomarkers found at elevated levels in humans. Any recommendations regarding changes to consumption of specific traditional foods must be done in co-development with the affected communities, taking into account the needs and experiences of the community (222). These recommendations should also be informed by environmental monitoring, as well as risk assessments to estimate contaminant exposure.

3.5 Conclusion

This study was initiated in response to Old Crow community concerns regarding elevated exposure levels of metals, including cobalt, lead, manganese, and HCB, all of which may be concentrated in some types of traditional foods. In particular, animal bones and organs can accumulate high concentrations of metals, and fatty tissue and organs can accumulate lipophilic compounds such as HCB (52, 223, 224). The aim of this study was to identify possible determinants of biomarker levels to complement ongoing sampling of local traditional foods and inform risk assessments based on intake of these foods. This study found that consumption of some traditional foods was positively associated with exposure levels of some contaminants and nutrients, including manganese, cobalt and lead, in Old Crow. Additionally, HCB analysis in

traditional food samples is ongoing in Old Crow, in an effort to estimate intake and identify possible driver(s) for elevated levels in community members.

In addition to the consumption of some traditional foods, several other independent variables were associated with elevated levels of key parameters. These included the consumption of untreated river water, vitamins, and smoking. Smoking rates in northern communities are higher than those in the general Canadian population, and this may contribute to elevated levels of some contaminants, including lead, in these populations.

Traditional foods remain an important source of nutrients in the diets of community members in Old Crow and the reference populations (54, 225). These foods also provide other benefits, including increased physical activity through harvesting, mental health improvements, as well as spiritual wellness (133). Given the importance of these foods, future efforts should focus on monitoring and decreasing the levels of these contaminants in traditional foods, followed by exposure estimates to further understand the benefits and risks within these communities.

4 Hexachlorobenzene and Omega-3 Fatty Acid Intake From Traditional Foods in the Northern Yukon: A Risk and Benefit Analysis

Drysdale, M., Gamberg, M., Brammer, J., Majowicz, S., Packull-McCormick, S., Skinner, K., Laird, B. Hexachlorobenzene and omega-3 fatty acid intake from traditional foods in the Northern Yukon: A risk and benefit analysis. (2022).

4.1 Abstract

A human biomonitoring study was conducted in the community of Old Crow, Yukon, in 2019, finding that levels of hexachlorobenzene in plasma were elevated in the community relative to the general Canadian population. The aim of this study was to estimate dietary intake of both hexachlorobenzene, and the nutrient omega-3 fatty acids from locally harvested traditional foods in Old Crow, with the aim of identifying possible regional sources of exposure. A stochastic model was constructed to estimate intake of both hexachlorobenzene and the omega-3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Average predicted hexachlorobenzene exposure levels from traditional food consumption in Old Crow were below the tolerable daily intake of 1600 – 1700 ng/kg body weight/day in both average (18 ng/kg body weight/day) and short-term maximum (27 ng/kg body weight/day) exposure models. The primary contributors to average hexachlorobenzene intake were caribou fat, bone marrow, ribs, and kidneys, and Chinook salmon muscle. Average estimated dietary EPA+DHA intake levels from traditional foods were below the recommendation of 2.1 to 3.2 g of EPA+DHA per week in the average (1.6 g/week) exposure model, but above this recommendation in the short-term maximum model (3.3 g/week). The primary contributors to average EPA+DHA intake were the

meat of Chinook, coho, and, chum salmon muscle, and whitefish muscle and eggs. The results of this study support the message that traditional foods continue to be an important source of nutrients and other health benefits and that the health benefits of traditional foods generally outweigh contaminant risks.

4.2 Introduction

The Arctic is a geographic area that is particularly vulnerable to environmental contamination from the long-range transport of airborne contaminants (10). These can include persistent organic pollutants (POPs), which are a range of synthetic materials that can remain in the environment for decades. As part of the effort to quantify human exposure to these compounds in the Arctic, plasma POP levels were analyzed during a 2019 contaminant and nutrient biomonitoring clinic conducted in the community of Old Crow, Yukon Territory (YT). The results of this study indicated that plasma levels of hexachlorobenzene (HCB), an organochlorine pesticide and persistent organic pollutant (POP), were found at higher concentrations in people in Old Crow than in the general Canadian population and First Nations communities across the ten provinces (166).

HCB is a synthetic fungicide that was previously used to prevent disease in crops, until its use was banned globally under the 2001 Stockholm Convention on POPs (167, 226). Like many POPs, HCB can undergo long-range transport to remote northern regions both in the atmosphere and through migrating birds. Once it reaches the northern ecosystem, it can accumulate in aquatic and terrestrial wildlife (227, 228). Due to its lipophilic nature, HCB bioaccumulates and biomagnifies in the tissue of long-lived biota (217). In human adults, dietary exposure accounts for 90% of the source of exposure to organochlorine pesticides, including HCB (217). Due to the lipophilic nature of HCB, dietary exposure occurs primarily through the consumption of fatty

animal tissue. This can include traditional foods harvested in regions where POPs can accumulate, such as Arctic communities (229). Elevated exposure to HCB has been associated with adverse health effects in humans, including damage to the liver and negative effects on thyroid function (167).

Though POPs, including HCB, can accumulate in some traditional foods, such as wild game, birds and fish, traditional foods are also critically important for both cultural, spiritual, and physical wellbeing and maintaining food security for many Indigenous Peoples in Arctic communities, including the primarily Gwich'in community of Old Crow (21). Traditional foods can be important sources of beneficial nutrients, including omega-3 fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (21, 54). Clinical and epidemiological studies have shown that consumption of these fatty acids is associated with a reduction in the incidence of cardiovascular disease and can decrease the risk of some other chronic diseases including diabetes and arthritis (230, 231). Traditional food gathering has also been associated with higher physical activity levels (58) and benefits including increased spiritual connection and emotional healing (59). This study was designed to estimate dietary intake of HCB in Old Crow from locally harvested traditional foods, with the aim of identifying possible regional sources of exposure.

4.3 Methods

4.3.1 Community Partnership and Ethics

This project was conducted using data collected as part of the human biomonitoring project in Old Crow, YT, in partnership with the Vuntut Gwitchin Government (VGG). In accordance with community-based research methods employed for this project, a Community Research

Agreement (CRA) was drafted between the VGG and the university research team. The CRA incorporates the four components of OCAP® (Ownership, Control, Access, and Possession), and principles for data sovereignty and governance designed for work within First Nations communities (166, 167). Collaboration with the community is outlined in the CRA, and includes components designed for capacity building, and Indigenous knowledge integration (168). Importantly, the CRA was based on a template drafted by the VGG, and is annually updated following review by the VGG's Heritage Committee. Consistent communication is also a vital component of community-based research, including and included the ongoing identification and prioritization of new research questions and returning of results to the community on a regular basis and prior to publication. The Waterloo Research Ethics Board provided approval for the collection and use of biomonitoring data (#32076), and the collection and analysis of traditional food samples (#41141). Additionally, a Scientists and Explorers Research License was obtained from the Yukon Government (12-27S&E).

4.3.2 Old Crow Biomonitoring Project

A human biomonitoring clinic was conducted in Old Crow, YT, in February of 2019. During the clinic, participants from the community had the option of submitting hair, blood, and/or urine samples which were analyzed for substances including trace metals (e.g. lead, cadmium, arsenic), omega-3 fatty acids, and POPs, as well as participating in surveys regarding traditional food consumption, lifestyle risk factors for exposure, and health messaging, as described by Drysdale et. al. (166) and Chapter 2 of this thesis. This study includes the use of data collected from the 69 adult (18+) participants who completed the dietary survey, and uses other data

collected during the clinic, including participant sex, age, and weight, and concentrations of plasma HCB and omega-3 fatty acids.

4.3.3 Calculating Individual Intake of HCB and EPA+DHA

Oracle Crystal Ball V.11.1.2.4 (Crystal Ball) was used to construct a stochastic exposure model to estimate *dietary* intake (D) of HCB and omega-3 fatty acids. Crystal Ball is a spreadsheet-based program within Excel used to conduct predictive modeling with inputs including both deterministic and stochastic data. The program can produce outcome distributions, as well as conduct sensitivity analyses for the impact of assumptions on model variance. As part of the dietary intake calculation, responses from a traditional food survey were used to calculate individual *intake rate* (IR) distributions for each participant for each of the 43 traditional foods included in this study. For each individual, the intake rate for a specified traditional food was then multiplied by the distribution of *concentration* (C) of the substance (HCB or EPA+DHA) in that food. This generated a distribution of estimated intake of a substance for each individual for each of the 43 foods. The distributions for consumption of the substance from each traditional food were summed at the individual level to determine total predicted intake of the substance from traditional foods for each participant. Exposure to EPA+DHA is described in weight EPA+DHA per unit time for comparison to dietary recommendations. In the case of calculating HCB exposure, the summed intake HCB for each individual was then divided by that individual's body weight to determine a dietary intake rate per unit body weight for each individual for comparison to toxicological guidance values.

See equation 1:

$$(1)\ D_i(\text{HCB}) = \frac{\sum_{f=1}^{n=43} IR_i\ x\ C}{BW_i}\ or\ D_i(\text{EPA+DHA}) = \sum_{f=1}^{n=43} IR_i\ x\ C$$

Where:

D_i distribution of an individual's (i) dietary intake (D) of HCB or EPA+DHA

IR_i distribution of an individual's (i) intake rate (IR) of a specified traditional food (f)

C is the concentration distribution of HCB or EPA+DHA in the specified traditional food (f)

f is the traditional food (n=43 foods)

BW_i is the point value of the individual's (i) measured body weight, or distribution of an individual's estimated body weight

4.3.4 Traditional Food Intake Rate (IR)

Weekly consumption rates and portion sizes for traditional foods were input on an individual basis, based on the individual's responses to a Food Frequency Questionnaire (FFQ) administered as part of the Old Crow Biomonitoring Clinic in 2019 (127, 166). This survey was based on the questionnaire created for contaminant research in Dene communities in the Northwest Territories (127) and was adapted for use in Old Crow. The FFQ included 60 harvested traditional food species, 33 of which are animals, plus individual animal organs. Only animal-based traditional foods were included in this model, due to the lipophilicity and biomagnification of HCB up the food chain (217). The exclusion of plants and water is supported by the analysis of local river water and berries, which indicated low levels of HCB in these foods (232). Foods were included in the model (n=43) when more than 10% of participants reported eating them within the previous year. Consumption frequencies for traditional foods were

reported across four categories, including: less than one day per week, one to two days per week, three to five days per week, or six to seven days per week. These consumption frequencies were input as uniform distributions with the range reported by the participant (e.g. six to seven days per week) as the minimum and maximum.

To convert the consumption frequency distributions described above to IRs for each traditional food, the consumption frequency distribution was multiplied by serving size (in grams) for each food. The FFQ asked participants about the typical serving size for each food category, including fish, land animals, land animal organs, and birds. Participants were not asked about serving sizes for individual foods within these categories, and therefore only one portion size was used for all foods in each category (e.g., one portion of rabbit meat was assumed to be the same as one portion of caribou meat). Serving sizes for each participant were multiplied by that participant's frequency of consumption distribution to calculate an estimated weekly IR distribution in grams for each individual.

The results of the FFQ, which were used to calculate IRs, were self-reported, and were therefore susceptible to recall bias. An evaluation of the validity of FFQs for estimating intake noted that overestimates are more likely to occur than underestimates when using an FFQ, however both are possible, and the uncertainty can vary for different foods within the same FFQ and population (233). To account for over or underestimates of consumption of individual foods, as well as seasonality of harvesting, participants were asked for their typical weekly frequency of consumption of each food category (fish, land animals, land animal organs, birds) for six two-month periods throughout the year. These values were also reported across four categories, including: less than once per week, one to two times per week, three to five times per week, or six to seven times per week, and were input as stochastic variables with uniform distribution with

the minimum and maximum set to the consumption frequency range. In general, self-reported IRs for an entire food category were lower than the sum of foods consumed within that category. To account for these overestimates, as well as seasonal variability, IR distributions within each category were normalized to the total IR distributions for foods within that category. Two models were run:

1. **Long-Term Average Exposure:** the average IR distribution for each food category was calculated for the six two-month time periods to determine an annual average.
2. **Short-Term Maximum Exposure:** the seasonal IR distribution with the highest mean value was selected from within the six two-month time periods reported for each food category.

For example, if a participant reported eating an average of two 200 g servings each of caribou and moose meat per week, the non-normalized consumption for that participant would have an average consumption rate of 400 g/week each of caribou and moose meat. However, this example participant reported eating all land animal meat at an average annual rate of 100 g/week, and a maximum rate with an average of 200 g/week. In the long-term average exposure model, the average IRs would be 50 g/week each of caribou and moose meat, and in the short-term maximum exposure model, the average IRs would be 100 g/week each of caribou and moose meat. The long-term average exposure model gives an annual average estimate for consumption for each participant, while the short-term maximum exposure model can be used to determine whether the highest short-term consumption estimates approach or exceed any health-based guidance values. Summary statistics of the IRs used in the model are shown in Tables 4-1 (for individual foods) and 4-2 (for food categories and portion sizes).

Table 4-1 - Consumption of Traditional Foods in Old Crow based on Food Frequency Questionnaire

Food*	Percent Consuming	Average weekly consumption (g) for consumers	Maximum weekly consumption (g) for consumers
Land Animal Muscle			
Caribou	94%	210	1500
Moose	91%	150	940
Rabbit	49%	60	240
Muskrat	23%	42	180
Porcupine	12%	37	130
Lynx	10%	84	240
Land Animal Organs			
Caribou Ribs	77%	52	470
Caribou Bone Marrow	71%	21	140
Caribou Heart	70%	24	210
Caribou Fat	65%	31	350
Caribou Head	65%	20	89
Caribou Bones in Soup or Broth	62%	40	370
Caribou Tongue	62%	18	89
Moose Ribs	59%	30	270
Caribou Kidney	51%	19	140
Moose Head	51%	19	89
Caribou Stomach	48%	26	210
Moose Heart	48%	21	89
Moose Tongue	46%	20	89
Moose Bones in Soup or Broth	43%	54	352
Moose Fat	43%	46	220
Moose Kidney	35%	22	89
Moose Bone Marrow	35%	27	89
Caribou Liver	30%	18	89
Moose Intestines	29%	24	89
Moose Tripe	16%	31	89
Moose Liver	16%	24	89
Caribou Brain	13%	19	89
Caribou Blood	12%	14	41
Fish/Seafood			
Chinook Salmon	90%	41	450
Whitefish	83%	29	300
Whitefish Eggs	39%	11	200
Coho Salmon	36%	42	350
Burbot	29%	31	270
Arctic Grayling	28%	21	210
Inconnu	22%	29	120
Lake Trout	16%	22	100
Salmon Eggs	16%	6.6	65
Muktuk	15%	19	55
White-Winged Scoter	33%	48	490
Burbot Liver	14%	31	270
Wild Birds			
Canada Goose	35%	44	490
Ptarmigan	20%	30	110
Speck Belly Goose	17%	63	490
Mallard	12%	54	490
Spruce Grouse	10%	19	200

* Foods are muscle tissue unless tissue is specified

Table 4-2 – *Input Assumptions for Intake and Body Weight*

Assumption[1]	Units	Min	Max	Average	Standard Deviation	Source
Land Animal Muscle (Eaten by 100%, n=69/69)						
Portion Size	g	38	225	136	44	FFQ
Average Consumption Frequency	days/week	0.083	6.5	1.9	2.0	FFQ
Maximum Consumption Frequency	days/week	0.50	6.5	2.5	2.3	FFQ
Land Animal Organs (Eaten by 65%, n=45/69)						
Portion Size	g	38	225	87	39	FFQ
Average Consumption Frequency	days/week	0.083	6.5	1.9	2.0	FFQ
Maximum Consumption Frequency	days/week	0.50	6.5	2.5	2.3	FFQ
Fish/Seafood (Eaten by 99%, n=68/69)						
Portion Size	g	38	225	114	37	FFQ
Average Consumption Frequency	days/week	0.083	4.4	0.85	0.82	FFQ
Maximum Consumption Frequency	days/week	0.50	6.5	1.7	1.8	FFQ
Wild Birds (Eaten by 57%, n=39/69)						
Portion Size	g	38	225	114	42	FFQ
Average Consumption Frequency	days/week	0.083	3.8	0.58	0.65	FFQ
Maximum Consumption Frequency	days/week	0.50	6.5	1.3	1.5	FFQ
Body Weight	**kg**	**50**	**124**	**82**	**17**	**Clinic[2]**

1. Portion size and consumption frequency statistics for consumers only
2. When body weight was not measured in clinic, values were imputed based on methods described in Section 4.3.6.

4.3.5 Substance Concentrations (C) in Traditional Foods

Hexachlorobenzene

Levels of HCB in foods were input as log-normal distributions, using mean, standard deviation, minimum, and maximum values derived from this study and the scientific literature, as shown in Supplemental Table 4-1 (end of Chapter 4). A log-normal distribution was selected based on best-fit analyses of HCB in animal tissue from other studies (234, 235). If only a mean was available, the standard deviation, minimum, and maximum were calculated based on the method shown in Supplemental Table 4-1. The data sources for HCB levels included samples collected

in Old Crow, concentrations reported in the scientific literature, and assumptions based on lipid content of a tissue, as described below.

Samples of some traditional foods were collected by harvesters in Old Crow and analyzed for HCB levels in 2020 and 2021 (232). These included samples of caribou fat, bone marrow, and liver, moose fat, bone marrow, and liver, and loche (fish) liver. Additionally, chum salmon from the same watershed were provided by Fisheries and Oceans Canada. Foods not included in the sampling program were assigned HCB concentrations based on a review of the scientific literature. Priority was given to studies of northern foods collected in close proximity to Old Crow, however, northern foods from other jurisdictions, including the Canadian territories, Alaska, Greenland, Russia, and northern Europe, were included when no close proximity foods were available. Studies were prioritized when samples were collected within the previous 10 years, however, due to the slow decline/plateau in environmental HCB levels in the North (19), results from the 1990s were also used when no recent results were available. In some cases, limited information was available regarding specific tissue types (e.g. caribou stomach). In these instances, HCB levels were assumed to remain consistent in lipids throughout an animal, and were normalized to reflect lipid concentrations in the targeted tissue. Supplemental Table 4-1 includes all assumed HCB levels used in the model, citing the source of literature used.

HCB levels in all traditional foods were measured in raw meat, though these concentrations generally increase as the overall volume of meat decreases during cooking from moisture loss, with the total HCB in the food portion remaining relatively constant (236). To maintain consistency with other studies of traditional meat consumption, meat was assumed to shrink by 25% during cooking (56). This model did not account for differences in food preparation methods, such as smoking or drying meats, which may affect HCB levels (237).

Omega-3 Fatty Acids (EPA+DHA)

The methods used for assumed EPA+DHA concentrations were generally similar to those reported above for HCB. Based on the results of a best fit analysis conducted on EPA+DHA concentration distributions in animal tissue, the minimum EPA+DHA concentration distribution for each food was assumed to be log-normal (238).

When available, EPA+DHA concentrations in traditional foods were assumed based on nutritional data for traditional foods compiled from the Canada Nutrient File (CNF), or other scientific literature (239). Results for cooked meat were preferred, as this was the primary preparation method used for meat by community members in Old Crow (114). However, raw food data was used when cooked food data was unavailable, as the concentration of EPA+DHA decreases by less than 5% during cooking (240). No cooking adjustments were made for EPA+DHA levels in this model. Supplemental Table 4-1 includes all assumed EPA+DHA levels used in the model. As noted above, this model did not account for differences in food preparation methods, which may affect levels of EPA+DHA (241).

4.3.6 Body Weight (BW) and Demographics

Demographic data, including sex and age, and body weight, were collected during the participant intake process of the biomonitoring clinic. Sex and age data were self-reported, and provided by all 69 adult participants included in this study. Though body weight is required to estimate intake, some participants (19%) did not want to be weighed during the clinic. In these cases, participants were assigned assumed weights using normal distributions, based on the average, minimum, maximum, and standard deviation of the weight for their sex and age range (18 – 39,

40 – 59, 60+) in this dataset for the purposes of modeling. Summary statistics for body weight assumptions are shown in Table 4.2.

4.3.7 Stochastic Modelling

The three model parameters: IR (stochastic), C (stochastic), and BW (see Section 4.2.6), were input into Crystal Ball for each study participant to complete the calculation described in Equation 1. Monte Carlo simulations were run with 100 trials per individual for 69 individuals to create distribution forecasts. These model forecast results were extracted to show individual-level predictions for dietary intake of HCB and EPA+DHA, and population-level prediction statistics for these same outcomes. A sensitivity analysis of the relative influence of assumption variables on outcome variance was also run.

4.3.8 Statistical Analysis

Statistical analysis was performed using SAS Software Version 9.4 and in Crystal Ball. At the population level, predicted individual distributions for each of HCB and EPA+DHA intake were used to create one predicted population distribution for each of the two models for each of the two parameters. Descriptive statistics, including means, 10^{th} and 90^{th} percentiles, minimums and maximums, were used to summarize population-level predictions. For each population distribution, Crystal Ball was used to conduct a sensitivity analysis to rank the input assumptions based on impact on the predicted forecast variable. To estimate the relative contribution of each traditional food to the total intake of HCB and EPA+DHA, average population-level intakes were calculated for each food, adjusting for body weight in the case of HCB. This calculation

was also done for a sub-population, which included the participants with the highest 25th percentile of predicted HCB intake from traditional foods.

At the individual level, the association between age and predicted HCB and EPA+DHA intake rates was analyzed using Spearman rank correlation coefficients (Spearman rho). Means between two groups (e.g. male and female exposure levels) were compared using independent two-sample T-tests and a visual comparison of outcome distributions. Individual level predictions for both HCB and EPA+DHA in both the average and maximum models were compared to plasma concentrations for these substances using generalized linear modeling to determine the extent to which modeled HCB and EPA+DHA levels are predictive of observed plasma levels of these substances in individuals. Both biomarker levels, as well as predicted HCB and EPA+DHA intake were log-transformed to achieve linearity for generalized linear modeling. In each model, the outcome variable: individual plasma HCB or EPA+DHA concentrations, was treated as a continuous variable. Predictor variables included sex (binary), age (continuous), and the predicted average individual HCB or EPA+DHA intake values from the stochastic models (continuous). Each generalized linear model's r^2 and Type III sums of squares were reported to evaluate model goodness of fit and proportion of variance attributable to each predictor variable. Residuals were checked after each analysis to confirm the assumptions of linearity and homoscedasticity.

4.3.9 Risk and Benefit Assessment of Dietary HCB and EPA+DHA Intake

The results of estimated population-level intake of EPA+DHA and HCB from the stochastic model were compared to available health-based guidance values or recommendations for these substances. Health Canada recommends eating at least two servings of fish per week, for a

minimum intake of 2.1 to 3.2 g of EPA+DHA (242). This is within the range reported during a review of epidemiological and toxicological studies, which indicated that minimum EPA+DHA intake for healthy adults appears to be between 250 to 500 mg per day, or 1.7 to 3.5 g per week (243).

At the population level, plasma HCB concentrations were also compared to a biomonitoring equivalent of 25 ng/g lipid, which can be used as a screening tool to identify priority contaminants for the analysis of risk (189). A Tolerable Daily Intake (TDI) was used to specify a maximum intake rate for a substance over a lifetime that is considered to be of no appreciable health risk. The United States Environmental Protection Agency (USEPA) lists a reference dose for oral exposure of 0.8 µg/kg body weight/day for HCB (244) and previous studies addressing HCB intake in northern communities have used a provisional TDI of 0.27 µg HCB/kg body weight/day (245). The World Health Organization (WHO) lists a lower TDI of 0.17 µg HCB/kg body weight/day for hepatic effects and 0.16 µg HCB/kg body weight/day for neoplastic effects, both of which were used for comparison purposes in this study (246). The higher TDI values were not used for comparison. Estimated exposure levels were compared to these two TDIs using a Hazard Quotient (HQ), with a threshold of 0.2 to indicate a risk of possible health effects when no other background exposures are being considered.

4.4 Results

4.4.1 Hexachlorobenzene Intake

Population level summary statistics for dietary HCB exposure in both the long-term average and short-term maximum exposure models are summarized in Table 4-3. The association between predicted HCB exposure and age was not significant in both the long-term average and short-

term maximum exposure models (Spearman rank correlation coefficients = 0.062 and 0.032%, p>0.05). Though mean predicted intake rates for HCB in both the average and short-term maximum exposure models were higher in males (23 ng/kg body weight/week [95% CI= 12 – 36 ng/kg body weight/week] and 35 ng/kg body weight/week [95% CI= 22 – 55 ng/kg body weight/week]) than females (13 ng/kg body weight/week [95% CI= 8.7 – 18 ng/kg body weight/week] and 21 ng/kg body weight/week [95% CI= 16 – 30 ng/kg body weight/week]), the difference was not statistically significant in either model. The small sample size of the study

Table 4-3 - *Population-Level Predicted Dietary HCB Exposure from Traditional Foods (ng/kg body weight/week)*

	Long-Term Average Exposure Model			**Short-Term Maximum Exposure Model**		
	Whole Population (n=69)	**Females (n=39)**	**Males (n=30)**	**Whole Population (n=69)**	**Females (n=39)**	**Males (n=30)**
Mean	18	13	23	27	21	35
Standard Deviation	23	14	30	33	22	42
Minimum	0.35	0.35	0.61	0.82	0.82	1.4
Maximum	160	94	160	190	140	190

Though approximately 18% of participants had plasma HCB levels exceeding the biomonitoring equivalent of 25 ng/g lipids (189), predicted HCB exposure levels from traditional food consumption in Old Crow were well below the health-based thresholds of 0.16 – 0.17 µg HCB/kg body weight/day (1,100 – 1,200 ng HCB/kg body weight/week) for neoplastic and hepatic effects in both models (Table 4-3), and HQs for all participants in both models were below 0.2. Estimated HCB intake was correlated with total combined intake of traditional foods in this study (Spearman rho=59%, p<0.0001). Table 4-4 shows the top 5 contributors to overall average HCB intake for the population, based on average HCB intake from each food.

Additionally, the top sources of HCB are shown for participants who had the highest predicted dietary HCB intake.

Table 4-4 - Top 10 Contributors to Average Predicted Dietary HCB Exposure

Traditional Food	Percent Contribution of Each Food to Predicted HCB Intake from Traditional Foods			
	Long-Term Average Exposure Model		Short-Term Maximum Exposure Model	
	All Participants	Consumers > 75P HCB Intake[a]	All Participants	Consumers > 75P HCB Intake[b]
	n=69	n=17	n=69	n=17
Caribou Fat	19%	23%	18%	22%
Caribou Bone Marrow	15%	17%	13%	15%
Caribou Ribs	14%	18%	13%	16%
Caribou Kidney	11%	13%	10%	12%
Chinook Salmon Meat	8.9%	4.9%	12%	7.7%
Muktuk	8.2%	3.7%	9.0%	4.6%
Caribou Meat	7.3%	6.1%	6.8%	5.9%
Caribou Tongue	2.6%	3.0%	2.3%	2.7%
White-winged Scoter Meat	2.1%	1.6%	3.3%	2.6%
Moose Fat	1.6%	1.7%	1.2%	1.5%

a. Estimated HCB intake greater than 19 ng/kg body weight/week
b. Estimated HCB intake greater than 32 ng/kg body weight/week

A sensitivity analysis showed that the main contributors to the variance in total predicted dietary HCB exposure at the population level were intake rates of caribou organs. These contributed to 38% of the variance in both the long-term average and short-term maximum exposure models, with the primary contributors (long-term average model, short-term maximum model) including the IRs of caribou ribs (6.7, 6.4%), bone marrow (6.4, 6.1%), tongue (5.9, 5.8%), kidneys (5.8, 5.7%), and fat (5.6, 5.5%). The parameters contributing most to variance in total exposure were IRs of the same foods that contributed most to total exposure for each substance. Generally, for each traditional food, the consumption frequency and the portion size contributed similarly (35-

40% each) to variance in the intake of HCB from that food. Therefore, assumptions including portion size and consumption frequency contributed more to total outcome variance for foods with a higher overall contribution to outcome variance (i.e. caribou organs). The highest contribution to variance for an individual food to total estimated HCB intake was approximately 2% for both consumption frequency of that food and portion size. Other factors, including body weight, shrinkage due to cooking, and the concentration of HCB in the food, had smaller contributions (<0.5% each).

Table 4-4 includes a sub-group of participants with the highest estimated HCB intake (top 25th percentile). This sub-group consists of a higher proportion of males (59%) in comparison to the whole study group (43%). The average age of the highest HCB intake sub-group (45 years, ranging from 20 to 76 years) was similar to the whole study population (43 years, ranging from 25 to 65 years). Geometric mean lipid-normalized plasma HCB levels were similar between the whole participant group for this study (14 µg/kg lipids) and the high HCB intake group (15 µg/kg lipids). The high HCB intake subgroup consumed relatively more dietary HCB through caribou organs and less from muktuk and fish, including Chinook salmon, than the study group as a whole in both the average and maximum intake models. However, this sub-group consumed 27 – 52% more volume of all the top ten contributing foods, on average, than the whole study group. The one exception was muktuk, where average consumption was 3% lower in the highest estimated HCB intake sub-group compared to the whole study group.

Log-transformed individual-level predictions were compared to log-transformed biomarker levels for all participants where available (n=49). The parameter estimates for each possible model are shown in Table 4-5. Possible interaction effects between the three predictor variables were assessed, and none were significant ($p>0.05$).

Table 4-5 – Generalized Linear Model Selection for Predicting Log-Transformed Plasma HCB Levels[a] (n=48)

Model ID	Predictor Variables	Long-Term Average Exposure Model				Short-Term Maximum Exposure Model			
		β	p	Type III SS[e]	r^2	β	p	Type III SS[e]	r^2
1	Log(Estimated HCB Intake)[b]	0.13*	0.049	0.25	0.39	0.14*	0.049	0.25	0.40
	Age[c]	0.011**	<0.001	1.5		0.011**	<0.001	1.4	
	Sex[d]	0.10	0.23	0.13		0.10	0.22	0.12	
2	Log(Estimated HCB Intake)[c]	0.14*	0.046	0.28	0.37	0.14*	0.043	0.28	0.37
	Age[d]	0.011**	<0.001	1.5		0.011**	<0.001	1.5	
3	Age[c]	0.011**	<0.001	1.4	0.34	-	-	-	-
	Sex[d]	0.11	0.16	0.15		-	-	-	
4	Age[c]	0.011**	<0.001	1.4	0.31	-	-	-	-
5	Log(Estimated HCB Intake)[b]	0.096	.27	0.13	0.071	0.11	0.21	0.16	0.078
	Sex[d]	0.12	0.23	0.17		0.12	0.25	0.16	
6	Sex[d]	0.12	0.20	0.19	0.042	-	-	-	-
7	Log(Estimated HCB Intake)[b]	0.12	0.27	0.15	0.033	0.12	0.21	0.19	0.042

** $p < 0.01$, * $p<0.05$

- Same in both the long-term average and short-term maximum exposure models

a. Plasma HCB levels are lipid-adjusted
b. Estimated HCB intake in ng/kg body weight/week
c. Age in years
d. Sex, where male = 1 and female = 0
e. Type III Sums of Squares for each variable

Estimated consumption of HCB traditional foods was significantly associated with the outcome of HCB levels in plasma, though only when adjusting for age (Models 1 and 2). For each generalized linear model, the Type III Sums of Squares indicated the relative proportion of variance on the outcome attributed to each predictor variable in a model that includes all predictor variables. Despite the significant of estimated HCB intake from traditional foods in Models 1 and 2, age accounted for more than six times the relative variance in the outcome plasma HCB levels when compared to predicted HCB intake from traditional foods, though both variables were significant ($p<0.05$). Sex was not significant in any of the models.

