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Combining data sets of organochlorines (OCs) in human plasma for the Russian Arctic

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ABSTRACT

As part of AMAP's human circumpolar study of POPs, an international effort was initiated to extend coverage to communities across the Russian Arctic. Two additional laboratories were invited to join the analytical component of this effort, resulting in four participating analytical centres. Although quality assurance measures were put in place, and the level of performance of the laboratories was generally acceptable, deficiencies in the analytical protocols used were recognized subsequent to the collection and analyses of the plasma specimens. The current paper describes the criteria employed to critically appraise the four data bases and guide their integration into a single data set. Summary statistics are presented for plasma concentrations of major PCBs, *p,p′*-DDE, *p,p′*-DDT, β-HCH, and HCB for communities/regions across the arctic/subarctic Russian continent, and for one community located in the Aral Sea area of Uzbekistan (a control group). Highly exposed people were identified in the coastal communities of Chukotka, which appears mainly related to marine mammal intake, but recent pesticide use is also suspected. Other communities with intermediate levels of PCBs had relatively elevated β-HCH, *p,p′*-DDT and HCB concentrations and low DDE/DDT ratios (<10), suggesting recent pesticide use.

1. Introduction

The Arctic is a pristine and therefore particularly vulnerable area that has received considerable attention during the last three decades in relation to the long-range transport of contaminants. High levels of persistent organic pollutants (POPs) constitute a special concern for native peoples living in remote Arctic communities. In order to map out circumpolar levels of contaminants in environmental media and human tissues, the Arctic Monitoring and Assessment Programme (AMAP) was set up in 1991. In terms of human samples, at the outset all were analysed by the same laboratory and the study sites were primarily located in Greenland, Canada and the Nordic countries. It was clear from the 1998 AMAP Assessment Report (AMAP, 1998) that coverage of communities in the Russian Arctic needed to be substantially increased because it features the world's largest Arctic population. As part of this expansion, two laboratories in Russia were invited to participate.

The analytical determination of organochlorine compounds (OCs) in human tissues is associated with inaccuracies that depend on the specific compounds tested, the analytical instrumentation available, and the quality of the analysis. Prior to the Russian initiative, the majority of the reported OCs concentrations had an inherent analytical accuracy of ≥80%. This level of performance was generally accepted as appropriate, since generally it resulted in a high score in the AMAP ring test and other inter-laboratory calibrations. Nevertheless when merging datasets from different laboratories, it is important to review carefully the performance of each laboratory because inaccuracies are additive and possible systematic errors have to be identified. This became an issue because four laboratories were involved in the expanded Russian coverage. The objective of the current paper is to share the critical appraisal guidelines that were used to evaluate the individual databases and create a combined dataset. This integrated dataset provides an indication of the human contamination burden across the Russian Arctic. Summary statistics that reflect the critical assessment described are presented for 12 Russian communities and one community in the Aral Sea area of Uzbekistan. This experience may be helpful to researchers faced with similar challenges.

2. Evaluation approach

2.1. Context

2.1.1. Laboratories and study area

Four different laboratories supplied data for the Russian initiative. In this paper they are identified only by a number for confidentiality

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Table 1
Number of samples analysed in this study, according to community, region and laboratory.

Lab[a]	Total (*n*)	Age (years)	Gender (% women)	Chukotka (coastal/inland)	Murmansk Oblast (Lovozero, Krasnoschelye, Kola City)	Lower Pechora River Area (Nenets AO)	Lower Yenisey River Area (Taimyr AO)	Norilsk (Taimyr AO)	Aral Sea	Kamchatka/Commander Islands
1	390	29.2	75.4	156	47	34	74	10	12	57
2	31	30.0	67.7	12	6	0	0	7	6	0
3	150	37.9	46.7	0	31	36	35	0	8	40
4	135	36.1	61.5	50	15	12	12	42	4	0
Tot	706	32.4	66.3	218	99	82	121	59	30	97

[a] There were four laboratories supplying data for this study, numbered 1, 2, 3, 4 throughout the text.

