Concentrations of persistent organochlorine contaminants in bowhead whale tissues, other biota, and store bought food from northern Alaska: Human exposure implications

Todd M. O'Hara[1, 3], Paul Hoekstra[2], Cyd Hanns[1], S.M. Backus[4], Derek Muir[4]

[1] Department of Wildlife Management, North Slope Borough, Box 69, Barrow, Alaska, 99723 USA

[2]Golder Associates, Ltd., 2390 Argentia Rd., Mississauga, Ontario, L5N 5Z7 Canada

[3]Institute of Arctic Biology, University of Alaska Fairbanks, Box 757000, Fairbanks, Alaska 99775-7000 USA (O'Hara current address)

[4]National Water Research Institute, Environment Canada, Burlington, Ontario, L7R4A6 Canada

ABSTRACT

Bowhead whale (*Balaena mysticetus*) blubber, liver, muscle, kidney, heart, diaphragm, tongue and uncooked maktak (epidermis and blubber) were collected during subsistence hunts at Barrow, Alaska USA (1997-1999) to measure the concentrations of persistent organochlorine contaminants (OCs) in this long-lived mysticete. The exposure of OCs to humans from bowhead whales and other biota as part of a subsistence diet was evaluated. Concentrations of OCs in bowhead whale tissues were correlated with lipid content (p<0.001) and were less than levels in other marine mammals reported herein and reflects the lower trophic status of this cetacean. Concentrations were compared to store bought foods with expected lower concentrations of OCs as compared to the marine mammals. Based on Canadian and World Health Organization (WHO) daily intake guidelines, "safe" human consumption rates of bowhead whale tissue and other marine biota were calculated. The most restrictive mean daily intake amounts for the bowhead whale and beluga whale (*Delphinapterus leucas*) blubber were 67 g and 32 g, compared to 302 g and 78 g for the much more commonly consumed maktak and maktaaq, respectively (both are combinations of epidermis and blubber). Blubber is rarely eaten alone and should not be used to give consumption advice unless considered as a portion of the food item (i.e., maktak). The tolerable daily intake limit (TDIL) of dioxin-like compounds from the consumption of bowhead whale blubber and liver by a 70 kg human was calculated to be 199 g (range: 141 to 348 g) and 2222 g (range: 1892 to 2390 g), respectively, as worst case scenarios (tissues with the highest levels of OCs). We compared these bowhead whale contaminant concentrations to those from select foods purchased from a local store (Barrow). We conclude that the consumption of bowhead whale and other marine biota from northern Alaska are safe based on current toxicological and contaminant data analyzed in this study and that store bought food alternatives are not free of contamination (e.g., <0.01 to 22.5 ng/g w.w. HCB). However, a detailed profile of traditional/country foods consumed by subsistence communities of northern Alaska is required to address chronic exposure in more detail. Overall, the consumption of bowhead whale tissues and other biota from northern Alaska is safe to consume at, or below, the levels calculated in this study. Many wildlife tissues had concentrations of OCs similar to the OCs concentrations found in local store bought food.

Keywords: bowhead whale, organochlorines, pollutants, whaling - aboriginal

INTRODUCTION

The presence of persistent organochlorine contaminants (OCs), a structurally diverse group of agricultural and industrial compounds (or by-products), in the Arctic is well known. These chemicals were first detected in the region in the late 1960s (Jensen, 1972) and have been found in virtually every compartment in the Arctic due to their environmental recalcitrance and long-range transport from industrial and agricultural activities via atmospheric and oceanic currents (de Wit et al., 2003). The persistence, toxicity and bioaccumulation potential of OCs is particularly significant in the arctic marine environment where many species feed on prey with greater lipid content compared to phylogenetically similar species or agricultural species inhabiting lower latitude ecosystems; resulting in the

accumulation of OCs to relatively high concentrations in top predatory marine species such as polar bears (*Ursus maritimus*) and ringed seals (*Phoca hispida*) (de Wit et al., 2003). The accumulation of OCs in arctic biota remains relevant to indigenous peoples of this region, who may be exposed to OCs at greater concentrations than populations in southern Canada or the USA due to the consumption of lipid-rich traditional foods (Sandau et al., 2000).

