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Concentrations and geographical patterns of persistent organic pollutants (POPs) in meat from semi-domesticated reindeer (*Rangifer tarandus tarandus* L.) in Norway

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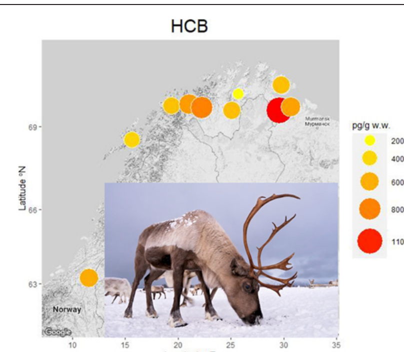
HIGHLIGHTS

- Concentrations of POPs in muscle from reindeer in Norway were generally low and below EU MLs.
- Higher POPs in calves compared to young and older animals, and in males compared to females
- Slightly elevated POPs in districts with previous mining activities, military trenches, and near the Russian border
- Reindeer meat is not likely to be a substantial contributor to the human body burden of POPs.

GRAPHICAL ABSTRACT



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ABSTRACT

The study aimed at investigating the concentrations and geographical patterns of 11 polychlorinated biphenyls (PCBs) and 15 organochlorine pesticides (OCPs) in reindeer muscle samples ($n = 100$) collected from 10 grazing districts in Norway, 2009. Concentrations were examined for patterns related to geographical region as well as age and sex of animals. Concentrations measured for PCBs and OCPs in reindeer meat samples were generally low. Geographical patterns were revealed and districts with previous mining activities, military trenches, or those that were in the vicinity of the Russian border exhibited slightly elevated concentrations compared to other districts. Calves (10 months) exhibited higher concentrations than young (1.5 year) and old animals (>2 years) adjusted for sex, whereas males exhibited higher concentrations than females, adjusted for age. All PCB congeners inter-correlated strongly with each other, whereas oxy-chlordane and heptachlor epoxide were the strongest inter-correlated OCP compounds. Concentrations of PCBs and OCPs in reindeer meat were all considerably lower than the maximum levels set for those contaminants in foodstuffs for safe human consumption by the European Commission. Thus, reindeer meat is not likely to be a substantial contributor to the human body burden of persistent organic pollutants.

1. Introduction

The introduction of persistent organic pollutants (POPs) to the environment has resulted in their accumulation in various ecosystems including animals and human food chains (AMAP, 2010; Andersen et al.,

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2015; Gamberg et al., 2005; Holma-Suutari et al., 2014; Kelly and Gobas, 2001). Polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCPs) including dichloro-diphenyl-trichloroethane derivatives (DDTs), are the POPs regarded as the highest concern for humans. This has further led to concern about the possible risk of human exposure to such compounds through ingestion of contaminated foods, and investigation of their sources and occurrence (AMAP, 2015; Donaldson et al., 2010; Kan and Meijer, 2007; Kim et al., 2017; Odland et al., 2003).

Reindeer meat has expanded from being a traditional indigenous food to a commonly consumed food item in Fenno-Scandinavia. With the high nutritional density of several vitamins, essential elements and polyunsaturated fatty acids, this meat is considered to be healthy and nutrient-rich (Wiklund et al., 2007; Hassan et al., 2012a, 2012b; Sampels et al., 2004). However, as an Arctic traditional food, reindeer meat potentially contains POPs transported to the region from remote industrial areas by long range atmospheric transportation, or from local sources (Holma-Suutari et al., 2014; Octaviani et al., 2015; Kallenborn et al., 2015). In Norway, few studies have focused on reindeer with regard to occurrence of POPs and studies on geographical variations in Norway are still lacking (Hassan et al., 2013).

In the reindeer food web, contaminants accumulate in lichens via atmospheric deposition and waterborne POPs (Harrad, 2001; Kelly and Gobas, 2001; Kelly and Gobas, 2003). Wild animals are important components of human diets and therefore it is necessary to evaluate their role as a potential source of exposure to POPs as oral ingestion is considered the main route of exposure to POPs for humans (AMAP, 2015; de Voogt, 2016). Reindeer feeds mainly on lichens in wintertime which are known to accumulate POPs (Conti and Cecchetti, 2001; Kelly and Gobas, 2001; Kelly and Gobas, 2003; Nash and Gries, 1995). Therefore, knowledge of occurrence, intensity and distribution of lichens across the studied areas and knowledge of local sources of POPs could contribute to explanations of any possible geographical patterns that may be revealed in concentration of POPs in reindeer. Nevertheless, data is scarce on distribution of lichens across reindeer grazing districts in Norway as priority was given to areas with diminishing lichens and high reindeer population densities when such investigations were carried out (Tømmervik et al., 2014).

The study aimed at investigating the concentrations and geographical patterns of PCBs and OCPs, including dichloro-diphenyl-trichloroethane derivatives in meat from semi-domesticated reindeer in Norway. Detailed abbreviation list was provided as supplementary material (Supplementary Material I).

2. Materials and methods

2.1. Geographical area

The reindeer from which samples were collected originated from ten grazing districts in four different counties distributed as follows: Finnmark County (7 districts), Troms County (one district), Nordland County (one district) and Sør-Trøndelag (one district). The ten grazing districts included in the study were Eastern Sør-Varanger, Pasvik, Varanger Peninsula, Spierttagáisá, Karasjok, Ábborašša, Favrrosorda, Tromsdalen, Kanstadfjord and Essand, Fig. 1.

2.2. Sample collection and preparation

Reindeer muscle samples ($n = 100$) from the dorsal neck muscle region were collected during the slaughter season in the period from October-December 2008 and September-December 2009. The number of samples collected was equally distributed among the ten grazing districts. Detailed information on animals' weight, age and sex was provided in Table S1 (Supplementary Material II). To facilitate comparison to other studies, we aimed at collecting samples from young animals (1.5 years old). However, due to limited availability of 1.5 years olds in some districts ($n = 4$), calves (approximately 10 months old) and older animals (>2 years old) were selected (12% and 11%, respectively). Thus, 77% of the total samples consisted of young animals. The age of reindeers was obtained directly from the tags attached to animals' carcasses when they passed the weighing post in the slaughterhouses. All samples were collected directly after the slaughter/ dressing process and carcass weighing in pre-marked plastic bags prior to further division in dedicated glass containers. The samples were chilled in a cooling box (approximately 4 °C) immediately after collection and division, and then moved the same day to a –20 °C freezer until they were transported frozen to the laboratory for analysis. All animals from which samples were collected were healthy, i.e., passed the ante- and post mortem inspection.

