

Seeking the Source: Dioxin Exposure Levels and Determinants and Fluoroalkyl Substance Determinants  
in Arctic and Subarctic Communities within Canada

by

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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**

This thesis is the work of Ashlyn Simpson in direct collaboration with their supervisor Brian Laird and committee members Kelly Skinner and Ken Froese.

This thesis includes two manuscripts that were prepared for publication in collaboration with co-authors.

The chapter of this thesis titled, “Human Biomonitoring of Dioxins, Furans, and Non-Ortho Dioxin-Like PCBs in Blood Plasma from Old Crow, Yukon, Canada (2019)” was co-authored with Mallory Drysdale, Mary Gamberg, Ken Froese, Jeremy Brammer, Pierre Dumas, Mylene Ratelle, Kelly Skinner, and Brian D. Laird.

Mylene Ratelle planned the Old Crow Biomonitoring clinic in collaboration with the research team, and Mallory Drysdale administered the biomonitoring clinic in Old Crow in collaboration with other research team members and a local coordinator. Mary Gamberg provided continued supervision and guidance on study design and development. Analysis of the blood plasma samples was coordinated by Alain LeBlanc (INSPQ-CTQ) and analyzed by Pierre Dumas (INSPQ-CTQ) and for dioxins and like-compounds. Ken Froese provided editorial advice and supported result contextualization. Jeremy Brammer provided local insights, support, and feedback as a part of our research agreement with the Vuntut Gwitchin Government. Brian Laird and Kelly Skinner were the Principal Investigators on grants from the Northern Contaminants Program (NCP) which supported biomonitoring data collection. All co-authors provided editorial advice prior to journal submission.

The thesis chapter titled, “Traditional foods and other determinants of exposures to persistent organic pollutants (POPs) in Old Crow, Yukon, and the Dehcho Region, Northwest Territories” was coauthored by Joshua Garcia-Barrios, Sara Packull-McCormick, Mallory Drysdale, Mylene Ratelle, Mary Gamberg, Jeremy Brammer, Mike Low, Ken Froese, Kelly Skinner, and Brian Laird.

This research was informed by prior investigation of PFAS contaminant levels in blood conducted by Joshua Garcia-Barrios (University of Waterloo). Sara Packull-McCormick provided statistical guidance. Mallory Drysdale conducted prior investigations of determinants of contaminant exposure that informed the methods in this chapter. Mylene Ratelle planned and executed the biomonitoring clinics and food frequency questionnaires (FFQ) in the Dehcho Region and planned the biomonitoring clinic in Old Crow. Mike Low provided local perspective, support, and feedback. Mary Gamberg, Jeremy Brammer, Ken Froese, Kelly Skinner, and Brian Laird acted in capacities similar to those for the human biomonitoring dioxins and dioxin-like congeners chapter.

## **Abstract**

### **Background**

Dioxins, furans, and non-ortho dioxin-like polychlorinated biphenyls (PCBs), and per- and poly-fluoroalkyls (PFAS) are persistent toxic chemicals that have been detected in areas far from known emission sources. Following biomonitoring projects conducted in the Dehcho Region, Northwest Territories (2016-2018) and Old Crow, Yukon Territory (2019), elevated levels of PFNA were detected, and dioxins, and like-congeners were yet to be investigated. This thesis reports on dioxin exposure levels and identifies determinants that may influence dioxin and PFAS exposures in the study areas.

### **Research Questions**

To assess dioxin, furan, and non-ortho dioxin-like PCB exposures, two research questions are raised: *What are the levels of dioxins in blood plasma samples from Old Crow and how do these compare to the general population of Canada?* and *are there specific demographic variables that are associated with higher or lower exposure?* The determinants of exposure are then explored among the participating communities with dioxin and PFAS exposure measures: *Are there lifestyle factors or traditional foods consumption patterns that are associated with biomarkers of these analytes?*

### **Methods**

Biobanked plasma samples (n=54) from Old Crow were analyzed for dioxins, furans, and non-ortho dioxin-like PCBs. Data from surveys on traditional food consumption and lifestyle factors were collected in Old Crow and the Dehcho Region. Descriptive statistics were used to quantify differences in exposure between the Old Crow and Canadian Health Measures Survey (CHMS) data, then simple linear regression and multiple variable regression was used to identify the traditional foods and lifestyle factors that may influence PFAS, and dioxin and dioxin-like congener exposures.

### **Results**

Most dioxins, furans, and non-ortho dioxin-like PCB exposures were lower, or similar in the study areas in comparison to the respective levels in the general population of Canada. Like the previous findings with PFNA, PCB 169 levels appeared to be approximately two-fold elevated in Old Crow participants aged 20 to 39 years and 60 to 79 years when compared to the general population of Canada. The investigation of exposure determinants revealed that traditional foods were generally negatively associated with PFAS exposures, indicating that those who consumed traditional foods may have eaten fewer processed and packaged foods. However, some exceptions to this were observed. For example, PFNA exposure was positively associated with consumption of some moose tissues in Old Crow, while whitefish eggs, Canada goose meat, lake trout, and ptarmigan showed similar directionality and significances of association in the Dehcho Region. Unexpectedly, height was positively associated with PFOA, PFOS, and PFHxS levels in the Dehcho Region, but this association was not consistent with the same variable in Old Crow. Determinants analysis among dioxins and dioxin-like congeners showed different trends; PCB 126 was positively associated with multiple foods across categories. Coho salmon was significantly positively associated with exposures to 1,2,3,6,7,8-HxCDD, 2,3,4,7,8-PeCDF, and PCB 126. PCB 169 exposure was significantly positively associated with employment in an occupation of risk.

It is notable that some traditional foods appeared to be associated with some persistent organic pollutant exposures; however other aspects of health, such as culture, social, and nutritional benefits were also considered in the interpretation of the results. The processes that surround the harvesting, preparation, consumption, and sharing of traditional foods promote physical activity, spiritual well-being, and socialization. It is concluded that the benefits of eating traditional foods continue to outweigh the risks of environmental contaminant exposures in the researched communities.

## **Contribution**

Regional partners and community representatives were included in developing the contextualization, interpretation, and communication of the results synthesized in this thesis. The results from these investigations were provided to the respective study participants, participating communities, and governments through an in-community meeting (e.g., Vuntut Gwitchin Research Round-up), personalized biomarker results letters, and infographic flyers. Knowledge sharing in Old Crow led to continued development of community questions surrounding local sources of contamination, and knowledge that may be applied to further investigate the sources of persistent organic pollutant (POP) exposures, potentially empowering communities to enact local policy, and reduce population exposures to contaminants. Aggregate results have been shared with researchers (e.g., the International Society of Exposure Science Conference (Chicago, 2023) and publications, according to processes outlined in community research agreements.

Research on POP exposures in inland First Nations across the territories has been limited. Nationally, these results help to inform peoples' exposures to POPs and the exposure sources among Indigenous communities located in Arctic and subarctic areas within Canada. These results are in alignment with the research priorities of the Northern Contaminants Program (Canada), Arctic Monitoring and Assessment Programme (AMAP), and Stockholm Convention which continue to monitor the levels and exposure patterns of persistent organic pollutants. This thesis has analyzed data and information from Indigenous communities that have not been represented in national biomonitoring studies. Through the biomonitoring studies and analyses conducted prior to, and in parallel with this thesis, several data gaps regarding environmental exposures in northern Indigenous populations have been filled, addressing inequities in baseline exposure information, and understanding of the potential determinants of exposure. This approach aims to enhance understandings of environmental contaminant exposures among First Nations living in participating regions while also empowering communities with local environmental health data that complements Traditional Knowledge.

## **Acknowledgements**

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**Dedication**

This thesis is dedicated to the Indigenous Peoples of Old Crow (Vuntut Gwitchin First Nation), Fort Providence (Deh Gáh Got'ie First Nation), Hay River (K'atl'odeeche First Nation), Jean Marie River (Tthets'éhk'edélj First Nation), Kakisa (Ka'a'gee Tu First Nation), Smbaa K'e (First Nation), and West Point First Nation.

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## List of Abbreviations

AhR	aryl hydrocarbon receptor
AM	arithmetic mean
AMAP	Arctic Monitoring and Assessment Programme
ATSDR	Agency for Toxic Substances and Disease Registry
BMI	body mass index
BW	body weight
CDC	Centers for Disease Control and Prevention
CEPA	Canadian Environmental Protection Act
CDF	chlorinated dibenzofurans
CHMS	Canadian Health Measures Survey
CI	confidence interval
DLCs	dioxin-like congener
EPA	Environmental Protection Agency (US)
EU	European Union
FFQ	Food frequency questionnaire
FNBI	First Nations Biomonitoring Initiative
GM	geometric mean
HCB	hexachlorobenzene
HxCDD	hexachlorodibenzo- <i>p</i> -dioxin
HpCDD	heptachlorodibenzo- <i>p</i> -dioxin
IARC	International Agency for Research on Cancer
LOD	limit of detection
MIREC	Maternal-Infant Research on Environmental Chemicals
NOAEL	no observed adverse effect level
NQN	Nutaratsaliit Qanuingsiarningit Niqituinnanut
NWT	Northwest Territories
OCDD	octachlorodibenzo- <i>p</i> -dioxin
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzo- <i>p</i> -dioxin
PeCDD	Pentachlorodibenzo- <i>p</i> -dioxin
PFAS	polyfluoroalkyl substances, perfluoroalkyl substances
PFDA	perfluorodecanoic acid
PFHxS	perfluorohexanesulphonic acid
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctanesulfonic acid
POP	persistent organic pollutant
ROS	reactive oxygen species
TCDD	Tetrachlorodibenzo- <i>p</i> -dioxin
TEF	toxic equivalency factor
TEQ	toxic equivalency
US	United States of America
YT	Yukon Territory
WHO	World Health Organization
WW	wet weight

# 1. Literature Review

## 1.1. The Dehcho Region: Geography, Climate, and Indigenous Populations

The Dehcho Region is one of five land claim regions, encompassing 215 000 km<sup>2</sup>, in the Northwest Territories (NWT) of Canada, as shown in Figure 1. The region has two distinct geological areas including the Mackenzie Mountain range to the west and interior plains in the east [1]. The climate is subarctic, with temperatures near 20°C through summer months and -20°C in the winter months [2]. Typically, temperatures are cooler throughout the north of the region and precipitation is generally higher in the mountains and to the south [1]. Average temperatures have increased by 3 to 4 degrees Celsius over the past 50 years in the NWT and are expected to continue increasing at this rate or greater [3]. The Dehcho Region provides habitat for many species of fish, small game, moose, caribou, berries, and plants.

The Dehcho Region includes the communities (and respective populations in 2018) of Fort Liard (566), Fort Providence (717), Fort Simpson (1286), Hay River Dene Reserve (330), Jean Marie River (88), Kakisa (39), Nahanni Butte (102), Sambaa K'e (92), and Wrigley (121) [4]. The total population of the Dehcho Region in 2018 was 3400 and 84% of residents identified as Indigenous, primarily Métis and Dene [4].

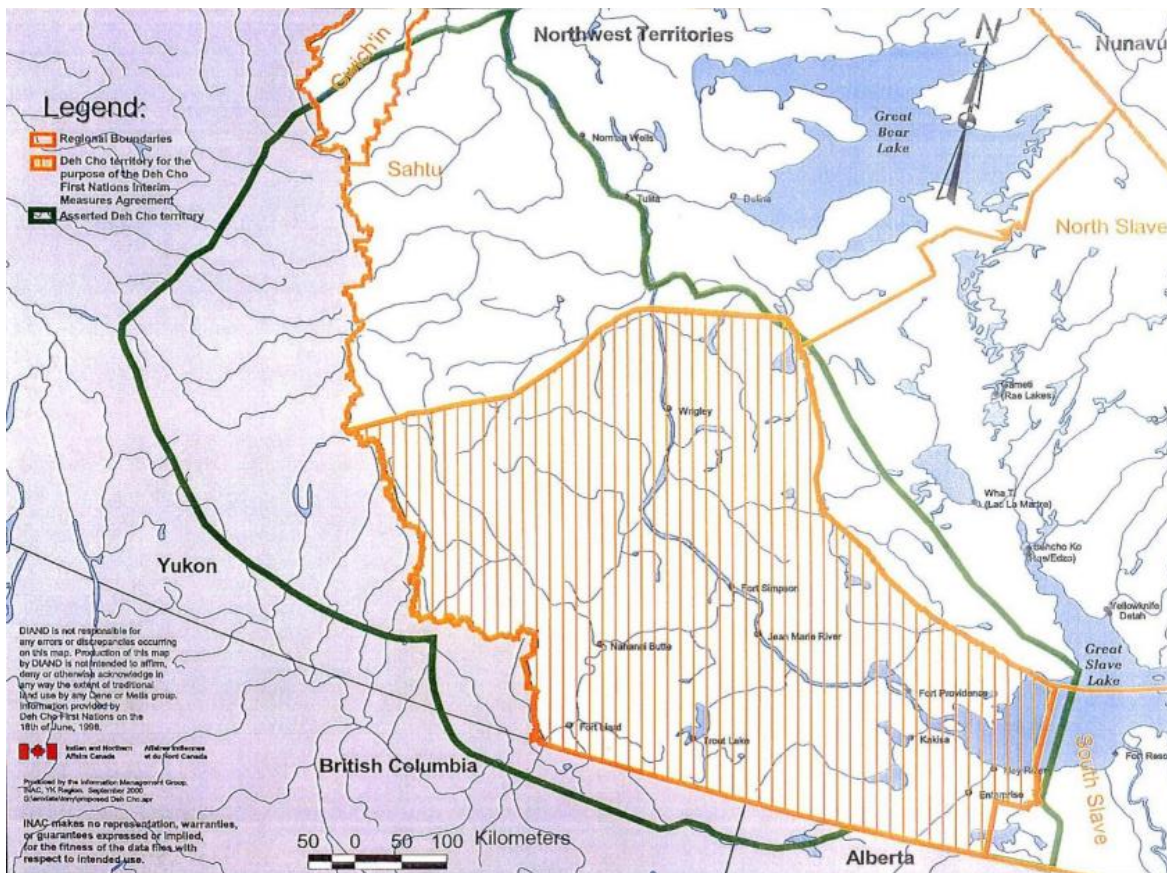


Figure 1: Map of the Interim Measures Agreement Area for Dehcho Region First Nations. This land claim area has had ongoing negotiations with the Government of Canada and the Government of the Northwest Territories since 1999 [5].

## 1.2. Old Crow: Geography, Climate, and Indigenous Populations

Old Crow is the northernmost community in Yukon Territory (YT), with 7744.06 km<sup>2</sup> of Vuntut Gwitchin settlement lands, agreed to in 1993 and depicted in Figure 2. Old Crow is a fly-in community, with seasonal winter road access when required by construction projects. Old Crow Traditional Lands are comprised of open water, high and low elevation sparse vegetation, shrub lands, herb lands, and coniferous forest. Some areas also have exposed rock or wetland ecosystems [6]. This area has a subarctic climate, characterized by typically mild summers (20°C to 27°C) and harsh winters (approximately -25°C to -30°C) [7]. Precipitation on average ranges from 9.5 mm in April, to 46.7 mm in August [7]. The traditional lands surrounding Old Crow provide habitat for the Porcupine Caribou herd, moose, many species of fish, small game, berries, and plants. The habitats for flora and fauna are changing. In 2019, Chief Dana Tizya-Tramm declared a climate state of emergency and stated that the traditional way of life in Old Crow is under threat from climate change [8]. Since 2019, chinook and chum salmon that migrate local Fishing Branch River and other Old Crow waterways have not been able to successfully reproduce due to dewatering [9].

In 2016, the population of Old Crow was 221, and 86% of people identified as Indigenous, primarily Gwich'in [10]. The Vuntut Gwitchin are one of 19 Gwitchin communities across Alaska, Yukon, and NWT and the Gwitchin Nation has a total population of 7500 people [11].

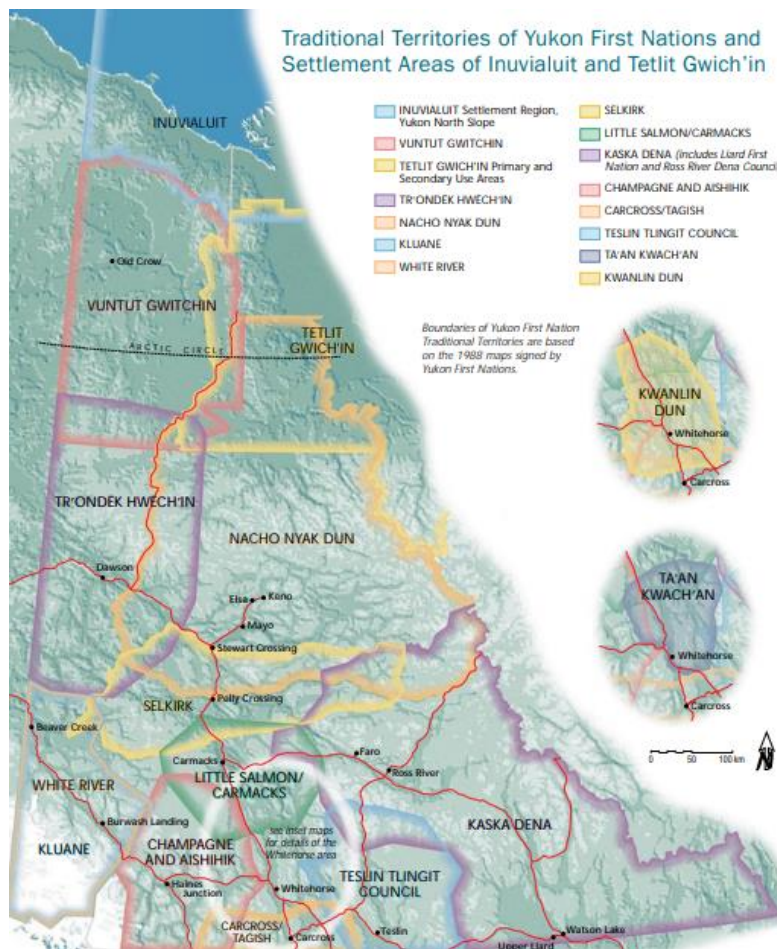


Figure 2: Map representing the boundaries of Yukon First Nation Traditional Territories based on the 1988 maps signed by First Nations [12].

### 1.3. Food Systems and Food Quality

In many Indigenous communities of YT and NWT food is sourced from market, traditional, and locally grown systems. Market foods are often processed and expensive in Northern communities (Figure 3) because of transportation distances. Traditional foods are regionally specific foods, and food preparations, derived from local lands that have been consumed for many generations. Examples of these foods include land animals (e.g., caribou, moose), fish, wild plants, wild berries, birds, and small game (e.g., beaver and muskrat). Consumption of traditional foods is associated with nutrition, well-being, knowledge, heritage, and culture [13]. Preservation of traditional food systems promotes the rights of people to access healthy and culturally appropriate foods. Vuntut Gwitchin residents of Old Crow have diets with high proportions of traditional foods in comparison to other Yukon communities [14] and the average of other First Nation communities across Canada [15]. In the Dehcho Region, it has been estimated that 31% of resident Dene adults consume traditional foods [16].



Figure 3: A box of cookies (\$12.99), diced peaches in light syrup for (\$11.39), and canned peas and carrots for (\$6.19) for sale in February 2023 at the Old Crow COOP store.

Foods are a common route for human exposure to toxicants. Indigenous hunters and gatherers have traditional methods to qualitatively assess the food before consuming it; for example, if loche liver is 'spotty', this indicates that the fish is 'no good to eat' [17]. A limitation of this method of quality assessment is that some contaminants may not result in visible effects at lower trophic levels, but these contaminants can bioaccumulate, and impact higher trophic level species, including people. While quantitative maximum limits for contaminants are monitored in foods in the Canadian market foods by the Canadian Food Inspection Agency and Health Canada, the same approach is not appropriate for traditional foods. Territorial governments have issued consumption notices for cadmium in southern Mackenzie Mountain moose liver and kidney, and mercury in various fish species from specific lakes. Food consumption notices are typically developed through quantitative risk assessment and are intended to reduce exposure to a potentially harmful contaminant. However, these notices have not always considered all the nutritional, sociological, and anthropological implications of changes to consumption patterns (Figure 4). The risks that these contaminants pose do not always outweigh the benefits from consuming contaminated foods. Further, POP contamination is also often widespread, and may not be avoidable, even if individuals would like to reduce their personal exposure. For these reasons, this thesis uses a holistic approach in the contextualization of the results and community communications.



Figure 4: Visual representation of determinants of health as they relate to traditional foods. The importance that individual people place on each of these factors may vary [17, 18, 19].

#### 1.4. Contamination Sources and Exposure Pathways

Contaminants can enter traditional food systems through various mechanisms. One pathway, called Global distillation is a main source of persistent organic pollutants in Arctic and subarctic areas [18, 20]. Industrial processes such as those in metal refinement, chemical production, and manufacturing can release contaminants into the air. These chemicals can remain airborne in warmer temperatures and travel hundreds of thousands of kilometers in global air currents. As the air cools nearer to the global poles, these chemicals precipitate out of the air, depositing on land or water and potentially entering the food-chain (Figure 5). Examples of contaminants that are known to undergo long-range transport include mercury, PFAS, and POPs [such as PCBs, dioxins, furans, and hexachlorobenzene (HCB)] [21]. Notably, contaminants are not always of anthropogenic origin. Forest fires and volcanoes can produce pyrogenic atmospheric pollutants, including dioxins, furans, and non-ortho dioxin-like PCBs [herein referred to as dioxin-like congeners (DLCs)], that can also undergo atmospheric transport.

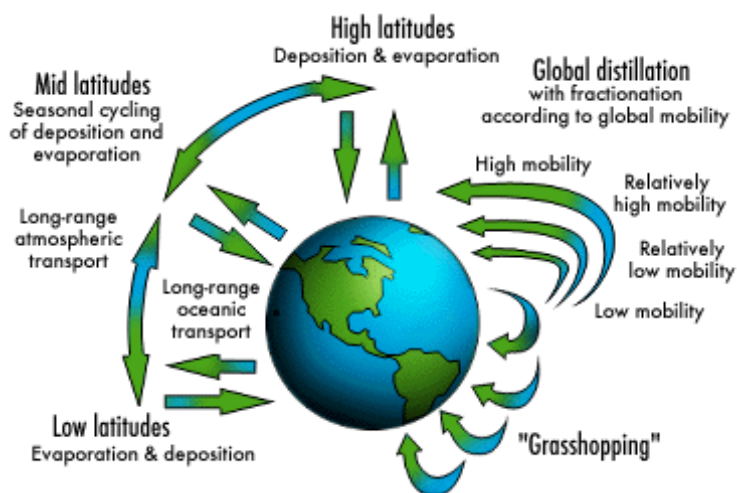


Figure 5: Diagram illustrating global distillation of POPs [22].

Some contaminants may be derived from regional specific sources. Municipal waste burning, open burning of household waste (especially plastics) or yard waste, burning of diesel fuel, wood burning, and tobacco smoke are all sources of dioxins and DLCs [23, 24]. Leachate from landfills may also be a contamination source. For example, leachate samples from 10 Canadian municipal landfills had PFOS and PFOA concentration ranges of <9.5 to 744 ng/L (48% detect) and 50.3 to 1590 ng/L (100% detect), respectively [25].

Some contaminants, such as PFAS, are present throughout Canada. Several airport and military sites have been identified with elevated concentrations of PFAS in surface water, ground water, sediment, and soil, typically due to the use of PFAS containing firefighting foams, as depicted in Figure 6. A variety of fire retardants are applied for forest fire suppression in the NWT and YT; the PFAS content of these foams is not always disclosed publicly [26, 27, 28, 29]. Notably, on June 25, 2023, the Canadian Interagency Forest Fire Centre declared the 2023 wildfire season the worst in Canadian history with respect to the hectares (ha) burned. As of October 2023, 223 866 ha of land were burned in wildland fires in YT and 4 163 426 ha were burned in NWT [30]. Exposure to PFAS can also occur within peoples' homes. Consumer products such as raincoats, fire extinguishers, carpet, and non-stick cookware often contain PFAS, and have been detected in house dust [31, 32, 33, 34].

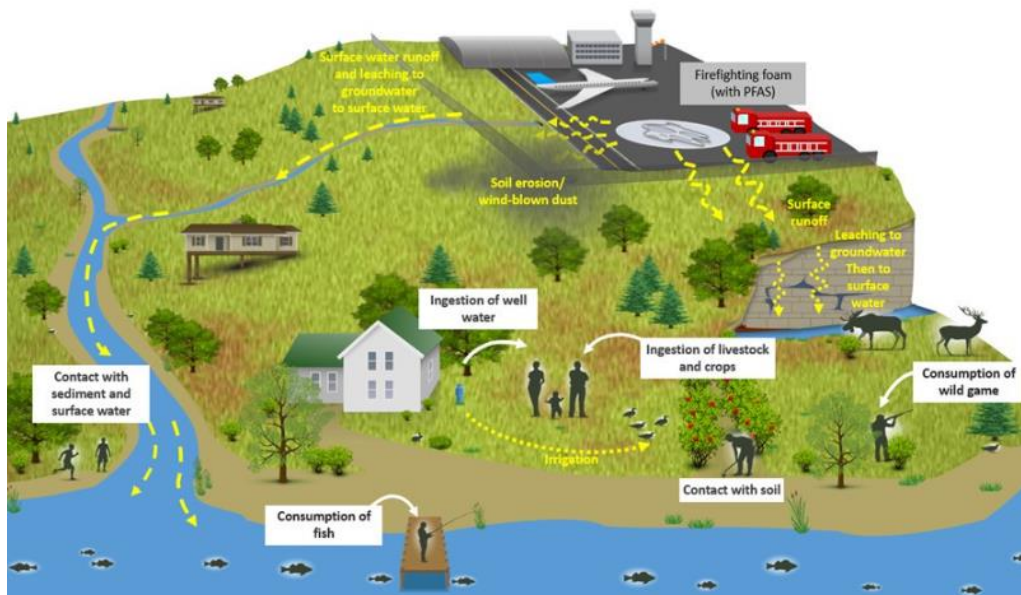


Figure 6: Diagram of pathways for widespread PFAS contamination [35].

## 1.5. Human Biomonitoring Research in Canada

While contaminants in some traditional foods have been quantified [36, 37, 38, 39, 40], the level of contaminants in people living on First Nations in the Yukon and NWT have been limited. Human biomonitoring can be used to detect many xenobiotics in humans, including, but not limited to metals, PCBs, PFAS, dioxins, and DLCs [41, 42]. The goal of human biomonitoring is to measure the concentration of specific chemicals and/or their metabolites in individuals and populations. An analyte, which may be a metabolite of the target chemical, is measured to describe the individual's exposure to the chemical of interest. This methodology is the current standard for investigating biological load of trace contaminants [43].

In Canada, the CHMS measures contaminant exposure levels through collection from a minimum of 5700 participants across ~400 collection sites in 10 provinces. Although representative of those living in urban and suburban areas in southern parts of Canada, the CHMS excludes persons living in Indigenous settlements and the three territories [42]. Another Canadian national study is the Maternal-Infant Research on Environmental Chemicals (MIREC) study (2008-2011) which was focused on researching the impact of prenatal exposure to environmental contaminants [44]. Some biomonitoring projects in Canada have been conducted with Indigenous populations. The First Nations Biomonitoring Initiative (FNBI) (2011) was a biomonitoring project that was specific to First Nations Peoples living on-reserve among the 10 provinces and included ~500 participants residing in 13 First Nation communities. The Nutaratsaliit Qanuingsiarningit Niqituinnanut (NQN) project, based in Nunavik, Quebec, investigated the wellness of Inuit mothers through pregnancy with a focus on environmental contaminants and traditional foods [45]. The results from these biomonitoring projects generally do not describe human health risks or the potential for toxicity but instead characterize the exposures to contaminants in the study population.

### **1.5.1. Human Biomonitoring in the Northwest Territories and Yukon**

The safety of traditional foods and diet are community research priorities in Old Crow and the Dehcho Region. Community concern surrounding the safety of traditional foods lead to human biomonitoring projects in the Dehcho and Sahtú Regions of the NWT (2016-2018) and in Old Crow, YT (2019). Several analyses (2016 to 2023) have been conducted with these biomonitoring data, which have examined mercury, lead, cadmium, HCB, other metals and POPs [46, 47, 48, 49, 50, 51, 52, 53, 54], represented in Figure 7. Through collaborative community engagement, dioxins, DLCs, and PFAS were identified as additional contaminants of concern in traditional foods due to their toxicity at low levels.

One of the biomonitoring data analyses conducted by Garcia-Barrios et al. (2021) examined nine PFAS from blood serum and plasma samples. The geometric mean PFNA levels were 2.8 and 1.8 times elevated in the Dehcho Region, and Old Crow respectively, in comparison to the Canadian general population [48]. PFOS and PFOA were significantly lower by 2.1 times, on average, in comparison to the levels observed from FNBI and CHMS [48]. Male participants had higher concentrations of PFAS in comparison to females, on average, and blood concentrations were also higher with age, on average. The determinants of these exposure differences were yet to be explored.

In Old Crow and the Dehcho Region, human biomonitoring data has also been analyzed for PCBs. In Old Crow and the Dehcho Region, plasma PCBs were lower than the observed levels from CHMS (2010 to 2019) and FNBI (2011) [50]. New information for the plasma concentrations of non-ortho substituted dioxin-like PCBs was collected as a part of the dioxin and DLC analysis. These new data were analyzed as a component of this proposed research.

This thesis assesses the exposure levels of dioxins and DLCs and assesses potential traditional food determinants of exposure to dioxins, DLCs and PFAS.

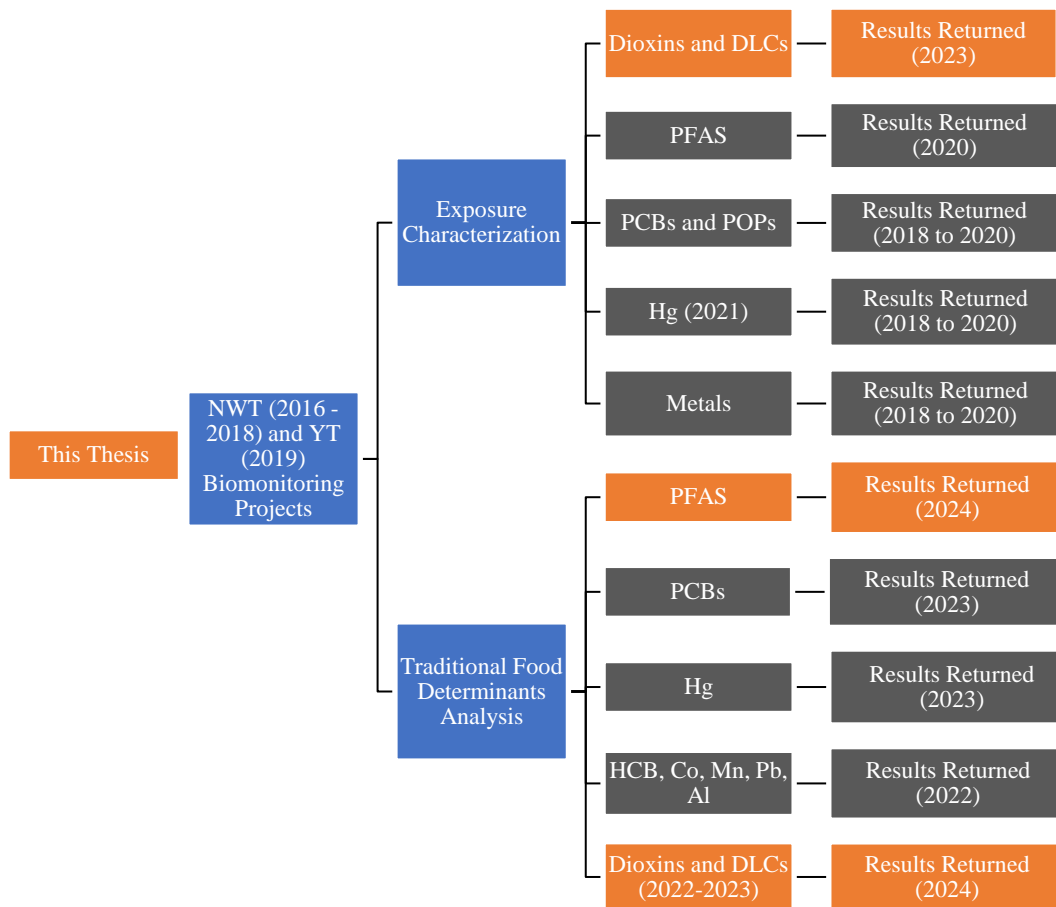


Figure 7: Analysis components of the YT and NWT biomonitoring project conducted by Brian Laird's research group.

## 1.6. Dioxins and Like Congeners

### 1.6.1. Concentrations in Environment and Foods

From 1990 to 2020, emissions of dioxins and DLCs in Canada declined by 70%, largely due to a reduction in emissions from waste incinerators [55]. Throughout the same time period, chemical monitoring in northern parts of Canada has documented elevated levels of dioxins and DLCs (and other organochlorines) in environmental matrices (*e.g.*, caribou, marine mammals, and fish). For example, in 1993, unusually high dioxin (2100 pg/g OCDD) and furan (62.4 pg/g HpCDF total) mean concentrations in caribou fat (n=5) were reported. At the time of publication, it was hypothesized that the exposure may be the result of a combustion source contaminating air, and subsequently contaminating lichens which draw their nutrients from the air; lichens then serve as the main winter food source for caribou [40]. As currently understood, marine mammal tissues tend to accumulate higher levels of dioxins and DLCs in comparison to land mammals [56, 57]. Persistent organochlorine contamination research has also been conducted with fish in northern Canada. For example, 10 sites along the Yukon River Basin in 2002 were quantified for total PCB (<20 to 87 ng/g) and toxicity equivalence (TEQ) ( $\leq 1.7$  pg/g) levels in northern pike, longnose-sucker, and burbot [58]. These levels did not exceed the toxicity upper limits for growth and reproduction effects in fish [59].

### 1.6.2. Absorption, Distribution, Metabolization, and Excretion

Human exposure to dioxins and DLCs primarily occurs through diet. Foods with evidence of higher levels of dioxins and DLCs, in comparison to other foods in a typical North American diet, include dairy (which contributes to ~20.3% of exposure), pork (~10.3%), chicken (~10.9%), beef (~31.2%), fish (~6.6%), and eggs (~3.4%) [60, 61, 62]. Likewise, traditional foods that are lipid-rich may also contribute to exposure. For example, the eggs of sea birds along the St. Lawrence River in Quebec had elevated levels of dioxin-like PCBs [63]. Inhalation of dioxins and DLCs may account for 1 to 2% of total exposure, or  $\sim 5.07 \times 10^{-2}$  pg TEQ/kg bw/d, on average [23, 64]. However, cigarette smokers may have increased dioxin and DLC exposures through inhalation since these contaminants are present in tobacco smoke at a concentration of 1 to 3 pg TEQ/kg bw/d per 20 cigarettes smoked [65]. Interestingly, in one study the half-life of dioxins and DLCs was significantly shorter among those who smoked when compared to those who did not smoke. Smoking upregulates the CYP450 1A2 enzyme in the lungs, which is thought to aid in the degradation of dioxins and DLCs in the body [66]. In a separate study, serum dioxin and DLC levels were found to be 40% higher among male smokers in comparison to non-smokers, whereas in women, smoking was significantly associated with lower serum dioxins [67]. The authors hypothesized a sex-dependent synergistic potentiation of dioxin elimination. Additionally, workers in some occupations are known to have elevated exposure to dioxin in comparison to the general population. Chemical manufacturing, waste disposal, firefighting, gardening, laboratory research are all occupations that have been associated with various elevated dioxin exposures [68, 69, 70, 71, 72].