The subsistence diet of indigenous peoples of the Arctic varies by region due to prey availability and local hunting practices. In northern Alaska, Inuit have hunted and consumed arctic wildlife and marine mammals, especially the bowhead whale (*Balaena mysticetus*) for many generations (Stoker and Krupnik, 1993). While the bowhead whale stock found in the Bering-Chukchi-Beaufort Seas region was greatly reduced by commercial whaling (Shelden and Rugh, 1996), this population is increasing at a rate of ≈3% per year (Raftery and Zeh, 1998) and remains a sociocultural and nutritionally important species to coastal Alaskan subsistence communities (Kassam, 2001).

Several studies have recognized the sociocultural and nutritional benefit of traditional foods to arctic peoples (e.g. Van Oostdam et al., 2003). However, the accumulation of OCs in Native populations from subsistence arctic communities has raised some questions concerning the suitability of terrestrial and marine wildlife from this region for human consumption (Kuhnlein and Chan, 2000; Rubin et al., 2001; Sandau et al., 2000; Van Oostdam et al., 2003). Concentrations of OCs in bowhead whale blubber and liver, along with blubber from other marine mammals from northern Alaska, have been reported (Hoekstra et al., 2002b; Hoekstra et al., 2003b; Krahn et al., 2000; Kucklick et al., 2002; O'Hara et al., 1999). However, the exposure to OCs from consumption of other bowhead whale tissues as part of a subsistence diet and local store bought alternatives has not been investigated.

In this paper we discuss the potential human exposure to OCs and implications for human consumption of bowhead whale tissues and other biota as part of a subsistence diet. We examined the presence of several persistent OC groups in bowhead whale tissues that had not been examined previously (muscle, kidney, heart, diaphragm, and tongue) and uncooked bowhead whale maktak, a traditional food item comprised of bowhead whale epidermis and blubber. The concentrations and relative abundance of OCs in these bowhead whale tissues were investigated and compared to select foods purchased locally.

METHODOLOGY

Sample collection (wildlife)

Samples were collected from 1997 to 1999 at Barrow, AK (71°17′N, 156°45′W), Nuiqsut, AK (70°21′N, 151°02′W) and Pt. Lay, AK (69°43′N, 163°00′W) through the North Slope Borough Department of Wildlife Management (Fig. 1) as part of a larger study to investigate the trophic ecology and transfer of persistent OCs in the arctic marine environment of northern Alaska (Hoekstra et al., 2003b). Blubber samples from ringed seals (*Phoca hispida*), bearded seals (*Erignathus barbatus*), and beluga whale (*Delphinapterus leucas*; including epidermis) were collected from Inuit subsistence harvests. Bowhead whale tissues were obtained from the Inuit's subsistence hunt with the permission of the Alaska Eskimo Whaling Commission and Barrow Whaling Captains Association (Barrow, AK). Several species of fish; including arctic char (*Salvelinus alpinus*), pink salmon *(Oncorhynchus gorbuscha*), broad whitefish (*Coregonus nasus*), arctic grayling (*Thymallus arcticus*), and burbot (*Lota lota*), were provided by Native (Inuit) subsistence fishers.

Field sampling techniques of mammalian tissues have been previously described (Becker et al., 1991; Hoekstra et al., 2002b). Representative samples of uncooked bowhead and beluga whale maktak and maktaaq, respectively, were prepared using an epidermis-to-blubber size ratio of 1:2 (i.e. typically consumed dimension). Samples were transported to the National Water Research Institute (Environment Canada, Burlington, ON, Canada) under U.S. Export and Canadian Import permits in accordance with the Convention on International Trade in Endangered Species (US694250 and CA-CW-IM-0053-00, respectively) and via provision of the U.S. Marine Mammal Protection Act (Permit No. 782-1399). All samples were homogenized and stored at -20˚C in pre-cleaned glass containers.