2.3. Chemical analyses

POP analysis was performed at the laboratories of NILU - Norwegian Institute for Air Research, Tromsø, Norway. Meat samples of 4–6 g were separately homogenized by addition of pre-treated sodium sulphate Na_2SO_4 (600 °C, 8 h) in a ratio of 1:20. Twenty (20) μL ^{13}C-isotope labeled internal standards were added to each sample, and included the following compounds: ^{13}C-labeled PCBs 28, 52, 101, 105, 118, 138, 153, 180, ^{13}C-*p,p′*-DDE, and ^{13}C-*p,p′*-DDT at a concentration of 100 pg/mL of each standard. The homogenized mixture was extracted three times using cold column extraction with 50 mL cyclohexane: acetone (3:1; *v*/v). The extract (150 mL) was then concentrated to 0.5 mL and collected in a 4 mL vial (Herzke et al., 2009). The amount of extractable lipid was determined gravimetrically.

Lipid removal was performed on a gel permeation chromatography (GPC) system. An additional fractionation was carried out on a florisil column prior to analyses on a low-resolution gas chromatography–mass spectrometry (GC–MS) instrument (Sandanger et al., 2006). A 8560 Mega gas chromatograph (CE Instruments, Milan, Italy) was equipped with a 30 m DB5-MS column (0.25 mm id and 0.25 μm film thickness; J&W, Folsom, USA), a guard column (0.53 mm id, 2.5 m length deactivated, J&W) and a restriction capillary (0.18 mm id, 1.5 m length deactivated, J&W). Helium (6.0 quality, Hydrogas, Porsgrunn, Norway) was used as carrier gas at a flow rate of 1 mL/min. Two μL of the sample extract were injected on-column with an AS800 automatic injection system (CE Instruments). The following temperature program was used: 70 °C (2 min), then 15 °C/min to 180 °C and 5 °C/min to 280 °C (10 min isothermal). Quantification was carried out by low resolution mass spectrometry (LRMS) using a MD 800 mass spectrometer (Finnigan, San Jose, CA, USA) with an ionisation energy of 70 eV. The transfer line temperature was held at 280 °C and the source temperature was set to 220 °C. This procedure has been presented in detail elsewhere (Herzke et al., 2009). The quality of the methods used was regularly verified and samples were quality assured during analysis using both blank and standard reference material (SRM) samples between sets of 10 biological samples each. To assess laboratory-derived sample contamination and method accuracy and reproducibility, we processed blanks ($n = 9$) and standard reference materials (SRMs) [SRM® 1958 ($n = 10$) and 1957 ($n = 6$), both from the National Institute of Standards and Technology, Gaithersburg, MD, USA] along with the samples. Results for SRMs indicated analytical uncertainties within ±20% of assigned values (within ±5% for many compounds). The NILU laboratory routinely participates in the international AMAP Ring Test for Persistent Organic Pollutants in Human Serum and has performed well (within ±20% of assigned values). Concomitantly, summed lipid concentrations in the test samples ($n = 10$) were within a 15% deviation from assigned values. [Ring test results are available from the Institut National de Santé Publique du Québec, 2015].

The lowest level of detection (LOD) for individual compounds was defined as a concentration corresponding to three times the background noise in chromatograms. Recoveries ranged from 22 to 108% for PCBs