4.4.2 Omega-3 Fatty Acid (EPA+DHA) Intake

Population level summary statistics for dietary EPA+DHA exposure in both the long-term average and short-term maximum exposure models are summarized in Table 4-6. The association between predicted EPA+DHA exposure and age was not significant in both the average and maximum intake models (Spearman rank correlation coefficients = 0.050 and 0.064, $p>0.05$). Though mean predicted intake rates for EPA+DHA in both the average and short-term maximum exposure models were higher in males (2.0 g/week [95% CI= 1.4 – 3.2 g/week] and 4.1 g/week [95% CI= 3.3 –6.8 g/week]) than females (1.3 g/week [95% CI= 0.99 – 2.0 g/week] and 2.8 g/week [95% CI= 2.1 – 4.6 g/week]), the difference was not statistically significant in either model.

Table 4-6 - *Population-Level Predicted Dietary EPA+DHA Exposure from Traditional Foods (g/week)*

	Long-Term Average Exposure Model			**Short-Term Maximum Exposure Model**		
	Whole Population (n=69)	**Females (n=39)**	**Males (n=30)**	**Whole Population (n=69)**	**Females (n=39)**	**Males (n=30)**
Mean	1.6	1.3	2.0	3.3	2.8	4.1
Standard Deviation	1.7	1.4	1.3	3.8	3.5	4.1
Minimum	0.0043	0.0043	0.030	0.010	0.010	0.15
Maximum	13	9.2	13	23	20	23

Estimated EPA+DHA intake was correlated with total combined intake of traditional foods in this study (Spearman rho=52%, $p<0.0001$). Table 4-7 shows the top five contributors to overall average dietary EPA+DHA exposure for the population, based on average EPA+DHA intake from each food. Additionally, the top sources of EPA+DHA are shown for participants who had the highest predicted dietary HCB intake. Participants with the highest HCB intake from

traditional foods (estimated HCB intake greater than 19 ng/kg body weight/week in the long-term average exposure model and 32 ng/kg body weight/week in the short-term maximum exposure model) also had predicted mean intake rates for EPA+DHA that were more than 75% higher than for the study group as a whole (2.8 g/week in the average intake model and 6.2 g/week in the maximum intake model), and these risks and benefits of traditional food consumption are discussed further in the sections below. There was no significant difference ($p>0.05$) in geometric mean plasma EPA+DHA levels between the whole participant group for this study (76 mg/L) and the high HCB intake group (88 mg/L).

Table 4-7 - *Top 10 Contributors to Average Predicted Dietary EPA+DHA Exposure*

Traditional Food	Percent Contribution			
	Long-Term Average Exposure Model		Short-Term Maximum Exposure Model	
	All Participants	Consumers > 75P HCB Intake[a]	All Participants	Consumers > 75P HCB Intake[b]
	n=69	n=17	n=69	n=17
Chinook Salmon Meat	44%	42%	45%	42%
Coho Salmon Meat	9.9%	9.8%	9.4%	12%
Chum Salmon Meat	8.9%	11%	9.8%	12%
Whitefish Meat	7.3%	5.6%	7.4%	5.0%
Whitefish eggs	6.2%	8.6%	6.3%	8.3%
Loche Liver	4.8%	3.0%	4.5%	2.0%
Muktuk	4.4%	3.4%	3.6%	2.8%
Grayling Meat	2.6%	2.6%	3.0%	3.6%
Inconnu Meat	2.1%	1.9%	1.9%	2.0%
White-winged Scoter Meat	2.1%	3.0%	2.5%	3.0%

a. Estimated HCB intake greater than 19 ng/kg body weight/week
b. Estimated HCB intake greater than 32 ng/kg body weight/week

A sensitivity analysis showed that the main contributors to the variance in total predicted dietary EPA+DHA exposure at the population level were the IRs of fish, with the primary contributors (average model, maximum model) including the IRs of chinook salmon (31, 30%), whitefish (16,

17%), chum salmon (8.4, 7.4%), and coho salmon (6.6, 5.8%). As with estimated HCB, the consumption frequency and the portion size contributed similarly (36-42% each) to variance in the intake of EPA+DHA from each traditional food. Other factors, including body weight and the concentration of EPA+DHA in the food, had smaller contributions (<10% each).

Log-transformed individual-level predictions were compared to log-transformed biomarker levels for all participants where available (n=49). The parameter estimates for each possible generalized linear model are shown in Table 4-8. Possible interaction effects between the three predictor variables were assessed, and none were significant (p>0.05).

Table 4-8 - *Model Selection for Predicting Plasma EPA+DHA Levels (n=48)*

Model ID	Predictor Variables	Long-Term Average Exposure Model				Short-Term Maximum Exposure Model			
		β	p	Type III SS[e]	r^2	β	p	Type III SS[e]	r^2
1	Log(Estimated EPA+DHA Intake)[a]	0.082*	0.042	0.067	0.33	0.081*	0.035	0.083	0.35
	Age[c]	0.0028**	0.017	0.090		0.0027*	0.024	0.085	
	Sex[d]	-0.13**	0.005	0.20		-0.13**	0.035	0.20	
2	Age[c]	0.0025*	0.030	0.077	0.26	-	-	-	-
	Sex[d]	-0.12**	0.0016	0.18		-	-	-	
3	Log(Estimated EPA+DHA Intake)[a]	0.073	0.077	0.053	0.24	0.077	0.080	0.075	0.26
	Sex[d]	-0.12**	0.001	0.19		-0.13**	0.001	0.19	
4	Sex[d]	-0.12**	0.0023	0.17	0.18	-	-	-	-
5	Log(Estimated EPA+DHA Intake)[a]	0.064	0.16	0.041	0.12	0.069	0.14	0.069	0.14
	Age[d]	0.0026*	0.043	0.082		0.0026*	0.038	0.0026	
6	Age[c]	0.0025	0.055	0.072	0.076	-	-	-	-
7	Log(Estimated EPA+DHA Intake)[a]	0.056	0.22	0.032	0.033	0.065	0.23	0.054	0.057

** p < 0.01, * p<0.05

- Same in both the long-term average and short-term maximum exposure models

a. Estimated EPA+DHA intake in g/week
b. Age in years
c. Sex, where male = 1 and female = 0

Estimated consumption of EPA+DHA from traditional foods was predictive of EPA+DHA levels in plasma, though only when adjusting for both age and sex. In the model including all three variables (Model 1), sex accounted for more than double the relative variance in the outcome plasma EPA+DHA levels when compared to predicted EPA+DHA intake from traditional foods and age, though all three variables were significant ($p<0.05$).

4.5 Discussion

Despite elevated HCB levels observed in some traditional foods, including caribou organs, estimated intake from these sources was below health-based guidance values. The primary sources of estimated HCB intake from traditional foods were fatty caribou organs, and the primary sources of estimates EPA+DHA intake from traditional foods were fish, including whitefish and Chinook salmon. All predicted HCB exposure levels from traditional food consumption in Old Crow were well below health-based intake thresholds, including the lowest thresholds of 0.16 – 0.17 μg HCB/kg body weight/day (1,100 – 1,200 ng HCB/kg body weight/week) for neoplastic and hepatic effects in both the average and maximum intake models (Table 4-3). However, these results may underestimate exposure, because total dietary intake of HCB includes both traditional food and market food sources. Previous studies in the Yukon indicate that traditional foods contributed approximately 19% of calories in Yukon Indigenous communities, including Old Crow (115). This is generally higher than in some other Northern communities, where a 2007-2008 study showed that traditional foods contributed 6.4 to 19.6% of total caloric intake for Inuit adults in Canada (247).

Estimated combined intake of HCB from traditional and market foods was below health-based guidance values for all participants. Irrespective of caloric intake, traditional foods have been shown to contribute important beneficial nutrients, including omega-3 fatty, proteins, vitamins,

and metal nutrients such as iron, zinc, copper, magnesium, phosphorus, and potassium (21, 53-56). A Total Diet Study conducted in Whitehorse reported an average HCB intake from market foods of 2.7 ng/ kg body weight/week (248). Based on this value, a diet consisting of 19% traditional foods and 81% market foods, the maximum estimated total HCB intake for community members was 192 ng/kg body weight/week. This maximum value remains well below the health-based thresholds for HCB. Additionally, the relatively small contribution of market foods to dietary HCB suggests that traditional foods may be a driving factor in the elevated HCB levels observed in Old Crow when compared to the general Canadian population.

Though estimated dietary intake of HCB was below the TDI for all participants, approximately 18% of participants had plasma HCB levels exceeding the biomonitoring equivalent of 25 µg/L (189). This result is consistent with the regression modeling shown in Table 4-5, which noted that the model including age, sex, and estimated HCB intake from traditional foods explained 0.39 of the variance in plasma HCB levels.

Some traditional foods, including primarily caribou organs, contributed most of the estimated dietary HCB for Old Crow community members. This was expected, as levels of HCB in Arctic and sub-Arctic traditional foods, including fatty tissue of some fish, birds, and land animals such as caribou, contain elevated levels of organochlorine pesticides, including HCB, in comparison to many market meats (219, 223, 249). Similarly, HCB levels in the caribou organs collected locally by Old Crow community members, were elevated with respect to market meats and within the range reported in other Northern regions (232).

This study found that estimated HCB intake from traditional foods was predictive of plasma HCB levels, however, the association was only significant when adjusting for age, which also accounted for more than six times the relative proportion of variance on the outcome than

estimated HCB intake (see Table 4-5). Despite the significance of estimated HCB intake on the outcome, the relatively low impact of the variable suggests that age is the primary predictor of HCB levels, and other variables could be excluded from the model. The association between age and HCB in plasma is supported by the literature, which shows that HCB, like other POPs, is persistent and poorly eliminated, and has a long half life (>6 years) in humans (250). The large effect of age has been observed in other populations when comparing dietary intake of HCB and other POPs to plasma levels of same compounds. For instance, in Greenland, dietary intake modeling showed that the relative contribution of age to the r^2 value predicting plasma levels of POPs was more than three times higher than the relative effect of dietary consumption of the foods high in the contaminants (251).

Though sex was included as a predictor of plasma HCB levels, it was not statistically significant in any model (Table 4-5). In several large-scale biomonitoring projects, sex-based differences in plasma HCB levels have been observed in individuals 60+, where higher plasma HCB levels were observed in females than males; however, no significant difference in younger adults was observed in these studies (74, 90). Though sex was not a significant predictor of plasma HCB levels in this study, the lack of association could be due to the small number of participants over 60 years old (under 5 participants of each sex), where differences might be expected to occur. Additionally, other factors that can significantly affect HCB levels in plasma, including lactation, childbirth, hormonal changes, and changes in body weight (252), were not included in this study. Plasma HCB levels have also been associated with cigarette smoking (221, 253). Though smoking data was available in the community, it was not associated with HCB levels when accounting for age and sex (Chapter 3).

Estimated EPA+DHA intake from traditional food was predictive of EPA+DHA levels in plasma. The generalized linear model including age, sex, and predicted EPA+DHA intake from traditional foods explains approximately 33% of the variation in plasma levels of EPA+DHA (Table 4-8). The results of this study suggest that sex, in particular, is an important driver of EPA+DHA concentrations in plasma (Table 4-8). The relationship between EPA+DHA levels and sex is well-documented, showing that plasma EPA+DHA levels are generally higher in females than males, after adjusting for EPA+DHA intake (254). This is consistent with this study, which found higher EPA+DHA levels in females, despite lower predicted EPA+DHA intake for females than males. Sex-related differences in EPA+DHA levels have been attributed to an increase in the synthesis and decrease in metabolism of DHA related to the presence of female hormones (255).

The positive association between plasma EPA+DHA levels and age observed in this study have been observed in other populations (254, 256). In some studies, age-related differences in EPA+DHA have been attributed to dietary differences with age (257, 258). This theory has not been consistently observed across the literature, including in this study, which found no relationship between dietary EPA+DHA exposure and age (259). These differences may be due to factors including cultural variability in diet between study populations. Another hypothesis is that the increase in EPA+DHA status with age may be due to changes in sex-related hormones with age, or potentially changes in body composition or insulin sensitivity (254). Other factors not included in this model that can significantly affect EPA+DHA levels in plasma include intake of dietary omega-3 supplements such as fish oil, alcohol intake, and changes in body fat content (254).

Health Canada recommends a minimum intake of approximately 2.1 to 3.2 g of EPA+DHA per week (two servings of fish) (242). Estimated dietary EPA+DHA intake levels from traditional foods were below this recommendation, on average, but within or above this recommendation at maximum intake levels. The difference between the average and maximum intake models suggests possible seasonal variation in terms of whether community members are meeting the recommendation for EPA+DHA intake with traditional foods alone. Notably, the difference between the average and maximum intake model was higher for predicted EPA+DHA intake (100% higher) than for predicted HCB intake (50% higher), suggesting consumption rates of foods contributing to predicted EPA+DHA intake (primarily fish) may have higher seasonal variability than consumption rates for foods contributing to predicted HCB intake (primarily land animal organs). In all cases, estimated intake of EPA+DHA from traditional foods were well below the suggested maximum of 5 g/day recommended by the American Food and Drug Association (FDA) (260).

Though all traditional meats are harvested seasonally in the region, a study conducted in Yukon First Nations communities, including Old Crow, showed that frequency of consumption of caribou, the primary contributor to HCB intake, increased by about 21% from winter to summer, while the consumption frequency of Chinook salmon, the primary contributor to EPA+DHA intake, increased by 64% in the same period (21). A higher seasonal variability of consumption of fish, such as salmon, was observed in this study, which showed that Chinook salmon contributed a higher relative proportion of HCB in the maximum intake model when compared to the average intake model. These results may be used to inform the timing of future studies, as well as potential messages to promote nutrient intake during periods when fish consumption is low.

Notably, some of the primary contributors to estimated dietary HCB intake from traditional foods, including Chinook salmon and muktuk, were also the highest contributors of healthy omega-3 fatty acids, including EPA and DHA, from traditional food sources (Tables 4-4 and 4-7). Participants with the highest HCB intake from traditional foods also had predicted mean intake rates for EPA+DHA that were more than 75% higher than for the study group as a whole, and estimated intake of both EPA+DHA and HCB correlated with overall traditional food intake. Most of the major contributors to predicted intake of both HCB and EPA+DHA from traditional foods, including freshwater fish, and both moose and caribou tissue, were eaten by the majority of community members.

Muktuk, however, was eaten by only 15% of participants and is the 6th highest contributor to predicted HCB intake and 7th highest contributor to predicted EPA+DHA intake (Tables 4-1, 4-4 and 4-6). Muktuk is a marine food, consisting of whale blubber and skin, that is not harvested near the community of Old Crow, but is brought in from coastal communities such as Inuvik. The type of muktuk consumed was not described as part of the FFQ, and therefore could include muktuk from beluga whales in the region. Muktuk had the highest assumed average concentrations of both HCB (35 ng/g) and EPA+DHA (2.2 g/100g) of any other traditional food included in this model (Supplemental Table 4-1). All Old Crow community members who ate muktuk ate it less than once per week, and therefore weekly consumption rates may overestimate average annual consumption. It is also not possible to create a sufficiently powered model consisting of the sub-group of participants who eat muktuk who also submitted plasma samples for HCB and EPA+DHA analysis (n=7), while adjusting for important toxicokinetic factors such as age and sex. Though levels of HCB in muktuk were high, no participants had HQs above 0.2

for HCB exposure, and this food remains a significant source for healthy omega-3 fatty acids such as EPA+DHA in the community.

4.6 Limitations

This study relied on assumptions related to both the consumption of, and concentration of contaminants and nutrients in, traditional foods. The level of variability and uncertainty of some of these assumptions, including contaminant and nutrient concentrations, portion size, consumption frequency, and the influence of cooking, were tested during modeling. Generally, the foods with the largest impact on estimated intake were the most commonly eaten foods in Old Crow. Foods with higher uncertainty regarding portion size, such as land animals other than moose or caribou, had a lower impact on model outcomes. All of the assumptions related to consumption were based on self-reported dietary surveys that are susceptible to overestimates or underestimates of the frequency of consumption and portion size of foods (261). The FFQ was administered at one time point, and therefore cannot accurately reflect a lifetime of dietary habits. This is particularly relevant for HCB, which is persistent in the body for years after exposure. The small sample size of the study does not allow for the inclusion of some potentially relevant predictor variables in modeling, such as smoking, or lactation history.

4.7 Conclusion

This study was initiated in response to Old Crow community concerns regarding elevated exposure levels of HCB, which can concentrate in some northern harvested traditional foods. In particular, large animal organs and other fatty tissue can accumulate high concentrations POPs such as HCB. However, traditional foods can also be significant sources of essential nutrients, including EPA+DHA, healthy omega-3 fatty acids. The results of this study indicate that though

consumption of traditional foods, including primarily fatty caribou organs, in Old Crow was associated with HCB levels in plasma, age was the primary predictor of these levels . However, dietary intake rates of HCB from traditional foods were well below health-based thresholds. Additionally, consumption of Old Crow traditional foods, including primarily salmon and whitefish, was predictive of EPA+DHA status in participants. When intake rates of these foods are at their highest, such as during the summer and fall fishing seasons, EPA+DHA intake from traditional foods sufficiently fulfills health recommendations for this nutrient. The results of this study support the message that traditional foods continue to be an important source of nutrients and other health benefits and that the health benefits of traditional foods generally outweigh contaminant risks.

5 Conclusion

5.1 Overview

The Arctic and sub-Arctic are regions that are particularly susceptible to contamination from both metals and organic contaminants in the environment, both through local point sources and long-range transport from industrialized areas (3). These contaminants can then reach water and local biota, including plants and animals, which can be important traditional foods for northern Indigenous Peoples. Though traditional foods can contain contaminants from the local environment, these foods are also important sources of healthy nutrients, and the harvesting and consumption of traditional foods provides other health and wellness benefits (21). In response to elevated levels of some contaminants, such as mercury and cadmium, observed in northern traditional foods, consumption notices have been created in some northern regions, including in Old Crow, Yukon Territory (53, 61, 62). These consumption notices were designed with the intention to reduce community exposure to specific contaminants flagged as elevated in certain foods or in the environment. However, prior to this thesis, the levels of human exposure to these contaminants, as well as other contaminants of interest in the Arctic, were largely unknown for community members in Old Crow, and in the Yukon more broadly. This thesis was designed to fill this significant knowledge gap and address community questions regarding contaminant exposure and traditional food safety by measuring levels of contaminants and nutrients in Old Crow community members and identifying possible local determinants of biomarker levels in the region, including traditional foods.

The community of Old Crow initiated the partnership with Dr. Brian Laird and Dr. Kelly Skinner's research groups the University of Waterloo in the interest of measuring contaminant exposure in community members, with a particular focus on the safety of local traditional foods.

This thesis summarized the results of the Old Crow Biomonitoring Project, and then addressed emerging follow-up questions from the community as results were analyzed. The initial biomonitoring project results, including analysis of levels of individual biomarkers in blood, hair, and urine, addressed community questions about levels of contaminants in Old Crow community members in comparison to both health-based guidance values (when available) and to reference populations in Canada (Chapter 2).

Four contaminants and nutrients of interest, including HCB in plasma, and lead, cobalt, and manganese in whole blood and urine, were elevated in Old Crow community members relative to the reference populations. Levels of these contaminants and nutrients were compared to demographic data collected during the Project, including age and sex, as well as responses to surveys asking about risk factors for exposure and traditional food consumption (Chapter 3). The results of these analyses in Old Crow were compared to and combined with results from two other Northern regions: the Dehcho and Sahtú regions of the NWT. In an effort to further identify possible local sources for elevated HCB exposure in Old Crow, a stochastic model was constructed to estimate dietary HCB exposure in the community (Chapter 4). The model used traditional food consumption data from the FFQ, as well as results of a traditional food sampling program combined with data from the literature to estimate dietary HCB intake. Additionally, the same model and traditional foods were used to estimate intake of EPA+DHA, healthy omega-3 fatty acids, in the study population.

5.2 Key Findings

The results of the Old Crow Biomonitoring Program included in this thesis, including levels of contaminant and nutrient biomarkers, and determinants of blood and urinary biomarker levels and estimate intake of key contaminants and nutrients, support the conclusion that the benefits of

traditional food consumption generally outweigh the risks of contaminant exposure for this population.

Chapter 2 of this thesis showed that levels of lead, cadmium, and mercury were below health-based guidance values for the majority (>95%) of Old Crow community participants and the majority of contaminants and nutrients measured in community members were within the range observed in the general Canadian population. However, levels of some contaminants, including lead in whole blood and urine, HCB in plasma, as well as some essential trace elements (that can have adverse health effects at elevated exposure levels), including cobalt and manganese in whole blood and urine, were elevated in Old Crow community members relative to both the general Canadian population and other First Nations communities in the provinces.

In Chapter 3, associations were observed between eating some traditional foods, including whitefish, and caribou and moose organs, and levels of some key contaminants and nutrients, including lead, cobalt, and manganese in urine and blood, and HCB in blood, in Old Crow. Participants who ate caribou kidneys in the previous year had 22% higher average blood manganese levels and 58% higher average blood lead levels than those who did not, and participants who ate whitefish in the previous year had 28% higher average blood cobalt levels than those who did not. Old Crow participants who reported drinking untreated river water (sometimes to often) had 29% higher average blood manganese levels and 120% higher average blood lead levels than those who do not. When data from Old Crow was pooled together with data from the two NWT regions, smokers had higher average levels of lead in blood (22% higher) and urine (51% higher) than non-smokers. Additionally, in the pooled population, significant associations were observed between eating some caribou and moose organs, including bones, fat, bone marrow, and kidneys, with higher average lead and HCB levels. However, no

significant associations between HCB levels and any dietary or lifestyle factors were observed in Old Crow.

Chapter 4 of this thesis showed that estimated intake of HCB from traditional foods was below select health-based guidance thresholds, and these traditional foods represent a significant source of healthy omega-3 fatty acids in the community. Some traditional foods, including mainly fatty caribou tissue, contributed the majority (>60%) of estimated dietary HCB intake for study participants in Old Crow. Even at the highest consumption levels, estimated HCB intake rates for all study participants were well below health-based thresholds for dietary consumption for all participants. However, these results did not explain the 18% of participants with plasma HCB levels exceeding the biomonitoring equivalent. The primary traditional foods contributing to more than 70% of dietary intake of healthy EPA+DHA were generally fish: primarily salmon and whitefish. Estimated intake rates of these healthy nutrients from traditional foods varied between meeting health recommendations during seasons of high fish consumption, to being below the health recommendations during periods of low fish consumption.

The results of this thesis continue to support local messaging in Old Crow, and regional messaging in the Yukon that traditional foods remain an important source of nutrients and other health and wellness benefits and that the benefits of harvesting and eating traditional foods generally outweigh contaminant risks.

5.3 Contribution to the Literature for Biomonitoring and Exposure

This thesis fills a significant data gap in terms of human biomonitoring results in the Yukon and the Western Arctic more broadly. Prior to this work, only one small human biomonitoring study, where levels of one contaminant were measured in hair, had been conducted in the Yukon Territory. This thesis includes results from the Yukon's first comprehensive biomonitoring

dataset, where results of multiple contaminants and nutrients were compared to other larger biomonitoring studies in Canada, including the FNBI and CHMS. The results in this thesis represent a portion of the overall findings from the Old Crow Biomonitoring Project and the biomonitoring work that was conducted in the NWT. Other studies that have used data from these projects have investigated, for example, levels of PFAS, dioxins, and furans in blood, and determinants of biomarker levels of these contaminants, as well as mercury and PCBs. The broader picture created by these biomonitoring projects allows communities, government agencies, and researchers to better understand the extent of exposure to contaminants and nutrients in Canada's North, as well as to use these results as baseline levels to understand temporal changes in the future.

This thesis is also the first to identify associations between contaminant and nutrient exposure levels through biomonitoring with the consumption of regional traditional foods in the Yukon. The work in Chapters 2 to 4 are the first to link contaminant and nutrient monitoring in local foods and human exposure in the region, which can be used to inform existing and future recommendations regarding traditional food consumption and other behaviours. Some of the links observed in Chapter 3, including, for example, the higher average lead levels in those who consumed certain land animal organs, or lower average lead levels in those who consumed whitefish, are insufficient evidence of a causative relationship. However, this information can be added to the small but growing body of research related to traditional food safety, as supported by human biomonitoring studies.

The traditional food sampling component of this thesis was the first to analyze some local traditional foods, including berries, and chum salmon, for organochlorine levels, and the most recent analysis of these parameters in the other foods in the Yukon by more than 20 years. The

largest study on HCB levels in Yukon traditional foods included analysis of HCB in land mammals, plants, and birds near Whitehorse, and was conducted prior to the Stockholm Convention, between 1998 and 2000 (30, 262). The results of the Whitehorse sampling program do not reflect current levels, and also may have not been applicable to more northern regions, including Old Crow, at the time of sampling in 1998 – 2000. More recently, HCB levels in Yukon birds were analyzed in the vicinity of Lake Laberge, however, the dataset was limited in size and scope, and did not include the most commonly eaten traditional foods in the region (263, 264).

At the national level, this thesis complements the work of the FNBI and CHMS to identify populations with elevated exposure levels to certain contaminants. The CHMS and FNBI do not conduct sampling in the northern territories, resulting in a significant data gap for a population that is particularly vulnerable to exposure for some contaminants. This thesis also included analytical results for some contaminants which are not included in national-scale biomonitoring projects in Canada. These included blood and urine levels of some metals, such as aluminum, barium, beryllium, gallium, lithium, strontium, blood levels of cesium and vanadium, and plasma levels of omega-3 fatty acids. The results of this work can be used to inform future decisions at the CHMS about the identification of, and prioritization of future contaminant and nutrient monitoring.

At the international level, this thesis adds to a growing body of research into human exposure to contaminants in the Arctic more broadly, including to the understanding of spatial trends in the region. The results of this thesis have been included in the upcoming Human Health Report from the Arctic Monitoring and Assessment Programme (AMAP), an international program dedicated to addressing contaminant burdens in the Arctic (17). Additionally, this thesis reports baseline

levels for the region which, along with future biomonitoring programs, can be used evaluate the effectiveness of international initiatives designed to reduce the load of contaminants in the Arctic, including the Stockholm Convention for POPs and the Minamata Convention for mercury (12, 13).

5.4 Implications for Public Health Practice

The following section discusses the implications of this thesis work for public health practice, including implications at the regional scale in the Yukon, extending into the NWT, and the implications for public health practice more broadly. This thesis was conducted in partnership with the VGG, who works closely with regional public health agencies in the Yukon. In addition to the ongoing collaboration with the VGG, the results of this thesis have been, and will continue to be, shared with the relevant regional public health agencies, including Yukon Health and Social Services and the Chief Medical Officer of Health in the Yukon, in the case of results reported in Chapters 2 to 4. The results of Chapter 3 have also been shared with community partners in the NWT, Northwest Territories Health and Social Services and the Chief Medical Officer of Health in the Northwest Territories. When results include recommendations, as is the case with individual results letters (Appendix D), or the general health recommendations included in the return of results for Chapter 3 (Appendix D), documents are reviewed by these agencies to ensure consistency with local and regional health recommendations and existing consumption notices. These regional agencies also use the results of this thesis to inform existing and future consumption notices and general health information regarding traditional foods and contaminant exposure.

5.4.1 Traditional Food Messaging and Consumption Notices

The results of this thesis are and will continue to be used to inform messaging related to traditional foods. Local and regional consumption notices have been released in Old Crow and the Yukon with the aim of reducing exposure to certain contaminants found in traditional foods, including mercury in some fish, and cadmium in some terrestrial animal organs (61, 62). The biomonitoring work described in Chapter 2 showed that levels of mercury and cadmium in Old Crow were not elevated relative to the general Canadian population or relative to health-based guidance values for the majority (>95%) of participants. This thesis does not evaluate the effectiveness of these existing consumption notices, as it does not include samples collected from prior to the implementation of these notices, or account for any other factors that might affect the levels of these contaminants. However, regional health authorities can use the results from Chapter 2 to justify a re-evaluation of existing consumption notices for mercury and cadmium using the up to date consumption data collected as part of this thesis (Chapter 4), along with regional environmental monitoring to estimate exposure and risk (265). Due to the generally low exposure levels of mercury and cadmium in the community, future environmental monitoring combined with the consumption data shown in Chapter 4 could be used to conduct an updated risk assessment for these contaminants, which may justify changes to or removals of these consumption notices if risk is determined to be low.

In addition to issuing consumption notices, both local and regional agencies develop other health messaging related to traditional food consumption. One of the primary project priorities for the community of Old Crow was understanding the safety and benefits of locally harvested traditional foods, which are important both culturally, and for subsistence and food security in the region (21). This thesis identified several linkages between concentrations of some

contaminants that were elevated in Old Crow, including lead, manganese, cobalt, and HCB, and consuming certain traditional foods. These results do not necessarily indicate causation, and require further monitoring work before recommendations can be conducted or population risk can be assessed. Some of these linkages are already under investigation as part of ongoing public health and environmental programs. For instance, consumption of some moose and caribou organs was associated with higher average levels of blood and urinary lead (Chapter 3). Ongoing monitoring of lead in the Porcupine caribou herd has found that levels have been generally stable since 2005 and were below health-based thresholds for lead in foods (121). Other observed associations, such as elevated cobalt levels in those who consumed whitefish, have not been assessed through monitoring and may be targeted in future public health investigations.

This thesis flagged some traditional foods, primarily fatty caribou tissue, as both high in levels of the contaminant HCB relative to market foods, and contributing to the majority of estimated dietary intake for HCB in the community (Chapter 4). Elevated levels of HCB observed in commonly eaten traditional foods, such as caribou, which was eaten by 94% of participants, may be reflected in the elevated plasma HCB levels observed in community members in Old Crow. The results of this detailed HCB work can be used in a public health context to inform existing messaging related to the safety of some of these commonly eaten traditional foods. For instance, current messaging in the Yukon regarding the consumption of caribou tissue focuses on these foods as an important source of protein and essential metal nutrients (266). This messaging is supported by the literature, which found that caribou meat was one of the top contributors to dietary protein, iron, and zinc in Yukon First Nations communities (21). Despite elevated levels of HCB in Old Crow community members, this thesis found that estimated HCB intake were well below health-based dietary thresholds (Chapter 4), which supports existing public health messaging emphasizing the benefits of caribou and other traditional foods in the community.

Some of the other results of this thesis can also be used to support existing public health messaging in the region emphasizing the benefits of traditional food consumption. Chapter 3 presents evidence of a possible link between the consumption of some traditional foods, such as berries and whitefish, and lower lead exposure levels. This evidence is insufficient for creating new public health recommendations, but can be added in support of existing health promotion materials emphasizing the benefits of these foods (266, 267). Some of these messages, including the health benefits of consuming caribou organs and fish, were included in the return of results process (Appendix D) after a review by regional health agencies for each region. Further, fish, including Chinook salmon in particular, were found to be the highest source of estimated dietary omega-3 fatty acids from traditional foods in Old Crow (Chapter 4). These results support existing communications regarding the benefits of fish consumption in the Yukon and more broadly (267, 268).

5.4.2 Health Promotion Materials for Lifestyle Risk Factors

In addition to traditional foods, relationships were described between levels of key contaminants and nutrients in participants with lifestyle risk factors, such as smoking, drinking untreated water, and using lead ammunition. These associations can be used in combination with other epidemiological, toxicological, and environmental studies to support existing public health recommendations in the regions. For instance, cigarette smoking is known to cause a variety of adverse health effects, and has therefore been the subject of public health promotion materials in both the Yukon and NWT (269, 270). Elevated levels of toxic heavy metals, including lead, have been observed in current and former smokers in several large-scale biomonitoring studies (207-209). The results of this thesis were consistent with this finding, showing that participants from the Yukon and NWT who smoked cigarettes had higher average lead exposure levels than non-

smokers (Chapter 3). The return of results process for Chapter 3 in Old Crow and the NWT included a recommendation for communities to reduce exposure to cigarette smoke (Appendix D) that was supported by regional health authorities.