Sample collection (store bought foods)

Various commercially available foods [Cornish game hen, boneless pork loin chop, milkfish (*Chanos chanos*), smoked salmon strips (*Oncorhyncus sp.*), imitation crab flakes, beef shank and tongue, honeycombed tripe (rumen), reindeer steak and steak marrow (*Rangifer tarandus*), lobster tail (possibly *Panulirus argus*), chicken egg yolk, sardines (Western Family Sardines, lightly smoked in soybean oil; salt/Thailand *likely Sardinella auritas*), and

canned salmon (*O. gorbusha*; salt)] were obtained from a local market by local residents in 2002. Samples were selected based on their availability and potential dietary importance as a substitute for subsistence foods (i.e. country-based diet).

Samples were transported to the National Water Research Institute (Environment Canada, Burlington, Ontario, Canada). We expected that the concentrations of OCs in the store-bought foods would be low; and consequently, this presumption led to pooling of samples to increase the available mass for chemical analyses. All samples were homogenized and stored at -20˚C in pre-cleaned glass containers.

Chemicals and Standards

All solvents (pesticide grade) were obtained from Caledon Laboratories. (Georgetown, ON, Canada). American Chemical Society-grade granular sodium sulfate (Na_2SO_4) was obtained from EM Science (Gibbstown, NJ, USA). Pesticide-grade dry silica (60 – 200 mesh) was obtained from ACP (Montréal, PQ, Canada). SX-3 Biobeads (200 – 400 mesh) used in gel permeation chromatography columns were purchased from Bio-Rad Laboratories (Hercules, CA, USA).

Extraction and analysis of non-planar PCBs, OC pesticides

Biota samples were extracted and analyzed using previously described techniques with only minor modification (Hoekstra et al., 2002b). In brief, fish samples and full thickness blubber cores from marine mammals were homogenized prior to OC extraction. Tissue subsamples were mixed with sodium sulfate (Na_2SO_4) and spiked with a mixture of internal standards (two polychlorinated biphenyl (PCB) congeners, CB-30 and CB-204; δ-HCH, 1,3,5-tribromobenzene, and 1,2,4,5-tetrabromobenzene) to monitor analyte recovery. Fish and bowhead whale tissues (except blubber and maktak) were extracted with dichloromethane (DCM) via Soxhlet, whereas marine mammal blubber and maktak/maktaaq samples were extracted with DCM by using a Polytron® homogenizer (Brinkmann, Westbury, NY). Lipids and other bioorganic materials in each sample were removed using gel permeation chromatography and lipid percent determined gravimetrically.

The analytes for each sample were concentrated and separated on 100%-activated silica gel into two fractions: hexane (Fraction 1) and hexane: DCM (1:1 by volume; Fraction 2). Samples were transferred to 2,2,4-trimethylpentane (iso-octane) and concentrated to 100 μL. The 2,3,4,4′,5,6-hexachlorobiphenyl, CB-166, was added as a performance standard prior to analysis. Analysis of PCB (Fraction 1) and OC pesticides (Fractions 1 and 2) for all samples was performed using a Hewlett-Packard 5890 gas chromatograph (Wilmington, DE, USA) with a ^{63}Ni-electron capture detector (ECD) (Hoekstra et al., 2002c). Sample quantification of PCBs and OC pesticides (and related products) was performed using multiple external standards provided by the National Laboratory for Environmental Testing (NLET; Environment Canada, Burlington, ON, Canada) that were analyzed after every 10 samples. The sum (Σ) group concentrations of OC classes reported herein (Tables 1 to 3) includes hexachlorobenzene (HCB), ΣCHL (sum of chlordane technical products *cis*- and *trans*-chlordane, *cis*- and *trans*-nonachlor, and oxychlordane); ΣDDT (sum of *o,p′*- and *p,p′*-substituted DDT, DDE, and DDD), the sum of α-, β-, and γ-hexachlorocyclohexane isomers (ΣHCH) isomers, and the sum of PCB congeners (ΣPCB) CB-4/10, 7/9, 6, 8/5, 19, 12/13, 18, 15/17, 24/27, 16, 32, 54/29, 26, 25, 50, 28, 31, 33/21/53, 51, 22, 45, 46, 52, 49, 43, 47/48, 44, 59, 42, 64, 41/71, 40, 100, 63, 74, 76/98, 70, 95/66, 91, 55, 56/60, 92/84, 101, 99, 119, 83, 97, 87, 81, 85, 136, 110, 82, 151, 135, 144, 107/147, 149/133, 118, 114, 143, 141, 145, 153, 132, 105, 141/179, 137, 176/130, 163, 138, 158, 129/178, 175, 187, 182, 183, 128, 167, 185, 174, 177, 171, 156, 202/173, 172, 197, 180, 193, 191, 199, 170/190, 198, 201, 196/203, 189, 206, 195, 207, 194, 205, 208, and 209 (IUPAC designation).