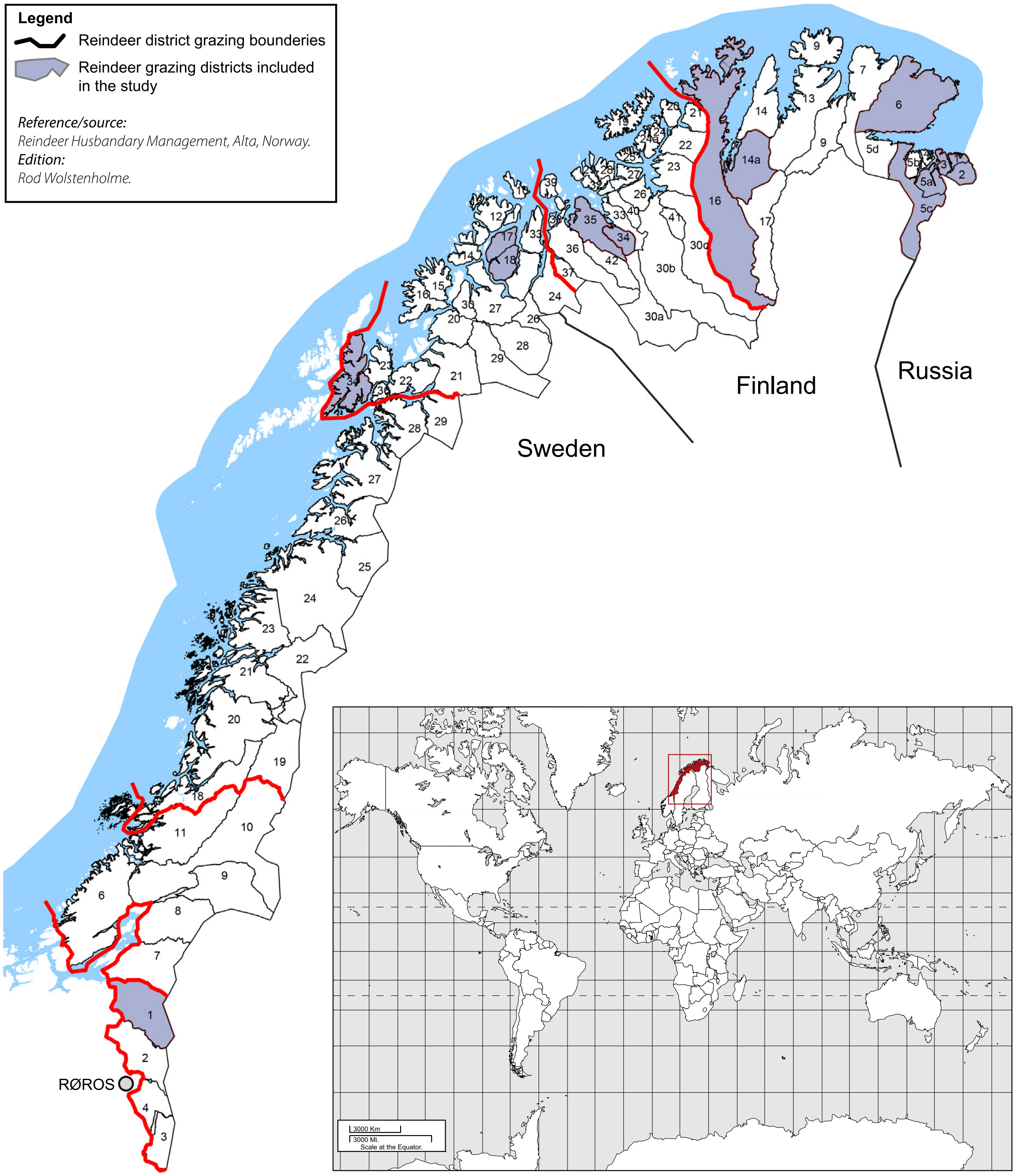

Fig. 1. Map of the study area.

and 19-106% for OCPs. Samples with low recoveries (<40%) were excluded from the statistical analyses. Number of samples with low analytical recoveries (< 40%) for PCBs ranged from 4 to 6 (9-37%), and for OCPs form 4 to 52 (4-38%), Tables 1 and 2. With exception of *p,p′*-DDE which had a recovery of x%, the other DDT compounds had a low recovery rate (< 40%), ranged 4- 32%. The results for SRM samples indicated that concentrations were 93% of assigned values on average for PCBs (ranged 36% - 159%) and 91% (ranged 44% - 241%) for OCPs. The average coefficients of variance were 14% for 10 SRM samples for PCBs and 9% for 6 SRM samples for OCPs. Due to coelution of two PCB congeners in three peaks in the chromatograms using the instrument method described, we present concentrations for PCBs 28/31, 105/126 and 118/149 combined.

2.4. Statistical analyses

STATA/MP 16.0 for Windows (STATA Corp. College Station, TX, USA) was used for statistical analyses. Analytical results for POPs below the limit of detection (LOD) were assigned a numeric value at half the respective detection limit (LOD/2). The statistical models included the specific POP as a response (dependent) variable, and district, age and sex as factor variables. Analysis of variance (ANOVA) with Bonferroni adjustment was used to test for significant differences in concentrations of POPs among the grazing districts, age and sex groups. Welch test was used whenever homogeneity of variance was violated. The level of significance was set at ($p < 0.05$) for all statistical analyses. POP concentrations are presented as mean ± standard deviation, median and range

Table 1
Concentrations for polychlorinated biphenyls (PCBs) in reindeer muscle.

PCB congener	n[a]	ng/g lw			pg/g ww			% over LOD[e]	Number of sample with recovery < 40%
		Mean±SD[b]	Median	Min.[c]–max.[d]	Mean ± SD	Median	Min.–max.		
PCB 28/31	94	0.6 ± 0.5	0.5	0.1–2.8	6 ± 3	5	3–15	100	6
PCB 52/126	96	1.2 ± 1.2	0.9	0.1–7.1	10 ± 5	9	5–28	100	4
PCB 99	96	3.3 ± 3.7	2.1	0.3–24.9	30 ± 19	25	5–109	100	4
PCB 101	96	4.4 ± 5.6	2.7	0.3–37.9	38 ± 28	29	6–166	100	4
PCB 105	95	7.7 ± 8.9	5.1	0.5–55.2	69 ± 45	59	9–293	100	5
PCB 118/149	96	17 ± 17	11.4	1.7–111.7	163 ± 90	149	25–497	100	4
PCB 138	96	9.6 ± 10.7	6.2	0.7–67.2	86 ± 57	71	15–338	100	4
PCB 153	96	7.8 ± 7.6	5.2	0.6–43.9	75 ± 46	59	16–236	100	4
PCB 163	96	2.1 ± 2.1	1.5	0.2–12.8	20 ± 11	17	5–57	100	4
PCB 170	95	1.4 ± 1.3	0.9	0.2–8.9	14 ± 8	13	3–45	100	5
PCB 180	96	2.9 ± 2.6	2.2	0.3–8.9	29 ± 15	25	9–85	100	4

Note: Total number of samples were 100 and the (n) expressed in the table is the number after exclusion of samples with low recoveries (<40%). Mean lipid percentage in muscle samples: 1.5 ± 1.3 (range; 0.2–9.8%).
[a] n = Number of samples included in the statistical analyses.
[b] SD = Standard deviation.
[c] Min. = Minimum.
[d] Max. = Maximum.
[e] % > LOD = Percentage of samples with concentrations above limit of detection.

(min. – max.). POP concentrations are presented on a wet weight basis (pg/g wet weight; w.w.) and lipid weight basis (ng/g lipid weight; l.w.). Correlations between the compounds were assessed using the Pearson's correlation (r).

3. Results and discussion

The present work is the first of its kind to present results on geographical patterns of persistent organic pollutants (POPs) in reindeer from Norway. Knowledge regarding POPs in meat from cervid species including reindeer and caribou is still generally lacking. Therefore, broad comparison of results from this study with previous results has been limited.

Mean lipid percentage in muscle samples was 1.5 ± 1.3 (range; 0.2–9.8%). Mean concentrations of PCBs and OCPs in reindeer meat samples from this study were generally low (ranged 6 ± 3–163 ± 90, 1 ± 1–606 ± 366 pg/g ww and 0.6 ± 0.5–17 ± 17, 0.1 ± 0.1–55.2 ± 39.1 ng/g lw, respectively). Geographical, age and sex patterns were observed. Districts with previous mining activities, military trenches, and those in the vicinity of the Russian border exhibited slightly elevated concentrations compared to the rest of the districts ($p < 0.05$). All PCB-congeners inter-correlated strongly with each other, whereas oxy-chlordane and heptachlor epoxide were the strongest inter-correlated OCP compounds.