Additionally, the results of this thesis showed that participants in Old Crow who drank untreated river water had higher average blood lead and manganese levels than those who did not (Chapter 3). These results can be added to the growing body of evidence in the region supporting messaging regarding drinking water sources. For instance, both the Yukon and NWT have issued recommendations that drinking water be obtained from treated or tested sources, due to the risk of pathogen and contaminant exposure (271, 272). This message was reiterated during the return of results process for Chapter 3, and the recommendations to communities regarding drinking water sources are shown in Appendix D.

Not all public health messaging in the region was supported by observed significant associations in this thesis. For instance, Old Crow participants who ate food hunted with lead ammunition did not have significantly different lead exposure levels from those who did not (Chapter 3). This lack of association was attributed to factors including food sharing and uncertainty with regards to ammunition type. The use of lead shot for hunting migratory game birds is prohibited in Canada, and regional health authorities in both the Yukon and NWT recommend against the use of lead ammunition for all hunting (273, 274). This messaging is supported by studies that the use of lead ammunition is a source of lead exposure for consumers of hunted foods (210). No change in public health messaging regarding the use of lead ammunition is recommended based on the results of this thesis.

5.4.3 Targeted Contaminant and Nutrient Studies

Though levels of most contaminants and nutrients in Old Crow were similar to the ranges reported in the general Canadian population, some substances, including lead, cobalt, manganese, and HCB, were elevated in the community. In the case of lead, a small number of participants (<5%) also had elevated levels relative to health-based guidance values. Understanding the level of exposure in the community allows public health officials to identify community members at risk of adverse health effects, both at the individual level, when health-based guidance values are available, and at the population level. Contaminant levels in people and traditional foods observed in this thesis can be used by public health practitioners to design or inform human health risk assessments for contaminant exposure in the region, as is outlined in federal best practices documents by Health Canada (275). These results can also inform targeted population or environmental monitoring, such as the metal monitoring currently being conducted for Yukon caribou, by identifying contaminants of interest in the region (121). Future monitoring programs may target contaminants identified as elevated in Old Crow in Chapter 2, such as HCB, lead, manganese, and cobalt.

In addition to the application of these results for risk assessment in the region, biomonitoring results, such as the ones included in this thesis, can be used to inform targeted studies looking at specific health effects associated with exposure. For example, previous research conducted in Nunavik looked at associations between three contaminants: mercury, lead and PCB, and behavioural outcomes in children (276). These contaminants were flagged for the further evaluation due to elevated exposure levels observed in this region relative to the general Canadian population (276). One example of this type of study that was conducted in Old Crow is the single other biomonitoring study, which looked at the relationship between mercury levels in

hair and gastrointestinal pathologies such as severe gastritis (107). The use of a combination of exposure and health data collected in partnership with communities prior to the development of intervention programs or public health policy is recommended by public health researchers when working with vulnerable communities in remote locations, such as the Arctic (277).

At the national and international level, the results of this thesis can inform the scope and parameters analyzed in future biomonitoring projects. For instance, this thesis includes some of the only non-occupational biomonitoring results for Canadian adults for several metals, including as aluminum and beryllium, that were not included in previous cycles of the CHMS or the single cycle of the FNBI (Section 5.3). Public health agencies, such as Health Canada, are continuing to update and create new toxicological guidance values, and these levels may inform the prioritization of selection for future target contaminants (87, 278). For instance, Health Canada has recently developed biomonitoring equivalents for aluminum (279). In conducting risk assessments for the general Canadian population, they may compare the results in Old Crow to these BEs to determine whether further biomonitoring is recommended in the North, and the country more broadly.In the case of expansion of the CHMS into the North or another large or small-scale biomonitoring project in the region, the contaminant exposure levels observed in Old Crow, as described in Chapter 2, can also be used as baseline levels to evaluate long-term trends.

5.4.4 Returning Results to Communities

This thesis was conducted in partnership with the community of Old Crow, and therefore involved the creation of public health materials as part of the return of results process. These documents provided the community with messaging related to contaminant risk, including advice for reducing contaminant exposure, as well as information about the benefits of traditional foods. The creation of these materials has implications for best practices in return of results for

biomonitoring in northern communities, as well as when linking contaminant risk with traditional food benefits. These documents are included in Appendix D.

The framework used for balancing risks and benefits for traditional foods is discussed in more detail in Section 1.4. One of the requests from community partners during the return of results process was to be mindful of the unquantifiable benefits of traditional foods, including mental health and wellness, as well as cultural benefits. Therefore, a qualitative assessment of risks and benefits was necessary. To minimize negative behavioural changes resulting from consumption notices and new dietary recommendations, the burden of proof for recommending reducing consumption of certain traditional foods was placed on contaminant risk, as described in Section 1.4. This was particularly challenging in Chapter 3, where no additional assessment of contaminant risk (i.e. in comparison to health-based guidance values) was conducted. In this case, the lack of new information regarding risk resulted in no change to existing public health messaging regarding traditional foods.

The collaborative nature of this thesis allowed for a reflexive return of results process based on informal feedback from partners. Though return of results documents initially (e.g. Chapter 2) focused on plain language reports, public-facing results documents for each subsequent chapter (e.g. Chapters 3 and 4) included more photographs, diagrams, and other visual components. Feedback from community partners was positive when results included fewer words and only one primary message. For instance, the written return of results documents for Chapter 2 included primarily a long and short plain language report. In Chapter 4, this increased to three posters and a single page plain language summary, with no long form plain language report. In all cases, messaging was consistent both with the results of the studies, as well as between all return of results documents.

5.5 Limitations

5.5.1 Cross-Sectional Study Design

This thesis employed a cross-sectional design. Biomarker samples and traditional food samples were collected at a single time point for each person and traditional food item and represent a period of exposure based on the biomarker used. Survey results generally requested information from the immediate time period or from the previous year. The limitations of this design are that analysis of determinants of biomarker levels (Chapter 3) describes association, which does not necessarily indicate causation, and that the thesis does not provide insight into temporal changes in contaminant and nutrient levels in the population. Exposure levels and sources are generally not constant over time, and contaminants and nutrients are metabolized and stored differently from each other, and differently in different bodies. Therefore, a single snapshot of levels and associations may require follow-up sampling, such as the collection of a second round of biological samples from participants to determine temporal trends, or environmental monitoring for contaminants of interest, to evaluate risk and identify major exposure sources. However, this thesis does include other evidence supporting possible causal relationships, including statistical analysis, the validation of modeling using biological sampling, the description of biological plausibility for observed associations, and comparisons with the academic literature to establish consistency.

5.5.2 Recruitment

When working in remote communities, such as Old Crow, recruitment is a challenge. In the case of data collection for this thesis, the research team was only able to be in the community for two weeks to both recruit participants and conduct the clinic. A short recruitment period may result in

a smaller sample size if researchers are unable to reach many community members. In the case of Old Crow, this phase of the Project was conducted during the winter, to maximize the number of community members in Old Crow at the time, as many people leave during the summer and fall for traditional food harvesting. However, cold winter temperatures and minimal sunlight results in challenges in meeting community members casually, as people were generally not lingering outdoors for long periods. One of the mitigation strategies for this limitation included working with a local coordinator to begin recruitment prior to the research team's arrival in the area. Hiring a local research assistant is a recommended component of community-based research with Indigenous communities (280). The recruitment process was conducted using methods agreed upon with the VGG to maximize inclusivity and access, including both random recruitment by phone and passive recruitment using a variety of methods described in Chapter 2. This combination of methods resulted in a non-random sample, as most community members were welcome to participate (see Chapter 2). Non-random sampling creates bias in the results, as the participants may not represent a typical cross-section of the target community.

5.5.3 Sample Size

One of the challenges when working in the North is the small population size of many of the communities. As noted by Odland et. al. (281), the small sample sizes in Arctic biomonitoring studies can limit the use of epidemiological methods, and these studies generally do not have sufficient sample size to identify statistical trends related to rare outcomes. In particular, the authors discuss the challenge of managing confounders when working with small data sets (281). This was a challenge in all three Chapters, particularly Chapters 3 and 4, where modeling could not include all suspected confounders. In general, caution was used so as not to overstate the generalizability of the conclusions of this work. By using confidence intervals for descriptive

statistics, and clearly noting the number of participants included in each analysis, the limitations of the data can be made clear to readers. Statistical methods appropriate for small sample sizes, such as the Fisher's exact test, were conducted where possible. In other cases, such as the modeling work conducted in Chapter 3, the number of predictor variables had to be limited to the highest priority factors (e.g. age and sex).

One of the mitigation methods for small sample size in remote work proposed by Odland et. al. (281) involved combining several studies to create a larger database of data for a region. This method was used in Chapter 3 by combining data from Old Crow with data from two regions in the Northwest Territories to create a larger dataset for some analyses. This dataset allowed for increasing the power of generalized linear models to identify significant independent variables with smaller effect sizes. It was important to use caution during the analysis and interpretation of the combined dataset, as the samples represent several different communities across a large geographical area, and with different cultures and traditional food practices. Stratification by location was also conducted, though resulted in fewer significant associations due to the decrease in sample size.

5.5.4 Interpreting Biomarker Levels

The results of this thesis included the concentrations of contaminants and nutrients in matrices including hair, blood, and urine. The interpretation of these biomarkers required an understanding of the pharmacokinetics of each parameter to determine whether the biomarker is reliable, and also an understanding of the exposure period that the biomarker represents. This background information is summarized in Appendix A. For each of the parameters of interest in Chapters 3 and 4, the reliability of each biomarker, as well as the potential exposure window, are noted. The exposure windows can vary significantly, with some parameters. For example, HCB

can remain in the blood for months to years (282), while most manganese circulates out of the blood into tissue within hours to days of exposure (283).

Biomarker interpretation is also complicated due to the lack of health-based guidance values for the majority of the substances measured in this thesis. Additionally, very little information is available regarding the mixing of contaminants and nutrients and the effects of mixing on possible health outcomes. As the field of toxicology advances, this type of information could become available, in which case the results of this thesis could be reinterpreted. In the meantime, the interpretation of biomarker levels is generally conducted by comparing results in a target population to other reference populations (as described in Chapters 1 and 2), which does not allow for assessment of individual health risk due to exposure.

5.5.5 Contaminant and Nutrient Levels in Traditional Foods

The construction of a stochastic model in Chapter 4 required several assumptions related to contaminant and nutrient concentrations in traditional foods. In an attempt to address uncertainty related to HCB concentrations, the traditional food sampling program was developed. However, this program only included some of the most commonly eaten traditional foods, and other concentrations assumptions were made based on the literature. When no regional traditional food studies were available, studies looking at other northern regions were used in place of studies local to Old Crow. Additionally, several assumptions were made regarding preparation methods and their effects on contaminant concentrations. Generally, the effect of these assumptions was evaluated as part of the sensitivity analysis conducted during modeling, where the foods with the highest impact on estimated intake were generally foods that were analyzed as part of the traditional food sampling program (e.g. caribou organs). However, there is uncertainty with regard to some of the other traditional foods that are less commonly eaten (e.g. birds) or where

sampling was not conducted (e.g. muktuk), which could be addressed in future monitoring programs if the foods are available.

5.5.6 Contaminant and Nutrient Bioaccessibility and Bioavailability

Total concentrations of contaminants and nutrients in foods were used when calculating input concentrations for the stochastic model. However, these values may not represent the concentrations that are solubilized and hence available for absorption in the body (bioaccessibility) and the concentrations that ultimately reach systemic circulation (bioavailability). Using total contaminant and nutrient concentrations results in an overestimation of exposure levels, which may therefore be conservative in the case of contaminants and liberal in the case of nutrients, when it comes to estimating risks and benefits. In the case of the HCB model described in Chapter 4, exposure levels were well below health-based thresholds, despite using the conservatively high assumed bioavailability of 1.0. In this case, knowing the bioavailability of HCB and omega-3 fatty acids in each food item would improve model accuracy, which would possibly increase the strength of association between modeled levels of contaminants and nutrients with the levels observed in participant biomarkers. Notably, there may also be changes in the bioaccessibility and bioavailability of HCB and omega-3 fatty acids depending on the preparation method of the foods (236, 284). Therefore, a model integrating bioavailability or bioaccessibility may require differentiation of the frequency of consumption and serving size for the different cooking methods.

5.5.7 Self-Reported Survey Data

Both the FFQ and the HMS were self-reported and are therefore susceptible to recall bias. This is relevant for the interpretation and analysis conducted as parts of Chapters 3 and 4.The use of

self-reported data is a particularly significant issue when working with nutritional surveys like the FFQ, potentially resulting in an overestimate or underestimate of the frequency of consumption of foods (261). An evaluation of the validity of FFQs noted that overestimates are more likely to occur than underestimates, however both are possible (127, 233). In Chapter 4, food intake rates are estimated based on the results of the FFQ, and those levels have been capped based on estimated intake of food categories (e.g. fish, land animal organs). The list of foods included was also limited based on consumption rates in the region. To limit overestimation of consumption, comparable studies have employed similar techniques including capping the maximum consumption rate, or limiting the foods included in the model to the ones consumed by a certain proportion of the population (285).

5.5.8 Gaps in Nutritional Survey Data

In addition to the limitations of using self-reported consumption data, there are some other data gaps for traditional food consumption affecting the analysis for Chapters 3 and 4. The FFQ was designed to collect the most information possible regarding traditional food consumption while also not overwhelming participants with details and survey length (127). For the sake of brevity and ease of use, some details were not included in the survey, and these details represent a limitation in the analysis for Chapters 3 and 4. For instance, the FFQ requests average weekly consumption data for each species, but seasonal data is requested only for large categories of foods (e.g. fish, land animals). Traditional food consumption in Yukon communities varies by month, seasons and also year as the availability and migration patterns of some species change (21). The lack of detailed seasonal data for individual species consumption is a source of uncertainty that may affect the interpretation of biomarker levels, where, as noted above, biomarker levels may represent a limited exposure window (286). Other examples where some

data is limited to large categories of traditional food rather than individual species, include typical portion sizes, and the waterbodies or herds from which the food was fished or hunted.

In Chapter 3, the data gaps described above limit the depth of analysis for some of independent variables included in the models. For example, the lack of seasonal data for each species may affect the associations between biomarker concentrations and consumption rates. These data gaps also represent a possible limitation in the construction of the model for Chapter 4. In addition to the gaps in data regarding traditional food consumption, the FFQ did not include any consumption data for market foods. These foods were not included in the probabilistic model, however, estimated intake of contaminants and nutrients from market foods based on the literature was included in the overall risk calculation.

5.5.9 Returning Results

The majority of this thesis, with the exception of Chapter 2, was conducted during the Covid-19 pandemic, when results could not be returned in person due to travel restrictions in the community. During the single in person return of results trip for Chapter 2, the research team had the opportunity to engage with individual community members to discuss the results and respond to questions. The results of Chapters 3 and 4 were returned virtually, or via a community partner. In these cases, any feedback from the community was relayed back to the research team by the community partner. During these virtual returns of results, it was not always possible to see that results were being effectively returned. For all three research chapters (Chapters 2, 3, and 4), no formal evaluation of the return of results process was conducted. Therefore, the level of community engagement with project results is not well understood.

5.6 Recommendations for Future Work

This thesis summarizes the results of an enormous dataset, and there are many future projects that can be found within. As always, future research projects must consider the priorities of the community and be designed in consultation with community partners. The recommendations in this section are part of ongoing discussions with community partners, which are continuing as part of and beyond the scope of this thesis .

Follow-up Biomonitoring: One of the broader justifications for this thesis was that it would summarize baseline biomarker levels for the community, so that long-term trends could be evaluated during a similar project conducted at a later date. A follow-up project could be conducted in the community after approximately 10-15 years, collecting the same sample types and analyzing for the same analytes, and possibly new and emerging contaminants, or contaminants that would provide more context for source identification (e.g. lead isotopes). Additionally, further biomonitoring is recommended in other Yukon communities, to complement the results of this study and establish the generalizability of the results. These would provide valuable information about contaminant exposure trends in the region.

One of the benefits of this type of work is that it would help to inform and evaluate some of the international programs designed to limit and monitor contaminant exposure in the North, including the Stockholm Convention to limit exposure to POPs, and the Minamata Convention to limit exposure to mercury. These results are presented in documents including AMAP reports, where temporal data trends are evaluated across multiple Arctic regions (287).

Analysis of Environmental Samples: This thesis included sampling of some traditional foods for organochlorine levels, including HCB. However, there are still some data gaps identified

either within this thesis or during consultations with the community as part of the return of results:

- **Metals in fish:** Consuming whitefish was identified as a possible determinant of blood and urinary cobalt in Old Crow (Chapter 3). Cobalt levels have been observed to be elevated in whitefish, in comparison to other freshwater fish, in other Arctic regions (199). Analysing cobalt levels in local fish would provide additional information about possible local exposure sources, as well as to estimate dietary intake for comparison to health-based guidance values for cobalt.
- **Tap water:** Drinking water in Old Crow is sourced from a local, treated well, which is then trucked to household water tanks for consumption. During visits to the community, community members brought up concerns regarding contaminant levels in their household tap water, particularly related to chlorine disinfection by-products, but also plastics leaching from domestic water tanks. A possible follow-up project would involve end-of-tap and treatment centre testing of household water in Old Crow for disinfection by-products and plasticizers to determine the level of change in water quality from well to consumption.

Analysis of Prepared Traditional Foods: This thesis included sampling of traditional foods in their raw form, submitted by harvesters prior to any preparation for consumption. However, most of the highest estimated contributors to HCB exposure, including lipid-rich caribou organs, fish, and birds are consumed cooked or smoked or prepared in some way (174). A more accurate estimate of exposure could be conducted if the study included traditional food samples that were prepared for consumption using common methods. This proposed study would involve either

community members submitting portions of their prepared foods, or research team members preparing foods in the lab, per community member instructions.

Analysis of Bio-Banked Samples: There are several analytes which could be of interest for analysis of the bio-banked samples. However, due to the limited number of, and volume of, bio-banked samples remaining, careful community consultation is recommended prior to selecting additional analyses. The prioritization of contaminants for future analysis will be conducted in consultation with the VGG and the community of Old Crow. There may be a focus on contaminants of interest from other northern regions, such as polycyclic aromatic hydrocarbons (PAHs) in urine, which were found at elevated levels with respect to the general Canadian population in the NWT, with possible determinants of blood and urinary biomarker levels including smoking status and eating cooked meats (104). Alternatively, emerging contaminants of concern could be targeted, where the contaminant was not included in Canada's national-scaled biomonitoring projects. For example, organotins, a type of anti-foulant for ships, has been identified as emerging contaminants of concern in the Arctic by AMAP, but limited biomonitoring has been conducted in the region (288).

Additional nutrients could also be added to analytical suite to bolster the risk and benefit analyses conducted as part of this project. For instance, though a full suite of metals, including iron, was analyzed in urine, blood analyses did not include iron levels. Iron is an essential metal nutrient, and many of the metals included in this thesis (e.g. lead, cobalt, manganese) can replace iron in some cellular processes (289-291). Blood iron (serum ferritin) would be a valuable biomarker to use to illustrate the benefits of some sources of exposure for metals, including the organs of terrestrial animals such as caribou, that are not also sources of omega-3 fatty acids (53). Iron levels could also inform some of the recommendations provided to community

members, as iron can have protective effects against some toxic metals, such as lead and cadmium (292).

In addition to the contaminants and nutrients listed above, bio-banked urine samples could be analyzed for levels of cotinine, a metabolite of nicotine, which would provide additional context about the smoking status of participants. As noted in Sections 3.4 and 4.5, smoking can impact contaminant exposure levels for several of the key contaminants identified in this report, including lead, and HCB. Smoking status was self-reported in the HMS, with questions asking whether participants had smoked in the previous two hours, the number of cigarettes smoked in the previous 24 hours, and the general smoking status of the participant (i.e. a smoker, an occasional smoker, a non-smoker, a former smoker). A systematic review of the literature found that self-reported smoking status generally underestimated the level of smoking observed in participant cotinine concentrations (293). However, results from a biomonitoring study in the NWT found that higher urinary cotinine levels were observed in those who reported smoking in the previous 24 hours than those who did not (294). To confirm the validity of this assumption in Old Crow, a more accurate understanding of smoking status through the cotinine biomarker in urine might provide additional context about contaminant levels observed in participants.

Food Sharing: One of the data gaps that was identified in Chapter 4 is the extent of food sharing from outside of the community. Some foods, such as muktuk, were eaten by approximately 15% of Old Crow community members in 2018-2019. Muktuk is not harvested locally in Old Crow, as it is a marine food. A study looking at the extent of food sharing and importing from other communities, including commonly shared foods, the source of these foods, and sharing frequency is recommended. Food sharing is also an important factor associated with food security in remote regions (295). A deeper understanding of food sharing patterns both outside of

and within the community, and factors affecting food sharing in the community, could provide additional context about contaminant exposure, as well as broader information about the determinants of food security in Arctic communities (296).

Harvesting Practices: The majority of participants in the biomonitoring study did not know what type of ammunition was used for the meat they consumed (Chapter 3). Another study is recommended to assess harvesting practices for traditional foods. In particular, factors such as the availability of lead ammunition in the community, hunter preferences, frequency of use, and type of ammunition used for each type of food. Additionally, this study could include a traditional food sampling component to analyze lead levels in harvested traditional foods. This study could provide additional information regarding the elevated lead levels observed in the community, particularly as they may relate to the use of lead ammunition.

Dietary Surveys: As noted in Sections 5.5.7 and 5.5.8, there are significant limitations to the use of an FFQ, particularly when it focuses only on traditional foods, for estimating contaminant and nutrient intake. The results of future FFQs could be validated against 24 hour recall surveys conducted in tandem, which has been shown to marginally improve precision in intake estimation (297). Including a 24 hour recall in future work would also allow for the inclusion of market foods in contaminant and nutrient intake estimates.

Untreated Water Survey: One of the lifestyle factors that was associated with higher average levels of some key biomarkers in Chapter 3 was drinking untreated water. This analysis was based on a single survey question asking how often participants drank untreated water in the previous year. However, the source of this water and the exact frequency of consumption were not defined. Untreated water, including from the nearby Porcupine River, has the potential to be a source for contaminants, including both lead and manganese (196). To determine the risk of

exposure from drinking untreated water, further study is needed both of the sources of water (i.e. snow, ice, river), as well as the frequency of consumption. This study could also include an environmental sampling component for the different sources of untreated water being consumed.

Returning Results: As noted in Section 5.4.4, the effectiveness of the return of results process for this thesis is generally unknown, due to both the inability to travel to the community to engage directly with the public during the Covid-19 pandemic, as well as the lack of evaluation of the return of results process. An evaluation could be conducted for the return of results process. This evaluation could include two primary components: 1) investigating whether participants and community members heard about and understood all of the results that have been returned, and 2) asking participants for feedback about the methods used to return results. In particular, it would be beneficial to show participants the different return of results documents and ask about preferences related to the use of diagrams vs. text, or whether they prefer to hear about results from a researcher visiting the community vs. from the community research partner. This process could also include an informal question and answer component about the results returned so far, allowing researchers to understand which points to clarify on return of results documents.

5.7 Summary

This thesis includes the results of a human biomonitoring study conducted in Old Crow, Yukon Territory, including the collection of biological samples, and the administration of dietary and lifestyle surveys to identify possible determinants of, and estimate risk from, exposure to key contaminants and nutrients. Levels of the majority of contaminants and nutrient measured in Old Crow participants were similar to those in the general Canadian population. However, some parameters, including cobalt, manganese, lead, and hexachlorobenzene, were elevated in Old

Crow relative to these comparison populations. This thesis identified possible determinants of biomarker levels for these contaminants and nutrients, including certain traditional foods, such as caribou organs and fish, and lifestyle factors, including smoking and drinking untreated water. A stochastic model showed that estimated intake of HCB from traditional foods was well below health-based thresholds for all participants, and that traditional foods are significant sources of healthy omega-3 fatty acids. Overall, the results of all three chapters, which build upon each other in detail, support existing public health messaging in the community that states that traditional foods remain an important source of nutrients, as well as providing other health and wellness benefits from both harvesting and consumption. Generally, the results of this thesis reinforce existing messaging that the benefits of consuming local traditional foods in Old Crow outweigh the risks of contaminant exposure.

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Appendices

Appendix A – Toxicology and Exposure Background for Key Contaminants and Nutrients

This thesis discusses a variety of contaminants and nutrients, however, there is a focus on four contaminants and nutrients based on results observed in Chapter 2. These contaminants and nutrients include manganese, cobalt, lead, and HCB. The following appendix provides some background context for these substances, including common exposure sources, nutritional importance, health effects from exposure, substance toxicokinetics, reliable biomarkers, and available guidance values for interpretation.

Manganese (Mn)

Manganese is a metal found naturally in the environment, mainly in the form of metal oxides, but also less commonly bound to anionic compounds such as carbonates and hydroxides (298). Uses for manganese include industrial processes such as metallurgical processing, battery production, glass manufacturing, and in fertilizer (298). The metal is also one of the primary anti-knocking agents used in engines in some countries, including Canada, after leaded gasoline was phased out in 1997 (299).

Manganese is an essential metal nutrient necessary for multiple biological mechanisms including blood clotting, and bone, brain, and tissue development. The metal is also a vital cofactor for enzymes involved in neurotransmission and metabolism (300). Though rare, manganese deficiency can result in a variety of health effects. The effects of significant and prolonged manganese deficiency can include impairment of growth and bone development, reproductive health effects including reduced fertility, neurological conditions such as epilepsy, and impaired metabolism of some proteins, carbohydrates, and lipids (300). Some of the first symptoms of manganese deficiency include muscle weakness, slow growth of hair and fingernails, and weight loss (301). To maintain sufficient manganese levels, Health Canada lists an Adequate Intake for

manganese of 2.0 mg/day for pregnant adults, 2.3 mg/day for adult males, and 1.8 mg/day for adult females (302). Generally, a typical manganese concentration in whole blood ranges from 4 to 15 μg/L, and this is considered adequate for biological functioning (289).

Manganese exposure occurs primarily through respiratory and oral pathways (303). Foods rich in manganese include nuts, cereals and grains, and legumes, and manganese concentrations can also be high in drinking water and teas (304). When ingested, only a fraction (<10%, generally) of manganese in food or other substances is bioavailable and is subsequently absorbed into the blood via active transport from the gastrointestinal tract (303). This fraction depends on the form of the manganese, including both its oxidation state and the compound to which it is bound (289). When inhaled, manganese can cross the nasal mucosa and/or the pulmonary epithelial lining for absorption into the blood stream (305). Once manganese is in the blood, the majority is removed by the liver, however a small fraction of absorbed manganese is transported throughout the body and its tissues by transferrin and other iron-transporting divalent metal transporters (306). The proportion of manganese that remains in the body after passing through the liver is dependent on the body's manganese and iron status, as well as the oxidation state of the manganese (306). The relationship between manganese and iron transporters has been used to explain the observed negative association between plasma manganese and iron levels, as they may be competing for bonding sites on transporters (303). This relationship has also been used to explain sex-specific differences in manganese biomarker levels, as average iron levels tend to be lower in females (303). Manganese is primarily excreted by the liver through bile, and ultimately in feces, where it combines with the unabsorbed manganese being released through the gastrointestinal tract (289).

Though only a small proportion of ingested or inhaled manganese enters systemic circulation, this fraction does have the potential to cross the blood-brain barrier into the brain. The mechanism for manganese crossing the blood-brain barrier is not fully understood, but studies have suggested it is possibly mediated by a mechanism involved in calcium uptake (305, 307). Some manganese is necessary in the brain for activation of essential neurotransmitting enzymes. However, excess manganese can accumulate in the brain and cause adverse health effects (307). Elevated exposure to manganese is called manganism, and this has been observed primarily in occupational settings (289). Health effects of manganism can include neurological disorders resulting in spasms and gross motor control issues, cognitive effects including decreases to memory and concentration, and mood effects such as irritability (289). Manganism has been compared to and occasionally misdiagnosed as Parkinson's Disease due to the similarity of symptoms, including tremors, falling backwards, and dystonia (308). Some effects of elevated manganese exposure are specific to the exposure pathway, including pneumonia and lung inflammation, or inflammation to the gastrointestinal tract (289). The modes of action for manganism include oxidative stress (the accumulation of reactive oxygen species), damage to DNA and mitochondrial dysfunction (307).

The establishment of one reliable biomarker of exposure for manganese is still being debated. An investigation into possible biomarkers of exposure for manganese found that hair and toenail manganese levels were associated with manganese exposure from drinking water, while saliva levels did not show an association (309). Similar results were found in a meta-analysis of studies related to manganese biomarkers in children, which determined that the hair manganese levels were more reliable for predicting cognitive outcomes than blood or tooth manganese levels (310). This study also found that a non-invasive method: analyzing manganese in drinking water, showed an association with children's cognitive outcomes (310). Blood manganese levels have

been used effectively at the population level to identify elevated exposure groups, particularly in occupational settings, but several studies have indicated that they are less reliable at the individual level than hair and bone (283, 311). Though often included in the full metal analytical suite, urinary manganese levels are currently not considered reliable biomarkers of exposure, as only a small fraction of the manganese that enters the body is excreted via urine (303).

Cobalt (Co)

Cobalt is a naturally occurring metal found primarily in iron and nickel-rich deposits, often associated with arsenic-bearing minerals (312). Industrial uses for cobalt include in pigment, metal alloys, catalysts, and magnets and the metal is also a common by-product of base metal mining, and can be found in elevated concentrations in mine wastes (312). Cobalt is an essential metal nutrient required for the formation of Vitamin B12 (cobalamin), which is required for biological processes including methionine synthesis, gene regulation, metabolism of fatty and amino acids, and in the maturation of red blood cells (313). Though somewhat rare, cobalt or vitamin B12 deficiency can lead to health effects, primarily to the thyroid, including goiter and reduced thyroid activity (312). Other possible symptoms of cobalt/vitamin B12 deficiency can include anemia, pancytopenia (reduced platelet and red and white blood cell formation) and neurological effects including depression, dementia, and memory impairment (314). To maintain sufficient vitamin B12 levels, Health Canada lists a Recommended Dietary Allowance (RDA) for vitamin B12 of 2.4 to 2.8 µg/day (315). There is no RDA for metallic cobalt independent of vitamin B12.

Like manganese, cobalt exposure in humans occurs primarily through diet. Foods naturally rich in cobalt include seeds, yeast products, coffee, grains, and animal livers (316, 317). Like manganese, the bioavailable fraction of cobalt in a food or other ingested substance, such as dust, soil, or in vitamins, depends on the form in which cobalt is bound, with the most bioavailable

forms being either bound within vitamin B12 or soluble in water or stomach acid (45). When ingested, cobalt is primarily absorbed in the small intestine, where it is transported into the blood by active transport with a divalent metal transporter (45). Similar to manganese, some hypothesize that cobalt and iron may compete for bonding sites during distribution, resulting in sex-related differences in cobalt biomarker levels (198). Though less common for the general public, people working in certain occupational settings, such as industrial metal processing, can be exposed to high levels of cobalt through inhalation. In these cases, cobalt can enter the blood stream through active or passive transport in the epithelial lining (290). Because cobalt is part of the essential vitamin B12, it is distributed throughout the body in most tissues, however, it can be found at higher levels in the liver, kidneys, blood, and heart (290). The level of cobalt absorption is negatively correlated with iron status, meaning cobalt absorption is higher in people with anemia (290). Excretion of unabsorbed cobalt occurs primarily in urine (290).

