Abandoned Mid-Canada Radar Line Site 500 in the Western Hudson Bay region of sub-Arctic, Canada: A source of organochlorines for the people of Weenusk First Nation?

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Author's declaration for electronic submission of a thesis

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Abstract

Interest in the presence of environmental contaminants in the Canadian arctic and sub-arctic arises in part over concerns that Aboriginal people residing in these regions continue to rely on subsistence harvesting. Organochlorines (OCs) are a type of persistent organic pollutant (POP) that have a unique chlorine-carbon bond; this bond facilitates their unprecedented environmental longevity, lipophilicity and hydrophobic nature. OCs have been found in both the biotic and non-biotic compartments of northern ecosystems.

This study examined patterns of differences with respect to body burden of organochlorines (lipid-adjusted) between the residents of the Ontario First Nations of Fort Albany (the site of MCRL Site 050), Kashechewan (no radar site), and Peawanuck (the site of MCRL 500) to assess whether geo-proximity to abandoned radar sites influenced organochlorine body burden with respect to the people of Fort Albany and Peawanuck.

Correspondence analysis (CA-1) revealed people from Fort Albany had relatively higher pesticide concentrations (β-HCH and DDT, but not Mirex) and relatively lower CB (156 and 170) body burdens when compared to participants from Kashechewan and Peawanuck. CA- 2 revealed Peawanuck residents had relatively higher concentrations of CB180, DDE and hexachlorobenzene and relatively lower levels of DDT and mirex compared to participants from Kashechewan and Fort Albany. Results are suggestive but not conclusive that MCRL Site 500 may have influenced body burdens of Peawanuck residents.

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Chapter 1.0 Introduction

1.1. Background

Interest in the presence of environmental contaminants in the Canadian arctic and sub-arctic arises in part over concerns that Aboriginal (Inuit, First Nations and Metis) people residing in these regions continue to rely on subsistence harvesting (Evans et al. 2005). Since the early 20th century, persistent organic pollutants (POPs) have been used ubiquitously for a multitude of purposes ranging from agricultural to manufacturing processes (Dallaire et al. 2004). Organochlorines (OCs) are a type of POP and are a family of compounds that contain carbon, chlorine, and hydrogen atoms (Macdonald et al. 2000). All OCs are synthetic and it is for this reason why biological degradation processes struggle to compromise the chlorine-carbon bonds; thus, giving them their unprecedented environmental longevity (Braune et al. 2005). In addition, OCs are highly insoluble in water and have a high affinity to fatty molecules which allows them to bond to lipid substances (e.g., adipose tissue, cell membranes) of organisms that are exposed to them (Dallaire et al. 2004). This family of compounds includes chlorinated pesticides (e.g., dichlorodiphenyltrichloroethane [DDT], mirex, and *trans*-nonachlor) and industrial compounds (e.g., hexachlorobenzene [HCB] and polychlorinated biphenyls [PCBs]; Dallaire et al. 2004).

Organochlorine contamination has recently been documented at Mid Canada Radar Line (MCRL) stations located throughout the Canadian sub-arctic (ESG 1999a). These abandoned military radar bases were constructed in the mid-1950s to serve as advanced warning stations for impending nuclear threats from Russia (Huebert 2000). After seven years of operation, the radar stations were closed and improperly decommissioned (Thorne 2003; ESG 1999a). The presence of contaminants in the subsistence environments of First Nations people is a subject of critical concern. The present study examined OCs in human plasma of First Nations people residing in the Hudson Bay region of northern Ontario, Canada, in an attempt, to elucidate the relationship between human OC body burden and proximity to abandoned MCRL sites. In this first chapter, I will give a brief review of OCs in the context of contamination of MCRL sites in Ontario. The second chapter of this thesis will describe my actual project; while, the third chapter will offer recommendations for future endeavours.

1.2. Ecosystem Approach to Health

The ecosystem approach to health is the guiding theoretical framework driving this study, as it recognizes the important links between human health and the biophysical, social, and economic environments (Lebel 2003). This approach to human health recognizes the importance of positive action toward the environment through sustainable economic and social behaviour, which will in turn, improve the communal well-being and health of the ecosystem (Lebel 2003).

Assumptions of the ecosystem approach to health suggest all systems and sub-systems of the ecosystem and/or biosphere are interrelated, intertwined, and more importantly, are not mutually exclusive of one another (Rapport and Mergler 2004). Moreover, this approach argues that all trophic levels or networks of the ecosystem are interconnected in ways that allows for each individual or environmental variable to influence other individuals regardless of their respective trophic level (Lebel 2003). The key recognition of this framework suggests that the increasing imbalances of the ecosystems are producing situations of increasing human vulnerability to disease, such as, malaria, cholera, dengue fever and many others (Rapport and Mergler 2004). Furthermore, the build up of toxic substances from sources, such as agricultural pesticides and environmental contaminants (e.g., industrial processes, mining sites, etc.) are commencing the slow alteration of physiological and psychological functions amongst the human populace (Rapport and Mergler 2004). These toxic substances are transmitted via complex pathways (e.g., soil, air, and water) and are commonly passed from mother to fetus during embryological development and breast-feeding as well as during lifestyle pursuits (i.e., the traditional diet), resulting in significant human health complications (Rapport and Mergler 2004).

The premise of this framework assumes that the strategy for maintaining healthy human populations can be accomplished through the rehabilitation of compromised ecosystems

(Rapport and Mergler 2004). The ecosystem approach attempts to identify and assess the determinants of a healthy ecosystem as well as the health of the populace inhabiting the specific ecosystem (Forget and Lebel 2001).

1.3. OCs

Organochlorines include a wide array of industrial compounds and pesticides that are chemically persistent and semi-volatile (Macdonald et al. 2000). Because of their low cost and generic efficacy, OCs have been in use throughout a large part of the globe since the 1950s through to the present (Macdonald et al. 2000). Although banned in many parts of the world, OCs continue to be used predominantly as pesticides and dielectrics and hydraulic fluid in developing regions of the world (Macdonald et al. 2000). Though OCs are diverse in their chemical structure, they all share common characteristics, such as, low water solubilities, high lipophilicity (affinity to fatty molecules) and resistance to biodegradation (AMAP 1998; Braune et al. 2005). These combined traits facilitate their uptake and accumulation in fatty tissues of living organisms (AMAP 2002). Organochlorines used as pesticides were typically toxic to non-target organisms as well as the targeted pest (AMAP 1998). Examples of such pesticides are DDT, hexachlorocyclohexanes (HCHs), chlordanes, aldrin, mirex, toxaphene, and HCB (AMAP 1998). Since OCs have relatively high vapour pressures, this characteristic allows these compounds to cycle between condensed and gaseous states in the environment, allowing OCs to travel great distances (Macdonald et al. 2000). These "multi-hop" contaminants are differentiated from other contaminants in that once emitted into the atmosphere, transported and deposited, they can re-enter into the atmosphere through the process of volatilization (AMAP 1998). This process is known as the "grasshopper effect" (Wania and Mackay 1996).

Organochlorines were first isolated in the Canadian arctic freshwater and anadromous fish in the early 1970s (Reinke et al. 1972). The presence of OCs in the Canadian north is largely attributed to long-range contaminant transport; however, abandoned radar line sites in northern Canada are also acting as point sources of contamination (e.g., ESG 1999a,b; Tsuji et al. 2005a,b,c; 2006). Specifically, many MCRL stations were constructed adjacent to or in close proximity to First Nation communities (Peawanuck, Fort Albany; AMAP 1998). For this reason, it is important to understand the relationships between FN proximity to abandoned MCRL sites and FN organochlorine body burden. Organochlorines that have been found relevant to the above issues are briefly described below.

1.3.1. PCBs – Industrial Products

The Monsanto Chemical Corporation introduced the world to PCBs in 1929; PCBs were subsequently manufactured in the USA, Japan, the former Soviet Union and eastern and western Europe under various names (e.g., Aroclor, Clophen, Phenoclor; AMAP 1998). From 1929 to 1977, approximately 40 000 tonnes of PCBs produced in the United States were imported into Canada (ESG 1999a). PCBs are a family of OCs that were used ubiquitously in North American industry from roughly the 1950s to the late 1970s (Macdonald et al. 2000). Though the manufacturing of PCBs in North America ceased in the later portion of the 1970s, they continue to be present in landfills, ocean and lake sediments, fish, and wildlife (Safe 1994; AMAP 2002). The production and sale of PCBs was restricted in the mid 1970s due to legislation (see AMAP 1998, for a review); however, many PCBs are still present in many of the transformers and capacitors in use today (Dallaire et al. 2004). These chemically stable compounds are still being released into the environment because of improper storage and disposal, and their ongoing use in other parts of the world (Dallaire et al. 2004). PCBs are mixtures of up to 209 individual chlorinated compounds (known as congeners) that take the form of oily liquids, solids (colourless to yellow) and can exist as vapour in the atmosphere (Dewailly et al. 1993). The positioning of the rings as well as the number of chlorine molecules influences the physical properties and biological activity of PCB congeners (AMAP 1998). The "half-lives" of PCB congeners can vary from weeks to years in air and often up to decades in biota (AMAP 1998). It is estimated that PCB congeners with low molecular weight have half-lives ranging between 6-21 years (Evans et al. 2005). Half-lives in biota can vary; de Boer et al. (1994) examined PCB half-lives in adult fish and found that CB156 had a half-life of more than ten years in adult eels.

There are no known natural sources of PCBs, meaning all PCBs found within the environment are the result of industrial and related processes (Dewailly et al. 1993). Prior to their regulation in the1970s, PCBs were used heavily in industry as heat transfer chemicals in electric transformers and capacitors as well as in hydraulic fluids and lubricants in heavy electric equipment because of their heat resistant properties (Muckle et al. 2001). Some examples of household products that contained PCBs prior to the 1970s are as follows: fluorescent lights, electrical devices with capacitors, microscopes, hydraulic oils, etc. (Dewailly et al. 1993). Therefore, prior to their prohibition, they were used in numerous commercial and residential products (Dewailly et al. 1993).

Polychlorinated biphenyls (PCBs) enter the biosphere in many ways, including manufacturing usage, disposal, accidental spills and leaks during transport and improper storage and disposal (Macdonald et al. 2000; Dewailly et al. 1993). Once released into the environment at middle and lower latitudes, PCBs reach the arctic and sub-arctic via long-range atmospheric transport, waterways, and ocean currents (AMAP 2002; Barrie et al. 1992). There are three pathways in which PCBs can move in the environment; these are by leaching, through run off, or through the atmosphere (Poland et al. 2001). PCBs have shown to travel several kilometres away from their original source (Bright et al. 1995). This is known as the “halo effect” and can result in contaminant dispersion in all cardinal directions (Bright et al. 1995). It is generally accepted that PCBs are not readily volatilized into the atmosphere, but more commonly are carried on water or soil particles to which they are attached (Poland et al. 2001).

1.3.2. HCB – Industrial Product

The compound HCB is a by-product resulting from the production of a large number of chlorinated products (chlorinated benzenes, pesticides, fungicide; AMAP 1998). HCB enters atmospheric pathways as flue gas generated by waste incineration processes as well as from metallurgical industries (AMAP 1998). HCB has relatively high bioaccumulation potential (high lipophilicity), has an estimated field “half-life” of 2.7-5.7 years and has a long half-life in biota (AMAP 1998; Howard 1991; Niimi 1987). Further, HCB has amongst the highest concentrations recorded in the atmosphere, which is the principal medium for transport (AMAP 1998).

