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QUANTITATIVE RESEARCH

# Socio-economic inequalities in blood mercury (Hg) and serum polychlorinated biphenyl (PCB) concentrations among pregnant Inuit women from Nunavik, Canada

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## Abstract

**Objective** We examined the relationships between socio-economic characteristics and mercury (Hg) and polychlorinated biphenyl (PCB) concentrations among pregnant Inuit women from Nunavik.

**Method** We used biomonitoring data from 208 pregnant Inuit women recruited in the 14 villages of Nunavik between September 2011 and December 2013. Blood samples were collected to monitor levels of blood Hg and serum congener PCB-153 (surrogate of total PCB concentration). Ratio of omega 3/omega 6 polyunsaturated fatty acids, a validated biomarker of marine country food consumption, was also measured in red blood cell membranes to determine maternal dietary profile. Data on socio-economic characteristics (income and education), health-related lifestyles, and reproductive history were collected through questionnaires. Association between socio-economic characteristics and contaminant concentrations was assessed using linear regressions.

**Results** We observed a significant inverse relationship between education and Hg levels. Lower concentrations of Hg were observed among women who had completed high school compared to women who had not completed high school. However, no association was observed between level of education and concentration of PCBs.

**Conclusion** Socio-economic disparities in maternal exposure to Hg exist in Nunavik. Further research is needed to determine whether environmental health inequalities also exist in other subgroups of the Nunavik population and in other Indigenous communities in Canada.

## Résumé

**Objectif** Nous avons examiné les associations entre les caractéristiques socioéconomiques et les concentrations en mercure (Hg) et biphényles polychlorés (BPCs) chez les femmes enceintes Inuit du Nunavik.

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**Méthode** Un total de 208 femmes enceintes Inuites ont été recrutées entre septembre 2011 et décembre 2013 dans les 14 villages du Nunavik. Des échantillons de sang ont été prélevés pour mesurer la concentration sanguine en Hg et la concentration sérique en congénère BPC-153 (marqueur de la concentration totale en BPCs) des participantes. Le ratio des acides gras polyinsaturés oméga 3/oméga 6, un biomarqueur valide de la consommation d'aliments marins, a également été mesuré dans les membranes des globules rouges pour déterminer le profil alimentaire des participantes. Des informations sur les caractéristiques socioéconomiques (revenu et éducation), les habitudes de vie et l'historique de reproduction des participantes ont aussi été recueillies par le biais de questionnaires. Les associations entre les caractéristiques socioéconomiques et les concentrations en contaminants ont été examinées à l'aide de régressions linéaires.

**Résultats** Une relation inverse et statistiquement significative entre le niveau d'éducation et la concentration en Hg a été observée. Les femmes qui avaient complété leurs études secondaires présentaient une concentration sanguine en Hg plus faible que celles qui n'avaient pas complété leurs études secondaires. En revanche, aucune association n'a été observée entre le niveau d'éducation et la concentration en BPCs.

**Conclusion** Des disparités socioéconomiques dans l'exposition maternelle au Hg existent au Nunavik. Des recherches supplémentaires sont nécessaires pour déterminer si des inégalités en matière de santé environnementale existent également dans d'autres sous-groupes de la population du Nunavik et dans d'autres communautés autochtones du Canada.

**Keywords** Socio-economic characteristics · Environmental exposure · Pollutants · Inuit · Pregnant women · Mercury · Polychlorinated biphenyls

**Mots-clés** Caractéristiques socio-économiques · Exposition environnementale · Polluants · Inuit · Femmes enceintes · Mercure · Biphényles polychlorés

## Introduction

Environmental health inequalities can be defined as "situations in which a specific social group is disproportionally affected by environmental hazards" (Brulle and Pellow 2006) (p. 2). One underlying hypothesis of environmental health inequalities is that socio-economic factors (e.g., income, education, occupation, or ethnicity) are determinants of population levels of exposure to environmental hazards, such as environmental contaminants. A second hypothesis is that minorities or socially disadvantaged groups are disproportionally exposed and affected by environmental hazards compared to dominant or more advantaged groups (Belova et al. 2013). Several studies conducted among pregnant women from the USA, UK, and Spain evidenced the existence of socio-economic disparities in chemical exposure (Borrell et al. 2004; Miranda et al. 2011; Tyrrell et al. 2013; Vrijheid et al. 2012; Sanders et al. 2012; Taylor et al. 2013); however, comparison of study findings reveals that direction and statistical significance of these associations vary depending on the chemical, the socio-economic characteristic, or the population considered.

Circumpolar areas were considered for a long time as pristine environments, but studies showed that atmospheric and oceanic currents transport chemicals from industrialized southern regions to Arctic regions (Tenenbaum 1998; Durnford et al. 2010). Several of these toxicants are bioaccumulated and biomagnified in the marine food chain and reach high concentrations in some predatory fish and marine mammals at the top of the Arctic food web (Van Oostdam et al. 2005; Braune et al. 2015). Among these, mercury (Hg) (found under methylated form) and polychlorinated biphenyls (PCBs) are classified by the World Health Organization among the "ten chemicals of major public health concern" (World Health Organization (WHO) 2017).