Though cobalt plays an essential role in bodily functions as part of vitamin B12, excess exposure may cause adverse health effects. To that end, cobalt is classified as a Group 2B carcinogen (possibly carcinogenic) by the International Agency for Research on Cancer (IARC) (318). Some of the health effects associated with cobalt exposure can vary depending on the exposure pathway. For instance, prolonged inhalation of cobalt-bearing dusts is associated with asthma or lung tissue inflammation and the most common symptom of excess dermal cobalt exposure is a rash at the contact site (169). When cobalt reaches the blood, elevated systemic exposure is associated with effects to the neurological, endocrine, and cardiovascular systems. Some of the symptoms of elevated systemic cobalt exposure can include jerking limbs, impaired memory, nausea, vomiting, weight loss, and impaired vision (169). The modes of action for cobalt toxicity include oxidative stress (the accumulation of reactive oxygen species), and mitochondrial dysfunction, and disruption of iron homeostasis in blood (307).

Both blood and urine are considered reliable biomarkers of recent cobalt exposure, and are the most commonly used biomarkers when assessing cobalt exposure in both occupational and non-occupational settings (290). Urinary cobalt is considered indicative of short-term high levels of exposure, with the peak occurring within approximately 3-5 hours of inhalation or ingestion, while blood cobalt levels are considered indicative of exposure within the previous several months (169). Though there is no health-based threshold for cobalt biomarkers, the American Conference of Governmental Industrial Hygienists (ACGIH) lists a biomonitoring equivalent index (BEI) for cobalt of 1 µg/L in whole blood and 15 µg/L in urine (169). Some researchers have recommended lowering these BEIs based on more up to date pharmacokinetic modeling (319). The BEI is similarly derived to the biomonitoring equivalent, but targeted at people who are occupationally exposed. These values are not recommended for use outside of occupational settings, but can be useful benchmarks when working with a highly exposed population.

Lead (Pb)

Lead is a heavy metal, which can be found naturally occurring in the Earth's crust, commonly in the form of lead sulfides, carbonates, and sulfates (320). Due to the metal's soft, malleable, and durable nature, it has been used for many industrial and household purposes, including, but not limited to: use as an anti-knocking agent in gasoline, as a paint additive, to construct potable water pipes, in batteries, and as a softening additive in plastic toys (320). Due to the toxic nature of lead, its use in many of these practices has been phased out in recent decades. In Canada, the use of lead pipes in new buildings was prohibited after 1986, and lead paint was no longer used in houses after 1978, though remained in limited use in Canada until 1991 (81, 321). Homes and other buildings constructed prior to these dates may still have lead-bearing paint or pipes. The phasing out of lead in gasoline began in 1990 in Canada, and currently more than 99% of all Canadian gasoline does not include lead as an additive (322).

Lead exposure pathways vary, depending on factors such as age or occupation. Similar to other heavy metals, the highest exposed groups are exposed through their occupation, including resource extraction, smelting, battery recycling, and other industrial metal processing (323). The most common pathway for non-occupational lead exposure is ingestion, followed by inhalation (81). In Canada, lead-contaminated water, caused by lead pipes and lead solder in pipe connectors, is one of the most significant sources of ingested lead (81). Other common sources of exposure for adults are through the ingestion of inhalation of lead-bearing materials such as lead paint in older homes or at construction sites, or in lead-bearing cosmetics (81). Babies, toddlers, and younger children are particularly vulnerable to lead exposure due to increased hand-to-mouth contact, and increased absorption of lead in the stomach (81, 323). In addition to ingestion via water, food, or soil/dust, certain lifestyles can be associated with increased lead exposure. For instance, biomonitoring studies have observed elevated lead levels in current and former smokers, as tobacco smoke contains lead (207-209).

Unlike cobalt and manganese, lead is not an essential element necessary for bodily functions, and therefore there is no recommended minimum intake level. After inhalation, lead can enter the blood stream through both active and passive transport in the respiratory tract, depending on particle size and composition (291). When lead is ingested, it is primarily absorbed in the duodenum, through the same transport pathway as calcium (291, 324). Once in the blood, lead binds primarily to red blood cells for distribution throughout the body (325). National biomonitoring projects have observed higher average urinary and blood lead levels in men than in women, with one hypothesis being sex-specific differences in blood erythrocyte volume resulting in additional lead-bonding sites in males (203, 204). In adults, the majority (>90%) of the body burden of lead is found in bones, however, it can also accumulate in soft tissue, including the liver and kidneys (324). The half life of lead in blood and soft tissue is

approximately 35 – 40 days, however that half life extends to 20 to 30 years when lead is bound within bones (325). Due to this long half-life, lead is bioaccumulative in bones, including teeth, and increases with age (325). Lead excretion is generally low, due to its propensity to bind to and remain in bones for long periods, however, when it occurs, it is primarily excreted in urine and feces (291, 325).

Similar to manganese and cobalt, lead can induce oxidative stress through the generation of reactive oxygen species (ROS) and the depletion of antioxidant reserves (326). This process can cause cell death, or hemoglobin peroxidation due to the inhibition of δ-Aminolevulinic Acid Dehydratase (ALAD) (326). Lead's propensity to share electrons like many essential cations (e.g. zinc, calcium, iron, magnesium) can result in the inhibition/inactivation of several enzymes, including ones that synthesize heme, an iron-bearing precursor to hemoglobin, which binds oxygen in blood (325). Lead can also interfere with cell processes that require these cations, including protein folding, ion transport, neurotransmission, and cell signalling (326). The heavy metal can readily cross the blood brain barrier by substituting for calcium ions (326).

Due to the propensity of lead to occupy the bonding sites of these elements, calcium and iron status can affect processes including gastrointestinal lead absorption, lead distribution in the body, including the rate of accumulation in organs, and lead excretion (81). These minerals are also used both prophylactically, to reduce the proportion of lead absorbed, distributed, and reacting with bodily functions (327). In some cases, these minerals have also been used as part of a course of treatment for lead poisoning (328, 329). Other nutrients, including vitamin C, vitamin E, and zinc, have been identified as possibly having a protective effect against the adverse health effects of lead following exposure (213, 214).

Inorganic lead is classified as Class 2A carcinogen ("probably carcinogenic") by the IARC (330). Symptoms of acute excess lead exposure in adults can abdominal, muscle, and head pain, vomiting, seizures, and coma (326). Acute lead poisoning is rare in Canada, due to modern restrictions on lead usage and exposure. These symptoms have been observed at blood lead levels exceeding 100 – 120 µg/L (325). Symptoms of chronic exposure to elevated lead levels include fatigue, nausea, delirium, anemia, and neurological issues including behavioural changes, memory loss, and, a decrease in IQ (326). Currently, Health Canada has issued a health-based threshold for lead in whole blood of 100 µg/L (for women 50 and older and men) and 50 µg/L (for children and women of child-bearing age) (81). However, there is no known safe threshold for lead exposure (181). Symptoms of lead exposure have been observed in children with blood lead levels as low as 1-2 µg/dL and several researchers have argued in favour of lowering the intervention level to 2 µg/dL (181, 331).

Whole blood is the most commonly used biomarker of exposure for lead, and is generally the target for testing and interventions for health-based outcomes (181). However, some experts have argued that plasma lead is a more reliable indicator of lead toxicity because it is the most exchangeable (332). Though lead in blood or plasma provides a snapshot of current mobile lead in the body, the accumulation of most lead in the body in bones leads to complications in determining the whole body burden of lead using blood (332). Bones provide a more accurate picture of long-term lead exposure, though are not generally feasible to collect for analysis (325). Understanding the whole body burden of lead is relevant, because lead in bones can be remobilized under certain conditions, including cancer or some cancer treatments, osteoporosis, hyperthyroidism, pregnancy, and breastfeeding (325). Similar to bones, teeth are considered a reliable biomarker of lead exposure, and are less complicated to collect than bones (332). Teeth can also provide temporal lead exposure data across years (332). Other commonly used reliable

biomarkers for lead include urine, breastmilk, and cord blood (332). Biomarkers that have been used in some cases to measure exposure, but are not yet considered reliable, include saliva, and fingernails (332).

Hexachlorobenzene (HCB)

HCB is a synthetic chemical that was previously used as fungicide to prevent disease in crops such as wheat, until it was banned globally under the 2001 Stockholm Convention on POPs (167, 226). Although HCB is no longer produced intentionally, it can form as a by-product of municipal or industrial waste combustion and other manufacturing processes (227). Like other POPs, though HCB is not highly mobile in water or soil, it is persistent in the environment and both bioaccumulates in humans and other species, and biomagnifies up food chains (167).

HCB is a contaminant, and is not an essential element or nutrient required for bodily functioning. Therefore, there is no recommended minimum level of HCB intake. Dietary exposure accounts for 90% of exposure to organochlorine pesticides, including HCB, in humans (217). Like many other POPs, HCB is a lipophilic contaminant, most likely to be found in fatty tissue, and both bioaccumulates and biomagnifies (217). Therefore, it is most likely to be found in lipid-rich tissues of long-lived biota. Due to the lipophilic nature of HCB, dietary exposure occurs primarily through the consumption of fatty animal tissue, however, the consumption of foods grown in contaminated soil, and contaminated water can both be sources of exposure to HCB (229). Though HCB inhalation can occur, it is a rare exposure pathway, due to a combination of factors including reduced occupational sources after the Stockholm Convention, and the low vapour pressure of HCB (333).

There is also a documented association between HCB biomarker levels and smoking status, which some have hypothesized suggests cigarettes may be a significant source of exposure due

to its use during tobacco farming prior to 2001 (221, 253). However, this theory is not supported by the observance of higher concentrations of other POPs, such as PCBs, in smokers, as they were not used for the same purposes (253). Some studies have posited a possible biological mechanism for the increase in POPs, such as HCB, in smokers, that is independent from direct exposure due to the presence of the target contaminant in cigarettes. Other theories include a decrease in HCB metabolism due to the inhibition of P-450 cytochrome CYP-3A by nicotine (334).

When ingested, HCB is primarily absorbed in the gastrointestinal system within the intestinal tract, after which it is rapidly distributed throughout the body (229). The bioavailability of HCB depends on the matrix in which it is ingested, with fattier foods (such as oils) having a higher proportion of bioavailable HCB (229). HCB distribution has been theorized to occur via both blood, and more commonly, the lymphatic system. This theory has been supported by higher observed lipid-adjusted HCB levels in some fatty tissues, such as bone marrow, than in the liver, which may indicate a fraction of distributed HCB does not occur in blood (333). Due to its lipophilic nature, HCB accumulates readily in fatty tissues, including adipose tissue, bone marrow, and skin, with lower concentrations accumulating in the liver, kidneys, lungs, and blood (333). Hexachlorobenzene is primarily metabolized by reductive dichlorination from cytochrome P-450s, with metabolites including pentachlorophenol, pentachlorobenzene, and tetrachlorobenzene (333). Excretion of HCB occurs in feces (primarily in its parent form of HCB), with a lesser extent excreted in urine (primarily in the form of its metabolites) (333). Excretion and metabolism of HCB are slow, resulting in a half-life of approximately 6 years in adults. This long half-life contributes to the increase in HCB concentrations observed as age increases in humans (333). However, other factors can contribute to significant changes in the body burden of HCB in humans over time, including changes in body weight, age-related

hormonal changes, and lactation (335). The sample size of this study is too small to include these variables in any statistical or predictive modeling.

Similar to lead, hexachlorobenzene exposure can induce oxidative stress, resulting in effects including DNA damage and changes in cell layer and barrier integrity (336). Additionally, HCB can induce porphyria, which is the build-up of porphyrins due to the inhibition of heme synthesis (336). Elevated exposure to HCB has been associated with acute toxic effects, including weakness, paralysis, and convulsions (229). Long-term exposure to HCB has been associated with adverse health effects, including damage to the liver and kidneys, decrease immune system activity, and effects on thyroid function (167, 229). The IARC classifies HCB has a group 2B carcinogen (possibly carcinogenic to humans) (337).

The most commonly used biomarker of exposures for HCB are in blood, including plasma, serum, and whole blood, which are considered reliable for these purposes (333). Other possible biomarkers of exposure include feces, cord blood, and fatty tissue such as liver, fat, and bone marrow (333). However, these methods are not commonly used in large-scale biomonitoring projects due to the complicated and intensive collection processes. Urinary HCB is not considered a reliable biomarker of exposure, as the HCB in urine is primarily in the form of its metabolites (333). These metabolites can also be used to estimate HCB exposure. There is no health-based threshold for HCB biomarkers, however, 95th percentile population reference values between 23 and 32 µg/kg lipids in plasma have been observed in the Canadian population (85). Biomonitoring equivalents ranging from 16 to 250 ng/g lipids HCB in plasma have also been proposed based on carcinogenicity (189).

Appendix B – Recruitment and Consent Forms for the Biomonitoring Clinic

INFORMATION LETTER FOR PARTICIPANT (18+)

Dear Vuntut Gwitchin community member,

Would you like to take part in a study looking at contaminant levels in people? Mary Gamberg, a scientist from Whitehorse and Brian Laird, a researcher from the University of Waterloo in Ontario were in the community last year to learn what traditional foods people eat and what people have heard about traditional food and their health.

For the next phase of the project, our research team is going to look at the levels of contaminants (like mercury) in the people of Old Crow. We will be collecting samples from people this fall, testing samples in winter 2019, and the results will be returned to the community and the people who took part by the end of 2019.

How does this study benefit your community?
This study will benefit your community by helping to answer questions about

- What level of contaminants are in the people of Old Crow
- How does food effect people's contaminant levels
- What are the benefits and risks of people's food choices

What is the purpose of this study?

- To learn what traditional foods people eat in Old Crow
- To see what level of contaminants and nutrients are in the people of Old Crow
- To find out ways to help people eat more traditional foods that are healthy for them, and make sure that people are not being exposed to high levels of contaminants through these foods

What will be involved if you agree to do this study?
There are five parts to this study. If you would like to be involved in this study, you can choose to do whichever parts you want. This study will take no more than 2 hours.

Part 1: Food Survey (25 minutes)

A researcher will help you answer survey questions on an iPad™. This survey will ask you what traditional foods you ate over the past year.

Part 2: Health Message Survey (20 minutes)

A researcher will help you answer survey questions on an iPad in a private room. This survey will ask you about some lifestyle factors, for example: have you had a metal tooth filling?

Part 3: Hair Sample (20 minutes)

A researcher will take a five millimeter wide sample of full length hair using disinfected scissors from the back of your head.

Part 4: Urine Sample (20 minutes)

A researcher will ask you to urinate in a small container.

Part 5: Blood Sample (20 minutes)

A medical laboratory assistant will take blood sample in four tubes (each about the amount of a tablespoon) from a vein on the inside of the elbow. The blood sample will only be taken by a medical laboratory assistant. This will be similar to when your doctor or nurse asks you to give a blood sample at a routine check up. You can ask questions at any time during the blood sample, or ask to stop at any time.

If you decide to do some or all of the parts of the study, we will ask if you would have your height and weight measured so that we can better understand your results. A research team member will be in the community for an additional week following the clinic. If you would like to complete the surveys during this time, please let one of the researchers know.

Are there any risks if you do the study?

- There are no expected risks from doing the surveys or a urine sample.
- There are minimal possible risks from the hair sample (e.g. cut from scissors).
- There are potential low risks for doing a blood sample. There is a potential to experience bruising or discomfort from the site of needle insertion. The blood withdrawal might cause low blood pressure, dizziness or fainting.

Will you receive any benefits for doing the study?

You may not directly benefit from the research project. However, to show appreciation for your time, you will receive a $25 gift card to either the Co-op Store or Air North. You can also enter into a raffle for two $250 gift cards of either the Co-op Store or Air North. Your name will enter the raffle for each part of the study you do. So, if you do all five parts of the study (two surveys, blood, hair and urine samples) you will get five tickets for the raffle. Raffle tickets will still be given to you if your surveys are completed in the week after the clinic with the researcher who will remain in the community during that time. All gift card amounts received are taxable. This amount can be reported for income tax purposes.

Will you get feedback from us about the samples you give?

Yes, if you give a hair, urine and/or blood sample, you will get a confidential letter explaining your contaminant levels. This letter will compare your contaminant levels to levels seen in other Canadian populations, with the average levels in the people of Old Crow, and with the recommended limits for some contaminants.

Hair, urine and blood samples are currently being tested for mercury. Urine and blood are being tested for several metals (e.g. arsenic, cadmium, lead, selenium, uranium, etc.). Blood plasma is being tested for fatty acids (e.g. omega-3) and organic pollutants (e.g. PCBs, pesticides, etc.). Finally, serum will be tested for vitamins.

What if my levels are high?
If your levels are higher than the recommended limits, your results letter will explain what the levels mean and what you can do to lower them. The research team will come back to the community a year after the first samples were collected to follow up with people who had contaminant levels that were either 1) much higher than normal, or 2) above the Health Canada guidelines for mercury, lead or cadmium. People with one or more high contaminant levels will be invited to give more samples to be measured.

If your levels are high enough to be an immediate health risk, our research team will contact you by phone immediately (within 6 months of when we collected samples). Our research team will work with the Yukon Government Department of Health to make sure that you are referred to a doctor for follow up and medical advice as soon as possible.

How will my information be kept private?
If you did surveys about traditional food and health messages in the winter of 2018 with our research team, we will match your survey answers from then to your survey answers in this part of the project.

Since all parts of this study will be done in the community center, your involvement will not be completely private. However, the researchers will keep your answers and samples confidential. Once you answer questions to the surveys on the iPad, your answers will be sent to a secure online server in Canada. An ID number will be used on your answers and samples instead of your name to protect your privacy. All information from this study will be kept at the University of Waterloo on a password-protected computer in a locked room. Answers from surveys will also be kept with VGG Natural Resources on a password-protected computer in a locked room. If you agree to do the study, your answers will be kept for at least 10 years.

Hair, urine and blood samples will be brought to the University of Montreal, the University of Western Ontario, the University of Waterloo, and the National Institute of Public Health (INSPQ) in Quebec to have contaminants and nutrients measured. Any samples (hair, urine, blood) you give will be stored and kept by the researchers. They will be kept at the University of Waterloo in a locked, secure laboratory for up to ten (10) years. We can't profit from selling your samples, and they cannot be sold. No genetic testing will be done on any of the samples.

Where will the findings from this study be reported?
No research performed under this project, no research products, and no traditional or indigenous knowledge will be used for commercial purposes.
A results report will be returned to the community within a year after the sampling. After the results have been returned to the community, de-identified results may be presented in theses, papers, and presentations at national and international meetings.

Biobank
You will also have the option to allow your hair, urine and blood samples to be kept in a biobank at the University of Waterloo. Your samples would be stored in a freezer (blood and urine) and a locked cabinet (hair) in a locked room at the University of Waterloo for up to ten years. If you decide to have your samples kept in a biobank, we will measure your samples for other contaminants or nutrients if we get the funding to do so. If we measure your samples for other contaminants or nutrients, then we will send you a results letter about your levels by email or mail when they are available. If you decide you do not want your samples to be held in the biobank, then your samples will be discarded after they are measured by the researchers.

Can I change my mind after I agree to let my sample(s) or survey answers be used?
Yes, at any point during the study you can change your mind if you do not want your samples or survey answers used. You can withdraw from the study by contacting Brian Laird by phone or email. If you withdraw from the study your survey answers will be erased and your samples will be discarded. You can contact us within ten years from when we collected your samples and you can ask to have your samples discarded and/or survey answers erased. If you decide to withdraw from the study after this time, the key that links your name to your survey answers will be destroyed, and we may not be able to remove your answers because we will not know which ones are yours. If you change your mind you will still receive the gift card for your time.

Still have questions about the study?
This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#23192). If you have any questions for the Committee contact the Office of Research Ethics at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca. This study has been approved by the VGG and will operate under the VGG Research Agreement.

Contact Information:
Feel free to contact Brian Laird for more information at any time during the study.

Yours sincerely,

Brian Laird, PhD
School of Public Health and Health Systems
University of Waterloo

Mary Gamberg
Gamberg Consulting

Co-investigators:
William Josie (Vuntut Gwitchin Government)
Megan Williams (Vuntut Gwitchin Government)
Kelly Skinner, PhD (University of Waterloo)
Mylene Ratelle, PhD (University of Waterloo)
Chris Furgal, PhD (Trent University)
Amanda Boyd, PhD (University of Washington)

ID:_____

PARTICIPANT CONSENT FORM (18+)

By agreeing to do this study, you are not giving up your legal rights or releasing the researchers or involved institutions from their legal and professional responsibilities. This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#23192). If you have any questions or ethics concerns, you may contact the Office of Research Ethics, at the contact information on the information letter. This study has also been approved by the VGG and will operate under the VGG Research Agreement.

By agreeing to participate, you are agreeing to the following:

- *You have read and received a copy of the information letter*
- *You had a chance to ask questions and discuss the study*
- *You understand your involvement in the research study*
- *The privacy of your answers and information has been explained to you*
- *You understand who will have access to your answers and samples*
- *You agree to get your results at the end of the project*
- *You are aware of the possible risks with blood sampling*
- *You are aware you can refuse to answer any question*
- *You are aware you can withdraw at any time during the study, by contacting Brian Laird*
- *You are aware that you will receive a $25 gift card for your involvement*

You can now agree to do some or all parts of the study. Please indicate yes or no:

- I agree to take part in this study……Yes No
- I agree to have my height and weight measured for the study……..……..Yes No
- I agree to give a hair sample and have it tested…….…...…Yes No
- I agree to give a urine sample and have it tested……..……Yes No
- I agree to give a blood sample and have it tested……Yes No
- I agree to complete the food survey……..……..….Yes No
- I agree to complete the health messages survey……...……..…..Yes No
- I agree to let my hair, urine and blood samples be stored in a biobank for up to 10 years for the testing of other contaminants and nutrients…….....Yes No
- I would like to be entered into a raffle for two $250 gift cards for each part of the study I do ……...Yes No
- I agree that the researchers can contact me with my results by email if they cannot contact me in person ……..……...Yes No
- I agree that the researchers can contact me in the future to inform me about or invite me to similar studies in the future ……....…….…..…..Yes No

Name (Please Print): _____

(Page to be detached and be kept at University of Waterloo)

INFORMATION LETTER FOR A YOUNG PARTICIPANT (4 to 12 years old)

Dear Vuntut Gwitchin community member,

Are you the guardian or the parent of a child who would like to take part in a study looking at contaminant levels in people? Mary Gamberg, a scientist from Whitehorse and Brian Laird, a researcher from the University of Waterloo in Ontario were in the community last year to learn what traditional foods people eat and what they heard about traditional foods and their health.

For the next phase of the project, our research team is going to look at the levels of contaminants (like mercury) in the people of Old Crow. We will be collecting samples from people this fall, the testing samples in winter 2019, and the results will be returned to the community and the people who took part by the end of 2019.

How does this study benefit your community?
This study benefits your community by helping to answer questions about:

- What levels of contaminants are in the people of Old Crow
- How does food effect people's contaminant levels
- What are the benefits and risks of people's food choices

What is the purpose of this study?

- To learn what traditional foods people eat in Old Crow
- To see what level of contaminants and nutrients are in the people of Old Crow
- To find out ways to help people eat more traditional foods that are healthy for them, and make sure that people are not being exposed to high levels of contaminants through these foods

What will be involved if I agree to let my child do this study?
There are five parts to the study. If you agree to have your child involved, you can choose which parts you would like your child to do. This study will take no more than 2 hours in total.

Part 1: Food Survey (25 minutes)

You (the child's parent or guardian) will help the child answer survey questions on an iPad™. This survey will ask your child what traditional foods they ate over the past year.

Part 2: Health Messages Survey (20 minutes)

You (the child's parent or guardian) will help the child answer survey questions on an iPad. This survey will ask your child about some lifestyle factors, for example: have they had a metal tooth filling?)

Part 3: Hair Sample (20 minutes)

A researcher will take a five millimeter wide sample of full length hair using disinfected scissors from the back of your child's head.

Part 4: Urine Sampling (20 minutes)

A researcher will ask your child to urinate in a small container. He/she doesn't have to fully fill the container.

Part 5: Blood Sample (20 minutes)

A medical laboratory assistant will take blood sample in four tubes (each about the size of a tablespoon) from a vein on the inside of the elbow. The blood sample will only be taken by a medical laboratory assistant. This will be similar to when your doctor or nurse asks you to give a blood sample at a routine check up. You or your child can ask questions at any time during the blood sample, or ask to stop at any time.

If you decide to allow your child to do the study, we will also ask if you will allow your child to have their height and weight measured so that we can better understand your results. A research team member will be in the community for an additional week following the clinic. If you and your child would like to complete the surveys during this time, please let one of the researchers know. Raffle tickets will still be given for completing the two surveys during this time.

Are there any risks if your child does the study?

- There are no expected risks from the food survey, the health messages survey or the urine sample.
- There are minimal possible risks from the hair sample (e.g. cut from scissors).
- There are potential low risks from blood sample. There is a potential to experience bruising or discomfort from the site of needle insertion. The blood withdrawal might cause low blood pressure, dizziness or fainting.

Will your child receive any benefits for doing the study?

Your child may not directly benefit from this research. However, for your child's time, he/she will receive a $25 gift card for the Co-op Store or Air North. The child can also enter his/her name into a draw for two $250 gift cards from Co-op Store or Air North. Your child will receive a single raffle entry for each part of the study that they do. For example, if your child does all five parts of the study (food survey, lifestyle survey, blood, hair and urine samples) they will get five tickets for the raffle. Raffle tickets will still be given to your child if the surveys are completed in the week after the clinic with the researcher who will remain in the community during that time. All gift card amounts received are taxable. It is your responsibility to report this amount in the child's income tax.

Will you get feedback from us about the samples that your child gives?

Yes, if your child gives a hair, urine and/or blood sample, you will receive a confidential results letter explaining his/her contaminant levels. This letter will compare their contaminant levels to levels seen in other Canadian populations, with the average levels in the people of Old Crow, and with the recommended limits for some contaminants.

Hair, urine and blood samples are currently being tested for mercury. Urine and blood are being tested for several metals (e.g. arsenic, cadmium, lead, selenium, uranium, etc.). Finally, blood plasma is being tested for fatty acids (e.g. omega-3) and organic pollutants (e.g. PCBs, pesticides, etc.). Finally, serum will be tested for vitamins and other nutrients.

What if my child's contaminant levels are high?

If your child's contaminant levels are above the recommended limits, the letter will explain what the results mean and what you can do to lower them. The research team will come back to the community a year after the first samples were collected to follow-up with people that had contaminant levels that were either: i) much higher than normal; or ii) above the Health Canada guidelines for mercury, lead, and cadmium. People with one or more high contaminant levels will be invited to give more samples to be tested.

If the level is high enough to be an immediate health risk for your child, you would be contacted by phone as soon as possible (within 6 months of when we collected samples). If their levels are this high, our research team will work with the Yukon Government Department of Health to make sure that your child is referred to a doctor for follow up and medical advice as soon as possible.

How will my child's answers and samples be kept private?

Since all parts of this study will be done in the community center, your child's involvement will not be completely private. However, the researchers will keep your child's answers and samples confidential. Once your child has answered questions to the surveys on the iPad, their answers are sent to a secure online server in Canada. An ID number will be used on your child's survey answers instead of their name to protect their privacy. All information from this study will be kept at the University of Waterloo on a password-protected computer in a locked room. Answers from surveys will also be kept with VGG Natural Resources on a password-protected computer in a locked room. If you agree to have your child do the study, your answers will be kept for at least 10 years.

Hair, urine, and blood samples will be brought to the University of Montreal, the University of Western Ontario, the University of Waterloo, and the National Institute of Public Health (INSPQ) in Quebec to have contaminants and nutrients measured. Any samples (hair, urine, blood) your child gives will be stored and kept by the researchers. They will be kept at the University of Waterloo in a locked, secure laboratory for up to ten (10) years. We can't profit from selling your child's samples, and they cannot be sold. No genetic testing will be done on any of the samples.

Where will the findings from this study be reported?

The samples will be used for research. No research performed under this project, no research products, and no traditional or Indigenous knowledge will be used for commercial purposes.

A results report will be returned to the community within a year after the sampling. After the results have been returned to the community, de-identified results may be presented in theses, papers, and presentations at national and international meetings.

Biobanking
You will also have the option to allow your child's hair, urine and blood samples to be kept in a biobank at the University of Waterloo. Your child's samples would be stored in a freezer (blood and urine) and a locked cabinet (hair) in a locked room at the University of Waterloo for up to ten years. If you decide to have your child's samples kept in a biobank, we will measure their samples for other contaminants or nutrients if we get the funding to do so. If we measure their samples for other contaminants or nutrients, then we will send you a results letter about their levels by email or mail when they are available. If you decide you do not want your child's samples to be held in the biobank, then their samples will be discarded after they are measured by the researchers.

Can I change my mind after agreeing to let my child's samples or answers be used?
Yes, at any point during the study you can change your mind if you do not want your child's samples or survey answers used. You can withdraw your child from the study by contacting Brian Laird by phone or email. If you withdraw from the study your survey answers will be erased and your samples will be discarded. You can contact us within ten years from when we collected your samples and you can ask to have your samples discarded and/or survey answers erased. If you decide to withdraw from the study after this time, the key that links your name to your survey answers will be destroyed, and we may not be able to remove your answers because we will not know which ones are yours. If you change your mind your child will still receive the gift card for their time.

Still have questions about the study?

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#23192). If I have any questions for the Committee contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca. This study has been approved by the VGG and will operate under the VGG Research Agreement.

Contact Information:
Feel free to contact Brian Laird for more information at any time during the study.
Yours sincerely,

Brian Laird, PhD School of Public Health and Health Systems University of Waterloo	Mary Gamberg Gamberg Consulting 708 Jarvis St. Whitehorse, Yukon

Co-investigators:
William Josie (Vuntut Gwitchin Government)
Megan Williams (Vuntut Gwitchin Government)
Kelly Skinner, PhD (University of Waterloo)
Mylène Ratelle, PhD (University of Waterloo)
Chris Furgal, PhD (Trent University)
Amanda Boyd, PhD (University of Washington)

CONSENT SCRIPT FOR YOUNG PARTICIPANTS

The following script will be read by a local research coordinator to the young participants who are 4 years old to 12 years old. This will require the child to give a verbal assent. The parent will also be required to give verbal consent on behalf of the child in order for the child to participate.

Your parent said I could talk to you about a project we are doing. The goal of our project is to learn more about traditional foods like caribou, fish, and berries. We know that traditional foods are known to be good for your health, but, they can have chemicals that might be risky. I am going to spend a few minutes telling you about our project, and then I am going to ask you if you want to do it.

(Who are we?)

I, _____, work with Mary Gamberg, Brian Laird, _____ and _____, who are scientists from Whitehorse and the University of Waterloo.

(Why are we meeting with you?)
Mary and Brian are coming to learn about what chemicals are in people.

(What will happen if you are in the project?)
If you want to do the project, there are four parts you can do, and it is your choice which parts you want to do. Here is what parts of the study you can do if you want:

> ***If parents agreed to surveys:*** With your parents help, you will be asked to answer questions about the foods you eat. An example of the questions is: this past year, did you eat any moose? You might not remember and this is why your parent will help you to remember.
>
> ***If parents agreed to hair sampling:*** If you agree to let us cut some of your hair, a research team member would cut a small piece. We will cut the hair where you cannot see it.
>
> ***If parents agreed to pee sampling:*** If you agree, we will ask you to pee once in a cup.
>
> ***If parents agreed to blood sampling:*** If you agree to let us take some of your blood, a health professional will take a little bit of blood from your arm. This may cause some pain or fear, but you can decide to not give a blood sample. Let me or the health professional know and we will stop right away. If you give some blood you might feel dizzy after.

If you decide to do this project, we will also measure your height and weight.

ALL: This will take no more than 2 hours. You can decide to give hair or not. Then, you can give blood or not. Same for urine. It is your choice, not your parent's choice. If you do the

project, you will get a $25 gift card to the Co-op Store or Air North, and you will have your name put in a raffle for a bigger gift card prize.