Dioxins and DLCs are highly lipophilic compounds that preferentially partition into body fat-stores from blood. However, the association between body mass index (BMI) and blood levels of dioxins and DLCs is unclear. Some studies have demonstrated BMI to be positively associated with plasma dioxin and DLC levels [73, 74]. Other studies have demonstrated that higher BMI in men is associated with higher plasma TEQ. Another report indicated no association between total dioxin and DLC body burden and BMI [74, 75]. Over time, an increase in adipose tissue was associated with greater storage of dioxin and DLCs rather than excretion or metabolization [66]. The body burden of dioxins and DLCs has been found to have a strong positive correlation with age [76].

Environmental dioxins and DLCs increased throughout the 1960s and 1970s before declining to today's levels. As such, older individuals often have greater body burdens of dioxins and DLCs than young people (with increases greater than expected due solely to their biological persistence) [77]. Elimination of dioxins and DLCs may also change with age; the results from a biomonitoring study conducted with a population of 305 residents from Shenzhen, Guangdong province in China demonstrated that the elimination half-lives of two dioxin-like PCB congeners increased with age [78]. Dioxins and DLCs degrade in the human body at a half-life of an estimated 7 to 11 years [23]. There is no known natural mechanism for males to reduce total dioxin and DLC body burden, while females can pass dioxins and DLCs to offspring *in utero* via the placenta, and in breastmilk [61]. The body burden of PCBs, a related group of organochlorines, can be reduced by 20% or more in women who are lactating [79]. Given the long half-life and lack of metabolization, dioxins and DLCs may accumulate and elicit toxic effects as body burden increases.

### 1.6.3. Dioxin and Dioxin-Like Compound Toxicity

Dioxins and DLC are associated with numerous sensitive chronic health endpoints. Dioxins and DLCs interact with the aryl hydrocarbon receptor (AhR) in the cytoplasm of cells with various strengths. Among dioxins and DLCs, 2,3,7,8-TCDD has one of the strongest binding affinities with the AhR [80]. Other dioxins that are hazardous to human health have fractional binding affinities relative to 2,3,7,8-TCDD,

called toxicity equivalence factors (TEFs) (Appendix A). When dioxins or DLCs bind to the AhR, the receptor separates from a chaperone complex; it then moves into the nucleus of the cell, and in combination with the AhR nuclear translocator (commonly ARNT), it upregulates gene expression of some CYP450 genes, such as CYP1A1 and 1A2. These cytochromes then slowly metabolize the dioxin or DLC, which generates reactive oxygen species (ROS). In turn ROS can cause cellular damage [81].

TCDD is listed as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC) and positive associations have been drawn between TCDD exposure and soft-tissue sarcoma, non-Hodgkin lymphoma, and pulmonary cancer [82]. The California Office of Environmental Health Hazard Assessment under the California Proposition 65 has established a no-significant-risk-level of 0.000005 µg/day for TCDD [83].

Reproductive toxicity is a particularly sensitive endpoint for dioxins and furans. Rats dosed (gavage) with 0.01 µg TCDD/kg bw/day showed decreased fertility, litter size, live birth body weight, and survivability for two successive generations. Notably, TCDD reproductive effects were limited in male mice who were dosed with up to 2.4 µg TCDD/kg bw/day when mated with unexposed females [84]. Human epidemiology studies investigating the reproductive effects of TCDD have been subject to many limitations including confounding exposures to potentially harmful pesticides, incomplete data, and inappropriate controls [85]. There have been no human studies that investigated TCDD exposure and reproductive effects in women or in their offspring [84].

Although less sensitive endpoints than carcinogenicity or reproductive toxicity, some studies suggest that other chronic toxic effects are notable, such as thyroid signaling changes, alterations in glucose metabolism, and immunosuppressive effects [86, 87, 88, 89]. Interestingly, many of these toxicities overlap with those of PFAS.

## **1.7. PFAS**

### **1.7.1. Concentrations in Environment and Foods**

Similarly, to dioxins and DLCs, atmospheric emission of PFAS can occur by direct air release. Additionally, PFAS may also be emitted to air mechanically via marine aerosolization. Once airborne, PFAS may be in a gaseous state or form particulate compounds with other atmospheric molecules. Ionic PFAS have a lower vapor pressure and greater water solubility; these tend to be the dominant congeners that form particulates in the air [90]. Deposition of PFAS primarily occurs by precipitation in the form of rain or snow, or as dry deposition from the cooling of air within a few days of atmospheric emission [91, 92, 93]. PFAS often have a negatively charged active group in the environment and repel from sediment. Surface water serves as the primary environmental sink for PFAS [94].

Across Canada, a national survey conducted by Health Canada measured PFOA contamination in raw and treated water samples from 35 locations in 2009 and 30 locations in 2010. PFOA was detectable in 68% of raw water samples and 64% of treated water samples. The average detected levels were 0.067 ng/L (2009) and 0.071 ng/L (2010). PFOS environmental contamination is also far-reaching. From 2007 to 2010, 569 water samples from across 11 drainage basins, including the Yukon drainage region, were measured for surface PFOS and the maximum reported level was 10 ng/L in British Columbia; 200-fold lower than the Canadian federal environmental quality guideline, set at 6.8 µg/L [95]. It should be noted that regulatory thresholds of safety for PFAS are regularly changing. During a follow-up study PFOS levels in some fish of the Yukon drainage region were found to exceed the federal environmental quality guidelines for the protection of mammals (4.6 µg/kg wet weight (ww) food) and birds (8.2 µg/kg ww

food) which eat the fish. This suggests that animals that eat fish may be at risk of higher PFOS exposure [95].

PFOA, PFNA, PFDA, and PFOS among other perfluorinated carboxylates and perfluorinated sulfonate concentrations were investigated in the Porcupine caribou herd in the YT and the Bathurst caribou herd of the NWT. This study indicated that PFOA, PFNA, PFDA, and PFOS were regularly detectable in all species studied, with caribou liver containing 1.4 to 1.7 ng/g PFOS [38]. In another study, PFAAs, including PFOS and PFOA, were measured in the traditional foods of Chesterfield Inlet, Igloodik, Pond Inlet, and Qikiqtarjuaq in Nunavut (1997 to 1999). Caribou liver (0.7 ng/g baked, 0.1 ng/g raw) and caribou stomach (0.8 ng/g raw), among other animal tissues, were found to be contaminated with PFOA [39].

### **1.7.2. Absorption, Distribution, Metabolization, and Excretion**

The main sources of human PFAS exposure are ingestion of contaminated foods and drinking water. Foods may be contaminated by the migration of PFAS from food packaging, or from consuming food grown in a contaminated area. Drinking water may be contaminated by run-off from contaminated sites such as waste facilities or airports, or environmental atmospheric deposition [96]. Dermal contact and inhalation of contaminated air can also contribute to PFAS exposure but tends to be less significant sources [97].

The mechanism for PFAS uptake and distribution has been investigated in animal models. PFAS are primarily absorbed through transporter in the small intestine, with a lesser extent of absorption occurring through the stomach [98]. PFAS bind to fatty-acid binding protein in the liver and albumin in plasma [99]. Absorption rates through oral exposure range from >50% (PFHxS) to >95% (PFOA and PFNA among other congeners) [99]. PFAS bind to plasma albumin in transport, and concentrate in primarily blood, renal, and hepatic tissues, [99] but may also accumulate in pulmonary, and brain tissues [100]. There are no known pathways for metabolism of PFAS in humans [99].

PFAS are also concerning due to their potential long elimination half-lives in humans. Research on the persistence of PFAS is emerging, and current findings indicate half-lives of 2.4 days to 35 years [101]. Hepatic excretion is the major route of elimination of PFAS compounds in humans. Biliary excretion and elimination by feces occur but are not major elimination pathways due to intestinal resorption [101]. Sex-based excretion pathways such as menses may account for some of the sex-based differences in PFAS levels [48]. Females can pass biological load of PFAS to offspring *in utero*, and PFAS can be present in breast milk [99]. In a multinational study, the milk to serum concentration ratios for PFOA, PFOS, PFHxS, and PFNA ranged from 0.01 to 0.07, on average [102]. Additionally, menstruation may also serve as an elimination pathway and pharmacokinetic modeling had indicated that 30% of the sex-based difference of PFOS elimination in women is accounted for by menses [103].

### **1.7.3. Toxicity**

PFAS at high levels in humans have been associated with a linear dose-dependent decrease in birth weight, pregnancy-induced hypertension, and pre-eclampsia, decreased immunologic response to vaccines, increased total and low-density lipoprotein cholesterol, liver function alterations, and cancer [101]. Specific human health hazards associated with PFAS exposure are hypothyroidism, liver damage, kidney cancer, testicular cancer, and delayed mammary gland development [104]. Additional human health hazards that are associated with PFAS by less or weaker evidence include breast cancer, inflammatory bowel disease, increased time to pregnancy, increased risk of miscarriage, and obesity and early puberty onset of offspring [105]. The toxic dose of PFAS varies depending on the congener, or

mixture of congeners present. No-observed-adverse-effect-levels (commonly NOAELs) for each congener have been identified in animal models and range from 0.1 to 110 mg/kg/day [99]. The toxicodynamic mechanisms of PFAS toxicity continue to be debated [105]. On a cellular level, PFAS exposure has been associated with oxidative stress mechanisms *in vivo* and *in vitro* models. Cellular antioxidative defense mechanisms are activated by PFAS but have demonstrated limited capacity to prevent cellular oxidative damage [106].

## 1.8. Chemical Regulation

International regulations of dioxins and DLCs have been well established since the early 2000s [107], while regulation of PFAS continue to be redefined as new evidence emerges. In 2001, the Stockholm Convention was developed, unifying the global goal to eliminate or restrict production and application of persistent organic pollutants. Polychlorinated dibenzo dioxins (PCDDs) were listed in Annex C, requiring member parties to have measures in place to reduce unintentional emissions, with the goal of release minimization, and eventual elimination. PFOS and its related salts were listed as persistent organic pollutants in Annex B of the Stockholm Convention, which restricts the production and allowable uses of these chemicals [108, 109]. PFOA and PFHxS and their related salts are listed under Annex A as of 2019 and 2022, respectively. Member countries must take measures to eliminate production and use of chemicals subject to Annex A regulation. Other long-chain perfluorocarboxylic acids are under review for listing in Annex A [110]

The Canadian Environmental Protection Act (commonly referred to as CEPA) (1999) includes dioxins and furans on Schedule 1 of the list of Toxic Substances [111]. Dioxins and furans are also regulated as persistent, bioaccumulative and toxic chemicals in Canada [112]. The Government of Canada prohibited the manufacture, use, sale and import of PFOS, PFOA and long-chain perfluorocarboxylic acids in December 2016 after adverse human health and environmental effects were known and considered to pose a risk in Canada [113] a. A growing body of evidence suggests that replacement PFAS compounds (e.g., HFPO-DA [GenX], ADONA, F-53B), which are not regulated, may present the same hazards as the prohibited PFAS compounds [114]. The Government of Canada has committed to reviewing emerging global policies and positions on PFAS as a class of compounds [114]. In May 2023, Health Canada and Environment Canada released a draft “State of PFAS” report, concluding that PFAS as a class of compounds meet one or more of the toxic criteria as set out in section 64 of CEPA. The knowledge synthesized in this thesis can directly inform the exposures experienced by people living within Canada to classified and proposed CEPA “toxic” chemicals and identify some determinants of exposure.

## 1.9. Study Rationale and Objective

The overall goal of this thesis is to evaluate the exposure levels of dioxins and DLCs in Old Crow and to identify if traditional foods and lifestyle factors are associated determinants of exposure to dioxins, DLCs, and PFAS in Old Crow and the Dehcho Region.

The research questions addressed in this thesis are:

### **Chapter 1: Human Biomonitoring of Dioxins, Furans, and Non-Ortho Dioxin-Like PCBs in Blood Plasma from Old Crow, Yukon, Canada (2019)**

1. What are the levels of specific congeners of dioxins and DLCs in blood plasma samples from Old Crow?
2. How do the dioxins and DLC levels in Old Crow (2019) differ from the levels presented in the pooled CHMS Cycle 5 data (2016-2017)?

3. Are there specific demographics (e.g., sex, age, smoking status, and BMI) that are associated with biological levels of select dioxin and DLC congeners?
4. Are there specific demographics (e.g., sex, age, smoking status, and BMI) that are associated with biological levels of dioxin and DLC congeners, according to TEQ?

### **Chapter 2: Traditional foods and other determinants of exposures to persistent organic pollutants (POPs) in Old Crow, Yukon, and the Dehcho Region, Northwest Territories**

1. How are potential exposure sources, such as dietary intake of traditional foods (*e.g.*, fish, land animals, birds, berries, and other plants) associated with the concentrations of dioxins and DLCs in Old Crow?
2. How are potential exposure sources, such as dietary intake of traditional foods (*e.g.*, fish, land animals, birds, berries, and other plants) and lifestyle factors (*e.g.*, smoking status), associated with the concentrations of blood PFAS concentrations in Old Crow and the Dehcho Region?

The results of this project have been returned to participants as new results emerged, within one year of analysis. Results from this thesis were shared in person through community meeting and/or by plain language letter. The materials used to communicate study results from this research are included in Appendices **Error! Reference source not found.** & **Error! Reference source not found.**

## **2. Human Biomonitoring of Dioxins, Furans, and Non-Ortho Dioxin-Like PCBs in Blood Plasma from Old Crow, Yukon, Canada (2019)**

Simpson, A.K., Drysdale, M., Gamberg, M., Froese, K., Brammer, J., Ratelle, M., Skinner, K., Laird, B.D. Human Biomonitoring of Dioxins, Furans, and Dioxin-like PCBs in Blood Plasma from Old Crow, Yukon, Canada (2019). In coauthor review. To be submitted to Science of the Total Environment (2023).

### **2.1. Abstract**

Dioxins, furans, and dioxin-like PCBs are a group of persistent and toxic chemicals that are known to have human health effects at low levels. These chemicals have been produced for commercial use (PCBs) or as by-products of industry or natural processes (dioxins and furans). Additionally, dioxin-like PCBs were formerly used in electrical applications before being banned internationally (2004). These chemicals are widely dispersed in the environment as they can contaminate air and travel hundreds to thousands of kilometres before depositing on land or water, thereafter, potentially entering food chains. Community concerns surrounding the safety of traditional foods prompted a human biomonitoring project in Old Crow, YT, Canada (2019). Through collaborative community engagement, dioxins and like compounds were identified as a priority for exposure assessment from biobanked samples.

Blood plasma samples (n=54) collected in Old Crow were used to measure exposures to seven dioxins, ten furans, and four dioxin-like PCBs. 1,2,3,6,7,8 HxCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,4,6,7,8 HpCDD, OCDD, 2,3,4,7,8 PeCDF, 1,2,3,6,7,8-HxCDF, PCB 126, and PCB 169 were detected in at least 50% of samples. Among these analytes, the only congener at elevated levels was PCB 169, which was approximately ~2-fold higher than the General population of Canada. No significant sex based or BMI differences in biomarker concentrations were observed. Generally, the concentrations of the detected congeners increased with age, except for 1,2,3,4,6,7,8 HpCDD.

For the first time, this research measures dioxin and like-compound exposures in Old Crow, advancing the information available on chemical exposures in the Arctic. Further research could be directed towards the investigation of PCB 169 exposure sources and temporal monitoring of exposures and determinants.

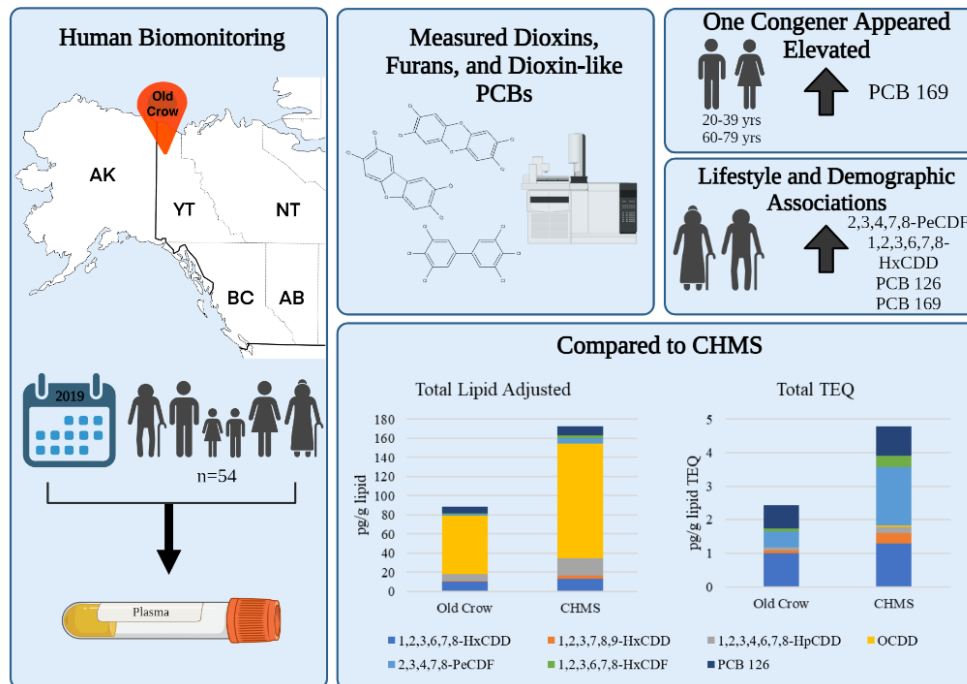


Figure 8: Graphical abstract for dioxin and DLC biomonitoring results in Old Crow, YT [115].

## 2.2. Introduction

Dioxins and DLCs are persistent bioaccumulative chemicals of global concern; these chemicals are subject to strict national and international regulations, such as the Stockholm Convention, which have prohibited their use since 2004 [109, 116]. Dioxins were formed as byproducts during the synthesis of some pesticides (e.g., 2,4,5-T, discontinued). Dioxins and DLCs can derive from combustion reactions, such as those in metal refinement, some municipal waste incinerators, burning, and other sources of combustion. Also, some dioxin-like PCBs (e.g., PCBs 77, 81, 126, 169) were formerly used in electrical transistors [20, 86, 117, 118, 119]. These chemicals can also be produced and emitted naturally, through forest fires and volcanic emissions [86, 120]. Once in the atmosphere, dioxins and DLCs can travel distances of hundreds to thousands of kilometers from the source of emission via global distillation [86, 120].

Global concerns about the impacts of these chemicals on human health were based on their potential toxic effects, as well as the ongoing human exposure, including their persistence, and their release via multiple industrial chemical accidents. Typically, diet is the main source of human exposure to these chemicals [86]. The foods that contribute most to dioxin and DLC exposures in a typical North American diet are lipid-rich, and include meats, dairy products, fish, and eggs [60, 117]. Likewise, traditional foods that are lipid-rich may also contribute to exposure. For example, the eggs of sea birds along the St. Lawrence River in Quebec were found to have elevated levels of dioxin-like PCBs [121].

Once in the body, metabolism of dioxins and DLCs is limited due to their poor affinity with xenobiotic biotransformation enzymes [122]. These compounds typically partition into fatty tissues after absorption in the gastrointestinal tract [123]. On average, the whole-body elimination half-life for these chemicals is 7 to 11 years [23]. Dioxins and DLCs interact with the AhR in the cytoplasm of cells with various strengths. Among dioxins and DLCs, 2,3,7,8-TCDD has one of the strongest binding affinities with the AhR [80]. Other dioxins that are hazardous to human health have fractional binding affinities relative to 2,3,7,8-TCDD, called TEFs (Appendix A). Animal studies have indicated that elevated exposures to dioxins and DLCs are associated with chronic health outcomes, including carcinogenic effects (e.g., soft-

tissue sarcoma, non-Hodgkin lymphoma, pulmonary cancer); reproductive effects (e.g., decreased fertility, litter size, live birth body weight, and survivability for two successive generations); and immunologic effects (e.g., immunosuppression, and non-specific stimulation of immune response) [86, 124].

Human biomonitoring by the CHMS included measurements of dioxins and DLCs in Cycle 1 (2007 to 2009), and Cycles 3 (2012 to 2013) to 5 (2016 to 2017) [41]. While these data are considered representative of the general population of Canada, it is not known if the exposures observed from the CHMS are generalizable to First Nations located in the Arctic within Canada. Polar regions are particularly vulnerable to persistent organic pollutants (POPs) because the cold conditions promote the deposition of semi-volatile chemicals in the global distillation process, which can result in contamination of traditional foods from both aquatic and terrestrial food chains [120]. There are a lack of data to accurately measure the extent of exposures experienced by people residing in the Arctic and subarctic regions of Canada.

Old Crow, YT (67.57, -139.83), is a fly-in only community in Arctic Canada that is home to the Vuntut Gwitchin First Nation. Vuntut Gwitchin residents of Old Crow have diets with high proportions of traditional foods (such as wild meat, fish, and plants) in comparison to other Yukon communities [14] and the average of other First Nation communities across Canada [15]. Traditional foods are integral to food security, food sovereignty, and culture in Old Crow and the safety of their traditional diet is a community research priority [125, 126, 127, 128]. This priority prompted a human biomonitoring project beginning in 2019 [47]. The initial results from biomonitoring in Old Crow indicated elevated blood levels of HCB, lead, cobalt, and manganese in comparison to the general population of Canada [47].

The influence of traditional diets on dioxin and DLC exposures in Old Crow remains uncertain. The purpose of this study is to report on the dioxin and DLC exposure levels in Old Crow and compare these to the General population of Canadas; furthermore, the relationships of biomarkers to lifestyle and demographic factors such as sex, age, and BMI were investigated.

## **2.3. Methods**

This cross-sectional study utilized biobanked blood plasma samples collected as a part of a human contaminants biomonitoring project conducted in Old Crow, YT (2019). The following sections briefly describe the data collection methods.

### **2.3.1. Community Partnership and Ethics**

This study was conducted in alignment with the community research agreement set out between the Vuntut Gwitchin Government and the University of Waterloo (2018 to 2023) [129]. The data and knowledge synthesized from this study have been returned to study participants and the community of Old Crow. The conduct of this study was also approved by the University of Waterloo Research Ethics Board (#32076) and through a Scientists and Explorers Research License obtained from the Yukon Government (12-27S&E).

## **2.4. Recruitment**

Anyone in Old Crow four years of age and older who was able to provide free and informed voluntary consent was eligible to participate in the biomonitoring study. Those who were unable to provide free and informed consent, including individuals experiencing symptoms of dementia, impairment, or minors without the consent of their parent or guardian, were not permitted to participate. Eligibility for study participation also required the participant to agree, through informed consent, to receive their results.

Participants were recruited through passive methods, such as word-of-mouth and community posters, and randomly by phone call. A local coordinator was hired to phone 40% of residents (randomized) from a list

of local phone numbers. The coordinator described the objectives of the study and the informed consent process. Additional details on the recruitment process and remuneration for participation are documented elsewhere [46, 47].

## 2.5. Samples

Samples of blood, urine, and hair were collected from ~44% of Old Crow residents to measure nutrients and contaminants. The analytes measured in the original panel of testing included the plasma lipid content, several metals, persistent organic pollutants, and nutrients, such as selenium, and omega-3 fatty acids [47]. Following these analyses, 54 biobanked blood plasma samples with adequate volume (>1 mL) remained in a -80°C freezer for dioxin and DLC analysis.

## 2.6. Analytical Methods

The analyses of seven dioxin congeners (i.e., 2,3,7,8-TCDD, 1,2,3,7,8-PeCDD, 1,2,3,4,7,8 HxCDD, 1,2,3,6,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,4,6,7,8-HpCDD, OCDD), ten furan congeners (i.e., 2,3,7,8-TCDF, 1,2,3,7,8-PeCDF, 2,3,4,7,8-PeCDF, 1,2,3,4,7,8 HxCDF, 1,2,3,6,7,8-HxCDF, 1,2,3,7,8,9 HxCDF, 2,3,4,6,7,8-HxCDF, 1,2,3,4,6,7,8-HpCDF, 1,2,3,4,7,8,9-HpCDF, OCDF), and four non-ortho dioxin-like PCB congeners (i.e., PCB 77, PCB 81, PCB 126, PCB 169) were completed at the Centre de Toxicologie du Québec within the Institut National de Santé Publique du Québec. C 13 analog spiked plasma samples (1 mL aliquots) were first denatured with ethyl alcohol and saturated ammonium sulfate solution, followed by hexane liquid-liquid extraction. The hexane extract's purification was performed on neutral aluminum column. Dioxins and DLCs were recovered with a dichloromethane:hexane (50:50) wash fraction. The solvents were then evaporated to near dryness and 10 µl of toluene was added as a carrier solvent. The analytes were quantified using an atmospheric pressure positive ionisation gas-chromatograph coupled to a tandem mass spectrometer (Waters) (APGC MS/MS TQXS) via an analytical column (DB XLB 30 m x 0.25 µm x 0.1 µm). The limit of detection ranged from 0.004 to 0.012 pg/g plasma. Method accuracy was evaluated and controlled by analysing certified reference material (NIST SRM 1958), and proficiency test materials (AM-SD-1404 and AM SD 1604), from the Québec External Quality Assessment Scheme. Mean percent recovery for the analytical method ranged from 58% for PCB 77 to 79% for 1,2,3,4,6,7,8-HpCDF, and are included in Appendix B. The median percent recovery differed from the respective means by a maximum of 2%, indicating that there were no major recovery outliers. The largest single standard deviation was observed with 1,2,3,7,8 PeCDD at 12%. Results of this testing were provided as the concentration of the dioxin congeners in pg/g plasma and pg/g lipids adjusted for % recovery.

## 2.7. Comparison Data

In this study the CHMS AMs from the Cycle 5 (2016 to 2017) pooled analysis served as the general population of Canada comparison group. The dates of collection for CHMS Cycle 5 were closest to that of the Old Crow biomonitoring study (2019). The seven dioxins, ten furans, and four dioxin-like PCBs, consistent with the congeners analyzed in this study, were included for analysis within CHMS Cycle 5. Analyses for part of the CHMS were conducted at the Food Laboratory Toronto. Additional details on the preparation and analytical detection of the pooled samples are published and publicly available [41]. In the absence of health-based guidance values, comparison to CHMS data is intended to contextualize the level of exposure and does not serve as an estimate of health risk. This approach is consistent with other biomonitoring results reported as part of biomonitoring research in Old Crow [47, 48].

## 2.8. Data Analysis

The community average results of dioxin and DLCs from blood plasma samples were compared to the 2016 to 2017 Cycle 5 CHMS pooled serum data. Although this investigation uses measurements from plasma and comparison data from serum, other dioxin, and DLC biomonitoring studies have used cross-matrix comparison for contextualization of results without any adjustment for matrix differences [130, 131, 132]

Comparison and statistical analysis were completed when the detection rate of the congener was >50%. Results that were below the limit of detection were assigned a value of ½ the respective individualized limit of detection (LOD). This method of substitution is consistent with the approach used by CHMS for the dioxin, furan, and dioxin and furan TEQs [41] Percentiles that were calculated as <LOD are reported as such.

Lipid-adjusted values were used to control for variations in individual blood lipid concentrations. CHMS reports the arithmetic means (AM) of dioxins and DLCs rather than geometric means (GM); to maintain a consistent approach, the AMs from the Old Crow data were used for comparison [42]. The GMs were also reported for consistency with other research protocols [42, 47, 133].

Descriptive statistics including 5<sup>th</sup>, 10<sup>th</sup>, 25<sup>th</sup>, 50<sup>th</sup>, 75<sup>th</sup>, 90<sup>th</sup>, and 95<sup>th</sup> percentiles, AM, GM, and respective bootstrapped 95% confidence intervals (CI) (B=2000) were calculated by simple sampling in IBM SPSS Statistics Software Version 28.0.0.0 (or 29.0.0.0 where specified) for all congeners detected in >50% of study participants. GMs and AMs were also calculated for age and sex-stratified groups in alignment with those specified in CHMS (20 to 39, 40 to 59, 60 to 79) [41]. Age-based analysis for participants <20 years of age was not performed due to the small sample size and to preserve confidentiality.

The distributions of dioxin congeners were evaluated using histograms and Shapiro-Wilk tests of normality ( $p < 0.05$ ). The data were tested for log-transformation normality, which was determined to be appropriate for all congeners. AMs and CIs were used to identify differences between the Old Crow data and CHMS Cycle 5 pooled reference data on average, and across age and sex-stratified data; these differences cannot be considered statistically different because CIs for CHMS data were not available. Spearman correlations were calculated to assess associations between dioxin and DLCs with >50% detection rates.

The relationships between dioxin and DLCs with >60% detection rates and demographic and lifestyle factors, including age, sex, BMI, and smoking were investigated. The 60% detection rate inclusion cut-off was based on exploratory data analysis and satisfaction of linear regression model assumptions. Simple linear regression was used to assess associations between the biomarkers and the continuous determinants age and BMI. Tobit simple linear regression was used for 2,3,4,7,8-PeCDF and 1,2,3,7,8,9-HxCDD since these congeners had less sensitive quantification close to the limit of detection. Details on the points of censor are available in Appendix D. Comparisons of GMs and CIs were used to assess significant differences in biomarker average levels between sexes and smoking status.

## 2.9. Results & Discussion

### 2.9.1. Age and Sex of Participants

The demographics of study participants are presented in Table 1. Dioxins and DLCs were measured in about 27% of the eligible population. All participants but one were  $\geq 20$  years of age; the results for this participant are excluded to maintain confidentiality. The mean and median ages of Old Crow participants were 43 (95% CI: 39, 48) and 41 (95% CI: 34, 52), while the same statistics of Old Crow census participants were 40 and 39, respectively.

The proportion of study participants 25 to 44 years of age was higher (41%) in comparison to the proportion of the same demographic in the census data (32%). Other age stratifications (45 to 59, and 60+) were proportionally similar to the census data; notably, those in the 60+ age group were marginally underrepresented. Generally, the sex stratifications of study participants were proportional to the demographics observed in the Old Crow census data informed by a two-sided Fisher exact test ( $p=0.76$ ).

**Table 1: Participant Demographics for Old Crow**

Demographic		Old Crow, YT	Census Data Old Crow, YT (2016)
		n (% of total)	n (% of total)
Age group <sup>a</sup>	10-24 <sup>b</sup>	7 (13%)	40 (21%)
	25-44	22 (41%)	60 (32%)
	45-59	15 (28%)	45 (24%)
	60+	10 (19%)	45 (24%)
	Total	54	190
Sex <sup>c</sup>	Male	27 (50%)	105 (53%)
	Female	27 (50%)	95 (48%)
	Total	54	200

n=sample size; YT=Yukon Territory.

<sup>a</sup> Age ranges based on the census stratifications from Old Crow, YT to permit comparison.

<sup>b</sup> Ages were reported in the census as 10-14 and 15-24 but were combined for this presentation to preserve participant confidentiality.

<sup>c</sup> Includes sex demographics for those within the age range of study eligibility

## 2.9.2. Frequencies of Detection and Comparison to the General Population of Canada

Out of the 21 dioxins and DLCs analyzed, eight were detected in >50% of samples; these included 2,3,4,7,8-PeCDF, 1,2,3,6,7,8-HxCDF, 1,2,3,6,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,4,6,7,8-HpCDD, OCDD, PCB 126, and PCB 169, as shown in Figure 1, Table 2, and Appendix E. Four congeners (2,3,4,6,7,8-HxCDF, 1,2,3,7,8,9-HxCDF, 1,2,3,4,7,8,9-HpCDF, and OCDF) were not detected in any samples, while two dioxin congeners, 1,2,3,4,6,7,8-HpCDD, and OCDD, were detected in all the samples.

Most of the AMs for dioxins and DLCs in Old Crow were lower or similar to the respective CHMS AMs, where data were available for comparison. The total exposure of dioxin and DLCs in Old Crow residents (AM: 3.6 pg/g lipids) is approximately two-fold lower than the average for the general population of Canada (AM: 7.5 pg/g lipids) and the associated health effects are not of concern at these levels of exposure. For additional health risk context, the Agency for Toxic Substances and Disease Registry (ATSDR) derived a MRL of 1 pg/kg/d which informed derivation of the currently most conservative biomonitoring equivalent at 15 pg TEQ/g lipid for a sum of dioxins, furans, and dioxin-like PCBs [134]. It should be noted that the TEQs documented in this research exclude dioxin-like PCBs as ortho substituted dioxin-like PCBs were not measured as a part of this work. In another study, mono-ortho dioxin-like PCBs and other PCBs were measured in the Dehcho Region and Sahtú Region of the NWT and Old Crow, YT. None of the PCBs previously measured in Old Crow were found to be elevated in comparison to CHMS biomonitoring data from Cycle 1 (2007) [50].

Data stratifications including total community data, males, females, and the 40 to 59 age group were lower across all comparisons. The 20 to 39, and 60 to 79 age groups showed lower levels of all contaminants tested except for PCB 169, which was approximately two-fold elevated [4.6 pg/g lipids (95% CI: 3.5, 5.9) compared to 2.4 pg/g lipids (CHMS 20 to 39 age group), and 26 pg/g lipids (95% CI: 14, 41) compared to 12 pg/g lipids (CHMS 60 to 79 age group)]. Table 3 shows that higher levels of PCB 169 were significantly positively associated with age. This indicates that as age increases,  $\log_{10}$  plasma

concentrations of PCB 169 increase by a rate of  $\log_{10} 0.0.22$  pg/g lipids, on average. This finding is consistent with other data, indicating that PCB 169 is bioaccumulative [86].

It remains unclear if there may be, or has been, a local emission source that contributed to this elevated exposure of PCB 169. In other geographical areas, PCB 169 contamination may also be independent of other dioxins and DLCs. A biomonitoring study conducted in Anniston, Alabama, USA, known for elevated PCB environmental contamination due to local industrial emissions, utilized principal component analysis to examine clustering patterns of PCBs, dioxins, and DLCs, and revealed potential distinct sources of PCB 169 exposure compared to other PCBs (Yang et al., 2018). Another study, centered in Tokyo Bay (1993), measured PCB 77, PCB 81, PCB 126, and PCB 169 in a sediment core sample. PCB 169 was found to increase in concentration proportionally with PeCDFs in the sediment core and did not share sedimentary patterns with the other PCBs. The authors suggest that PeCDFs are mainly combustion related DLCs, and incineration has been estimated to be a greater source of PCB 169 than PCB formulations and herbicides [135]. Since all municipal waste is burned in an open-air pit fire in Old Crow, combustion-related emissions represent a potential source for the elevated concentrations of PCB 169 in Old Crow residents.