The number of samples included in the statistical analyses varied depending on the POP. All PCB congeners were found with detectable concentrations. With exception of *p,p′*-DDE in which all samples exhibited detectable concentrations, the other DDT compounds; *p,p′*-DDT, *op′*-DDE and *op′*-DDD, had a low recovery rate (<40%), ranged 4-32%.

3.1. Geographical patterns in concentrations of PCBs

Summary statistics for PCB concentrations in reindeer meat are presented in Table 1.

PCB- 118/149, 138, 153 and 105/126 were the congeners with the highest concentrations. The mean concentrations of PCB- 105/126 (7.7 ± 8.9) and 118/149 (17 ± 17 ng/g l.w.) were 18 to 27 times higher than those previously reported in meat from Finnish reindeer (0.27 and 0.69 ng/g l.w.) and moose (0.27 and 0.86 ng/g l.w), respectively (Suutari et al., 2012). Furthermore, concentrations of PCB- 99, 105/126, 118/149, 138 and 153 in the present study were comparable with those previously reported for reindeer from Ábborašša included in this study and other five districts from northern Norway in 2005 by the same authors (Hassan et al., 2013). The sum of PCB- 28/31, 52, 101,

Table 2
Concentrations of organochlorine pesticides (OCPs) in reindeer muscle.

OCP-compound	n[a]	%>LOD[b]	Number of sample with recovery < 40%	ng/g lw			pg/g ww		
				Mean ± SD[c]	Median	Min.[d]–max.[e]	Mean ± SD	Median	Min.–max.
α-HCH	94	99	6	1.2 ± 1.2	0.9	0.3–10.7	13 ± 10	12	<6–89
β-HCH	92	95	8	2.5 ± 3.1	1.7	0.1–25.7	22 ± 14	19	<5–65
γ-HCH	94	100	6	0.5 ± 0.5	0.3	0.1–3.3	4 ± 2	4	1–22
HCB	95	100	5	55.2 ± 39.1	44.8	4.6–271.7	606 ± 366	509	130–2174
Heptachlor	56	86	44	0.6 ± 0.6	0.4	0.1–4.1	5 ± 1	5	2–7
Heptachlor epoxide	95	99	5	2.4 ± 1.7	2.1	0.3–12.5	22 ± 4	22	2–34
cis-Chlordane	52	50	48	0.1 ± 0.1	0.1	0.1–0.4	1 ± 1	1	<1– 3
oxy-Chlordane	95	98	5	3.3 ± 2.8	2.6	0.1–21.9	31 ± 5	31	<4–41
trans-Nonachlor	50	50	50	0.1 ± 0.1	0.1	0.1–0.5	1 ± 1	1	<1–3
cis-Nonachlor	96	99	4	6.6 ± 10.9	3	0.2–60.9	55 ± 59	29	<1–304
Mirex	48	85	52	0.5 ± 0.3	0.4	0.1–1.3	5 ± 3	4	<4–15
p,p′-DDE	95	95	5	1.9 ± 2.8	1.1	1.2–22.6	17 ± 13	14	<4–84

Note: Total number of samples were 100 and the (n) expressed in the table is the number after exclusion of samples with low recoveries (<40%). Mean lipid percentage in muscle samples: 1.5 ± 1.3 (range; 0.2–9.8%).
[a] n = Number of samples included in the statistical analyses.
[b] % > LOD = Percentage of samples with concentrations above limit of detection.
[c] SD = Standard deviation.
[d] Min. = Minimum.
[e] Max. = Maximum.

138, 153 and 180 in this study (26.5 ng/g l.w) was considerably lower than the EC ML for the sum of the above mentioned congeners (40 ng/g l.w) (European Commission, 2006). PCB-105/126 and 118/149 are regarded as dioxin like - PCBs (DL-PCBs) with higher toxicity compared to non-DL-PCBs. Hence any elevated concentrations of these compounds are of human health concern. Atmospheric long-range transport from secondary and primary sources is regarded as the major contributor of PCBs to the Arctic region (Carlsson et al., 2018).

Ábborašša, Karasjok and Pasvik were the districts that revealed the highest concentrations for the different PCB-congeners ($p < 0.05$), Fig. 2.

All PCB congeners were statistically significant correlated with each other (ranged 0.71–0.98, $p < 0.01$).

3.2. Geographical patterns in concentrations OCPs

Concentrations of the OCPs analyzed are presented in Table 2.

Concentration of HCB of 55.2 ± 39.1 ng/g l.w measured in this study was comparable to that previously measured in reindeer meat from Norway by the same authors and was considerably lower than the EC ML for HCB of 200 ng/g l.w. (European Commission, 2006). Likewise, the sum of HCHs (α-, β- and γ-) in this study (4.2 ng/g l.w.) was considerably lower than the EC ML of the sum of these congeners of 2300 ng/g l.w. Ábborašša, Passvik and Karasjok were the districts that revealed the highest concentrations of the different OCPs, with HCB exhibiting the highest concentration ($0.01 < p < 0.001$), Fig. 3. The elevated concentrations of HCB possibly reflect recent HCB-containing feed intake such as lichens, due to high exposure from the surrounding environment.

All OCP compounds were significantly inter-correlated with each other (ranged 0.51–0.98, $p < 0.05$), with the exception of α -HCH which only correlated with β-HCH ($r = 0.62$) and β-HCH not correlated with *cis*-Nonachlor. Oxy-chlordane and heptachlor epoxide were the strongest inter-correlated OCP compounds ($r = 0.98$, $p < 0.05$).

With the exception of *p,p′*-DDE in which all samples exhibited detectable concentrations, the concentrations of other DDT compounds had a low recovery (< 40%), ranged 4-32%. Hence, only results from *p,p′*-DDE were included in the statistical analyses. Mean concentration of *p,p′*-DDE was 17 ± 13 pg/g w.w and slightly above the LOD. Ábborašša (38 ± 27 pg/g w.w.) followed by Karasjok (30 ± 7 pg/g w.w.) were the districts that revealed the highest concentrations, compared to the remaining 8 grazing districts (p < 0.05), Fig. 3.