(Will you have to answer all the questions and do everything you are asked to do?)
You don't have to answer any question you do not want to. If you feel uncomfortable at any time and want to stop the project, tell me and we will stop it. You will still receive your gift card.

(Who will know that you are in the study?)
No one else will know what answers you give to the questions we ask. We will not let anyone else see the information you give us. Your hair, urine and blood will be safe where we work. If you give us permission, we will be keeping your hair, urine and blood for up to ten (10) years. Any report we share with others will not have your name on it. If you decide later to get out of the project and we are not here anymore, ask your parent to call us so we will erase your information.

(Do you have any questions?)
You may ask questions at any time, including after the project you can reach us by phone with the phone numbers given to your parent.

Title of Project: Yukon Contaminant Biomonitoring: Old Crow

ID:_____

CONSENT FORM FOR A YOUNG PARTICIPANT (GUARDIAN)

By agreeing to have your child do this study, you are not giving up your or your child's legal rights or releasing the researchers or involved institutions from their legal and professional responsibilities. This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#23192). If I have any questions or ethics concerns you can contact the Office of Research Ethics at the contact information on the information letter. This study has also been approved by the VGG and will operate under the VGG Research Agreement.

By agreeing to have your child participate, you are agreeing to the following:

- *You have read and received a copy of the information letter*
- *You had a chance to ask questions and discuss the study*
- *You understand your child's involvement in the research study*
- *The privacy of your child's information has been explained to you*
- *You understand who will have access to your child's answers and samples*
- *You agree to get your child's results at the end of the project*
- *You are aware of the possible risks with blood sampling*
- *You are aware your child can refuse to answer any question*
- *You are aware you or your child can withdraw at any time, by contacting Brian Laird*
- *You are aware that your child will receive a $25 gift card for their involvement*

You can now agree to have your child do some or all parts of the study. Please indicate yes or no:

- I agree to have my child take part in the study.……..... Yes No
- I agree to have my child's height and weight measured for the study.……..… Yes No
- I agree to my child giving a hair sample and have it tested…..……..……. Yes No
- I agree to my child giving a urine sample and have it tested……..……..……. Yes No
- I agree to my child giving a blood sample and have it tested…… Yes No
- I agree to assist my child to complete the food survey ……..……..…..……..… Yes No
- I agree to assist my child to complete the health messages survey……...…..... Yes No
- I agree to let my child's urine and/or blood samples be stored for up to 10 years for the testing of other contaminants and nutrients…….……. Yes No
- I would like my child to be entered into a raffle for two $250 gift cards for each part of the study they do ……..…… Yes No
- I agree that the researchers can contact me with my child's results by email if they cannot contact me in person ……..…… Yes No
- I agree that the researchers can contact my child and I in the future to inform us about or invite my child to similar studies in the future …….……..…. Yes No

Guardian's Name (Please Print): _____

Participant's Name (Please Print): _____

Relationship to Participant: _____

(Page to be detached and be kept at University of Waterloo)

Title of Project: Yukon Contaminant Biomonitoring: Old Crow **ID:**_____

CONSENT FORM FOR A YOUNG PARTICIPANT (4-12)

Do you have any questions?

You ask questions at any time, even after the project is over. If you have any questions, please ask your parent to call Brian. His phone number is on the letter we gave to your parent.

By telling us you want to do the project, you are agreeing that:

- *You agree to do this project*
- *You had a chance to ask questions and talk about this study with me*
- *You understand that we will keep your answers private*
- *You know the possible small risks that could happen if we take some of your blood*
- *You know you don't have to answer any question if you do not want to.*
- *You know if you feel uncomfortable and want to stop the project, you can tell me and we will stop it.*
- *You know that you will receive a $25 gift card for doing the project*

Now we are going to ask you what parts of the study you would like to do:

- Do you agree to do this project……...Yes No
- Do you agree to have your height and weight measured ……..Yes No
- Do you agree to answer questions about traditional foods you eat …….....Yes No
- Do you agree to answer questions about your lifestyle... …….....Yes No
- Do you agree to give a hair sample and have it tested…….....Yes No
- Do you agree to pee in a cup and have it tested…….…..Yes No
- Do you agree to give a blood sample and have it tested……..…...Yes No
- Do you agree to let you hair, urine and blood samples be kept for ten years to test other chemicals ……...….....Yes No
- Do you agree to have your name put into a raffle for two $250 gift cards for each part of the study you do …….……Yes No

Name (Please Print): _____

INFORMATION LETTER FOR PARTICIPANT (13-17 years old)

Dear Vuntut Gwitchin community member,

Would you like to take part in a study looking at contaminant levels in people? Mary Gamberg, a scientist from Whitehorse and Brian Laird, a researcher from the University of Waterloo in Ontario were in the community last year to learn what traditional foods people eat and what people have heard about traditional food and their health.

For the next phase of the project, our research team is going to look at the levels of contaminants (like mercury) in the people of Old Crow. We will be collecting samples from people this fall, testing samples in winter 2019, and the results will be returned to the community and the people who took part by the end of 2019.

How does this study benefit your community?
This study will benefit your community by helping to answer questions about

- What level of contaminants are in the people of Old Crow
- How does food effect people's contaminant levels
- What are the benefits and risks of people's food choices

What is the purpose of this study?

- To learn what traditional foods people eat in Old Crow
- To see what level of contaminants and nutrients are in the people of Old Crow
- To find out ways to help people eat more traditional foods that are healthy for them, and make sure that people are not being exposed to high levels of contaminants through these foods

What will be involved if you agree to do this study?
There are five parts to this study. If you would like to be involved in this study, you can choose to do whichever parts you want. This study will take no more than 2 hours.

Part 1: Food Survey (25 minutes)
A researcher will help you answer survey questions on an iPad™. This survey will ask you what traditional foods you ate over the past year.

Part 2: Health Messages Survey (20 minutes)
A researcher will help you answer survey questions on an iPad in a private room. This survey will ask you about some lifestyle factors, for example: have you had a metal tooth filling?

Part 3: Hair Sample (20 minutes)
A researcher will take a five millimeter wide sample of full length hair using disinfected scissors from the back of your head.

Part 4: Urine Sample (20 minutes)

A researcher will ask you to urinate in a small container.

Part 5: Blood Sample (20 minutes)

A medical laboratory assistant will take blood sample in four tubes (each about the amount of a tablespoon) from a vein on the inside of the elbow. The blood sample will only be taken by a medical laboratory assistant. This will be similar to when your doctor or nurse asks you to give a blood sample at a routine check up. You can ask questions at any time during the blood sample, or ask to stop at any time.

If you decide to do some or all of the parts of the study, we will ask if you would have your height and weight measured so that we can better understand your results. A research team member will be in the community for an additional week following the clinic. If you would like to complete the surveys during this time, please let one of the researchers know.

Are there any risks if you do the study?

- There are no expected risks from doing the surveys or a urine sample.
- There are minimal possible risks from the hair sample (e.g. cut from scissors).
- There are potential low risks for doing a blood sample. There is a potential to experience bruising or discomfort from the site of needle insertion. The blood withdrawal might cause low blood pressure, dizziness or fainting.

Will you receive any benefits for doing the study?

You may not directly benefit from the research project. However, to show appreciation for your time, you will receive a $25 gift card to either the Co-op Store or Air North. You can also enter into a raffle for two $250 gift cards of either the Co-op Store or Air North. Your name will enter the raffle for each part of the study you do. So, if you do all five parts of the study (two surveys, blood, hair and urine samples) you will get five tickets for the raffle. Raffle tickets will still be given to you if your surveys are completed in the week after the clinic with the researcher who will remain in the community during that time. All gift card amounts received are taxable. This amount can be reported for income tax purposes.

Will you get feedback from us about the samples you give?

Yes, if you give a hair, urine and/or blood sample, you will get a confidential letter explaining your contaminant levels. This letter will compare your contaminant levels to levels seen in other Canadian populations, with the average levels in the people of Old Crow, and with the recommended limits for some contaminants.

Hair, urine and blood samples are currently being tested for mercury. Urine and blood are being tested for several metals (e.g. arsenic, cadmium, lead, selenium, uranium, etc.). Blood plasma is being tested for fatty acids (e.g. omega-3) and organic pollutants (e.g. PCBs, pesticides, etc.). Finally, serum will be tested for vitamins.

What if my levels are high?
If your levels are higher than the recommended limits, your results letter will explain what the levels mean and what you can do to lower them. The research team will come back to the community a year after the first samples were collected to follow up with people who had contaminant levels that were either 1) much higher than normal, or 2) above the Health Canada guidelines for mercury, lead or cadmium. People with one or more high contaminant levels will be invited to give more samples to be measured.

If your levels are high enough to be an immediate health risk, our research team will contact you by phone immediately (within 6 months of when we collected samples). Our research team will work with the Yukon Government Department of Health to make sure that you are referred to a doctor for follow up and medical advice as soon as possible.

How will my information be kept private?
If you did surveys about traditional food and health messages in the winter of 2018 with our research team, we will match your survey answers from then to your survey answers in this part of the project.

Since all parts of this study will be done in the community center, your involvement will not be completely private. However, the researchers will keep your answers and samples confidential. Once you answer questions to the surveys on the iPad, your answers will be sent to a secure online server in Canada. An ID number will be used on your answers and samples instead of your name to protect your privacy. All information from this study will be kept at the University of Waterloo on a password-protected computer in a locked room. Answers from surveys will also be kept with VGG Natural Resources on a password-protected computer in a locked room. If you agree to do the study, your answers will be kept for at least 10 years.

Hair, urine and blood samples will be brought to the University of Montreal, the University of Western Ontario, the University of Waterloo, and the National Institute of Public Health (INSPQ) in Quebec to have contaminants and nutrients measured. Any samples (hair, urine, blood) you give will be stored and kept by the researchers. They will be kept at the University of Waterloo in a locked, secure laboratory for up to ten (10) years. We can't profit from selling your samples, and they cannot be sold. No genetic testing will be done on any of the samples.

Where will the findings from this study be reported?
No research performed under this project, no research products, and no traditional or indigenous knowledge will be used for commercial purposes.

A results report will be returned to the community within a year after the sampling. After the results have been returned to the community, de-identified results may be presented in theses, papers, and presentations at national and international meetings.

Biobank
You will also have the option to allow your hair, urine and blood samples to be kept in a biobank at the University of Waterloo. Your samples would be stored in a freezer (blood and urine) and a locked cabinet (hair) in a locked room at the University of Waterloo for up to ten years. If you decide to have your samples kept in a biobank, we will measure your samples for other contaminants or nutrients if we get the funding to do so. If we measure your samples for other contaminants or nutrients, then we will send you a results letter about your levels by email or mail when they are available. If you decide you do not want your samples to be held in the biobank, then your samples will be discarded after they are measured by the researchers.

Can I change my mind after I agree to let my sample(s) or survey answers be used?
Yes, at any point during the study you can change your mind if you do not want your samples or survey answers used. You can withdraw from the study by contacting Brian Laird by phone or email. If you withdraw from the study your survey answers will be erased and your samples will be discarded. You can contact us within ten years from when we collected your samples and you can ask to have your samples discarded and/or survey answers erased. If you decide to withdraw from the study after this time, the key that links your name to your survey answers will be destroyed, and we may not be able to remove your answers because we will not know which ones are yours. If you change your mind you will still receive the gift card for your time.

Still have questions about the study?
This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#23192). If you have any questions for the Committee contact the Office of Research Ethics at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca. This study has been approved by the VGG and will operate under the VGG Research Agreement.

Contact Information:
Feel free to contact Brian Laird for more information at any time during the study.

Yours sincerely,

Brian Laird, PhD
School of Public Health and Health Systems
University of Waterloo

Mary Gamberg
Gamberg Consulting
708 Jarvis St. Whitehorse, Yukon

Co-investigators:
William Josie (Vuntut Gwitchin Government)
Megan Williams (Vuntut Gwitchin Government)
Kelly Skinner, PhD (University of Waterloo)
Mylene Ratelle, PhD (University of Waterloo)
Chris Furgal, PhD (Trent University)
Amanda Boyd, PhD (University of Washington)

ID:_____

PARTICIPANT CONSENT FORM (13+)

By agreeing to do this study, you are not giving up your legal rights or releasing the researchers or involved institutions from their legal and professional responsibilities. This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#23192). If you have any questions or ethics concerns, you may contact the Office of Research Ethics, at the contact information on the information letter. This study has also been approved by the VGG and will operate under the VGG Research Agreement.

By agreeing to participate, you are agreeing to the following:

- *You have read and received a copy of the information letter*
- *You had a chance to ask questions and discuss the study*
- *You understand your involvement in the research study*
- *The privacy of your answers and information has been explained to you*
- *You understand who will have access to your answers and samples*
- *You agree to get your results at the end of the project*
- *You are aware of the possible risks with blood sampling*
- *You are aware you can refuse to answer any question*
- *You are aware you can withdraw at any time during the study, by contacting Brian Laird*
- *You are aware that you will receive a $25 gift card for your involvement*

You can now agree to do some or all parts of the study. Please indicate yes or no:

- I agree to take part in this study……Yes No
- I agree to have my height and weight measured for the study……..……..Yes No
- I agree to give a hair sample and have it tested…….…...…Yes No
- I agree to give a urine sample and have it tested……..……Yes No
- I agree to give a blood sample and have it tested……Yes No
- I agree to complete the food survey……..……Yes No
- I agree to complete the health messages survey……...……..…..Yes No
- I agree to let my hair, urine and blood samples be stored in a biobank for up to 10 years for the testing of other contaminants and nutrients…….....Yes No
- I would like to be entered into a raffle for two $250 gift cards for each part of the study I do ……...Yes No
- I agree that the researchers can contact me with my results by email if they cannot contact me in person ……..……...Yes No
- I agree that the researchers can contact me in the future to inform me about or invite me to similar studies in the future …….....…….…..…..Yes No

Name (Please Print): _____

(Page to be detached and be kept at University of Waterloo)

CONSENT FORM FOR GUARDIAN (For participants aged 13-17)

By agreeing to have your child do this study, you are not waiving your or your child's legal rights or releasing the investigators or involved institutions from their legal and professional responsibilities. This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#23192). If I have any questions or ethics concerns, you may contact the Office of Research Ethics at the contact information on the information letter. This study has also been approved by the VGG and will operate under the VGG Research Agreement.

By agreeing to have your child participate, you are agreeing to the following:

- *You have read and received a copy of the information letter*
- *You had a chance to ask questions and discuss the study*
- *You understand your child's involvement in the research study*
- *The privacy of your information has been explained to you*
- *You understand who will have access to your child's answers and samples*
- *You agree to get your child's results at the end of the project*
- *You are aware of the possible risks associated with blood sampling*
- *You are aware your child can refuse to answer any question*
- *You are aware you or your child can withdraw at any time, by contacting Brian Laird*
- *You are aware that your child will receive a $25 gift card for their involvement*

You can now agree to have your child do some or all parts of the study. Please indicate yes or no:

- I agree to have my child participate in the study……..Yes No
- I agree to have my child's height and weight measured for the study……..Yes No
- I agree to my child giving a urine sample and have it tested……..……..……Yes No
- I agree to my child giving a hair sample and have it tested……..……..……Yes No
- I agree to my child giving a blood sample and have it tested…….Yes No
- I agree to my child completing the food survey……...……...Yes No
- I agree to my child completing the health messages survey……..……...Yes No
- I agree to let my child's urine and/or blood samples be stored for up to 10 years for the testing of other contaminants and nutrients…….……..…Yes No
- I would like my child to be entered into a raffle for two $250 gift cards for each part of the study they do ……..……...Yes No
- I agree that the researchers can contact me with my child's results by email if they cannot contact me in person ……..……...Yes No
- I agree that the researchers can contact my child and I in the future to inform us about or invite my child to similar studies in the future …….……..…..Yes No

Guardian's Name (Please Print): _____

Participant's Name (Please Print): _____

Relationship to Participant: _____

(Page to be detached and be kept at University of Waterloo)

Title of Project: Yukon Contaminant Biomonitoring: Old Crow

INFORMATION SCRIPT FOR PARTICIPANTS

The following script will be read by a local research coordinator to people 18 years old and older.

Would you like hear about a study looking at contaminants in people? Our research team from Whitehorse and the University of Waterloo in Ontario were in Old Crow last year to learn what traditional foods people eat and what people have heard about traditional food and their health.

For the next phase of the project, we are going to look at the levels of contaminants (like mercury) in the people of Old Crow. We will be collecting samples from people this fall, measuring samples over the winter, and returning results next year to everyone who took part.

The purpose of this study is to learn about what traditional foods people in Old Crow eat and to see what levels of contaminants and nutrients are in these same people. We are hoping to find out ways to help people eat more traditional foods that are healthy for them, and make sure that people are not taking in large amounts of contaminants through these foods.

If you would like to participate in this study, there are five parts, and you can choose to do whichever parts you want. The study won't take longer than 2 hours. The survey portion of the study can also be completed the week after the clinic by appointment or drop-in.

> The first part is a food survey, where you will answer questions on an iPad about the traditional foods you ate in the last year.
>
> The second part is a health messages survey, where you will answer questions on an iPad about your lifestyle (for example: asking if you smoke) and what you have heard about traditional food and health
>
> The third part is a hair sample, where a researcher will take a 5 millimeter wide piece of full length hair from the back of your head.
>
> The fourth part is a urine sample, where a researcher will give you a small container that you will urinate into.
>
> Finally, the fifth part is a blood sample, where a medical laboratory assistant or a nurse from Whitehorse will take 4 small blood samples from the inside of your arm, each is about the amount of a tablespoon. This will be similar to when a doctor or nurse takes a blood sample for a check up.

If you decide to do some or all of the parts of the study, we will also ask your permission to have your height and weight measured. We want to know your height and weight so that we can better understand your results.

There are no risks expected from doing the surveys or giving a urine sample. If you give a hair sample there is a minimal risk that you may get cut by the scissors. If you give a blood sample, there is a potential low risk that you might experience bruising or discomfort at the site of the needle insertion. There is also potential low risk that giving the blood sample might cause low blood pressure, dizziness or fainting.

If you decide to take part in the study you will get a $25 gift card to your choice of either the Co-op Store or Air North. You will get the gift card even if you change your mind during the study and want to stop. You will also be able to enter a raffle for two $250 gift cards to either the Co-op Store or Air North. If

you would like to do the raffle, you will receive a raffle ticket for each of the five parts of the study you decide to do. So, if you do all six parts of the study, you will get five raffle tickets.

If you provide a blood, urine or hair sample for this study, we will give you a results letter that will tell you what levels of contaminants and nutrients were in your samples and explain what these levels mean. We will bring you a result letter in a year, and will answer any questions you have.

Hair, urine and blood samples are currently being tested for mercury. Urine and blood are being tested for several metals, like cadmium and lead. Blood plasma is being tested for fatty acids and organic pollutants. Finally, serum might be tested for other nutrients (like calcium and vitamin C).

The letter will explain what your results mean, and if your levels are higher than normal it will tell you what you can do to lower them. The research team will come back to the community in a year and offer follow up with you if you have levels much higher than normal. If you agree, the research team would take more samples and return the results to you once they have been measured. If your levels are high enough to be an immediate health risk, then we will contact you on the phone as soon as possible and ask if you would accept an appointment with a doctor. If you agree, we will work with the Yukon Government Department of Health to make sure that you get an appointment with a doctor for follow-up and receive medical advice as soon as possible.

Since all parts of this study will be done in the community center, your involvement will not be completely private. However, the researchers will keep your answers and samples confidential. Your name will not be linked with any of your answers; an ID number will be used in the answer files instead.

We will also give you the option to have your hair, urine and blood samples kept in a biobank at the University of Waterloo. These samples would be kept at the University of Waterloo for up to ten years. If you decide to have your samples kept in a biobank, we will measure your samples for other contaminants if we get the funding to do that. If we measure your samples for other contaminants, then we will send you a results letter about your levels and what they mean.

You can change your mind if you do not want your samples or survey answers used in this study, and your samples will be discarded and your information erased. You can stop being in the study at any time by contacting Brian Laird by phone or email (contact information is on the information letter).

Title of Project: Yukon Contaminant Biomonitoring: Old Crow

INFORMATION SCRIPT FOR PARTICIPANTS

The following script will be read by a local research coordinator to guardians or parents of participants aged 4 years old to 17 years old. For young participants (4-17 years old) this will require the minor to give their assent, and the parent or guardian to give their consent.

Would you like hear about a study looking at contaminants in people? Our research team from Whitehorse and the University of Waterloo in Ontario were in Old Crow last year to learn what traditional foods people eat and what people have heard about traditional food and their health.

For the next phase of the project, we are going to look at the levels of contaminants (like mercury) in the people of Old Crow. We will be collecting samples from people this fall, measuring samples over the winter, and returning results next year to everyone who took part.

The purpose of this study is to learn about what traditional foods people in Old Crow eat and to see what levels of contaminants and nutrients are in these same people. We are hoping to find out ways to help people eat more traditional foods that are healthy for them, and make sure that people are not taking in large amounts of contaminants through these foods.

If you agree to have your child take part, you can choose which parts of the study you give permission for them to do. The study will take no more than 2 hours. The survey portion of the study can also be completed the week after the clinic by appointment or drop-in.

> The first part is a food survey, where your child will answer questions on an iPad about the traditional foods they ate in the last year.
>
> The second part is a health messages survey, where your child will answer questions on an iPad about their lifestyle (for example: asking if they smoke).
>
> The third part is a hair sample, where a researcher will take a 5 millimeter wide piece of full length hair from the back of your child's head.
>
> The fourth part is a urine sample, where a researcher will give your child a small container that they will urinate into.
>
> The fifth part is a blood sample, where a medical laboratory assistant from Whitehorse will take 4 small blood samples from the inside of your child's arm, each is about the amount of a tablespoon. This will be similar to when a doctor or nurse takes a blood sample for a check up.

If you decide to allow your child to do some or all the parts of the study, we will ask your permission to measure their height and weight. We want to know your child's height and weight so that we can better understand their results.

There are no risks expected from doing the surveys or giving a urine sample. If your child gives a hair sample there is a minimal risk that they may get cut by the scissors. If your child gives a blood sample, there is a potential low risk that they might experience bruising or discomfort at the site of the needle insertion. There is also potential low risk that giving the blood sample might cause low blood pressure, dizziness or fainting.

If you allow your child to take part in the study, they will get a $25 gift card to their choice of either the Co-op Store or Air North. They will get the gift card even if you or your child change their mind during

the study and want to stop. Your child will also be able to enter a raffle for two $250 gift cards to either the Co-op Store or Air North. If you agree to have your child entered into the raffle, they will receive a raffle ticket for each of the parts of the study they do. So, if they do all five parts of the study, they will get five raffle tickets.

If your child provides a blood, urine or hair sample for this study, we will give you a results letter that will tell you what levels of contaminants and nutrients were in their samples and explain what these levels mean. We will bring you a result letter in a year, and will answer any questions you have.

Hair, urine and blood samples are currently being tested for mercury. Urine and blood are being tested for several metals, like cadmium and lead. Blood plasma is being tested for fatty acids and organic pollutants. Finally, serum might be tested for other nutrients (like calcium and vitamin C).

The letter will explain what your child's results mean, and if their levels are higher than normal it will tell you and our child what can be done to lower them. The research team will come back to the community in a year and offer to do a follow up with your child if they have levels much higher than normal. If you agree, the research team would take more samples and return the results to you and your child once they have been measured. If their levels are high enough to be an immediate health risk, then we will contact you on the phone as soon as possible and ask if you would accept to have an appointment set up between your child and a doctor. If you agree, we will work with the Yukon Government Department of Health to make sure that your child gets an appointment with a doctor for follow-up and receives medical advice as soon as possible.

Since all parts of this study will be done in the community center, your child's involvement will not be completely private. However, the researchers will keep your child's answers and samples confidential. Your child's name will not be linked with any of their answers; an ID number will be used in the answer files instead.

We will also give you the option to have your child's hair, urine and blood samples kept in a biobank at the University of Waterloo. These samples would be kept at the University of Waterloo for up to ten years. If you decide to have the samples kept in a biobank, we will measure the samples for other contaminants if we get the funding to do that. If we measure the samples for other contaminants then we will send you a results letter about their levels and what they mean.

You can change your mind if you do not want your child's samples or survey answers used in this study, and we will discard their samples and erase their information. You can take your child out of the study at any time by contacting Brian Laird by phone or email (contact information is on the information letter).

Title of Project: Yukon Contaminant Biomonitoring: Old Crow

INFORMATION SCRIPT FOR PARTICIPANTS

The following script will be read by a local research coordinator to people 13 years old and older. For minor participants (13-17 years old) this will require the minor to give their assent, and the parent or guardian to give their consent.

Would you like hear about a study looking at contaminants in people? Our research team from Whitehorse and the University of Waterloo in Ontario were in Old Crow last year to learn what traditional foods people eat and what people have heard about traditional food and their health.

For the next phase of the project, we are going to look at the levels of contaminants (like mercury) in the people of Old Crow. We will be collecting samples from people this fall, measuring samples over the winter, and returning results next year to everyone who took part.

The purpose of this study is to learn about what traditional foods people in Old Crow eat and to see what levels of contaminants and nutrients are in these same people. We are hoping to find out ways to help people eat more traditional foods that are healthy for them, and make sure that people are not taking in large amounts of contaminants through these foods.

If you would like to participate in this study, there are five parts, and you can choose to do whichever parts you want. The study won't take longer than 2 hours. The survey portion of the study can also be completed the week after the clinic by appointment or drop-in.

> The first part is a food survey, where you will answer questions on an iPad about the traditional foods you ate in the last year.
>
> The second part is a health messages survey, where you will answer questions on an iPad about your lifestyle (for example: asking if you smoke) and what you have heard about traditional food and health.
>
> The third part is a hair sample, where a researcher will take a 5 millimeter wide piece of full length hair from the back of your head.
>
> The fourth part is a urine sample, where a researcher will give you a small container that you will urinate into.
>
> Finally, the fifth part is a blood sample, where a medical laboratory assistant from Whitehorse will take 4 small blood samples from the inside of your arm, each is about the amount of a tablespoon. This will be similar to when a doctor or nurse takes a blood sample for a check up.

If you decide to do some or all of the parts of the study, we will also ask your permission to have your height and weight measured. We want to know your height and weight so that we can better understand your results.

There are no risks expected from doing the surveys or giving a urine sample. If you give a hair sample there is a minimal risk that you may get cut by the scissors. If you give a blood sample, there is a potential low risk that you might experience bruising or discomfort at the site of the needle insertion. There is also potential low risk that giving the blood sample might cause low blood pressure, dizziness or fainting.

If you decide to take part in the study you will get a $25 gift card to your choice of either the Co-op Store or Air North. You will get the gift card even if you change your mind during the study and want to stop.

You will also be able to enter a raffle for two $250 gift cards to either the Co-op Store or Air North. If you would like to do the raffle, you will receive a raffle ticket for each of the five parts of the study you decide to do. So, if you do all six parts of the study, you will get five raffle tickets.

If you provide a blood, urine or hair sample for this study, we will give you a results letter that will tell you what levels of contaminants and nutrients were in your samples and explain what these levels mean. We will bring you a result letter in a year, and will answer any questions you have.

Hair, urine and blood samples are currently being tested for mercury. Urine and blood are being tested for several metals, like cadmium and lead. Blood plasma is being tested for fatty acids and organic pollutants. Finally, serum might be tested for other nutrients (like calcium and vitamin C).

The letter will explain what your results mean, and if your levels are higher than normal it will tell you what you can do to lower them. The research team will come back to the community in a year and offer follow up with you if you have levels much higher than normal. If you agree, the research team would take more samples and return the results to you once they have been measured. If your levels are high enough to be an immediate health risk, then we will contact you on the phone as soon as possible and ask if you would accept an appointment with a doctor. If you agree, we will work with the Yukon Government Department of Health to make sure that you get an appointment with a doctor for follow-up and receive medical advice as soon as possible.

Since all parts of this study will be done in the community center, your involvement will not be completely private. However, the researchers will keep your answers and samples confidential. Your name will not be linked with any of your answers; an ID number will be used in the answer files instead.

We will also give you the option to have your hair, urine and blood samples kept in a biobank at the University of Waterloo. These samples would be kept at the University of Waterloo for up to ten years. If you decide to have your samples kept in a biobank, we will measure your samples for other contaminants if we get the funding to do that. If we measure your samples for other contaminants, then we will send you a results letter about your levels and what they mean.

You can change your mind if you do not want your samples or survey answers used in this study, and your samples will be discarded and your information erased. You can stop being in the study at any time by contacting Brian Laird by phone or email (contact information is on the information letter).

UNIVERSITY OF WATERLOO

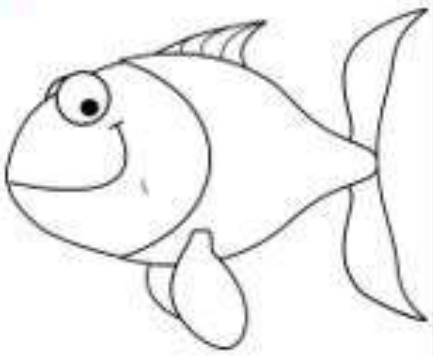
Would you like to take part in a study on Contaminants and Human Health in your community?

Mary Gamberg a scientist form Whitehorse, Yukon and Brian Laird, PhD, from University of Waterloo in Ontario will be in your community to offer you the chance to participate.

Why?

This study will help to answer important questions about:

- The current levels of **contaminant** exposure in the body.
- The **sources** of contaminant exposure to people in Old Crow, Yukon.
- The balance between risks and benefits from **traditional food**.



Who?

Everyone 4 years old and older are welcome!

How?

Each participant is free to take part in only the components they want to complete (2 hours in total):

- Completing a food questionnaires
- Completing a health messages survey
- Collect a five millimeter width sample of full length hair
- Collect urine sample
- A nurse will collect blood samples

Results will be returned to each participant within 12 months after sampling.

You will receive a **$25 gift card** for the Co-op Store or AirNorth right after you are done participation. Additionally, you can enter your name into a draw for a $500 gift card to the Co-op Store and AirNorth.

Come to meet us!

When: _____

Where: _____

Contact us by email at:

Appendix C – Old Crow Traditional Food Sampling

Results from Organochlorine Assessment in Old Crow Traditional Foods – Updated Technical Report

June 2022

This report has been updated to reflect data from two new moose samples received in January 2022, historical caribou samples collected from 2002 to 2014, and re-analysis of some organochlorines in loche, caribou, and moose samples (described in previous versions of this technical report) for lower detection limits.

Key Messages

- The organochlorine analysis program for Old Crow traditional foods is currently ongoing, and this report presents results for river water, berries, chum salmon, moose, caribou, and loche liver. Additional Chinook salmon samples are proposed for collection in summer 2022.
- Levels of most organochlorine pesticides were too low to be detected in river water and berries. When pesticides were detected in water and berries, levels were well below available guidelines for food and drinking water
- Organochlorine pesticides levels in Old Crow chum salmon were similar to those observed in British Columbia chum salmon and below all available commercial limits
- HCB levels in caribou and loche liver were similar to those observed in other northern samples of these foods, though were higher than some market foods.
- HCB levels in moose were similar or lower than those observed in other northern samples of these foods and market foods.
- HCB levels in Old Crow caribou have remained stable between 2002 to 2021, which is similar to HCB trends in other northern regions.
- Further work is currently being conducted to compare HCB intake from Old Crow traditional foods to available health-based guidelines.
- Modeling of these results will help to shed some light on whether HCB levels in some northern foods are associated with elevated HCB levels in blood samples of people from Old Crow.