Studies conducted in the 1980s–1990s in Nunavik—one of the four Inuit regions in the Canadian Arctic located in the province of Quebec (Fig. 1)—showed that Nunavimmiut (Inuit of Nunavik) presented significantly higher levels of Hg and PCBs in biological samples compared to the southern Quebec population (Charlebois 1978; Dewailly et al. 2001; Dewailly et al. 1989). Ingestion of marine country food was identified as the main route of exposure: beluga meat, seal liver, and Lake trout were identified as the main sources of Hg (Lemire et al. 2015), while the fat of seals, belugas, and other whales constitutes the primary source of PCBs (Dewailly et al. 1993; Kuhnlein et al. 1995). Comparison of biological samples collected in the 1990s revealed that Hg and PCB levels among Nunavimmiut pregnant women were respectively 18 times and 3 times higher than those among pregnant women from southern Quebec (Muckle et al. 2001a).

Pregnant woman exposure to Hg and PCBs is a concern for public health authorities. Accidental exposure of pregnant women to high doses of Hg and PCBs through the diet revealed that these toxicants can cross the placenta barrier and disturb fetal neurodevelopment (Amin-Zaki et al. 1974; Harada 1978; Lai et al. 2001). Prenatal exposure to lower doses of Hg and PCBs was also associated with neurodevelopmental


**Fig. 1** Map of Nunavik, Quebec, Canada (Makivik Corporation 2017)

and motor impairments during childhood (Grandjean and Landrigan 2006; Jurewicz et al. 2013), including among children from Nunavik (Boucher et al. 2014; Ethier et al. 2012; Jacobson et al. 2015). Temporal trend analyses suggest that maternal Hg and PCB levels among pregnant Nunavimmiut women significantly decreased from 1992 to 2007 (Donaldson et al. 2010; Dallaire et al. 2003). Investigations are underway to explain this decline that could be due to a decrease of marine country food consumption and/or a decrease of Hg and PCB levels in the environment and country foods (Braune et al. 2015; Donaldson et al. 2010; Dallaire et al. 2003; Blanchet and Rochette 2008; Proust et al. 2014; Rigét et al. 2010). While studies were conducted to identify anthropometric, dietary, lifestyle, and reproductive characteristics associated with this exposure, the impact of socio-economic characteristics on Hg and PCB levels has not been looked at so far.

Disparities in maternal exposure to Hg and PCBs related to socio-economic characteristics were reported in other populations (Borrell et al. 2004; Miranda et al. 2011; Vrijheid et al. 2012; Arbuckle et al. 2016; Fisher et al. 2016; Ibarluzea et al. 2011; Wolff et al. 2005). In contrast with the second hypothesis of environmental health inequalities, several studies suggested that pregnant women with higher socio-economic characteristics might be more likely to present higher levels of Hg and PCBs compared to women with lower socio-economic characteristics (Borrell et al. 2004; Miranda et al. 2011; Vrijheid et al. 2012; Arbuckle et al. 2016; Fisher et al. 2016; Ibarluzea et al. 2011; Wolff et al. 2005). Higher education levels and household income were associated with significantly higher levels of blood Hg and serum PCBs among pregnant women from Canada (non-Inuit) (Arbuckle et al. 2016; Fisher et al. 2016) and the US (Borrell et al. 2004; Miranda et al. 2011; Wolff et al. 2005). Similar results were observed in Spain, where pregnant women with higher education or social class (based on participant's current or last occupation) exhibited significantly higher blood Hg and serum PCB levels compared to women with lower education or social class (Vrijheid et al. 2012;

Ibarluzea et al. 2011). In contrast, two studies conducted among Swedish (Glynn et al. 2007) and American pregnant women (Borrell et al. 2004) did not report a significant influence of maternal education on serum PCB levels.

As highlighted by Vrijheid et al. (Vrijheid et al. 2012), examining the relationships between contaminant blood levels and socio-economic factors in various contexts/populations might be helpful to test the underlying assumptions of environmental health inequalities. Further, determining whether there are subgroups among pregnant Nunavimmiut women—or generally speaking among pregnant Indigenous women—more vulnerable to Hg and PCB exposure is also relevant for researchers, public health authorities, and communities concerned by reduction of social health disparities.

The objective of this study is to examine the relationships between socio-economic characteristics and blood Hg and serum PCB levels among pregnant Nunavimmiut women. In line with the environmental health inequality assumptions, we hypothesize that socio-economically advantaged pregnant women will exhibit lower blood Hg and serum PCB concentrations compared to socio-economically disadvantaged pregnant women.

## Methods

### Population

In Nunavik, approximately 12,000 Nunavimmiut live in the 14 villages scattered along Hudson Bay, Hudson Strait, and Ungava Bay coasts (Institut de la Statistique du Québec 2017a). Socio-economic and demographic conditions in Nunavik are different from those prevailing in southern Quebec (Nunavik Regional Board of Health and Social Services 2011). The fertility rate in Nunavik is higher compared to that in southern Quebec (Nunavik Regional Board of Health and Social Services 2011). On average, 330 births occur per year during the 2010s in Nunavik (Institut de la Statistique du Québec 2017b). In 2006, more than 52% of Nunavimmiut aged 25 and older had not completed high school (Nunavik Regional Board of Health and Social Services 2011). Unemployment rate was twofold higher compared to that of southern Quebec and particularly high among Nunavimmiut between 15 and 24 years of age (27%). In 2005, the average annual income of Nunavimmiut women was $22,912 (Nunavik Regional Board of Health and Social Services 2011). Recent information on income by level of education among pregnant Nunavimmiut women is not available. However, a survey conducted across Canada in 2012 showed that median annual employment income of Inuit women who not had completed high school ranged from $10,000 to $20,000, while it ranged from $30,000 to $40,000 among those who have completed high school (Bougie et al. 2013).