1.3.3. Chlordane – Chlorinated Pesticide

Production of chlordane in North America began in 1947 and peaked at 5000 tons/year by 1974 (Van Oostdam et al. 2005). In Canada, chlordane was first registered as a pesticide in 1949 and was prohibited in 1995 (Van Oostdam et al. 2005). Technical grade chlordane is a mixture of over 120 compounds, with the major constituents being *cis*-chlordane, *trans*-chlordane, *cis*-nonachlor, *oxy*-chlordane and *trans*-nonchlor (AMAP 1998). *Oxy*-chlordane and *trans*-chlordane are both metabolites of chlordane. Chlordane was used extensively as a termiticide in the United States where it is estimated that over 30 million houses were treated with it (Van Oostdam et a. 1998). Chlordane has an estimated half-life in soil of 1-4 years and compared to other chlorinated pesticides, it is readily volatilized from water and soils (AMAP 1998).

1.3.4. HCH – Chlorinated Pesticide

Hexachlorocyclohexane consists of numerous isomers; specific to this study is ß-HCH (AMAP 1998). HCH isomers (Lindane is still in use throughout the northern hemisphere) have been used as insecticides for hardwood logs and lumber, seeds and on vegetables and fruits (AMAP 1998). HCH is much less bioaccumulative than other organochlorines because of its relatively low lipophilicity and short half-life in biota (Niimi 1987). However, HCH isomers are extremely volatile compounds capable of long-range transport in the atmosphere (AMAP 1998).

1.3.5. Mirex – Insecticide and Fire Retardant

Prior to its prohibition, mirex was used as an insecticide and as a fire retardant, largely in Canada and the USA (AMAP 1998). Mirex is a highly volatile compound and is extremely persistent in soils and sediment with an estimated half-life of five to ten years (AMAP 1998).

The presence of mirex in the arctic is consistent with its high volatility and persistence (AMAP 1998).

1.3.6. DDT - Insecticide

Though restricted in Canada, the USA and Western Europe for nearly four decades, DDT remains a prominent contaminant in the Canadian arctic and sub-arctic (AMAP 1998). It remains in use in southern Asia, Africa and Central and South America and may be still used in Russia and China (AMAP 1998). Introduced in 1945 as an insecticide, DDT was used liberally to combat invertebrates and subsequent infectious diseases (e.g., malaria). Both DDT and its metabolite DDE are highly persistent organic compounds, have a long half-life in biota and detrimentally influence the nervous system and the liver (AMAP 1998; ESG 1999a). In the Canadian north, DDT was used extensively as a chemical spray to combat mosquitoes and black flies (ESG 1999a).

1.4. Long-Range Transport and Point Sources

The Canadian arctic and sub-arctic may appear as a pristine environment unscathed by industrialization; however, research over the past several decades suggests otherwise (Evans et al. 2005). Though remote, the Canadian arctic and sub-arctic are intricately connected to the rest of the world by the currents of the atmosphere and oceans (Macdonald et al. 2000). The first indication of anthropogenic contaminants in the arctic occurred in the 1950s when pilots started reporting haze; this haze was later understood to be contaminants from industrial emissions and was coined “arctic haze” (Macdonald et al. 2000). Pathways of contaminant transport to the Canadian sub-arctic and arctic regions of Canada have long been attributed to long-range transport (Gamberg et al. 2005). Atmospheric transport, rivers and ocean currents deliver contaminants to northern regions from southern and/or industrialized regions (Gamberg et al. 2005). Airborne contaminants are removed from the atmosphere by wet and dry deposition and are subsequently absorbed by snow, water, soil, sediment and plant surfaces (Gamberg et al. 2005). Ocean currents and northward flowing rivers deposit the more hydrophobic contaminants (i.e., organochlorines) after years to decades in solution

(Gamberg et al. 2005). Only a small fraction of the chemicals released in the mid to low latitudes reach the Canadian arctic, however, this sometimes results in significantly high contaminant concentrations that exceeds levels in temperate regions (Macdonald et al. 2000). The pathways followed by an individual contaminant molecule are complex (AMAP 1998).

When considered on a global or continental scale, local point sources of OCs are considered to be only minor contributors to contamination of terrestrial and aquatic environments (Gamberg et al. 2005). On a local scale, research by the Environmental Sciences Group (ESG; 1999a,b) and others have attributed abandoned military stations as point sources for OC contamination (Tsuji et al. 2005a,b,c; 2006). For example, Reimer et al. (1993a,b) examined soil-plant-lemming (*Dicrostonyx groenlandicus*) relationships in the sewage outfall and background areas at the Cambridge Bay radar site (Distance Early Warning [DEW]; 70th parallel) to examine bioavailability of PCBs. Soil PCB concentrations in the sewage outfall area were significantly greater than background values with averages, in some cases, differing by an order of magnitude or more (Reimer et al. 1993a,b). Indeed, plant-herbivore biomagnification (see below) was at a 6.5-fold increase in PCB concentration between lemming's average whole body and plants (Reimer et al. 1993a,b). Although Reimer et al. (1993a,b) report on the abandoned DEW line, this research elucidates the complex relationship between environmental contaminants and abandoned military radar stations in the north.

In summation, abandoned military radar stations are point sources for contamination (Reimer et al. 1993a,b; ESG 1999a,b; Tsuji et al. 2005a,b,c; 2006). Studies examining bioavailability and biomagnification suggest contaminants from abandoned military sites are influencing body burden concentrations of organisms in the surrounding area (Reimer et al. 1993a,b). In addition, abandoned radar stations are located in close proximity to Aboriginal communities in the Canadian arctic and sub-arctic and FN residents have reported hunting and gathering activities in proximity to abandoned radar buildings (Sistili et al. 2006). Therefore, examining radar stations-environmental contaminants-traditional diet relationships has become indispensable.

1.5. Trophic Level, Bioaccumulation and Biomagnification

Trophic levels are assigned to species by ecologists based on their main source of nutrition and energy uptake; thus, making every ecosystem a dynamic and interconnected web of energy transfers (Campbell and Reece 2002). In every ecosystem, the trophic level that ultimately supports all other organisms are called the autotrophs or primary producers, that is, organisms that can derive their own energy from the sun that rely on water, soil, nutrients and solar radiation to produce organic molecules (Braune et al. 2005). The remainder of the ecosystem is classified as heterotrophs (i.e., organisms that consume other organisms in order to fulfill their metabolic energy needs) and as a result, energy is passed from lower trophic levels (e.g., plants and algae [*Chlorophytes, Cryptophytes,* etc.]) to higher trophic levels (e.g., insects, birds, large carnivores; Fisk et al. 2005). Both energy and non-biotic compartments are transferred and cycled between organisms through photosynthesis and dietary relationships in an ecosystem (Bright et al. 1995). Meaning, organisms in an ecosystem are not mutually exclusive of one another and organisms that have limited feeding associations can significantly influence one another (Bright et al. 1995). Primary producers (e.g., *Chlorophytes*) uptake OCs which then flow in an ascending motion from one trophic level to the next, until reaching top-predator species (e.g., humans; Braune et al. 1999). As OCs ascend through the various trophic levels, OCs accumulate (i.e., OCs bioaccumulate [are stored] in fatty/adipose tissue; AMAP 1998). In other words, bioaccumulation occurs when organisms are exposed to OCs (e.g., ingestion) and the OCs are retained within the cells of the organism (Ayotte et al. 2003; Klaassen 2001). Exposure routes generally consist of the external environment (e.g., air, water) and from food consumption (Klaassen 2001). High lipophilicity and resistance to biodegradation allow OCs to concentrate in lipid tissues of organisms (Ayotte et al. 2003). Once bound to high lipid tissues, metabolism and elimination of OCs is often slow, which leads to a temporal net increase of the contaminants in the organism (AMAP 1998).

Biomagnification is a phenomenon in which top-predator organisms incur body burden concentrations of environmental contaminants that are magnified relative to lower-trophic level organisms (Muir et al. 1999). Johansen (2003) notes that POPs, such as, PCBs and DDT biomagnify “along the food chain, sometimes to thousands of times their original [concentration], posing special perils to animals, including human beings, who eat meat and fish”. This occurs because OCs are retained in the fatty tissue of organisms regardless of their position in the food web and are subsequently sequestered during energy pathway transfers from one trophic level to the next, until reaching top-predator organisms (e.g., humans; Muir et al. 1999). Colborn et al. (1996) demonstrates biomagnification by following an example of a POP that has lodged itself in lake sediment. The cycle begins when the POP is sequestered by a single celled organism which in turn is consumed by zooplankton (*Acartia tonsa*); the zooplankton is then eaten by mysids (*Neomysis americana)* which are consumed by lake trout (*Salvelinus namaycus;* Colborn et al. 1996). Finally, by the time the lake trout is consumed by a top-predator (e.g., humans), its body burden may contain 25 million times the concentration of the pollutant found in the initial sediment (Colborn et al. 1996). Thus, as a result, top-predator organisms serve as depositories for OCs that have accumulated in lower trophic levels and consequently, top-predators have significantly higher body burden concentrations of contaminants (Braune et al. 1999a). The processes of bioaccumulation and biomagnification are of concern to First Nations people because they continue to subsist on country foods (i.e., wild fauna and flora), making them susceptible to the contaminants that accrue in the foods they consume (Braune et al. 1999a).

In addition, spatial trends from research conducted in the 1990s have demonstrated that organisms inhabiting the arctic and sub-arctic realms of North America have significantly elevated levels of OCs relative to organisms inhabiting mid and lower latitudes of the western hemisphere (Braune et al. 1999a). The unique characteristics of the Canadian sub-arctic and arctic provide more conducive (than temperate regions) circumstances in which OCs bioaccumulate and/or cause stresses in biota that may make them more vulnerable to the effects of OCs (AMAP 1998). Briefly, the most notable characteristics of northern ecosystems compared to temperate regions are described below.

Cold conditions in northern latitudes influence the physical characteristics of the abiotic environment, the chemical and physical characteristics of contaminants, the metabolic rates of biological processes and a large number of physiological and behavioural adaptations of biota to colder temperatures (AMAP 1998). Of critical importance to the survival of biota over the relatively elongated winters (compared to temperate regions) is the metabolic adaptation of lipids as an energy source and as stored energy (AMAP 1998). As a result, large amounts of lipids are exchanged during energy transfers between different trophic level categories and often included in this exchange are OCs (AMAP 1998). This metabolic adaptation amongst biota in the Canadian north is the most important factor relating to OC accumulation and biomagnification (AMAP 1998). The opportunity for biomagnification in southern human populations is significantly reduced compared to human populations in northern latitudes who subsist significantly on these organisms (AMAP 1998).

Because of recent and repeated glaciations, low absolute biological productivity and a relatively short evolutionary history of ecosystems has resulted in relatively low species diversity in northern latitudes (AMAP 1998). As a result, low species diversity renders many food chains in the arctic very simple and short, for example, the lichen-caribou-wolf food chain in the Canadian sub-arctic and arctic (AMAP 1998). This chain is of importance because many northerners rely on caribou as a major source of food (AMAP 1998). Individual species in the arctic tailor their feeding habits, growth rates, migration patterns and reproductive characteristics according to climatic factors or the availability of food (AMAP 1998). Consequently, low species diversity significantly limits the type of country food available for northerners (AMAP 1998).

Growing parameters associated with low levels of solar radiation and low levels of nutrient input are responsible for low biological productivity in the Canadian arctic and sub-arctic (AMAP 1998). Low productivity can result in slower growing and longer-lived poikilotherms than in temperate climates (AMAP 1998). As well, fish and invertebrates may be exposed to OCs for a long period of time before being consumed by higher trophic level organisms in the next category of the food web (AMAP 1998).