Introduction

Contaminant biomonitoring was done in Old Crow, YT in 2018-2020. Blood levels of hexachlorobenzene (HCB), an organochlorine pesticide, were found at higher concentrations in people in Old Crow than in the general Canadian population and First Nations communities across the ten provinces (166). Based on feedback from the community after the return of biomonitoring results, a traditional food monitoring project was designed to: 1) generate current, regional data on HCB levels in commonly eaten traditional foods in Old Crow; 2) identify possible sources of HCB exposure using the dietary surveys conducted in 2019. This research builds on existing environmental monitoring programs and partnerships with the VGG. Over the two-year project, traditional food samples including caribou (liver, fat, bone marrow),

moose (liver, fat, bone marrow), chinook salmon muscle, loche liver, berries, and local river water have been collected through community-based sampling, and analyzed for HCB and other organochlorine pesticide levels. Historical caribou liver and muscle samples from 2002 to 2014 were also analyzed for levels of HCB (not a full suite of organochlorines) to detect changes over time.

This memorandum includes the results for organochlorine analysis of samples including water, berries, and fish, caribou, and moose tissue. Any remaining results, including potential Chinook salmon sampling in 2022, will be reported as they are received. All results will be returned to the community within one year of sampling.

Methods

Sampling

Sample collection by local harvesters began in July, 2020 and is ongoing as of June, 2022. Table 1 shows the status of sampling as of June, 2022.

Table 1 – Proposed Sampling and Progress

Sample Type	Sample Details	Spring/ Summer 2020	Fall 2020/ Winter 2021	Fall 2021/ Winter 2022	Total
Water	Up Porcupine River	2	0	0	**2**
	Down Porcupine River	2	0	0	**2**
	Up Crow River	2	0	0	**2**
Moose Tissue	Liver, Fat, Bone	0	1	2	**3**
Caribou Tissue	Liver, Fat, Bone	0	9	0	**9**
	Historical Liver and Muscle	0	0	10	**10**
Chum Salmon	Muscle	10	0	0	**10**
Chinook Salmon	Muscle	0	0	0	**0**
Loche	Liver	0	10	0	**10**
Berries	Low Cranberries	1	0	0	**1**
	Low Blueberries	2	0	0	**2**
	Salmonberries	1	0	0	**1**
	Crowberry	1	0	0	**1**

The numbers in this table may change, as Chinook salmon sampling is being conducted in the region in 2022. The methods for processing each sample type varied, as follows: In the case of moose and caribou, harvesters removed the targeted parts, such as fat (surrounding the kidney or subcutaneous fat), liver, and bone (one long bone from the animal's hind leg), then packaged these samples for shipment to Mary Gamberg in Whitehorse for processing. In addition to the samples listed above, harvesters collected the incisors of moose and caribou for age estimation and noted the date of collection, sex of the animal, and description of the area from which the animal was hunted. M Gamberg aged moose teeth, and extracted moose and caribou bone marrow for analysis. In addition to the caribou samples collected by Old Crow harvesters in 2020, ten historical Old Crow caribou liver and muscle samples from 2002 to 2014 were provided by Environment and Climate Change Canada for HCB analysis.

The type of salmon proposed for collection is Chinook, due to the high consumption rates of this type of fish in the community. However, the community outreach campaigns in 2020 and 2021 did not result in the collection of any Chinook salmon samples in season. Due to sample availability, chum salmon, the

second most common type of salmon eaten, was used instead. Whole fish samples were shipped to M Gamberg in Whitehorse for processing. Further collection of Chinook sampling is proposed in the region for summer 2022.

Berry samples were collected by local harvesters. In addition to the three proposed berries, including blueberries, cranberries, and salmonberries, an additional sample of crowberries was collected for analysis. Berry samples collected on the land were wrapped in aluminum foil, sealed in Ziploc bags, and frozen for storage prior to shipping.

Water samples (2,000 mL each) were proposed for collection from the Crow and Porcupine Rivers during the spring and fall. Water samples were collected in 1 liter amber glass bottles, and shipped to the laboratory immediately upon collection.

Sample Analysis

Sample analysis was conducted at ALS Burlington for all samples collected in 2020 and 2021. The laboratory uses high resolution mass spectrometry (HRMS) to analyze HCB and other organochlorine pesticide levels in samples. In animal tissue, the laboratory also reported lipid content for the adjustment of organochlorine concentrations to lipid levels. Some organochlorine levels have been refined after specific samples were re-analyzed in January 2022 due to high detection limits when first measured. These include alpha-BHC, heptachlor, DDE, DDT, DDD, nonachlor, oxychlordane, and chlordane levels for moose, caribou, and loche organs.

Historical caribou samples were analyzed for HCB and lipid levels at the National Wildlife Research Centre using gas chromatography mass spectrometry.

Results Interpretation

The results of organochlorine analysis were compared to guidelines for contaminants in food or water. However, these comparisons do not take frequency of consumption or diet diversity into account. Based on community feedback, a risk assessment is currently being conducted to estimate dietary exposure to HCB from traditional foods. Dietary exposure will be compared to health-based intake guidelines for HCB to evaluate risk.

Though the primary source for drinking water in Old Crow is treated water from the community well, some community members consume some of their drinking water from the local rivers. River water quality was compared to drinking water guidelines or standards. If territorial or federal guidelines for contaminants were not available, as is the case for many organochlorines, standards used in other areas, including the United States, were used for comparison. The results from these river water samples may not reflect exposures of people in Old Crow, since these sampling sites are not where people access most of their drinking water.

Contaminants in berries and animal tissue were compared to maximum residue limits (MRLs), which are standards for pesticides in a commercial food product. MRLs are intentionally set below the level of exposure known to cause adverse health issues (338). Because MRLs are conservative guidance values, it is quite common for some foods, particularly meats, to be higher than these levels. In this report, pesticides in berries and tissues were compared to MRLs from Health Canada (339), the World Health Organization (340), the United States Food and Drug Administration (FDA) (341), and the European

Union (342). When no MRL is available, the European Union recommends a provisional MRL of 0.01 mg/kg of meat or food when fat content is below 10% (343). If fat content in the food is greater than 10%, and the contaminant is fat-soluble, contaminant levels were adjusted to ng/g of fat (344). Table 2, below, shows the MRLs that were used for comparison in this report when organochlorines were detected in samples.

Table 2 – Maximum Residue Limits Used for Comparison

Sample Type	Tissue/Sample Details	Organochlorine	MRL used for Comparison
Berries	All Berries	Chlorobenzenes	10 ng/g sample (343)
Chum Salmon	Muscle	DDT+DDE	5000 ng/g tissue (339, 341)
		Chlordanes	300 ng/g tissue (341)
		Chlorobenzenes	10 ng/g tissue (343)
Loche	Liver	DDT+DDE	5000 ng/g fat (339)
		Chlorobenzenes	10 ng/g fat (343)
Caribou	Bone Marrow	HCB	10 ng/g fat (343)
	Fat	HCB	10 ng/g fat (343)
	Liver	HCB	10 ng/g tissue (343)
Moose	Bone Marrow	HCB	10 ng/g fat (343)
	Fat	HCB	10 ng/g fat (343)
	Liver	HCB	10 ng/g tissue (343)

Results and Discussion

Geometric means and ranges for select organochlorine pesticides are shown below in Table 3 (water), Table 4 (berries), Table 5 (salmon), Table 6 (loche liver), Table 7 (caribou), and Table 8 (moose). These tables highlight results from the contaminants that were detected in at least 10% of samples. Where average lipid levels of a tissue were greater than 10%, organochlorine levels were also normalized to lipid levels. The full results of sampling are shown in Appendix A for all sample types.

River Water

The primary source for drinking water in Old Crow is the local well, which is delivered to water tanks in individual homes and buildings by truck. However, river water is an alternate drinking water source for some community members. The majority of parameters, including hexachlorobenzene, were below the analytical detection limits for all water samples (Appendix A). Exceptions include some chlorobenzenes, which were above the detection limit in some or all locations. HCB levels were above the detection limit in one sample from the Crow River. Table 3 shows summary statistics for organochlorines where any samples were over the detection limit.

Table 3 – Select Organochlorines in Old Crow Water Samples

		Fall 2020 Samples (n=3)		Spring 2021 Samples (n=3)	
		% of Samples Above LOD	**Geometric Mean** (Min – Max)	**% of Samples Above LOD**	**Geometric Mean** (Min – Max)
1,2,4,5-Tetrachlorobenzene	ng/L	100	**0.067** (0.033 – 0.11)	0	**<LOD**
1,2,3,4-Tetrachlorobenzene	ng/L	67	**<LOD** (<LOD – 0.085)	0	**<LOD**
Pentachlorobenzene	ng/L	33	**0.035** (<LOD – 0.069)	33	**0.017** (<LOD – 0.044)
Hexachlorobenzene	ng/L	0	**<LOD**	33	**0.046** (<LOD – 0.97)

Drinking water standards or guidelines for tetrachlorobenzenes, HCB, and pentachlorobenzene have not been established federally, territorially or provincially in Canada. However the United States Environmental Protection Agency (EPA) set a maximum contaminant limit of 1000 ng/L HCB in drinking water (345). Additionally, the EPA has established provisional drinking water limits of 30 ng/L tetrachlorobenzene and 100 ng/L pentachlorobenzene (346). Concentrations of these parameters observed in the Porcupine and Crow Rivers were more 100-times lower than these standards.

> **Conclusion: Pesticide levels, including HCB, in river water near Old Crow were generally too low to be detected, and were within drinking water standards.**

Berries

The results for organochlorine analysis of berry samples are shown in Appendix A and Table 4 shows summary statistics for organochlorines where any samples were over the detection limit. Parameters detected during analysis included several chlorobenzenes, including HCB. One blueberry sample (collected at the north side of the fence by the airport) reported the highest concentrations of 1,2,4,5-tetrachlorobenzene (0.00048 ng/g), pentachlorobenzene (0.025 ng/g), and HCB (0.047 ng/g).

Table 4 – Organochlorines in Old Crow Berry Samples

		% of Samples Above LOD	**Geometric Mean** (Min – Max)
1,2,4,5-Tetrachlorobenzene	ng/g	40	**<LOD** (<LOD – 0.0048)
1,2,3,4-Tetrachlorobenzene	ng/g	40	**<LOD** (<LOD – 0.0034)
Pentachlorobenzene	ng/g	100	**0.0079** (0.0037 – 0.025)
Hexachlorobenzene	ng/g	60	**0.0086** (<LOD – 0.047)
Endosulfan I	ng/g	20	**<LOD** (<LOD – 0.011)

The crowberry sample collected from Crow Mountain had endosulfan I concentrations above the detection limit (0.011 ng/g). This value is lower than the detection limits reported in the other samples (0.013 – 0.025), meaning this sample may not have actually had higher levels of this pesticide than other berries collected in Old Crow. Between Health Canada, the WHO's Codex, and the EU, the lowest MRL for berries is the EU's limit of 0.01 mg/kg (10 ng/g) for most organochlorines (339, 340, 342). All berry samples from Old Crow were well below this value.

> **Conclusion: pesticide levels, including HCB, in berries near Old Crow were generally low, and wild berries continue to be a healthy food choice.**

Fish

The results for organochlorine and lipid analysis of salmon and loche liver samples are shown in Appendix A, and Tables 5 and 6 (salmon, and loche, respectively) show summary statistics for organochlorines where any samples were over the detection limit. Mean lipid concentrations in the salmon tissue were 0.78% (ranging from less than 0.5% to 1.5%). These levels are similar to levels of lipids reported in wild chum salmon samples from British Columbia (BC), which had a mean of 1.0% (218).

Several organochlorines were below the limit of detection in all samples, including beta-hexachlorocyclohexane (BHC), pentachloronitrobenzene, heptachlor, aldrin, endosulfan, and methoxychlor. Generally, organochlorine levels were similar to those from 12 wild chum salmon from BC (218). Most organochlorines from Old Crow chum salmon, including chlorobenzenes and chlordanes, were similar to those reported in chum salmon from BC (218). The main exception was that DDT levels in Old Crow samples were, on average, 2.8 times higher than in BC chum salmon (218). The study in BC found that exposure to organochlorines via fish consumption was generally low compared to available health guidelines (218).

Table 5 – Select Organochlorines in Old Crow Chum Salmon Samples

		% of Samples Above LOD	Geometric Mean (Min – Max)
Lipids	%	80	**0.78** (<LOD – 1.5)
1,2,4,5-Tetrachlorobenzene	ng/g	60	**0.0017** (<LOD – 0.0046)
1,2,3,4-Tetrachlorobenzene	ng/g	70	**0.0036** (<LOD – 0.0075)
Pentachlorobenzene	ng/g	100	**0.014** (0.0063 – 0.029)
Hexachlorobenzene	ng/g	100	**0.55** (0.088 – 1.2)
Heptachlor Epoxide B	ng/g	60	**0.0082** (<LOD – 0.032)
Oxychlordane	ng/g	100	**0.059** (0.022 – 0.13)
trans-Chlordane	ng/g	80	**0.066** (<LOD – 0.14)
cis-Chlordane	ng/g	100	**0.28** (0.094 – 0.70)
trans-Nonachlor	ng/g	80	**0.42** (<LOD – 0.85)
Dieldrin	ng/g	60	**0.04** (<LOD – 0.14)
Endrin	ng/g	50	**<LOD** (<LOD – 0.029)
cis-Nonachlor	ng/g	90	**0.15** (<LOD – 0.25)
2,4'-DDE	ng/g	30	**<LOD** (<LOD – 0.091)
4,4'-DDE	ng/g	100	**1.6** (0.42 – 5.2)
2,4'-DDD	ng/g	60	**0.053** (<LOD – 0.15)
4,4'-DDD	ng/g	90	**0.19** (<LOD – 0.48)
2,4'-DDT	ng/g	90	**0.23** (<LOD – 0.96)
4,4'-DDT	ng/g	70	**0.31** (<LOD – 1.6)
Mirex	ng/g	80	**0.033** (<LOD – 0.13)

The average lipid concentration in loche liver (Table 6) was 34% (ranging from 20 to 50%). These levels are similar to levels of lipids reported in loche liver samples from other Yukon lakes (means ranging from 21 – 42%), and lakes in the Sahtu region of the Northwest Territories (means ranging from 29 – 40% lipids) (249, 347).

Several organochlorines were below the limit of detection in all samples, including beta-hexachlorocyclohexane (BHC), aldrin, dieldrin, pentachloronitrobenzene, heptachlor, endrin, endosulfan, and methoxychlor. Generally, organochlorine levels, including chlorobenzenes, chlordanes, and DDE observed in Old Crow loche liver were less than half of the levels observed in Arctic burbot livers in the 1990s, where mean total chlorobenzene levels ranged from 28 to 68 ng/g lipid weight and mean DDE levels ranged from 27 to 1000 ng/g lipid weight (249). DDE levels observed in Old Crow loche liver were within the range observed in a 2005 study on loche liver from three southern Yukon lakes (means of 11, 18, and 0.32 ng/g tissue weight) (347). In the same study, mean total chlorobenzene levels ranged from 5.1 to 42 ng/g tissue weight (347). Loche liver from Old Crow were generally lower or similar to these levels.

Table 6 – Select Organochlorines in Old Crow Loche Liver Samples

	% of Samples Above LOD	**Geometric Mean** (Min – Max)	
	%	ng/g tissue	ng/g lipids
Lipids	100	**35** (20 – 50)	
1,2,4,5-Tetrachlorobenzene	100	**0.23** (0.14 – 0.33)	**0.68** (0.32 – 1.1)
1,2,3,4-Tetrachlorobenzene	100	**0.21** (0.17 – 0.32)	**0.61** (0.34 – 1.04)
Pentachlorobenzene	100	**0.64** (0.19 – 4.5)	**1.1** (0.76 – 1.3)
Hexachlorobenzene	100	**3.0** (1.9 – 6.8)	**8.7** (5.8 – 21)
Oxychlordane	30	**<LOD** (<LOD – 4.3)	**<LOD** (<LOD – 13)
cis-Nonachlor	90	**0.48** (<LOD – 2.2)	**1.4** (<LOD – 6.6)
trans-Nonachlor	50	**<LOD** (<LOD – 2.7)	**<LOD** (<LOD – 11)
4,4'-DDD	30	**<LOD** (<LOD – 3.0)	**<LOD** (<LOD – 9.3)
4,4'-DDE	100	**3.9** (0.76 – 24)	**11** (1.8 – 73)
4,4'-DDT	30	**<LOD** (<LOD – 1.1)	**<LOD** (<LOD – 3.3)
Mirex	80	**0.47** (<LOD – 1.2)	**1.4** (<LOD – 4.1)

With the exception of DDT, Health Canada, the WHO, and the EU do not have MRLs for organochlorines in fish (339, 340, 342). Both the Health Canada and US FDA MRLs for total DDT are 5 mg/kg (5000 ng/g) (339), which is far above the maximum total DDT level observed in Old Crow salmon (8.1 ng/g) and loche liver (28 ng/g). The US FDA has MRLs of 300 ng/g for Aldrin and Dieldrin, chlordanes, and heptachlor (341). Fish from Old Crow is more than 100 times lower than the Canadian standard for DDT in commercially sold fish.

When no MRL is available, as is the case for hexachlorobenzene and other chlorobenzenes, the EU recommends an MRL of 0.01 mg/kg (10 ng/g) or 0.01 mg/kg lipids if fat content exceeds 10% for all meats, and the WHO's Codex has the same MRL for some organochlorines in saltwater fish (340, 342). It should be noted that the EU MRL is a conservatively low guidance value and does not regulate market fish sales in any jurisdiction. Many market fish, including salmon and loche, have been found to exceed this level. Figure 1 compares the proportion of salmon exceeding the EU MRL for total chlorobenzenes from several regions in Canada (and Internationally) compared to those exceeding the level in Old Crow. For instance, the majority of commercial salmon samples analyzed in a 2004 study in Europe, Canada, USA, and Chile, had levels of HCB over this MRL (348). The BC study of wild and farmed salmon reported

total chlorobenzene levels below this threshold in all samples (218). However, a study of wild loche samples from the Canadian Arctic in the 1990s found that all samples exceeded this threshold (249). All samples of chum salmon and 20% of loche liver samples from Old Crow were below the MRL of 10 ng/g for total chlorobenzenes. Though loche liver samples did exceed this level, the observed chlorobenzene levels were below those reported in the Canadian north in the 1990s, and were similar to internationally available market fish.

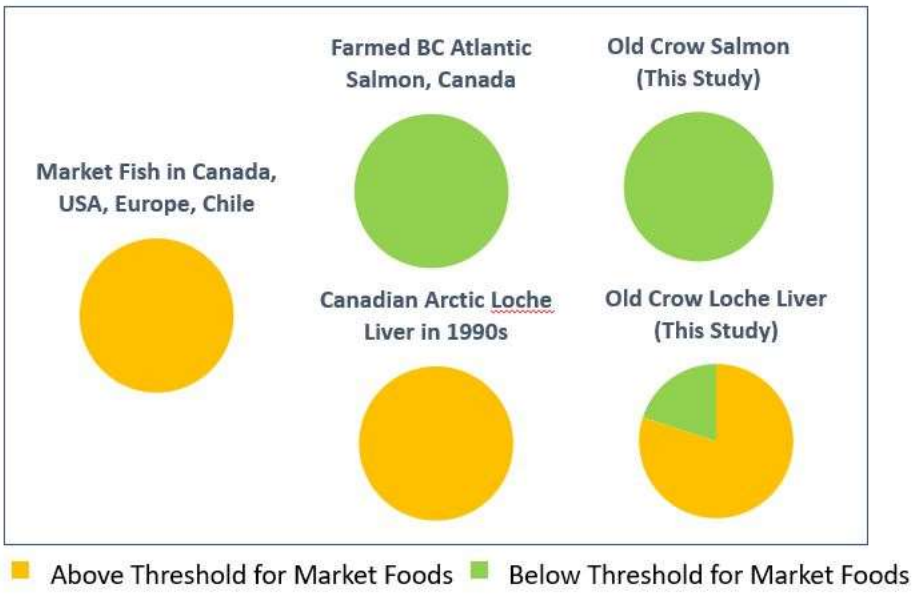


Figure 1 – Proportion of Fish Samples Exceeding 10 ng/g for Chlorobenzenes (218, 249, 342, 348)

Conclusion: wild salmon and loche from Old Crow continues to be a healthy food choice, with levels of pesticides within the normal range for the region, and below those found in many market fish.

Caribou

The results for organochlorine and lipid analysis of caribou samples collected in 2020 are shown in Appendix A, and Table 7 shows summary statistics for organochlorines where any samples were over the detection limit. Lipid levels in caribou varied depending on the tissue, with the highest average lipid concentrations reported in bone marrow (94%), followed by fat (67%), and then liver (4.5%). These levels are similar to levels of lipids reported in the Northwest Territories (means of 45 to 85% in fat and under 10% in liver), and to reindeer analyzed in Norway (means of 6% in liver, 80% in fat, and 72 to 92% in bone marrow) (219, 349).

Many organochlorines were below the limit of detection in all samples, including beta-hexachlorocyclohexane (BHC), aldrin, chlordanes, DDT, DDE, mirex, dieldrin, pentachloronitrobenzene, heptachlor, endrin, endosulfan, nonachlors, and methoxychlor. Hexachlorobenzene levels were typically lower than average HCB values observed in caribou in the Northwest Territories in the 1990s (33 to 110 ng/g lipids) (349) and Norwegian reindeer in 2013 (36 to 42 ng/g lipids in fat and bone marrow) (219). In a 2005 study looking at foods available at Alaska grocery stores, the sample of commercially-available

caribou bone marrow had HCB levels of 37 ng/g lipids, which is higher than the levels observed in Old Crow caribou in 2020 (223).

Table 7 – Select Organochlorines in Old Crow Caribou Tissue Samples Collected in 2020

	% of Samples Above LOD	Geometric Mean (Min – Max)	
	%	ng/g tissue	ng/g lipids
Bone Marrow			
Lipids	100	**94** (88 – 99)	-
1,2,4,5-Tetrachlorobenzene	78	**0.18** (<LOD – 0.54)	**0.16** (<LOD – 0.56)
1,2,3,4-Tetrachlorobenzene	67	**0.094** (<LOD – 0.22)	**0.092** (<LOD – 0.23)
Pentachlorobenzene	100	**0.54** (0.47 – 0.70)	**0.57** (0.49 – 0.67)
Hexachlorobenzene	100	**21** (13 – 33)	**23** (13 – 34)
Fat			
Lipids	100	**67** (49 – 81)	
1,2,4,5-Tetrachlorobenzene	44	**<LOD** (<LOD – 0.67)	**<LOD** (<LOD – 1.0)
1,2,3,4-Tetrachlorobenzene	22	**<LOD** (<LOD – 0.34)	**<LOD** (<LOD – 0.64)
Pentachlorobenzene	100	**0.72** (0.47 – 1.4)	**1.0** (0.73 – 1.9)
Hexachlorobenzene	100	**19** (10 – 30)	**28** (20 – 41)
Liver			
Lipids	100	**4.5** (3.6 – 5.9)	-
1,2,4,5-Tetrachlorobenzene	100	**0.50** (0.40 – 0.61)	-
1,2,3,4-Tetrachlorobenzene	100	**0.40** (0.34 – 0.54)	-
Pentachlorobenzene	100	**0.48** (0.38 – 0.75)	-
Oxychlordane	33	**<LOD** (<LOD – 0.59)	-
Hexachlorobenzene	100	**1.8** (1.0 – 2.6)	-

There is no MRL available for caribou or any other large terrestrial animal for chlorobenzenes, including HCB, in Canada. However, the EU does have an MRL for HCB that applies to wild terrestrial animals, including reindeer, (or 10 ng/g tissue of 10 ng/g lipids when fat content exceeds 10%) (342). It should be noted that the EU MRL is a conservatively low guidance value and does not regulate market or traditional foods in Canada. Levels of HCB were below 10 ng/g tissue for all caribou liver samples, and greater than 10 ng/g lipids for bone marrow and fat samples. Figure 2 compares the proportion of caribou samples exceeding the EU MRL for hexachlorobenzene from several regions in Canada and for reindeer in other regions, as well as market meats including beef and pork. The proportion of samples above this guidance value in Old Crow caribou is similar to that observed in similar northern terrestrial animals including caribou from the NWT, and reindeer in Norway and Russia (28, 219, 220). However, proportions are higher than those typically observed in market beef (350, 351). The threshold of 10 ng/g HCB in tissue or lipids is not a health-based guidance value, and does not take into account the amount or frequency at which something is eaten.

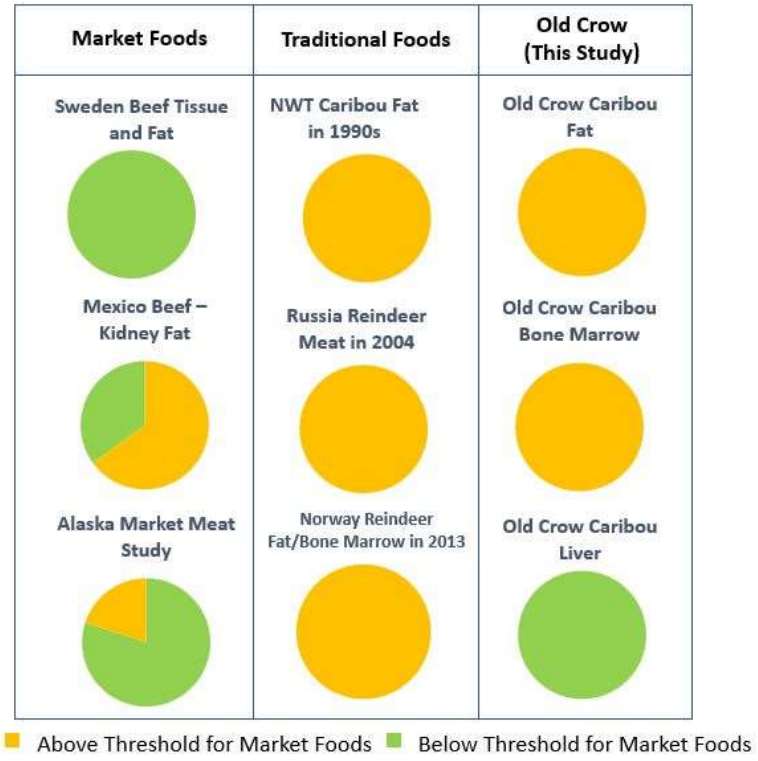


Figure 2 – Proportion of Caribou Samples Exceeding 10 ng/g for Chlorobenzenes (219, 220, 223, 349-351)

Levels of most organochlorine pesticides in northern biota have generally been decreasing since the Stockholm Convention banned the use of many of these contaminants in the early 2000s, however, HCB does not always follow this same trend (19, 352). Generally, HCB levels appear to be decreasing slowly or plateauing in Arctic biota (19). A generally stable trend was also observed in Old Crow caribou liver samples collected from 2002 to 2021, though all samples were well below 10 ng/g HCB (Figure 3). HCB concentrations in Old Crow caribou muscle were at or below the detection limit (0.6 ng/g) throughout this sampling period, with no trend observed.

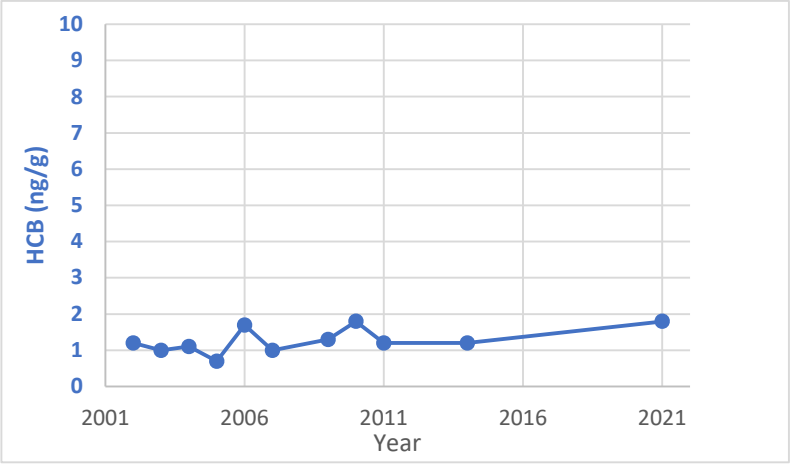


Figure 3 – Old Crow Caribou Liver HCB Concentrations from 2002 to 2021

Conclusion: Caribou had levels of pesticides in the range normally observed in the north but were higher than observed in some market foods. Further work is currently being conducted to determine whether consumption of these organs exceeds health-based guidance thresholds for HCB. Based on available information, caribou from Old Crow continues to be a healthy food choice

Moose

The results for organochlorine and lipid analysis of moose samples are shown in Appendix A and Table 8 shows the results any samples that were over the detection limit. Three moose samples have been submitted, each including three tissues. Lipid levels in moose varied depending on the tissue, from 89% and 88% in bone marrow and fat, respectively, to 4.9% in liver. These levels were within the same range as those reported in Old Crow caribou, and those reported for moose livers in the NWT (353).

Most organochlorines were below the limit of detection in all samples, including BHC, aldrin, DDT, DDE, mirex, dieldrin, pentachloronitrobenzene, heptachlor, endrin, endosulfan, nonachlors, and methoxychlor. Detectable organochlorine levels were lower in this sample than those observed in caribou. This difference may be attributable to dietary differences between moose and caribou – as airborne organochlorines have been found to accumulate in lichen (354, 355).

Table 8 – Select Organochlorines in Old Crow Moose Samples

	Number of Samples	% of Samples Above LOD	Geometric Mean (Min – Max)	
		%	ng/g tissue	ng/g lipids
Liver				
Lipids	3	100	**4.9** (2.5 – 4.9)	
1,2,4,5-Tetrachlorobenzene	1	100	**0.26**	
1,2,3,4-Tetrachlorobenzene	1	100	**0.21**	
Pentachlorobenzene	3	67	**0.012** (<LOD – 0.22)	
Hexachlorobutadiene	2	50	<LOD & 0.012	
Oxychlordane	3	33	**<LOD** (<LOD – 0.0063)	
Eldrin Aldehyde	2	50	<LOD & 0.031	
Hexachlorobenzene	3	100	**0.052** (0.044 – 0.29)	
Bone Marrow				
Lipids		100	**91** (89 – 92)	
1,2,4,5-Tetrachlorobenzene	1	100	0.39	0.44
1,2,3,4-Tetrachlorobenzene	1	100	0.35	0.39
Pentachlorobenzene	3	100	**0.14** (0.075 – 0.42)	**0.15** (0.082 – 0.47)
Hexachlorobutadiene	2	100	0.27 & 0.53	0.30 & 0.57
Hexachlorobenzene	3	100	**0.89** (0.46 – 1.6)	**0.98** (1.0 – 1.8)
Fat				
Lipids	3	100	**81** (79 – 86)	
Pentachlorobenzene	3	100	**0.18** (0.12 – 0.38)	**0.22** (0.14 – 0.49)
Hexachlorobutadiene	2	100	0.26 & 0.85	0.33 & 0.99
Hexachlorobenzene	3	67	**0.93** (<LOD – 1.7)	**1.1** (<LOD – 2.1)

Though no MRL applies to HCB in moose in Canada, the EU does have an MRL for HCB in wild terrestrial animals of 10 ng/g tissue of 10 ng/g lipids when fat content exceeds 10% (342). Levels of HCB were below 10 ng/g tissue or lipids for all three moose samples.

> **Conclusion: Moose from Old Crow continues to be a healthy food choice, with levels of pesticides within the normal range for the region and below market limits.**

Conclusion

The organochlorine assessment program in Old Crow traditional foods is currently ongoing. As of January, 2021, samples including river water, berries, salmon, loche, caribou, and moose have been analyzed for organochlorine levels. Further Chinook salmon sampling is proposed for summer 2022.