Coplanar PCBs and PCDD/Fs in bowhead whale blubber and liver

A limited number of bowhead whale blubber and liver tissues (n=5) were randomly selected for analysis of coplanar PCBs, polychlorinated dibenzo-*p*-dioxin and dibenzofuran (PCDD/F) congeners. Other tissues were omitted from this analysis because coplanar PCBs and PCDD/Fs concentrations in arctic wildlife are generally found at a fraction of ΣPCB levels (de Wit et al., 2003), and were likely to be below method detection limits. This analyses would then represent a "worst case" scenario for the human consumer as blubber is not eaten alone and liver is not commonly eaten.

For coplanar PCBs, bowhead whale blubber (1-2 g) and liver (5-10 g) samples were accurately weighed and homogenized with Na_2SO_4. Samples were spiked with ^{13}C-labelled surrogate standards of CB-77, CB-126, and CB-169 to monitor extraction efficiency. Samples were extracted overnight in *n*-hexane: DCM (50:50, by volume) using a Soxhlet apparatus and concentrated to 10 mL. A 1 mL aliquot was removed for gravimetric lipid determination. The remaining portion was concentrated and eluted through an acidified silica gel column (22% H_2SO_4 by weight, 6 g) to remove lipids and volume reduced to 200 µL.

Coplanar PCBs were separated from nonplanar OCs by high-pressure liquid chromatography (HPLC) (Bagheri et al., 1993; Lundgren et al., 2002). In brief, samples were manually injected into an Agilent 1100 HPLC system equipped with a diode-array detector (Agilent Technologies, Wilmington, DE, USA). The HPLC separation of planar from non-planar PCBs was performed on two 15 cm × 4.6 mm (internal diameter, i.d.) Cosmosil PYE-5 columns with a particle size of 5 µm (Nacalai Tesque, Japan). Columns were connected in series and temperature was maintained at 20 °C. Hexane was used for the elution of PCBs at a flow rate of 1 mL min^{-1}. The fraction containing planar PCBs was collected between 11 and 20 mL.

The coplanar PCB fraction was fortified in isooctane and concentrated to 100 µL. Analysis of coplanar PCBs was performed using an Agilent 6890N gas chromatograph equipped with a 5973N mass selective detector using negative chemical ionization (Bagheri et al., 1993). The GC capillary fused-silica column used was an Agilent HP-5MS (30 m × 0.25 mm i.d. × 0.25 µm film thickness). Samples were injected (2 µL) in pulsed-splitless mode with an initial pressure of 25 psi, held for 1.25 min and then at a constant flow of 1.2 mL min^{-1}. The column temperature was initially programmed at 80 °C for 2 min, and then the temperature was increased at a rate of 10 °C min^{-1} to 110 °C, followed by 3 °C min^{-1} to 285 °C, where column temperature was maintained for 5 minutes. The injector temperature was set at 250 °C, the transfer line at 290 °C and the ion source and quadrople at 150 °C and 106 °C, respectively. Helium was selected as the carrier and methane was used as the chemical reagent gas.