1.6. First Nations People – Subsistence harvesting

The First Nations people of the Hudson-James Bay region of northern Ontario can be characterized as ancestors of individuals who inhabited North America prior to European colonisation (Evans et al. 2005). First Nations people that participated in this study are Cree and continue to subsist to a large extent on the land (Evans et al. 2005; Van Oostdam et al. 2005). The Cree for generations have used this land for traditional purposes and consequently, traditional pursuits have brought the First Nations people of this region into contact with the military sites during their construction, operation and abandonment (ESG 1999a).

A traditional diet can broadly be defined as using the "land" to maintain one's health through hunting, fishing, trapping and/or gathering of wild flora and fauna (Van Oostdam et al. 2005; ESG 1999a). In FN Cree populations, living organisms are an integral part of their lifestyle as plants and animals supply both food and medicine as well as help them maintain their spiritual attachment to the land (Evans et al. 2005; Van Oostdam et al. 1999). Berkes et al. (1994) reports on the major type and frequency of food harvested by FN hunters from the Hudson James Bay Lowland (Table 1). Specifically, hunters from Kashechewan and Peawanuck FN harvest similar quantities and genre of foods (except fish), while Fort Albany FN hunters, in most cases, harvested relatively less reported game. Frequency of consumption can play an important role in OC body burden, as the variation of OC body burden in country food is well documented (e.g., skin and fat of waterfowl can be a significant source of PCBs; Tsuji et al. 2008). The consumption of local food is beneficial to Canadian arctic and sub-arctic indigenous people for three primary reasons: traditional food is more nutritious than food imported from southern Canada; cash resources are limited and indigenous food production is a more economical investment than the purchase of store bought foods; and the sharing of indigenous foods is critical to the social relationships and indigenous cultures (AMAP 1998). The nutritional benefit of country food includes relatively more protein, iron and zinc when compared to diets based on more southern-market foods (Van Oostdam et al. 2005). Further, subsistence harvesting (hunting, fishing and gathering) for northern Aboriginals is a deeply rooted source of cultural identity, through the processes

Table 1

Mean catch per harvester among harvesters from Peawanuck, Kashechewan and Fort Albany[a]

Communities	Moose	Caribou	Waterfowl	Trapping	Small Game	Fishing
Fort Albany	1.8	7.4	50.7	12.2	15.9	63.3
Kashechewan	1.7	3.9	139.7	63.3	90.9	100.8
Peawanuck	1.2	7.8	170.6	64.6	101.6	235.5

[a]Berkes et al. 1994.

of harvesting, consumption and distribution of foods and other products (AMAP 1998). The cultural dynamics of exchanging country food in northern communities involves a complex set of social and cultural rules and procedures that pertain to the structure and organization of these societies (Van Oostdam et al. 2005). The traditional diet of First Nations people has facilitated their success as a culture for millennia and continues to be practiced as a means of survival in the sub-arctic and arctic regions of Canada (AMAP 1998). However, research over the past several decades has indicated that subsistence foods in the Canadian north contains elevated levels of OCs; this finding is of concern to northern communities (Evans et al. 2005). Further understanding the relationships between human OC body burden and the traditional diet is imperative to the health and wellness of FN individuals who continue to rely on subsistence (Evans et al. 2005). Moreover, because First Nations people have reported conducting traditional pursuits in close proximity to abandoned radar sites, it is of pressing concern to further understand the relationship between OC body burden and proximity to abandoned MCRL base stations (Tsuji et al. 2005c).

1.7. Mid-Canada Radar Line – 1957-1965

During the Cold War there was a perceived threat of an impending nuclear attack from the former Soviet Union (Myers and Munton 2000). In 1954, fear of a nuclear attack heightened after the Soviets heralded they had a functional hydrogen bomb (Huebert 2000). Because the most direct route from Russia to North America was over the arctic, it was deemed prudent to build an early warning defence system in the arctic and sub-arctic as a means of protecting populated areas in North America (Myers and Munton 2000). Therefore, a series of radar stations were built along the 49th (Pine Tree Line), 55th (Mid-Canada Line), and 70th parallel (Distant Early Warning) to detect any unidentified aircraft entering the arctic region of North America (Myers and Munton 2000). Once detected by a radar station, American fighter jets would intercept the incoming Soviet bombers and destroy them before they reached striking distance of large American cities (Sistili et al. 2006). Together, the Mid-Canada Line sites included 264 permanent buildings, a multitude of airstrips and helicopter pads, 370 towers and radio masts, 16 larger scatter dishes, 322 diesel alternator units and thousands of tonnes of radar and radio equipment (ESG 1999a).

The Mid-Canada Radar Line (MCRL) stretched across the 55th parallel and consisted of eight Sector Control Stations and 90 unmanned radar stations spaced approximately 48 km apart stretching 4320 km from Dawson, British Columbia to Hopedale, Newfoundland (ESG 1999a). Numerous radar stations were integrated within FN communities and in surrounding areas (Sistili et al. 2006). The MCRL was solely a Canadian endeavour funded and constructed by the Canadian federal government, costing in excess of 200 million dollars (Sistili et al. 2006; ESG 1999a). After two years of construction and only seven years of service, the MCRL was rendered redundant for economic and strategic reasons and the radar stations were subsequently abandoned (Sistili et al. 2006). Once rendered redundant, the base stations and associated paraphernalia (e.g., fuel tanks, electrical equipment, drum barrels, etc.) were abandoned and remain at the radar stations to this day (except Site 050 which has been remediated; ESG 1999a). The improper decommissioning has left a legacy of contamination of the MCRL sites and prompted concern among FN communities (ESG 1999a). Thus, the relationship between FN OC body burden, MCRL sites and the traditional diet needed to be addressed.

1.8. Mid-Canada Radar Line Site 050 – Fort Albany First Nation

Site 050 was a medium-sized station located on Anderson Island near the community of Fort Albany FN (ESG 1999a). In 1991, Fort Albany FN community leaders reported the presence of PCBs in and around the MCRL base buildings and expressed concern for the health and safety of FN members (Sistili et al. 2006). Empirical measurements ensued and in 1999, the ESG (1999a) reported that abandoned MCRL sites were indeed point sources of chemical contamination. Elevated levels of PCBs and other OCs were reported in soils and plant material surrounding numerous MCRL sites (ESG 1999a). Specifically, soil and vegetation analyses surrounding Site 050 found PCB contamination levels that exceeded 21 000 parts per million (ppm) in soil and up to 500 ppm in vascular plant tissue (ESG 1999a). This finding was of considerable concern because substances containing concentrations greater than 50 ppm are considered hazardous waste in Canada (ESG 1999a). In Canada, material that contains over 50 ppm PCBs is regulated under the *Canadian Environmental Protection*

Act (CEPA) and soil contamination exceeding this concentration represents a legal contravention (ESG 1999a). To further complicate matters, Site 050 is located in proximity to the village proper of Fort Albany FN (ESG 1999a). In addition, it was documented in a land use study that Fort Albany FN community members had been involved in activities (e.g., swimming, harvesting [plants, berries, fish, small game], collecting drinking water, etc.) on and around the area of Site 050, on Anderson Island (Tsuji et al. 2005c).

1.9. Mid-Canada Radar Line Site 500 – Weenusk First Nation

It should be mentioned that the FN community of Winisk was originally located near the mouth of the Winisk River near Hudson Bay (ESG 1999a). In 1986, a catastrophic ice jam and subsequent flooding forced community members of Winisk to relocate 32 km up-river on higher ground at the village now known as Peawanuck (ESG 1999a). Similar to Fort Albany, community members of Peawanuck have voiced their concerns with respect to contaminants originating from an abandoned MCRL – in this case Site 500 - that was located in close proximity to Winisk (ESG 1999a).

The Winisk Control Station (Site 500) was built at the mouth of the Winisk River across the river from the Cree community of Winisk (ESG 1999a). Site 500 was the largest Mid-Canada Radar Line site in Ontario and can be divided into five distinct areas: 1. Airport Area – with a 1525 m runway, five buildings, a communications dish, the vehicle dump, domestic dump and barrel dump; 2. Town Site – with 12 buildings; 3. Flagstaff Point – with three large vertical petroleum, oil and lubricant (POL) tanks and 16-20 horizontal 5000-gallon (22 000 L) tanks; 4. Pumphouse – with a single deteriorating building; and 5. Tank Farm – with nine large POL tanks. Sections of Site 500 are still being used by residents of Peawanuck and/or hunters and tour groups from the south (ESG 1999a). Specifically, the airstrip is used to fly people in and out and the old barracks at the Town Site has been converted into a Goose Camp (mid-1980s; ESG 1999a). Hunters use the Goose Camp for a three-to-four week period in both the spring and fall (ESG 1999a). It is estimated that approximately 150-300 visitors from Canada, Europe, Japan and the USA visit Winisk and are active in and around the abandoned buildings (ESG 1999a). The station site is littered with debris and dilapidated buildings dominate the immediate and peripheral area of the abandoned station (ESG 1999a). For example, the barrel dump area contains an estimated 40 000 45-gallon barrels (ESG 1999a). Despite the deplorable state of the area, the ESG (1999a) study concluded that relatively little chemical contamination (e.g., PCB, DDT) other than total petrol hydrocarbons had occurred at Site 500 and that the cleanup would consist largely of dealing with physical structures and debris rather than the decontamination of soil and plant material (ESG 1999a). Paint chips at two different locations in the vicinity of Winisk airport found PCBs concentrations of Aroclor 1254 at 2200 ppm and 1800 ppm, respectively (ESG 1999a). Samples taken from both soil and plant material failed to record concentrations exceeding the detection limit for chlorinated pesticides (ESG 1999a). Nevertheless, there exist concerns regarding contamination from the abandoned radar buildings.

1.10. Human Exposure

Food is the primary route of exposure for most contaminants in any population whether in a northern or southern location (Van Oostdam et al. 2005). Since, Aboriginal peoples subsist largely on traditional/country food, Aboriginals have greater risk of OC exposure than non-Aboriginal peoples who do not consume fish and/or wild game (Van Oostdam et al. 2005). Accordingly, First Nation peoples are exposed to low-doses of contaminants throughout their life history, which places them at a significant risk to health complications associated with OC contamination (Van Oostdam et al. 2005).

There is a dearth of studies dealing with contamination in the Canadian sub-arctic region relative to the arctic region, although this situation is improving (Tsuji et al. 2006). As well, there are limited data pertaining to human exposure to contaminants originating from abandoned radar stations in Canada's north (Tsuji et al. 2006). As the ESG (1999a) suggested, the potential exists for human exposure to contaminants originating from abandoned MCRL sites. Ontario-wide studies conducted by Health Canada in the 1980s regarding plasma PCB levels in First Nation communities revealed that communities in proximity to abandoned radar sites often had elevated PCB levels in their blood. The community of Winisk (MCRL Site 500) which has since been renamed Peawanuck, reported the highest plasma PCB levels in the western James Bay region (Peawanuck FN; n = 22; Aroclor 1254; range: 2-82 µg/L; Health Canada 1999). In addition, numerous other communities (i.e., Attawapiskat FN; n = 49; Aroclor 1254; range: 4-88 µg/L; Moose Factory FN; n = 50; Aroclor 1254 µg/L; 2-32 µg/L; Health Canada 1999) potentially influenced by being close to or having abandoned radar sites in their traditional territories demonstrated plasma PCB levels significantly higher in comparison to other Canadians (the Canadian average is 2.0 µg/L; Health Canada 1999). However, the 1980s studies should be interpreted with caution because PCBs were expressed as different mixtures and were analyzed by different laboratories (Tsuji et al. 2005c). Nonetheless, the 1980 studies reported invaluable preliminary information with respect to FN communities PCB body burden.