Based on these results, organochlorine levels in water, chum salmon, moose, and berries, are lower than thresholds for commercial foods available federally and internationally. Organochlorines in both berries and water are generally below or near the analytical detection limits. In salmon, though organochlorine levels are generally greater than the detection limits, most are similar to those observed in the neighbouring province of BC, where risk of health impacts due to dietary exposure was determined to be low. Levels of DDT were higher than those observed in BC, but below the standards for commercial fish sales. Organochlorine levels in pesticides were also lower than levels observed in commercial salmon from Canadian and international fisheries. Loche liver samples reported higher HCB concentrations than salmon tissue, however, levels were lower than those reported in samples of loche liver from northern lakes in the 1990s and early 2000s.

Levels of chlorobenzenes in Old Crow caribou tissue were similar to those reported in other northern regions, including the NWT, Norway, and Russia. However, levels of these contaminants were generally higher than those found in market meats such as beef. As with loche liver, concentrations of chlorobenzenes in caribou tissue were lower than those reported in the 1990s and early 2000s, though generally plateaued after this period. Levels of chlorobenzenes in moose tissue were generally lower than those observed in Old Crow caribou.

During the 2018 Old Crow biomonitoring study, elevated concentrations of HCB were observed in Old Crow when compared to the general (southern) Canadian population. Based on the results of this sampling program, elevated concentrations of HCB have been observed when compared to market foods in some caribou tissue samples. Though the levels are consistent with those observed in other parts of the north, this may contribute to differences observed between northern populations and those in the south. To evaluate this hypothesis, a model is being constructed to calculate dietary exposure levels and estimate the contribution of various traditional foods to HCB levels in the body. These estimates will be compared to available health-based guidelines.

Based on the organochlorine pesticide results included in this report, the health risks posed by the contaminant levels observed to date appear low, and the health and cultural benefits offered by traditional foods remain high.

Overall, these initial results reinforce that the health benefits of traditional foods generally outweigh contaminant risks. We look forward to working with community leaders and government representatives to make sure that these messages are brought back in ways that are useful and meaningful.

Appendix D – Select Short Plain Language Results Reports and Letters

Summary of Results

Contaminant Biomonitoring in Old Crow: Investigating the Links Between Contaminant Exposure, Nutritional Status, and Traditional Food

Traditional food is an important part of the diet for many Yukon residents, particularly First Nations, who traditionally harvest caribou, moose, fish, waterfowl, small game and many plants. Traditional food consumption among First Nations peoples is associated with improved nutrition, food security, and lower rates of chronic diseases; however, these foods can also pose potential risks via exposure to contaminants such as mercury and cadmium. A human biomonitoring survey was done in Old Crow in February 2019. This project is an initiative of the Vuntut Gwitchin Government and funded by the Northern Contaminants Program. The key messages are presented in this report.

Logistics and participation

- The research team spent 19 days in Old Crow (January 31st to February 18th, 2019) to complete the sampling for the biomonitoring project.
- A total of 77 participants agreed to participate, representing about 35% of residents living in Old Crow.
- Participants were aged from 13 to 76 years old, 44% males and 56% females, 56% smokers, with and average of the body mass index for adults of 28.
- A total of 178 samples were collected: 73 hair samples, 49 urine samples and 56 blood samples.

Biological Sample Analysis

- Participants' levels of mercury, cadmium or lead levels in blood and urine were generally lower than the health-based guidance values for these metals.
- Some participants (5%) had levels of mercury, lead or cadmium higher than the available guidance values. Follow-up testing and advice on how to lower exposure was offered.
- Despite having been banned in 2001, several POPs biomarkers (including the pesticides DDT and Hexachlorobenzene) were detected in almost all participants' blood samples.
- Urine samples had relatively high levels of manganese, an important nutrient and essential trace elements. This level appeared higher than observed in the Canadian general population.
- Levels of healthy omega-3 fatty acids, mainly ingested through fish consumption, were in the usual range for people living in Canada. Increasing access to these important nutrients could reduce the risks from cardiovascular disease and help the brain development of children.
    - Lake whitefish and cisco, which are both low in mercury, are especially rich in these healthy fats.
    - Lake trout can also be very rich in omega-3 fatty acids; but, Lake trout can sometimes have high mercury levels. Smaller Lake trout tend to have less mercury and have high levels of omega-3's.

Surveys

- Across the participants, 92% completed the survey on the traditional foods they ate in the previous year and 82% on the risk factors and health messages they had heard.
- The vast majority of participants had eaten traditional foods over the previous year. The species consumed by at least 80% of the participants are: caribou (94%) moose (93%), chinook (90%) and whitefish (82%).
- The majority of participants reported hearing the message that eating traditional foods contributes to a healthy, nutritious diet (86%) and that traditional foods can provide a significant variety of nutrients (96%).
- While smoking rate is 56%, 44% of the respondent had heard that reducing exposure to cigarette smoke will reduce cadmium exposure. In general (77%), participants had not heard health messages about caribou with high levels of cadmium.
- The majority of respondents reported caribou kidney and liver consumption rates of once or less per week, which may fall within the recommendation for the Porcupine herd of 25 kidneys and 12 livers per year.
- The community of Old Crow has issued recommendations for consumption of loche and inconnu of 1 to 2 servings per week for children and women of childbearing age. All children and women of childbearing age reported eating loche and inconnu less than twice per week, within the recommendation.

Summary

The majority of participants' exposure levels fell below the biomonitoring guidance values available for lead, cadmium, uranium, arsenic, and mercury. Most of the other contaminants measured in this project do not have guidance values to distinguish whether the participants' levels are probably safe. Although some participants had contaminant level higher than the guidance value, the observed levels are not associated with immediate risks for health. Such levels could, however, pose risks over time. Therefore, these participants were offered follow-up testing and additional advice on how they can lower their exposure. Across participating communities in the North, lead (in blood and urine) appeared higher than normally observed in other parts of Canada. This is also what is observed in Old Crow. We are currently investigating the source of lead. It worth noting that the use of lead shot can increase the levels of lead in some traditional foods, especially if the animals are not cleaned carefully soon after it is shot. It is safer to use lead-free (steel, bismuth, or iron) shot to hunt. The levels observed for the other contaminants (e.g., cadmium, mercury) were generally lower or similar to the levels seen in other biomonitoring studies in Canada. Therefore, for most participants, the health risks posed by these contaminants appears to be low. Furthermore, the levels of some nutrients appeared higher than seen in other studies in Canada. Overall, these results reinforce that the health benefits of traditional foods generally outweigh contaminant risks. We look forward to working with community leaders and government representatives to make sure that these messages are brought back in ways that are useful and meaningful.

For any questions or comments:

Brian Laird
University of Waterloo

Megan Williams
Vuntut Gwitchin Government

UNIVERSITY OF WATERLOO
FACULTY OF APPLIED HEALTH SCIENCES
School of Public Health and Health Systems

October 31st, 2019

University of Waterloo

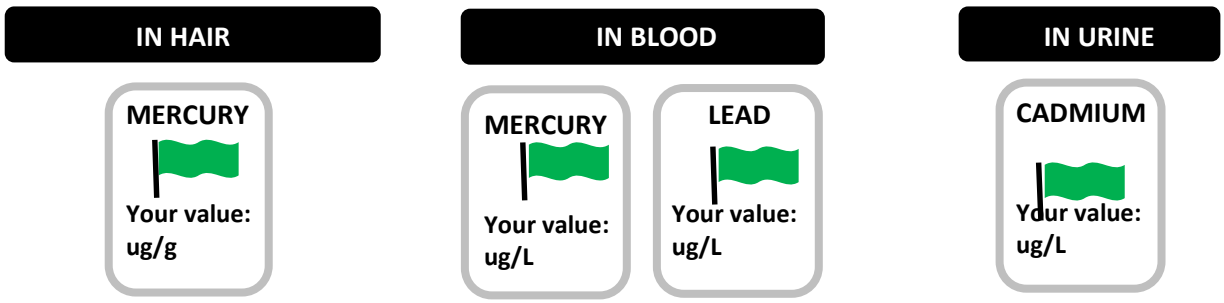
To: (Participant Name)

Subject: Results from the Old Crow Biomonitoring Project

In February 2019, you took part in a research project, funded by the Northern Contaminants Program, studying the levels of contaminants participants are exposed to by consuming foods harvested in the community of Old Crow. Some foods shown to have higher levels of contaminants are also important sources of beneficial nutrients. To understand the balance between these benefits and risks, it is important to study contaminants and nutrients. To help with this research, you provided hair, urine, and/or blood samples to a research team led by Dr. Brian Laird. In this letter you will find the results from the samples you provided and additional information to help you to understand what your results mean. When you participated you had the option to agree that the research team could keep your sample(s) so that more contaminants or nutrients could be measured in the future. If you agreed and we receive any additional information about your samples, we will provide another letter with those results too.

Here is a preview of your results for mercury, cadmium, and lead.

You provided: [ ] Hair [ ] Blood [ ] Urine



These results mean that your levels of mercury, lead, and cadmium were in the normal range.
These levels are well below those known to cause health problems.

Even though these contaminants are sometimes found in country foods, **the benefits of eating country foods most often outweigh the risks posed by these low exposures.**

The rest of your results can be found in a separate document enclosed in this letter.

As the project continues, Dr. Laird's research team will be able to provide more information on the exposure levels of people living in Old Crow. Information discovered through this research will first be shared with the VGG and community members.

These results only cover your exposure levels at the time when samples were collected, and may not represent your values over the whole year. This letter does not replace regular visits to your doctor or health care professional. If you have any health concerns, you should discuss these with a health professional. You may wish to provide your health care provider with a copy of these results for your health records. In the future, these results may be useful to you, so we recommend keeping this letter in a safe place for long-term storage in case you need it.

If you have any questions or comments, we will be pleased to talk with you.

Thank you very much for your participation in this project.

To follow the project:

Facebook:

Twitter:

Brian Laird
Principal Investigator

Mallory Drysdale
PhD Candidate

UNIVERSITY OF WATERLOO
FACULTY OF APPLIED HEALTH SCIENCES
School of Public Health and Health Systems

CONFIDENTIAL RESULTS

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YOUR RESULTS

Name:
Date of Participation: February, 4th - 7th, 2019
Samples Provided: [ ] Hair [ ] Blood [ ] Urine

To understand your results, we compared them with Canadian guidelines for each contaminant. For example, the health guidelines from Health Canada recommend limits for levels of mercury in blood (20 ug/L or 8 ug/L for children or woman of 45 years old and below), lead in blood (100 ug/L or 50 ug/L for children or woman of 45 years old and below).

Only some of the contaminants measured in this study have clear health guidelines; but, most have population 95th percentiles that describe the range of normal exposures in Canada. The colour code on Page 2 helps explain what these results mean. For each of the yellow and red contaminants, you may want to lower your levels. We provide more information on how people can lower their exposure to these contaminants.

Some measurements we made do not have either health guidelines or 95th percentiles. Not having such reference values makes it difficult to determine what these results mean for your health. It is important to remember that just because a contaminant is measured in the body, it does not mean that the contaminant will cause health problems.

Upon request, we will provide you with all of the values for the 95th percentiles that were used when comparing your results to the normal range observed in Canada, according to your age and sex.

Colour indicators

On the next pages, each of your results has been given a colour code to help you understand what these levels mean.

	What do my results mean?	What can I do?
	Your result was less than all available health guidelines for this contaminant. There are no known health risks at this exposure level. Your result was less than all of the 95th percentiles available for this contaminant. This means that your result was in the normal range observed in Canada.	We do not recommend that you do anything differently.
	There is no available health guideline for this contaminant. But, your result was higher than at least one of the 95th percentiles available for this contaminant. This means that your result was higher than the normal range observed in Canada.	We do not recommend that you do anything differently.
	Your result was less than all available health guidelines for this contaminant. There are no known health risks at this exposure level. But, your result was higher than at least one of the 95th percentiles available for this contaminant. This means that your result was higher than the normal range observed in Canada.	You may want to lower your exposure. We have included some advice on how you could lower your exposure.
	Your result is above the health guideline for this contaminant. If your exposure level stays this high, it could put your health at risk.	We recommend that you lower your exposure. We have included some advice on how you could lower your levels. We would like to meet with you to answer any of your questions and talk with you more about your result. We recommend that you bring a copy of this letter to your health center.
	Very little is known about this contaminant. The population 95th percentile is not known. There are no health guidelines available.	We do not recommend that you do anything differently.

Legend for your results
If "<LOD": Level very low so it was not detected by the machine.

Participant ID:

MEASUREMENTS WITH HEALTH GUIDELINES AND 95th PERCENTILES

METALS	
YOUR HAIR RESULTS (ug/g)	
Contaminants	
Mercury	
YOUR BLOOD RESULTS (ug/L)	
Contaminants	
Cadmium Lead Mercury	
YOUR URINE RESULTS (ug/L)	
Contaminants	
Cadmium Lead Uranium	

MEASUREMENTS WITH 95TH PERCENTILES BUT NO HEALTH GUIDELINES

METALS	
YOUR BLOOD RESULTS (ug/L)	
Contaminants	
Arsenic Uranium	
Nutrients	
Cobalt Copper Manganese Nickel Selenium Zinc	
YOUR URINE RESULTS (ug/L)	
Contaminants	
Arsenic Cesium Thallium Vanadium Uranium	
Nutrients	
Cobalt Copper Manganese Nickel Selenium Zinc	

Participant ID:

MEASUREMENTS WITH 95th PERCENTILES BUT NO HEALTH GUIDELINES

PERFLUOROALKYLATED SUBSTANCES	
YOUR SERUM RESULTS (ug/L)	
Contaminants	
Perfluorobutanoic acid (PFBA)	
Perfluorohexanoic acid (PFHxA)	
Perfluorooctanoic acid (PFOA)	
Perfluorononanoic acid (PFNA)	
Perfluorodecanoic acid (PFDA)	
Perfluoroundecanoic acid (PFUnDA)	
Perfluorobutane sulfonate (PFBS)	
Perfluorohexane sulfonate (PFHxS)	
Perfluorooctane sulfonate (PFOS)	

Participant ID:

MEASUREMENTS WITH 95th PERCENTILES BUT NO HEALTH GUIDELINES

PERSISTENT ORGANIC POLLUTANTS			
YOUR BLOOD RESULTS (ug/L of PLASMA)		**YOUR BLOOD RESULTS (ug/L of PLASMA)**	
Contaminants		**Contaminants**	
PCB , Aroclor 1260		PBDE # 15	
PCB # 28		PBDE # 17	
PCB # 52		PBDE # 25	
PCB # 66		PBDE # 28	
PCB # 74		PBDE # 33	
PCB # 99		PBDE # 47	
PCB # 101		PBDE # 99	
PCB # 105		PBDE # 100	
PCB # 118		PBDE # 153	
PCB # 128		PBB # 153	
PCB # 138		Aldrin	
PCB # 146		gamma-Chlordane	
PCB # 153		alpha-Chlordane	
PCB # 156		cis-Nonachlor	
PCB # 163		trans-Nonachlor	
PCB # 167		gamma-HCH	
PCB # 170		beta-HCH	
PCB # 178		Hexachlorobenzene	
PCB # 180		Mirex	
PCB # 183		Oxychlordane	
PCB # 187		p,p'-DDE	
PCB # 194		p,p'-DDT	
PCB # 201		Toxaphene Parlar # 26	
PCB # 203		Toxaphene Parlar # 50	
PCB # 206			

Participant ID:

MEASUREMENTS WITHOUT HEALTH GUIDELINES OR 95th PERCENTILES

FATTY ACIDS	
YOUR PLASMA RESULTS (ug/L)	
Nutrient	
Omega-3	

METALS	
YOUR URINE RESULTS (ug/L)	
Contaminant	
Aluminium Barium Beryllium Gallium Lithium Rubidium Strontium	
Nutrient	
Chromium Iron	
YOUR BLOOD RESULTS (ug/L)	
Contaminant	
Aluminium Barium Beryllium Cesium Gallium Lithium Rubidium Strontium Thallium Vanadium	
Nutrient	
Chromium	

Additional Information

Definitions

- **Contaminant:** Polluting substance found in the environment, animals, or people.
- **Essential trace element:** A type of nutrient the body needs to be healthy. Examples include copper, iron, manganese, and zinc.
- **Metal:** Chemical elements naturally present in the environment. Examples include essential trace elements, and toxic metals, like mercury.
- **Nutrient:** Substances that the body needs to be healthy. Examples include vitamins, essential trace elements, and omega-3 fatty acids.
- **Omega-3 fatty acids:** Healthy fats present in some country foods and some store-bought foods. They are needed for proper brain development in children and good heart health in adults. Fish and seafood are some of the best sources of these healthy fats.
- **Persistent Organic Pollutants (POPs):** Man-made chemicals that can harm human and environmental health. Many of these chemicals are decreasing in the environment since their global ban in 2001. Examples include pesticides like DDT and industrial chemicals like PCBs.
- **Perfluoroalkylated Substances (PFAS):** Man-made chemicals that can harm human and environmental health. These are found in many consumer products including fire-fighting foams and cleaning products.

How to lower your levels

Some of your contaminant/nutrient levels may have been higher than we usually see in the general population of Canada. ***This does not mean that your health is at risk***. But, you may want to lower your exposure. We have included some information describing what you could do to try to lower your levels of contaminants:

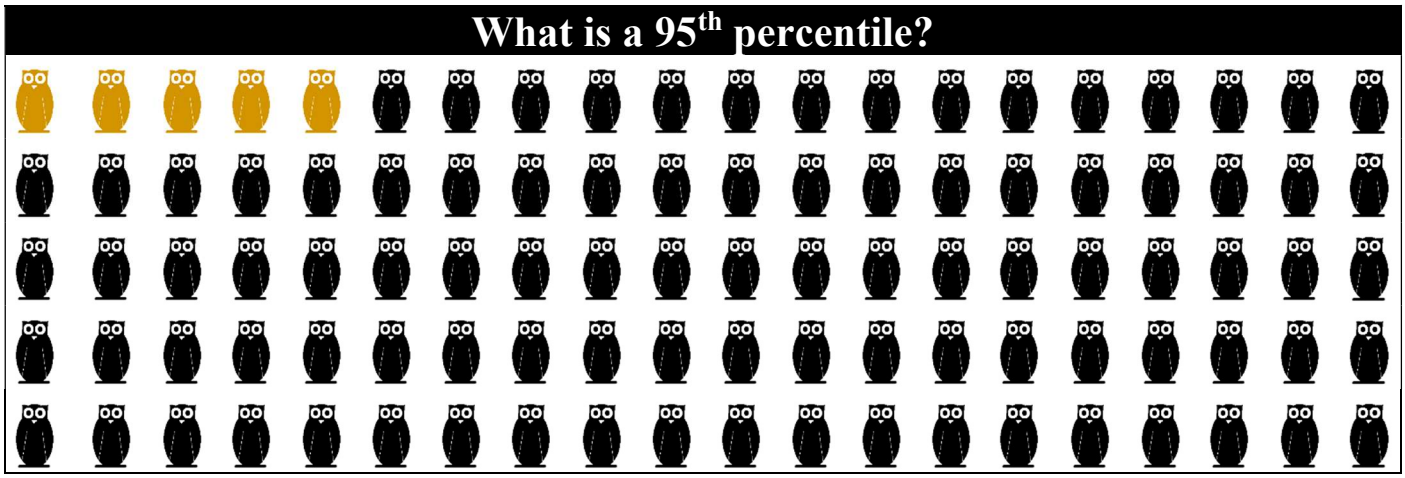
Recommendations:

- Eating a healthy diet rich in zinc, iron, and calcium can help reduce many contaminants levels over time (cadmium, lead).
- Reducing your exposure to tobacco smoke (from smoking and second hand smoke) will reduce some contaminants, such as cadmium.
- Some organs (liver/kidney) of moose and caribou might also contain high cadmium levels, but meat is always a safe and healthy alternative.
- Using lead-free ammunition can also help lower your lead exposure.
- Choosing small fish over big fish can lower your mercury exposure. Recommendations on fish consumption can be found on the Yukon Governments' website: http://www.hss.gov.yk.ca/pdf/mercuryfish_en.pdf
- Choosing non-predatory fish (whitefish, grayling, suckers, salmon, and inconnu) over predatory fish (jackfish, lake trout, and loche/burbot) can also lower your mercury exposure. Public health messages on fish can be found on the Yukon Governments' website: http://www.hss.gov.yk.ca/mercury.php
- Bring water with you on the land. Choose the treated water over the untreated water on the land. Municipal drinking water is tested regularly for several chemicals, including uranium, and is safe to drink.
- If you are taking a multi-vitamin and your level of some nutrients were higher than usual, you may want to talk to your doctor about your choice of multi-vitamin.
- You can get additional information about contaminants on the Factsheets (ToxFAQs) from the Agency of Toxic Substances and Disease Registry, a branch of the U.S. Centers of Disease Control. Each of these short factsheets summarize answers to the most commonly asked questions about contaminants. https://www.atsdr.cdc.gov/toxfaqs/Index.asp

What is a 95th percentile?

In statistics, a percentile lets you know where your data stands in relation to everyone else's data. The number of the percentile tells you how many people have scores at or below your score. For example, in the context of this study, the normal range has been set from the 95th percentile of exposure from the National study. This means that 95 out of 100 people, or almost all the people, had data at or below this level. The comparative percentiles used in this study are from the Canadian Health Measures Survey[3] and the First Nations Biomonitoring Initiative[4].

If your result is less than the 95th percentile, this means your value is represented by one of the black owls in the figure below; your score is within the normal range observed in Canada. If your result is above the 95th percentile, this means value is represented by one of the yellow owls in the figure below; your result is higher than the normal range observed in Canada.



[3] https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/pdf/pubs/contaminants/chms-ecms-cycle2/chms-ecms-cycle2-eng.pdf

[4] https://www.afn.ca/uploads/files/afn_fnbi_en_-_2013-06-26.pdf

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School of Public Health and Health Systems

Summary of Preliminary Results

Contaminant Biomonitoring in Old Crow: Measuring Pesticide Levels in Traditional Foods

Traditional food is an important part of the diet for many Yukon residents, particularly First Nations, who traditionally harvest caribou, moose, fish, waterfowl, small game and many plants. Traditional food consumption among First Nations peoples is associated with improved nutrition, food security, and lower rates of chronic diseases; however, these foods can also pose potential risks via exposure to contaminants. To measure the levels of some contaminants and nutrients in the community of Old Crow, a human biomonitoring survey was done in February 2019. Blood levels of hexachlorobenzene (HCB), a type of organochlorine pesticide, were found at higher concentrations in people in Old Crow than in the general Canadian population and other First Nations communities (166). Many organochlorine pesticides, including HCB, have been banned for international use for more than a decade, but can remain in the environment for long periods of time. This report includes the initial results for pesticide analysis of samples including river water, berries, and fish tissue muscle. The remaining results will be returned to the community in fall 2021 or winter 2022. This project is an initiative of the Vuntut Gwitchin Government and funded by the Northern Contaminants Program.

Project Logistics

- Sample collection by local harvesters began in July, 2020 and is planned to continue until fall 2021.
- As of March, 2021, the following samples have been collected:
    - Three water samples from the Porcupine and Crow Rivers
    - One moose sample (liver, fat, and bone)
    - Nine caribou samples (liver, fat, and bone)
    - Ten chum salmon samples (muscle)
    - Ten loche samples (liver)
    - Five berry samples
- As of March, 2021, pesticide levels have been measured in water, chum salmon, and berries. Remaining samples, including moose, caribou, and loche, are currently being analyzed.
- The full results of this project will be returned to the community by winter 2022.

Results

- Levels of most organochlorine pesticides, including DDT and chlordane, in water and berries were generally too low to be measured.
- Some pesticides, including chlorobenzenes, a group of pesticides that includes HCB, were detected in river water. However, the levels of these contaminants were well below recommended limits for safe drinking water. River water is not the primary source of drinking water in the community.
- Some pesticides, including chlorobenzenes, were detected in berry samples. The levels of these pesticides were well below levels recommended in market berries by Health Canada.

- Most pesticides in Old Crow chum salmon were at similar levels to salmon from British Columbia. In that study, risks from eating salmon was very low (218).
- DDT level in Old Crow chum salmon were higher than in salmon from BC. But, all pesticides in salmon were below levels recommended for market fish or meats by Health Canada and other regulatory bodies (see Figure 1).

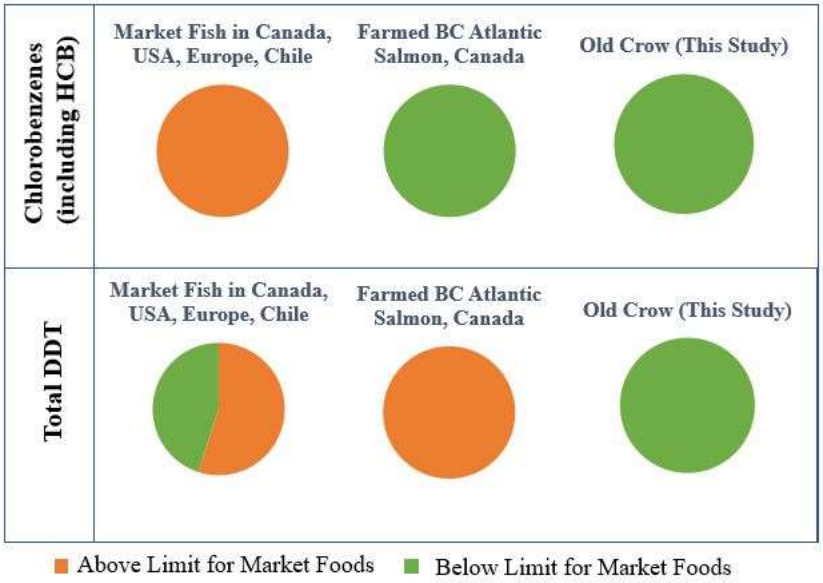

Figure 1 – Proportion of Salmon Samples Exceeding Lowest Limit for Pesticides in Meats (218, 342, 348)

Summary

Organochlorine pesticide levels in river water, berries, and salmon were below all available guidelines. Most organochlorine pesticides were too low to be detected in both water and berries. Though many organochlorine pesticides were detected in salmon samples, the levels were generally similar to salmon found in British Columbia. Though DDT levels in salmon were higher than those observed in British Columbia, blood DDT levels in Old Crow were low (below the detection limit), and within the range of those reported in the general Canadian population and other First Nations communities (166). In all three foods, the levels of organochlorine pesticides were lower than Canadian and international limits for pesticides in market foods. The results of this study will be used to estimate community exposure levels to pesticides and healthy nutrients from traditional food. Based on these preliminary results, the risks posed by organochlorine pesticides in Old Crow traditional foods appears to be low. We look forward to working with community leaders and government representatives to make sure that these messages are brought back in ways that are useful and meaningful.

For any questions or comments:

Brian Laird Jeremy Brammer

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School of Public Health and Health Systems

Organochlorines in Old Crow Traditional Foods - Summary of Results

The Project: A biomonitoring study was done in Old Crow from 2018-2020. Blood levels of hexachlorobenzene (HCB), a type of pesticide, were found at higher levels in people in Old Crow than in southern First Nations communities and the general Canadian population. The use of HCB and some other organochlorine pesticides has been banned for nearly 20 years, and levels of these pesticides are generally decreasing in the environment. However, they are still being found in some plants and animals, including those in the North. Based on feedback from the community, this project was designed to measure levels of HCB and other pesticides in some commonly eaten traditional foods to help identify the source for the higher levels found in Old Crow.

What was done?: Samples of traditional foods, including water from the Porcupine and Crow Rivers, wild berries, chum salmon (meat), loche (liver), caribou (bone marrow, fat, and liver), and moose (bone marrow, fat, and liver) were collected and analyzed for levels of HCB and other pesticides.

What was found?:

WATER: Levels of most measured pesticides were too low to be detected in river water. When pesticides were detected, they were well within the guidelines for drinking water.

BERRIES: Pesticide levels, including HCB, in berries near Old Crow were generally low, and wild berries continue to be a healthy food choice.

FISH: Wild chum salmon meat and loche liver from Old Crow continue to be healthy food choices, with levels of pesticides within the normal range for the region, and below those found in many market fish.

MOOSE: Moose fat, bone marrow, and liver from Old Crow continue to be a healthy food choice, with levels of pesticides within the normal range for the region and below market limits.

CARIBOU: Caribou fat, bone marrow, and liver had levels of pesticides in the range normally found in the North but were higher than in some market foods. Based on available information, caribou fat, bone marrow, and liver from Old Crow continue to be a healthy food choices.

Overall, these initial results reinforce that the health benefits of traditional foods generally outweigh contaminant risks.

What's next?: Results are still coming in for the full list of pesticides in moose, caribou, and new whitefish samples. These results will be brought back to the community once they are received. Because a single source of high HCB levels was not identified, more work will be done in 2021/2022 to calculate how much HCB community members in Old Crow are eating in a combination of traditional foods and to see whether these levels are higher than health-based guidelines. These results will help to shed some light on whether HCB levels in some northern foods are associated with the higher HCB levels in blood samples of people from Old Crow.

For any questions or comments:

Brian Laird

Jeremy Brammer

HEXACHLOROBENZENE IN OLD CROW TRADITIONAL FOODS

Mary Gamberg (Gamberg Consulting)
Mallory Drysdale (U Waterloo)

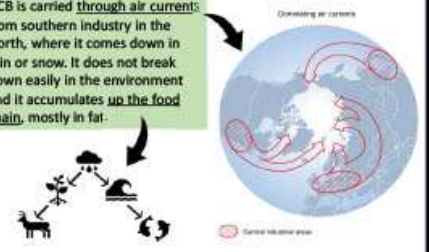
Dr. Brian Laird (U Waterloo)
Jeremy Brammer (VGG, ECCC)

HEXACHLOROBENZENE (HCB): What is it?

- A type of **pesticide/fungicide**
- Use was **banned internationally** under the Stockholm Convention in 2001
- Exposure to very high levels can cause damage to the liver and effects on thyroid
- Generally found in **fatty tissue**

HCB: How does it get to Old Crow?

HCB is carried through air currents from southern industry in the North, where it comes down in rain or snow. It does not break down easily in the environment and it accumulates up the food chain, mostly in fat.



SAMPLING

Analysis is Finished:
- River water
- Caribou (bone marrow, fat, liver)
- Chum salmon (meat)
- Loche (liver)
- Berries

Samples were chosen based on:

- Being a **commonly eaten traditional food** in Old Crow
- Targeting **fatty tissue** where possible

Analysis is Ongoing:
- Whitefish (meat)
- Moose (bone marrow, fat, liver)

KEY MESSAGES/NEXT STEPS

- We will have more results in 2022, including more pesticide results and modeling to look at how much HCB people are eating in traditional foods
- Levels of HCB in Old Crow traditional foods are **similar to levels seen in traditional foods in other northern regions**
- Based on available information, Old Crow berries, chum salmon, loche liver, and caribou and moose bone marrow, fat, and liver **continue to be healthy food choices**

Overall, these initial results reinforce that **the health benefits of traditional foods generally outweigh contaminant risks.**

Contaminant and Nutrient Biomonitoring in Old Crow

This project began due to community questions about higher levels of some contaminants (cadmium and mercury) in certain traditional foods. Our team was in the community in 2019 measuring contaminant and nutrient levels in **hair, blood, and urine**. We also ran **surveys** asking about traditional foods, lifestyle, and health messages.

The biomonitoring study found that Almost everyone's levels fell **below the health guidelines** for mercury, cadmium, and lead and most contaminants and nutrients were similar to other parts of Canada.

A small group of contaminants, including hexachlorobenzene, lead, cobalt, and manganese, were higher in Old Crow than in the general Canadian population and southern First Nations communities.