Another PCB 169 exposure source to explore may be the contribution of long-range atmospheric transport of chemicals as this is commonly reported as the main mechanism for exposure to PCBs in the Arctic [136, 137, 138, 139]. However, atmospheric distribution does not appear to be significantly contributing to other dioxin and DLC, as would be expected if atmospheric distillation was the main driver of exposure. Furthermore, as climate change continues to alter atmospheric air patterns in the Arctic, the deposition trends of PCBs and other POPs may also change [120]. PCB 169 has been identified as a priority compound for additional research according to community interest and questions from participants surrounding the origin of PCB 169 in local environments. The Vuntut Gwitchin Government has expressed interest in obtaining more information on exposure sources to PCB 169 to potentially inform community-based monitoring and management actions.

Based on a visual inspection of the PCB 169 exposure data, it was confirmed that a single outlier was observed with approximately six-fold higher exposure than the community average, and 3.5-fold higher than their respective age group average. All datapoints were included within the statistical analysis; but, it is noted that one outlier may be influencing the PCB 169 data based on a comparison of the AM to the GM [AM: 26 (95% CI: 14, 41), GM: 19 (95% CI: 12, 31)] (Appendix E).

Additionally, the coefficients of variation reported for the CHMS PCB 169 measurements in the 20 to 39 age group, and the 60 to 79 age group were 54% and 21%, respectively (Table 2). This indicates that the CHMS 20 to 39 age group measurement may not be reliable and should be used in interpretations with a high degree of caution. CHMS data stratified by sex (male, female), ages 40 to 59, and all ages (6-79) were not available due to data loss. Without these additional values for context, the conclusion is limited in scope.

### **2.9.3. Relative Toxicity**

It is important to contextualize these results by the total proportional hazard posed by the exposures because these chemicals have similar toxicokinetic mechanisms. For instance, despite OCDD exposures being relatively abundant in Old Crow compared to the other dioxin and DLC congeners, OCDD's low TEF of 0.0003 minimizes its toxicity contribution within the sum of dioxins and DLCs (Appendix F). The dioxins TCDD and PeCDD, which have TEFs of 1, were detected in 9% and 48% of study participants, respectively (Table 3). Among the congeners detected in >50% of participants, the greatest TEQ was 0.1 for 1,2,3,6,7,8-HxCDF, 1,2,3,6,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, and PCB 126, respectively (Appendix A). The total TEQ exposures in Old Crow appear to be approximately half of those observed in CHMS Cycle 5 (Table 2). This suggests that the cumulative exposures to dioxins from all environmental, dietary, and lifestyle sources are less than those experienced by people living in the provinces of Canada.

#### 2.9.4. Lifestyle and Demographic Factors

Table 4 shows significant positive correlations between age and the concentrations of specific congeners, namely 2,3,4,7,8-PeCDF, 1,2,3,6,7,8-HxCDD, PCB 126, and PCB 169. However, no associations were detected among the other congeners (1,2,3,7,8,9-HxCDD, 1,2,3,4,6,7,8-HpCDD, and OCDD). No significant negative relationships were found between age and DLC biomarker concentrations.

Other demographic or lifestyle factors such as sex, age, and BMI were generally not associated with blood plasma dioxin levels, with one exception: non-smokers exhibited significantly higher average exposure levels of 1,2,3,4,6,7,8-HpCDD [GM: 8.8, 95% CI: (7.4, 11)] in comparison to smokers [GM: 4.7, 95% CI (4.1, 5.4)]. Smoking is a known exposure source of this congener [140]. A study by Muto and Takizawa (1989) identified that HpCDD was the most abundant congener group detected in cigarette smoke [141], suggesting that smoking upregulates CYP detoxification mechanisms of this congener which are not otherwise upregulated by typical background exposure levels. It is known that CYP1A1 is involved in dioxin metabolism [142], and is upregulated in active smokers [143]. Smoking has also been positively associated with CYP1A2 activity but negatively associated with PCB 105:PCB 153 and PCB 118: PCB153 congener ratios indicating that only smoking has a significant correlation with biomarkers of hepatic enzyme induction [144]. Alternatively, smoking may be a confounding variable associated with another exposure risk factor, such as dietary consumption that differs from non-smokers. The potential effect of smoking on 1,2,3,4,6,7,8-HpCDD levels should not downplay the serious negative health consequences that are well established for smoking. Additionally, there may be weak positive associations between smoking and dioxin-like PCB exposures (PCB 126 and PCB 169) (Table 4); the CIs slightly overlap [PCB 126: non-smokers (3.2, 5.6) vs smokers (4.1, 7.2), and PCB 169: non-smokers (3.3, 7.1) vs smokers (6.2, 15)], which indicates insufficient evidence of an association or a limitation of the small sample size.

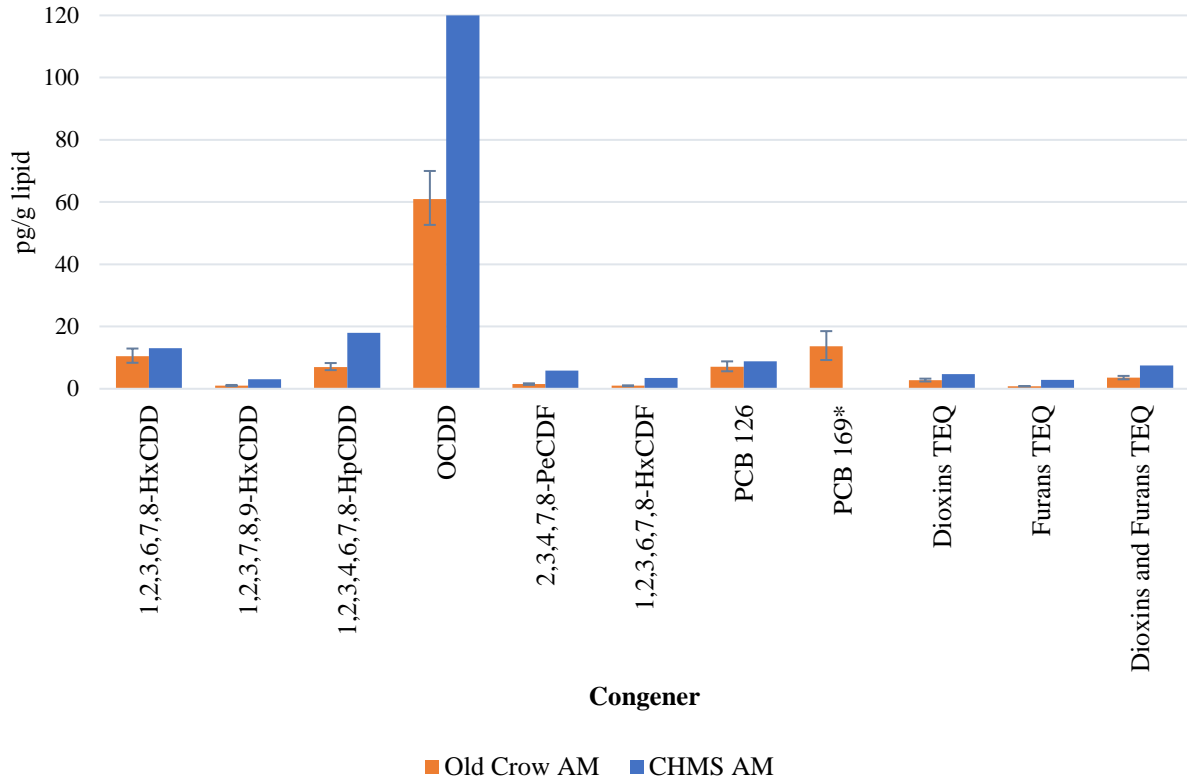
Inconsistent findings regarding the direction and strength of associations between BMI, smoking status, and dioxins and DLC levels have been observed in other studies. For example, a Seveso observational cohort study reported a negative correlation between dioxin plasma levels and BMI, as well as lower TEQ levels in current smokers compared to never smokers. Additionally, women in this cohort had 17% higher TEQ exposures to dioxins and DLCs in comparison to men [145]. In a study involving consumers of fish from a contaminated lake in Norway, BMI and age were associated with elevated blood concentrations of dioxins and PCBs [146]. Another study that directly measured dioxins in adipose tissue found significant positive associations with age and some dioxins and furan congeners but did not observe any sex differences in exposure [147]. This information suggests that BMI and smoking are not the main drivers of exposure in Old Crow.

#### 2.9.5. Associations Between Biomarkers

Associations among lipid-adjusted dioxins and DLCs are included in Table 5. Most congeners had significant moderate positive (0.30 – 0.78) Spearman associations indicating that the congeners were commonly detected in combination, and higher concentrations among the same participants. The strongest associations appeared between 1,2,3,6,7,8-HxCDD and PCB 169 (78%), 2,3,4,7,8-PeCDF and 1,2,3,6,7,8-HxCDF (73%), 2,3,4,7,8-PeCDF and 1,2,3,6,7,8-HxCDD (72%). To date, associations among dioxins and DLCs among participants in CHMS have not been reported.

Associations between dioxins and DLCs have been observed in another human biomonitoring study conducted with Vietnam Veterans which demonstrated Spearman associations of similar magnitude and direction: 1,2,3,6,7,8-HxCDD + 123478-HxCDD and PCB 169 (56%), 2,3,4,7,8-PeCDF and 1,2,3,6,7,8-HxCDD + 123478-HxCDD (60%) [148]. Additional information on environmental levels of dioxins in air, surface sediments, and foods may help to establish if these associations are evidence of co-exposure, a related exposure pathway, or coincidence.

**Figure 9: Arithmetic mean dioxins, furans, and dioxin-like PCBs detected in blood plasma samples from Old Crow (13-74 years of age) (n=54) relative to CHMS (6-79 years of age) levels in serum<sup>a</sup>**



AM= arithmetic mean; CHMS= Canadian health measures survey; TEQ= toxicity equivalence.

<sup>a</sup> Whiskers represent 95% confidence intervals. CHMS Cycle 5 data presents only a % coefficient of variation.

\* PCB 169 does not have CHMS data for the 6 to 79 age group.

**Table 2: A comparison of the Old Crow lipid adjusted arithmetic means of congeners detected in >50% of participants, and calculated TEQs to the CHMS Cycle 5 pooled arithmetic means.**

	1,2,3,6,7,8-HxCDD (pg/ g lipid)	1,2,3,7,8,9-HxCDD (pg/ g lipid)	1,2,3,4,6,7,8-HpCDD (pg/ g lipid)	OCDD (pg/ g lipid)	2,3,4,7,8-PeCDF (pg/ g lipid)	1,2,3,6,7,8-HxCDF (pg/ g lipid)	PCB 126 (pg/ g lipid)	PCB 169 (pg/ g lipid)	Dioxins TEQ (pg/ g lipid)	Furans TEQ (pg/ g lipid)	Dioxins and Furans TEQ (pg/ g lipid)
<b>Old Crow LOD [AM (min, max)]<sup>d</sup></b>	1.1 (0.7, 1.7)	0.6 (0.35, 0.85)	1.3 (0.78, 1.9)	1.4 (0.86, 2.1)	0.85 (0.52, 1.3)	0.85 (0.52, 1.3)	1.1 (0.69, 1.7)	1.7 (1.0, 2.5)	N/A	N/A	N/A
<b>CHMS LOD [AM (min, max)]</b>	0.49 (0.19, 1.2)	0.49 (0.19, 1.3)	0.43 (0.13, 0.96)	1.1 (0.41, 2.5)	0.39 (0.10, 1.4)	0.34 (0.084, 4.2)	2.1 (0.40, 8.7)	1.5 (0.22, 6.9)	N/A	N/A	N/A
<b>n</b>	54	54	54	54	54	54	54	54	54	54	54
<b>Old Crow GM (95% CI)</b>	7.7 (6.1, 9.6)	0.80 (0.65, 0.98)	6.1 (5.4, 7.1)	54 (47, 62)	1.23 (1.0, 1.5)	0.83 (0.71, 0.97)	5.4 (4.4, 6.5)	7.7 (5.7, 10)	2.4 (2.0, 2.8)	0.73 (0.65, 0.82)	3.1 (2.7, 3.6)
<b>Total</b>											
<b>Old Crow AM (95% CI)</b>	10 (8.4, 13)	1.0 (0.85, 1.2)	7.0 (6.0, 8.3)	61 (53, 70)	1.5 (1.3, 1.8)	0.97 (0.84, 1.1)	7.0 (5.6, 8.8)	14 (9.2, 19)	2.8 (2.4, 3.3)	0.80 (0.71, 0.89)	3.6 (3.0, 4.1)
<b>CHMS AM</b>	13	3.1	18	120	5.8	3.5	8.8	NR	4.7	2.9	7.5
<b>CHMS CV (%)</b>	1	4	4	3	5	10	12	NR	1	5	1
<b>Comparison to CHMS</b>	↔	↓	↓	↓	↓	↓	↔	N/A	↓	↓	↓
<b>n</b>	27	27	27	27	27	27	27	27	27	27	27
<b>Old Crow GM (95% CI)</b>	7.5 (5.7, 9.7)	0.73 (0.56, 0.95)	6.2 (5.2, 7.6)	53 (44, 64)	1.3 (0.99, 1.6)	0.81 (0.66, 0.99)	5.9 (4.6, 7.8)	10 (7.1, 15)	2.3 (1.9, 2.7)	0.74 (0.64, 0.87)	3.0 (2.6, 3.5)
<b>M</b>											
<b>Old Crow AM (95% CI)</b>	9.3 (7.0, 12)	0.95 (0.70, 1.2)	7.3 (5.7, 9.4)	59 (48, 72)	1.5 (1.2, 1.9)	0.93 (0.75, 1.1)	8.0 (5.5, 11)	17 (10, 26)	2.5 (2.1, 3.1)	0.80 (0.68, 0.94)	3.3 (2.8, 4.0)
<b>CHMS AM</b>	13	3	16	100	6.5	3.8	6.7	NR	5	3.2	8.2
<b>CHMS CV (%)</b>	0	10	2	3	6	14	29	NR	4	7	0
<b>Comparison to CHMS</b>	↓	↓	↓	↓	↓	↓	↔	N/A	↓	↓	↓
<b>n</b>	27	27	27	27	27	27	27	27	27	27	27
<b>Old Crow GM (95% CI)</b>	7.8 (5.5, 11)	0.87 (0.63, 1.1)	6.1 (5.1, 7.3)	55 (46, 67)	1.2 (0.94, 1.5)	0.81 (0.70, 1.1)	4.8 (3.7, 6.3)	5.7 (3.7, 8.5)	2.5 (2.0, 3.1)	0.71 (0.60, 0.84)	3.2 (2.6, 4.0)
<b>F</b>											
<b>Old Crow AM (95% CI)</b>	12 (8.1, 16)	1.1 (0.86, 1.4)	6.7 (5.6, 8.0)	63 (51, 77)	1.5 (1.1, 1.8)	1.0 (0.81, 1.2)	6.1 (4.6, 7.7)	9.9 (6.4, 13)	3.0 (2.3, 3.8)	0.79 (0.66, 0.92)	3.8 (3.0, 4.7)
<b>CHMS AM</b>	NR	NR	NR	NR	NR	NR	NR	NR	4.4	2.6	6.9
<b>CHMS CV (%)</b>	NR	NR	NR	NR	NR	NR	NR	NR	1	2	1
<b>Comparison to CHMS</b>	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	↓	↓	↓

	1,2,3,6,7,8- HxCDD (pg/ g lipid)	1,2,3,7,8,9- HxCDD (pg/ g lipid)	1,2,3,4,6,7, 8-HpCDD (pg/ g lipid)	OCDD (pg/ g lipid)	2,3,4,7,8- PeCDF (pg/ g lipid)	1,2,3,6,7,8- HxCDF (pg/ g lipid)	PCB 126 (pg/ g lipid)	PCB 169 (pg/ g lipid)	Dioxins TEQ (pg/ g lipid)	Furans TEQ (pg/ g lipid)	Dioxins and Furans TEQ (pg/ g lipid)	
20 to 39 <sup>b</sup>	n	26	26	26	26	26	26	26	26	26	26	
	Old Crow GM (95% CI)	4.6 (3.6, 5.7)	0.70 (0.52, 0.92)	6.3 (5.4, 7.4)	47 (40, 56)	0.93 (0.75, 1.2)	0.67 (0.55, 0.84)	3.3 (2.8, 4.0)	3.6 (2.7, 4.8)	1.7 (1.5, 1.9)	0.61 (0.53, 0.71)	2.3 (2.0, 2.6)
	Old Crow AM (95% CI)	5.3 (4.3, 6.5)	0.90 (0.66, 1.1)	6.8 (5.8, 7.9)	52 (42, 61)	1.1 (0.84, 1.4)	0.79 (0.62, 0.99)	3.7 (3.1, 4.3)	4.6 (3.5, 5.9)	1.8 (1.6, 2.1)	0.66 (0.56, 0.78)	2.4 (2.1, 2.8)
	CHMS AM	7.2	3.1	18	110	4.9	3.7	5.3	2.4	2.7	2.6	5.4
	CHMS CV (%)	4	1	3	8	9	3	35 <sup>b</sup>	54 <sup>c</sup>	17	5	6
	Comparison to CHMS	↓	↓	↓	↓	↓	↓	↓	↑	↓	↓	↓
	n	17	17	17	17	17	17	17	17	17	17	17
40 to 59	Old Crow GM (95% CI)	12 (8.9, 16)	0.96 (0.68, 1.3)	6.5 (4.9, 8.8)	63 (51, 77)	1.6 (1.2, 2.1)	1.0 (0.80, 1.3)	8.3 (6.1, 11)	16 (11, 22)	3.2 (2.5, 4.0)	0.85 (0.71, 1.0)	4.0 (3.2, 5.0)
	Old Crow AM (95% CI)	14 (10, 18)	1.2 (0.85, 1.5)	8.0 (5.6, 11)	70 (56, 86)	1.9 (1.4, 2.3)	1.2 (0.90, 1.4)	10 (7.1, 15)	21 (13, 31)	3.6 (2.8, 4.4)	0.91 (0.75, 1.1)	4.4 (3.5, 5.5)
	CHMS AM	NR	NR	NR	NR	NR	NR	NR	NR	4.7	2.6	7.3
	CHMS CV (%)	NR	NR	NR	NR	NR	NR	NR	NR	7	9	8
	Comparison to CHMS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	↓	↓	↓
60 to 79	n	10	10	10	10	10	10	10	10	10	10	
	Old Crow GM (95% CI)	16 (10, 24)	0.85 (0.49, 1.5)	5.2 (3.8, 7.2)	60 (42, 86)	1.7 (1.1, 2.4)	1.1 (0.76, 1.4)	9.3 (6.7, 13)	19 (12, 31)	3.7 (2.6, 5.1)	0.90 (0.7, 1.2)	4.6 (3.2, 6.3)
	Old Crow AM (95% CI)	19 (13, 25)	1.2 (0.70, 1.8)	5.9 (4.2, 7.7)	71 (46, 98)	2.0 (1.5, 2.6)	1.2 (0.89, 1.4)	11 (7.5, 14)	26 (14, 41)	4.2 (3.0, 5.5)	0.99 (0.76, 1.2)	5.2 (3.8, 6.7)
	CHMS AM	27	4.5	23	160	7.7	3.8	16	12	9.1	3.6	13
	CHMS CV (%)	7	1	4	0	1	18	2	21	2	3	2
	Comparison to CHMS	↓	↓	↓	↓	↓	↓	↓	↑	↓	↓	↓

AM = arithmetic mean; CHMS = Canadian health measures survey; CI = confidence interval; GM = geometric mean; LOD = limit of detection; n = sample size; N/A = not applicable; NR = not reported because 40% pools were <LOD or due to sample loss; TEQ= toxicity equivalence.

<sup>a</sup> Arrows indicate that values are lower (↓), higher (↑), or similar (↔) to values reported in CHMS cycle 5.

<sup>b</sup> For the age-stratified results, participants < 20 years of age were excluded from the analysis to maintain confidentiality.

<sup>c</sup> These data have CVs that are >33.3%, indicating that the AM may be considered the least reliable due to high sampling variability; interpretation of these data should be used with a high degree of caution.

<sup>d</sup> Details on the calculated limits of detection for the pg/g lipids results are in Appendix C.

**Table 3: Age and body mass index (continuous) as predictor variables in simple linear regression with biological levels of select dioxin and dioxin-like congeners (n=54).**

Congener	LOD [AM (min, max)] <sup>a</sup>	Detection rate	TEF	Normality	Age		BMI	
					Regression coefficient	p-value	Regression coefficient	p-value
<b>2,3,4,7,8- PeCDF</b>	0.8 (0.35, 4.5)	74%	0.3	Log transformed Tobit	0.011*	<0.0001	0.0053	0.34
<b>1,2,3,6,7,8- HxCDD</b>	0.8 (0.26, 2.2)	98%	0.1	Log S-W: p=0.3502	0.37*	<0.0001	0.0031	0.62
<b>1,2,3,7,8,9- HxCDD</b>	1.1 (0.67, 35)	67%	0.1	Log transformed Tobit	0.0050	0.051	0.0011	0.098
<b>1,2,3,4,6,7,8- HpCDD</b>	0.6 (0.21, 3.4)	100%	0.01	Log S-W: p=0.3857	-0.0053	0.88	0.0033	0.40
<b>OCDD</b>	1.3 (2.1, 28)	100%	0.0003	Log S-W: p=0.8438	0.0030	0.096	0.0016	0.68
<b>PCB 126</b>	1.4 (19, 170)	98%	0.1	Log S-W: p=0.8731	0.013*	<0.0001	0.0090	0.11
<b>PCB 169</b>	1.1 (0.84, 39)	89%	0.03	Log S-W: p=0.6076	0.022*	<0.0001	0.0072	0.39

AM = arithmetic mean; BMI = body mass index; S-W = Shapiro-Wilk; TEF = toxicity equivalence factor.

\* Result is significant (p<0.05)

<sup>a</sup>Details on the calculated limits of detection for the pg/g lipids results are in Appendix C.

**Table 4: Descriptive statistics for dioxins, furans, and dioxin-like PCBs measured in blood plasma (pg/g lipids) from biomonitoring study participants, aged 13 to 74 years, from Old Crow, Yukon, stratified by smoking status and sex <sup>a</sup>.**

	LOD (range) (pg/g lipids)	Detection n rate	TEF	GM (pg/g lipids)	Smoking status		Sex	
					Non-smokers GM (95% CI)	Smokers GM (95% CI)	Male GM (95% CI)	Female GM (95% CI)
<b>n</b>	-	-	-	<b>54</b>	<b>20</b>	<b>23</b>	<b>27</b>	<b>27</b>
<b>2,3,4,7,8- PeCDF</b>	0.8 (0.35, 4.5)	74%	0.1	1.2 (1.0, 1.5)	1.2 (0.94, 1.5)	1.2 (0.87, 1.6)	1.3 (0.99, 1.6)	1.2 (0.9, 1.5)
<b>1,2,3,6,7,8 -HxCDD</b>	1.2 (0.7, 1.7)	98%	0.1	7.7 (6.1, 9.6)	6.8 (5.2, 9.3)	7.9 (5.3, 12)	7.5 (5.7, 9.7)	7.9 (5.5, 11)
<b>1,2,3,7,8,9 -HxCDD</b>	0.6 (0.35, 0.85)	67%	0.1	0.80 (0.65, 0.98)	0.78 (0.58, 1.0)	0.78 (0.56, 1.1)	0.73 (0.56, 0.95)	0.87 (0.63, 1.1)
<b>1,2,3,4,6,7, 8-HpCDD</b>	1.3 (0.78, 1.9)	100%	0.01	6.1 (5.4, 7.1)	8.8* (7.4, 11)	4.7* (4.1, 5.4)	6.2 (5.2, 7.6)	6.1 (5.1, 7.3)
<b>OCDD</b>	1.5 (0.86, 2.1)	100%	0.000 3	54 (47, 62)	60 (50, 73)	53 (43, 65)	53 (44, 64)	55 (46, 67)
<b>PCB 126</b>	1.2 (0.69, 1.7)	98%	0.1	5.4 (4.4, 6.5)	4.3 (3.2, 5.6)	5.5 (4.1, 7.2)	5.9 (4.6, 7.9)	4.8 (3.7, 6.3)
<b>PCB 169</b>	1.7 (1.0, 2.5)	89%	0.03	7.7 (5.7, 10.)	4.8 (3.3, 7.1)	9.5 (6.2, 15)	10 (7.1, 15)	5.7 (3.7, 8.6)

AM = arithmetic mean; CI = confidence interval; GM = geometric mean; LOD = limit of detection; n = sample size; p = percentile; TEF= toxicity equivalence factor.

\* result is significant

<sup>a</sup> The percentiles and means were calculated in SPSS Version 28.

**Table 5: Spearman correlation<sup>a</sup> coefficients of dioxin and dioxin-like compounds in lipid-adjusted blood plasma levels of the Old Crow biomonitoring project (n=54)**

	2,3,4,7,8- PeCDF	1,2,3,6,7,8- HxCDF	1,2,3,6,7,8- HxCDD	1,2,3,7,8,9- HxCDD	1,2,3,4,6,7,8- HpCDD	OCDD	PCB 126	PCB 169
2,3,4,7,8-PeCDF	1							
1,2,3,6,7,8-HxCDF	0.67***	1						
1,2,3,6,7,8-HxCDD	0.73***	0.61***	1					
1,2,3,7,8,9-HxCDD	0.52***	0.57***	0.51***	1				
1,2,3,4,6,7,8-HpCDD	0.21	0.27	0.0091	0.33*	1			
OCDD	0.41**	0.45***	0.36**	0.47***	0.59***	1		
PCB 126	0.55***	0.43**	0.65***	0.31*	0.077	0.32*	1	
PCB 169	0.66***	0.45***	0.78***	0.36**	-0.18	0.24	0.73***	1

\*p<0.10

\*\*p<0.05

\*\*\*p<0.01

<sup>a</sup> Spearman correlation analysis was limited to congeners that were detected in >50% of subjects.

### **2.9.6. Limitations**

The interpretations of the findings should be approached cautiously due to inherent limitations. One of these limitations is in the cycle 5 CHMS data, as they exhibit some unstable coefficients of variation due to a small number of pools (~30) [41]. This variation may be exacerbated by the imputation in TEQ calculations, warranting further caution in interpretation (Canada, 2020).

Additionally, some age demographics were not well represented in the biomonitoring study, such as elementary-school-aged children who were present in the community but had limited participation. Some residents move away from Old Crow for various reasons, including seeking healthcare, employment, or education. For this reason, adolescents of high school age, and Elders requiring full-time care may not have been in the community at the time of the study and are not represented in these results. These results should not be extrapolated to children, youth, Elders >74 years of age, or citizens living outside of Old Crow. Dioxin and DLC exposure levels representative of pregnant and breastfeeding women are still not known.

The sample size of the Old Crow dataset is 54, which is relatively small for a biomonitoring study; however, it is representative of the population, as Old Crow has ~221 residents [10]. The sensitivity in statistical analysis to significant effect sizes may have been reduced by this sample size. Further, there were some skews in results that may have stemmed from the small sample size. Notably, the BMI results for PCB 126 may be influenced by a single outlying data point which, when removed, resulted in a significant change in t-test p-value for the regression model (p=0.11 with the outlier; p=0.03 without the outlier), suggesting potential bias towards the null hypothesis.

Many biomarker data in the Old Crow dataset were <LOD. Some congeners with lower levels of detection, such as 1,2,3,6,7,8-HxCDF (56% detect) are subject to greater uncertainty because of ½ LOD substitution. There is minor variation in the LODs from the Old Crow dataset in comparison to the CHMS dataset, which may also contribute to some uncertainty when the results of each are compared given this method of imputation. It should be noted that since 2022, the ATSDR has recommended a Kaplan-Meier estimation method of TEQ [142]. Multiple imputation is another more robust approach to address missing data, but these alternative calculation methods were not conducted in the interest of consistency with comparison data and other reports on this dataset [41, 47, 48].

Several analyses have been conducted with the biomonitoring data collected using similar methodologies in Old Crow and the Dehcho and Sahtú Regions of the NWT [55, 56, 57, 58, 62, 63]. Results of these analyses have indicated some significant differences in exposures, and associated determinants, despite each area of study being within ~2000 km. For example, relative to the general population of Canada, average HCB levels were found to be elevated in Old Crow and the Sahtú Region, but not the Dehcho Region [47]. Some results from this study, such as the average negative association with smoking and 1,2,3,4,6,7,8-HpCDD plasma concentration may be atypical and unique to a confounding exposure in Old Crow.

There are some indications that dioxin levels in the Arctic are decreasing over time [120]. Before the 2004 Stockholm convention regulation of dioxins and DLCs, environmental emissions in Canada were 84.4% higher than the measurement observed in 2017 [149]. As climate change continues to influence global air currents and the migration patterns of animal species, the exposure sources of these congeners may also change [19]. Additional exposure data over time from Old Crow would be necessary to establish exposure trends.

### **2.10. Conclusions**

These results serve as a baseline measurement of dioxins and DLCs in Old Crow; when compared to CHMS, dioxins, and DLCs appeared to be equal or lower than the levels observed in CHMS. An exception to this general observation is PCB 169, which appeared elevated in Old Crow in comparison to

the average for the general population of Canada. Since diet is a main driver of dioxin and DLC exposures, it is important to consider the dietary differences between people living in Old Crow, and those living across the provinces; most people living in Old Crow consume traditional foods harvested from traditional Vuntut Gwitchin lands and neighboring areas. Alternatively, PCB 169 may be of pyrogenic origin, potentially from smoking, incineration, or other burning activities. It is noteworthy that municipal waste continues to be openly burned near the community. In a February 2023 community meeting, participants expressed concern that the source of this elevated exposure remains unknown. Notably, CHMS Cycle 5 data for this congener had high variability and was limited to those in the 20 to 39 and 60 to 79 age groups. Further investigations into potential exposure sources, including traditional foods via regression analysis and food sampling, local outdoor air emissions, and historic environmental emissions via sediments may help to develop understanding of the elevated appearance of PCB 169.

This project contributes to the continued monitoring of dioxins, DLCs, and persistent organic pollutants which is of interest to the Vuntut Gwitchin Government, Northern Contaminants Program (Government of Canada), Stockholm Convention (United Nations Environment Programme), and the AMAP. Additional research into the temporal trends of exposure could also be informative for these global monitoring efforts and regulators.

There are no health-based guidance values or biomonitoring equivalents for exclusively dioxins and furans available to contextualize human health risks from these results. Since most measured congeners measured in Old Crow were below the average for the general population of Canada, this work supports existing messaging that the cultural, social, and nutritional benefits of consuming traditional foods continue to outweigh the risks of contaminant exposure in this area.

### **3. Traditional foods and other determinants of exposure to persistent organic pollutants (POPs) in Old Crow, Yukon, and the Dehcho Region, Northwest Territories**

Simpson, A.K., Packull-McCormick, S., Drysdale, M., Garcia-Barrios, J., Gamberg, M., Brammer, J., Froese, K., Ratelle, M., Skinner, K., Laird, B.D. Traditional foods, and other determinants of exposures to persistent organic pollutants (POPs) in Old Crow, Yukon, and the Dehcho Region, Northwest Territories. In co-author review.

#### **3.1. Abstract**

Studies conducted in Old Crow, Yukon, and the Dehcho Region, Northwest Territories, Canada, investigated the levels of persistent organic pollutants in the residents' blood relative to national averages. Specifically, two-fold elevated blood levels of PFNA were observed in both regions, while PCB 169 levels were similarly elevated in Old Crow. This study aimed to identify lifestyle factors and traditional foods associated with the regionally specific dioxin, dioxin-like congener, and PFAS exposures. Multivariable regression ( $p < 0.05$ ) modeling was used to identify associations with age and sex controlled.

Among these models, associations of various directions and significances were observed between the consumption of specific traditional food and contaminant biomarkers. In the Dehcho Region ( $n=103$ ), significant positive associations were observed between PFNA exposures and consumption of whitefish eggs and Canada goose meat; in Old Crow ( $n=49$ ), PFNA was positively associated with moose ribs, heart, and tongue. PFOA, PFOS, and PFHxS exposures in the Dehcho Region were positively associated with height. Notably, many of the traditional foods consumed in the Dehcho Region were strongly correlated (Chi-square  $p < 0.001$ ). In Old Crow, PCB 169 exposures ( $n=48$ ) were positively associated with employment in the last two years in an 'occupation of risk' which included gardening, farming, automobile repair, waste disposal, oil and gas, laboratory research, chemicals, firefighting, soil decontamination, emergency remediation, or road paving. Several significant positive associations were observed between dioxin exposures and consumption of moose ribs, coho salmon, piscivorous birds, and high or lowbush cranberries and dioxin exposures. Conversely, several determinants were associated with lower PFAS.

While some traditional foods were found to be associated with contaminant exposures, the nutritional and cultural benefits of continued consumption outweigh public health risks from contaminant exposures. This research demonstrates the complex interactions between traditional foods and environmental contaminants in these regions and may help inform community-based decision-making.

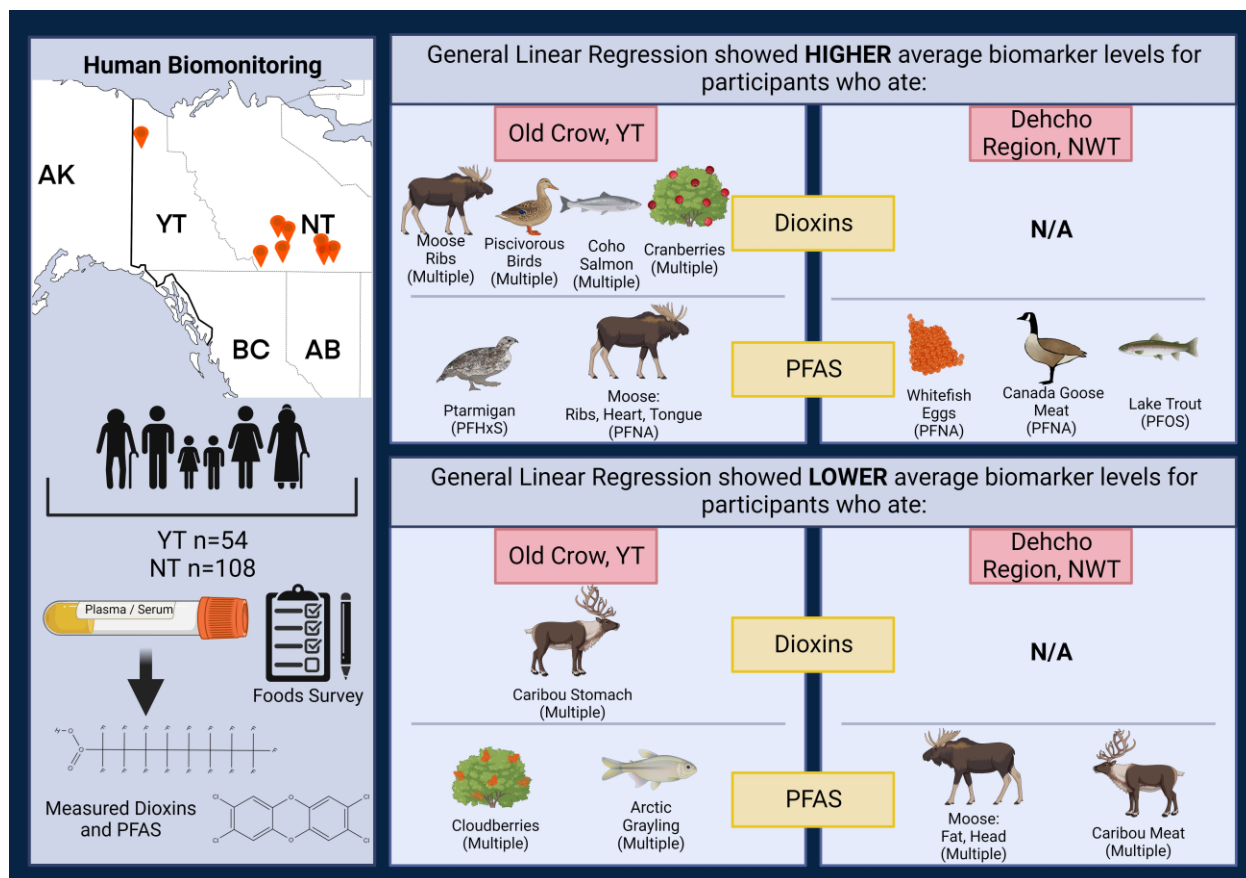


Figure 9: Graphical abstract for Traditional foods and other determinants of exposures to persistent organic pollutants (POPs) in Old Crow, Yukon, and the Dehcho Region, Northwest Territories.