Tsuji et al. (2005c) compared plasma OC concentration (unadjusted for total lipids) frequency distribution data for Fort Albany (MCRL Site 050), Kashechewan (a neighbouring community without a radar installation), and Hamilton, a city in southern Ontario, Canada. Employing a two-state log-linear model (using detectable and non-detectable OC frequency data) and a four state log-linear model (using OC, quartile concentration-frequency data), organochlorine body burdens were compared between the three communities and revealed significant differences in detectable and non-detectable organochlorine frequency data (Tsuji et al. 2005c). Differences were based only upon location with no sex differences being noted: people from Hamilton generally had significantly higher than predicted frequencies of detection in the first quartile (low concentrations) for most organochlorines analyzed compared to the FN communities (Tsuji et al. 2005c). Concentrations (wet-weight, ug/L) of PCBs and sum of DDT (DDE + DDT) for Fort Albany and Kashechewan females were respectively, similar or greater than values reported for Inuit females living in the central Northwest Territories, Canada (Tsuji et al. 2005c). Frequency of detection of many organochlorines (excluding ß-HCH) for Kashechewan males scored significantly greater than expected in the fourth quartile (higher-concentration; Tsuji et al 2005c).

A follow-up study (Tsuji et al. 2006) that compared lipid-adjusted body burden of OCs between the same residents of Fort Albany, Kashechewan, and Hamilton found the following: 1. Fort Albany and Kashechewan subjects had elevated PCB and DDE-plasma levels relative to Hamilton participants. 2. PCB and DDE-plasma levels in FN women were at comparable concentrations to those reported for Inuit women living in the west/central Northwest Territories (this is unusual as Inuit FN consume sea mammals which have characteristically higher levels of contaminants). 3. Significantly lower DDE/DDT ratios were observed for Fort Albany, indicating higher levels of DDT compared to Kashechewan; the likely source of DDT exposure for Fort Albany people would be the contaminated soil surrounding buildings of Site 050. 4. People from Hamilton had relatively higher pesticides and lower PCB body burdens, while subjects from the FN communities had relatively higher PCBs and lower pesticide levels. 5. The presence of Site 050 on Anderson Island appears to have influenced organochlorine body burden of the people of Fort Albany. 6. Results of DDE/DDT ratio data and congener 187 suggest that Site 050 did influence organochlorine body burden of people from Fort Albany (Tsuji et al. 2006). In addition, Tsuji et al. (2005b) found that the PCB congener composition (with respect to body burden) in Fort Albany samples closely resembled Aroclor 1260, the prevalent PCB mixture identified at MCRL Site 050 (Fort Albany; ESG 1999a,b); however, the other two communities (Kashechewan and Hamilton) also most closely resembled Aroclor 1260.

The present study builds on the described body of work and will further elucidate the relationship between proximity to MCRL sites and OC body burden in First Nations people by assessing OC body burden in people from Peawanuck. This study used OC body burden data for Kashechewan and Fort Albany FN published in a previous study conducted by Tsuji et al. (2006) as well as reported on new plasma OC data for the people of Peawanuck and examined the patterns of differences with respect to OC body burden (lipid-adjusted) between these three populations: Fort Albany FN, the site of MCRL Site 050; Kashechewan FN, the control site; and Peawanuck, the site of MCRL 500. This study will provide FN community leaders with more data to make informed decisions concerning the prioritization of MCRL sites for remediation as well as hunting and gathering decisions with respect to their communities.

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Chapter 2. Abandoned Mid-Canada Radar Line Site 500 in the western Hudson Bay region of sub-Arctic, Canada: A source of organochlorines for the people of Weenusk First Nation?

2. Introduction

During the Cold War there was a perceived threat of an impending nuclear attack from the Soviet Union (Huebert 2000; Myers and Munton 2000). As the most direct route from Russia to the U.S.A. was over the northern portion of North America, it was deemed prudent to build an early warning defence system in the arctic and sub-arctic as a means of protecting populated areas in North America (Poland et al. 2001). Thus, a series of radar stations were built along the 49^{th} (Pine Tree Line), 55^{th} (Mid-Canada Line), and 70^{th} parallel (Distant Early Warning) to detect any unidentified aircraft entering the arctic and sub-arctic region of North America (Poland et al. 2001; Myers and Munton 2000). If anything was detected, American fighter jets would be launched to intercept the incoming aircraft at a safe distance from populated areas (Sistili et al. 2006).

The Mid-Canada Radar Line (MCRL) stretched across the 55^{th} parallel and consisted of 98 manned and unmanned radar stations that spanned from Dawson, British Columbia, in the west to Hopedale, Newfoundland in the east; many radar stations were located in close proximity to First Nation communities and/or their traditional hunting territories (Sistili et al. 2006). The MCRL was an entirely Canadian endeavour funded and constructed by the Canadian federal government (Sistili et al. 2006; Environmental Sciences Group [ESG] 1999a). After only seven years in operation, the MCRL was considered redundant for strategic (and economic) reasons and the radar stations were subsequently “decommissioned” (Sistili et al. 2006). Since, the decommissioning of the radar stations were not regulated, concerns regarding abandoned MCRL stations acting as point sources of contamination were first voiced by FN people of the western James Bay region in the late 1980s (Sistili et al. 2006). Field studies ensued and in 1999, the ESG (1999a) reported that abandoned MCRL sites were indeed point sources of chemical contamination. Elevated levels of polychlorinated biphenyls (PCBs) and other contaminants were reported in soils and plant material surrounding numerous MCRL sites (ESG 1999a). Specifically, PCB contamination surrounding Site 050 (near Fort Albany FN) was reported to have exceeded 21 000 ppm in soil and up to 500 ppm in vascular plants (ESG 1999a). As well, paint chips at two different locations in the vicinity of the airport at Winisk (Site 500) were reported to contain high levels of PCBs: 2 200 and 1 800 ppm of Aroclor 1254 (ESG 1999a). In Canada, material that contains over 50 parts per million (ppm) PCBs is regulated under the *Canadian Environmental Protection Act* and any material exceeding this concentration represents a legal contravention (ESG 1999a). The findings of the field studies were of critical concern because FN members from both Fort Albany and Weenusk First Nation communities participated in traditional pursuits on and/or in the vicinity of these abandoned MCRL sites (ESG 1999a). Indeed, it has been documented in a land use study that people of Fort Albany FN have participated in harvesting (e.g., plants, berries, fish, small game), collecting (e.g., water) and recreational activities on Anderson Island (where MCRL Site 050 is located) (Tsuji et al., 2005a).

In a study by Tsuji et al. (2005c), they compared plasma organochlorine frequency-distribution data using log-linear contingency modelling for inhabitants of Fort Albany FN (MCRL Site 050), Kashechewan FN (a neighbouring FN community without a radar installation), and Hamilton, a city in southern Ontario, Canada. Employing a two-state log-linear model (using detectable and non-detectable organochlorine frequency data) and a four state log-linear model (using organochlorine, quartile concentration [μg/L] - frequency data), organochlorine body burdens were compared between the three communities and revealed significant differences in detectable and non-detectable organochlorine frequency data (Tsuji et al. 2005c). Differences were based only upon location with no sex differences being noted: people from Hamilton generally had significantly higher than predicted frequencies of detection in the first quartile (low concentrations) for most organochlorines analyzed compared to the FN communities (Tsuji et al 2005c). In addition, body burdens of PCBs and sum of DDT (DDE + DDT) for Fort Albany and Kashechewan females were similar or greater than values reported for Inuit females living in the central Northwest Territories, Canada, respectively. This finding is of interest as the Cree of the western James Bay region do not consume marine mammals (which contain relatively large amounts of organochlorines) while the Inuit of the central Northwest Territories do occasionally consume marine mammals (Berkes et al. 1994; AMAP 1998; Tsuji et al. 2005c). A follow up study (Tsuji et al. 2006) examined the patterns of differences with respect to body burden of organochlorines (lipid-adjusted, μg/kg) for the same residents of Fort Albany, Kashechewan and Hamilton to further elucidate whether the presence of Site 050 influenced organochlorine body burden with respect to the people of Fort Albany. Briefly, it was found that Fort Albany and Kashechewan participants had elevated PCB and DDE-plasma levels relative to Hamilton participants; while, significantly lower DDE/DDT ratios were observed for Fort Albany compared to Kashechewan and Hamilton (Tsuji et al. 2006). The lower DDE/DDT ratios reported in Fort Albany were the result of relatively higher body burdens of DDT in comparison to DDE for people from Fort Albany; the likely source of DDT exposure for Fort Albany people would be the DDT-contaminated soil (Tsuji et al. 2006) that has been documented to surround buildings on Site 050 (ESG, 1999a,b). The presence of Site 050 on Anderson Island appears to have influenced the body burden of DDT for the people of Fort Albany; however, PCB body burdens were not significantly different between Fort Albany and the control site Kashechewan, as the PCB contribution of the traditional diet could not be discounted. In addition, Tsuji et al. (2005b) found that the PCB congener composition with respect to body burden in Fort Albany, Kashechewan and Hamilton all most closely resembled Aroclor 1260, the prevalent PCB mixture identified at MCRL Site 050 (Fort Albany; ESG 1999a,b). The present study extends the previous work of Tsuji et al. (2005b, c; 2006) in examining whether First Nations people residing in close proximity to abandoned MCRL sites have different body burdens of organochlorines than First Nations people not living by and/or active on abandoned MCRL sites, as it is not entirely clear how these factors impact organochlorine body burden in First Nation Cree of the Mushkegowuk Territory (western James Bay and south-western Hudson Bay).

2.1. Methodology

2.1.1. Study Sites

In 1987, an ice-jam on the Winisk River and subsequent flooding devastated the village of Winisk and forced the community (Weenusk FN) to relocate upstream to what is now known as Peawanuck (55°15’N, 85°12’W; ESG 1999a). Prior to the relocation of Winisk, MCRL

Site 500 was located adjacent to the village proper. Fort Albany FN (52°15’ N, 81°35’ W) is located on Sinclair Island in the southern channel of the Albany River in the western James Bay region of northern Ontario, Canada (Tsuji et al. 2001). Most members of Fort Albany FN live on Sinclair Island but some reside on Anderson Island (the location of MCRL Site 050 which was remediated in 2001) and the nearby mainland (Tsuji et al. 2001; Fig. 1). The islands and mainland are connected via gravel roads (Tsuji et al. 2005c). Kashechewan FN is located approximately 20 km north of Fort Albany on the mainland, north of the northern channel of the Albany River; this community is not located in close proximity to an abandoned radar base and will therefore be used as the control community for this study.

All three communities are remote fly-in communities accessible only by air year-round, by barge during late spring to early fall, and by ice-snow road in the winter (Tsuji et al. 2006). Peawanuck is the smallest of the three communities with a population of approximately 180 people; Fort Albany with 850 people; and Kashechewan with the largest population of 1,400 people (Tsuji et al. 2006). All three communities still consume fish and wild game.