reasons. People from six different regions (in some regions communities were specified) of the Russian Arctic donated plasma specimens. As illustrated in Table 1, the number of individuals and gender distribution were different in each study area, as well as the total number analyzed by each laboratory. The six different regions in Russia and an Aral Sea site were (see Fig. 1): the Kola Peninsula (Murmansk Oblast; represented by the two Saami communities of Lovozero and Krasnoschelye, and the city of Kola near Murmansk); lower Pechora River area (Nenets Autonomous Okrug (Nenets AO)); lower Yenisey River area (Taimyr AO; the industrial city of Norilsk is considered separately); the Chukotka Peninsula, divided into coastal (e.g., Uelen) and inland(e.g., Kanchalan) communities (see Anda et al., 2007); Kamchatka; the Commander Islands (east coast, below the Arctic Circle); and the Aral Sea area of Uzbekistan. All but the Norilsk and some of the Aral participants were indigenous: primarily Saami (Murmansk Oblast); Nenets (Pechora and Taimyr); Dolgans (Taimyr); Chukchi (Chukotka); Eskimos (Chukotka); Aleuts (Commander Islands) and Itelmens, Koryaki and Eveni (Kamchatka) (AMAP, 2004). Of these indigenous peoples, the Chuckchi and Eskimos (and the Aleuts) hunt marine mammals and harvest seafood, while the remaining groups are primarily involved in hunting (especially reindeer) and fishing (Kolga et al., 1991, 2001; AMAP, 2004). The refining of nickel and related metals constitutes the major industrial activity in Norilsk, while soil and water in the Aral Sea area have been documented to be high in pesticides and other industrial pollutants (e.g., Hooper et al., 1997; Erdinger et al., 2004; AMAP, 2004). Clearly, this lack of even coverage by region between the laboratories, as well as the diverse ethnic origin of the indigenous peoples who participated, complicated the assessment of the comparability of the data.

2.1.2. Analytical methodology

All laboratories measured OCs in plasma volumes of 2–6 ml depending on availability. Laboratories 1 and 3 analyzed variable volumes of plasma and laboratories 2 and 4 always used 2 ml of plasma. Only for a limited number of samples was the available volume actually less than 2 ml. Two laboratories (2 and 4) used the same liquid–liquid extraction procedure as described by Sandanger et al. (2003a). The other two laboratories used a solid-phase extraction method as described by Konoplev (2003). All laboratories used GC-MS for quantification of the analytes in their extracts reducing the likelihood of identification errors. Depending on the

Fig. 1. Map of the Russian Arctic with the regions and communities involved in this study indicated. (AMAP).

analytes both negative chemical ionization (NCI) and electron-impact ionization (EI) was employed for ionization of the compounds. Laboratories 1 and 3 determined the lipids gravimetrically; another laboratory used only enzymatic determination of lipids and the remaining laboratory used both enzymatic and gravimetric determinations.

2.1.3. AMAP Ring Test

One important measure of standardizing laboratory performance is participation in international interlaboratory comparisons. AMAP encouraged and has tried to ensure that the laboratories involved in their human health program would participate in the AMAP Ring Test that was initiated in 2001. Le Centre de Toxicologie du Québec, Institut national de santé publique du Québec (INSPQ), an International Organisation for Standardization (ISO) accredited laboratory, has organized and administered the AMAP Ring Test since then. A total of 23 laboratories participated in this international comparison in 2007. In 2003 the determination of lipids was introduced into the ring test to standardize the laboratories' performance in lipid determination, thus allowing for the compatibility of lipid-adjusted POP concentrations. Unfortunately the lipids were not included in the ring test at the time the analytical work for the present surveys was conducted, and the laboratories performance at that time cannot be fully assessed. For the AMAP Russian initiative, one of the laboratories (No 3) did not participate in the ring test primarily due to logistical problems; whereas the other three laboratories participated from the initiation or shortly after its formal establishment in 2001. Consequently, it is impossible to assess the respective performances of all the four laboratories in the ring test exercise.

2.1.4. Critical appraisal guidelines

Perusal of the study dataset suggested the following guidelines would be helpful in our assessment:

- Ring test performance and quality assurance (QA) and quality control (QC) compliance;
- Sample size, distribution and mean values produced by the different laboratories of samples collected in regions from groups with similar age and gender distributions;
- Differences in limits of detection (LOD) and how values below LOD are treated;
- The percentage of values above LOD (detection frequency);
- Concentration distributions, normality and the identification of outliers;
- PCB congener ratios and correlations between compounds;
- Lipid adjustments: the importance of methods of lipid determination and physiologically accepted ranges.

3. Evaluation tools considered

3.1. Ring test performance and QA/QC issues

At the outset of the Russian initiative, QA/QC protocols were prepared for use by the laboratories and participation in the ring test was intended to be a measure of performance. As pointed out earlier not all laboratories participated fully in the ring test, circumventing a full assessment of their performance. The three laboratories which did participate performed in an acceptable manner with no systematic deviations in their OCs measurements. There were however differences in coefficient of variation (CV) for the different compounds and the different laboratories that could affect maximum or minimum values. The distribution of a common pooled sample among all four laboratories for direct comparison of performance was initiated but not completed, and thus not possible to assess. This is an essential step in the QA/QC assessment of data produced by several laboratories.

3.2. Sample size, distribution and mean values

Ideally the levels determined by each laboratory should be compared within each region for participants with similar age and gender distribution. Unfortunately, too few samples in total and the uneven distribution of samples between laboratories did not allow such stratification (Table 1). This prevented a direct comparison of concentrations, something that would have been a valuable step in such an assessment.