Project Purpose

1. **Measure HCB levels** in commonly eaten traditional foods
2. Find possible **sources for high HCB** levels found in Old Crow

Project Timeline

2020
- Design project with community
- Traditional food sampling begins

2021
- Traditional food sampling ends
- Analyze results
- Community gathering

2022
- Modeling
- Final report

RESULTS: Berries and River Water

- River water from Crow and Porcupine Rivers
- Cranberries, blueberries, salmonberries, crowberries
- Most pesticides were too low to be measured
- All pesticide levels were within drinking water limits and limits for market foods

RESULTS: Fish

- HCB levels in chum salmon and loche liver were similar to BC wild and farmed chum salmon and loche from other Arctic areas
- HCB in chum salmon was well below market guidelines for meats
- HCB levels in loche liver were lower than found in many market fish from Canada, but higher than some market fish guidelines

Wild chum salmon meat and loche liver from Old Crow continue to be healthy food choices, with levels of pesticides within the normal range for the region, and below those found in many market fish

RESULTS: Moose

- Measured HCB in one sample each of bone marrow, fat, liver – with more incoming

Moose fat, bone marrow, and liver from Old Crow continue to be a healthy food choice, with levels of pesticides within the normal range for the region and below market limits.

RESULTS: Caribou

- Measured HCB in caribou bone marrow, liver, and fat
- HCB levels in Old Crow caribou organs were similar or lower than caribou from other northern regions and higher than guidelines for beef in some markets

Caribou fat, bone marrow, and liver had levels of HCB in the range normally found in the North but were higher than in some market foods. Based on available information, caribou fat, bone marrow, and liver from Old Crow continue to be a healthy food choices

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Factors Linked to Levels of Metals and a Pesticide in the Sahtú Region

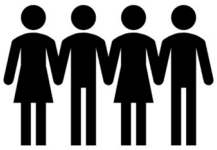
THE PROJECT

A human biomonitoring study was done in Old Crow, Yukon as well as the Sahtú and Dehcho regions of the NWT from 2016-2020. Levels of the pesticide **hexachlorobenzene (HCB)**, and two metals (**cobalt and lead**) were found at higher levels in the Sahtú participants than elsewhere in Canada. The metal **manganese** was also found at higher than usual levels in Old Crow.

Lead and HCB are contaminants, while manganese and cobalt are essential metal nutrients, but can pose health risks when levels are high. Based on community feedback, this project is studying why levels of these contaminants and nutrients were higher than in other parts of Canada.

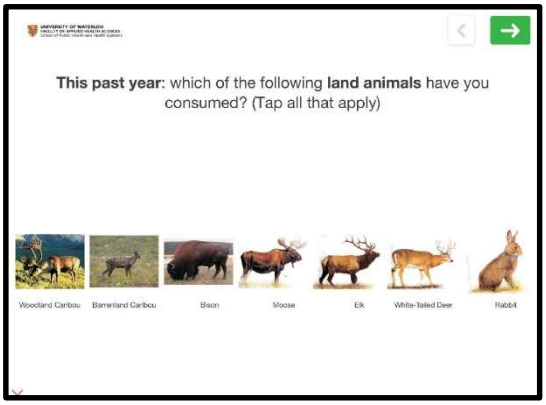
METAL AND HCB LEVELS IN PEOPLE

Though levels of HCB, lead, cobalt, and manganese were higher than usual, the majority of participants still had levels below the relevant health guidance limits or reference value.



WHAT WAS DONE?

We compared participants' levels of lead, manganese, cobalt, and HCB in blood and urine to their answers to survey questions about which traditional/country foods they eat, and whether they smoke cigarettes. In Old Crow, the study also looked at drinking untreated river water, using lead ammunition for hunting, and taking vitamins. These results tell us whether people who eat a certain traditional/country food, smoke, or have another lifestyle factor (e.g. take vitamins) have different levels of contaminants than those who don't.



KEY MESSAGES AND RECOMMENDATIONS

SAHTÚ, DEHCHO, & OLD CROW

SMOKING: Sahtú participants who smoked cigarettes had higher levels of lead urine than non-smokers. Reducing your exposure to tobacco smoke lowers your exposure to some contaminants.

MOOSE AND CARIBOU ORGANS: Sahtú participants who ate caribou fat and bone marrow had higher levels of HCB in blood, and lead in urine. In other northern regions, there were links between eating moose and caribou organs and higher levels of manganese, lead, and HCB in blood. Organs, including blood, kidneys, and liver, are good sources of both protein and iron.

FISH: In other northern regions, participants who ate lake trout and whitefish had lower levels of lead in blood and urine. Fish, such as lake trout, are important sources of omega-3 fatty acids and other nutrients.

OLD CROW ONLY

DRINKING UNTREATED RIVER WATER: Old Crow participants who said they sometimes or often drink untreated river water had higher levels of lead and manganese in blood. Water that has been tested and treated is the safest source for drinking water.

TAKING VITAMINS: Old Crow participants who said they take a daily multivitamin had lower levels of lead and higher levels of cobalt, in blood. Cobalt is a part of Vitamin B12. A healthy diet and adequate vitamins intake help to keep contaminant levels low.

LEAD AMMUNITION FOR HUNTING: Most Old Crow participants did not know what kind of ammunition was used for hunting, and therefore our research on the link between lead levels and ammunition was inconclusive. Using lead-free ammunition can help to lower lead exposure.

Further study is needed to provide clarity and guidance with respect to the consumption of fish and moose and caribou organs in relation to HCB levels.

Traditional foods continue to be an important source of nutrients and other health benefits. The health benefits of traditional foods generally outweigh contaminant risks.

For any questions or comments, please contact:

Brian Laird (University of Waterloo)

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Factors Linked to Levels of Metals and a Pesticide in the Dehcho Region

The Project: A human biomonitoring study was done in Old Crow, Yukon as well as the Dehcho and Sahtú regions of the NWT from 2016-2020. Levels of lead, cobalt and manganese (metals) were found at higher levels in Dehcho participants than elsewhere in Canada. The pesticide hexachlorobenzene (HCB), was also found at higher than usual levels in Old Crow participants. Lead and HCB are contaminants, while manganese and cobalt are essential metal nutrients, but can pose health risks when levels are high. Based on community feedback, this project is studying why levels of these contaminants and nutrients were higher than in other parts of Canada.

METAL AND HCB LEVELS IN PEOPLE

Though levels of HCB, lead, cobalt, and manganese were higher than usual, the majority of participants still had levels below the relevant health guidance limits or reference value.

What was done?: We compared participants' levels of lead, manganese, cobalt, and HCB to their answers to survey questions about eating traditional/country foods, and smoking. In Old Crow, the study also looked at drinking untreated water, using lead ammunition for hunting, and taking vitamins.

Key Messages and Recommendations:

SAHTÚ, DEHCHO, & OLD CROW

SMOKING: Participants in the Dehcho region who smoked cigarettes had higher levels of lead in blood than non-smokers. Reducing your exposure to tobacco smoke lowers your exposure to some contaminants.

MOOSE AND CARIBOU ORGANS: Dehcho participants who ate moose kidneys had higher levels of HCB in blood. In other northern regions, there were links between eating moose and caribou organs and higher levels of manganese, lead, and HCB in blood. Organs, including blood, kidneys, and liver, are good sources of both protein and iron.

FISH: Dehcho participants who ate lake trout had lower levels of lead in urine. In other northern regions, participants who ate whitefish had lower levels of lead in blood and urine. Fish, such as lake trout, are important sources of omega-3 fatty acids and other nutrients.

OLD CROW ONLY

DRINKING UNTREATED RIVER WATER: Old Crow participants who said they sometimes or often drink untreated river water had higher levels of lead and manganese in blood. Water that has been tested and treated is the safest source for drinking water.

TAKING VITAMINS: Old Crow participants who said they take a daily multivitamin had lower levels of lead and higher levels of cobalt, in blood. Cobalt is a part of Vitamin B12. A healthy diet and adequate vitamins intake help to keep contaminant levels low.

LEAD AMMUNITION FOR HUNTING: Most Old Crow participants did not know what kind of ammunition was used for hunting, and therefore our research on the link between lead levels and ammunition was inconclusive. Using lead-free ammunition can help to lower lead exposure.

Further study is needed to provide clarity and guidance with respect to the consumption of fish and moose and caribou organs in relation to HCB levels. Traditional foods continue to be an important source of nutrients and other health benefits. The health benefits of traditional foods generally outweigh contaminant risks.

For questions or comments, contact Dr. Brian Laird at the University of Waterloo

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Factors Linked to Levels of Metals and a Pesticide in Old Crow

STUDY SUMMARY: Further study is needed to provide clarity and guidance with respect to the consumption of fish and moose and caribou organs in relation to hexachlorobenzene (HCB) levels. Traditional foods continue to be an important source of nutrients and other health benefits. The health benefits of traditional foods generally outweigh contaminant risks.

The Project: A biomonitoring study was done in Old Crow, Yukon as well as the Dehcho and Sahtú regions of the NWT from 2016-2020. Levels of hexachlorobenzene ((HCB), a type of pesticide), and lead, cobalt and manganese (metals) were found at higher than usual levels in Old Crow. Lead and HCB are contaminants, while manganese and cobalt are essential metal nutrients, but can pose health risks when levels are high. Based on community feedback, this project is studying why levels of these contaminants and nutrients were as high as they were.

What was done?: We compared participants' levels of lead, manganese, cobalt, and HCB with their answers to survey questions about eating traditional foods, smoking, drinking untreated river water, using lead ammunition for hunting, and taking vitamins. We also compared these results from Old Crow to what was seen in the Dehcho and Sahtú regions of the NWT from 2016 to 2018.

Key Messages and Recommendations:

METAL & HCB LEVELS: Though levels of HCB, lead, cobalt, and manganese were higher than the general Canadian population, the majority (>95%) of participants had levels below health guidance limit for lead.

SMOKING: We did not see a link between smoking and these contaminants in Old Crow, but there were links between smoking cigarettes and higher levels of lead in blood in the Dehcho and Sahtú regions. Reducing your exposure to tobacco smoke lowers your exposure to some contaminants.

DRINKING UNTREATED RIVER WATER: Participants who said they drink untreated river water (sometimes or often) had higher levels of lead and manganese in blood. Both of these metals can be at higher levels in local rivers during spring runoff. Water that has been tested and treated is the safest source for drinking water.

TAKING VITAMINS: Participants who said they take a daily vitamin had lower levels of lead in blood and had higher levels of cobalt, which is a part of Vitamin B12, in blood.

LEAD AMMUNITION FOR HUNTING: Most participants did not know what kind of ammunition was used for hunting, and therefore no link was found between lead levels and ammunition. Using lead-free ammunition can also help lower your lead exposure.

MOOSE AND CARIBOU ORGANS: Old Crow participants who ate land animal organs, including caribou kidney and using moose bones in soup or stock, had higher levels of manganese and lead in blood. In other northern regions, there were links between eating moose and caribou organs and higher HCB levels in blood. Organs, including blood, kidneys, and liver, are good sources of both protein and iron.

WHITEFISH: Old Crow participants who ate whitefish had higher levels of cobalt in blood, and lower levels of lead in blood and urine. Whitefish and other fish are important sources of omega-3 fatty acids and other nutrients.

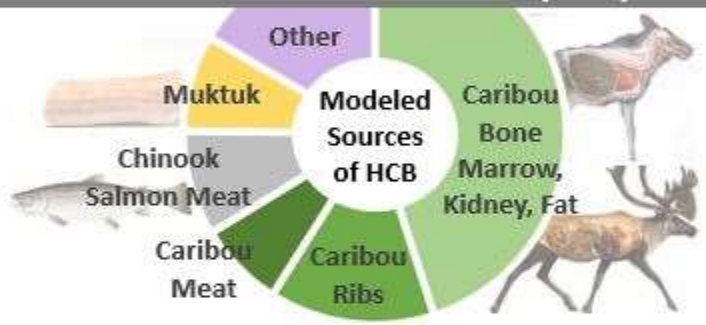
For questions or comments, contact Dr. Brian Laird at the University of Waterloo

A PESTICIDE AND HEALTHY FATS IN TRADITIONAL FOODS

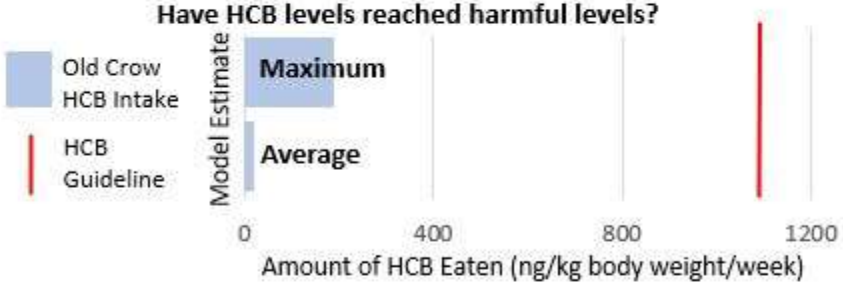
THE PROJECT: A 2019 study showed that levels of hexachlorobenzene (HCB), a pesticide, were higher in people in Old Crow than in southern Canada. Traditional foods can be sources of HCB, but can also have high levels of healthy nutrients.

WHAT WE DID: We designed this project to estimate **how much HCB and healthy omega-3 fatty acids people in Old Crow are eating in traditional foods.** We used computer modeling and traditional food sampling to predict these levels.

Hexachlorobenzene (HCB)



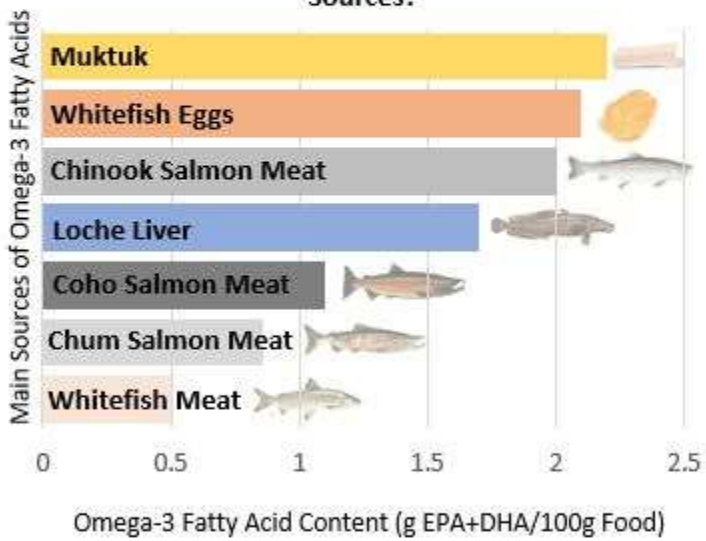
Have HCB levels reached harmful levels?



Levels of HCB eaten by people in Old Crow are well below the levels at which health effects are expected to occur

Healthy Omega-3 Fatty Acids

How much Omega-3 Fatty Acids is in the Main Sources?



Traditional foods are an important source of healthy fats.

These results reinforce that health benefits of traditional foods generally outweigh contaminant risks.

For any questions or comments, please contact Brian Laird (University of Waterloo)

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Hexachlorobenzene and Omega-3 Fatty Acids in Traditional Foods

The Project: A human biomonitoring study was done in Old Crow in 2019. The project showed that most contaminants and nutrients in Old Crow community members were within the normal range in Canada. However, levels of hexachlorobenzene (HCB) were higher in people in Old Crow than in southern Canada. Traditional foods can be a source of HCB, but are also sources of healthy nutrients, like omega-3 fatty acids.

This project was designed to calculate how much HCB and healthy omega-3 fatty acids people in Old Crow are eating in traditional foods.

What is Hexachlorobenzene? HCB is a pesticide that's been banned for nearly 20 years, but lasts a long time in the environment. It can build up in the fatty tissues of animals. High levels of HCB can cause negative health effects.	**What are Omega-3 Fatty Acids?** Omega-3 fatty acids are a healthy type of fat that are important for heart health, and can also lower risk for other chronic diseases, like diabetes and arthritis.

What we did: We used food surveys from the biomonitoring clinic, and the results of traditional food sampling to understand how much HCB and omega-3 fatty acids are in traditional foods. Computer modeling was done to calculate the amount of HCB and omega-3 fatty acids that people are eating.

What we found:

HEXACHLOROBENZENE (HCB):

What are the main traditional food sources of HCB? In Old Crow, the main sources of HCB in traditional foods were fatty caribou tissue (bone marrow, kidney fat), followed by caribou ribs. Other main sources included Chinook salmon meat, muktuk, and caribou meat.

Have HCB levels reached harmful levels for health? Levels of HCB eaten by people in Old Crow are well below the levels at which health effects are expected to occur.

OMEGA-3 FATTY ACIDS:

What are the main traditional food sources of omega-3 fatty acids? In Old Crow, the main sources of omega-3 fatty acids were salmon meat (Chinook, coho and chum), fish eggs, meat from whitefish, grayling, and inconnu, loche liver, and muktuk.

Are people meeting health recommendation for omega-3 fatty acids? During times of year when people were eating more fish, they were meeting the health recommendation for omega-3 fatty acids (about 2 servings of fish per week) by eating traditional foods.

KEY MESSAGES:

This project showed that while some traditional foods were higher in HCB than market meats, the amount of HCB eaten by people in Old Crow was more than five times lower than the level at which health effects are expected to happen. Traditional foods are also important sources of omega-3 fatty acids and other nutrients.

These results reinforce the message that the health benefits of traditional foods generally outweigh contaminant risks.

For questions or comments, contact Dr. Brian Laird at the University of Waterloo

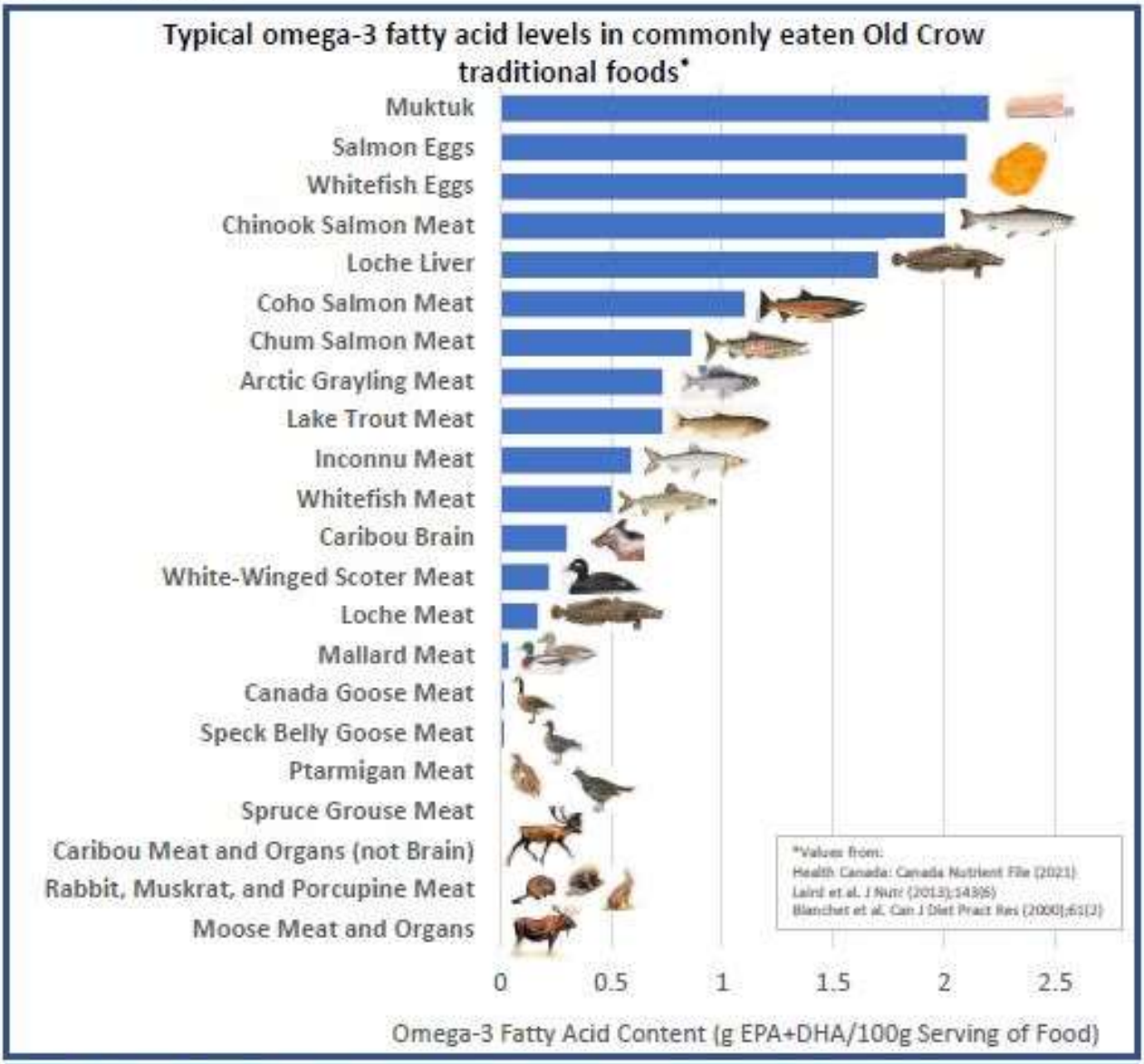
Omega-3 Fatty Acids in Traditional Foods

What are omega-3 fatty acids?

Omega-3 fatty acids are a healthy type of fat that are important for heart health, and can also lower risk for other chronic diseases, like diabetes and arthritis.

Do traditional foods provide omega-3 fatty acids?

Yes! Some traditional foods are naturally high in omega-3 fatty acids. For instance, one small serving of muktuk or Chinook salmon meat per week can meet the weekly health recommendation for omega-3 fatty acids



Traditional foods are important sources of omega-3 fatty acids and other nutrients, and the benefits of eating these foods generally outweigh contaminant risks.

Appendix E – Supplementary Tables

Supplementary Table 2-1 - *Determinants of Biomarker Levels Selected for Inclusion in this Analysis*

Determinant of Biomarker Levels	Source	Data Type	Key Parameter	Criteria for Inclusion
Demographics				
Sex	Biomonitoring clinic intake demographics	Binary (Male/Female)	Co, Mn, Pb, HCB	In other biomonitoring studies, Mn, Co, and HCB have been higher in women (192, 198, 356) and Pb is often higher in men (203)
Age	Biomonitoring clinic intake demographics	Continuous	Co, Mn, Pb, HCB	In other biomonitoring studies, Mn and Co (75, 192) have been shown to decrease with age, while Pb and HCB often increase (203, 356)
Lifestyle Risk Factors				
Smoking Status	Risk Factors Survey (Old Crow), Biomonitoring clinic intake demographics (Ref. Populations)	Binary (Smoked in the previous 24h)	Co, Mn, Pb, HCB	Smoking cigarettes can increase exposure to metals and HCB Co, Mn (207, 221, 357)
Drinking water source	Risk Factors Survey*	Binary (Sometimes or often drinks untreated river water)	Co, Mn, Pb	Drinking water can be an exposure source for metals, including Co, Pb, Mn (290, 358, 359)
Use of lead ammunition	Risk Factors Survey*	Binary (Sometimes or often uses lead ammunition)	Pb	Eating food hunted using lead ammunition may be a source for Pb exposure (210)
Vitamin intake	Risk Factors Survey*	Binary (Takes a daily multivitamin)	Co, Mn, Pb	Mn and Co (as part of B12) are components of many multi-vitamins. Pb absorption can be affected by Ca and Vitamin D status (200, 360)
Traditional Food Consumption				
Birds	Food Frequency Questionnaire	Binary (Eats the food)	Co, Mn, Pb, HCB	All four parameters have been found at elevated levels in some game birds, and birds can also become contaminated by lead ammunition during hunting (52, 210, 361)
Berries	Food Frequency Questionnaire	Binary (Eats the food)	Co, Mn, Pb	Berries can contain high levels of metal nutrients (Mn, Co) and become contaminated on the surface by Pb-bearing soils (51, 52)
Moose Organs	Food Frequency Questionnaire	Binary (Eats the food)	Co, Mn, Pb, HCB	All four parameters can accumulate in moose organs (50, 52, 362)
Caribou Organs	Food Frequency Questionnaire	Binary (Eats the food)	Co, Mn, Pb, HCB	Concentrations of all four parameters can accumulate in caribou organs (52, 223, 224)
Whitefish	Food Frequency Questionnaire	Binary (Eats the food)	Co, Mn, Pb, HCB	Food can be high in trace metals, fatty tissue can accumulate HCB (52, 361)
Chinook	Food Frequency Questionnaire	Binary (Eats the food)	Co, Mn, Pb, HCB	Food can be high in trace metals, fatty tissue can accumulate HCB (52, 218, 361)

Supplementary Table 2-2 - *Assumed HCB and EPA+DHA Concentrations in Traditional Foods*

Traditional Food[1]	HCB (ng/g of food)[2]				Source	EPA + DHA (g/100 g of food)[2]				Source
	Min	Max	Mean	Std		Min	Max	Mean	Std	
Whitefish	**0.32**	0.82	0.64	**0.32**	Northern British Columbia (52)	**0.25**	**1.0**	0.50	**0.25**	(239)
Inconnu	0.11	2.9	1.1	0.77	Alaska (363)	**0.14**	**1.5**	0.59	**0.45**	(364)
Chinook Salmon	0.52	5.2	3.7	0.92	Alaska (363)	**0.98**	**3.9**	2.0	**0.98**	(239)
Lake Trout	0.22	1.5	0.84	0.87	Alaska (363)	**0.37**	**1.5**	0.73	**0.37**	(239)
Burbot	0.060	0.070	0.060	0.010	Alaska (363)	**0.083**	**0.33**	0.17	**0.083**	(239)
Burbot Liver	1.9	6.8	3.0	1.5	Old Crow	**0.85**	**3.4**	1.7	**0.85**	(239)
Chum Salmon	0.088	1.2	0.55	0.43	Old Crow	**0.43**	**1.7**	0.86	**0.43**	(239)
Coho Salmon	0.030	2.8	1.2	**0.59**	Northern British Columbia (52)	**0.54**	**2.2**	1.1	**0.54**	(239)
Arctic Grayling	0.21	0.89	0.48	0.30	Alaska (363)	**0.37**	**1.5**	0.73	**0.37**	Assumed same as lake trout
Muktuk	**30**	**45**	35	5.2	Alaska (365)	**0.92**	**4.8**	2.2	**1.3**	(364)
Whitefish Eggs	1.5	2.6	1.9	0.32	Assumed same as salmon eggs	**1.2**	**3.7**	2.1	**0.83**	(364)
Salmon Eggs	1.5	2.6	1.9	0.32	Alaska (363)	**1.2**	**3.7**	2.1	**0.83**	(364)
Caribou	0.31	1.1	0.56	0.27	Norway (219)	**0.0050**	**0.050**	0.020	**0.015**	(364)
Caribou Liver	1.0	2.6	1.8	0.56	Old Crow	**0.00025**	**0.0024**	0.0010	**0.00071**	(364)
Caribou Kidney	10	30	20	6.1	Old Crow	**0.00025**	**0.0024**	0.0010	**0.00072**	(364)
Caribou Bone Marrow	13	33	22	7.1	Old Crow	**0.00026**	**0.0024**	0.0010	**0.00071**	(364)
Caribou Fat	10	30	20	6.1	Old Crow	**0.00025**	**0.0024**	0.0010	**0.00072**	(364)
Caribou Ribs	**3.9**	**16**	7.8	**3.9**	F (366)	**0.00026**	**0.0024**	0.0010	**0.00071**	(364)
Caribou Heart	**0.55**	**2.2**	1.1	**0.55**	F (366)	**0.00025**	**0.0024**	0.0010	**0.00072**	(364)
Caribou Head	**0.31**	**1.1**	0.56	**0.27**	F (366)	**0.00026**	**0.0024**	0.0010	**0.00071**	(364)
Caribou Tongue	**2.4**	**9.5**	4.8	**2.4**	F (366)	**0.00025**	**0.0024**	0.0010	**0.00072**	(364)
Caribou Stomach	**0.29**	**1.2**	0.59	**0.29**	F (366)	**0.00026**	**0.0024**	0.0010	**0.00071**	(364)
Caribou Brain	**1.8**	**7.3**	3.6	**1.8**	F (366)	**0.15**	**0.60**	0.30	**0.15**	(239)
Moose	**0.016**	**0.065**	0.032	**0.016**	F (31)	**0.00025**	**0.0024**	0.00096	**0.00071**	(364)
Moose Liver	0.15	0.58	0.29	0.15	Old Crow	**0.00025**	**0.0024**	0.00096	**0.00071**	Assumed same as muscle tissue
Moose Kidney	0.85	3.4	1.7	0.85	Old Crow	**0.00025**	**0.0024**	0.00096	**0.00071**	Assumed same as muscle tissue
Moose Bone Marrow	0.80	3.2	1.6	0.80	Old Crow	**0.00025**	**0.0024**	0.00096	**0.00071**	Assumed same as muscle tissue
Moose Fat	0.85	3.4	1.7	0.85	Old Crow	**0.00025**	**0.0024**	0.00096	**0.00071**	Assumed same as muscle tissue
Moose Heart	**0.037**	**0.15**	0.074	**0.037**	F (based on caribou)	**0.00025**	**0.0024**	0.00096	**0.00071**	Assumed same as muscle tissue
Moose Tongue	**0.16**	**0.65**	0.32	**0.16**	F (based on caribou)	**0.00025**	**0.0024**	0.00096	**0.00071**	Assumed same as muscle tissue
Moose Intestines	**0.020**	**0.080**	0.040	**0.020**	F (based on caribou)	**0.00025**	**0.0024**	0.00096	**0.00071**	Assumed same as muscle tissue
Moose Tripe	**0.020**	**0.080**	0.040	**0.020**	F (based on caribou)	**0.00025**	**0.0024**	0.00096	**0.00071**	Assumed same as muscle tissue
Moose Ribs	**0.016**	**0.065**	0.032	**0.016**	Assumed same as muscle tissue	**0.00025**	**0.0024**	0.00096	**0.00071**	Assumed same as muscle tissue
Moose Head	**0.016**	**0.065**	0.032	**0.016**	Assumed same as muscle tissue	**0.00025**	**0.0024**	0.00096	**0.00071**	Assumed same as muscle tissue

Traditional Food[1]	HCB (ng/g of food)[2]				Source	EPA + DHA (g/100 g of food)[2]				Source
Rabbit	0.020	0.10	0.060	**0.030**	Nunavut (367)	**0.00025**	**0.0024**	0.0010	**0.00072**	(364)
Muskrat	**0.030**	**0.12**	0.060	**0.030**	Yukon (132)	**0.00025**	**0.0024**	0.00096	**0.00071**	(364)
Porcupine	**0.12**	**0.46**	0.23	**0.12**	Yukon (132)	**0.00025**	**0.0024**	0.00096	**0.00071**	(364)
Spruce Grouse	**0.20**	**0.80**	0.40	**0.20**	Yukon (132)	**0.0027**	**0.016**	0.0073	**0.0045**	Assumed same as ptarmigan
Ptarmigan	**0.085**	**0.34**	0.17	**0.085**	Greenland (368)	**0.0027**	**0.016**	0.0073	**0.0045**	(364)
White-Winged Scoter	**1.0**	8.0	2.0	**1.0**	Canada (369)	**0.19**	**0.27**	0.22	**0.025**	(370)
Mallard	**0.25**	**0.98**	0.49	**0.25**	Yukon (132)	**0.010**	**0.11**	0.035	**0.039**	(364)
Speck Belly Goose	**0.05**	**0.20**	0.10	**0.050**	Assumed same as snow goose, Northern Ontario (371)	**0.0044**	**0.043**	0.017	**0.013**	Assumed same as Canada goose
Canada Goose	**0.15**	5.6	0.30	**0.15**	Yukon (132)	**0.0044**	**0.043**	0.017	**0.013**	(364)

1 – Foods are muscle tissue unless tissue is specified

2 – **Bolded** values show assumed statistics where standard deviation is equal to half of the mean, maximum value is equal to the mean plus two standard deviations, and minimum value is equal to the mean minus one standard deviation

F – Value was calculated using concentration of substance in specified animal's fat, converted to other tissues based on lipid content of those tissues. Source indicates reference used to determine lipid content.