Extraction and analysis of PCDD/Fs in bowhead whale blubber and liver samples by Axys Analytics (Sidney, BC, Canada) used previously described techniques with only minor modification (U.S. EPA, 1994). Bowhead blubber and liver samples were homogenized with Na_2SO_4 and spiked with mixture of ^{13}C-labelled PCDD (2,3,7,8-TCDD, 1,2,3,7,8-pentaCDD, 1,2,3,4,7,8-hexaCDD, 1,2,3,4,7,8-hexaCDD, 1,2,3,6,7,8-hexaCDD, 1,2,3,7,8,9-hexaCDD, 1,2,3,4,6,7,8-heptaCDD, and OCDD) and PCDF isomers (2,3,7,8-TCDF, 1,2,3,7,8-pentaCDF, 2,3,4,7,8-PeCDF, 1,2,3,4,7,8-hexaCDF, 1,2,3,6,7,8-hexaCDF, 1,2,3,7,8,9-hexaCDF, 2,3,4,6,7,8-hexaCDF, 1,2,3,4,6,7,8-heptaCDF, 1,2,3,4,7,8,9-heptaCDF, and OCDF) surrogate standards to monitor extraction efficiency. Samples were extracted in toluene via Soxhlet under clean-room laboratory conditions (positive pressure, carbon and HEPA™ filters) and concentrated. Extracts were cleaned-up and PCDD/Fs were isolated through a series of chromatographic columns (U.S. EPA, 1994). Analysis is performed using a high-resolution chromatograph coupled to a high-resolution mass spectrometer (HRGC-HRMS). Compound separation was accomplished using a DB-5 capillary chromatography column (60 m × 0.25 mm i.d. × 0.1 µm film thickness; J&W Scientific, Folsom, CA, USA). A second column, DB-225 (30 m × 0.25 mm i.d. × 0.15 µm film thickness), was used for confirmation of 2,3,7,8-tetraCDF. All analytical procedures are carried out according to protocols as described in U.S. EPA (1994).

Analytical quality assurance for wildlife samples

Recovery of nonplanar PCB and OC surrogate standards ranged from 70% to 98% and concentrations were adjusted accordingly. Detection limits ranged from 0.02 to 0.1 ng g^{-1} for individual PCB congeners (including non-ortho Cl substituted PCBs) and OC pesticides, and 0.2 to 5.0 pg g^{-1} for PCDD/F analysis. Quality assurance protocol included extraction and analysis of laboratory blanks with every batch of 10 samples and the use of two standard reference materials (SRM1588 Organics in Cod Liver Oil and SRM1945 Organics in Whale Blubber Homogenate) from the National Institute of Standards and Technology (NIST; Gaithersburg, MD, USA). Results of SRM analysis were within 20% of certified values. The laboratory that conducted coplanar PCB analyses (NLET) had successfully participated in an international interlaboratory comparison program on PCB analysis (QUASIMEME, Aberdeen, UK).

Extraction and clean-up of store bought food samples

Samples of store-bought foods (approximately 10 – 20 grams, wet weight) were extracted using previously described techniques with minor modification (Hoekstra et al., 2002). Samples were homogenized with sodium sulphate (Na_2SO_4) and spiked with a mixture of internal standards (two polychlorinated biphenyl (PCB) congeners, CB-30

and CB-204; δ-substituted hexachlorocyclohexane (δHCH), 1,3,5-tribromobenzene, and 1,2,4,5-tetrabromobenzene) to monitor the efficiency of the extraction protocol. Samples were extracted with dichloromethane (DCM) using Soxhlet extraction for 16 hours and subsequently passed through an Allihn funnel containing sodium sulfate, and concentrated. Lipids and other bioorganic materials in each sample were removed using gel permeation chromatography (GPC) and lipid percent was determined gravimetrically. The analyte sample was concentrated and separated on 8 grams of 100%-activated silica gel into two fractions: 65 ml of 100% hexane (F1) and 90 ml of 50% hexane: 50% dichloromethane (F2). Endrin ketone and 1,3-dibromobenzene were added as laboratory spiking surrogates to determine fractionation performance. Samples were rotary evaporated, transferred to 2,2,4-trimethylpentane (iso-octane) and concentrated to 1000 µl.