### Study design and data collection

Data are from a sample of 208 pregnant Nunavimmiut women enrolled from September 2011 to December 2013 as a part of an ongoing biomonitoring project funded by the Northern Contaminants Program and managed by Indigenous and Northern Affairs Canada (Government of Canada 2016a). The overall objective of the 2011–2013 biomonitoring project was to describe levels of food chain contaminants in blood of pregnant women and assess spatial and temporal trends of contaminants found in maternal blood. Specific objectives were to compare the contaminant levels to previous results from 10 to 20 years ago, follow trends of nutrients (such as polyunsaturated fatty acids) to interpret contaminant trends, detect and quantify new contaminants that were not observed before, detect effects from contaminants on growth indices, and use the monitoring tool for evaluation purposes (nutritional policies, smoking, etc.). This last objective encompasses all analyses to better understand and identify the significant determinants of pollutant levels in maternal blood, such as socio-economic characteristics.

The data collection consisted of a blood sampling for environmental contaminant analyses and for measurement of omega-3 and omega-6 polyunsaturated fatty acids (n-3 and n-6 PUFAs) content in red blood cell membranes. Blood sampling was immediately followed by completion of an interviewer-administered questionnaire to retrieve information on common indicators of socio-economic characteristics, maternal health-related lifestyles, and reproductive history. We proposed to use these data for examining associations between socio-economic characteristics and blood Hg and serum PCB levels among pregnant Nunavimmiut women.

Recruitment and data collection were carried out during a prenatal visit to local health centres by a trained French/English-speaking research nurse accompanied, when required, by a local interpreter (Inuktitut/French or English). Women aged 18 years and older, self-identifying as Inuk and living in one of the 14 villages, were included, regardless of their stage of pregnancy. Because of logistical difficulties encountered during the implementation of the biomonitoring project in local communities in the first year (Dewailly et al. 2012), only 17 pregnant women were recruited in 2011. Most of the participants were recruited in 2012 ($n = 95$) and 2013 ($n = 96$); refusal rates for these years were respectively 20.8% and 24.6%.

### Ethical considerations

All participants were provided information on the objectives of 2011–2013 biomonitoring project and signed an informed consent form, asking whether they agree to provide blood samples for measurement of contaminants and nutrients, as well as information on their socio-economic characteristics, maternal health-related lifestyles, and reproductive history. The 2011–2013 biomonitoring protocol was approved by research ethics committee from Centre Hospitalier Universitaire de Québec Research Centre and the Nunavik Nutrition and Health Committee (NNHC). The proposal to conduct the current study and the final manuscript were also reviewed and approved by the NNHC.

The NNHC is a multiple stakeholder group composed of Inuit and non-Inuit representatives from local organizations concerned about nutrition, contaminants, environment, and public health issues. Established in 1989, this committee has been implemented to "facilitate and provide guidance for research on health nutrition and contaminants, so that the needs and expectations of Nunavimmiut are met" (Nunavik Regional Board of Health and Social Services 2015). The NNHC acts as "the authorized review and advisory body for health and nutrition issues in the region[...]" (Government of Canada 2016b). More specifically, it serves "as a liaison for researchers and agencies, directs work on priority issues, communicates with and educates the public on health and environment topics and research projects, and represents Nunavik interests at the national and international levels" (Government of Canada 2016b).

## Dependent variables

The Centre de Toxicologie du Québec of Institut National de Santé Publique du Québec (INSPQ) carried out Hg and PCB analyses. Quality and accuracy of analytical methods were ensured by ISO/IEC 17025 accreditation of this laboratory by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) and its involvement in different inter-laboratory comparison programs for metals and persistent organic pollutants.

The whole blood sample for Hg determination (3 mL) was collected in a vacutainer containing ethylenediaminetetraacetic acid (EDTA), transferred in a plastic vial, and stored at − 80 °C until time of analysis. Total mercury in blood samples was measured by inductively coupled plasma mass spectrometry (ICP-MS) on an ELAN DRC II system (Perkin Elmer), as previously described (INSPQ, method M-572) (Fontaine et al. 2008).

For PCB analysis, the whole blood sample (10 mL) was collected in a vacutainer without anti-coagulant, kept at room temperature for a few hours, and then centrifuged. The serum was transferred in a glass vial, pre-washed with hexane, and stored at − 20 °C until time of analysis. Concentrations of PCBs (and other organochlorines) were measured as previously described (INSPQ, method E-458) (Azandjeme et al. 2014). Serum concentration of PCB congener 153 (PCB-153) was used as a surrogate of total PCB concentration (Muckle et al. 2001b). Limits of detection for Hg and PCB-153 were respectively 0.1 μg/L of blood and 0.01 μg/L of serum.