3.3. Limits of detection (LODs)

Because of differences in analytical methods and sample volumes analyzed, the laboratories assigned divergent LODs. Consequently a common approach was required to join the data from the four sources. Techniques of low sensitivity result in high LOD values; alternatively, high sensitivity result in low LOD values. Further, larger sample volumes permit lower LODs. To overcome this impasse, a common conservative LOD was assigned for each compound. It corresponded to the highest reported LOD at 2 ml of plasma analysed by any lab. A second decision involved replacement concentrations. We adopted the approach, in which values below LOD were replaced by LOD/sqrt 2. The rationale for both these choices is provided by Anda et al. (2007). Clearly some information in the data set is lost in this way, but this approach reduces the chance of misclassification due to laboratory differences in LOD.

3.4. Detection frequencies

Using the above approach, the percentages of values below the newly assigned LOD were calculated for the major OCs in each of the four data sets. The contaminant-specific LOD values employed and the extent of imputation required is summarized in Table 2. In order to optimize the available data for the presentation of the summary statistics and future health impact analyses while minimizing the introduction of bias (Anda et al., 2007), a cut-off point of 70% was selected for the detection frequency. Thus the data for PCB 28/31, α-HCH, *oxy*-chlordane and the toxaphenes were not carried forward; that for PCB 118 was however assessed further because it was borderline (31.6% non-detects).

3.5. Concentration distributions and outliers

It was difficult to use absolute concentration values to detect outliers because of the exposure diversity for individuals in different

Table 2
Detection frequencies and percentage imputation when merging datasets.

OCs[a]	LOD (μg/L)	Number<LOD	Total replacements (%)
PCB 28	0.04	418	59.2
PCB 99	0.04	118	16.7
PCB 118	0.14	223	31.6
PCB 138	0.07	94	13.3
PCB 153	0.05	31	4.4
PCB 180	0.03	88	12.5
p,p′-DDE	0.03	0	0
p,p′-DDT	0.08	88	12.5
α-HCH	0.03	531	78.7
β-HCH	0.03	101	15.0
Oxy-CD	0.02	351	49.7
HCB	0.02	8	1.1
Trans-NC	0.02	175	24.8
Tox 26	0.02	360	58.0
Tox 50	0.02	294	57.3

Abbreviations for the different compounds: PCB — Polychlorinated biphenyls, *p,p*-DDE — 2,2′-bis(*p*-chlorophenyl)-1,1-dichloroethylene, *p,p′*-DDT — 1,1′-bis(*p*-chlorophenyl)-2,2,2-trichloroethane, HCH — Hexachlorocyclohexanes, HCB — Hexachlorobenzene, oxy-CD — oxy-chlordane, trans-NC — trans-nonachlor, tox — toxaphene.

[a] The OCs listed in this Table constitute the raw dataset of OCs that all four laboratories supplied data for.

Table 3
PCB congener ratio and DDE/DDT ratio obtained by the different laboratories.

	Lab 1 ($N=390$) AM (Min/max)	Lab 2 ($N=31$) AM (Min/max)	Lab 3 ($N=150$) AM (Min/max)	Lab 4 ($N=135$) AM (Min/max)
DDE/DDT	12.6 (0.24–136.5)	17.9 (4.88–90.0)	15.3 (0.35–194)	12.9 (1.68–47.7)
PCB 99/153	0.33 (0.04–1.60)	0.38 (0.07–0.86)	1.13 (0.01–15.7)	0.31 (0.07–0.96)
PCB 118/153	1.13 (0.02–37.9)	1.60 (0.21–6.03)	1.28 (0.01–35.3)	0.79 (0.03–19.7)
PCB 138/153	0.53 (0.09–1.77)	0.62 (0.27–1.43)	0.98 (0.09–19.9)	0.57 (0.13–1.43)
PCB 153/180	3.39 (0.27–41.4)	2.99 (1.75–3.95)	4.45 (0.06–27.1)	3.56 (0.94–22.4)

AM — arithmetic mean.

communities. However, we removed outliers (to the right of the concentration distributions by more than 3 × standard deviations) to eliminate 3 spurious concentrations in the data set.

3.6. Congener ratios

It was reasoned that PCB-congener concentration ratios are independent of exposure differences, except in cases of occupational exposure. We calculated these ratios relative to the most prominent PCB-congener, namely PCB 153. This may assist in finding systematic errors and deviations from trends. The DDE/DDT ratio was also calculated, and even though this ratio will vary according to recent or current DDT exposure, it nevertheless gives an indication of potential laboratory differences. The laboratory specific ratios and the range of values are summarized in Table 3. This compilation indicates reasonable agreement when inspecting the mean and maximum ratios, except for PCB 99/153. In this case, both appear to be considerably higher for Laboratory 3 compared to the others.