2.1.2. Sample collection

This study incorporates plasma sample data for Kashechewan and Fort Albany FNs collected for a previous study conducted by Tsuji et al. (2005b,c; 2006) as well as new plasma sample data for Peawanuck. A detailed account of sampling protocol for Kashechewan and Fort Albany participants can be found in Tsuji et al. (2005b,c; 2006). For the present study, only adults (≥18 years old) were recruited from Peawanuck (Weenusk FN). A total of 20 Peawanuck community members (females, n=10, males, n=10) participated in the study. A consent form was signed after the study details had been reviewed with the participants; Cree interpreters were used when required. The consent form and study were approved by the McMaster University Research Ethics Board. Prior to blood collection, participants were advised verbally not to eat or drink anything after midnight on the day prior to collection unless the person was diabetic; these participants were advised to eat something in the morning as long as it did not contain fat. Blood collection commenced in the morning and prior to blood collection, participants were questioned on food and beverage consumption

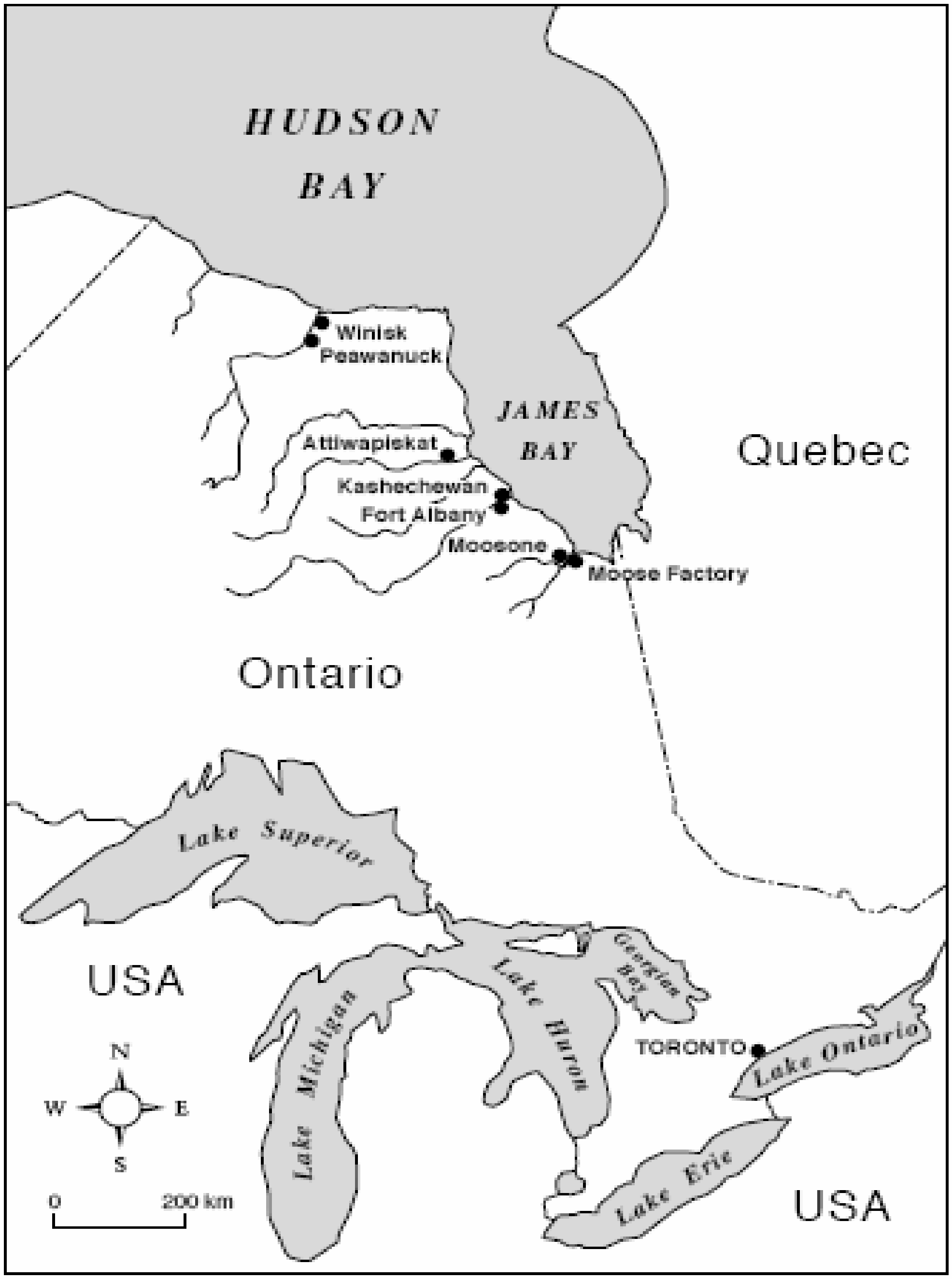


Fig. 1. The communities of Peawanuck (Mid-Canada Radar Line Site 500), Kashechewan First Nation (no radar site) and Fort Albany First Nation (Mid-Canada Radar Line Site 050), Ontario, Canada.

prior to the sampling. Any participants that had consumed lipids were rescheduled and the importance of fasting was re-emphasized (Tsuji et al. 2005c). Participants were also asked to complete a lifestyle questionnaire in an interview format.

Blood samples to be analysed for organochlorines were collected in 10 ml glass vacutainers (containing the anticoagulant, EDTA, Becton-Dickinson). Immediately following blood collection, the blood was gently mixed with the anticoagulant and then centrifuged at room temperature for 10 minutes. Once the plasma was separated, it was transferred from the vacutainer with polyethylene pipettes (Baxter) to pre-cleaned (with hexane) glass vials (Supelco) and sealed with Teflon coated lids. The plasma samples were then frozen at –20°C and shipped in insulated coolers with frozen gel packs to the Centre de toxicologie du Quebec, Quebec, for analyses (see Tsuji et al. 2005c for a detailed explanation).

2.1.3. Sample Analyses

Plasma concentrations of total PCBs have been expressed as the sum of 14 PCB congeners (28, 52, 99, 101, 105, 118, 128, 138, 153, 156, 170, 180, 183, 187). Other organochlorines that were quantified included DDT (and DDE), aldrin, ß-hexachlorocyclohexane (ß-HCH), α-chlordane, γ-chlordane, *cis*-nonachlor, hexachlorobenzene [HCB], mirex, *oxy*-chlordane, and *trans*-nonachlor. This suite of organochlorines is part of the standard organochlorine screen of the Arctic Monitoring and Assessment Programme.

Plasma samples were thawed overnight at 4°C and then a 2 mL aliquot was extracted with hexane. Lipid extracts were then cleaned-up on Florisil columns and adjusted to a final volume of 100 µL. Organochlorine concentrations were quantified using gas chromatography (HP-5890 series II, dual capillary columns, dual Ni-63 electron-capture detectors) as described in Tsuji et al. (2005c). Detection limits were as follows: 0.02 µg/L for PCB congeners 28, 52, 99, 118, 138, 153, 180 and for chlorinated pesticides HCB and DDE; 0.01 µg/L for PCB congeners 156, 170, 183, 187 and for chlorinated pesticides mirex, aldrin, α-Chlordane, *trans*-nonachlor and ß-HCH; and 0.005 µg/L for γ-chlordane, DDT, *cis*-nonachlor and *oxy*-chlordane. The percent recoveries for reference standards were >90% for all organochlorines. Enzymatic methods were used to measure total free cholesterol, triglycerides and phospholipids on the Technicon automatic analyser (RA-500) with appropriate testpaks (Tsuji et al. 2006). Plasma total lipids were estimated using the summation method; the lipid percentage for each Peawanuck study participant is presented in Table 2 (Patterson et al. 1991). As well as the routine use of laboratory standards, the quality assurance and control protocol also included participation in intra- and inter-laboratory comparisons, and the use of a "control-performance chart" described in Nadkarni (1991). For a detailed description of protocols refer to Tsuji et al. (2005c; 2006).

2.1.4 Statistical Analyses

Prior to statistical analyses, the organochlorine dataset for participants from Peawanuck was combined with the organochlorine dataset for Fort Albany and Kashechewan. As described in Tsuji et al. (2006), frequencies of detectable concentrations were used to determine which of the organochlorines were examined in greater detail. Only organochlorines with a frequency of detection >90% (see Tsuji et al. 2006, for an explanation) were analyzed (i.e., PCBs congeners [118, 138, 153, 156, 170, 180, 187], sum of 14 PCB congeners [for congener concentrations <DL, zero was used in the summation], DDT, DDE, HCB, oxy-chlordane, *trans*-nonachlor, mirex, hexachlorobenzene, and ß-HCH). If an organochlorine was undetectable, an imputed value of ½ DL was assigned for these and subsequent analyses. It should be noted that when the Peawanuck dataset was combined with the Fort Albany and Kashechewan dataset - the combined dataset was harmonized with respect to DLs - the lower of the two DLs was adopted as the DL for the combined dataset and used in the imputation of concentrations <DL. Organochlorine data were then lipid adjusted. Arithmetic means and standard deviations of organochlorines were calculated for both genders at Peawanuck. The ratio DDE/DDT also was calculated for both males and females at Peawanuck, Fort Albany and Kashechewan and analyzed by ANOVA and appropriate post-hoc tests.

Organochlorines with >90% detectability were summarized in lower dimensionality using correspondence analysis (CA). This eigen analysis model reduced the large number of intercorrelated variables to four, more easily examined, variables (Gauch 1982; Thioulouse et al. 1997). The new CA variates were examined in a multivariate analysis of variance (MANOVA) of location and sex differences. If there was a significant ($p \leq 0.05$) LOCATION x SEX interaction for a CA axis, this axis was excluded from further analyses. To determine if age adjustment was necessary, the new CA variates were examined by MANOVA for location and age differences. As the interactive term AGE x LOCATION was significant for CA-1 ($p=0.027$) and CA-2 ($p=0.000$); heterogeneity of slopes existed between locations for these variables. Thus, pair-wise ANCOVA analyses of the three locations was performed to determine if the slope coefficients for age on CA-1 and 2 differed significantly by LOCATION. To examine the differences in age slopes between locations, pair-wise comparisons were performed and tested at a Bonferroni corrected p-value to maintain a constant experiment-wise error rate of $p=0.017$. The reasoning for the pair-wise comparison is to determine which combinations of communities have heterogeneous or homogeneous slopes. If specific community pairs reported homogenous slopes, the effects of age could be controlled in ANCOVA with age as the covariate. In contrast, the interactive term AGE x LOCATION was not significant for CA-3 ($p=0.412$) revealing that the slopes were homogeneous. Thus, for CA-3 the effect of LOCATION was examined using ANCOVA to adjust for variation in AGE. Following ANCOVA, all three locations for CA-3 were compared (i.e., *post-hoc* pair-wise tests adjusted for multiple comparisons) to determine which communities differed significantly in contaminant mixtures as described by CA-3.

2.2. Results

2.2.1. Descriptive Statistics

Descriptive statistics are presented for organochlorines with >90% frequency of detection (Table 3). Aldrin and γ-chlordane were not detected in any of the samples. Arithmetic means for DDE/DDT ratios were 36.3 (females) and 38.9 (males) in Fort Albany; 46.6 (females) and 92.8 (males) in Kashechewan; and 374.8 (females) and 1238.5 (males) in Peawanuck. Post-hoc tests between locations (Tamhane's T2 test, protected for multiple comparisons of data with heterogeneous variances) revealed that the DDE/DDT ratios were significantly different between all three communities: Fort Albany and Kashechewan ($p=0.001$), Fort Albany and Peawanuck ($p=0.006$), and Kashechewan and Peawanuck ($p=0.008$).

Table 2
Total Plasma Lipids for Peawanuck study participants

ID #	Sex	Lipid %
5001	Female	52.0
5002	Female	25.0
5003	Female	69.0
5004	Female	41.0
5005	Female	62.0
5006	Female	23.0
5007	Female	54.0
5008	Female	67.0
5009	Female	63.0
5010	Female	59.0
5500	Male	67.0
5501	Male	25.0
5502	Male	71.0
5503	Male	42.0
5504	Male	66.0
5505	Male	58.0
5506	Male	70.0
5507	Male	38.0
5508	Male	24.0
5509	Male	54.0

Table 3
Statistical characteristics of organochlorines (µg/kg lipid) from males and females from Peawanuck, Ontario, Canada.