PCB/OC pesticide analysis

PCB and OC pesticide analysis on both sample fractions was performed using a Hewlett-Packard (Wilmington, DE, USA) 6890 gas chromatograph (GC) with a ^{63}Ni-electron capture detector (ECD). Pulsed splitless injections of 1µl volumes were performed by a HP 7683 autosampler and a HP 7683 Series Inject with a splitless time of 1.0 min (injector temperature set at 250 ^{o}C). Compound separation was completed using a 30 m × 0.25 mm (i.d.) HP-5MS column (internal film thickness 0.25-µm; Wilmington, DE, USA) with H_2 carrier gas (at a constant flow rate of 1.1 ml/min). Nitrogen was used as the makeup gas for the ECD (detector temperature: 350 ^{o}C). The oven temperature program was initiated at 80 ^{o}C (held 2.0 min), ramped to 90 ^{o}C at 10^{o}C/min, then ramped at 2.5 ^{o}C/min to 285 ^{o}C (5 min hold time) and maintained till the completion of the 86-minute run. Sample quantification was performed using multiple external standards obtained from the National Laboratory for Environmental Testing (Environment Canada, Burlington, ON, Canada) that were analyzed after every 10 samples.

Analytical quality assurance (store bought foods)

Average (± 1 standard deviation, SD) sample recovery of PCB and OC surrogate standards was 103% ± 18% and concentrations were adjusted accordingly. Detection limits ranged from 0.02 to 0.1 ng g^{-1} for individual PCB congeners and OC pesticides and related compounds. Quality assurance protocol included extraction and analysis of laboratory blanks with every batch of 10 samples, the use of a standard reference material (SRM1974a Organics in Muscle Tissue (*Mytilus edulis*) from the National Institute of Standards and Technology (NIST; Gaithersburg, MD, USA), and participation in an international inter-laboratory comparison program on PCB analysis (QUASIMEME, Aberdeen, UK).

Statistical analysis and calculations

Statistical analyses were conducted using the SYSTAT® statistical package, Version 8.0 (SPSS, Chicago, IL, USA). All statistical tests were two-tailed and maximum probability of a Type-I error (α) was established at 0.05. The relationship between PCB and OC concentrations (wet weight; w.w.) with the percentage of extractable lipids in various bowhead whale tissues was investigated using Model-II linear regression. All other statistical comparisons of OC concentrations were performed using lipid-normalized (l.w.) concentrations to reduce the variability of lipid content on analyte concentrations (Hebert and Keenleyside, 1995). The influence of tissue-type and lipid content on the relative proportion of ΣOCs among bowhead whale tissues were investigated using a General Linear Model (GLM):

$$(1)\ \Sigma\text{OCs proportion} = \mu + \text{tissue} + \text{lipid} + (\text{tissue} \times \text{lipid}) + \varepsilon$$

where μ is a constant and ε is the error term. Preliminary analysis indicated that the 1st-order interaction term, (tissue × lipid), was not a significant factor according to Type-III Sums-of-Squares and was subsequently removed from the GLM. The Scheffé's method was selected to assess all *a-posteriori* pair-wise comparisons of group means deemed significant by the GLM. Due to the limited number of tissues available, the Scheffé's test was chosen over other post hoc techniques because it reduces Type-I errors but has a higher rate of Type-II (i.e. failing to detect a "true" significant difference), making this test relatively more conservative than other pair-wise statistical comparisons.