3.7. Correlations between compounds

Inter-OCs correlations are well established, especially for PCB congeners and the DDTs (Anda et al., 2007), and should be amenable for use in identifying systematic errors. The corresponding correlation coefficients for the Log(natural)-transformed linear regressions are reported in Table 4, along with those for *trans*-nonachlor and β-HCH plotted against HCB. For PCB 118/153, the rather poor correlations shown for 3 of the 4 laboratories suggest the possibility of some fundamental analytical limitation for congener 118. The detection frequency for this compound was also only around 70%. For PCB 99/153, the results from Laboratory 3 seem out of line. This reflects what was observed for the congener ratio (see above and Table 3). The disparity between Laboratory 3 and the others also occurs for the correlation of *trans*-nonachlor/HCB. The correlation of HCB/β-HCH was however comparable for all laboratories. Consequently, we refrained from including PCB 99, PCB 118 and *trans*-nonachlor results from all four laboratories in the final data set.

3.8. Lipid adjustments

In general, lipid values reported by different laboratories should have the same average and operate in ranges of what is biologically acceptable. Lipid adjustments of wet-weight values are particularly useful in intercompartmental comparisons and helpful for global comparisons (Phllips et al., 1989; Sandanger et al., 2003a). It is evident from the data in Table 5 that two of the laboratories (particularly No 3, but also No 1) appear to have systematically underestimated the lipid content. This underestimation cannot be explained by the different analytical methods employed (gravimetric versus enzymatic; Sandanger et al, 2003a), since these differences are only in the range of 10–20%. The minimum lipid values reported by Laboratories 1 and 3 were well below what is reported to be the expected normal range in fasting individuals (0.45–1.0%) (Henry et al., 1974). Considering that these individuals were not fasting when the samples were obtained, the amount of lipids was expected to be higher than the minimum reference value. However, 63% of the data from the one laboratory reported lipid values below 0.3%. The cut off point was set to 0.3% lipids and all values below this were excluded. This reduced the complete dataset by 25.8%.The underestimation of the lipids by one of the two laboratories is supported by their later ring test performance on the lipid determination in which they undervalued the lipids slightly. As already indicated, the lipids were not included in the ring test at the time the analytical work for the present surveys was conducted, and thus a systematic error cannot be ruled out. For these reasons, the current assessment is limited to wet-weight OCs concentrations.

Table 4
Inter-OCs correlations for each laboratory.[a,b]

Lab	PCB 99 and PCB 153	PCB 118 and PCB 153	PCB 138 and PCB 153	PCB 180 and PCB 153	Trans-NC and HCB	*p,p′*-DDE and *p,p′*-DDT	HCB and β-HCH
1	0.84	0.052	0.88	0.91	0.61	0.60	0.37
2	0.78	0.17	0.89	0.96	0.72	0.66	NA
3	0.23	0.012	0.78	0.69	0.017	0.31	0.31
4	0.88	0.54	0.97	0.94	0.77	0.69	0.37

NA — not available.
[a] Pearsons regression coefficient (r).
[b] All values log-transformed (Ln).

Table 5
Lipid content of the plasma samples (%) as reported by the laboratories without making any replacements of low values.

Lab	N	Mean (min–max)
1	390	0.448 (0.05–1.08)
2	31	0.714 (0.39–1.06)
3	150	0.260 (0.03–1.03)
4	135	0.659 (0.30–1.30)

3.9. Final data set

The summary statistics for the remaining OCs are presented by community and region in Tables 6, 7 and 8. Some of the data for some of the regions have been presented previously by Anda et al. (2007) and Sandanger et al. (2003b). Due to established gender differences and the focus on the unborn child in human health research, the data is divided into pregnant women, and men and women from the general population. In these tables, geometric mean, arithmetic mean and ranges are reported to facilitate comparison to other studies; the age range and its mean are also provided.

4. Interpretation and conclusions

4.1. The critical appraisal process

Available AMAP Ring test data gave no indication of systematic errors in OCs data produced by the three laboratories who participated, supporting the merging of the datasets. However, the large CVs do indicate that care should be taken if data are to be stratified into smaller groups than done here.

One of the most important steps in assessing the comparability of the four datasets would have been to compare mean concentrations by age and gender in each community. This was unfortunately not possible due to very different sample sizes and distribution of the datasets. This is clearly a weakness and emphasis should be put on even distribution of samples in the case of similar future surveys. There were however several other important comparisons that were made.

First, a common conservative LOD value was introduced and replacements were made for levels below this value. Using this conservative approach obviously reduces the amount of information

Table 6
Plasma OCs for pregnant women by area (μg/L).