Arithmetic Statistics	Sex of Subject	N	Mean	S.D.	Minimum	Maximum
ß-HCH (µg/kg lipid)	Female	10	8.1	9.7	0.9	33.9
	Male	10	6.2	2.2	2.7	9.7
Congener 118 (µg/kg lipid)	Female	10	49.1	42.5	4.2	109.1
	Male	10	19.9	17.4	3.3	61.1
Congener 138 (µg/kg lipid)	Female	10	94.1	79.2	7.3	238.1
	Male	10	62.8	61.5	7.9	208.3
Congener 153 (µg/kg lipid)	Female	10	247.1	231.5	14.7	730.2
	Male	10	173.9	180.6	18.9	611.1
Congener 156 (µg/kg lipid)	Female	10	36.0	40.7	0.9	134.9
	Male	10	27.2	28.5	2.5	94.4
Congener 170 (µg/kg lipid)	Female	10	66.1	71.3	2.9	238.1
	Male	10	51.1	53.0	4.7	175.0
Congener 180 (µg/kg lipid)	Female	10	274.0	308.4	12.2	1032.0
	Male	10	215.9	225.8	16.1	750.0
Congener 187 (µg/kg lipid)	Female	10	88.1	92.2	2.9	301.6
	Male	10	57.3	63.9	4.9	213.9
Sum of 14 CBs (µg/kg lipid)	Female	10	897.5	872.4	53.6	2846.5
	Male	10	636.2	647.1	72.5	94.4
p'-DDE (µg/kg lipid)	Female	10	1312.9	1184.3	122.0	3809.5
	Male	10	836.2	706.2	122.2	2333.3
p'-DDT (µg/kg lipid)	Female	10	10.9	11.8	0.4	37.5
	Male	10	3.5	6.6	0.3	18.0
p'DDT + DDE (µg/kg lipid)	Female	10	1323.7	1191.8	122.5	3822.1
	Male	10	839.7	709.7	122.6	2351.4
DDE/DDT (µg/kg lipid)	Female	10	374.8	519.4	61.1	1760.0
	Male	10	1238.5	1122.6	35.8	3080.0
Hexachlorobenzene (µg/kg lipid)	Female	10	90.2	56.3	20.3	190.0
	Male	10	69.8	59.6	15.2	222.2
Mirex (µg/kg lipid)	Female	10	62.0	63.7	0.8	189.1
	Male	10	61.0	104.2	1.7	333.3
Oxy-chlordane (µg/kg lipid)	Female	10	25.0	16.9	2.5	47.5
	Male	10	21.1	13.6	5.0	47.2
Trans-nonachlor (µg/kg lipid)	Female	10	49.1	33.7	3.9	98.1
	Male	10	40.2	28.1	6.4	94.4

2.2.2. Correspondence Analysis

Four Correspondence Analysis (CA) axes were extracted from the matrix of $\log_{10}(x+1)$ transformed original variables. These CA axes accounted for 82.14% of the variance in the original matrix (CA-1, 44.73%; CA-2, 19.41%; CA-3, 9.76%; and CA-4, 8.24%; Table 4). A MANOVA of the CA scores revealed significant differences with respect to location and sex. A significant ($p<0.05$) effect was seen for the LOCATION x SEX interaction only for CA-4 ($p=0.016$). For the individual variates, ANOVA followed by post-hoc multiple comparison tests (Bonferroni, or Tamhane's T2 for heterogeneous variances) showed the following for CA-1: Kashechewan-Peawanuck ($p=0.34$), Kashechewan-Fort Albany ($p=0.01$), Peawanuck-Fort Albany ($p=0.00$); CA-2: Kashechewan-Peawanuck ($p=0.00$), Kashechewan-Fort Albany ($p=0.33$), Peawanuck-Fort Albany ($p=0.00$), and CA-3: Kashechewan-Peawanuck ($p=1.00$), Kashechewan-Fort Albany ($p=0.00$), Peawanuck-Fort Albany ($p=0.67$). Statistical results between males and females in each respective community is as follows: CA-1: Kashechewan ($p=0.001$), Fort Albany ($p=0.010$), Peawanuck ($p=0.693$); CA-2: Kashechewan ($p=0.050$), Fort Albany ($p=0.839$), Peawanuck ($p=0.205$); CA-3: Kashechewan ($p=0.370$), Fort Albany ($p=0.492$), Peawanuck ($p=0.301$); CA-4 could not be further analysed because a significant interaction was observed.

Regression analysis of CA-1 found the following slopes: Peawanuck (-0.51), Kashechewan (-0.65) and Fort Albany (-0.62; Table 5). The three communities were compared in a pair-wise fashion to determine homogeneity of slopes (AGE x LOCATION) using ANOVA (Bonferroni adjusted significance is at the 0.017 level for an experiment-wise error rate of 5 percent). Homogeneity tests of slopes for CA-1 revealed that no significant differences (p-protected value of 0.017 for multiple comparisons) of slopes existed between any of the three possible pairs of communities (Peawanuck-Kashechewan ($p=0.056$); Kashechewan-Fort Albany ($p=0.026$), Peawanuck-Fort Albany ($p=0.372$). Thus, ANCOVA was performed separately on the three pair-wise comparisons with the following results: Peawanuck-Fort Albany ($p=0.000$); Peawanuck-Kashechewan ($p=0.599$); Kashechewan-Fort Albany ($p=0.000$).

Table 4
Correspondence analysis (CA) scores of 14 organochlorines at >90% frequency of detection (relatively large negative and positive scores appear in bold).

Organochlorine					
	Correspondence Axis	CA Axis- 1	CA Axis-2	CA Axis-3	CA Axis-4
	Variance Explained	44.73%	19.41%	9.76%	8.24%
Congener 118 (µg/kg lipid)		-0.015	-0.022	**0.085**	0.022
Congener 138 (µg/kg lipid)		0.000	0.015	0.001	-0.012
Congener 153 (µg/kg lipid)		0.002	0.034	-0.010	-0.015
Congener 156 (µg/kg lipid)		**-0.139**	-0.006	0.036	-0.031
Congener 170 (µg/kg lipid)		**-0.111**	0.011	0.036	**-0.035**
Congener 180 (µg/kg lipid)		-0.048	**0.040**	-0.014	-0.027
Congener 187 (µg/kg lipid)		-0.100	0.005	0.018	**-0.036**
p'DDE (µg/kg lipid)		0.127	**0.059**	**-0.049**	0.017
p'DDT (µg/kg lipid)		**0.194**	**-0.248**	-0.025	**-0.080**
Hexachlorobenzene (µg/kg lipid)		0.095	**0.072**	**-0.044**	0.000
Mirex (µg/kg lipid)		**-0.186**	**-0.103**	**-0.088**	**0.100**
Oxy-chlordane (µg/kg lipid)		-0.009	-0.009	0.034	-0.001
Trans-nonachlor (µg/kg lipid)		0.000	0.015	0.014	-0.011
ß-HCH (µg/kg lipid)		**0.172**	-0.030	**0.123**	**0.125**

Table 5

Standardized and Unstandardized Coefficients for Age - Correspondence Analysis Axis 1 and 2

		Std. Coefficients			Unstd. Coefficient.			95% CI for B	
CA Axis 1		Beta	t	Sig.	B	R Sq.	Y-int	Lower Bound	Upper Bound
	Peawanuck	-0.51	-2.5	0.022	-0.003	0.258	0.096	-0.005	0
	Kashechewan	-0.65	-8.3	0	-0.005	0.428	0.251	-0.007	-0.004
	Fort Albany	-0.62	-7.8	0	-0.004	0.386	0.219	-0.005	-0.003
CA Axis 2	Peawanuck	-0.67	-3.8	0.001	-0.004	0.449	0.359	-0.007	-0.002
	Kashechewan	-0.22	2.2	0.031	-0.001	0.049	0.034	-0.001	0
	Fort Albany	-0.39	-4.1	0	-0.001	0.149	0.053	-0.002	-0.001

For CA-2, regression analysis of CA-2 revealed the following slopes: Peawanuck (-0.67), Kashechewan (-0.22) and Fort Albany (-0.39; Table 5). As with CA-1, the three communities were further analysed for CA-2 in pair-wise tests to determine homogeneity of slopes. The results indicated that the slopes of CA-2 with AGE for the comparison Peawanuck vs. Fort Albany were significantly different ($p=0.002$), as were the slopes for the Peawanuck vs. Kashechewan comparison ($p<0.0001$); whereas, Kashechewan vs. Fort Albany were not significantly different ($p=0.106$; Table 6). ANCOVA results for Fort Albany and Kashechewan revealed no significant difference between locations ($p=0.106$; Table 6).

CA-3 was further examined in MANCOVA with age as the covariate to examine differences between locations without the influence of age. Pair-wise post-hoc comparisons between locations were as follows: Peawanuck-Kashechewan ($p=0.814$), Kashechewan-Fort Albany ($p=0.000$) and Peawanuck-Fort Albany ($p=0.057$; Table 6).

CA axis-1 illustrates a location effect whereby residents of Fort Albany were significantly different by MANOVA (and ANCOVA, adjusted for age by single pair-wise comparisons) than people from Kashechewan and Peawanuck. People from Fort Albany had relatively higher pesticide concentrations (β-HCH and DDT, but not Mirex) and relatively lower CB (156 and 170) body burdens when compared to participants from Kashechewan and Peawanuck (Fig. 2a; Table 4). Significant sex differences were noted for Fort Albany and Kashechewan, but not Peawanuck (Fig. 2a). Specifically, females from Fort Albany and Kashechewan have relatively higher levels of DDT and ß-HCH, and lower levels of mirex and CBs (156 and 170) compared to their males counterparts (Fig. 2a).

Analysis of CA-2 scores by MANOVA and post-hoc pair-wise comparisons (and ANCOVA, adjusted for age for the pair-wise comparison of Fort Albany vs. Kashechewan) revealed that people from Peawanuck were significantly different than inhabitants of Fort Albany and Kashechewan. Peawanuck residents had relatively higher concentrations of CB180, DDE and hexachlorobenzene and relatively lower levels of DDT and mirex compared to participants from Kashechewan and Fort Albany (Fig. 2b; Table 4). Sex differences were only apparent for Kashechewan where males had relatively higher levels of CB180, DDE, and hexachlorobenzene than females from Kashechewan (Fig. 2b). Further differentiation on CA axis-2 indicates that participants from Peawanuck have a larger range of contaminant body burden relative to participants from Kashechewan and Fort Albany (Fig. 2b).

MANCOVA (adjusting for age) of CA-3 scores revealed significant location effects between Fort Albany and Kashechewan but not Peawanuck. Participants from Fort Albany had relatively higher concentrations of CB 118 but relatively lower levels of DDE, hexachlorobenzene and β-HCH than people from Kashechewan (Fig. 2c). No significant differences were observed between sexes in any of the three communities (Fig. 2c).