ΣPCB concentrations (w.w.) in all biota were compared (via the Z-test) to threshold concentrations (w.w.) in food destined for human consumption that range from 0.2 µg g^{-1} (meat), 0.5 µg g^{-1} (poultry) to 2.0 µg g^{-1} in fish as recommended by Health Canada (Hing, 1998). Calculations of tolerable daily consumption (or intake) limits (TDIL) of bowhead whale tissues and other marine biota as food were calculated using the following equation:

$$(2)\ TDIL(g) = \frac{TDI(\mu g/kg/day) \times BW(kg)}{TC(\mu g/g, wet)}$$

where TC is the mean tissue concentration of ΣOC expressed in μg g^{-1} (w.w.) and BW is the assumed body weight of an average adult human consumer (70 kg). The established tolerable daily intake (TDI) guidelines indicate that daily intake should not exceed 20 μg kg^{-1} BW of ΣDDT, 0.3 for ΣHCH, 1.0 for ΣPCB, and 0.27 for HCB (Health Canada, 1996). For ΣCHL, the Provisional Tolerable Daily Intake (PTDI) value of 0.5 μg kg^{-1} of body weight was used (U.S. EPA, 1999; WHO, 1993). Estimating exposure to neonates and children was not attempted in this manuscript as separate studies addressing concentrations of OCs in cord blood, breast milk, etc. are underway.

The potential human exposure to PCDDs and other "dioxin-like" contaminants in bowhead whale blubber and liver was investigated by normalizing the toxic potential of each compound by the following equation:

$$(3)\ TEQ(pg/g\ wet\ weight) = TEF_i \times C_i$$

where TEF_i is the toxic equivalency factor of a compound relative to 2,3,7,8-tetraCDD (van den Berg et al., 1998) and C_i is the concentration (pg g^{-1}; w.w.) of a "dioxin-like" compound (e.g. non- and mono-*ortho* Cl substituted PCB congeners and other PCDD/F isomers). Sum TEQ for ΣPCDD, ΣPCDF, and "dioxin-like" PCBs were calculated using the following equation:

$$(4)\ TEQ = \sum_{i=1}^{i=n} TEF_i \times C_i$$

for all *n* congeners in each group of compounds (i.e. ΣPCDD, ΣPDDF, sum of mono-*ortho* and non-*ortho* Cl substituted PCBs). The ΣTEQ for all dioxin-like OCs was calculated as the sum of TEQs for each ΣPCDD, ΣPCDF, and coplanar PCB groups. As well, TCDD-equivalent TDIL values were calculated using the Canadian TDI value of 10 pg kg^{-1} BW d^{-1} (assuming a 70 kg adult consumer) from Health Canada (1996).

RESULTS AND DISCUSSION

OC concentrations in bowhead whale tissue

Concentrations of sum (Σ) OC groups in bowhead whale tissues and other biota, including fish, are presented in Tables 1 and 2. The trophic transfer of OCs in this near-shore marine food web has been previously discussed (Hoekstra et al., 2003b). In summary, the varying concentrations and relative bioaccumulation of OCs in marine mammals and fish species mostly results from differences in the physical-chemical properties of OCs, and the feeding strategy and biotransformation capacity of the species studied in this region (Hoekstra et al., 2003b).

Log_{10}-transformed, wet weight ΣOC and HCB concentrations in the bowhead whale were significantly correlated with the lipid content of each tissue ($p<0.01$, $r^2= 0.81–0.95$ for all comparisons). This relationship is exemplified in Fig. 2, where the 1st-order linear relationship between wet weight ΣPCB concentrations and lipid content of bowhead whale tissues was significant ($p<0.001$; $r^2=0.87$). The quadratic (i.e. second-order) linear regression equation ($\log_{10}\Sigma PCB = 0.22 + [0.57\log_{10}(lipid)] + 0.31[\log_{10}(lipid)]^2$) for all points offered a slightly more robust fit ($r^2= 0.95$; $p<0.0001$). However, this regression analyses is likely influenced by the greater abundance of tissues with low lipid content compared to more lipid-rich compartments analyzed in this study, such as blubber and maktak. Nevertheless, both 1st- and 2nd-order linear regressions clearly demonstrate the importance of lipid-content as a determining factor in OC concentrations in bowhead whale tissues, which is consistent with the known partition-based behaviour of these lipophilic contaminants.