OCs		Chukotka coastal $N=59$	Chukotka inland $N=67$	Kola City (Murmansk Oblast) $N=16$	Lower Pechora River Area (Nenets AO) $N=38$	Lower Yenisey River Area (Taimyr AO) $N=69$	Norilsk (Taimyr AO) $N=59$	Aral Sea $N=30$	Kamchatka $N=8$
Age	AM (min–max)	25.6 (15–41)	25.6 (18–40)	21.9 (18–32)	23.2 (16–38)	26.5 (16–42)	26.7 (16–37)	26.9 (18–41)	21.2 (15–39)
PCB 138	GM (min–max)	0.34 (0.09–1.18)	0.12 (0.05–0.72)	0.22 (0.05–0.57)	0.15 (0.05–0.56)	0.21 (0.05–0.74)	0.16 (0.05–0.58)	0.06 (0.05–0.32)	0.1 (0.05–0.19)
	AM	0.41	0.15	0.26	0.19	0.25	0.19	0.07	0.12
PCB 153	GM (min–max)	1.11 (0.19–4.81)	0.2 (0.03–0.98)	0.26 (0.04–0.5)	0.45 (0.04–2.39)	0.4 (0.10–1.61)	0.28 (0.04–1.40)	0.05 (0.04–0.26)	0.29 (0.12–0.52)
	AM	1.5	0.26	0.3	0.62	0.49	0.34	0.07	0.32
PCB 180	GM (min–max)	0.23 (0.05–1.04)	0.06 (0.02–0.29)	0.09 (0.02–0.28)	0.18 (0.02–1.30)	0.14 (0.02–0.56)	0.08 (0.02–0.36)	0.02 (0.02–0.06)	0.09 (0.05–0.12)
	AM	0.3	0.08	0.12	0.28	0.17	0.1	0.03	0.09
Arochlor 1260[a]	GM (min–max)	7.64 (1.52–29.9)	1.67 (0.44–8.47)	2.49 (0.44–5.43)	3.21 (0.44–15.34)	3.16 (0.78–12.22)	2.34 (0.44–10.31)	0.58 (0.44–3.02)	2.05 (0.87–3.24)
	AM	9.94	2.1	2.94	4.22	3.84	2.76	0.7	2.26
p,p′-DDE	GM (min–max)	2.26 (0.74–6.98)	1.42 (0.07–6.35)	2.06 (0.77–6.56)	1.59 (0.06–5.44)	1.5 (0.21–7.65)	3.16 (0.79–19.65)	7.79 (1.34–20.76)	1.74 (1.03–2.45)
	AM	2.66	1.83	2.51	2.12	2.08	3.86	9.03	1.8
p,p′-DDT	GM (min–max)	0.22 (0.06–1.20)	0.21 (0.06–1.02)	0.25 (0.06–0.8)	0.26 (0.06–1.85)	0.21 (0.06–0.85)	0.33 (0.09–6.27)	0.25 (0.06–3.66)	0.11 (0.06–0.34)
	AM	0.3	0.27	0.31	0.39	0.28	0.48	0.41	0.14
β-HCH	GM (min–max)	1.66 (0.33–7.60)	0.67 (0.09–2.48)	0.16 (0.02–1.72)	0.33 (0.02–1.13)	0.65 (0.02–3.03)	1.04 (0.02–5.71)	1.25 (0.02–20.45)	0.48 (0.30–1.05)
	AM	2.09	0.87	0.44	0.45	1	1.91	3.8	0.52
HCB	GM (min–max)	1.28 (0.33–6.04)	0.52 (0.14–2.72)	0.34 (0.15–1.63)	0.56 (0.15–2.08)	0.57 (0.07–2.10)	0.26 (0.08–1.24)	0.06 (0.02–0.34)	0.29 (0.19–0.55)
	AM	1.28	0.65	0.42	0.71	0.7	0.3	0.07	0.31
DDE/DDT ratio	AM (min–max)	12.72 (1.59–79.83)	7.73 (0.73–25.98)	11.77 (2.63–65.73)	7.97 (1.0–31.83)	8.87 (0.48–51.67)	10.74 (3.13–33.37)	44.92 (2.32–194.33)	19.2 (5.91–40.88)

AM — arithmetic mean, GM — geometric mean.
[a] Arochlor 1260 = 5.3 (PCB 153 + PCB 138) according to AMAP (2003).

available in the dataset, but at the same time mitigates the chance of erroneous findings. For some congeners this will increase mean values; in particular, for the compounds with low detection frequency. Care must however be taken when stratifying the data, that no single group/category has a higher percentage below LOD than 70. The choice of the most conservative LOD value partially addresses this issue. As pointed out by Duval and Karlsson (2002) and Anda et al. (2007), it appears that the choice of a detection frequency below 90% may introduce bias. Consequently utilising data beyond providing regional/community averages, such as exploring associations, should only be pursued for compounds with acceptable detection frequencies. On the other hand, detection frequency differences between communities may help in characterizing exposure sources (Tsuji et al., 2005).