Table 6

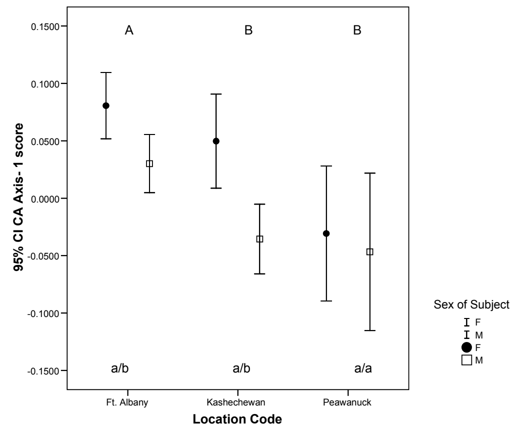
CA results for MANOVA and ANCOVA (age-adjusted)

CA Axis 1	MANOVA	P Value	DF	F Ratio	ANCOVA	P Value	DF	F Ratio
Peawanuck-Kashechewan	NSD	0.34	2	7.765	NSD (pair-wise comparison)	0.60[a]	1	0.278
Fort Albany-Kashechewan	SD	0.01	2	7.765	SD (pair-wise comparison)	0.00[a]	1	14.27
Fort Albany-Peawanuck	SD	0.00	2	7.765	SD (pair-wise comparison)	0.00[a]	1	13.65
CA Axis 2								
Peawanuck-Kashechewan	SD	0.00	2	43.16	Age could not be adjusted[b]			
Peawanuck-Fort Albany	SD	0.00	2	43.16	Age could not be adjusted[b]			
Fort Albany-Kashechewan	NSD	0.33	2	43.16	NSD (pair-wise comparison)	0.11[a]	1	2.64
CA Axis 3								
Peawanuck-Kashechewan	NSD	1.00	2	6.10	NSD	0.81	2	7.22
Peawanuck-Fort Albany	NSD	0.67	2	6.10	NSD	0.057	2	7.22
Fort Albany-Kashechewan	SD	0.00	2	6.10	SD	0.00	2	7.22

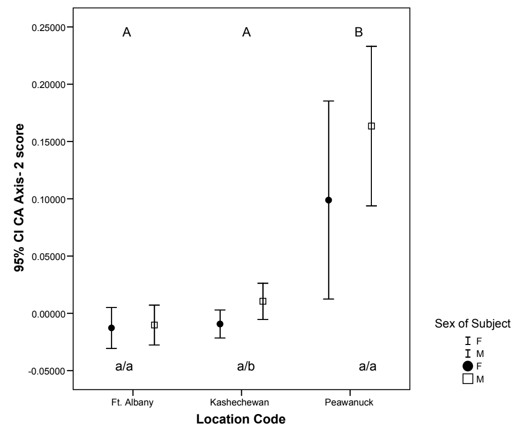
[a]Adjusted p values (p=0.017).

[b]Age could not be adjusted because heterogeneity of slopes was observed.

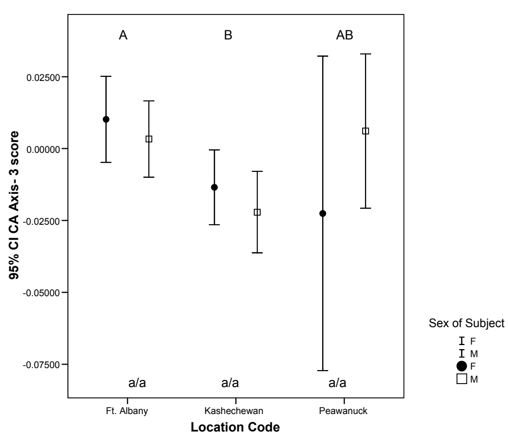
2a



2b



2c



2d

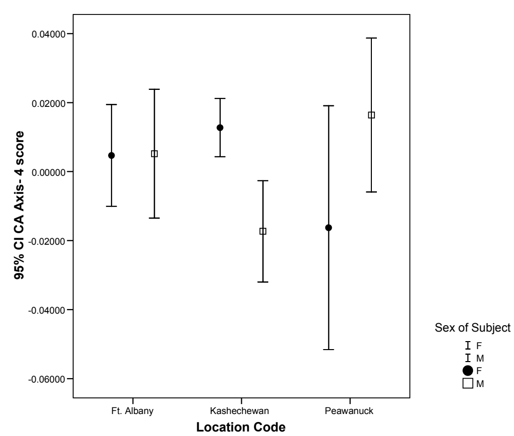


Fig. 2. Means for correspondence analysis scores of organochlorines, by location and sex. Within any plot, locations sharing the same upper case letter (A, B, or C) do not differ significantly in correspondence axis score. Sexes sharing the same lower case letter (a or b) at a location do not differ significantly in correspondence axis score.

2.3. Discussion

2.3.1. Qualitative comparison to other studies

With the exception of DDT, *oxy*-chlordane, and ß-HCH, organochlorine plasma levels in Peawanuck females were comparable or considerably higher relative to Inuit women living in the west/central Northwest Territories and in other arctic communities (Table 7). For example, plasma levels of DDE for females from Peawanuck were nearly six times greater than the levels reported for Inuit females from the Northwest Territories study and were considerably higher than the DDE levels reported for other females living in arctic communities (Table 7). This finding was unexpected because people of Peawanuck have been reported (Prevett et al. 1983; Berkes et al. 1994) not to consume marine mammals and rarely consumed piscivorous birds (a source also high in organochlorines; AMAP 1998); while, the Inuit of the Northwest Territories occasionally consume marine mammals (a source known to be heavily contaminated with organochlorines). Nevertheless, the consumption of traditional foods by women of Peawanuck may impact the body burden of DDE found in their plasma.

At the mouth of the Winisk River (where Peawanuck FN members have reported fishing activities), DDE was detected only in trace amounts in samples from northern pike (*Esox americanus*; n = 5; mean concentration: 0.004 µg/g wet tissue), not detected at all in common white sucker (*Catostomus commersoni*; n = 3; detection levels not quantifiable; McCrea and Fischer 1983), and at low concentrations in whitefish (*Coregonus clupeaformis*; n = 15; range: 0.150-0.979 µg/kg wet tissue; Tsuji et al. unpublished data); all are species consumed by the people of Peawanuck (Berkes et al. 1994). In migratory waterfowl of the western Hudson and James Bay region, DDE has been detected frequently in geese (Canada goose, *Branta Canadensis*; snow goose, *Chen caerulescens caerulescens*; 66-86%; n = 80, range: 0.001-3.280 µg/kg; Tsuji et al. 2007) and dabbling ducks (mallard duck, *Anas platyrhynchos*; northern pintail duck, *Anas acuta*; >90%; n = 56, range: 0.001-8.046 µg/kg; Tsuji et al. 2007). However, the concentration of DDE is minimal in these birds and more specifically, the concentrations found in birds from the Winisk area are at trace levels (n = 30, range:

Table 7
Female blood plasma levels of persistent organic pollutants (geometric means, µg/kg lipid) all analysed at the Centre de toxicologie du Quebec.

Organochlorine[a]	Canada NWT[b] (n=67)	FA[c] (n=48)	Kash[d] (n=48)	Peawanuck[e] (n=10)	Greenland[f] (n=117)	Sweden[g] (n=40)	Norway[h] (n=60)	Iceland[i] (n=40)	Russia[j] (n=51)
p'p-DDE	133.0	306.0	316.0	796.60	407.0	84.0	79.4	113.2	411.9
p'p-DDT	7.9	10.5	8.6	3.9	15.0	2.4	3.0	4.0	48.3
Hexachlorobenzene	55.1	19.1	22.4	71.7	97.6	15.6	23.1	41.0	62.8
Oxy-chlordane	27.8	11.3	11.3	17.0	60.8	1.9	3.7	6.6	3.3
Trans-nonachlor	30.5	13.5	15.6	32.2	110.0	3.8	6.8	12.2	11.5
Mirex	4.5	12.4	21.5	28.6	9.1	1.1	1.4	1.9	1.4
ß-HCH	9.3	6.9	5.6	4.5	18.5	9.2	8.1	32.1	222.5
Aroclor 1260	439.0	421.0	463.0	1005.9	1577.0	606.0	458.0	590.0	570.0
CB 118	8.8	13.8	16.4	27.63	33.7	11.4	10.5	16.2	31.3
CB 138	29.6	31.8	37.0	56.70	118.0	47.4	35.1	45.7	49.8
CB 153	54.7	50.2	53.6	137.0	185.0	69.3	53.0	67.8	59.8
CB 156	5.0	7.7	9.8	17.0	15.4	8.6	6.3	8.0	9.0
CB 170	9.7	14.0	15.1	34.75	34.4	18.6	12.1	16.4	10.0
CB 180	26.6	32.8	40.6	140.70	82.5	34.1	25.3	34.4	20.5
CB 187	10.2	14.9	18.4	44.9	41.3	11.0	10.3	13.3	8.1
Sum of 14 CBs	167.0	165.0	186.0	505.5	571.0	222.0	173.0	230.0	231.0

[a]Organochlorines detected >90% of the samples in the present study.
[b]Inuit women (child bearing) from west/central Northwest Territories (AMAP 1998).
[c]First Nation women from Fort Albany, Ontario (Tsuji et al. 2006).
[d]First Nation women from Kashechewan, Ontario (Tsuji et al. 2006).
[e]First Nation women in the present study from Peawanuck, Ontario (Tsuji et al. 2006).
[f]Women (child bearing) from the Disko Bay region (AMAP 1998).
[g]Women (child bearing) from Kiruna (AMAP 1998).
[h]Women (child bearing) from Hammerfest and Kirkenes (AMAP 1998).
[i]No further data given (AMAP 1998).
[j]Women (child bearing) from Nikel (AMAP 1998).

0.001-0.004 µg/kg; Braune et al. 1999); thus, making this dietary source an unlikely factor in explaining the observed DDE levels in Peawanuck subjects.

It should be noted that DDT was used extensively in and around Site 500 primarily to combat mosquitoes and black fly populations during the construction and operational years of Site 500 (ESG 1999a). Since, DDT has a variable half-life of around 10 years and that DDE is the metabolite of DDT (AMAP 1998), it is conceivable that the elevated DDE levels in the more elderly Peawanuck females may be the result of extensive DDT use in the late 1950s and early 1960s (ESG 1999a), as the range for DDE concentration in plasma is large (122.0-3809.5 µg/kg lipids). It is clear, however, that more comprehensive research is needed to identify DDE levels in other fish species and other wild game in the Peawanuck-Winisk area to further understand the source of human contamination.

Similar to DDE, concentrations of PCBs in Peawanuck females were relatively elevated. Recent studies of breast tissue (pectoral muscle) in migratory waterfowl (Canada goose and lesser snow goose) of the Hudson and James Bay region report relatively low concentrations of PCBs (n = 131, sum of PCB congeners; range: 0.0001-2.842 µg/kg; Tsuji et al. 2007). However, concentrations of PCBs were much higher in the intra-abdominal fat and skin of migratory game birds of the region, with the skin and fat of dabbling ducks (mallard and northern pintail duck) being an important source of PCBs (n = 39, range: 0.015-47.469 µg/kg; Tsuji et al. 2008). By contrast, McCrea and Fischer (1983) found only trace levels of PCBs in northern pike (n = 5; sum of PCB congeners; mean concentration: 0.01 µg/g wet tissue) and common white sucker fish (n = 3; sum of PCB congeners; mean concentration: 0.01µg/g wet tissue) samples collected from the mouth of the Winisk River; while, low concentrations of PCBs were present in whitefish collected by MCRL Site 500 (whitefish; n = 15; sum of PCB congeners; range: 0.12-1.6 µg/kg wet weight; Tsuji et al. unpublished data). As well, animal tissue captured in proximity to MCRL Site 500 demonstrated low concentrations of PCBs (Sum of 16 CBs; Table 8).

Differences were also observed when comparing Peawanuck FN female body burden of OCs to that found in Kashechewan and Fort Albany FN females (Table 7); the Peawanuck females typically had relatively high concentrations of all OCs except for DDT and β-HCH (Table 7). This finding was unexpected because all three communities subsist on similar foods; however, the more northerly communities (Kashechewan and Peawanuck) ate more traditional foods on a community basis (Table 9). Briefly, the mean catch-per-harvester in Peawanuck was similar to Kashechewan except for fish; while these two communities had larger mean catch-per-harvester than that of Fort Albany (Berkes et al. 1994).