### 3.2. Introduction

Persistent organic pollutants (POPs) are toxic bioaccumulative chemicals that can travel long distances through atmospheric air and contaminate areas far from known emission sources [20, 150]. Dioxins and DLCs are legacy POPs that can be found throughout land, water, and air ecosystems [151, 86]. Dioxins and DLCs can occur as unintentional byproducts of pesticide synthesis (e.g., 2,4,5-T, discontinued), manufacturing, and industrial processes, or through natural events, such as forest fires and volcanic emissions [86]. Another group of POPs is poly- and per-fluoroalkyl substances (PFAS), which are also widespread in the environment [101]. Current applications for PFAS include textiles (carpets, furniture, clothing), cosmetics, food packaging, and some firefighting foams [101].

PFAS, and dioxins and DLCs are two distinct groups of POPs; however, they share commonalities in their toxic effects. Dioxins, DLCs, and PFAS are characterized by their persistence in people and the environment and resistance to degradation over time, allowing them to accumulate in environments and organisms within them. The chronic toxic effects of these compounds occur as a range of adverse health outcomes with varying levels of evidence. Some of these effects include teratogenicity [152], developmental toxicities [86], endocrine disruptions [153], and increased risk of specific cancers [101, 105, 154]. In addition to these toxicities, other effects have been observed with PFAS exposures, including immunotoxicity, where vaccine efficacy was reduced or ineffective, and hypercholesterolemia [101]. It should be noted that some dioxins and DLCs are more hazardous than others. The dioxin

congener 2,3,7,8-TCDD is the most hazardous, and all other dioxins and DLCs have been assigned a TEF that can be used to estimate the additive relative toxicity of dioxin and DLC exposures.

People are primarily exposed to these POPs through the consumption of contaminated foods. Foods can become contaminated if they are grown with contaminated feedstock or if they are from contaminated areas. Among Indigenous communities in the Yukon (YT) and NWT, traditional foods are integral to food security and culture. These foods are often regionally specific and are harvested from traditional lands. Since POPs can travel long distances through atmospheric air currents, there is potential for traditional foods to become contaminated despite being far from any known primary environmental emission source. Understanding how these contaminants are related to the local food systems is essential to inform food safety, food sovereignty, and cultural preservation.

The community members' understanding of environmental contamination prompted questions surrounding the safety of traditional foods; to investigate, human biomonitoring studies and FFQ data were collected in collaboration with communities in the Dehcho Region (2016 – 2018) and Old Crow, YT (2019). These studies included measurements of metals, some POPs, and nutrients from blood, urine, and hair samples. Following these analyses, dioxins, DLCs, and PFAS were measured in blood samples.

The results of these studies were compared to nationally representative biomonitoring data for Canada (CHMS). These comparisons indicated that PFNA was elevated in Old Crow (1.8-fold) and the Dehcho Region (2.8-fold) [48]. PCB 169 appeared to be 2-fold elevated in Old Crow among two age groups (20 to 39, and 60-79). The other PFAS, dioxin, and DLC congeners were found to be about the same or lower than nationally representative comparison data. Additional information on these results is available elsewhere [48, 155]. While these results inform the contaminant exposure levels in the respective areas, dietary determinants and how they may have contributed to these exposures have yet to be investigated.

This study aimed to identify potential traditional dietary determinants or lifestyle factors that were associated with blood concentrations of PCB 169, PFNA, and other frequently detected PFAS, dioxins, and DLCs. Additionally, correlations between commonly consumed foods were explored to understand relationships among commonly consumed traditional foods. Further, patterns across multiple dietary and lifestyle determinants were investigated for associations with biomarkers.

### **3.3. Methods**

This cross-sectional analysis utilized prior blood contaminant analyses, demographic information, and FFQ data collected as a part of a contaminant biomonitoring project conducted in Old Crow, YT (2019) and the Dehcho Region (2016 to 2018). The following sections briefly describe the data collection methods. Additional details on model development are included in Appendix G.

#### **3.3.1. Community Partnership and Ethics**

Individual results and key messages from this project have been returned to participating communities according to community research agreements established in 2016 to 2018 with the Dehcho Region communities and 2019 with Old Crow. The conduct of this study was approved by the University of Waterloo Research Ethics Board (#32076 & #30543). The Yukon component of this research was conducted in alignment with the community research agreements set out between the Vuntut Gwitchin Government and the University of Waterloo (2018 to 2023) (Vuntut Gwitchin Government, University of Waterloo, 2018-2023). Further ethics approval was obtained through a Scientists and Explorers Research License from the Yukon Government (12-27S&E). For the NWT component of this research, ethics approval was obtained through the Aurora Research Institute (#15560, 15775, #15977, #16021), the

Stanton Territorial Health Authority for Human Research (December 29, 2015), and Health Canada [for the analysis of biobanked samples (REB, 2016-0022)].

### **3.3.2. Data Sources**

This investigation utilizes data collected from multiple biomonitoring clinics (2016-2018) conducted in K'atl'odeeche, Deh Gah Gotie, Ka'a'gee Tu, Samba K'e, Jean Marie River First Nation, and West Point First Nation in the Dehcho Region, and Old Crow, Yukon (2019); the procedures used in these clinics have been documented in other articles [46, 47, 48, 155, 156].

Demographic data, including self-reported age (years), sex (male or female), and smoking status in the past 24 hours (yes or no), were recorded by a member of the research team. Height and weight were measured using on-site apparatus by a research team member. Blood PFAS concentrations were measured from biobanked blood plasma samples for the Dehcho Region. In contrast, blood PFAS concentrations were measured as a part of the original panel of analyses for Old Crow from blood serum. Blood dioxin and DLC concentrations were measured from biobanked blood plasma samples from Old Crow only.

FFQs were administered through provided tablets in Old Crow and the Dehcho Region at the same times as the biomonitoring clinics. The FFQs assessed what traditional land animals, fish, birds, plants, and berries participants had consumed within the last year. Additional information on the design and administration of the FFQs are reported elsewhere [157]

### **3.3.3. Participants**

Anyone present during the data collection period who was four years of age and older in Old Crow or six years of age and older in Dehcho Region communities was eligible to participate in the biomonitoring study. A resident community research coordinator informed all participants on the purpose of the study, sample handling, and data use applications. People experiencing symptoms of dementia, impairment, or minors without the consent of a parent or guardian were not eligible to participate. The individual and community results were shared with each participant. All participants retain the right to withdraw from the study at any time.

The recruitment methods included passive methods, such as word-of-mouth, community posters, and systematic telephone recruitment. A local coordinator phoned 40% of residents from a randomized list and explained the objectives of the biomonitoring project. Further details of participant recruitment and remuneration are available elsewhere [46, 47].

### **3.3.4. Variable Selection**

Models were standardized for age and sex by holding these variables fixed in the regression models; therefore, those who 'presented as adults' without a specific age were removed (n=6) from the data set. Age and sex were included in the models to minimize the influence of other underlying determinants of exposure, both known and unknown. For example, a known factor was that moose liver is more frequently consumed by men >40 years of age in Old Crow and the Dehcho Region. An example of an unknown factor may be how age or disease status may affect the half-lives of these compounds in people [158].

Foods included for determinants analysis were refined through a two-step process: 1) the food was consumed by 15% or more of the surveyed population, and 2) The food had bin sizes  $\geq 5$  when stratified by sex. These criteria were set to allow for adequate sample size in model development and ensured that the included foods could be informative for many community members. Foods that were included or

excluded due to bin sizes <5 are specified in Table 6. Exceptions to this paradigm were the groupings of all birds, plants, berries, and piscivorous birds; details on the variables included in these groupings are listed in Appendix P.

The inclusion of some determinants, such as occupations of risk [i.e., those that reported working in gardening [68], farming [159], automobile repair [160], waste disposal [69, 70], oil and gas [160], laboratory research [71], chemical production [72], firefighting [160], soil decontamination [161], emergency remediation, or road paving [13], use of a fireplace in the home [162], and consumption of untreated water [163] were included based on evidence from the literature indicating that these may be exposure sources to dioxins, DLCs, or PFAS. Notably, some of the occupations of risk may result in exposure to PCB 169 from pyrogenic origins rather than PCB technical oils, such as in oil and gas industries, waste disposal (incineration), firefighting, and chemical production. The most reported occupations (n=3) were people employed in gardening, farming, and auto repair, and employment was reasonably evenly distributed among each of these occupations (n= 0 (road paving) to 3). Data on the geographical location of employment, Old Crow, or otherwise, was not collected. All these lifestyle variables were recorded in Old Crow only.

### 3.3.5. Data Analysis

All biomarkers included in the analysis had detection rates of  $\geq 60\%$ . The specific dioxin and DLC congeners analyzed were 1,2,3,6,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,4,6,7,8-HpCDD, OCDD, 2,3,4,7,8-PeCDF, PCB 126, and PCB 169. The PFAS congeners examined were PFNA, PFOS, PFHxS, PFDA, and PFOA. All dioxin congeners were modeled using lipid-adjusted values to control individual lipid concentrations. Dioxin and DLC data that were <LOD were substituted with  $\frac{1}{2}$  LOD for the individual and each congener [155]. Similarly, PFAS data that were <LOD were also substituted with  $\frac{1}{2}$  LOD for the respective congener. The data were log-transformed to achieve normal distribution for most biomarkers (Shapiro-Wilk:  $p > 0.05$ ).

The variable handling and model development approaches were consistent with those used to analyze other data from the same biomonitoring projects in YT and the NWT [52, 54]. Briefly, multiple linear regression models were constructed for each determinant, with age and sex held fixed in each model. Models were limited to age, sex, and one determinant to prevent model overfitting. Predictor variables were considered significant if the partial F-test met  $\alpha = 0.05$  ( $p < 0.05$ ). Predictor variables with  $p$ -values of  $0.10 \leq p < 0.05$  were noted in this study to indicate possible associations between commonly consumed traditional foods and the congeners that may be insignificant due to the sample size of the study [164, 165]. The strengths of associations between food determinants, calculated by Chi-square test statistics, were considered when multiple determinants were associated with the same biomarker. All statistical analyses were completed using SAS Software version 9.04.01.

Some unique limitations arose in these data. The  $\frac{1}{2}$  limit of detection substitution for 1,2,3,7,8,9-HxCDD and 2,3,4,7,8-PeCDF created peaks that interfered with the normal distribution. To mitigate this effect, Tobit models were used instead of GLMs (additional information on the Tobit models is in Appendix D). Total dioxin TEQ, total furans TEQ, and total dioxins and furans TEQ were excluded from the analysis due to high imputation with  $\frac{1}{2}$  LOD substitution, potentially introducing too much noise for reliable predictive values of true concentrations. Notably, the models for PFDA require additional caution in interpretation; the histograms and residuals for PFDA were determined to be satisfactory for model assumptions, but results may not be as reliable as the other regression models (Appendix Q).

### 3.4. Results and Discussion

**Table 6: Consumption Frequency of Traditional Foods**

Determinant of Exposure		Old Crow PFAS <sup>a</sup>	Dehcho Region PFAS
<i>Age</i>		54	103
<i>Weight</i>		52	98
<i>Height</i>		52	100
<i>BMI</i>		52	98
<i>Raw water</i>		60% (26/43)	-
<i>Main water source</i>		<b>14%*</b> (6/44)	-
<i>Occupation of risk</i>		25% (11/44)	-
<i>Smoking</i>		53% (23/43)	40% (43/108)
<i>Fireplace in home</i>		70% (30/43)	-
<i>Kidneys of both moose and caribou</i>		27% (13/49)	-
<i>Livers of moose and caribou</i>		<b>10%*</b> (5/49)	-
<i>Livers and kidneys of both moose and caribou</i>		<b>10%*</b> (5/49)	-
<i>n</i>		<b>49</b>	<b>67- 68</b>
<i>Barren Ground Caribou</i>	<i>Cooked</i>	<b>94%*</b>	-
	<i>Ribs</i>	74%	-
	<i>Heart</i>	67%	-
	<i>Head</i>	59%	-
	<i>Bone marrow</i>	67%	-
	<i>Tongue</i>	57%	-
	<i>Smoked</i>	59%	-
	<i>Kidney</i>	47%	-
	<i>Fat</i>	63%	-
	<i>Bones in soup or broth</i>	59%	-
	<i>Stomach</i>	47%	-
	<i>Liver</i>	29%	-
	<i>Brain</i>	<b>10%*</b>	-
	<i>Woodland Caribou</i>	<i>Meat cooked</i>	-
<i>Meat smoked</i>		-	27%
<i>Ribs</i>		-	<b>21%*</b>
<i>Bone marrow</i>		-	<b>16%*</b>
<i>Moose</i>	<i>Cooked</i>	<b>89%*</b>	<b>99%*</b>
	<i>Ribs</i>	61%	60%
	<i>Heart</i>	53%	40%
	<i>Head</i>	49%	31%
	<i>Tongue</i>	47%	49%
	<i>Bones in soup or broth</i>	47%	34%
	<i>Bone marrow</i>	39%	55%
	<i>Smoked</i>	47%	61%
	<i>Kidney</i>	37%	45%
	<i>Fat</i>	45%	45%
	<i>Liver</i>	<b>16%*</b>	33%
<i>Intestines</i>	33%	22%	
<i>Tripe</i>	<b>16%*</b>	-	
<i>Land Animals</i>	<i>Rabbit</i>	49%	61%
	<i>Muskrat</i>	27%	-
	<i>Beaver meat</i>	-	48%
	<i>Bison meat</i>	-	28%
	<i>Beaver tail and feet</i>	-	28%
	<i>Porcupine</i>	<b>14%*</b>	-

Determinant of Exposure	Old Crow PFAS <sup>a</sup>	Dehcho Region PFAS	
<i>Fish</i>	<i>All fish</i>	<b>98%*</b>	<b>97%*</b>
	<i>Chinook</i>	<b>90%*</b>	-
	<i>Chinook smoked dried</i>	39%	-
	<i>Chinook eggs</i>	<b>16%*</b>	-
	<i>Whitefish</i>	<b>86%*</b>	<b>90%*</b>
	<i>Whitefish smoked/dried</i>	37%	50%
	<i>Whitefish eggs</i>	43%	31%
	<i>Whitefish fish-pipe</i>	<b>25%*</b>	34%
	<i>Chum dog salmon</i>	51%	-
	<i>Coho salmon</i>	39%	-
	<i>Coho Salmon – Smoked/Dried</i>	<b>10%*</b>	-
	<i>Arctic grayling</i>	31%	-
	<i>Loche</i>	33%	-
	<i>Inconnu</i>	24%	31%
	<i>Northern Pike meat</i>	-	54%
	<i>Lake trout meat</i>	-	62%
	<i>Walleye meat</i>	-	53%
	<i>Sucker meat</i>	-	24%
<i>Birds</i>	<i>All birds</i>	59%	78%
	<i>Piscivorous birds</i>	41%	66%
	<i>Ptarmigan</i>	24%	<b>18%*</b>
	<i>White-winged scoter</i>	33%	-
	<i>Canada goose</i>	31%	64%
	<i>Mallard Meat</i>	-	51%
	<i>Spruce grouse meat</i>	-	34%
	<i>Black duck meat</i>	-	33%
	<i>Sharptailed grouse meat</i>	-	30%
	<i>Swan meat</i>	-	22%
<i>Speck belly goose</i>	<b>12%*</b>	-	
<i>Berries</i>	<i>All berries</i>	<b>86%*</b>	75%
	<i>Cranberries (High bush or bog)</i>	57%	51%
	<i>Blueberries (High or low bush)</i>	<b>84%*</b>	45%
	<i>Low (grey) blueberries</i>	61%	27%
	<i>Low bush cranberries</i>	53%	-
	<i>Salmonberries/ cloudberries</i>	57%	-
	<i>High (black) blueberries</i>	39%	22%
	<i>Crowberries</i>	22%	-
	<i>Highbush cranberries</i>	<b>14%*</b>	30%
	<i>Wild strawberries</i>	<b>6%*</b>	48%
	<i>Wild raspberries</i>	<b>18%*</b>	54%
	<i>Saskatoon berries</i>	-	42%
<i>Bog cranberries</i>	-	36%	
<i>Plants</i>	<i>All plants</i>	55%	48%
	<i>Labrador tea</i>	53%	30%
	<i>Spruce gum</i>	31%	34%
	<i>Wild rhubarb</i>	<b>20%*</b>	-
	<i>Wild onions</i>	23%	-
<i>Rat Root</i>	-	34%	

BMI= Body mass index; DLC= dioxin-like congener; FFQ= food frequency questionnaire; PFAS= per- and poly-fluoroalkyl substances.

\* This determinant has at least one bin (male + 'did not eat'; male + 'ate'; female + 'did not eat'; female + "ate") with <5 participants when stratified by sex. Models including these determinants may be overfit and were not constructed.

<sup>a</sup> There was one fewer participant in the Old Crow PFAS data compared to the Old Crow dioxins and DLC data, so similar consumption frequencies were observed. The difference in these data did not change the inclusion status of food variables. Data for PFAS (n=53) are reported.

-: Food was not eaten or included in the FFQ for this area because this food is not harvested in the area.

**Table 7: Study sample demographics and risk factor frequencies**

	<b>Old Crow (n=53)<sup>b</sup></b>	<b>Dehcho (n=109)</b>
<b>Sex</b>		
<i>Female</i>	28 (52%)	55 (50%)
<i>Male</i>	26 (48%)	54 (50%)
<b>Age (years)</b>		
<i>20 to 39</i>	26 (48%)	30 (29%)
<i>40 to 59</i>	18 (33%)	47 (46%)
<i>60+</i>	10 (19%)	26 (25%)
<b>Surveys</b>		
<i>Food Frequency Questionnaire</i>	49 (91%)	67 (61%)
<i>Risk Factors Survey</i>	44 (81%)	-
<b>Smoking status (has smoked in the previous 24 hours)</b>		
<i>Yes</i>	23 (53%)	44 (40%)
<i>No</i>	20 (47%)	65 (60%)
<b>Occupation of risk<sup>a</sup> (currently, or in the last 2 years worked in at least one occupation of risk)</b>		
<i>Yes</i>	11 (25%)	-
<i>No</i>	33 (75%)	-
<b>Drinking water (drinks untreated water sometimes or often)</b>		
<i>Yes</i>	26 (60%)	-
<i>No</i>	17 (40%)	-
<b>Fireplace in the home (has and uses a woodstove or fireplace at home)</b>		
<i>Yes</i>	30 (70%)	-
<i>No</i>	13 (30%)	-

<sup>a</sup> Occupation of risk includes work in gardening, farming, automobile repair, waste disposal, recycling, oil and gas, laboratory research, chemicals production, firefighting, or road paving [n = 0 (road paving) to 3].

<sup>b</sup> There was one fewer participant in the Old Crow PFAS data compared to the Old Crow dioxins and DLC data, so similar consumption frequencies were observed. The difference in these data did not change the inclusion status of food variables. Data for PFAS (n=53) are reported.

-: indicates that the risk factor survey was not conducted in this area.

**Table 8: A summary of the regression coefficients measuring associations between the biomarkers PFNA, PFOA, PFOS, and PFHxS and potential determinants of biomarker levels in plasma for study participants in the Dehcho Region. All models were controlled for age and sex.**

Determinant of Exposure <sup>a</sup>		PFNA	PFOA	PFOS	PFHxS	PFDA	
% Detected in Dehcho		100%	100%	99%	99%	88%	
	n <sup>b</sup>	Effect Estimate	Effect Estimate	Effect Estimate	Effect Estimate	Effect Estimate	
<i>Smokers (smoked cigarettes in the past 24 hours)</i>	44/109	-0.018	-0.016	-0.078	-0.028	-0.042	
<i>Weight</i>	98/109	0.0001	-0.0015	-0.0006	-0.0026*	-0.0017	
<i>Height</i>	100/109	0.0081	<b>1.4***</b>	<b>0.95**</b>	<b>1.0**</b>	0.36	
<i>Body mass index</i>	98/109	-0.0012	<b>-0.0078**</b>	-0.0051	<b>-0.011***</b>	-0.0056	
<i>Moose</i>	<i>Meat smoked dried</i>	41/67	-0.029	-0.079	-0.11*	-0.0037	-0.071
	<i>Ribs</i>	40/67	-0.031	-0.11*	-0.10	-0.034	-0.11
	<i>Bone marrow</i>	37/67	-0.011	-0.11*	-0.11*	-0.097	-0.079
	<i>Tongue</i>	33/67	0.0060	-0.10*	-0.11*	0.0053	-0.051
	<i>Fat</i>	30/67	-0.10	<b>-0.12**</b>	<b>-0.13**</b>	<b>-0.12**</b>	-0.13*
	<i>Kidney</i>	30/67	0.08	-0.096	-0.11	-0.11	-0.032
	<i>Heart</i>	27/67	-0.013	-0.071	-0.13*	-0.026	-0.055
	<i>Bones in soup broth</i>	23/67	0.076	-0.10*	-0.053	0.013	-0.001
	<i>Head</i>	21/67	0.059	<b>-0.21***</b>	<b>-0.22***</b>	<b>-0.17**</b>	-0.096
	<i>Liver</i>	22/67	0.030	-0.12*	-0.085	-0.073	-0.056
	<i>Intestine</i>	15/67	-0.027	<b>-0.15**</b>	-0.12	-0.079	-0.10
	<i>Woodland Caribou</i>	<i>Meat cooked</i>	32/67	<b>-0.19**</b>	-0.024	-0.11	-0.019
<i>Meat smoked</i>		18/67	<b>-0.21**</b>	<b>-0.17***</b>	<b>-0.19***</b>	-0.081	<b>-0.26***</b>
<i>Land Animals</i>	<i>Rabbit meat</i>	41/67	0.050	<b>-0.17***</b>	-0.018	-0.016	-0.032
	<i>Beaver meat</i>	32/67	0.024	<b>-0.2***</b>	-0.13	-0.034	-0.097
	<i>Bison meat</i>	19/67	-0.072	-0.043	-0.0091	0.0098	-0.021
	<i>Beaver tail and feet</i>	19/67	-0.078	<b>-0.19***</b>	-0.090	-0.026	-0.091
<i>Fish</i>	<i>Whitefish meat smoked</i>	34/68	0.12	-0.038	0.049	0.10	0.045
	<i>Whitefish fish pipe</i>	23/68	0.053	-0.12*	-0.052	-0.086	0.085
	<i>Northern pike meat</i>	37/68	0.079	-0.061	0.027	0.041	0.023
	<i>Lake trout meat</i>	42/68	0.14*	0.055	<b>0.16**</b>	0.099	0.075
	<i>Walleye meat</i>	36/68	0.059	0.037	0.015	-0.017	-0.070
	<i>Whitefish eggs</i>	21/68	<b>0.19**</b>	-0.016	0.015	0.040	0.098
	<i>Inconnu meat</i>	21/68	-0.072	<b>-0.16**</b>	-0.083	-0.092	-0.060
<i>Birds</i>	<i>Birds</i>	52/67	0.19*	-0.097	-0.09	0.031	0.032

	<i>Piscivorous birds</i>	44/67	0.12	-0.09	-0.096	-0.0016	0.0036
	<i>Canada goose meat</i>	43/67	<b>0.18**</b>	<b>-0.14**</b>	-0.042	0.040	0.038
	<i>Mallard meat</i>	34/67	0.049	<b>-0.14**</b>	<b>-0.12*</b>	-0.043	-0.087
	<i>Spruce grouse meat</i>	23/67	0.10	-0.085	<b>-0.14*</b>	-0.12	0.031
	<i>Black duck meat</i>	22/67	0.13	-0.0074	0.015	0.029	0.019
	<i>Sharp-tailed grouse meat</i>	20/67	0.035	-0.029	-0.080	-0.072	-0.0069
	<i>Swan meat</i>	15/67	0.034	-0.086	0.075	0.048	0.078
	<i>Berries</i>	50/67	0.0028	-0.051	0.031	0.066	-0.097
	<i>Any blueberry type</i>	31/67	0.0095	<b>-0.12**</b>	-0.083	-0.055	-0.075
	<i>Any cranberry type</i>	35/67	-0.010	-0.082	0.024	0.052	0.020
	<i>Wild raspberries</i>	36/67	0.011	-0.091	-0.028	-0.039	-0.11
	<i>Wild strawberries</i>	32/67	-0.016	-0.062	0.071	0.060	-0.08
	<i>Saskatoon berries</i>	28/67	-0.027	-0.079	0.0031	-0.036	-0.030
	<i>Low grey blueberries</i>	18/67	-0.057	-0.068	-0.054	-0.058	-0.068
	<i>Bog cranberries</i>	24/67	0.054	-0.032	0.052	0.031	0.018
	<i>High bush cranberry parts</i>	20/67	-0.060	-0.046	-0.013	0.069	-0.027
	<i>High black blueberries</i>	15/67	0.030	-0.096	-0.057	-0.017	-0.061
	<i>Plants</i>	32/67	0.0069	-0.015	0.042	0.045	-0.016
	<i>Spruce gum</i>	23/67	-0.019	-0.0043	0.031	0.038	-0.041
	<i>Rat root</i>	23/67	-0.073	-0.066	-0.037	0.0010	-0.068
	<i>Labrador tea</i>	20/67	-0.023	-0.013	0.075	0.073	0.011

n= the number of study participants

\*p<0.10

\*\*p<0.05

\*\*\*p<0.01

<sup>a</sup> Foods eaten by <15% of the sample group, and foods that had bin sizes smaller than n=5 were excluded from the analysis to maintain adequate sample size for model development unless specified otherwise.

<sup>b</sup> Presented as the number of study participants who consumed the traditional food indicated over the total number of participants who had biomarker data and food frequency data for the indicated determinant.

**Table 9: A summary of the regression coefficients measuring associations between the biomarkers PFNA, PFOA, PFOS, and PFHxS and potential determinants of biomarker levels in serum for study participants in Old Crow, YT. All models were controlled for age and sex.**

Determinant of Exposure <sup>a</sup>	n <sup>b</sup>	PFNA	PFOA	PFOS	PFHxS	PFDA	
% Detected in Old Crow	N/A	88.90%	100%	88.90%	100.00%	88.89%	
<i>Weight</i>	52/54	0.0022	0.0007	0.0002	0.0018	0.0016	
<i>Height</i>	52/54	-0.31	-0.083	-0.23	0.26	-0.41	
<i>Body mass index</i>	52/54	0.0067	0.0029	0.0027	0.0033	0.0063	
<i>Smoking (smoked cigarettes in the past 24 hours)</i>	23/43	0.14	-0.032	0.052	0.029	0.015	
<i>Occupation of risk <sup>c</sup></i>	11/44	0.47*	0.012	0.55	-0.038	0.08	
<i>Raw water</i>	26/43	-0.078	-0.071	0.085	0.050	-0.14	
<i>Kidneys of both moose and caribou</i>	13/49	0.068	-0.089	0.065	-0.037	-0.0028	
<i>Caribou</i>	<i>Ribs</i>	36/49	0.046	-0.0002	-0.098	0.021	0.021
	<i>Heart</i>	33/49	0.10	0.051	-0.033	0.0012	0.069
	<i>Head</i>	29/49	0.035	-0.076	-0.14	-0.036	-0.066
	<i>Bone marrow</i>	33/49	0.046	-0.011	-0.0018	0.059	0.0088
	<i>Tongue</i>	28/49	0.12	-0.001	-0.039	0.045	0.012
	<i>Smoked</i>	29/49	0.050	0.059	0.13	0.15	-0.012
	<i>Kidney</i>	23/49	0.10	-0.055	-0.020	-0.11	-0.012
	<i>Fat</i>	31/49	-0.0075	-0.017	-0.12	-0.063	-0.0062
	<i>Bones in soup or broth</i>	29/49	-0.0058	-0.040	-0.051	0.059	-0.051
	<i>Stomach</i>	23/49	0.11	0.032	0.093	0.030	0.084
	<i>Liver</i>	14/49	-0.047	-0.062	-0.0018	-0.041	-0.030
<i>Moose</i>	<i>Ribs</i>	30/49	0.19**	0.12	0.072	0.041	0.17
	<i>Heart</i>	26/49	0.20**	0.11*	0.075	0.014	0.14
	<i>Head</i>	24/49	0.089	-0.016	0.043	-0.032	0.015
	<i>Tongue</i>	23/49	0.21**	0.018	0.035	-0.18	0.11
	<i>Bones in soup or broth</i>	23/49	0.077	0.041	0.074	0.072	0.12
	<i>Bone marrow</i>	19/49	0.023	-0.041	0.0017	-0.023	-0.028
	<i>Smoked</i>	23/49	0.087	-0.067	0.11	0.016	-0.016
	<i>Kidney</i>	18/49	0.14*	-0.0019	0.048	-0.0003	0.098
	<i>Fat</i>	22/49	0.0073	0.024	-0.0096	0.029	0.0003
	<i>Intestines</i>	16/49	-0.020	-0.11	-0.10	-0.12	-0.047
<i>Land Animals</i>	<i>Rabbit</i>	24/49	-0.032	-0.030	0.024	0.063	-0.017
	<i>Muskrat</i>	13/49	-0.027	-0.027	-0.049	0.069	-0.024
<i>Fish</i>	<i>Chinook smoked dried</i>	19/49	0.082	0.047	0.12	0.086	0.024
	<i>Whitefish smoked/dried</i>	18/49	0.12	0.044	0.12	0.023	0.033
	<i>Whitefish eggs</i>	21/49	0.14	0.03	0.16*	0.11	0.11
	<i>Chum dog salmon</i>	25/49	0.032	0.045	0.056	0.060	0.10
	<i>Coho salmon</i>	19/49	-0.030	0.0057	0.076	0.18*	-0.11

Determinant of Exposure <sup>a</sup>		n <sup>b</sup>	PFNA	PFOA	PFOS	PFHxS	PFDA
	<i>Arctic grayling</i>	15/49	<b>-0.20**</b>	<b>-0.14**</b>	-0.15	-0.20*	-0.21*
	<i>Loche</i>	16/49	0.040	0.038	0.038	0.073	0.067
	<i>Inconnu</i>	12/49	<b>-0.16*</b>	-0.033	-0.064	-0.051	<b>-0.23*</b>
Birds	<i>Birds</i>	29/49	0.041	-0.05	0.037	0.0080	0.019
	<i>Piscivorous birds</i>	20/49	0.016	-0.056	-0.030	-0.13	-0.012
	<i>Ptarmigan</i>	12/49	0.019	0.051	0.10	<b>0.24**</b>	<b>0.20*</b>
	<i>White-winged scoter</i>	16/49	0.038	-0.047	0.016	-0.046	-0.0015
	<i>Canada goose</i>	15/49	0.14	-0.049	-0.04	-0.13	0.086
Berries	<i>Any cranberry type</i>	28/49	-0.071	0.011	0.045	0.17	-0.13
	<i>Low (grey) blueberries</i>	30/49	-0.059	0.046	0.024	0.0051	-0.062
	<i>Low bush cranberries</i>	26/49	-0.038	0.016	0.018	0.11	-0.042
	<i>Salmonberries/ cloudberrries</i>	28/49	0.0058	-0.012	<b>-0.23**</b>	<b>-0.24**</b>	-0.013
	<i>High (black) blueberries</i>	19/49	-0.071	0.044	0.047	0.14	-0.068
Plants	<i>Crowberries</i>	11/49	0.0088	0.079	0.093	0.071	0.0091
	<i>Plants</i>	27/49	<b>-0.16*</b>	0.0026	-0.0079	0.15	-0.048
	<i>Labrador tea</i>	26/49	<b>-0.15*</b>	0.012	0.0086	0.13	-0.048
	<i>Spruce gum</i>	15/49	-0.084	-0.039	-0.081	-0.026	-0.0048
	<i>Wild onions</i>	11/49	0.038	0.0097	0.018	0.045	0.057

n= The number of study participants

\*p<0.10

\*\*p<0.05

\*\*\*p<0.01

<sup>a</sup> Foods eaten by <15% of the sample group, and foods that had bin sizes smaller than n=5 were excluded from the analysis to maintain adequate sample size for model development unless specified otherwise.

<sup>b</sup> Presented as the number of study participants who consumed the traditional food indicated over the total number of participants who had biomarker data and food frequency data for the indicated determinant.

<sup>c</sup> Occupation of risk includes those who reported working in gardening, farming, automobile repair, waste disposal, oil and gas, laboratory research, chemicals, firefighting, soil decontamination, emergency remediation, or road paving [n = 0 (road paving) to 3].