Examination of congener ratios and inter-OCs correlations were helpful in the critical appraisal process. This approach is validated by the fact that for the PCB-congeners with acceptable detection frequencies, good correlations have been reported by others (Muckle et al., 2001; Anda et al., 2007). Our data suggest that the relatively large number of non-detects and analytical limitations explain the lack of correlations for PCB 118 (also see Anda et al., 2007). The unavailability of the data for this congener, and those with detection frequencies below 70%, is not a serious issue for future exploration of associations such as with birth weight and sex ratio because of the observed correlation between congener concentrations. Thus other congeners can be substituted for this purpose. Related to this is a practise that warrants comment. In the past researchers have singled out, for metabolic reasons, associations with congeners that have some dioxin-like activity (e.g. PCB 105 and 118) (Ayotte et al., 2003). However, intercongener-correlations make it difficult to isolate congener-specific contributions to any relationship between PCBs levels and a biological outcome. For these reasons, it is advisable to use congeners with a detection frequency close to 100% for establishing such associations.

Table 7
Plasma OCs for women (general population) by area (μg/L).

OCs		Chukotka coastal (Uelen) $N=26$	Chukotka inland (Kanchalan) $N=28$	Krasnoshchelye (Murmansk oblast) $N=17$	Lovozero (Murmansk oblast) $N=47$	Lower Pechora River Area (Nenets AO) $N=31$	Lower Yenisey River Area (Taimyr AO) $N=40$	Commander Islands $N=49$
Age	AM (min–max)	38.1 (21–69)	37.3 (19–81)	46.9 (26–76)	44.1 (18–78)	36.8 (18–65)	43.5 (20–72)	33.8 (18–46)
PCB 138	GM (min–max)	0.73 (0.10–4.18)	0.11 (0.05–0.38)	0.25 (0.10–0.82)	0.31 (0.05–1.02)	0.22 (0.05–2.84)	0.20 (0.05–0.72)	0.29 (0.07–1.80)
	AM	1.08	0.13	0.3	0.39	0.43	0.27	0.37
PCB 153	GM (min–max)	1.8 (0.31–10.91)	0.23 (0.07–1.20)	0.48 (0.18–1.16)	0.44 (0.05–1.71)	0.40 (0.03–2.78)	0.35 (0.06–1.25)	0.51 (0.16–3.32)
	AM	2.75	0.3	0.52	0.58	0.67	0.45	0.68
PCB 180	GM (min–max)	0.46 (0.07–3.75)	0.07 (0.02–0.33)	0.23 (0.12–0.64)	0.14 (0.02–0.69)	0.11 (0.02–1.11)	0.10 (0.02–0.48)	0.17 (0.02–1.05)
	AM	0.76	0.1	0.26	0.22	0.24	0.15	0.24
Arochlor 1260[a]	GM (min–max)	13.17 (2.40–78.49)	1.77 (0.67–8.26)	3.83 (1.77–10.34)	4.00 (0.53–12.95)	3.29 (0.44–29.28)	2.94 (0.60–9.29)	4.18 (1.35–26.70)
	AM	19.91	2.24	4.27	5.07	5.73	3.70	5.4538
p,p′-DDE	GM (min–max)	2.10 (0.46–6.76)	1.12 (0.29–2.48)	2.91 (0.37–9.10)	2.32 (0.08–22.76)	2.09 (0.23–11.81)	1.20 (0.06–4.57)	2.33 (0.05–28.83)
	AM	2.74	1.31	3.70	4.17	2.87	1.61	4.23
p,p′-DDT	GM (min–max)	0.17 (0.06–0.69)	0.11 (0.06–0.47)	0.36 (0.14–1.01)	0.43 (0.11–4.09)	0.40 (0.06–3.17)	0.21 (0.06–1.15)	0.20 (0.06–1.30)
	AM	0.24	0.13	0.43	0.61	0.55	0.27	0.25
B-HCH	GM (min–max)	1.71 (0.21–8.17)	0.18 (0.02–1.55)	0.98 (0.08–4.16)	0.75 (0.02–3.81)	0,58 (0.14–3.67)	1.06 (0.12–3.89)	0.62 (0.17–2.72)
	AM	2.66	0.45	1.36	1.15	0.82	1.31	0.78
HCB	GM (min–max)	0.69 (0.08–3.41)	0.75 (0.24–2.58)	0.75 (0.39–1.16)	0.57 (0.05–1.73)	0.80 (0.26–2.25)	1.29 (0.05–3.55)	0.42 (0.16–4.31)
	AM	1.04	0.92	0.80	0.70	0.94	1.57	0.53
DDE/DDT ratio	AM(min–max)	13.38 (4.32–29.90)	11.37 (2.86–29.78)	9.07 (2.48–16.73)	7.98 (0.35–46.16)	6,51 (1.13–17.51)	7.35 (0.77–22.97)	18.27 (0.24–65.90)

AM — Arithmetic mean, GM — Geometric mean.
[a] Arochlor 1260 = 5.3 (PCB 153 + PCB 138) according to AMAP (2003).

Table 8
Plasma OCs for men from the general population by area (μg/L).