Concentrations of *p,p′*-DDE measured in this study (17 ± 13, range 1–84 pg/g ww) were much lower than those ranged 100-890 pg/g ww previously reported from reindeer meat by the same authors (Hassan et al., 2013). Concentrations of *p,p′*-DDE as the only DDT compound detected in this study, were considerably lower than the EC ML for sum DDTs of 1000 ng/g l.w. (European Commission, 2006).

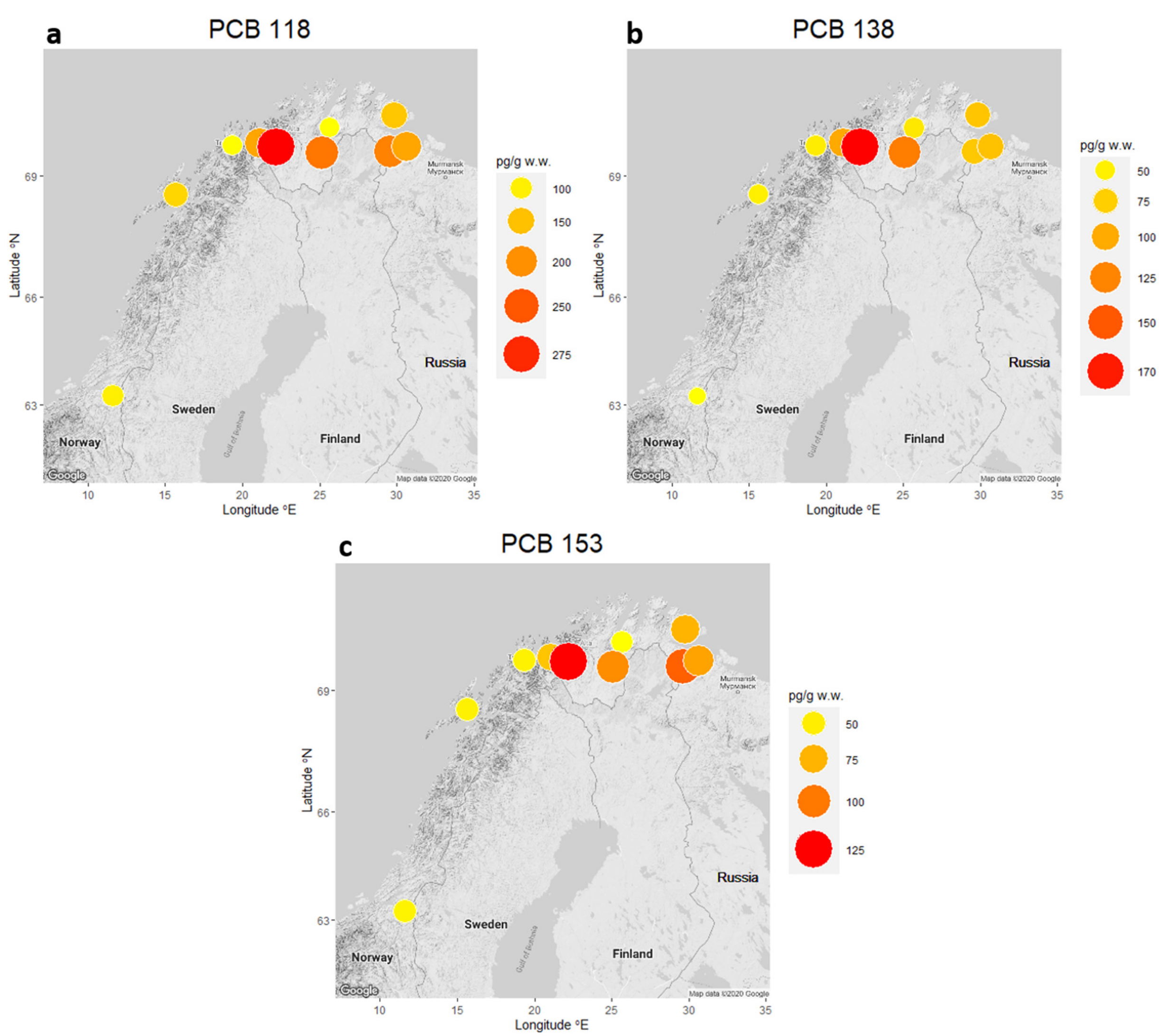

Fig. 2. Geographical patterns in concentrations of PCB- 118/149, 138 and 153.