It is worth noting that males from Peawanuck did not consistently have relatively higher concentrations of OCs than men from Fort Albany and Kashechewan (Table 10), as did the women from Peawanuck when compared to females from Fort Albany and Kashechewan (Table 7). For some OCs (DDE, HCB, *trans*-nonachlor), males from Peawanuck were found to have higher concentrations than males from Fort Albany and Kashechewan, but the relationship was reversed for DDT (Table 10). *Oxy*-chlordane and ß-HCH were of comparable magnitude for the three groups of males. No consistent pattern was seen for total PCBs.

The DDE/DDT ratios reflect time since last exposure to DDT, because DDT is metabolized to DDE; low ratio values indicate relatively recent DDT exposure (Tsuji et al. 2006). The significantly lower DDE/DDT ratio observed for Fort Albany participants indicates exposure sources that have relatively high levels of DDT compared to Kashechewan and Peawanuck participants. As DDT has not been used in Ontario for almost forty years (Frank et al. 1993), it is plausible that the high DDE/DDT ratio expressed for Peawanuck participants is the result of historical exposure to DDT during the operational years of MCRL Site 500 and its breakdown to DDE. Another explanation relates to the people of Peawanuck being exposed to large amounts of DDE through a traditional diet and little DDT through a traditional diet and other environmental exposure routes.

Table 8

Sum of 16 CBs for animal tissue (ng/g wet weight) from Site 500 (Winisk)

Organism[a]	Range - Sum of 16 CBs[bc]
Goose Tissue (n=5; *Branta candensis interior*)	0.12-0.20
Muskrat Tissue (n=5; *Ondatra zibethicus*)	0.17-0.35
Fox Tissue (n=1; *Alopex lagopus*)	2.6233
Caribou Tissue (n=1; *Rangifer tarandus*)	0.15478
Rabbit Tissue (n=1; *Lepus arcticus*)	0.14116
Greater Yellow-legs Tissue (n=1; *Tringa melanoleuca*)	3.5377
Common Snipe Tissue (n=1; *Gallinago gallinago*)	3.4519

[a]Muscle Tissue.

[b]Sum of 16 CBs (52, 83+99, 105, 118, 128+166, 153+168, 156+157, 170, 180+193, 183, 187)

[c]Congeners 28, 101, and 138 were not measured.

Table 9

Mean catch per harvester among harvesters from Peawanuck, Kashechewan and Fort Albany[a]

Communities	Moose	Caribou	Waterfowl	Trapping	Small Game	Fishing
Fort Albany	1.8	7.4	50.7	12.2	15.9	63.3
Kashechewan	1.7	3.9	139.7	63.3	90.9	100.8
Peawanuck	1.2	7.8	170.6	64.6	101.6	235.5

[a]Berkes et al. 1994.

Table 10

Male plasma levels of persistent organic pollutants (geometric means, μg/kg lipids) all analysed at the Centre de toxicologie du Quebec

Organochlorine[a]	FA[b] (n=48)	Kashechewan[c] (n=48)	Peawanuck[d] (n=10)
p'p-DDE	331.1	410.9	561.7
p'p-DDT	9.9	7.4	0.9
Hexachlorobenzene	21.3	28.6	53.9
Oxy-chlordane	13.2	17.5	17.0
Trans-nonachlor	17.5	25.4	30.1
mirex	19.7	37.3	19.0
ß-BHC	7.4	4.4	5.8
CB 118	10.9	15.0	13.7
CB 138	38.6	60.2	40.6
CB 153	64.9	92.1	106.6
CB 156	9.8	16.8	15.6
CB 170	19.0	26.3	30.6
CB 180	47.1	78.5	121.1
CB 187	19.0	33.0	31.6
Sum of 14 CBs	237.3	360.1	391.6

[a]Organochlorines detected >90% of the samples in the present study.

[b]First Nation men in the present study from Fort Albany, Ontario.

[c]First Nation men in the present study from Kashechewan, Ontario.

[d]First Nation men in the present study from Peawanuck, Ontario.

2.3.2. Correspondence analysis

Analysis of correspondence axes scores revealed significant differences between communities. On CA-1, Fort Albany was unique; while, on CA-2, Peawanuck was unique. On CA-3 none of the communities were unique. It is interesting that the only community that was not unique on any of the CA axes was the control community of Kashechewan.

CA-1 results suggest that people of Peawanuck were not exposed to DDT through their diet or other environmental routes as body burden of DDT was relatively small. As little DDT contamination at Site 500 has been recently reported (ESG 1999a), the low body burdens of DDT in people of Peawanuck were not unexpected. However, CA-2 scores suggest that DDE body burden is relatively high in residents of Peawanuck which is likely related to the more traditional diet of this community compared to the other two First Nation communities (Table 1). Perhaps past exposure to DDT (and subsequent metabolization to DDE) on MCRL Site 500 may be another factor, as previously suggested.

What is interesting when both CA-1 and 2 are examined together is that Fort Albany and Peawanuck are significantly different from each other on these axes and this separation of communities is partially based on the relative amounts of PCB congeners 156 and 170 (CA-1) and PCB congener 180 (CA-2). The significant differences between these two groups may be related to exposure to different sources of PCBs at MCRL sites: most of the PCB contamination (soil and vegetation) at MCRL Site 050 has been characterized as Aroclor 1260 (ESG 1999a); while at Site 500 there was little soil contamination with the main PCB source of contamination being the paint chips which were characterized as Aroclor 1254. PCB source identification can be accomplished through the use of PCB congeners and multivariate statistics and should be contemplated in the future to clarify this matter.

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Chapter 3. Conclusions

3.1. Methodical Issues

Conducting research in sub-arctic Ontario poses many challenges that can be associated with weather, travel, cultural differences, and other logistical issues. The successful attributes of past studies similar to this project were incorporated into this study to ensure that the above challenges would be minimized. Participation among First Nation communities can be extremely problematic; however, this can often be overcome with direct and frequent interaction with the community leaders, study participants and the health care providers that are facilitating the collection of samples. Further, explaining the significance of the project and the overall importance concerning the health and wellness of fellow community members can ensure healthy participation, which allows researchers to overcome this barrier (e.g., Tsuji et al. 1999; 2006). Past research conducted by Tsuji et al. (1999, 2006), suggests that FN people are highly motivated and cooperative when the importance of the study is lucidly explained and the reliability and trust of the researcher (s) is grounded within the communities.

Because of the confounding nature of the traditional diet, human organochlorine body burden results may not be entirely representative of the surrounding study sites. It should be understood that because of the dynamic nature of the biota inhabiting this region, external factors such as migratory routes of animal species might influence the results with respect to analyzing geo-proximity to abandoned radar sites. For example, all three communities consume caribou (*Rangifer tarandus*). Caribou are herbivorous species that migrates hundreds of kilometres annually throughout the arctic and sub-arctic landscape (AMAP 1998). Because of this phenomenon, caribou that are hunted in the study region may not accurately represent the study site conditions because they consume primary producers located throughout a vast region. Therefore, migratory species in the study region may not accurately represent the localized conditions surrounding each respective study community.

All three communities rely on traditional methods of food acquisition (i.e., hunting and gathering) and their dietary consumption behaviours are very similar (i.e., they don't rely on marine mammals; Table 9). Therefore, although the three communities are isolated from one another and are located in different geographical areas, their environments and hunting behaviours are relatively comparable with one another, allowing for valid comparisons between these communities. It should be noted that the Peawanuck sample size (20) is considerably smaller than the sample sizes from Kashechewan (98) and Fort Albany (99) and as a result, statistical power when comparing the three communities is compromised. The reason for the small sample size is because Peawanuck FN is a much smaller community. However, proportionally speaking, the Peawanuck sample size represents roughly 11% of the community while the Kashechewan and Fort Albany sample size represents 7% and 12%, respectively. Therefore, although statistical power is lost with the small sample size from Peawanuck, it is proportionally equivalent to the sample sizes from the other two communities.

3.2. Qualitative Conclusions

The qualitative analysis component of the study suggests body burdens of OCs for females from Peawanuck participants were unique when compared to Fort Albany and Kashechewan. With the exception of DDT and ß-HCH, Peawanuck females had considerably higher levels of organochlorines than that of females from Fort Albany and Kashechewan. Qualitative analysis suggested that female study participants from Peawanuck had considerably elevated levels of CBs 118, 138, 153, 170, 180, 187, sum of 14 CBs, Aroclor 1260, DDE, hexachlorobenzene, and *trans*-nonachlor compared to females from Kashechewan and Fort Albany. Conversely, females from Peawanuck had relatively less DDT and ß-HCH than females from Fort Albany and Kashechewan. In comparison to Aboriginal women from a Northwest Territory study, Peawanuck female plasma levels were considerably higher for CBs 118, 138, 153, 156, 170, 180, 187, sum of 14 CBs, Aroclor 1260, DDE, hexachlorobenzene, and mirex. Internationally, Peawanuck females were shown to have higher body burdens of DDE, CB 180 and mirex compared to a past study from Greenland. In comparison to female plasma levels from other circumpolar locations (i.e., Sweden, Norway, Iceland and Russia), Peawanuck females reported considerably higher levels of DDE, hexachlorobenzene, *oxy*-chlordane, *trans*-nonachlor, mirex, Aroclor 1260, CBs 153, 170, 180, 187, and sum of 14 CBs.

Qualitative intra-study comparison revealed that Peawanuck males had relatively elevated plasma levels of DDE, hexachlorobenzene, CB 153 and 180 and sum of 14 CBs than males from Fort Albany and Kashechewan. For DDT, males from Kashechewan and Fort Albany had as much as seven-times the amount than that of males from Peawanuck.

3.3. Quantitative conclusions

Analysis of correspondence axes scores revealed significant differences between communities. Results are suggestive but not conclusive that MCRL Site 500 may have influenced body burdens of Peawanuck residents. As both Fort Albany and Peawanuck were associated with MCRL sites, it is surprising that these two communities were never grouped together as being different from Kashechewan, the control community. As suggested by Tsuji et al. (2006), it is difficult to tease apart the input from point sources of OCs and the contribution of OCs from a traditional diet unless a unique signature is involved.

3.4. Recommendations

It is recommended that FN residents of Peawanuck do not harvest and/or hunt in proximity to MCRL Site 500 until more conclusive data concerning source of contamination becomes available. Existing wildlife data does not explain the elevated levels seen in Peawanuck blood plasma; therefore, issuing a warning against the consumption of specific foods is not possible. However, Tsuji et al. (2008) did report that the skin and fat of dabbling ducks from the western James Bay and south-western Hudson Bay region could be a source of PCB contamination; reducing the consumption frequency of fat and skin from dabbling ducks is recommended.

Further research concerning organochlorine concentrations in wildlife and fish is needed in the Hudson-James Bay Lowland area to identify potential sources of contamination. As well, future research needs to closely examine the community of Peawanuck to understand why it reported the OC levels in which it did. The suggested research should examine behavioural (e.g., specific genre and quantity of food consumption, specific [swimming, hunting, etc.] activity around Site 500, etc.) and lifestyle (e.g., smokers, exercise frequency, etc.) patterns at the individual level; in an attempt, to identify variables associated with elevated plasma levels of OCs. Furthermore, a more comprehensive examination of the soil and plant material in and around MCRL Site 500 needs to be undertaken. Further examining water quality in the region may be of importance in further understanding all potential sources of contamination. Without sufficient data pertaining to wildlife contamination, it is difficult to speculate on the source of OC contamination that has been manifested in the body burden of Peawanuck study participants.

The construction of the Mid Canada Radar Line was entirely a Canadian endeavour (ESG 1999); therefore, it is the responsibility of the Canadian government. To this day, Site 050 is the sole radar station to be successfully remediated; it is recommended that all MCRL sites are remediated in the near future. To achieve this, it is recommended that the Canadian government establish a political framework that would seek to promptly remediate all MCRL sites.

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