OCs		Chukotka coastal $N=24$	Chukotka inland $N=14$	Krasnoshchelye (Murmansk Oblast) $N=15$	Lovozero (Murmansk oblast) $N=4$	Lower Pechora River Area (Nenets AO) $N=13$	Lower Yenisey River Area (Taimyr AO) $N=12$	Commander Islands $N=40$
Age	AM (min–max)	34.7 (19–68)	31.6 (19–54)	41.3 (18–57)	55.3 (45–77)	34.6 (18–62)	38.5 (18–69)	39.2 (18–58)
PCB 138	GM (min–max)	1.67 (0.35–5.28)	0.18 (0.13–0.27)	0.34 (0.12–1.20)	0.59 (0.44–0.85)	0.25 (0.05–1.01)	0.31 (0.17–0.66)	0.26 (0.05–1.36)
	AM	1.97	0.18	0.4	0.61	0.37	0.33	0.39
PCB 153	GM (min–max)	4.44 (0.82–15.74)	0.33 (0.20–0.58)	0.70 (0.21–1.70)	1.38 (1.20–1.98)	0.51 (0.15–2.00)	0.61 (0.29–1.45)	0.30 (0.03–2.18)
	AM	5.42	0.36	0.82	1.41	0.66	0.67	0.5
PCB 180	GM (min–max)	1.30 (0.25–5.13)	0.11 (0.04–0.26)	0.38 (0.83–1.0)	0.64 (0.46–1.05)	0.22 (0.05–1.48)	0.23 (0.06–0.67)	0.15 (0.02–2.08)
	AM	1.68	0.12	0.47	0.67	0.34	0.29	0.32
Arochlor 1260[a]	GM (min–max)	31.84 (6.12–109.35)	2.68 (1.84–4.15)	5.45 (1.87–14.31)	10.35 (8.59–13.19)	4.70 (1.06–15.74)	4.81 (2.45–10.97)	3.19 (0.44–16.64)
	AM	38.41	2.81	6.35	10.49	5.33	5.23	4.65
p,p′-DDE	GM (min–max)	3.50 (1.33–8.33)	1.65 (1.05–3.18)	2.05 (0.42–6.99)	4.80 (1.89–16.75)	1.66 (0.10–10.28)	1.77 (0.90–4.15)	2.93 (0.66–9.93)
	AM	3.91	1.75	2.52	6.71	2.58	1.99	3.65
p,p′-DDT	GM (min–max)	0.20 (0.06–0.73)	0.14 (0.06–0.23)	0.26 (0.13–0.54)	0.58 (0.27–1.87)	0.29 (0.06–0.62)	0.17 (0.06–0.51)	0.20 (0.06–6.95)
	AM	0.23	0.15	0.29	0.77	0.33	0.21	0.78
β-HCH	GM (min–max)	2.16 (0.02–6.39)	0.45 (0.02–4.81)	0.67 (0.27–1.60)	0.90 (0.40–1.63)	0.49 (0.26–1.23)	1.0 (0.47–1.87)	0.14 (0.02–1.97)
	AM	2.97	1.06	0.77	1.01	0.56	1.07	0.39
HCB	GM (min–max)	0.93 (0.02–3.35)	0.62 (0.34–1.42)	0.67 (0.19–1.99)	0.97 (0.62–1.27)	0.83 (0.33–2.33)	1.43 (0.57–6.01)	0.24 (0.02–0.72)
	AM	1.23	0.67	0.79	1.01	0.97	1.87	0.29
DDE/DDT ratio	AM (min–max)	18.8 (10.90–44.82)	12.66 (8.4–20.93)	9.48 (1.68–23.14)	9.16 (4.01–14.91)	7.41 (1.77–21.80)	13.58 (4.30–47.45)	32.27(0.81–161.95)

AM — arithmetic mean, GM — geometric mean.
[a] Arochlor 1260 = 5.3 (PCB 153 + PCB 138) according to AMAP (2003).

As pointed out previously by us (Anda et al., 2007), lipid adjustments are useful for inter- compartmental comparisons (e.g., maternal plasma and mother's milk) because of different lipid contents. Since historically OCs concentrations have been reported in lipid-adjusted concentration units, it may be useful to continue reporting summary statistics in this manner alongside unadjusted concentrations.

On the basis of the above mentioned criteria, it was concluded that the following compounds could be assessed in a common data set without being affected by which specific laboratory did the analytic work. These compounds were PCB 138, 153, 180, *p,p′*-DDE, *p,p′*-DDT, β-HCH and HCB. As previously mentioned the data could only be assessed on a wet-weight basis.