## Independent variables

**Socio-economic characteristics** A questionnaire was used to retrieve information on the highest level of education attained, personal and family income before taxes, and other deductions. Given the distribution of socio-economic indicators in the sample, education level was grouped into two categories: high school not completed versus high school completed. Annual income (CAD$) was classified in two categories: < $20,000 versus ≥ $20,000.

## Covariates

Omega-3 polyunsaturated fatty acids (n-3 PUFAs) and omega-6 polyunsaturated fatty acids (n-6 PUFAs) are indicators of levels of marine country food consumption and store-bought food consumption, respectively. Because dietary questionnaires were not administered, we used the n-3/n-6 PUFA ratio in red blood cell membranes, a validated biomarker of individual levels of marine country food consumption (Deutch et al. 2004), as a surrogate of marine country food consumption.

The Lipid Research Centre of CHU de Québec Research Centre – Université Laval carried out the PUFA analyses. Fatty acid composition was determined in erythrocyte membranes. A 600-μL aliquot of red blood cells was thawed at room temperature, centrifuged at 3000×*g* for 5 min, and washed three times with a 0.9% saline solution. Lipids were extracted with chloroform/methanol (2:1, by volume). Then, extracted lipids were methylated with methanol/benzene 4:1 (*v*/*v*) and 200-μL acetyl chloride. The fatty acid profile of erythrocyte membranes was determined by gas chromatography using a HP 5890 gas chromatograph equipped with an automated injector 7673A and coupled to a flame ionization detector (Hewlett Packard, Toronto, Canada). The detailed procedure is described elsewhere (Rochette and Blanchet 2007). Total n-3 PUFAs are calculated as the sum of 18:3 + 18:4 + 20:3 + 20:4 + 20:5 + 22:5 + 22:6 PUFAs and total n-6 PUFAs as the sum of 18:2 + 18:3 + 20:2 + 20:3 + 20:4 + 22:2 + 22:4 + 22:5 PUFAs (Proust et al. 2014).

Other covariates included maternal age, trimester of pregnancy at time of blood sampling, and number of cigarettes per day, as these factors are identified in literature as determinants of maternal blood Hg (Miranda et al. 2011; Arbuckle et al. 2016; Golding et al. 2013; Morrissette et al. 2004) and serum PCB levels (Fisher et al. 2016; Ibarluzea et al. 2011; Wolff et al. 2005; Glynn et al. 2007; Bonefeld-Jorgensen 2010; Llop et al. 2010; Sarcinelli et al. 2003; Wang et al. 2009). Covariates also included parity (number of prior pregnancies resulting in a livebirth or stillbirth) (Fisher et al. 2016; Llop et al. 2010; Wang et al. 2009) and cumulative months of breastfeeding (total number of months of breastfeeding across all pregnancies) (Ibarluzea et al. 2011; Llop et al. 2010) identified as predictors of serum PCB levels. Finally, coast of residence (Hudson Bay, Hudson Strait, Ungava Bay) was considered given potential geographical disparities in Hg and PCB exposure, as observed in Nunavik (Lemire et al. 2015) and in different parts of the world (Vrijheid et al. 2012; Curren et al. 2014; Mahaffey et al. 2009).

### Statistical analyses

Statistical analyses were conducted using SAS Software version 9.4 (SAS Institute-Inc., Cary, NY, USA). The cutoff for statistical significance was set at 0.05. Given the skewed distributions of n-3/n-6 PUFA ratio, blood Hg, and serum PCB-153 concentrations in our sample, these variables were log-transformed.

Simple linear regression models were first used to examine unadjusted associations between contaminant concentrations, socio-economic characteristics, and other covariates. Multivariable linear regression models were used to examine associations between contaminant concentrations and socio-economic characteristics controlling for all covariates simultaneously. To reduce the risk of over-adjustment, parity and cumulative months of breastfeeding were not included together in multivariable regression models (Pearson $r = 0.53$).

Consumption of marine country food was treated as a simple covariate in multivariable regressions. Considering that consumption of country food is the main pathway of exposure to Hg and PCBs and that socio-economic characteristics could influence the consumption of country food, we tested the potential mediator effect of country food consumption on the relationship between socio-economic indicators and contaminant levels. Mediation analysis is presented in Supplemental material (Mediation analysis; Table S1).

## Results

Table 1 summarizes characteristics of participants. Women were ages 18 to 41 years, with an average of 24.1 years. Most participants were recruited during their first or second trimester of pregnancy (72.1%) and were residents of Hudson Bay communities (50.2%). More than 40% of women were multiparous and/or had already breastfed. Most participants smoked (89.4%), with an average consumption of eight cigarettes per day. The mean n-3/n-6 PUFA ratio was 0.27 with values ranging from 0.11 to 0.67. Almost 70% of women had not completed high school. Data on personal income were available for 57.7% of participants. Among these, approximately 60% estimated their personal annual income as below CAD $20,000 per year. Data on family income were missing for 76.0% of participants and therefore were not included in the analysis.