**Table 10: A summary of the regression coefficients measuring associations between the dioxin and dioxin-like congener biomarkers and potential determinants of biomarker levels in plasma for study participants in Old Crow, YT. All models were controlled for age and sex.**

Determinant of Exposure <sup>a</sup>	n <sup>b</sup>	1,2,3,6,7,8- HxCDD	1,2,3,4,6,7,8- HpCDD	OCDD	PCB 126	PCB 169	
% Detected in Old Crow	N/A	98.10	100.00	100.00	98.10	88.90	
<i>Weight</i>	51/53	-0.0017	0.0025	-0.0004	0.0038*	-0.0024	
<i>Height</i>	51/53	-0.45	0.13	-0.27	0.22	-0.49	
<i>Body mass index</i>	51/53	0.0	0.0037	0.0013	0.0054	-0.0006	
<i>Smoking (smoked cigarettes in the past 24 hours)</i>	22/42	-0.016	<b>-0.27***</b>	-0.087	0.041	0.18*	
<i>Fireplace in home</i>	29/42	-0.02	-0.074	-0.064	-0.076	0.050	
<i>Occupation of risk <sup>c</sup></i>	11/43	2.8	-1.4	-0.027	0.099	<b>0.27**</b>	
<i>Raw water</i>	26/42	-0.13	0.083	-0.0022	0.059	-0.099	
<i>Kidneys of both moose and caribou</i>	13/48	<b>-0.18**</b>	0.021	-0.017	0.12	-0.027	
<i>Barren Ground Caribou</i>	<i>Ribs</i>	36/48	-0.054	0.076	0.11	0.13*	-0.022
	<i>Heart</i>	33/48	-0.11	0.038	0.049	0.11	-0.039
	<i>Head</i>	29/48	-0.018	0.048	0.037	<b>0.18***</b>	0.0078
	<i>Bone marrow</i>	33/48	-0.033	0.088	0.063	<b>0.16**</b>	-0.025
	<i>Tongue</i>	28/48	-0.048	0.023	0.033	<b>0.19***</b>	0.0008
	<i>Smoked</i>	29/48	0.037	-0.0066	-0.028	<b>0.16**</b>	0.056
	<i>Kidney</i>	23/48	-0.11	-0.020	-0.011	<b>0.16**</b>	-0.029
	<i>Fat</i>	31/48	-0.043	0.013	0.057	0.020	-0.12
	<i>Bones in soup or broth</i>	29/48	-0.02	0.022	0.0046	<b>0.14**</b>	-0.033
	<i>Stomach</i>	23/48	<b>-0.15**</b>	0.066	0.017	0.13*	-0.077
<i>Liver</i>	14/48	-0.017	-0.065	-0.075	-0.025	-0.053	
<i>Moose</i>	<i>Ribs</i>	30/48	-0.0099	0.085	<b>0.14**</b>	<b>0.14**</b>	0.11
	<i>Heart</i>	26/48	-0.042	0.039	0.092	<b>0.15**</b>	0.11
	<i>Head</i>	24/48	-0.0061	0.037	0.066	0.11	0.079
	<i>Tongue</i>	23/48	-0.042	0.071	0.11*	<b>0.20***</b>	0.12
	<i>Bones in soup or broth</i>	23/48	-0.048	0.12*	0.068	0.073	0.060
	<i>Bone marrow</i>	19/48	-0.11	0.032	0.080	0.059	-0.020
	<i>Smoked</i>	23/48	-0.036	-0.077	-0.096	<b>0.17***</b>	0.096
	<i>Kidney</i>	18/48	-0.075	0.022	0.028	<b>0.15**</b>	0.088
	<i>Fat</i>	22/48	-0.065	0.0083	0.043	-0.019	-0.093
<i>Intestines</i>	16/48	-0.11	0.063	0.057	<b>0.14**</b>	-0.066	
<i>Land Animals</i>	<i>Rabbit</i>	24/48	-0.12*	0.020	-0.039	0.075	-0.020
	<i>Muskrat</i>	13/48	-0.13*	0.037	-0.0054	0.030	-0.055
<i>Fish</i>	<i>Chinook smoked/dried</i>	19/48	0.061	0.027	0.0069	0.13*	0.081
	<i>Whitefish smoked/dried</i>	18/48	0.023	-0.071	-0.017	0.091	0.038

Determinant of Exposure <sup>a</sup>	n <sup>b</sup>	1,2,3,6,7,8-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	PCB 126	PCB 169
<i>Whitefish eggs</i>	21/48	-0.010	0.094	0.068	<b>0.16**</b>	0.15
<i>Chum dog salmon</i>	25/48	0.0016	-0.025	-0.061	-0.0045	0.010
<i>Coho salmon</i>	18/48	<b>0.18**</b>	0.046	0.0059	<b>0.13**</b>	0.082
<i>Arctic grayling</i>	15/48	0.036	0.084	0.075	0.038	-0.081
<i>Loche</i>	16/48	-0.041	0.055	0.051	0.082	0.055
<i>Inconnu</i>	12/48	0.046	0.017	0.062	0.007	-0.0003
<i>All birds</i>	27/48	-0.020	0.13*	-0.0034	<b>0.18***</b>	0.059
<i>Piscivorous birds</i>	20/48	-0.013	<b>0.16**</b>	0.034	<b>0.15**</b>	-0.0084
<i>Ptarmigan</i>	12/48	-0.026	0.11	0.037	0.088	0.057
<i>White-winged scoter</i>	16/48	0.0016	0.095	-0.011	<b>0.14**</b>	0.029
<i>Canada goose</i>	15/48	-0.052	0.067	0.034	<b>0.19***</b>	0.15
<i>Any cranberry type</i>	27/48	-0.047	<b>0.15**</b>	0.083	<b>0.14**</b>	-0.011
<i>Low (grey) blueberries</i>	30/48	-0.061	0.089	0.024	0.012	-0.033
<i>Low bush cranberries</i>	26/48	-0.047	<b>0.16**</b>	0.082	0.13*	-0.0077
<i>Salmonberries/ cloudberrries</i>	28/48	-0.061	0.071	<b>0.15**</b>	0.066	-0.10
<i>High (black) blueberries</i>	18/48	0.0094	0.021	0.035	0.11	0.010
<i>Crowberries</i>	11/48	0.020	0.044	0.10	0.11	0.12
<i>Plants</i>	27/48	-0.025	<b>0.13**</b>	0.0070	0.062	-0.078
<i>Labrador tea</i>	26/48	-0.035	0.12*	0.010	0.048	-0.085
<i>Spruce gum</i>	15/48	-0.016	-0.0027	-0.015	-0.0045	0.022
<i>Wild onions</i>	11/48	<b>-0.17**</b>	-0.033	-0.061	0.050	-0.033

n= The number of study participants

\*p<0.10

\*\*p<0.05

\*\*\*p<0.01

<sup>a</sup> Foods eaten by <15% of the sample group, and foods that had bin sizes smaller than n=5 were excluded from the analysis to maintain adequate sample size for model development unless specified otherwise.

<sup>b</sup> Presented as the number of study participants who consumed the traditional food indicated over the total number of participants who had biomarker data and food frequency data for the indicated determinant.

<sup>c</sup> Occupation of risk includes those who reported working in gardening, farming, automobile repair, waste disposal, oil and gas, laboratory research, chemicals, firefighting, soil decontamination, emergency remediation, or road paving [n = 0 (road paving) to 3].

**Table 11: A summary of the regression coefficients measuring associations between the dioxin and dioxin-like congener biomarkers and potential determinants of biomarker levels in plasma for study participants in Old Crow, YT. All models were controlled for age and sex.**

Determinant of Exposure <sup>a</sup>	n <sup>b</sup>	1,2,3,7,8,9- HxCDD (log <sub>10</sub> - transformed, Tobit) <sup>d</sup>	2,3,4,7,8- PeCDF (log <sub>10</sub> - transformed Tobit)
% Detected in Old Crow	N/A	66.70	74.10
<i>Weight</i>	51/53	0.0037	-0.0001
<i>Height</i>	51/53	-0.75	-0.30
<i>Body mass index</i>	51/53	0.011*	0.0025
<i>Smoking (smoked cigarettes in the past 24 hours)</i>	22/42	-0.062	-0.069
<i>Fireplace in home</i>	29/42	0.15	0.013
<i>Occupation of risk <sup>c</sup></i>	11/43	0.37***	0.14
<i>Raw water</i>	26/42	-0.027	-0.0033
<i>Kidneys of both moose and caribou</i>	13/48	-0.14	-0.14*
<i>Caribou</i>			
<i>Ribs</i>	36/48	-0.053	-0.050
<i>Heart</i>	33/48	-0.094	-0.11
<i>Head</i>	29/48	0.060	0.0051
<i>Bone marrow</i>	33/48	-0.046	-0.021
<i>Tongue</i>	28/48	-0.050	-0.036
<i>Smoked</i>	29/48	-0.095	0.031
<i>Kidney</i>	23/48	-0.12	-0.059
<i>Fat</i>	31/48	-0.037	-0.10
<i>Bones in soup or broth</i>	29/48	-0.083	-0.075
<i>Stomach</i>	23/48	-0.22**	-0.070
<i>Liver</i>	14/48	-0.035	-0.061
<i>Moose</i>			
<i>Ribs</i>	30/48	0.18*	0.064
<i>Heart</i>	26/48	0.051	0.0098
<i>Head</i>	24/48	0.16	0.066
<i>Tongue</i>	23/48	0.046	0.041
<i>Bones in soup or broth</i>	23/48	0.11	0.063
<i>Bone marrow</i>	19/48	0.057	-0.017
<i>Smoked</i>	23/48	-0.11	0.091
<i>Kidney</i>	18/48	0.0052	-0.014
<i>Fat</i>	22/48	0.11	0.023
<i>Intestines</i>	16/48	0.070	0.098
<i>Land Animals</i>			
<i>Rabbit</i>	24/48	-0.11	-0.033
<i>Muskrat</i>	13/48	-0.023	-0.032
<i>Fish</i>			
<i>Chinook smoked dried</i>	19/48	-0.055	0.098
<i>Whitefish smoked/dried</i>	18/48	-0.13	0.049
<i>Whitefish eggs</i>	21/48	-0.014	0.10
<i>Chum dog salmon</i>	25/48	0.033	-0.049
<i>Coho salmon</i>	18/48	0.10	0.24**
<i>Arctic grayling</i>	15/48	0.064	0.033
<i>Loche</i>	16/48	-0.065	0.0009
<i>Inconnu</i>	12/48	0.10	0.10
<i>Birds</i>			
<i>Birds</i>	27/48	0.080	-0.088
<i>Piscivorous birds</i>	20/48	0.12	0.043
<i>Ptarmigan</i>	12/48	-0.050	0.081
<i>White-winged scoter</i>	16/48	0.091	0.13
<i>Canada goose</i>	15/48	0.071	-0.054

Determinant of Exposure <sup>a</sup>	n <sup>b</sup>	1,2,3,7,8,9- HxCDD (log <sub>10</sub> - transformed, Tobit) <sup>d</sup>	2,3,4,7,8- PeCDF (log <sub>10</sub> - transformed Tobit)	
<i>Berries</i>	<i>Any cranberry type</i>	27/48	0.031	0.040
	<i>Low (grey) blueberries</i>	30/48	0.13	-0.034
	<i>Low bush cranberries</i>	26/48	0.031	0.040
	<i>Salmonberries/ Cloudberries</i>	28/48	0.19*	0.044
	<i>High (black) Blueberries</i>	18/48	0.031	0.15*
	<i>Crowberries</i>	11/48	0.14	0.12
<i>Plants</i>	<i>Plants</i>	27/48	0.084	0.023
	<i>Labrador tea</i>	26/48	0.064	0.019
	<i>Spruce gum</i>	15/48	0.081	-0.092
	<i>Wild onions</i>	11/48	0.031	-0.093

n= The number of study participants

\*p<0.10

\*\*p<0.05

\*\*\*p<0.01

<sup>a</sup> Foods eaten by <15% of the sample group, and foods that had bin sizes smaller than n=5 were excluded from the analysis to maintain adequate sample size for model development unless specified otherwise.

<sup>b</sup> Presented as the number of study participants who consumed the traditional food indicated over the total number of participants who had biomarker data and food frequency data for the indicated determinant.

<sup>c</sup> Occupation of risk includes those who reported working in gardening, farming, automobile repair, waste disposal, oil and gas, laboratory research, chemicals, firefighting, soil decontamination, emergency remediation, or road paving [n = 0 (road paving) to 3].

<sup>d</sup> One observed value was censored from this model.

### 3.5. Study Population

The demographics of the study participants are described in Table 7. Among survey participants, male and female representation approximated 50%. The most considerable variability was in the Old Crow PFAS group, with 52% of participants being female and 48% male; this does not significantly deviate from the Old Crow census data for sex (2016) [10].

In Old Crow, there were proportionally fewer participants 60 years of age and older (19%) in comparison to 2016 census data (24%) [10]. Nearly 50% of participants in Old Crow were <40 years of age. Old Crow had proportionally higher participation among those 20 to 39 years of age in comparison to the Dehcho Region, despite each area having similar age distributions in 2016 [10, 166].

### 3.6. PFAS

The results for PFAS are presented in Tables 8 (Dehcho Region) and 9 (Old Crow). In the Dehcho Region, significant positive associations were observed between PFNA and whitefish eggs and Canada goose meat. In Old Crow, significant positive associations were observed between PFNA and consumption of moose ribs, moose heart, and moose tongue. Conversely, significant negative associations with PFNA exposure in the Dehcho Region were observed with cooked and smoked woodland caribou meat. In Old Crow, the consumption of arctic grayling demonstrated significant negative associations with PFNA exposure.

Among the other PFAS congeners investigated, additional associations were observed. In the Dehcho Region, significant positive associations were observed between height and PFOA, PFOS, and PFHxS exposures. The only other significant positive association was observed between consumption of lake trout and PFOS exposure. However, in Old Crow, no significant positive associations were observed across multiple PFAS congeners; only one significant positive association was observed between ptarmigan and PFHxS.

Several significant negative associations were observed between PFAS exposures and various determinants in the Dehcho Region in addition to those already mentioned. These included BMI (PFOA and PFHxS), moose fat (PFOA, PFOS, and PFHxS), moose head (PFOA, PFOS, and PFHxS), and woodland caribou meat smoked (PFOA, PFOS, and PFDA). Many foods, including moose intestine, rabbit meat, beaver meat, beaver tail and feet, inconnu meat, Canada goose meat, mallard meat, and any blueberry (high or low bush) were negatively associated with PFOA exposure (Table 8). In Old Crow, significant negative associations were observed between PFAS exposures and consumption of salmonberries/cloudberries (PFOS and PFHxS), and arctic grayling (PFOA) (Table 9). Notably, Chi-square statistics (non-parametric) were calculated for all food variables included in the analysis (Appendix R) to assess if the same people commonly consumed traditional foods. Strong ( $p < 0.001$ ) consumption patterns emerged with many of the foods; for example, beaver meat was strongly associated with consumption of beaver tail and feet, all birds, piscivorous birds, Canada goose meat, mallard meat, and spruce grouse meat in the Dehcho Region; this means that it is not possible to disseminate which of these foods is truly negatively associated with PFOA exposure.

Literature was reviewed for other information on traditional foods and PFAS exposures and data were limited. One study found that PFNA was one of the most abundant PFAS congeners detected (ranging from <0.01 to 7.4 ng/g wet weight) in caribou livers from Canada [167]. In another study, associations between PFHxS, PFOS, PFOA, PFNA, and PFDA and consumption of fish, land mammals, and wild birds were assessed through linear regression analyses. There were no significant findings between traditional foods and PFAS congeners [168].

Some studies reported determinants of PFNA exposures. In a cohort of 198 Anishinabe and Innu First Nation youth aged 3 to 19 years from Quebec, serum PFNA levels were associated with milk, yogurt, and cheese consumption. There was also a significant positive association between PFNA levels and consumption of ultra-processed foods among the Anishinabe participants. Among the Innu participants, wild fish and wild berry consumptions were positively associated with PFNA exposure [169]. While not a traditional food in Old Crow or the Dehcho Region, barnacle geese, a migrating Arctic bird species of Kongsfjorden, Svalbard, were found to have PFNA in 100% of 60 egg samples [170]. Furthermore, testing of market foods has demonstrated the presence of PFNA in milk (16 to <12 pg/g [171]), bread [172], cheese [172], beef [172], cookies [173], cold cuts, fish (<27 pg/g [171]), margarine/butter [174], French fries [174], frozen fish sticks/patties and baked cod [175].

When considering Old Crow and the Dehcho Region, most associations between PFAS and traditional food were negative, suggesting that dietary transition to market foods may have contributed to PFAS exposures in these Northern communities. PFAS are known to be present in Canadian food contact materials [176] and migrate into packaged foods from the food contact materials [177]. Based on the information available, it appears that the traditional food systems are not the main drivers of PFAS exposures in Old Crow and the Dehcho Region. Should the participating communities express interest in improving the certainty of these conclusions, testing for PFAS content in various moose tissues, whitefish eggs, and Canada goose meat could be informative.

The positive associations between height and PFOA, PFOS, and PFHxS exposures were atypical in comparison to other PFAS studies that examined height. Many studies that include height have been conducted with young children [101] and typically show no significant associations or, in limited cases, an inverse association between height and PFAS exposure. PFAS are known to reduce thyroid hormones, disrupt endocrine systems, and reduce insulin-like growth factor 1 (IGF-1); these effects are typically associated with reduced height [178, 179, 180]. In the Dehcho Region, people more often consume market foods, rather than traditional foods [16]. Perhaps increased caloric intake from consumption of market calorie-dense foods resulted in an overall increase in height [181]. Notably, the determinant BMI, which accounts for height, appears to be negatively associated with PFOA and PFHxS exposures. Oral PFOA exposures in animal studies have been associated with ~10% to 40% decreases in average body weight. The scientific literature regarding the relationship between BMI and PFAS exposures in humans remains conflicting [101]. Understanding how height and weight are associated with PFAS exposures in the general population of Canada would help to contextualize these associations and indicate if these are typical among residents of Canada.

### **3.6.1. Dioxins and DLCs**

The dioxin and DLC determinants analysis results revealed patterns of association different from those for PFAS (Tables 10 and 11). For the priority compound PCB 169, a weak positive association with smoking was observed but was not significant. No significant associations were observed between PCB 169 exposures and traditional food determinants. A significant positive association was observed between employment in an occupation of risk in the last two years and PCB 169 exposures. This category was broad and included 11 occupations across multiple industries. Additional investigation into the potential local combustion sources of PCB 169 may help verify that exposures are specific to occupational exposures and further understand the contamination source(s). Some examples of possible informative investigations are comparing PCB 169 concentrations to blood cotinine concentrations to assess smoking associations further or sediment analysis to retrospectively quantify environmental levels of dioxin-like PCBs over time.

More associations were observed among the other dioxins and DLCs. Multiple significant positive associations between PCB 126 exposure and traditional foods were observed. The determinants occupation of risk, moose ribs, coho salmon, piscivorous birds, and high or low bush cranberries were each found to have significant positive associations with at least two dioxins or DLCs. Among the Chi-square tests of foods (Appendix R), strong ( $p < 0.001$ ) consumption patterns emerged among all caribou tissues (except smoked meat), all moose tissues (except smoked meat), all land animals, and all whitefish tissues, but not typically across categories (i.e., caribou, moose, land animals, fish, birds, berries, and plants). Exceptions to this trend include those who consumed both caribou and moose kidneys, at least one cranberry type, and low-bush cranberries. Prior Spearman correlation analysis indicated that the dioxin exposures in Old Crow were moderately positively correlated (0.30 to 0.78) [155]. However, in this determinants analysis, relatively few foods contribute to multiple dioxin and DLC exposures (Tables 10 and 11).

Studies have been conducted on other POPs including HCB and PCBs (excluding non-ortho PCBs) in the same study area. Lake trout, piscivorous birds, and game bird consumption were positively associated with lipid-adjusted pooled PCB concentrations when data were combined across Old Crow, the Dehcho Region, and the Sahtú Region (NWT) [50]. Moose and caribou organ meats were associated with significantly higher plasma HCB levels. Notably, only HCB was elevated in comparison to the average for the general population of Canada [52].

### **3.7. Limitations**

Several limitations impact this investigation. Self-reported FFQ data were used to assess dietary consumption of traditional foods. While steps were taken in the design to mitigate recall bias, such as using food images in the questionnaire, these data may still be subject to bias as participants were asked to recall their food consumption over one year [156]. A benefit of this design is that a one-year recall is beneficial for capturing the total diet, including seasonal variations that may not be captured in a shorter time. The binary categorization of food consumption data (i.e., ate, did not eat) resulted in a loss of serving size information; however, serving size data from FFQs are often unreliable due to recall bias [182].

People consume many foods over a year from a variety of food systems. In the areas included in this research, there are traditional, market, and community agriculture food systems. While this study focuses on traditional foods and associations between the consumption of various traditional foods, unknown associations may be present between traditional food and other food systems. These consumption patterns may influence the results of this study and have been handled as background statistical ‘noise’. Without the ability to control food consumption patterns, the results may be biased towards the null hypothesis. Even within a single food system, consumption patterns often overlap as demonstrated in the Chi-square statistics that measured traditional food consumption correlations (Appendix R).

Another limitation was the variation in the TEQ sums for dioxin, furans, and dioxins and furans. The biomarker TEQ sums of dioxin and DLC were not included in the analysis because several congeners were below the limit of detection and the TEQ calculations were highly substituted with  $\frac{1}{2}$  LOD. Since the TEQ biomarkers would have increased statistical noise as a part of this substitution, these results would be biased towards the null. Additionally, dioxins TEQ, and dioxins and furans TEQ were not normally distributed with any common transformation techniques. Furthermore, some determinant data such as raw water consumption, and occupation were only collected in Old Crow. The information from these variables may have been informative for further understanding PFAS exposure determinants.

As climate change continues to impact the northern regions of Canada, animal migrations and populations may change, and subsequently the determinants of contaminant exposures may change. For example, salmon populations in Old Crow have been threatened by the dewatering of the Fishing Branch River [9]. Policies on POPs also continue to evolve and may eventually impact exposure sources in Canada. The Government of Canada is considering gathering information on options to reduce environmental and human PFAS exposures [183]. Additionally, the Stockholm Convention recently added PFHxS, its salts, and related compounds to Annex A (elimination) and is reviewing long-chain PFCAs for addition [184]. Repeating this cross-sectional design alongside future community-based data collection may be informative of how determinants of exposure have changed since this baseline analysis.

### **3.8. Conclusions**

In response to community questions about the safety of traditional food systems, this study investigated how traditional foods and lifestyle factors were related to environmental contaminant exposures. The findings revealed predominantly negative associations between determinants and PFAS exposures, and multiple positive associations were observed between determinants and dioxin exposures. Many of the foods in this study hold cultural importance, promote physical and mental well-being, are rich in nutrients, and support food security and sovereignty in the participating communities [185].

While positive associations were observed between some foods and dioxin exposures, it is imperative to emphasize that the overall dioxin exposure levels were lower than the averages for the general population of Canada. Significant positive associations were observed between the priority compound PFNA and specific traditional foods, including whitefish eggs, Canada goose meat, and moose ribs, heart, and tongue, compared to the general population of Canada. Additionally, a significant positive association was observed between working in an occupation of risk and PCB 169 exposure.

To refine the understanding of POP exposure determinants in Arctic and subarctic communities, further investigations, possibly focused on environmental testing (e.g., testing for PFNA in whitefish eggs, Canada goose meat, and moose tissues, and sediment studies for measuring local environmental dioxin levels), market food testing (e.g., PFAS content in processed and ultra-processed packaged foods), and measurement of additional arctic and subarctic community biomarker data may provide further insights. Overall, the findings from this study indicate that the array of benefits from consuming traditional food continues to outweigh the potential risks posed by contaminant exposure.

#### 4. Thesis Conclusions

Dioxins and PFAS are persistent hazardous chemicals identified in regions distant from recognized release origins [20, 150]. These chemicals share some chronic health endpoints of concern, such as increased risk of some cancers, reproductive toxicities, developmental toxicities, and endocrine effects [86, 101]. These contaminants can disproportionately impact communities in Arctic and subarctic regions because they are known to be transported globally and tend to be deposited in colder regions [18, 20]. These contaminants can then enter food webs as organisms uptake these chemicals from the land [120].

Some information gaps were first identified by community members who had questions about their exposures to environmental contaminants and were concerned about how traditional foods could be affected. People who live in these communities are aware of the potential health risks associated with exposure to these contaminants and have demonstrated interest in furthering the understanding of how these chemicals may affect their health and ways of living. This interest had prompted biomonitoring projects in the Dehcho Region and Sahtú Region of the NWT, and Old Crow, YT.

Several other analyses of these human biomonitoring data have been completed or are ongoing. For example, cadmium and lead were slightly elevated in the Dehcho Region but appeared similar to levels observed in the rest of Canada [46]. People living in Old Crow had elevated levels of HCB compared to the average for the general population of Canada, and their exposures were linked to consuming some moose and caribou organs, including bones, fat, bone marrow, and kidneys [47, 52]. PCBs were investigated in the Dehcho and Sahtú Regions, which revealed that overall PCBs were not elevated compared to the averages for the general population of Canada. However, consumption of fish-eating birds was associated with elevated PCB exposure levels [50].

This thesis aimed to report on the dioxin and DLC exposure levels among people in Old Crow, which had not yet been explored, and compare these levels to the averages for the general population of Canada. The relationships of these exposure levels to demographic and lifestyle factors such as sex, age, BMI, and smoking status were investigated. The determinants of exposure to dioxins and PFAS in Old Crow and the Dehcho Region were both unknown. This thesis also addressed this knowledge gap by investigating how traditional foods and other lifestyle factors were related to dioxin, DLC, and PFAS exposures. Correlations among foods consumed were investigated to refine the understanding of how commonly specific foods were consumed by the same people. By fulfilling the purpose of this thesis research, several knowledge gaps were addressed.

This preliminary investigation revealed several factors that may influence exposure levels of dioxins, DLCs, and PFAS in people. Across the study regions, common determinants of PFAS exposure were limited and sometimes appeared to be conflicting. Now, baseline information is available on the levels of dioxin and DLC exposures experienced by Vuntut Gwitchin People in Old Crow, which is the only community within YT where these congeners have been measured. Based on the literature review conducted in part for this thesis there were no dioxins and DLC human biomonitoring data representative of an inland First Nation community in Canada. This new information indicates that there may be notable differences in how First Nations are impacted by environmental PFAS contamination depending on their location [168]. Within Canada, information on how residents are exposed to PFAS continues to emerge, but the pathways are still not fully understood. This research is the first to explore determinants of exposure to PFAS, dioxins, and DLCs in First Nations located within Northwestern Canada.

#### 4.1. Key Findings

In the first research chapter, the exposure levels of dioxins and DLCs were reported and stratified by sex and age categories. The results indicated that most exposures to dioxin and DLCs in Old Crow, YT were similar to or lower than the averages of the general population of Canada. As expected, some congeners, such as 2,3,4,7,8-PeCDF, 1,2,3,6,7,8-HxCDD, PCB 126, and PCB 169 appeared to significantly increase with age. In two age groups (20 to 39 and 60 to 79), PCB 169 appeared to be elevated in comparison to the averages for the general population of Canada. Additionally, smoking was found to be negatively associated with exposures to 1,2,3,4,6,7,8-HpCDD. These results indicate that dioxin and DLC exposures in Old Crow may not be a driver of health concerns because the exposure levels were about half the average of the general population of Canada, and about four-fold lower than the biomonitoring equivalent derived for dioxins and DLCs.

The research explained in the second chapter focused on using regression modeling to identify demographic and lifestyle factors that were associated with PFAS, dioxin, and DLC exposures. Many significant associations were observed, both positive and negative. Generally, dioxins and DLCs were associated with some traditional foods, except for four foods and food groupings which were associated with exposures to multiple congeners. These included consumption of moose ribs (OCDD, PCB 126), coho salmon (1,2,3,6,7,8-HxCDD, PCB 126, 2,3,4,7,8-PeCDF), piscivorous birds (1,2,3,6,7,8-HxCDD, PCB 126), and high or lowbush cranberries (1,2,3,4,6,7,8-HpCDD, PCB 126). PCB 169 exposures were positively associated with employment in at least one ‘occupation of risk’, which included employment in gardening, farming, automobile repair, waste disposal, oil and gas, laboratory research, chemical production, firefighting, soil decontamination, emergency remediation, or road paving over the last two years.

PFAS were generally negatively associated with traditional foods, indicating that consumption of traditional food may offset PFAS exposures potentially derived from packaged and processed foods. This hypothesis is based on the determinants results that demonstrated numerous negative associations observed between traditional foods and PFAS exposures, especially in the Dehcho Region. PFNA, which was previously found to be elevated in both regions was positively associated with moose ribs, heart, and tongue in Old Crow; though, the consumptions of nearly all moose tissues were correlated with each other. This means that these associations are not truly independent, and therefore, the contribution of individual food items to exposures remains unclear. Conversely, in the Dehcho Region moose head and fat were significantly negatively associated with multiple PFAS congeners (PFOA, PFOS, and PFHxS). The contradictory direction of the associations across study areas indicate that additional investigation is needed to clarify how moose tissues are related to PFAS exposures. It was also revealed that 1,2,3,6,7,8-HxCDD and PCB 126 exposures were significant and positively associated with consuming piscivorous birds, which was consistent with the previous finding for PCBs.

The results from this investigation have directly contributed to the understanding of POP exposure in Arctic and subarctic Canada. The measured levels of PFAS, and dioxins and DLCs were generally about the same or lower than the general population of Canada with two exceptions (PFNA and PCB 169). The levels of PCB 169 were about two-fold elevated and are not expected to contribute to health outcomes based on exposures observed in Canada and the most conservative biomonitoring equivalent (15 pg/g TEQ) [41, 134]. The results of this thesis have also refined some of the potential sources of exposure to dioxins and PFAS that are specific for some Dene, Métis, and Vuntut Gwitchin people. In some related studies, positive associations have also been observed between traditional foods and contaminant exposures. The negative associations observed between PFAS exposures and traditional foods indicate that traditional foods may not be the main source of exposure and may indicate countervailing exposure

from market foods. Overall, the results of this thesis support ongoing public health messaging that the benefits of consuming traditional foods generally outweigh the risks of exposure to contaminants.

#### **4.2. Limitations**

Many steps were taken to mitigate the limitations of this research, both in initial design and in analysis, however, several limitations persisted. The cross-sectional study design utilized biomarker and FFQ data that were collected at a single time point. The determinants analysis results show associations without established sequence; it remains unknown if the consumption of the food preceded the exposure. Exposure levels and food consumption patterns may have fluctuated as dioxin and DLC emissions in Canada have changed, with food consumption changes, and as PFAS regulations emerge. Dioxin and furan emissions in Canada were 100.1 g TEQ in 2000 and reduced to 15.6 g TEQ in 2017 [186]. FFQ data for Old Crow from 1995 are published and show some notable differences compared to the FFQ data used in this analysis, especially for some fish consumptions [14]. These changes in emissions and exposure sources over time have not been captured by the cross-sectional nature of this investigation. In addition to temporality, other indicators of possible causal links were explored throughout this thesis. There is contextual evidence indicating biological plausibility, context and validation of measured exposure levels, and some consistency with other research that demonstrates the strength of the associations identified in this research.

The study participants were not entirely representative of the target populations. Low participation was observed among children, and Elders >74 years of age. Recruitment of study participants was conducted through both random and passive methods. The inclusion of convenience sampling may have led to some volunteer bias. Furthermore, the populations of the participating communities are relatively small in comparison to other biomonitoring studies. Inherently, this can present some bias in statistical analysis and negatively impact statistical power. Conversely, many participants relative to the community population were sampled, which led to a representative data set.

This research demonstrated that the determinants of exposure to PFAS appeared to be quite different in Old Crow versus the Dehcho Region, indicating that the determinants results should not be generalized across communities. Similar indications have been seen in other analyses conducted as a part of these biomonitoring projects. For example, PCB analysis revealed that those who smoked in the last 24 hours in the Dehcho and Sahtú regions had generally lower GM PCB blood levels, while those of the same lifestyle group in Old Crow had higher GM PCB levels than those who did not smoke. These differences could be the result of regionally specific levels of exposure, food consumptions, food sources, or environmental concentrations of contaminants.

In the development of linear regression models, sex and age were held fixed while each potential determinant was analyzed. The number of predictor variables included in this analysis was limited to three to reduce the likelihood of overfitting. This approach did not consider how foods may be often consumed together, how much of the food was consumed, or how often it was consumed. Chi-square correlations were calculated to assess how often foods are consumed by the same people. While data on portion sizes were collected, they are not thought to be reliable because they were recalled by participants for the past year. Self-reporting in FFQ and lifestyle factor surveys may have been subject to recall bias or desirability bias.

#### **4.3. Knowledge Sharing**

Communication of the findings of this research to participants and their communities was a priority. Ultimately, this research is intended to offer results from modern exposure science methods to

complement local Traditional Knowledge, which may support community-based decision-making. These results have been delivered to the participating communities through open workshops, individualized letters, and plain language written communications. During community meetings in Old Crow (February 2023) some residents reported that traditional foods taste good, that market alternatives are expensive, and that market meats taste bad and are somewhat socially stigmatized. This commentary highlights the qualitative values of traditional foods and demonstrates the benefits of continued monitoring of traditional food. Additionally, understanding human exposures in these communities is complementary to ongoing local environmental monitoring and food sampling programs.

Although some of these results link environmental contaminants and food, it is important to emphasize the roles of all determinants of health. The processes that surround the harvesting, preparation, consumption, and sharing of traditional foods promote physical activity, spiritual well-being, and socialization. Moose meats, whitefish eggs, and Canada goose meat are good sources of protein and some vitamins [187]. While contaminants and nutrients of traditional foods can both be quantitatively assessed, other qualities such as social benefits, food knowledge, sense of well-being, and sense of place should also be included when evaluating the overall benefits and risks that are linked to traditional foods. The skills needed for harvesting and preparing traditional foods have often been shared generationally and could be forgotten or not shared if these cultural practices are interrupted or stigmatized. Additionally, First Nations people use Traditional Knowledge and methods that are effective to identify sick animals which they do not consume. Overall, the results of this thesis reinforce that the benefits of eating traditional foods continue to outweigh the risks from exposure to contaminants in Old Crow, and the Dehcho Region.

#### **4.4. Future Community Communication**

Community feedback has indicated that graphical representations of results are preferred to text-based summaries. To facilitate graphical representation of findings, the applications Biorender and Procreate were used to develop graphical communication materials. Biorender is an online scientific illustration tool with numerous templates, vector art, and other design tools that can help generate visually engaging graphical abstracts and poster presentations. The two graphical abstracts (Figure 8: Graphical abstract for dioxin and DLC biomonitoring results in Old Crow, YT . and the conference poster presentation (Appendix U) were made using Biorender. If icons, maps, or illustrations were not available under a Creative Commons license, but necessary for effective visual communication, these were hand drawn using an iPad Pro, Apple Pencil (2<sup>nd</sup> Generation), and a software application called Procreate. This software has a user-friendly interface and enables the production of digital artwork. A wide variety of artistic tools, such as airbrushes, pencils, inks, smudge tools, and erasers are available by default in the application. Other artists have also developed brushes that are often free for download under a Creative Commons license agreement. A map of Northwestern Canada, a goose illustration, and a ptarmigan illustration were developed using Procreate and other Creative Commons resources.



Figure 10: Map of Northwestern Canada drawn using Procreate.

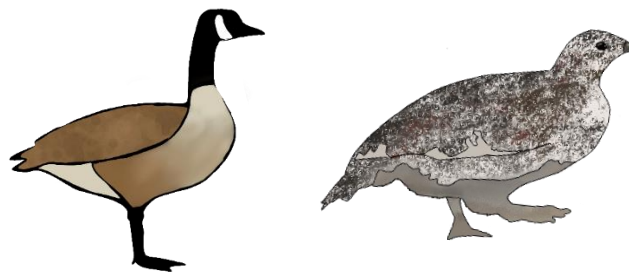


Figure 11: Canada goose and ptarmigan illustrations drawn using Procreate.

Most of the communication materials used throughout this thesis used icons or other illustrations to graphically represent findings. Many of these icons are from free Creative Commons sources (thenounproject.com, Microsoft Icon Library). While these graphics are easily accessible, future communication materials could support the arts and culture of the participating communities by commissioning local artists and photographers for visual content. This approach would emphasize the commitment to respecting culture and offer economic opportunity for community artists.