4.2. Inter-community comparisons

The summary concentration statistics reported in Tables 6–8 are not lipid adjusted, and are for non-fasting individuals. A potential concern is whether samples obtained a few hours after a big meal of; for example, marine mammal tissue could result in an increase in the CV of the data and possibly enhance mean values. A previous study from our group illustrated that the consumption by non-fasting individuals of a traditional Norwegian meal of cod liver, hard roe, fresh cod liver and potatoes with relatively high levels of *p,p′*-DDE and PCBs resulted in some positive or negative changes in the plasma levels of these compounds after 4 h and an overall reduction after 12 h (Sandanger et al., 2003a). Concomitantly, plasma lipids increased (first 4 h) and then decreased (when measured at 12 h). However these changes were not related to individual intake, which was not restricted. The overall impact on wet-weight and lipid-adjusted OCs concentrations was limited (<20%).

Within each of the subgroups of participants (pregnant women, women from general population and men), the mean age was comparable and thus are considered not to be the reason for the community differences discussed below. The mean age of the pregnant women was, as expected, lower than that of the women and men from the general population. The mean ages for the latter 2 subgroups were comparable.

As expected, for the majority of compounds the mean levels were lowest among the pregnant women, with the women of the general population having slightly lower levels than the men. There were however exceptions to this for some of the pesticides, for which the highest levels occurred among the women. This suggests some gender dependence of exposure and/or metabolism.

Generally speaking and in terms of PCBs levels, the coastal Chukotka communities (designated as Group 1) exhibit the highest concentrations. This may be attributed to the considerable intake of marine mammals in these communities (AMAP, 2003, 2004; Walker et al., 2003; Ayotte et al., 2003; Sandanger et al., 2003b). The observed concentrations are comparable in magnitude to those reported for Inuits in Greenland and Canada, who share similar diets (Muckle et al., 2003; Walker et al., 2003; AMAP, 2004; Dewailly et al., 2007). The three more western communities/regions, Nenets AO, Taimyr AO and Murmansk Oblast; Tables 7 and 8) as well as the Commander Islands (collectively referred to as Group 2) show the second highest body burdens of PCBs, followed by the city of Kola, Norilsk and Kamchatka and then the Chukotka Inland communities (collectively referred to as Group 3). The PCB levels are considerably lower in the participants from the Aral region (see Table 6). The PCB levels reported in Tables 6–8 for Group 2 are comparable to those reported for native communities who consume significant amounts of fish and wild terrestrial animals (Walker et al., 2003; AMAP, 2003; Dewailly and Nieboer, 2005; Bonnier-Viger et al., 2007); those for Group 3 are comparable to what is seen for individuals not consuming such traditional foods (Walker et al., 2003; Tsuji et al., 2005). The considerably lower concentrations found for the Aral Sea region reflect those reported previously in breast milk and for children in the Kazakstan Aral Sea region (Hooper et al., 1997; Erdinger et al., 2004). Interestingly all communities with the second highest plasma PCBs levels, except the Commander Islands, are known to be in zones and at latitudes with relatively high air concentrations (projected) and measured soil contents of these compounds (AMAP, 2004; Meijer et al., 2002, 2003; Sweetman et al., 2005). The reason for the alignment of the Commander Islands community with Group 2 is likely some consumption of marine mammals along with terrestrial animals and fish (Kolga et al., 1991, 2001).

In terms of OC pesticides exposure, the picture is complex with some communities showing elevated levels that can only be linked to high exposure (recent or past), and in other communities the elevated levels are explained by both recent exposure and marine mammal consumption. Examples of the first are the Aral Sea and Norilsk, where the β-HCH, *p,p′*-DDE and *p,p′*-DDT levels were relatively elevated and the PCB levels among the lowest in this study. This is supported by the poor correlation between PCB 153 and β-HCH ($r^2=0.05$) in these two communities, as opposed to the coastal Chukotka communities where the correlation is good ($r^2=0.60$). The high levels of both PCBs and other OCs together with good inter-OC correlations suggest similar dietary sources. Interestingly,

ocean currents to the Bering Sea appear to be a likely source of OC pesticides (Li et al., 2002). The mentioned nickel (and associated metals and metalloids) mining and refining industry in Norilsk may well constitute a local source, while historic pesticide contamination in the Aral Sea area is documented (Hooper et al., 1997; Erdinger et al., 2004). The high DDE levels in the Aral Sea community together with the high value (44.9) of the DDE/DDT ratio does support that the exposure happened a long time ago and that it was considerable. DDE is the metabolite of DDT, and has a considerable longer half life than DDT. A high DDE/DDT ratio like that observed normally occurs in communities for which exposure is only through the food chain and there are no fresh sources of DDT (Anda et al., 2007; Sandanger et al., 2003b).

The merging of four datasets into one permits an initial estimate of exposure to OCs across the Russian Arctic. This exercise thus constitutes the first step in overcoming a large knowledge gap in the circumpolar AMAP assessment of these compounds in humans. Highly exposed populations are identified on the northeast coast of the Russian Arctic, as well as in other communities with clear indications of recent pesticide use.

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