The mean (geometric) blood Hg concentration was 5.08 μg/L (95% CI = 4.42–5.83; range = 0.18–40.1). Almost 51% of participants exceeded the blood guidance value for Hg of 5.8 μg/L established in the US (National Research Council Committee on the Toxicological Effects of Methylmercury 2000), whereas 37% of them exceeded the provisional interim blood guidance value of 8 μg/L set by Health Canada (Legrand et al. 2010). The mean (geometric) concentration for PCB-153 was 39.8 μg/kg of serum lipids (95% CI = 35.1–45.0; range = 2.39–323).

Simple regression analyses indicate that education, coast of residence, and the n-3/n-6 PUFA ratio were significantly related to blood Hg levels, while coast of residence, the n-3/n-6 PUFA ratio, daily cigarette consumption, and cumulative months of breastfeeding were significantly associated with serum PCB-153 levels. For both contaminants, no significant associations were observed between personal income and contaminant levels after handling missing data using the maximum of likelihood approach. Thus, only education was retained as socio-economic indicator in the subsequent multivariable regression analyses. The characteristics of pregnant women by level of education are provided in Supplemental Material (Table S2).

Tables 2 and 3 present the results of multivariable regression analyses examining associations between education and contaminants levels, unadjusted (model 1) and adjusted (model 2) for all covariates. Statistically significant inverse relationships were observed between education and blood Hg levels in unadjusted and adjusted models (Table 2). In contrast, we did not observe significant association between education and serum PCB-153 levels, in unadjusted and adjusted models (Table 3).

In the adjusted models, lower Hg concentrations were observed among women who had completed high school compared to women who had not completed high school ($\beta = -0.43$; $p$ value $< 0.001$; effect size estimated from partial eta-squared = 0.08); adjusted geometric means were respectively 3.78 μg/L (CI 95% = 3.18–4.49) and 5.82 μg/L (CI 95% = 5.15–6.59). However, the difference in serum PCB-153 levels between women who had completed high school and women who had not completed high school did not reach statistical significance ($\beta = -0.22$; $p$ value = 0.0508; effect size estimated from partial eta-squared = 0.02). Adjusted geometric means were respectively 33.9 μg/kg lipids (CI 95% = 28.5–40.4) and 42.1 μg/kg lipids (CI 95% = 37.2–47.7). In adjusted multivariable regression analyses, n-3/n-6 PUFA ratio and coast of residence were significantly associated with blood Hg levels. In contrast, n-3/n-6 PUFA ratio, coast of residence, maternal age, daily cigarette consumption, and cumulative months of breastfeeding were significant predictors of serum PCB-153 levels.

We did not find evidence of a mediation effect for the consumption of marine country food on the relationship between education and contaminant blood levels. Indeed, additional regression analyses indicated that the level of education was not a significant determinant of n-3/n-6 PUFA ratio, which is a

**Table 1** Characteristics of 208 Nunavimmiut pregnant women recruited in 2011 to 2013 as part of project "Biomonitoring of environmental pollutants in maternal blood in Nunavik" (Government of Canada (2016a))

| | No. | Statistics | 95% CI |
|---|---|---|---|
| Maternal age, geometric mean [range] | 207 | 24.1 [18–41] | 23.4–24.7 |
| Smoker status (%) | | | |
| Non-smoker | 22 | 10.6 | 6.36–14.8 |
| Smoker | 186 | 89.4 | 85.2–93.6 |
| Missing data | 0 | 0 | |
| n-3/n-6 PUFA ratio, geometric mean [range] | 204 | 0.27 [0.11–0.72] | 0.26–0.28 |
| Number of cigarettes per day, arithmetic mean [range] | 208 | 8.18 [0–50] | 7.30–9.06 |
| Parity (%) | | | |
| 0 | 70 | 33.7 | 27.2–40.1 |
| 1 | 48 | 23.1 | 17.3–28.9 |
| > 1 | 85 | 40.9 | 34.1–47.6 |
| Missing data | 5 | 2.40 | |
| Prior breastfeeding (%) | | | |
| No | 97 | 46.6 | 39.8–53.5 |
| Yes | 111 | 53.4 | 46.5–60.2 |
| Missing data | 0 | 0 | |
| Cumulative months of breastfeeding, arithmetic mean [Range] | 208 | 12.2 [0–202] | 8.05–16.4 |
| Trimester of pregnancy (%) | | | |
| 1 | 64 | 30.8 | 24.4–37.1 |
| 2 | 86 | 41.3 | 34.6–48.1 |
| 3 | 58 | 27.9 | 21.7–34.0 |
| Missing data | 0 | 0 | |
| Coast of residence (%) | | | |
| Hudson Bay | 104 | 50.2 | 43.4–57.1 |
| Hudson Strait | 43 | 20.8 | 15.2–26.3 |
| Ungava Bay | 60 | 28.9 | 22.8–35.2 |
| Missing data | 1 | 0.48 | |
| Education (%) | | | |
| High school not completed | 131 | 62.3 | 56.4–69.6 |
| High school completed | 67 | 32.2 | 25.8–38.6 |
| Missing data | 10 | 4.81 | |
| Personal annual income, CAD (%) | | | |
| < $20,000 | 72 | 34.6 | 28.1–41.1 |
| ≥ $20,000 | 48 | 23.1 | 17.3–28.9 |
| Missing data | 88 | 42.3 | 35.5–49.1 |
| Family annual income, CAD (%) | | | |
| < $20,000 | 14 | 6.73 | 3.30–10.2 |
| ≥ $20,000 | 36 | 17.3 | 12.1–22.5 |
| Missing data | 158 | 76.0 | 70.1–81.8 |

validated biomarker of marine country food consumption (Supplemental material; Table S1), therefore excluding the possibility of a mediation effect of country food consumption.