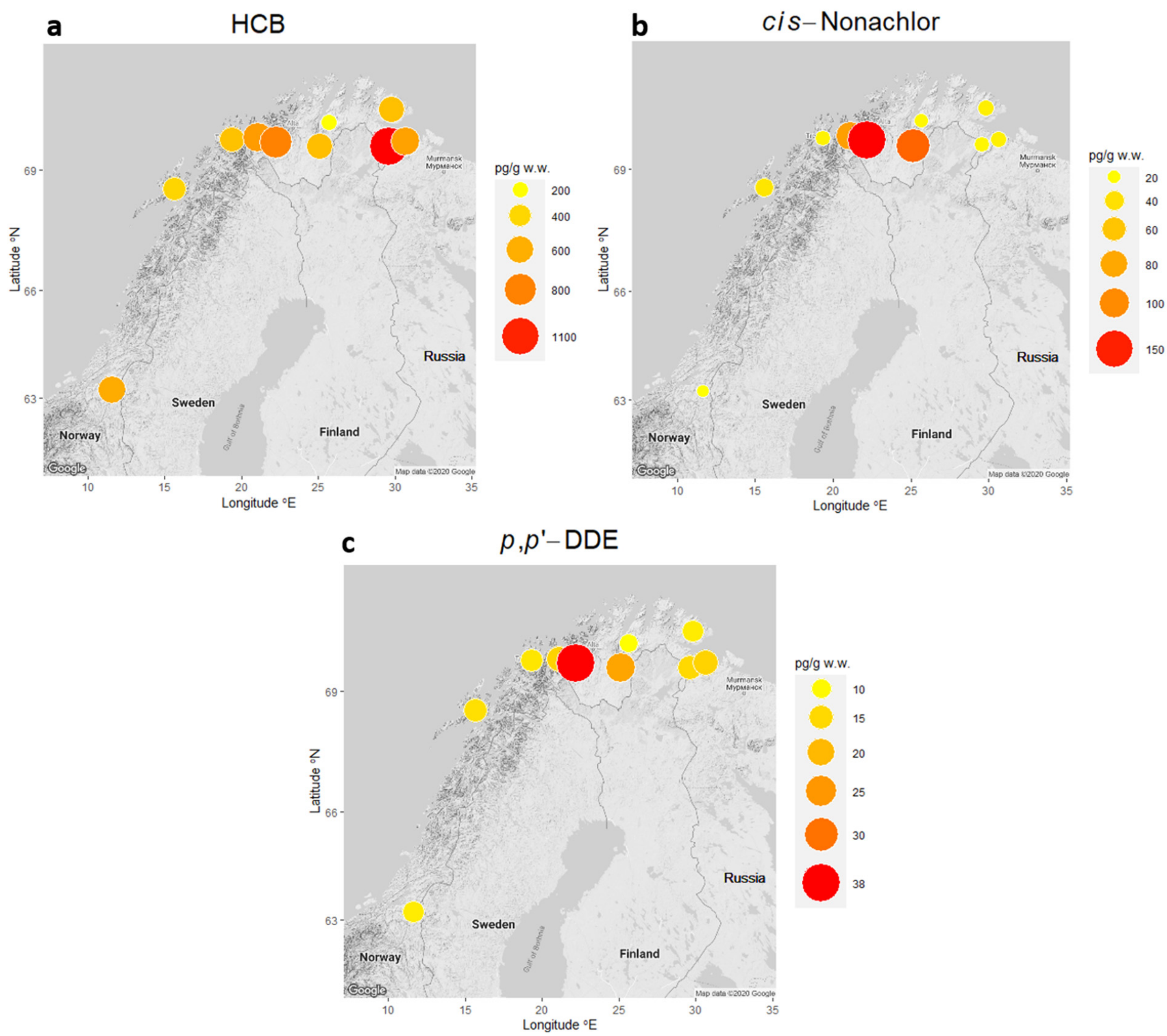

Fig. 3. Geographical patterns in concentrations of HCB, *cis*-Nonachlor and *p,p′*-DDE.

Districts with previous mining activities (Ábborašša), military trenches (Karasjok), and those in the vicinity of the Russian border (Pasvik) exhibited slightly elevated POP concentrations compared to the rest of the districts ($p < 0.05$). This might be due to high exposure from local environmental emissions sources, previous agricultural activities, or the influence of atmospheric long-range transport in those districts.

Table 3
Concentrations for polychlorinated biphenyls (PCBs) in reindeer muscle stratified by age.

PCBs	Mean±SD[a] pg/g ww $n = 12$				Mean ± SD ng/g lw			
	Calve (10 months, n[b]=12)	Young (1.5 year, $n = 73$)	Old (>2 years, $n = 11$)	P[c]	Calve (10 months, n = 12)	Young (1.5 year, n = 73)	Old (>2 years, n = 11)	P
PCB 28/31	6 ± 3	6 ± 3 ($n = 71$)	5 ± 1	0.142	0.5 ± 0.3	0.7 ± 0.5 (n = 71)	0.4 ± 0.3	0.151
PCB 52	9 ± 3	12 ± 5	9 ± 1	0.053	0.8 ± 0.6	1.4 ± 1.3	0.8 ± 0.5	0.087
PCB 99	41 ± 17	29 ± 21	23 ± 5	0.081	2.9 ± 1.9	3.5 ± 4.2	2.1 ± 1.3	0.485
PCB 101	28 ± 9	41 ± 32	30 ± 8	0.198	2.2 ± 2	4.9 ± 6.2	2.7 ± 1.7	0.162
PCB 105/126	74 ± 18	70 ± 51 ($n = 72$)	59 ± 14	0.683	5.7 ± 5.3	8.3 ± 9.8 (n = 72)	5.5 ± 3.9	0.446
PCB 118/149	219 ± 61	157 ± 97	143 ± 35	0.065	15.1 ± 9.4	17.9 ± 18.9	12.9 ± 8.1	0.613
PCB 138	101 ± 51	86 ± 61	69 ± 14	0.403	7.7 ± 6.3 (n = 11)	10.4 ± 11.9	6.5 ± 4.3	0.441
PCB 153	133 ± 57	69 ± 40	52 ± 13	0.001	9.4 ± 6.3	7.9 ± 8.2	4.9 ± 3.3	0.331
PCB 163	32 ± 10	19 ± 11	15 ± 3	0.001	2.3 ± 1.5	2.2 ± 2.3	1.4 ± 0.9	0.433
PCB 170	28 ± 8	13 ± 7 (n = 72)	10 ± 3	0.001	1.9 ± 1.3	1.4 ± 1.4 (n = 72)	0.9 ± 0.6	0.159
PCB 180	52 ± 20	26 ± 11	21 ± 7	0.001	3.7 ± 2.5	2.9 ± 2.7	1.9 ± 1.4	0.262

Note: Mean lipid percentage in muscle samples: 1.5 ± 1.3 (range; 0.2–9.8%).
[a] SD = Standard deviation.
[b] n = Number of samples included in the statistical analyses.
[c] P = *p*-value (statistically significant at the level of $p < 0.05$).

Table 4
Concentrations for polychlorinated biphenyls (PCBs) in reindeer muscle stratified by sex.