Furthermore, with the emergence of high-speed internet availability in areas that were previously poorly connected, new tools for communication of results are now available. Delivery of results through digital media, such as a video, may be more engaging for study participants, and provide automatic engagement metrics to measure the effectiveness of result delivery. For example, Meta platforms (*e.g.*, Facebook and Instagram), provide average reach (number of users who had the video on screen), number of times the post was clicked on, and reactions to the post (“likes”), comments, and/or shares [188]. YouTube provides creators with the number of views, “likes”, the estimated amount of time that viewers watch content, the number of viewers who are subscribed to content, ranking of the most popular video published on the channel, provides information on audience gender, age, and location, and reports on the audience’s online activity across other channels [189]. People who use these platforms agree to this

information being shared with creators when they consent to the terms and conditions of use. This data can also be used to inform the type of information people have interest in, and measure how people were reached in each communication strategy; these data can be used to demonstrate effective communication of results and community engagement in future grant applications. Among health message survey respondents from the Mackenzie Valley, social media was reported to be a main source of information, and 57% accessed information daily or weekly, but it was less trusted than other information sources [190]. If published regularly, this form of communication may also act as a reminder that this research project is ongoing and progressing in addition to the email newsletter that is circulated to study participants.

#### **4.5. Project Sustainability**

The biomonitoring projects that served as the basis for this thesis thoroughly considered community goals, scientific rigor, and future direction. Through the conduct of this research, some new themes and ideas emerged that could aid the success of future projects:

**Consistency of Statistics:** The analyses conducted in the two research chapters of this thesis were mainly consistent with those of other analyses conducted with the same biomonitoring data. This approach was intended to allow for comparability across multiple research projects. However, for this project, the percent detection for general linear model development was set at 60% which differs from other research projects. In model development, it became apparent that some of the congeners that had more than 50% detection, but less than 60% detection, had residual patterns that violated the assumptions of regression modeling. While 60% detection was used as a cutoff for model development in this study, this percentage of detection may not be appropriate in all investigations. Model residuals should be assessed on a case-by-case basis and subsequent model development based on satisfaction of linear regression assumptions.

**Broadened biomonitoring:** Biobanked tissue samples remain for additional analyses and these samples should be used completely and intentionally to respect their value. By using existing data, the benefits of these biomonitoring projects continue to expand as new information is provided to participants and communities without further biological sample collection; these additional analyses also follow through with community research agreements. Communities are interested in understanding how chemical exposures are changing with climate change, and how industrial projects may impact their communities. Some communities are also interested in implementing interventions to reduce and control exposures to contaminants.

Inclusion of additional communities in YT, or other regions within Arctic and subarctic Canada may help to further characterize contaminant exposures that have not previously been known. Decisions to conduct additional biomonitoring studies, and the timing thereof, should be directed by community leaders. Understanding of dioxins and PFAS exposures among First Nations located in the territories remains limited. Dioxins and DLC analysis in the Dehcho and Sahtú Regions would help to inform if exposure trends exist, that otherwise remain undetected. PFAS exposures in the Sahtú Region are also yet to be explored. These data could help to identify if there are common sources of exposure that extend beyond territorial borders. Some other regional data gaps from these biomonitoring projects remain, such as speciation of arsenic exposures, and polycyclic aromatic hydrocarbon and cotinine levels in Old Crow. Measuring these chemical exposures would enable these communities to monitor changes in exposure, and potentially identify exposure sources.

**Follow-up biomonitoring:** Follow-up biomonitoring studies in the participating communities, 10 to 15 years following initial measurement may allow for synthesis of temporal exposure trends. Studies of this nature should also be in alignment with community interests and directed by community leadership.

These data would also help to inform the generalizability of temporal trends observed from national biomonitoring data to people living in the territories. This information would be beneficial to the Northern Contaminants Program (Canada) to further knowledge on people's exposures to contaminants in territories of Canada. In turn, these data may also inform if global policies in place under the Stockholm Convention are effective in reducing human exposure to dioxins, DLCs, and PFAS.

Some exposure sources are emerging with greater precedence than in previous decades. This year (2023), wildfires burned the largest area of Canada on record. Firefighters are known to be at high risk of exposure to many contaminants including PFAS from fire suppression tools, and dioxins and DLCs from smoke [191, 192]. Community members may also be impacted by smoke inhalation and contamination from fire suppression foams. Investigating how wildfires contribute to chemical exposures in YT and the NWT could inform potential health risks and improvements in firefighting methods and community emergency management.

Furthermore, the Arctic Ocean is anticipated to have longer periods of no ice cover and is expected to emerge as a more economically beneficial shipping route [193]. This change could contribute to increased environmental pollutants in the Arctic and neighboring lands as ships use fuel and heavy fuel oils; combustion of these products can produce dioxins, DLCs, and PCBs. In the future, the dioxin and DLC levels identified in this investigation could serve as a critical baseline as the Arctic becomes a major global shipping route. This data can be used by the communities to raise concerns if exposure to these substances increases over time, allowing them to advocate for the protection of their health and traditional lifestyles.

**Analysis of environmental samples:** This research revealed that PCB 169 exposures were associated with occupational exposures. It remains unknown if people who worked in occupations of risk fulfilled those jobs in Old Crow or other locations. Sediment testing could be used to characterize historical air levels of PCB 169 and to understand if PCB 169 exposures are local to Old Crow. Active air sampling could be used to assess if ambient air exposure to PCB 169 is ongoing. It remains unclear why the broad category of occupations appeared to be significantly associated with PCB 169 exposures. Possibly, each of these occupations could have contributed to elevated exposures, but to varying degrees. Alternatively, occupation may be a confounding variable to a different determinant. To address this knowledge gap, expanded analysis of dioxins and DLCs in other communities may help to inform the validity of this association.

The PFAS analysis indicated some positive associations between exposures and traditional foods. Follow-up sampling of lake trout, fish-eating birds, and eggs from birds may help to define if observations from other Arctic species studies are generalizable to those within YT and the NWT.

**Vulnerable populations:** A biomonitoring study targeted to pregnant women, children, and Elders people would help to establish exposure data that are representative of all demographics in the participating communities [194, 195, 196]. This could be developed by recruiting from across communities and territories to develop an adequate sample size. Special considerations for accessibility may need to be integrated for participation to be more accessible for each population, such as traveling to Elder care facilities, providing means of transportation, and being held in areas where applicable healthcare is available [168].

**Food frequency questionnaire:** As climate change impacts the migration patterns of animals, it is expected that the consumption patterns of traditional foods may also be impacted. A follow-up FFQ including traditional and market foods may help to establish how food consumption has changed since initial collection and ensure that the determinants of exposure that are investigated remain relevant to

participants' diets. In future FFQs, the inclusion of a short answer question to gauge how diets may have changed over the past few years may be informative for determinants analysis. Conversationally, people in Old Crow mentioned the decrease in salmon over the last few years, which they attributed to warm water, and an increase in moose, which was attributed to an increase in willow shrub growth. These nuances are sometimes not captured through a multi-select questionnaire and could have gone unknown if in-person interaction with community members was not possible.

Quantification of PFAS in commonly purchased market foods, particularly processed and ultra-processed foods, may help to inform the potential sources of PFAS exposures in the study areas. National maximum levels for food PFAS content have not been set by the Food Directorate of Health Canada. Members of the Health Canada Consumer Product Safety Division, typically responsible for food contact materials, and the Canadian Food Inspection Agency, typically responsible for the inspection and enforcement of food regulations set out by Health Canada, may need to be involved to implement a food sampling program. Market food data could be developed through receipt collection, or a market food FFQ to identify what foods are commonly purchased and consumed.

**Youth engagement:** Involvement of youth is a key priority in many First Nation communities. Elder to youth knowledge sharing is especially valued across the First Nations participating in this research. Engagement with youth regarding contaminants, nutrients, and foods could enhance the sustainability and alignment of this project with community goals. This could be achieved through engagement with youth in age-appropriate artistic exploration of what nutrition and contamination mean to them, understanding their ideas about how they are affected, and considering how these chemicals could impact their futures.

#### **4.6. In Summary**

Many Indigenous communities across the territories rely on foods derived from local lands. Harvesting, preparing, sharing, and eating traditional foods have been linked to positive effects on mental health, physical health, sense of well-being, and preservation of culture. The results from previous national human biomonitoring projects (CHMS, FNBI) cannot be extrapolated to Indigenous communities across the territories, which lead to a limited understanding of how these Northern communities may be impacted by environmental contaminants. Through the community-based human-biomonitoring projects conducted in Old Crow, the Dehcho Region, and the Sahtú Region, people in these communities now have information about their biological levels of several environmental contaminants and preliminary knowledge about links to potential exposure sources. Continued monitoring of POPs is necessary to inform the potential health risks that people within Canada face, especially in Arctic and subarctic areas that are known to be impacted by long-range atmospheric transport. These monitoring initiatives can also inform the effectiveness of international regulations, such as those enacted under the Stockholm Convention.

The information synthesized in this thesis can be used by community members in complement to Traditional Knowledge to inform decision-making about what to harvest and consume, justify concern to external governments, and aid local policy development. Additionally, this work benefits the research community as investigations on dioxin and DLC exposures have been limited in the last decade, and this research provides a baseline of dioxin and DLC exposures for an Arctic, non-marine, Indigenous community. Furthermore, this thesis explores previously unexamined determinants of PFAS, dioxins, and DLC exposures within Indigenous Northwestern communities within Canada. These data may be used to inform future analyses in other areas or further refine the understanding of POP exposures in the Arctic and subarctic regions of Canada. This data may help to inform regional, national, and international policymakers on the necessity and effectiveness of bans and regulations as new data emerges.

Overall, the results of this thesis reinforce that the benefits of eating traditional foods continue to outweigh the risks from exposure to contaminants in Old Crow, YT, and the Dehcho Region.

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## Appendices

**Appendix A: Recommended toxicity equivalency factors for polychlorinated dibenzo-*p*-dioxins, dibenzo-furans and non-ortho substituted dioxin-like PCBs in human health risk assessment, from the World Health Organization re-evaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds [197].**

Category	Compound	2005 TEF
Chlorinated dibenzo- <i>p</i> -dioxins	2,3,7,8-TCDD	1
	1,2,3,7,8-PeCDD	1
	1,2,3,4,7,8-HxCDD	0.1
	1,2,3,6,7,8-HxCDD	0.1
	1,2,3,7,8,9-HxCDD	0.1
	1,2,3,4,6,7,8-HpCDD	0.01
	OCDD	0.0003
Chlorinated dibenzofurans	2,3,7,8-TCDF	0.1
	1,2,3,7,8-PeCDF	0.03
	2,3,4,7,8-PeCDF	0.3
	1,2,3,4,7,8-HxCDF	0.1
	1,2,3,6,7,8-HxCDF	0.1
	1,2,3,7,8,9-HxCDF	0.1
	2,3,4,6,7,8-HxCDF	0.1
	1,2,3,4,6,7,8-HpCDF	0.01
	1,2,3,4,7,8,9-HpCDF	0.01
	OCDF	0.0003
Non-ortho substituted PCBs	PCB 77	0.0001
	PCB 81	0.0003
	PCB 126	0.1
	PCB 169	0.03

TEF= toxicity equivalence factor

## Appendix B: C13 Analog Table of Recovery

	13C-2378-TCDF	13C-2378-TCDD	13C-12378-PeCDF	13C-23478-PeCDF	13C-12378-PeCDD	13C-123478-HxCDF	13C-123678-HxCDF	13C-234678-HxCDF	13C-123789-HxCDF	13C-123478-HxCDD	13C-123678-HxCDD	C13-123789-HxCDD	13C-1234678-HpCDF	13C-1234789-HpCDF	13C-1234678-HpCDD	13C-OCDF	13C-OCDD	13C-PCB81	13C-PCB77	13C-PCB126	13C-PCB169
Info.	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Mean recovery	71	74	74	70	71	77	75	74	77	76	78	76	79	77	77	77	76	59	58	74	73

## Appendix C: Individualized Limits of Detection

The concentration of total plasma lipids for each study participant was provided to INSPQ based on a previous assessment of the lipid content in the original panel of analyses. The results received from INSPQ were presented as the concentration of the dioxin congeners in pg/g plasma and pg/g lipids. The LOD for the plasma weight results was measured with an analytical standard for each congener while the lipids weight result LOD was determined mathematically.

To maintain precision, the individual limits of detection for each study participant, and for each congener were calculated. Additionally, since ½ LOD substitution was used for the calculation of TEQ for each participant, the substitution needed to be precise for the lipid concentration of each study participant. Plasma has an average mass density of  $1.035 \pm 0.005 \text{ g/cm}^3$  [198].

$$\text{Lipid LOD} \left( \frac{\text{pg}}{\text{g Lipid}} \right) = \text{LOD}_{\text{plasma}} * \frac{D}{P}$$

Where,

$D$  = The density of human plasma, 1035 (g/L) plasma, on average

$P$  = The study subject's total plasma lipids (g/L)

$\text{LOD}_{\text{plasma}}$  = The plasma limit of detection, analytically determined  $\left( \frac{\text{pg}}{\text{g lipid}} \right)$

## Appendix D: Tobit Models: Points of Censor

The relationship between the observed and latent variable, stated mathematically:

$$y_i = y_i^* \text{ if } y_i^* > c$$

$$y_i = c \text{ if } y_i^* \leq c$$

Where,

$c$  = The threshold of censoring

The threshold of censoring for PFDA was developed to investigate if the striated pattern close to the LOD was affecting the reliability of the GLM model. The threshold of censoring for dioxins and DLCs was based on the median between the highest LOD value and the lowest detected value; in one case these values overlapped:

Congener	$\frac{1}{2}$ LOD (max, min)	Observed minimum	Overlap	Left censored at	Log transformation point of left censor	N <LOD
PFDA	N/A	0.1	Yes	0.3	-0.5229	N/A
2,3,4,7,8- PeCDF	(0.3450, 0.6337)	0.6401	None	0.6369	-0.1959	N/A
1,2,3,7,8,9- HxCDD	(0.2070, 0.4224)	0.3345	Yes	0.3785	-0.4219	1

**Appendix E: Descriptive statistics for lipid-adjusted dioxins, furans, and dioxin-like PCBs measured in blood plasma (pg/g lipid) from biomonitoring study participants (n=54), aged 13 to 74 years, from Old Crow, YT.**

	LOD	Detection rate	5 <sup>th</sup> P <sup>a</sup> (95% CI)	10 <sup>th</sup> P <sup>a</sup> (95% CI)	25 <sup>th</sup> P <sup>a</sup> (95% CI)	50 <sup>th</sup> P (95% CI)	75 <sup>th</sup> P <sup>a</sup> (95% CI)	90 <sup>th</sup> P (95% CI)	95 <sup>th</sup> P (95% CI)	AM (95% CI)	GM (95% CI)
<b>2,3,7,8-TCDF</b>	0.70	4%	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.59 (0.49, 0.80)	b	b
<b>1,2,3,7,8-PeCDF</b>	0.70	2%	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.53 (0.47, 0.53)	b	b
<b>2,3,4,7,8-PeCDF</b>	0.85	74%	<LOD	<LOD	<LOD (<LOD, 1.1)	1.4 (1.1, 1.6)	2.1 (1.6, 2.5)	2.8 (2.3, 3.3)	3.1 (2.7, 4.5)	1.50 (1.3, 1.7)	1.23 (1.0, 1.5)
<b>1,2,3,4,7,8-HxCDF</b>	1.1	37%	<LOD	<LOD	<LOD	<LOD	1.3 (1.0, 1.5)	1.6 (1.5, 1.9)	1.9 (1.6, 2.1)	b	b
<b>1,2,3,6,7,8-HxCDF</b>	0.85	56%	<LOD	<LOD	<LOD	0.91 (0.54, 1.1)	1.4 (1.1, 1.6)	1.7 (1.5, 1.9)	1.9 (1.7, 2.2)	0.97 (0.84, 1.12)	0.83 (0.71, 0.97)
<b>2,3,4,6,7,8-HxCDF</b>	0.99	0%	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	b	b
<b>1,2,3,7,8,9-HxCDF</b>	0.70	0%	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	b	b
<b>1,2,3,4,6,7,8-HpCDF</b>	1.3	48%	<LOD	<LOD	<LOD	<LOD (<LOD, 1.5)	2.1 (1.5, 2.5)	2.8 (2.3, 3.4)	3.4 (2.6, 3.5)	b	b
<b>1,2,3,4,7,8,9-HpCDF</b>	0.56	0%	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	b	b
<b>OCDF</b>	1.4	0%	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	b	b
<b>2,3,7,8-TCDD</b>	0.56	9%	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD (<LOD, 0.84)	0.81 (0.42, 0.94)	b	b
<b>1,2,3,7,8-PeCDD</b>	0.85	48%	<LOD	<LOD	<LOD	<LOD (<LOD, 1.3)	1.6 (1.3, 1.9)	2.5 (1.7, 3.1)	3.0 (2.4, 3.4)	b	b
<b>1,2,3,4,7,8-HxCDD</b>	1.1	30%	<LOD	<LOD	<LOD	<LOD	1.1 (<LOD, 1.7)	1.8 (1.5, 2.5)	2.5 (1.8, 3.9)	b	b
<b>1,2,3,6,7,8-HxCDD</b>	1.1	98%	1.9 (<LOD, 3.1)	3.0 (1.9, 3.5)	4.1 (3.1, 5.8)	7.9 (5.8, 9.8)	15 (9.9, 20)	24 (17, 32)	32 (21, 35)	10 (8.3, 13)	7.7 (6.1, 9.6)

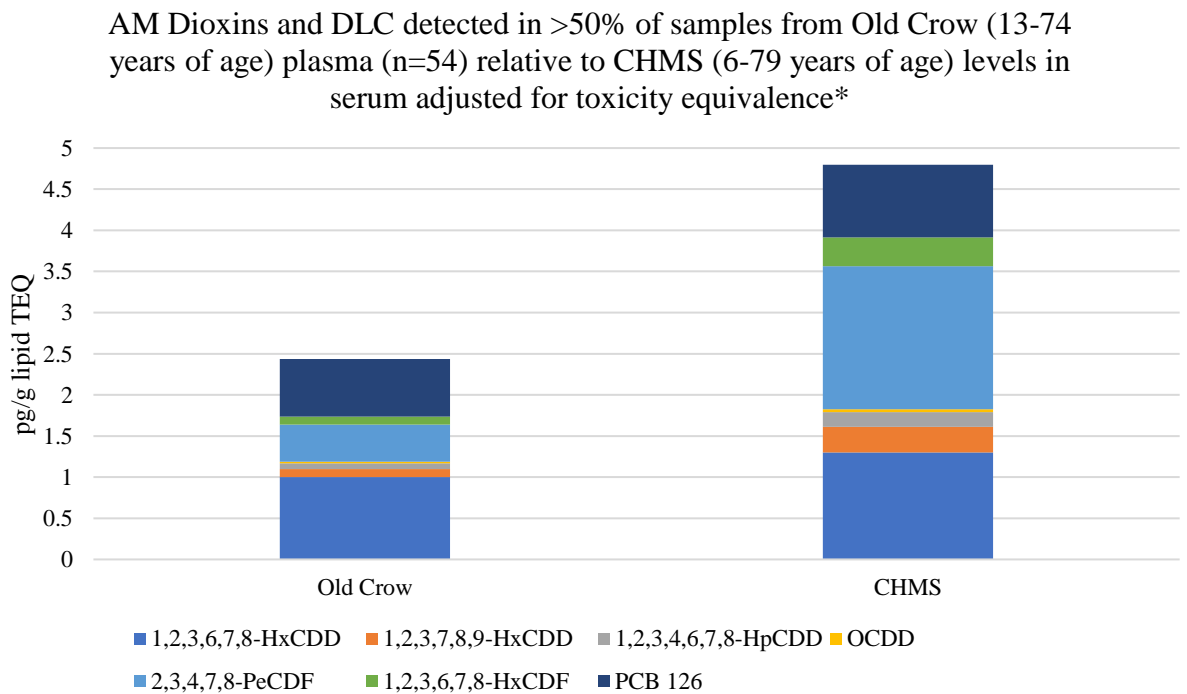
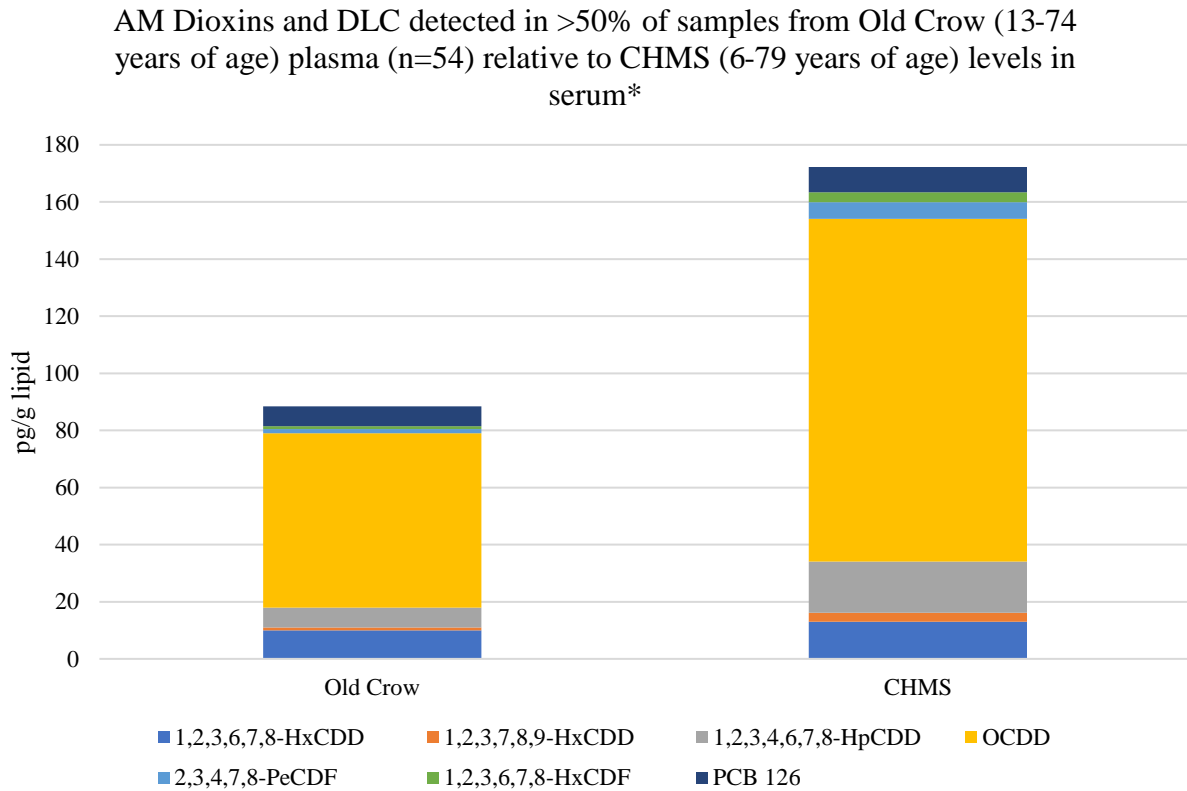
	<b>LOD</b>	<b>Detection rate</b>	<b>5<sup>th</sup> P<sup>a</sup> (95% CI)</b>	<b>10<sup>th</sup> P<sup>a</sup> (95% CI)</b>	<b>25<sup>th</sup> P<sup>a</sup> (95% CI)</b>	<b>50<sup>th</sup> P (95% CI)</b>	<b>75<sup>th</sup> P<sup>a</sup> (95% CI)</b>	<b>90<sup>th</sup> P (95% CI)</b>	<b>95<sup>th</sup> P (95% CI)</b>	<b>AM (95% CI)</b>	<b>GM (95% CI)</b>
<b>1,2,3,7,8,9- HxCDD</b>	0.56	67%	<LOD	<LOD	<LOD (<LOD, 0.63)	0.99 (0.67, 1.2)	1.4 (1.2, 1.7)	2.0 (1.6, 2.8)	2.7 (1.9, 3.4)	1.0 (0.86, 1.2)	0.80 (0.65, 0.98)
<b>1,2,3,4,6,7,8- HpCDD</b>	1.3	100%	2.9 (2.1, 3.4)	3.3 (2.8, 3.7)	4.1 (3.6, 4.7)	6.5 (4.7, 7.3)	8.2 (7.3, 10)	11 (9.2, 15)	14 (11, 28)	7.0 (6.0, 8.3)	6.1 (5.4, 7.1)
<b>OCDD</b>	1.4	100%	24 (19, 29)	29 (22, 33)	39 (32, 46)	56 (46, 62)	73 (62, 89)	100 (82, 150)	150 (96, 170)	61 (53, 70)	54 (47, 62)
<b>PCB 81</b>	0.70	9%	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD (<LOD, 0.84)	0.81 (0.53, 1.63)	b	b
<b>PCB 77</b>	0.99	15%	<LOD	<LOD	<LOD	<LOD	<LOD	1.24 (<LOD 2.05)	1.9 (1.0, 2.7)	b	b
<b>PCB 126</b>	1.1	98%	1.9 (0.84, 2.4)	2.3 (1.9, 2.7)	3.2 (2.4, 4.1)	4.9 (4.1, 6.5)	9.1 (6.5, 13)	14 (11, 18)	18 (13, 39)	7.0 (5.5, 8.8)	5.4 (4.4, 6.5)
<b>PCB 169</b>	1.7	89%	<LOD (<LOD, 2.1)	<LOD (<LOD, 2.9)	3.6 (2.7, 5.7)	7.6 (6.0, 12)	16 (12, 23)	32 (18, 67)	58 (28, 89)	14 (9.4, 19)	7.7 (5.7, 10)

AM = arithmetic mean; GM = geometric mean; LOD = limit of detection; n = sample size; p = percentile.

<sup>a</sup> Calculated in SPSS Version 29.

<sup>b</sup> The GM was not calculated as the detection rate was <50%

**Appendix F: Stacked bar graph of Old Crow blood plasma dioxin levels in comparison to CHMS Cycle 5 blood serum dioxin levels**



\*PCB 169 is excluded from these graphs because CHMS data are not available for the 6 to 79 age group.

## Appendix G: Regression Analysis

### General Linear Models

The fit diagnostics for each congener were visually analyzed and satisfied the assumptions of multiple linear regression. The assumptions include:

1. The distribution of error is random from zero
2. The unknown and random noise component is independent of the predictor variables
3. The variance is nearly constant
4. The residuals are normally distributed

Since these criteria are reasonably satisfied for the congeners 2,3,4,7,8-PeCDF, 1,2,3,6,7,8-HxCDF, 1,2,3,6,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,4,6,7,8-HpCDD, OCDD, PCB 126, PCB 169, PFNA, PFOS, PFHxS, and PFOA, when  $\log_{10}$  transformed these models should be reliable, and representative of the associations between each congener and the respective determinants. This means that p-values, CIs, and significance should remain true and representative of the data.

The models developed for PFDA may be less reliable than the models constructed for the other PFAS congeners, based on the data histograms:

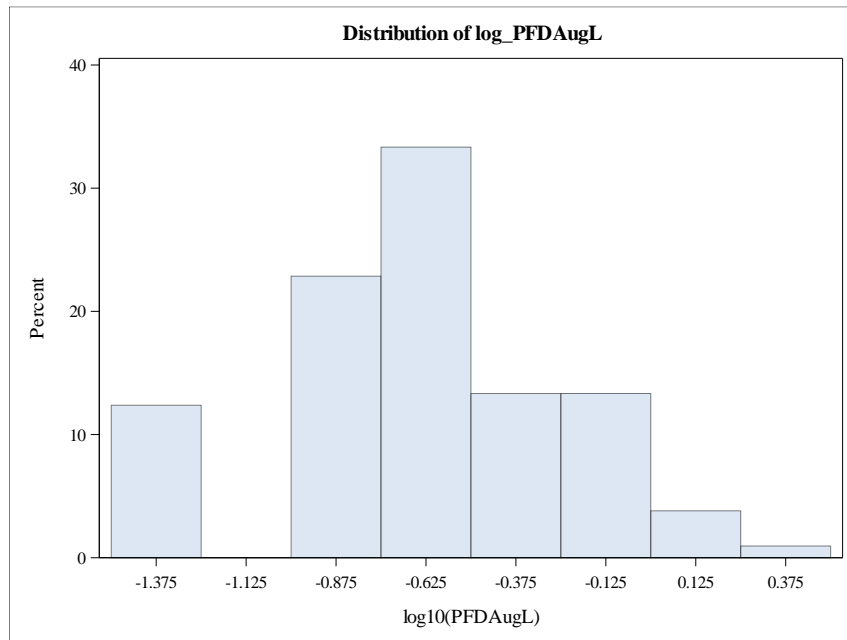


Figure 12: Dehcho Region histogram for  $\log_{10}$  transformed PFDA exposures. Shapiro-Wilk ( $p=0.015$ ).

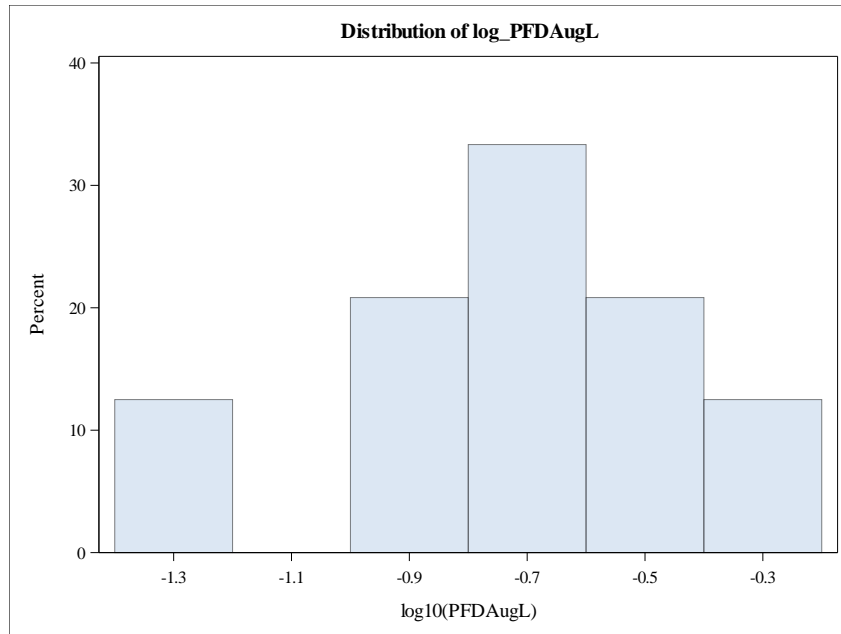


Figure 13: Old Crow histogram for  $\log_{10}$  transformed PFDA exposures. Shapiro-Wilk ( $p=0.0023$ ).

Through visual inspection it was determined that these data remained sufficiently normal for general linear regression, and that the method would remain sufficiently robust to this relatively minor violation of normality.

## Model Development

All the models run for determinant analysis followed similar structures:

Age and sex were retained in the model as known common confounders based on information from literature and known sex and age-related differences in Dioxins/DLCs/PFAS congener concentrations [48].

The models for differences in Dioxins/DLCs/PFAS *Congeners* individually regressed on *Determinants* with age and sex fixed in the model, follow the below structure:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \varepsilon_i$$

Where,

$Y_i$  = The  $\log_{10}$  (Dioxin/DLC/PFAS) congener concentration in blood matrix (serum/plasma) (pg/g lipid,  $\mu\text{g/L}$ ), an observed random outcome

$\beta_0$  = The overall Y-intercept (fixed, unknown)

$X_{i1}$  = Age, observed fixed continuous predictor

$\beta_1$  = The average change in age over 1 unit increase of age (fixed, unknown)

$X_{i2}$  = Sex, observed fixed binary predictor

$\beta_2$  = The regression coefficient for the average change in PFAS congener concentration between males and females, while holding the other variables fixed (fixed, unknown)

$X_{i3}$  = Determinant (i.e., ate smoked moose, ate caribou liver, consumed Labrador tea etc.), an observed fixed categorical predictor

$\beta_3$  = The regression coefficient for the average change in PFAS congener concentration between consumers and non-consumers, while holding the other variables fixed (fixed, unknown)

and,

$\varepsilon_i$  = The error in measurement, distributed normally, random, unobserved, has mean of zero and variance  $\sigma^2$ . Stated mathematically,  $\varepsilon_i \stackrel{iid}{\sim} N(0, \sigma^2)$ ,  $\varepsilon_i \perp X_{i1}, X_{i2}, X_{i3}$ ,  $(X_{i1}, X_{i2}, X_{i3}, Y_i) \perp (X_{j1}, X_{j2}, X_{j3}, Y_j)$ .

## Tobit Models

$$y_i^* = \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + u_i$$

Where,

$y_i^*$  = The true  $\log_{10}$  dioxin or DLC (1,2,3,7,8,9-HxCDD, 2,3,4,7,8-PeCDF) in plasma ( $\mu\text{g/L}$ ) for the  $i^{\text{th}}$  individual; a realized observed random outcome.

$y_i$  = The observed result, uncensored; an observed random outcome.

$X_{i1}$  = Age, observed fixed continuous predictor

$\beta_1$  = The average change in age over 1 unit increase of age (fixed, unknown)

$X_{i2}$  = Sex, observed fixed binary predictor

$\beta_2$  = The regression coefficient for the average change in dioxin or like congener concentration between males and females, while holding the other variables fixed (fixed, unknown)

$X_{i3}$  = Determinant (i.e., Ate Smoked Moose, Ate Caribou Liver, consumed Labrador tea etc.), an observed fixed categorical predictor

$\beta_3$  = The regression coefficient for the average change in dioxin or like-congener concentration between consumers and non-consumers, while holding the other variables fixed (fixed, unknown)

and,

$u_i$  = The error in measurement, distributed normally, random, unobserved, has mean of zero and constant variance  $\sigma^2$ . Stated mathematically,  $\varepsilon_i \stackrel{iid}{\sim} N(0, \sigma^2)$ ,  $\varepsilon_i \perp X_{i1}, X_{i2}, X_{i3}$ ,  $(X_{i1}, X_{i2}, X_{i3}, Y_i) \perp (X_{j1}, X_{j2}, X_{j3}, Y_j)$ .