## Discussion

The primary goal of our study was to examine the relation between socio-economic characteristics and circulating levels of Hg and PCBs among pregnant Inuit women from Nunavik. Our results indicate that education is a significant determinant of blood Hg, but not of serum PCB levels. Personal income did not appear to be associated with Hg and PCB levels; however, data for personal income were missing for more than 40% of participants.

Our findings on Hg are consistent with previous studies conducted in the US and Spain in which educational attainment was identified as a significant determinant of maternal blood Hg

**Table 2** Results of multivariable regression analyses examining associations between Hg concentrations and education among pregnant Nunavimmiut women, 2011 to 2013 ($n = 208$)

| | Model 1, $\beta$ (95% CI) | Model 2, $\beta$ (95% CI) |
|---|---|---|
| Education | | |
| High school not completed (ref) | – | – |
| High school completed | − 0.50 (− 0.80; − 0.21)‡ | − 0.43 (− 0.64; − 0.22)‡ |
| n-3/n-6 PUFA ratio | | 2.18 (1.86; 2.51)‡ |
| Maternal age | | − 0.01 (− 0.03; 0.01) |
| Daily cigarette consumption | | 0.01 (− 0.002; 0.029) |
| Trimester of pregnancy | | − 0.02 (− 0.15; 0.12) |
| Coast of residence | | |
| Hudson Bay (ref) | | – |
| Hudson Strait | | 0.21 (− 0.05; 0.47) |
| Ungava Bay | | − 0.25 (− 0.50; − 0.004)* |

$\beta$ = unstandardized regression parameter estimate; 95% CI = 95% confidence interval

Model 1, unadjusted model (missing data = 10)

Model 2, adjusted on all covariates (missing data = 10)

*$p$ value < 0.05; † $p$ value < 0.01; ‡ $p$ value < 0.001

(Miranda et al. 2011; Vrijheid et al. 2012). However, the direction of the association between education and Hg levels differed in our population sample. In Nunavik, a higher level of education was associated with significantly lower Hg concentrations, whereas it was associated with significantly higher Hg in studies conducted in the US and Spain (Miranda et al. 2011; Vrijheid et al. 2012). We did not observe significant variations of serum PCB concentration by maternal level of education. These findings are consistent with two previous studies conducted among Swedish (Glynn et al. 2007) and American pregnant women (Borrell et al. 2004), but contrast with observations made in two other groups of pregnant women in the US and Spain (Ibarluzea et al. 2011; Wolff et al. 2005).

The distribution of socio-economic indicators among pregnant Nunavimmiut women differs from those of Canadian (non-Inuit), American, Spanish, and Swedish pregnant women. Data presented in Table 1 indicate that almost 70% of women in the sample had not completed high school. A limited proportion of participants provided information on their income, and among these, 60% estimated their personal income to be less than CAD $20,000 per year. This contrasts with observations made in other settings where the proportion of pregnant women who had not completed high school was below 30%, where education categories comprised three or four categories up to "university level", and where most of participants provided information on their personal or family

**Table 3** Results of multivariable regressions examining associations between serum PCB-153 concentrations and education among pregnant Nunavimmiut women, 2011 to 2013 ($n = 208$)

| | Model 1, $\beta$ (95% CI) | Model 2, $\beta$ (95% CI) |
|---|---|---|
| Education | | |
| High school not completed (ref) | – | – |
| High school completed | − 0.22 (− 0.49; 0.05) | − 0.22 (− 0.43; 0.001) |
| n-3/n-6 PUFA ratio | | 1.33 (0.99; 1.66)‡ |
| Maternal age | | 0.03 (0.004; 0.048)* |
| Daily cigarette consumption | | 0.02 (0.002; 0.034)* |
| Trimester of pregnancy | | 0.07 (− 0.06; 0.21) |
| Cumulative months of breastfeeding | | − 0.01 (− 0.014; − 0.007)‡ |
| Coast of residence | | |
| Hudson Bay (ref) | | – |
| Hudson Strait | | 0.07 (− 0.20; 0.34) |
| Ungava Bay | | − 0.47 (− 0.72; − 0.22)‡ |

$\beta$ = unstandardized regression parameter estimate; 95% CI = 95% confidence interval

Model 1, unadjusted model (missing data = 10)

Model 2, adjusted on all covariates (missing data = 10)

*$p$ value < 0.05; † $p$ value < 0.01; ‡ $p$ value < 0.001

income (Borrell et al. 2004; Miranda et al. 2011; Vrijheid et al. 2012; Arbuckle et al. 2016; Fisher et al. 2016; Ibarluzea et al. 2011; Wolff et al. 2005; Glynn et al. 2007).