PCBs	Mean ± SD[a] pg/g ww					Mean ± SD ng/g lw				
	Male	n[b]	Female	n	*p*-Value	Male	n	Female	n	p-Value
PCB 28/31	6 ± 2	50	6 ± 2	44	0.289	0.8 ± 0.6	50	0.4 ± 0.3	44	0.001
PCB 52	12 ± 5	51	10 ± 3	45	0.092	1.6 ± 1.5	51	0.8 ± 0.5	45	0.001
PCB 99	32 ± 22	51	27 ± 16	45	0.201	4.3 ± 4.7	51	2.1 ± 1.5	45	0.004
PCB 101	42 ± 33	51	34 ± 20	45	0.152	5.9 ± 7.2	51	2.6 ± 1.9	45	0.004
PCB 105/126	75 ± 53	50	63 ± 33	45	0.189	9.9 ± 11.2	50	5.1 ± 4	45	0.007
PCB 118/149	169 ± 105	51	156 ± 71	45	0.478	21.5 ± 21.2	51	11.9 ± 8	45	0.006
PCB 138	94 ± 66	51	78 ± 44	45	0.172	12.6 ± 13.5	51	6.2 ± 4.5	45	0.003
PCB 153	81 ± 51	51	68 ± 40	45	0.156	9.9 ± 9.1	51	5.3 ± 4.3	45	0.002
PCB 163	22 ± 13	51	19 ± 9	45	0.203	2.7 ± 2.5	51	1.5 ± 1.1	45	0.004
PCB 170	16 ± 9	50	13 ± 7	45	0.081	1.8 ± 1.5	50	1 ± 0.9	45	0.003
PCB 180	31 ± 16	51	26 ± 13	45	0.130	3.7 ± 2.9	51	2.1 ± 1.7	45	0.001

Note: Mean lipid percentage in muscle samples: 1.5 ± 1.3 (range; 0.2–9.8%). p-Value statistically significant at the level of $p < 0.05$.
[a] SD = Standard deviation.
[b] n = Number of samples included in the statistical analyses.

3.3. Age and sex patterns in POP concentrations

For PCB congeners 153, 163,170 and 180, calves (133 ± 57, 32 ± 10, 28 ± 8 and 52 ± 20 pg/g ww, respectively) exhibited higher concentrations than young (69 ± 40, 19 ± 11, 13 ± 7 and 26 ± 11 pg/g ww, respectively) and old animals (52 ± 13, 15 ± 3, 10 ± 3 and 21 ± 7 pg/g ww, respectively) adjusted for sex, ($p < 0.05$), Table 3. Males exhibited significantly higher concentrations than females for all PCB congeners adjusted for age (pg/g ww), Table 4. Age and sex of animals were uniformly distributed across the 10 grazing districts included in this study. Hence, the effect of age and sex revealed was not due to a difference for geographical trends.

Similar trends for age and sex were observed on Sum PCBs, Fig. 4. The differences between the three age groups and sex in sum PCBs, adjusted for district (Fig. 4A, B) were significant (ANOVA test, MS = 381,908.23, $F = 8.19$, df = 12, $P = 0.0000$, $R^2 = 0.55$, based on wet weight values).

For β-HCH and HCB, calves (35 ± 13 and 1132 ± 435 pg/g ww) exhibited higher concentrations than young (21 ± 13 and 550 ± 300 pg/g ww) and old animals (22 ± 13 and 401 ± 123 pg/g ww) adjusted for sex, $p < 0.05$, Table 5. Males exhibited significantly higher concentrations (ng/g l.w.) than females for γ-HCH, heptachlor, heptachlor epoxide, oxy-chlordane, *trans*-nonachlor and *cis*-nonachlor adjusted for age ($p < 0.05$), Table 6. For *p,p′*-DDE, males had significantly higher

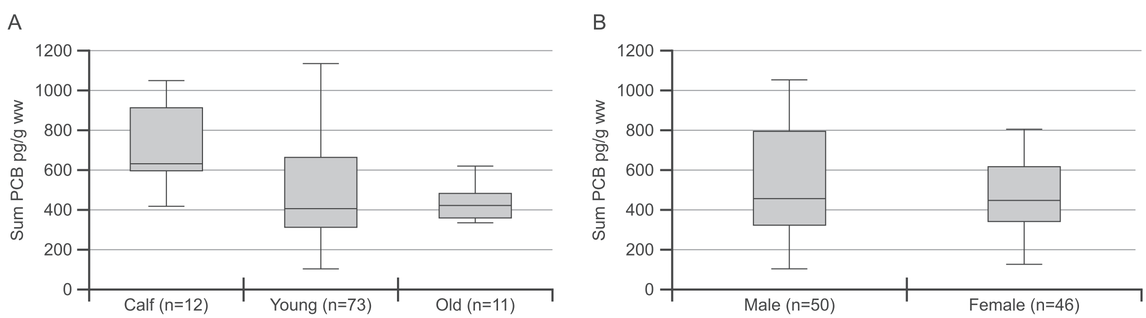

Fig. 4. Mean wet weight based concentrations of Sum PCBs in reindeer muscles, along with ranges of concentrations (maximum and minimum), from calves, young and adults (A) and in males and females (B).

Table 5
Concentrations of organochlorine pesticides (OCPs) in reindeer muscle stratified by age.