**Appendix H: Means of dioxins, furans, and non-ortho substituted PCBs that were measured in biomonitoring studies in Canada.**

	Old Crow (pg/g lipid) <sup>1</sup> (AM)	Alberta Health & Wellness (pg/g lipid) <sup>1</sup>	Saskatche wan (AM) (pg/g) [199]	Nunavik (GM) [42]	CHMS Cycle 1 (AM) (pg/g lipid) <sup>2</sup>	CHMS Cycle 3 (AM) (pg/g lipid) <sup>2</sup>	CHMS Cycle 4 (AM) (pg/g lipid) <sup>2</sup>	CHMS Cycle 5 (AM) (pg/g lipid) <sup>2</sup>
<b>Year conducted</b>	2019	2005	2011-2013	2013	2007-2009	2012-2013	2014-2015	2016-2017
<b>Demographic</b>	Adults (20 to 74)	Pregnant women and children	Pregnant women	Pregnant women	Anyone 6 to 79 years of age	Anyone 6 to 79 years of age	Anyone 6 to 79 years of age	Anyone 6 to 79 years of age
<b>Matrix</b>	Plasma	Serum	Serum	Plasma	Serum	Serum	Serum	Serum
<b>Dioxins</b>								
2,3,7,8-Tetrachlorodibenzo- <i>p</i> -dioxin (TCDD)	-	-	<0.010	-	0.91	-	-	-
1,2,3,7,8-Pentachlorodibenzo- <i>p</i> -dioxin (PeCDD)	-	-	<0.010	-	3.1	-	3.8	-
1,2,3,4,7,8-Hexachlorodibenzo- <i>p</i> -dioxin (HxCDD)	-	-	<0.010 to 0.040	-	2.7	2.7	-	2.6
1,2,3,6,7,8-Hexachlorodibenzo- <i>p</i> -dioxin (HxCDD)	10 (8.4 – 13)	19 to 57	-	Detected	21	14	-	13
1,2,3,7,8,9-Hexachlorodibenzo- <i>p</i> -dioxin (HxCDD)	1.0 (0.85 – 1.2)	1.1 to 16	-	-	3.2	-	-	3.1
1,2,3,4,6,7,8-Heptachlorodibenzo- <i>p</i> - dioxin (HpCDD)	7.0 (6.0 – 8.3)	23 to 50	<0.010 to 0.100	5.33	22	18	-	18
1,2,3,4,6,7,8,9-Octachlorodibenzo- <i>p</i> - dioxin (OCDD)	61 (53 – 70)	170 to 280	90 to 110	60.18	160	130	120	120
<b>Furans</b>								
2,3,7,8-Tetrachlorodibenzofuran (TCDF)	-	-	<1.9	-	0.67	-	2.1	1.1
1,2,3,7,8-Pentachlorodibenzofuran (PeCDF)	-	1.1 to 28	<1.9	-	-	-	1.4	-
2,3,4,7,8-Pentachlorodibenzofuran (PeCDF)	1.5 (1.3 – 1.8)	1.1 to 31	<1.9	-	4.2	3.7	6.7	5.8
1,2,3,4,7,8-Hexachlorodibenzofuran (HxCDF)	-	1.1 to 19	<1.9 to 3.8	Detected	-	3.6	-	3.5
1,2,3,6,7,8-Hexachlorodibenzofuran (HxCDF)	0.97 (0.83 – 1.1)	4.3 to 13	<1.9 to 3.8	-	3.5	3.7	-	3.5

1,2,3,7,8,9-Hexachlorodibenzofuran (HxCDF)	-	-	<1.9	5.33	-	-	-	-
2,3,4,6,7,8-Hexachlorodibenzofuran (HxCDF)	-	-	<1.9	60.18	1.4	-	-	1.8
1,2,3,4,6,7,8-Heptachlorodibenzofuran (HpCDF)	-	18 to 35	0 to 8.2	-	-	6.4	-	5.4
1,2,3,4,7,8,9-Heptachlorodibenzofuran (HpCDF)	-	-	<1.9	-	-	-	-	-
1,2,3,4,6,7,8,9-Octachlorodibenzofuran (OCDF)	-	-	<1.9	Detected	-	-	-	-
<b>Non-ortho substituted PCBs</b>								
PCB 77	-	-	0.16 to 0.50	-	-	12	16	14
PCB 81	-	-	<0.096	-	0.83	-	-	-
PCB 126	7.0 (5.6 – 8.8)	-	<0.077	-	13	-	10	8.8
PCB 169	14 (9.2 - 19)	-	<0.058	Detected	13	-	14	-

AM = arithmetic mean; GM = geometric mean.

<sup>1</sup> n = 48. Mean type not specified. [200].

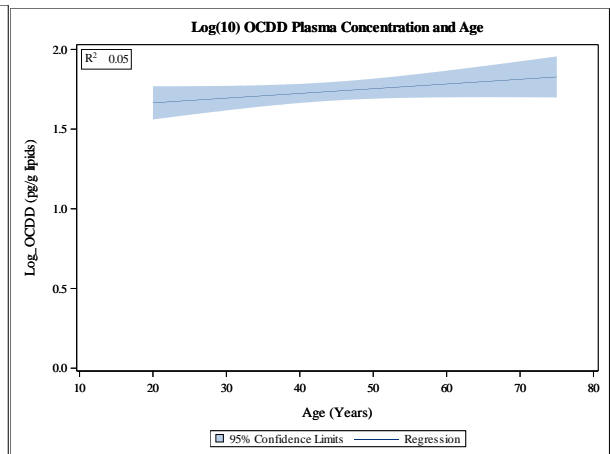
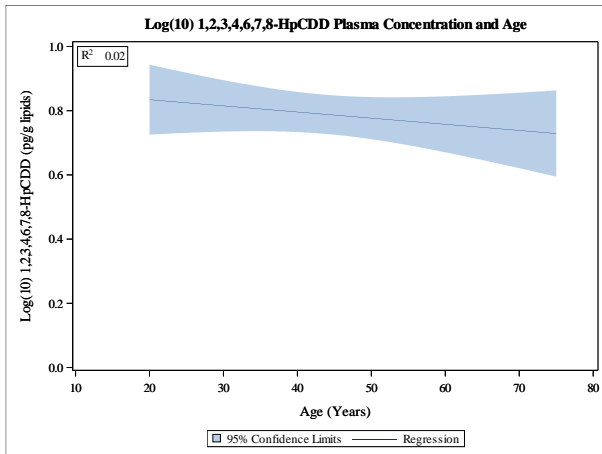
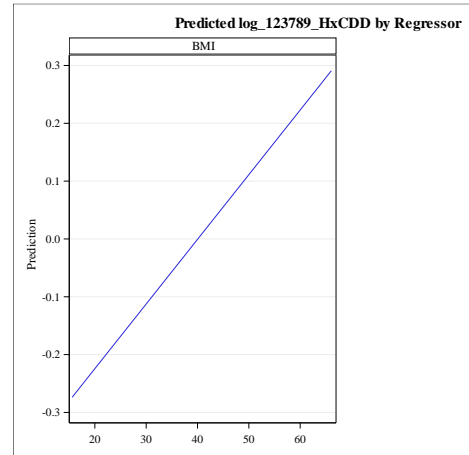
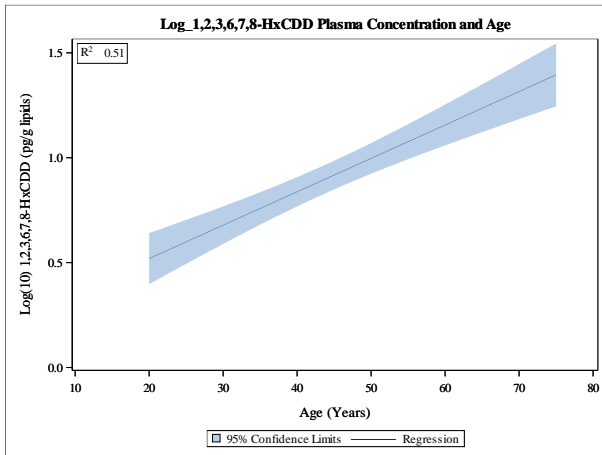
<sup>2</sup> [42]

**Appendix I: Tabulated data biological half-lives of the PFAS compounds that were included in the Old Crow and Dehcho Region biomonitoring projects [101].**

<b>PFAS Compound</b>	<b>Limit</b>	<b>Half life</b>	<b>Species</b>	<b>Matrix</b>	<b>Sex</b>	<b>Route of exposure</b>	<b>Source</b>
PFOA	Upper	8.5 y	Human (n=1029)	Serum	M, F	Oral	[201]
	Lower	2.1 y	Human ≤50 y (n=20)	Urine	F	N/A	[202]
PFOS	Upper	27 y	Human >50 y (n=66)	Urine	M, F	N/A	[202]
	Lower	3.1 y	Human (n=45)	Serum	M, F	N/A	[203]
PFNA	Upper	4.3 y	Human >50 y (n=66)	Urine	M, F	N/A	[202]
	Lower	2.5 y	Human ≤50 y (n=20)	Urine	F	N/A	[202]
PFHxS	Upper	35 y	Human >50 y (n=66)	Urine	M, F	N/A	[202]
	Lower	4.7 y	Human 15 to 50 y (n=30)	Serum	F	N/A	[203]
PFDA	Upper	12 y	Human >50 y (n=66)	Urine	M, F	N/A	[202]
	Lower	4.5 y	Human ≤50 y (n=66)	Urine	F	N/A	[202]
PFUdA	Not available						
PFBA	Upper	3.4 d	Human (n=3)	Serum	M	Occupational	[204]
	Lower	3 d	Human (n=9)	Serum	M (7), F (2)	Occupational	[204]
PFHxA	Upper	5.3 d	Cynomolgus monkey	Serum	M	IV	[205]
	Lower	2.4 d	Cynomolgus monkey	Serum	F	IV	[205]
PFBS	N/A	27.7 d	Human (n=6)	Serum	M (5), F (1)	N/A	[206]

d = days; f = female; h = hours; IV = intravenous; m = male; N/A = not applicable; y = years.

## Appendix J: Dioxin and DLCs Regressed by Age



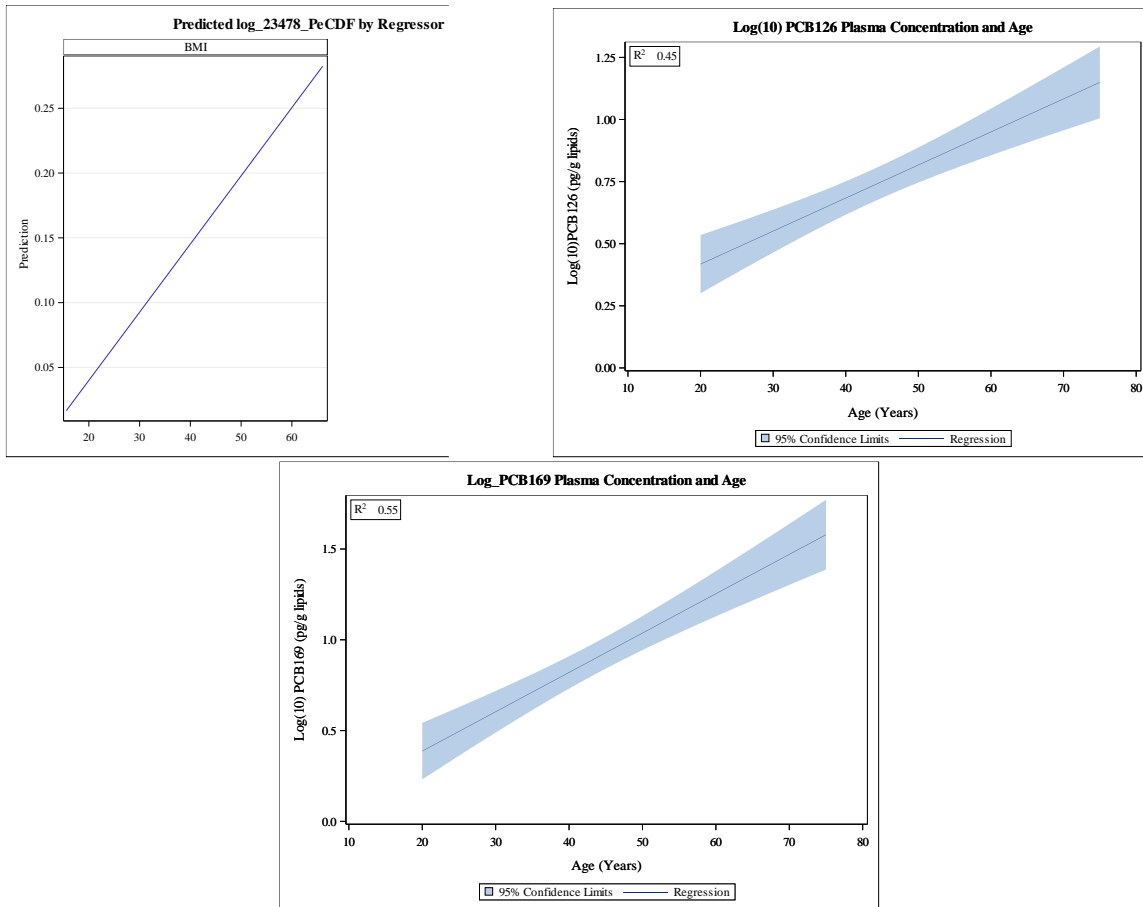
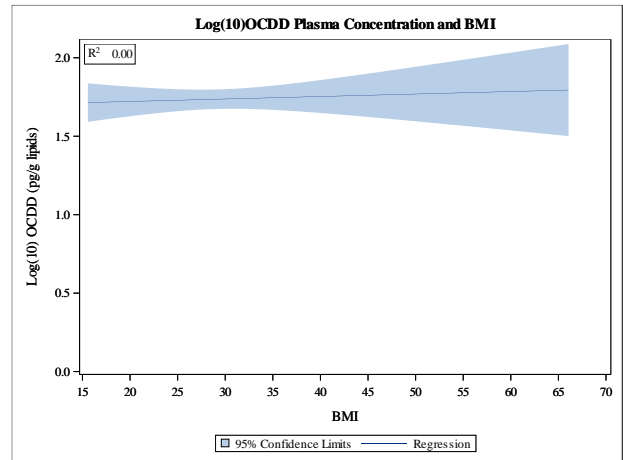
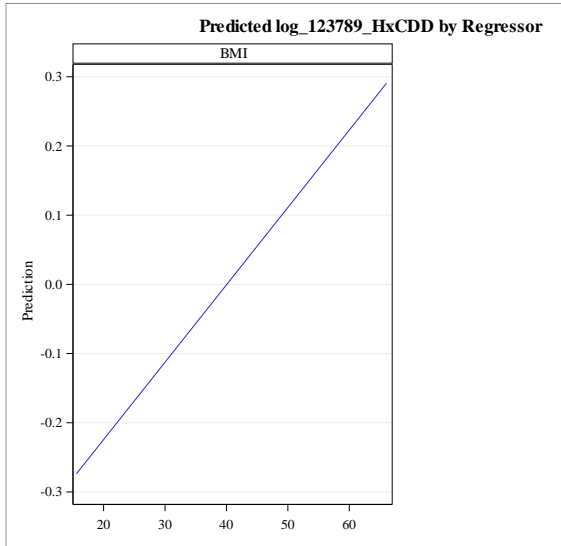
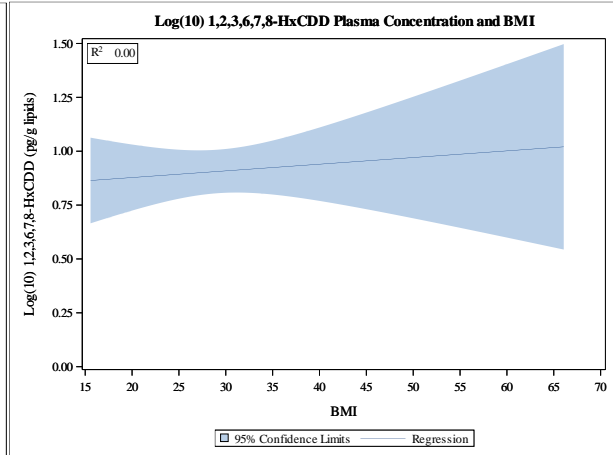
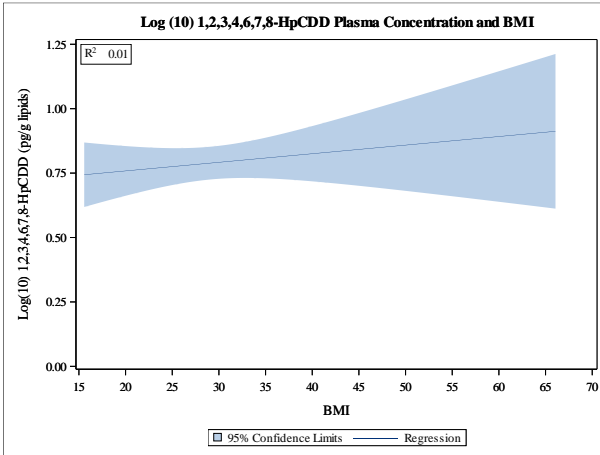


Figure 14: Plots of log-transformed congeners that were detected at >60%, versus age. Whiskers represent the 5<sup>th</sup> and 95<sup>th</sup> percentiles.

## Appendix K: Dioxins and Dioxin-Like Congeners Regressed by BMI



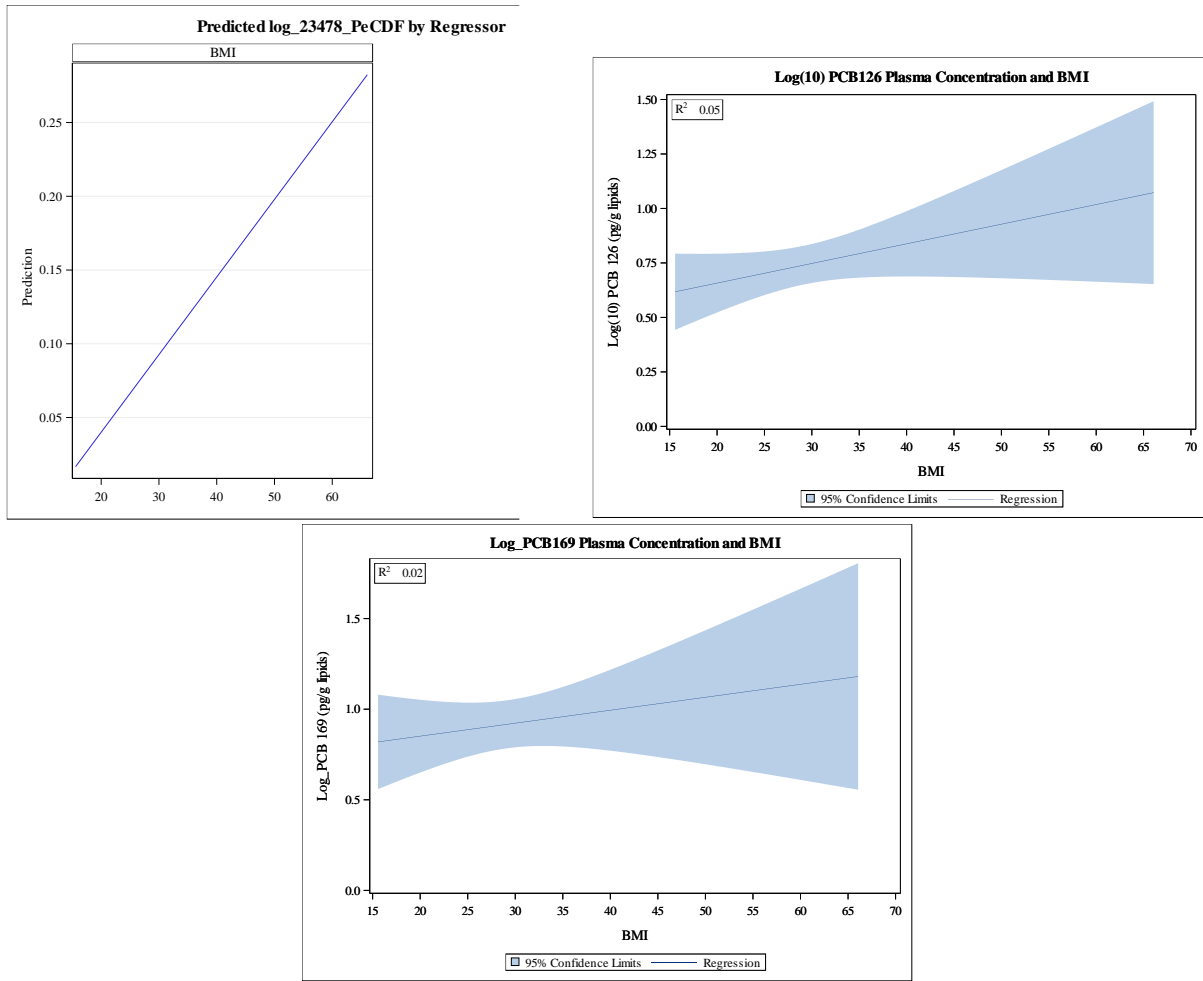
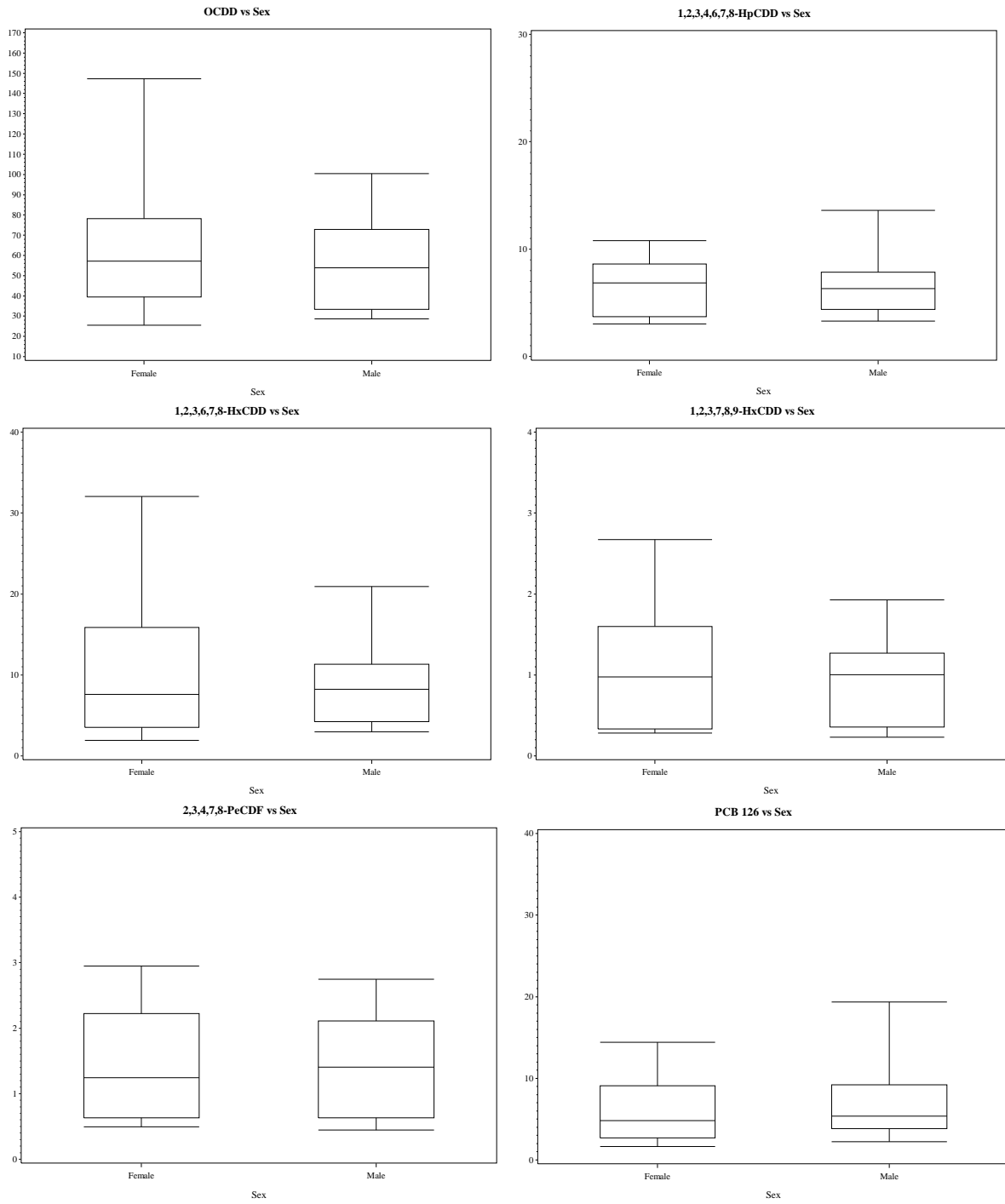


Figure 15: Plots of log-transformed congeners detected in >60% of study participants, regressed by BMI. Whiskers represent the 5<sup>th</sup> and 95<sup>th</sup> percentiles.

# Appendix L: Boxplots for Dioxins and DLC levels stratified by Sex



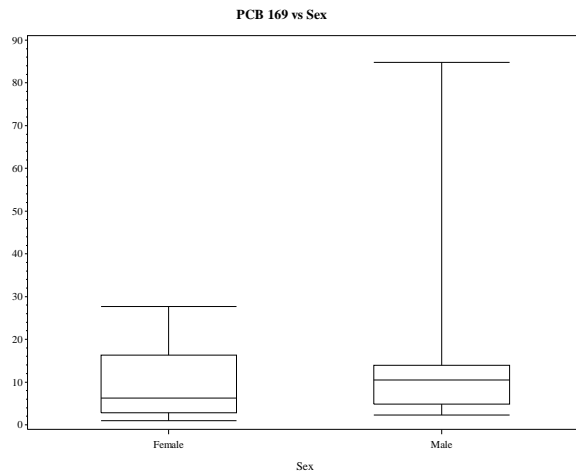
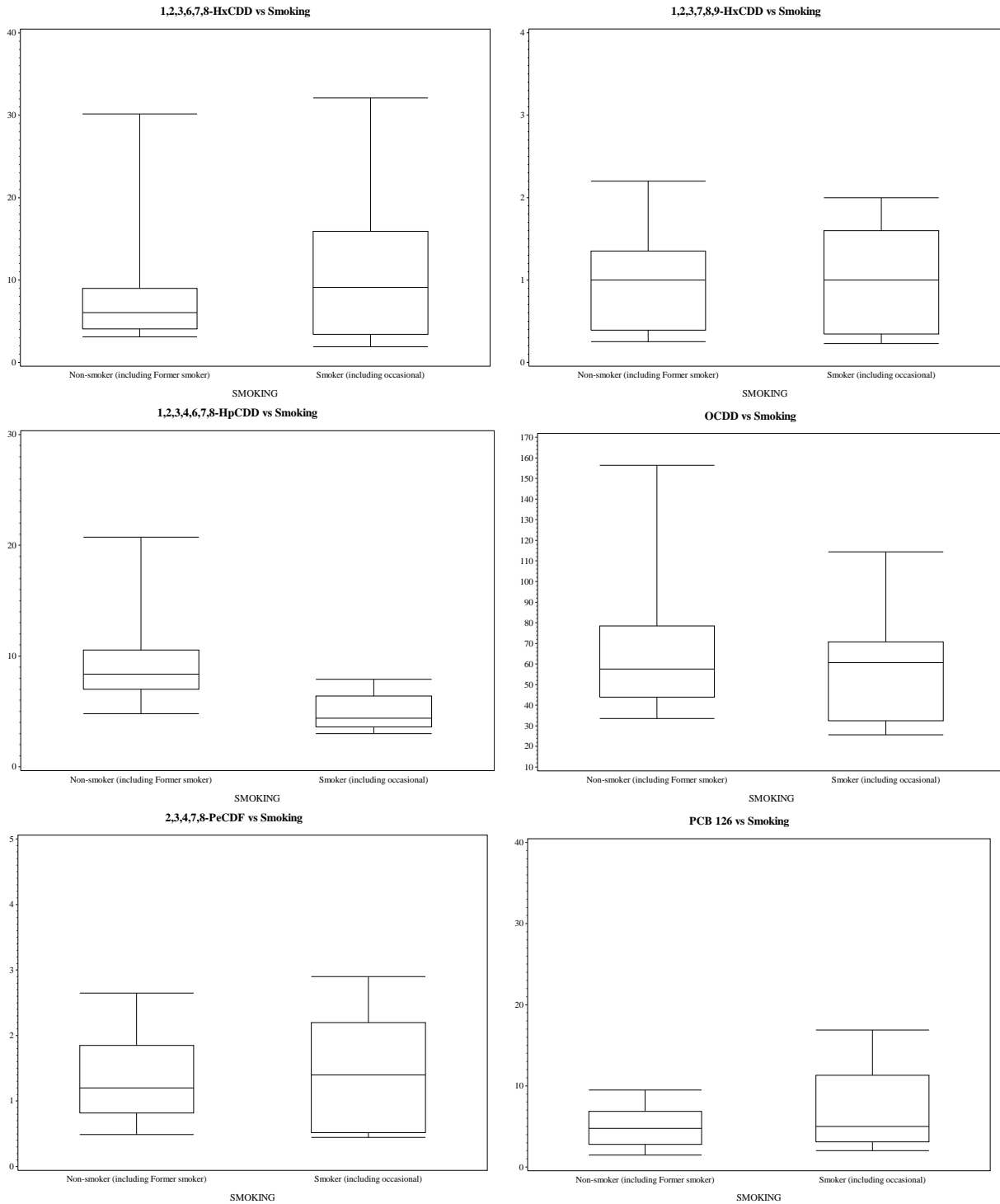


Figure 16: Boxplots for congeners with >60% detection stratified by sex. Whiskers represent the 5<sup>th</sup> and 95<sup>th</sup> percentiles.

# Appendix M: Boxplots for Dioxins and Dioxin-Like Congeners Stratified by Smoking Status



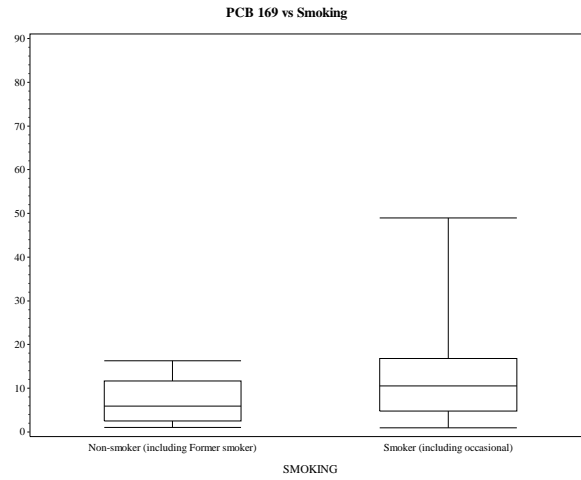
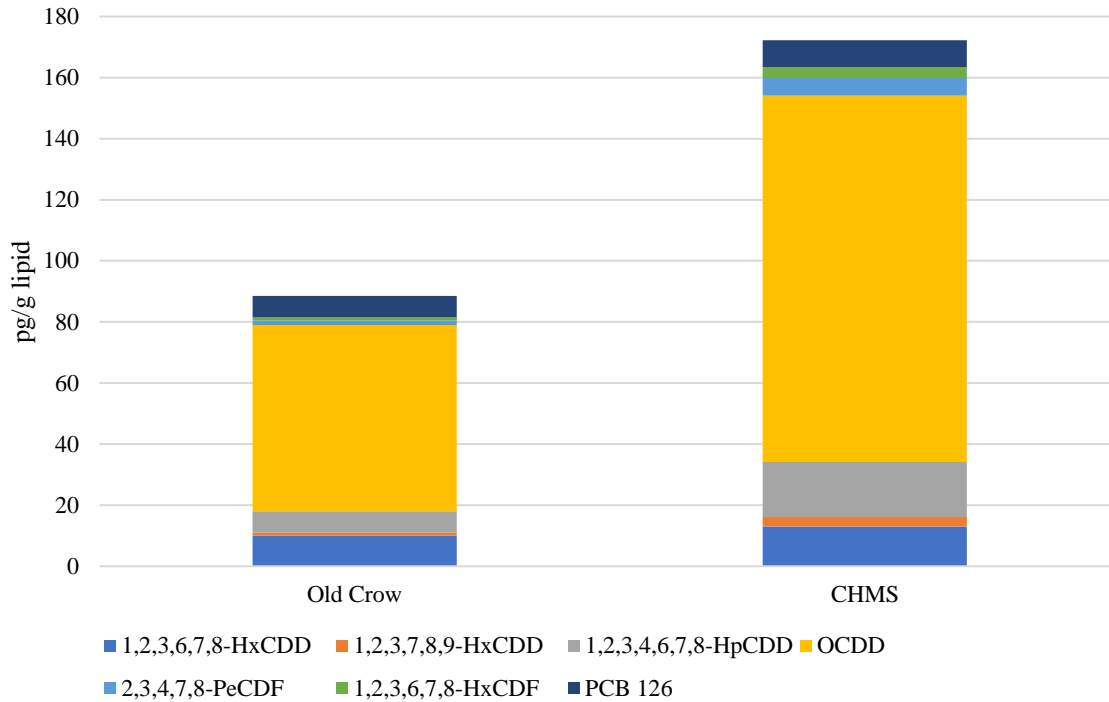


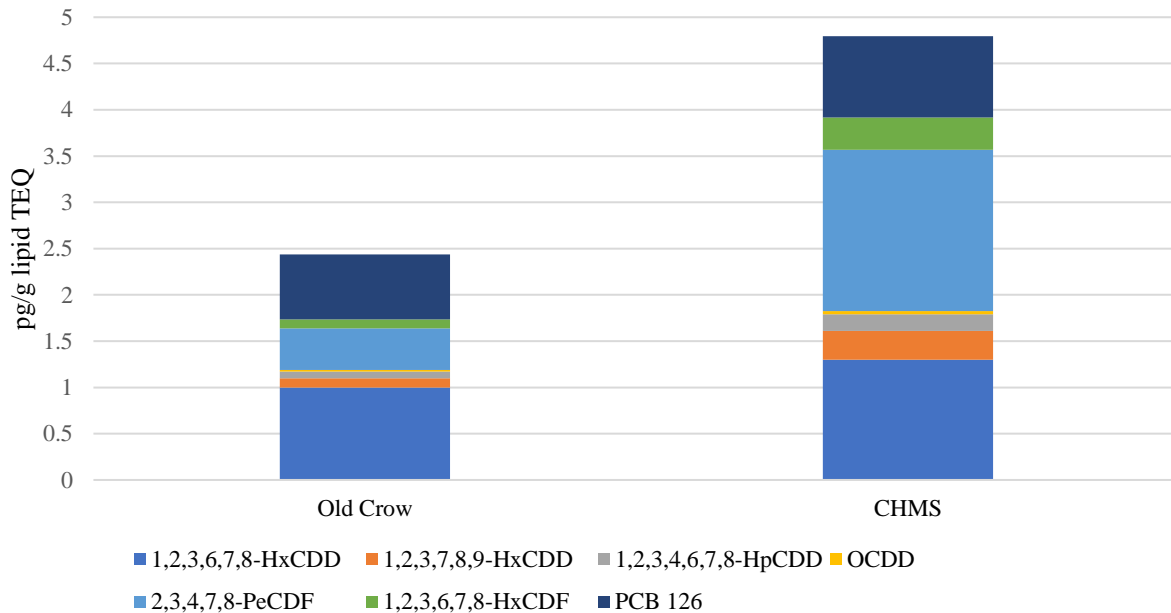
Figure 17: Biomarkers detected in >60% of study participants, organized by smoking status. Whiskers represent the 5<sup>th</sup> and 95<sup>th</sup> percentiles.

## Appendix N: Dioxins and Furans TEQ Stacked Bar Graph

AM Dioxins and DLC detected in >50% of samples from Old Crow (13 to 74 YoA) plasma relative to CHMS (6 to 79 YoA) levels in serum



AM Dioxins and DLC detected in >50% of samples from Old Crow (13 to 74 YoA) plasma relative to CHMS (6 to 79 YoA) levels in serum adjusted for toxicity equivalence



## Appendix O: Calculation of Limit of Detection for Lipids Weight Results

The concentration of total plasma lipids for each study participant was provided to INSPQ based on previous assessment of the lipid content from the original suite of analyses. The results received from INSPQ were presented as the concentration of the dioxin congeners in pg/g plasma and pg/g lipids. The LODs for the plasma results were measured with an analytical standard for each congener, while the lipids weight result LODs were determined mathematically.