Shepherd et al. (Shepherd et al. 2012) [p. 114], who investigated social gradients in the health of Indigenous Australians, underscored the "overrepresentation of Indigenous peoples in the lower levels of all constructs of socioeconomic status (SES)" and expressed their concern about this situation "which reduces statistical power for comparing outcomes across SES levels and potentially obscures the nature of the SES-health relationship." Following Shepherd et al. (Shepherd et al. 2012), we believe that the singular distribution of socio-economic factors among pregnant Nunavimmiut women, the use of distinctive scales of classification, or the small sample size ($n = 208$) might have affected the likelihood of our models to detect significant associations between contaminant levels and socio-economic indicators, especially for income. In line with these considerations, further research is needed to assess the validity of "standard" socio-economic indicators among Indigenous populations, assess their usefulness to capture social disparities, understand their meaning in Indigenous context, and develop culturally relevant indicators if required (Shepherd et al. 2012; Howe et al. 2012; Doocy and Burnham 2006).

The inverse association observed between education and Hg levels in Nunavik could be interpreted in the light of patterns of country food consumption. Fish and marine mammals that are part of Inuit diet represent the main sources of exposure to Hg (Van Oostdam et al. 2005). Recent studies conducted in other regions of the Canadian Arctic showed that the consumption of country food can vary by level of education, with significantly higher consumption of country food among those with lower education (high school not completed) (Galloway et al. 2015; Hopping et al. 2010). Two studies conducted in Nunavik also showed that adults and pregnant women with lower education reported consuming respectively more marine mammals (fat and meat) and fish compared to adult (Blanchet and Rochette 2008) and pregnant women with higher education (Muckle et al. 2001b).

Several assumptions have been formulated for explaining this inverse relationship between education and country food intake. For men, this "may be a result of higher education leading to increased employment and less time spent engaged in traditional activities, such as hunting and fishing" (Hopping et al. 2010) (p. 56). The rationale is less clear for women. Higher education attainment seems to be associated with acculturation, which might result in lower consumption of country food (Galloway et al. 2015). Positive associations between education and levels of income among Inuit women from Nunangat were also recently reported (Bougie et al. 2013). Assuming that education would be in fact a proxy of income, another possibility therefore might be that women who have completed high school earn higher income than women with less than high school education and have in turn access to more diversified food choices and alternatives to country foods.

Irrespective of the reason, an inverse relation between consumption of country food and education could potentially explain the significantly lower Hg levels observed among Nunavimmiut pregnant women with highest levels of education. However, our findings are not in line with this interpretation. Indeed, consumption of country food would be in this case a mediator of the relationship between education and contaminant levels; but mediation analysis presented in Supplemental material does not provide evidence that this is the case. In fact, we did not observe a significant association between education and n-3/n-6 PUFA ratio, which is a validated biomarker of country food consumption (Supplemental material; Table S1). Consistent with this finding, we also observed that pregnant women who had not completed high school and women who had completed high school exhibited similar n-3/n-6 PUFA ratio (Supplemental material; Table S2). This indicates that pregnant Nunavimmiut women consumed similar amounts of marine country food, no matter their level of education.

This led us to question the potential impact of education on the selection of country food consumed. Differences in marine country food choices by levels of education could explain why women who had completed high school presented lower Hg than those who had not completed high school, while globally consuming the same amounts of marine country foods. The rationale would be that women with higher education most often select marine country foods that are low in Hg and that disparities in exposure to Hg by level of education are in fact related to disparities in maternal health literacy, i.e., "people's knowledge, motivation and competences to access, understand, appraise, and apply health information in order to make judgments and take decisions in everyday life concerning healthcare, disease prevention and health promotion […]" (Sørensen et al. 2012) (p. 3).

In October 2011, the Nunavik Regional Board of Health and Social Services disseminated information about contaminants and consumption of country food across Nunavik (using various media such as radio show, website, simple language fact sheets, press release, YouTube videos). The messages invited Nunavimmiut to increase their consumption of country foods because of the health benefits, but invited women of childbearing age to limit their consumption of beluga meat, identified as the main source of Hg (Nunavik Regional Board of Health and Social Services (NRBHSS) 2011). Studies in health literacy suggest that socio-economic factors, such as education, can modulate access, interest, trust, understanding, and use of public health messages (Viswanath and Ackerson 2011). Variations in exposure, sensitivity, or ability to understand public health advice by education level could explain why significantly lower Hg levels were observed among Nunavimmiut women with highest levels of education.

Public health information concerning PCBs in country foods was also disseminated in the region. The last message was released in 2003 and conveyed "that women of childbearing age (13–45) must first ensure to eat a variety of nutritious foods in an adequate amount. Whenever possible, [health authorities] suggested that women select country foods that are rich in fatty acids and less contaminated with PCBs (Arctic char, misiraq made from seal blubber instead of beluga blubber)" (Nunavik Regional Board of Health and Social Services and Nunavik Nutrition and Health Committee 2003). Given this information, one might have expected to also detect significant variations of PCB concentration by maternal level of education, as was observed for Hg. However, there are two specificities that need to be considered in the case of PCBs. The first one is that the last public health food advice on PCBs was disseminated 10 years prior to this study. It would not be surprising that pregnant women recruited for this study, who are 24 years of age on average, have not heard about this recommendation. The second one is that PCBs have a long half-life (≈15 years) (Ritter et al. 2011). Contrary to Hg, PCBs are slowly excreted from the body, and it takes a long time for changes in food habits to be reflected in serum PCB levels. In our view, these two elements could explain why significant variations of PCB concentration by level of education were not observed in this study.