OCPs	Mean±SD[a] pg/g ww					Mean ± SD ng/g lw				
	Calve (10 months, n[b]=12)	Young 1.5 year	n	Old (>2 years, $n = 11$)	P[c]	Calve (10 months, $n = 12$)	Young (1.5 year)	n	Old (>2 years, n = 11)	P
α-HCH	18 ± 7	13 ± 11	71	14 ± 5	0.239	1.1 ± 0.4	1.2 ± 1.3	71	1.1 ± 0.6	0.934
β-HCH	35 ± 13	21 ± 13	69	22 ± 13	0.004	2.4 ± 1.6	2.6 ± 3.5	69	2.4 ± 2	0.975
γ-HCH	4 ± 1	4 ± 3	71	4 ± 1	0.919	0.3 ± 0.3	0.5 ± 0.6	71	0.4 ± 0.3	0.368
HCB	1132 ± 435	550 ± 300	72	401 ± 123	0.001	73.1 ± 36.8	55 ± 40.1	72	36.9 ± 26	0.084
Heptachlor	5 ± 1 (n = 7)	5 ± 2	42	5 ± 2 (n = 7)	0.399	0.5 ± 0.4 (n = 7)	0.6 ± 0.7	42	0.3 ± 0.3 (n = 7)	0.525
Heptachlor epox.	25 ± 4	22 ± 3	72	23 ± 3	0.121	1.7 ± 1	2.5 ± 1.9	72	1.9 ± 1.2	0.252
cis-Chlordane	1 ± 1 (n = 4)	1 ± 1	44	1 ± 1 (n = 4)	0.612	0.1 ± 0.1 ($n = 4$)	0.1 ± 0.1	44	0.1 ± 0.1($n = 4$)	0.152
oxy-Chlordane	33 ± 4	30 ± 5	72	31 ± 3	0.095	2.3 ± 1.3	3.6 ± 3	72	2.8 ± 1.9	0.289
trans-Nonachlor	1 ± 1 ($n = 5$)	1 ± 1	41	1 ± 1 (n = 4)	0.939	0.1 ± 0.1 (n = 5)	0.1 ± 0.1	41	0.1 ± 0.1(n = 4)	0.247
cis-Nonachlor	28 ± 9	63 ± 66	73	35 ± 15	0.082	2.2 ± 2.2	7.9 ± 12.3	73	2.9 ± 1.6	0.124
Mirex	8 ± 4 (n = 4)	5 ± 3	37	4 ± 1 (n = 6)	0.075	0.6 ± 0.3 (n = 4)	0.5 ± 0.3	37	0.3 ± 0.2 (n = 7)	0.386
p,p′-DDE	16 ± 4	18 ± 14	72	12 ± 6	0.287	1.2 ± 0.9	2.2 ± 3.1	72	0.9 ± 0.8	0.271

Note: Mean lipid percentage in muscle samples: 1.5 ± 1.3 (range; 0.2–9.8%).
[a] SD = Standard deviation.
[b] n = Number of samples included in the statistical analyses.
[c] P = p-value (statistically significant at the level of $p < 0.05$).

Table 6
Concentrations for organochlorine pesticides (OCPs) in reindeer muscle stratified by sex.

PCBs	Mean±SD[a] pg/g ww					Mean ± SD ng/g lw				
	Male	n[b]	Female	n	*p*-Value	Male	n	Female	n	p-Value
α-HCH	12 ± 7	51	15 ± 13	43	0.128	1.2 ± 0.6	51	1.1 ± 1.6	43	0.785
β-HCH	22 ± 14	50	24 ± 14	42	0.326	3.8 ± 3.8	50	2.1 ± 2.1	42	0.279
γ-HCH	5 ± 3	51	4 ± 1	43	0.141	0.6 ± 0.6	51	0.3 ± 0.2	43	0.002
HCB	571 ± 401	51	647 ± 321	44	0.311	60.7 ± 42.7	51	48.8 ± 33.7	44	0.139
Heptachlor	5 ± 1	30	4 ± 2	26	0.112	0.7 ± 0.8	30	0.4 ± 0.3	26	0.036
Heptachlor epoxide	23 ± 4	50	22 ± 3	45	0.630	2.9 ± 2.1	50	1.8 ± 1.1	45	0.002
cis-Chlordane	1 ± 1	24	1 ± 1	28	0.214	0.1 ± 0.1	24	0.1 ± 0.1	28	0.058
oxy-Chlordane	31 ± 4	51	30 ± 5	44	0.174	4.1 ± 3.4	51	2.4 ± 1.6	44	0.004
trans-Nonachlor	1 ± 1	20	1 ± 1	30	0.847	0.1 ± 0.1	20	0.1 ± 0.1	30	0.032
cis-Nonachlor	62 ± 69	51	48 ± 45	45	0.237	9.3 ± 14.3	51	3.5 ± 3.1	45	0.009
Mirex	5 ± 2	20	6 ± 3	27	0.289	0.6 ± 0.3	20	0.4 ± 0.3	28	0.072
p,p′-DDE	18 ± 13	50	16 ± 12	45	0.493	2.6 ± 3.7	50	1.2 ± 0.9	45	0.015

Note: Mean lipid percentage in muscle samples: 1.5 ± 1.3 (range; 0.2–9.8%). p-Value statistically significant at the level of p < 0.05.
[a] SD = Standard deviation.
[b] n = Number of samples included in the statistical analyses.

concentrations (2.6 ± 3.7 ng/g l.w.) than females adjusted for age (1.2 ± 0.9 ng/g l.w.), $p < 0.05$. However, no significant difference was observed among the various age groups for *p,p*′-DDE.

The higher concentrations of POPs in calves as well as males, compared to females in the older animal group, might be explained by the fact that female ruminants transfer part of their POP body burden to their calves in utero and through milk (Glynn et al., 2009; Ounnas et al., 2010; Rossi et al., 2010). Hence, calves can exhibit higher POP concentrations than their mothers (Rychen et al., 2014). Younger animals which depend on grazing and are no longer dependent on milk, are not affected by exposure to POPs through milk from dams and will consequently have lower concentrations than those of calves. POP concentrations in all animals, regardless of age or sex, were below the EC ML limits.

4. Conclusions

Concentrations measured for polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCPs) in reindeer muscle samples from this study were generally low. Geographical, age and sex patterns were revealed. Districts with previous mining activities, military trenches, and those that were in the vicinity of the Russian border exhibited slightly elevated concentrations compared to other districts. Calves (10 months) exhibited higher concentrations than young (1.5 years) and older animals (>2 years). Males exhibited higher concentrations than females. Concentrations of PCBs and OCPs in reindeer meat were all considerably lower than the maximum levels set for those contaminants in foodstuffs for safe human consumption by the European Commission. Thus, reindeer meat is not likely to be a substantial contributor to the human body burden of persistent organic pollutants.

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CRediT authorship contribution statement

Ammar Ali Hassan: Data collection, Statistical analyses, Writing-Original draft preparation, Reviewing and Editing.
Therese Haugdahl Nøst: Data collection, Writing- Reviewing, Editing and Visualization.
Magritt Brustad: Methodology, Writing- Reviewing and Editing.
Torkjell M. Sandanger: Methodology, Writing- Reviewing, Editing and Supervision.

Declaration of competing interest

The authors Ammar Ali Hassan, Therese Haugdahl Nøst, Magritt Brustad and Torkjel M. Sandanger declare no conflict of interest regarding the submitted research article.

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