The INSPQ pg/g lipids LOD calculation used an average blood lipid concentration (7.1 g lipids/L plasma) to calculate an average limit of detection for the samples. However, since this is not a precise method of calculation for the lipid-weight limit of detection, it appeared that some analytical detections occurred below the average limit of detection. To mitigate this, the individual limits of detection for each study participant, and ranges for each congener were calculated to preserve analytical precision and percent detection. Additionally, since ½ LOD substitution was used for the calculation of TEQ for each participant, it was important that the substitution be precise to the lipid concentration of each study participant. Plasma has an average mass density of  $1.035 \pm 0.003 \text{ g/cm}^3$  [198].

$$\text{Lipid LOD} \left( \frac{\text{pg}}{\text{g Lipid}} \right) = \text{LOD}_{\text{plasma}} * \frac{D}{P}$$

Where,

$D$  = The density of human plasma, 1035 g/L plasma, on average

$P$  = The study subject's total plasma lipids (g/L)

$\text{LOD}_{\text{serum}}$  = The serum limit of detection, analytically determined  $\left( \frac{\text{pg}}{\text{g lipid}} \right)$

**Appendix P: Determinant Groupings of Birds, Plants, Berries, Piscivorous Birds, Cranberries, and Blueberries.**

	<b>Old Crow</b>	<b>Dehcho Region</b>
<b>Birds</b>	spruce grouse, sharp-tailed grouse, ptarmigan, white-winged scoter, mallard, long tailed-duck, speck-belly goose, canvasback, Canada goose, or pintail <sup>a</sup>	spruce grouse, sharp-tailed grouse, ptarmigan, black duck, mallard, fish duck, long-tailed duck (oldsquaw), wigeon, canvasback, Canada goose, pintail, or swan
<b>Plants</b>	Labrador tea, wild peppermint, wild mushrooms, wild greens, wild onions, wild rhubarb, rat root, yarrow, juniper, willow (bark), alder (red willow) bark, spruce gum, spruce needles, or spruce bark	Labrador tea, wild peppermint, wild mushrooms, wild greens, wild onions, or wild rhubarb <sup>b</sup>
<b>Berries</b>	low (grey) blueberries, high (black) blueberries, low bush cranberries, high bush cranberries, crowberries, rosehips, wild raspberries, wild strawberries, salmonberries/cloudberries, red currants, black currants, or Saskatoon berries	low grey blueberries, high black blueberries, bog cranberries, high bush cranberry parts, green gooseberries, purple gooseberries, blackberries, wild raspberries, wild strawberries, cloudberries, red currants, black currants, Saskatoon berries, or rosehips
<b>Piscivorous birds</b>	mallard, long-tailed duck, canvasback, pintail, or white-winged scoter	black duck, mallard, fish duck/merganser, long-tailed duck (oldsquaw), canvasback, pintail, or white-winged scoter
<b>Any cranberry type</b>	low bush cranberries, or high bush cranberries	bog cranberries, or high bush cranberry parts
<b>Any blueberry type</b>	low (grey) blueberries, or high (black) blueberries	low grey blueberries, or high black blueberries

<sup>a</sup> Snow goose was surveyed, but no participants reported consumption.

<sup>b</sup> Dock was surveyed, but no participants reported consumption.

**Appendix Q: A summary of the regression coefficients measuring associations between the plasma biomarker Log<sub>10</sub> PFDA GLM compared to Log<sub>10</sub> PFDA censored in a Tobit model for study participants in the Dehcho Region.**

Determinant of Exposure <sup>a</sup>			<b>GLM PFDA</b>	<b>Tobit PFDA</b>
% Detected in Dehcho			87.60%	87.60%
	<b>n<sup>b</sup></b>		<b>Effect Estimate</b>	<b>Effect Estimate</b>
<i>Smoking (smoked cigarettes in the past 24 hours)</i>	44/109		-0.0420	0.0091
<i>Weight</i>	98/109		-0.0017	-0.0020
<i>Height</i>	100/109		0.36	0.15
<i>Body mass index</i>	98/109		-0.0056	-0.0058
<i>Moose</i>	<i>Meat smoked dried</i>	41/67	-0.071	-0.039
	<i>Ribs</i>	40/67	-0.11	-0.0022
	<i>Bone marrow</i>	37/67	-0.079	-0.010
	<i>Tongue</i>	33/67	-0.051	-0.017
	<i>Fat</i>	30/67	-0.13*	-0.12
	<i>Kidney</i>	30/67	-0.032	-0.033
	<i>Heart</i>	27/67	-0.055	-0.021
	<i>Bones in soup broth</i>	23/67	-0.0010	0.032
	<i>Head</i>	21/67	-0.096	-0.045
	<i>Liver</i>	22/67	-0.056	0.077
	<i>Intestine</i>	15/67	-0.10	-0.070
<i>Woodland Caribou</i>	<i>Meat cooked</i>	32/67	-0.13	-0.13*
	<i>Meat smoked</i>	18/67	-0.26***	-0.31***
<i>Land Animals</i>	<i>Rabbit meat</i>	41/67	-0.032	-0.028
	<i>Beaver meat</i>	32/67	-0.097	0.0085
	<i>Bison meat</i>	19/67	-0.021	-0.097
	<i>Beaver tail and feet</i>	19/67	-0.091	-0.055
<i>Fish</i>	<i>Whitefish meat smoked</i>	34/68	0.045	0.042
	<i>Whitefish fish pipe</i>	23/68	0.085	0.044
	<i>Northern pike meat</i>	37/68	0.023	0.015
	<i>Lake trout meat</i>	42/68	0.075	0.15**
	<i>Walleye meat</i>	36/68	-0.070	0.040
	<i>Whitefish eggs</i>	21/68	0.098	0.079
	<i>Inconnu meat</i>	21/68	-0.060	-0.078
	<i>Sucker meat</i>	16/68	0.053	-0.0028
<i>Birds</i>	<i>Birds</i>	52/67	0.032	0.090
	<i>Piscivorous birds</i>	44/67	0.0036	NA
	<i>Canada goose meat</i>	43/67	0.038	0.10
	<i>Mallard meat</i>	34/67	-0.087	-0.026
	<i>Spruce grouse meat</i>	23/67	0.031	0.013
	<i>Black duck meat</i>	22/67	0.019	0.014
	<i>Sharp-tailed grouse meat</i>	20/67	-0.0069	0.045
	<i>Swan meat</i>	50/67	0.078	-0.017
<i>Berries</i>	<i>Berries</i>	31/67	-0.097	-0.074
	<i>Any cranberry type</i>	35/67	-0.075	-0.022
	<i>Any blueberry type</i>	36/67	0.020	-0.12
	<i>Wild raspberries</i>	32/67	-0.11	-0.068
	<i>Wild strawberries</i>	28/67	-0.080	0.013
	<i>Saskatoon berries</i>	18/67	-0.030	-0.048
	<i>Low grey blueberries</i>	24/67	-0.068	-0.10
	<i>Bog cranberries</i>	20/67	0.018	0.010
	<i>High bush cranberry parts</i>	15/67	-0.027	-0.072
	<i>High black blueberries</i>	32/67	-0.061	-0.045

	<i>Plants</i>	23/67	-0.016	0.016
<i>Plants</i>	<i>Spruce gum</i>	23/67	-0.041	-0.062
	<i>Rat root</i>	20/67	-0.068	-0.033
	<i>Labrador tea</i>	41/67	0.011	-0.0057

n: The number of study participants; NA:

\*p<0.10

\*\*p<0.05

\*\*\*p<0.01

<sup>a</sup> Foods eaten by <15% of the sample group, and foods that had bin sizes smaller than n=5 were excluded from the analysis to maintain adequate sample size for model development unless specified otherwise.

<sup>b</sup> Presented as the number of study participants who consumed the traditional food indicated over the total number of participants who had biomarker data and food frequency data for the indicated determinant.

## Appendix R: A Heat Map of Traditional Food Consumption Patterns

Non-parametric chi-square testing was conducted to assess foods that were commonly consumed by the same FFQ respondents. For example, those who consumed moose liver were compared to those who consumed Labrador tea in Old Crow. No association was observed between those who consumed these foods, and it can be concluded that these variables are independent.

Figure 18 hyperlinks to a summary file of chi-square correlation statistics. Results that are dark green indicate foods that are commonly eaten by the same study participants, while orange and yellow indicate weaker associations. Foods that are dark green may be confounders or effect mediators in corresponding regression models.



Chi Square Test of  
Associations.xlsx

*Figure 18: Chi-square Associations between foods consumed by 15% or more of the FFQ participants.*

## Appendix S: Code Samples

```
1  OPTIONS NONUMBER NODATE FORMDLIM='~' LINESIZE=120;
2  %LET mydir=\\ahs-sas-appserv\sasusers$\aksimpso\Dioxin Data;
3  LIBNAME outlib "&mydir";
4  TITLE;
5
6  PROC IMPORT DATAFILE="&mydir\Dioxins and FFQ.csv" OUT=DioxinData REPLACE;
7  RUN;
8
9  DATA DioxinData;
10 SET DioxinData;
11 log_123678_HxCDD = log10(_123678_HxCDD);
12 log_123789_HxCDD = log10(_123789_HxCDD);
13 log_1234678_HpCDD = log10(_1234678_HpCDD);
14 log_OCDD = log10(OCDD);
15 log_23478_PeCDF = log10(_23478_PeCDF);
16 log_123678_HxCDF = log10(_123678_HxCDF);
17 log_PCB126 = log10(PCB126);
18 log_PCB169 = log10(PCB169);
19 log_TotalDioxins = log10(TotalDioxins);
20 log_TotalFurans = log10(TotalFurans);
21 log_TotalDioxinsAndFurans = log10(TotalDioxinsAndFurans);
22
23 LABEL
24 log_123678_HxCDD = "Log10(1,2,3,6,7,8-HxCDD)"
25 log_123789_HxCDD = "Log10(1,2,3,7,8,9-HxCDD)"
26 log_1234678_HpCDD = "Log10(1,2,3,4,6,7,8-HpCDD)"
27 log_OCDD = "Log10(OCDD)"
28 log_23478_PeCDF = "Log10(2,3,4,7,8-PeCDF)"
29 log_123678_HxCDF = "Log10(1,2,3,6,7,8-HxCDF)"
30 log_PCB126 = "Log10(PCB126)"
31 log_PCB169 = "Log10(PCB169)"
32 log_TotalDioxins = "Log10(TotalDioxins)"
33 log_TotalFurans = "Log10(TotalFurans)"
34 log_TotalDioxinsAndFurans = "Log10(TotalDioxinsAndFurans)";
35 RUN;
36
37 PROC FORMAT;
38 VALUE $SEXfmt
39 'F' = 'Female'
40 'M' = 'Male (REF)';
41 VALUE BMICATfmt
42 0 = 'Normal Weight (REF)'
43 1 = 'Over weight'
44 2 = 'Obese';
45 VALUE Occupationfmt
46 0 = 'General Occupation (REF)'
47 1 = 'Occupation with Risk';
48 VALUE RAWWATERfmt
49 0 = "Did not consume raw water (REF)"
50 1 = "Consumed raw water";
51 VALUE FIREPLACEfmt
52 0 = "No fireplace in home (REF)"
53 1 = "Fireplace in home";
```

```

326 /*Analysis*/
327 PROC ANOVA DATA=DioxinData;
328     CLASS SEX (REF='Male (REF)');
329     MODEL OCDD = SEX;
330     MEANS SEX/tukey;
331 RUN; QUIT;
332 PROC FREQ DATA= DioxinData;
333     TABLE OCDD SEX;
334 RUN;
335 ODS Graphics ON;
336 /*HGT*/
337 PROC GLM DATA=DioxinData ALPHA=0.05;
338     TITLE "Log (10) OCDD (pg/g lipid) vs AGE SEX and HGT";
339     CLASS Sex (REF='Male (REF)');
340     MODEL log_OCDD = AGE SEX HGT / SOLUTION CLPARM;
341 RUN; QUIT;
342
343 /*WT*/
344 PROC GLM DATA=DioxinData ALPHA=0.05;
345     TITLE "Log (10) OCDD (pg/g lipid) vs AGE SEX and WT";
346     CLASS Sex (REF='Male (REF)');
347     MODEL log_OCDD = AGE SEX WT / SOLUTION CLPARM;
348 RUN; QUIT;
349
350 /*BMI*/
351 PROC GLM DATA=DioxinData ALPHA=0.05;
352     TITLE "Log (10) OCDD (pg/g lipid) vs AGE SEX and BMI";
353     CLASS Sex (REF='Male (REF)');
354     MODEL log_OCDD = AGE SEX BMI / SOLUTION CLPARM;
355 RUN; QUIT;
356
357 /*OCCUPATION*/
358 PROC GLM DATA=DioxinData ALPHA=0.05;
359     TITLE "Log (10) OCDD (pg/g lipid) vs AGE SEX and OCCUPATION ";
360     CLASS SEX (REF='Male (REF)');
361     CLASS OCCUPATION (REF='General Occupation (REF)');
362     MODEL Log_OCDD = AGE SEX OCCUPATION / SOLUTION CLPARM;
363 RUN; QUIT;
364
365 /*RAWWATER*/
366 PROC GLM DATA=DioxinData ALPHA=0.05;
367     TITLE "Log (10) OCDD (pg/g lipid) vs AGE SEX and RAWWATER ";
368     CLASS SEX (REF='Male (REF)');
369     CLASS RAWWATER (REF='Did not consume raw water (REF)');
370     MODEL log_OCDD = AGE SEX RAWWATER / SOLUTION CLPARM;
371 RUN; QUIT;

```

Figure 19: Sample code for general linear models that were used to assess associations between traditional foods and contaminant exposures.

## Appendix T: Letter for Returning Dioxin Results

February 2023

To: Jane Doe



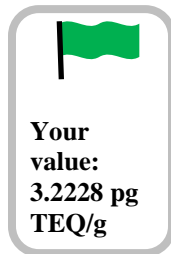
### Subject: Additional Results from the Old Crow Biomonitoring Project

In 2019, you agreed to participate in a human biomonitoring project led by Dr. Brian Laird funded by the Northern Contaminants Program. This research project studied people's exposures to contaminants by measuring levels of contaminants and nutrients in samples of hair, blood, and urine. You received the main results of the project in a previous letter. When you decided to take part in the project, you agreed that we could keep your biological sample(s) in a biobank for future analysis of contaminants and nutrition markers, if we got the funding to do so. In this letter you will find your additional results.

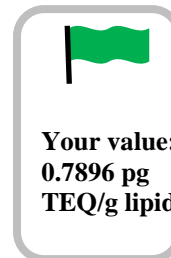
To learn more about people's exposures to contaminants in Old Crow, we measured dioxins, furans, and dioxin-like PCBs, in the biobanked blood samples. Dioxins, furans, and dioxin-like PCBs are human made contaminants that come from industrial activity and burning. Dioxins are not made on purpose. Some of these contaminants are more potent than others, with TCDD being one of the most potent. Most other contaminants in this report are not nearly as potent. People can be exposed to dioxins, furans, and dioxin-like PCBs by eating contaminated foods. These contaminants can build up in fatty meats and animal products. Exposure to these contaminants can be measured by adding them in a way that accounts for their different potencies.

#### Results Preview

##### DIOXINS



##### FURANS



These results mean that overall, your levels were lower than the Canadian national average.

Even though these contaminants may be found in traditional foods, **the benefits of eating traditional foods often outweigh the risks posed by these exposures.**

**The rest of your results can be found in this letter.**

In this letter, you will find your results. Currently, there are no Canadian health guidelines for dioxins, furans, and dioxin-like PCBs. Instead, your results were compared to the Canadian national average for 2016 to 2017. The colour code on page 3 explains what these results mean. If you want to lower your levels of these contaminants, we offer more information on the last page of this letter. For more information about understanding these levels see page 6.

The research team and I are available to discuss the results of the project to-date, answer your questions, and listen to your concerns. As the project continues, we will be able to provide more information on the exposure levels of people living in Old Crow. If we receive any additional information about your samples, we will provide another letter with those results too. We recommend keeping this letter in a safe place for potential future monitoring. This letter does not replace regular visits to your doctor or health care professional.

If you have any questions or comments, we will be pleased to talk with you. If you would like to opt out of updates or the research project, please contact me. Thank you very much for your participation in this project.

To follow the project:

Facebook: [BiomonitoringNorth](#)

Twitter: [NTBiomonitoring](#)



Regards,

Brian Laird

Principal Investigator

## Colour Indicators

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

<b>What do my results mean?</b>	
	Your results were higher than the Canadian national average.
	Your results were about the same or lower than the Canadian national average. There are no known health risks at this exposure level.
NA	Very little is known about this contaminant. The Canadian national average is not known. There are no health guidelines available.

<b>YOUR RESULTS</b>				
<b>Compound</b>	<b>Your blood results (pg/g of lipid)</b>	<b>All participants of Old Crow project (pg/g of lipid)</b>	<b>Canadian national average<sup>a</sup> (pg/g of lipid)</b>	<b>How your results compare to the Canadian average (higher or lower)</b>
<b>DIOXINS</b>				
2,3,7,8-TCDD	<LOD	NR	NR	NA
1,2,3,7,8-PeCDD	1.1234	NR	NR	NA
1,2,3,4,7,8-HxCDD	1.5678	NR	2.6	↓
1,2,3,6,7,8-HxCDD	11.0910	10.4761	13	↓
1,2,3,7,8,9-HxCDD	1.1112	1.0341	3.1	↓
1,2,3,4,6,7,8-HpCDD	16.1314	7.0190	18	↓
1,2,3,4,6,7,8,9-OCDD	107.1516	60.9480	120	↓
<b>FURANS</b>				
2,3,7,8-TCDF	<LOD	NR	1.1	NA
1,2,3,7,8-PeCDF	<LOD	NR	NR	NA
2,3,4,7,8-PeCDF	1.1718	1.4961	5.8	↓
1,2,3,4,7,8-HxCDF	1.1920	NR	3.5	↓
1,2,3,6,7,8-HxCDF	1.2122	0.9725	3.5	↓
1,2,3,7,8,9-HxCDF	<LOD	NR	NR	NA
2,3,4,6,7,8-HxCDF	<LOD	NR	1.8	NA
1,2,3,4,6,7,8-HpCDF	1.2324	NR	5.4	↓
1,2,3,4,7,8,9-HpCDF	<LOD	NR	NR	NA
1,2,3,4,6,7,8,9-OCDF	<LOD	NR	NR	NA
<b>DIOXIN-LIKE PCBs</b>				
PCB 77	<LOD	NR	14	NA
PCB 81	0.2526	NR	NR	NA
PCB 126	14.2728	7.0297	8.8	↑
PCB 169	16.2930	13.6413	NR	NA

<b>DIOXINS &amp; FURANS WEIGHTED TOTALS</b>				
<b>Compound</b>	<b>Your blood results (pg TEQ/g of lipid)</b>	<b>Participants of Old Crow Project (pg TEQ/g of lipid)</b>	<b>Canadian National Average<sup>a</sup> (pg TEQ/g lipid)</b>	<b>How your results compare to Canadian average (higher or lower)</b>
Total dioxins	3.2228	2.7845	4.7	↓
Total furans	0.7896	0.7956	2.9	↓
Total dioxins and furans	4.1897	3.5625	7.5	↓

<sup>a</sup> From the Report in Human Biomonitoring of Environmental Chemicals in Pooled Samples Cycle 5 (2016-2017) for both sexes 6-79 years of age (HC, 2019). Note: The CHMS did not report data (NR) for arithmetic mean if >40% of samples were below the limit of detection.

<LOD = Level very low so it was not detected by the machine.

NR = Not reported. The detection rate was below 50% or was too unreliable to report.

NA = Not applicable. Either your result was not detected by the machine or CHMS did not report data.

### **If you would like to lower your levels**

Some of your contaminant levels may have been higher than what is typical for Canadians. *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 dioxins, furans, and dioxin-like PCBs:

- **Eat a variety of foods from traditional and store-bought sources.**
  - Vegetables, fruits, and grains have fewer of these contaminants than meat, milk products, and fish.
  - Traditional foods have many good nutrients.
- Avoid open burning of garbage, especially construction materials that may contain wood preservatives or plastic.
- Reduce your exposure to tobacco smoke (from smoking and second-hand smoke).
- Learn about wood burning techniques that release fewer dioxins. For more information see: <https://www.lung.ca/news/advocacy-tools/our-position-statements/residential-wood-burning>

### **Additional information**

- 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 answer common questions about contaminants. <https://wwwn.cdc.gov/TSP/ToxFAQs/ToxFAQsDetails.aspx?faqid=363&toxid=63>  
<https://wwwn.cdc.gov/TSP/ToxFAQs/ToxFAQsDetails.aspx?faqid=937&toxid=194>
- Since Health Canada has not made health guidelines for these contaminants it is 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. Even though these contaminants may be found in traditional foods, **the benefits of eating traditional foods often outweigh the risks posed by these exposures.**



# Appendix V: Community Communication Materials for Results of Determinants Analysis



2023



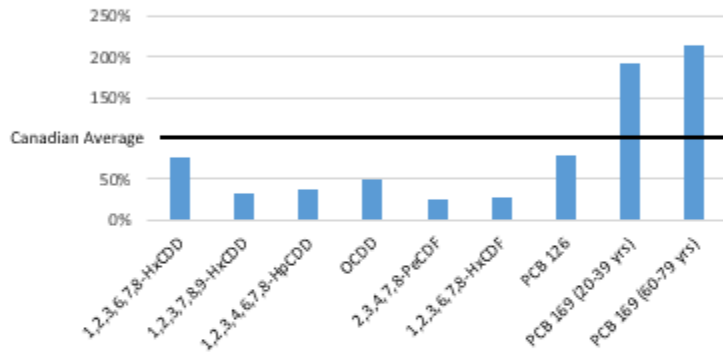
## Factors Linked with Dioxin Biomonitoring Results in Old Crow

### THE PROJECT:

Human biomonitoring studies were held in communities in the Dehcho and Sahtú regions (Northwest Territories), and Old Crow (Yukon) in 2016-2019. The levels of dioxins were measured in blood from volunteer participants only in Old Crow. Participants also shared information on the traditional foods they had eaten in the past year.

**What are dioxins?**  
 Dioxins are toxic chemicals that mostly come from industrial processes and burning. Dioxins can build up in the environment because they do not break-down easily. This means they can also build up in food chains and people.

Dioxin Levels in Old Crow, YT



**How are people exposed to dioxins?**  
 Most people are mainly exposed to dioxins is through animal-based foods (e.g. meat, milk, cheese). Dioxins can travel long distances through the atmosphere. When they cool over Arctic areas they can come out of the air and may contaminate lands and traditional foods.  
 Working in some jobs (e.g., waste disposal, oil and gas, firefighting) are sometimes linked with higher dioxins in blood.  
 Local burning may also contribute to differences in dioxin levels.

- Health effects are not expected at these levels.
- The levels of dioxins in blood in Old Crow were generally lower than the usual range seen in southern parts of Canada.
- The levels of PCB 169 appeared to be higher in those 20 to 39 and 60 to 79 years old in comparison to the Canadian average. There was no Canadian average comparison information on people who were 40 to 59 years old, or on average across all age groups.



WHAT WAS RESEARCHED	WHAT WAS DONE	WHAT THIS MEANS
Based on information about dioxins and Old Crow, we investigated factors that could have contributed to these levels.	We compared participants' levels of <u>dioxins</u> with their answers to questions on which <u>traditional foods</u> they ate over the past year.  We also compared peoples' dioxin levels to their <u>age, sex, body mass index and smoking status</u> .	These results tell us if people who eat a specific <u>traditional food</u> have either <u>higher or lower levels</u> of <u>dioxins</u> than those who didn't eat that food.



## KEY RESULTS AND MESSAGES

### Were some lifestyles or demographics linked to dioxin levels?



People who reported working specific jobs (gardening, farming, automobile repair, waste disposal, recycling, oil and gas, laboratory research, chemicals production, or firefighting) had higher levels of 1,2,3,7,8,9-HxCDD and PCB 169. It is known that some of these occupations can contribute to higher dioxin levels in blood.



As age increased, the levels of 2,3,4,7,8-PeCDF, 1,2,3,6,7,8-HxCDD, PCB 126, and PCB 169 in peoples' blood also increased. This is typical for these chemicals.



People who smoked had significantly lower levels of 1,2,3,4,6,7,8-HpCDD. But, smokers in other northern regions had higher levels of several other contaminants, like lead, cadmium, and cancer-causing chemicals called PAHs. Quitting cigarette smoking lowers your exposure to many contaminants.

### Were traditional foods linked to dioxin levels?



Eating moose ribs was linked to higher levels of OCDD and PCB 169 in blood. Moose meat is an excellent source of protein, iron, and other nutrients.



Participants who ate waterfowl that eat fish (like canvasback and fish duck) had higher levels of 1,2,3,6,7,8-HxCDD and PCB 126 in blood. Waterfowl are rich in iron, omega-3s, and other nutrients.



Eating coho salmon was linked with higher levels of 1,2,3,6,7,8-HxCDD, PCB 126, and 2,3,4,7,8-PeCDF in blood. Fish are excellent sources of many nutrients, including Vitamin D, protein, and omega-3s.



Eating highbush or lowbush cranberries was linked with higher levels of 1,2,3,4,6,7,8-HpCDD, and PCB 126 in blood. Berries are a good source of fibre and many vitamins.



Eating caribou stomach was linked with lower levels of 1,2,3,7,8,9-HxCDD, and 1,2,3,6,7,8-HxCDD in blood. Caribou meat and stomach are an excellent source of protein, iron, and Vitamin A.

**The results from this study reinforce the message that the health benefits of traditional foods generally outweigh contaminant risks.**

- Harvesting, sharing, preparing, and consuming traditional foods have positive effects on mental health, socialization, and spiritual health.
- Finding links between participant dioxin blood levels and the foods people ate cannot prove which foods contributed most to dioxin blood levels in Old Crow. But knowing these links can help inform community decisions on future environmental monitoring.
- Next steps could include gathering local environmental data on dioxins and linking this information with the foods people reported eating.

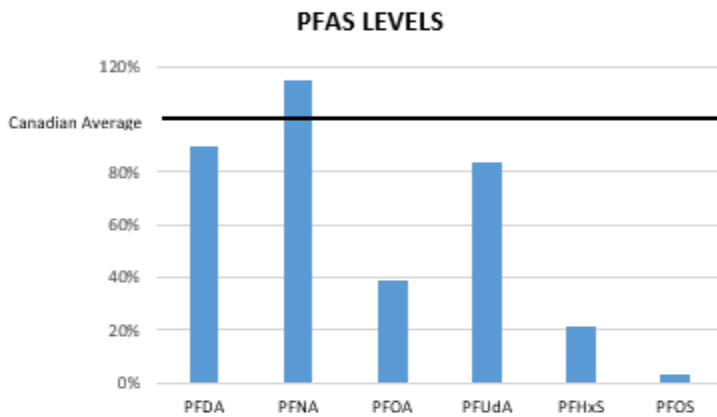
#### Questions/comments?

Please contact Dr. Brian Laird, University of Waterloo:

## Factors Linked with PFAS Biomonitoring Results in Old Crow

### THE PROJECT:

Human biomonitoring studies were held in communities in the Dehcho and Sahtú regions (Northwest Territories) and Old Crow (Yukon) in 2016-2019. The levels of PFAS were measured in blood from volunteer participants in Old Crow and the Dehcho region. Participants also shared information on the traditional foods they had eaten in the past year.



- The levels of PFAS in blood in Old Crow were generally lower, or about the same as the usual range seen in southern parts of Canada.
- PFOA and PFOS levels in residents were lower than the national average and First Nations across the provinces.
- PFNA levels were higher compared to the averages for Canadians and First Nations across the provinces.
- Similar levels were observed in the Dehcho Region.

**What are PFAS?**

PFAS are toxic chemicals. PFAS mostly come from firefighting foams or consumer products, like carpet, raincoats, or non-stick pans. PFAS can build up in the environment because they do not break-down easily. This means they can also build up in the food chain and people.

**How are people exposed to PFAS?**

Most people are exposed through the water they drink and food they eat. PFAS are sometimes in food packaging. Some jobs, such as firefighters or mechanics, can also result in higher exposures. Sometimes there are environmental hot spots for contamination. These are commonly airports and



WHAT WAS RESEARCHED	WHAT WAS DONE	WHAT THIS MEANS
Based on information about PFAS and Old Crow, we investigated factors that could have contributed to these levels.	We compared participants' levels of PFAS with their answers to questions on which traditional foods they ate over the past year.  We also compared their PFAS levels to their age, sex, body mass index and smoking status.	These results tell us if people who ate a specific traditional food have either higher or lower levels of PFAS than those who didn't eat that food.

## KEY RESULTS AND MESSAGES

- For many traditional foods in Old Crow, there was no clear link between PFAS blood levels and traditional foods.
- In the Dehcho Region, NWT, eating many different traditional foods (e.g. caribou, moose fat and moose head and others) were generally linked with lower PFAS in blood.

### Were traditional foods linked to higher PFAS levels in Old Crow?



Eating moose ribs, heart, and tongue were linked to higher levels of PFNA in blood. Moose meat is an excellent source of protein, iron, and other nutrients



Eating ptarmigan was linked to higher levels of PFHxS in blood. Ptarmigans are an excellent source of protein, iron, and niacin (Vitamin B3).

### Were traditional foods linked to lower PFAS levels in Old Crow?



Eating salmonberries/cloudberries were linked with lower levels of PFOS and PFHxS in blood. Berries are a good source of fibre and many vitamins.



Eating Arctic grayling was linked with lower levels of PFNA and PFOA in blood. Arctic grayling are excellent sources of protein, magnesium, and selenium.

**The results from this study reinforce the message that the health benefits of traditional foods generally outweigh contaminant risks.**

- Harvesting, sharing, preparing, and consuming traditional foods have positive effects on mental health, socialization, and spiritual health.
- Finding links between participant PFAS levels and the foods people ate cannot prove which foods contributed most to PFAS blood levels in Old Crow. But knowing these links can help inform community decisions on future environmental monitoring.
- Based on the information from both regions, we think that traditional foods are not a likely source of PFAS, and that they may be coming from packaged or processed foods. More research would be helpful to identify the sources.
- Next steps could include gathering local environmental data on PFAS and linking this information with the foods people reported eating.

#### Questions/comments?

Please contact Dr. Brian Laird, University of Waterloo

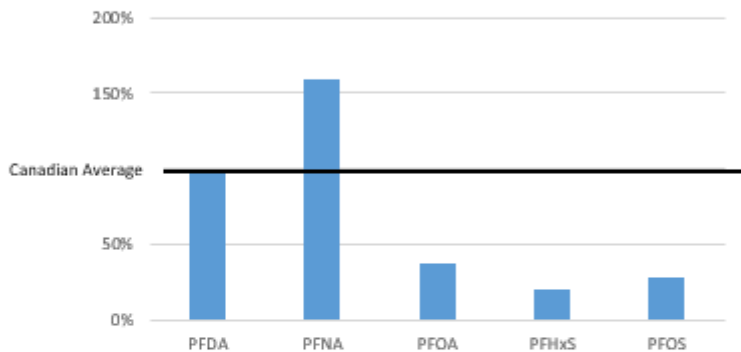


## Factors Linked with PFAS Biomonitoring Results in the Dehcho Region

### THE PROJECT:

Human biomonitoring studies were held in communities in the Dehcho and Sahtú regions (Northwest Territories) and Old Crow (Yukon) in 2016-2019. The levels of PFAS were measured in blood from volunteer participants in Old Crow and the Dehcho region. Participants also shared information on the traditional foods they had eaten in the past year.

PFAS LEVELS



- PFOA and PFOS were lower than the national average and First Nations across the provinces.
- The levels of PFAS in blood in the Dehcho region were generally lower or about the same as the usual range seen in southern parts of Canada.
- PFNA levels in residents of Old Crow and the Dehcho region were higher compared to the Canadian average and other First Nations across the provinces.
- Similar levels were observed in Old Crow, Yukon.

**What are PFAS?**

PFAS are toxic chemicals. PFAS mostly come from firefighting foams or consumer products, like carpet, raincoats, or non-stick pans. PFAS can build up in the environment because they do not break-down easily. This means they can also build up in the food chain and people.

**How are people exposed to PFAS?**

Most people are exposed through the water they drink and the food they eat. PFAS are sometimes in food packaging. Some jobs, such as firefighters or mechanics, can also result in higher exposures. Sometimes there are environmental hot spots for contamination. These are commonly airports and dumps.



WHAT WAS RESEARCHED	WHAT WAS DONE	WHAT THIS MEANS
Based on information about PFAS and the Dehcho Region, we investigated factors that could have contributed to these levels.	We compared participants' levels of PFAS with their answers to questions on which traditional foods they ate over the past year. We also compared their PFAS levels to their age, sex, body mass index and smoking status.	These results tell us if people who eat a specific traditional food have either higher or lower levels of PFAS than those who didn't eat that food.

## KEY RESULTS AND MESSAGES

### Were any demographics linked to PFAS levels?



Taller people appeared to have higher levels of PFOA, PFOS, and PFHxS in blood.



People with a higher weight-to-height ratio (body mass index) had lower levels of PFOA and PFHxS in their blood.

Other researchers have not reported these links. These patterns might come from other factors that are related to height and/or weight.

### Were traditional foods linked to higher PFAS levels in the Dehcho Region?



Eating whitefish eggs were linked with higher levels of PFNA in blood. Fish eggs are an excellent source of protein.



Eating lake trout was linked with higher levels of PFOS and PFDA in blood. Fish are excellent sources of many nutrients, including Vitamin D, protein, and omega-3s.



Eating Canada goose meat was linked with higher levels of PFNA in blood. Goose meat is an excellent source of protein, iron, omega-3s, and vitamins.

### Were traditional foods linked to lower PFAS levels in the Dehcho Region?



Eating moose fat and moose head were linked with lower levels of PFOA, PFOS, and PFHxS in blood. Moose are an excellent source of protein and iron.



Eating smoked woodland caribou meat was linked with lower levels of PFNA, PFOA, PFOS, and PFDA in blood. Caribou are an excellent source of protein and iron.



Eating moose intestine, rabbit meat, beaver meat, beaver tail and feet, inconnu meat, Canada goose meat, mallard meat, and blueberries were linked with lower levels of PFOA in blood. These foods are excellent sources of many nutrients.

**The results from this study reinforce the message that the health benefits of traditional foods generally outweigh contaminant risks.**

- Harvesting, sharing, preparing, and consuming traditional foods have positive effects on mental health, socialization, and spiritual health.
- Finding links between participant PFAS levels and the foods people ate cannot prove which foods contributed most to PFAS exposures in the Dehcho region. But knowing these links can help inform community decisions on future environmental monitoring.
- Based on the information from both regions, there were many more traditional foods that were linked with lower levels of PFAS. This indicates that these chemicals may be coming from packaged or processed foods. More research would be helpful to identify the sources.
- Next steps could include gathering local environmental data on PFAS and linking this information with the foods people reported eating.

#### Questions/comments?

Please contact Dr. Brian Laird, University of Waterloo