Some authors emphasized that the contribution of socio-economic factors in explaining variations of contaminants in the blood of pregnant women might be less important than the contribution of other determinants, such as maternal age, country of birth, or region of residence (Vrijheid et al. 2012; Gasull et al. 2013). This observation is, however, not supported by the results of our study. Among pregnant Nunavimmiut women, which is a more homogenous population compared to pregnant women in Spain, the influence of education appeared to be as important as that of other socio-demographic variables, such as maternal age or region of residence. Further research is needed to better understand the impact of education on circulating levels of Hg in pregnant Nunavimmiut women.

In conclusion, our study suggests that education is a major predictor of circulating Hg levels among pregnant Nunavimmiut women. Our results overall differed from those previously reported in the literature, but support the underlying assumptions of environmental health inequalities, i.e., some socio-economic characteristics are significant determinants of population level of exposure to environmental pollutants, and, less advantaged groups can face higher levels of exposure to pollutants compared to more advantaged groups. In particular, our results indicate that more educated Nunavimmiut pregnant women are likely to present lower blood Hg levels compared to less educated women. Further research is needed to determine why disparities in exposure to Hg related to maternal education were observed in Nunavik, but also to verify whether social disparities in environmental exposure exist in other Inuit or Indigenous communities.

## Limitations

From 2011 to 2013, 1007 births were declared in Nunavik (Institut de la Statistique du Québec 2017b). This suggests that a significant proportion of the target population participated in our study (21%). However, due to the recruitment process, only pregnant women visiting health centres for prenatal visits were recruited in the biomonitoring project. This might have introduced a selection bias affecting the external validity of our study but also affected the magnitude of associations observed between education and contaminant levels. Indeed, previous studies showed significant and positive associations between education and use of prenatal services (Guliani et al. 2014).

Level of income was not associated with significant variations in contaminant blood levels. However, the validity of our income measurements may be questioned. The significant proportion of missing data for income (personal and household) and our experience at the time of questionnaire administration suggest that it is very difficult for pregnant Nunavimmiut women to estimate their annual income. This is not surprising considering the employment market in this region (e.g., few long-term jobs). There is a need to develop more reliable indicators of financial resources of pregnant Nunavimmiut women.

Our variable of interest, education, was measured using the Canadian education/grading school system. However, education from an Inuit perspective is much broader (Munroe et al. 2013). For example, it also encompasses Inuit traditional knowledge and practice (Pauktuutit Inuit Women of Canada. Education 2018). Because pregnant women were questioned on the highest levels of formal education completed, this does not undermine the validity of results presented herein. However, this is critical information to interpret findings properly and understand the scope of the current study.

Several biological or behavioural variables identified as determinants of Hg and PCB levels in the literature were not associated with contaminant levels among pregnant Nunavimmiut women. It is possible that the effect of these covariates was not observed because of their homogenous distribution in the sample of participants (e.g., maternal age, smoker status). Finally, several studies identified pre-pregnancy body mass index (BMI) as an important determinant of maternal PCB levels (Glynn et al. 2007; Llop et al. 2010). However, information on pre-pregnancy BMI was not collected.

## Public health implications

Public health interventions that have been implemented to date for reducing the exposure of pregnant Nunavimmiut women to Hg and PCBs were developed considering their exposure to Hg and PCBs to be uniform across socio-economic levels. It is recognized that public health interventions that do not consider social inequities "may improve outcomes across the population, but unintentionally exacerbate the existing inequalities, by benefiting privileged groups more than disadvantaged groups" (Lorenc and Oliver 2014) (p. 289). Our study is the first to suggest non-uniform chemical exposure among pregnant Nunavimmiut women and the potential existence of subgroups more vulnerable to chemical exposure in this population.

Regional public health authorities could consider socio-economic disparities in maternal exposure to food chain contaminants when developing future interventions. This could be achieved by developing interventions that target more effectively pregnant women with lower education. Implementing universal interventions that focus on living conditions, such as the Minamata and Stockholm conventions that aim to reduce global emissions of respectively Hg and PCBs in the environment, could also be considered.

Formulating messages on contaminants in country food is very sensitive in Nunavik. The high prevalence of food insecurity (Huet et al. 2012), the unintentional adverse effects of prior interventions (Pirkle et al. 2016), the nutritional transition, and the sociocultural benefits of country food consumption by Nunavimmiut are elements that need to be considered in food advice formulation. If the dissemination of non-tailored food messages remains the privileged preventive strategy in the future, additional cautions beyond those mentioned above might be needed. Public health authorities could choose to take additional precautions to ensure that disseminated messages are adapted to the majority of pregnant women who do not have a high school education, while considering that alternative country food choices might not always be available, especially for the more vulnerable pregnant women.

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## Compliance with ethical standards

The 2011–2013 biomonitoring protocol was approved by the research ethics committee from Centre Hospitalier Universitaire de Québec Research Centre and the Nunavik Nutrition and Health Committee (NNHC). The proposal to conduct the current study and the final manuscript were also reviewed and approved by the NNHC.

**Conflict of interest** The authors declare that they have no conflict of interest.

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