The influence of lipid content on OC concentrations is particularly evident when comparing contaminant levels in maktak and blubber. The lipid content of maktak was approximately <30% of the lipid percentage in corresponding blubber samples. However, the geometric mean concentrations of ΣOC in maktak were approximately 15-30% of mean blubber values (Table 1). While the decrease in extractable portion of non-polar lipids from blubber to maktak is an important variable affecting OC concentrations, the likely heterogeneous stratification of OCs in blubber is also a significant factor (Aguilar et al., 1999). For example, white whale biopsy samples (i.e. epidermis and near-epidermis blubber layer) from the St. Lawrence River Estuary contained lower concentrations of most major OC analytes compared to results for blubber from stranded white whale carcasses (Hobbs et al., 2003). However, lipid-normalized OC concentrations in biopsy samples of white whales from the Cook Inlet, Alaska were similar to full-

core blubber samples obtained by necropsy (Krahn et al., 2003). Due to the discrepancy between these studies, direct comparisons of OC data from biopsy (or maktak) and complete blubber core samples should be conducted with caution.

In marine mammals, blubber is the major repository for many of the recalcitrant, lipophilic OCs (O'Shea, 1999). Subsequently, most investigations emphasize the determination of residue concentrations in this tissue to address various parameters related to organism health. Contaminant concentrations in cetaceans have been reported in other compartments, such as whole blood (or erythrocytes), liver, kidney, and muscle (e.g. Bruhn et al., 1995; Hoekstra et al., 2002b; Hoekstra et al., 2003a; O'Shea 1999). However, the detailed analysis of OCs in various cetacean tissues from the same specimen is limited compared to the predominance of existing literature on contaminants in blubber.

The overall percentage of HCB, ΣDDT, ΣCHL, and ΣPCBs to the total OC concentration in bowhead whale is generally consistent among all tissues analyzed. The relative proportions of HCB (GLM, $F_{7,31}$=0.61; p=0.74), ΣDDT (GLM, $F_{7,31}$=0.45; p=0.84), ΣCHL (GLM, $F_{7,31}$=2.20; p=0.08), and ΣPCB (GLM, $F_{7,31}$=0.14; p=0.91) were not statistically different among bowhead whale tissues. While the limited number of tissue samples available in this study decreased the power of statistical analysis, our findings are consistent with previous observations on the homogeneous distribution of lipid normalized OC levels in cetacean tissues (Marsili and Focardi, 1997; Muir et al., 1999).

The relative abundance of ΣHCH in bowhead whale was significantly influenced by tissue-type (GLM, $F_{7,31}$=10.9; p<0.001). Pair-wise comparisons of group means found that proportions of ΣHCH of total OC concentrations in heart and diaphragm were significantly greater compared to other tissues (Fig. 3; upper panel; Scheffé's; p<0.03 for all comparisons). The greater percentage of ΣHCH in heart and diaphragm compared to other tissues is due to the accumulation of β-HCH in these compartments (Fig. 3; lower panel; p<0.01 for all comparisons). These results are consistent with the tissue-specific accumulation of HCH in rats, in which the accumulation of β-HCH in the heart was significantly greater than α-HCH; the predominant isomer in all other tissues (Siddiqui et al., 2003). To our knowledge, this is the first report of isomer-specific accumulation of HCH in any mysticete, which may be important as preferential accumulation of isomers could have toxicological implications (Willett et al., 1998).

Human dietary exposure to ΣOCs, HCB

The ΣPCB concentrations in bowhead whale blubber exceeded the guideline for ΣPCB in meat (i.e. livestock) by approximately 80% (p<0.001), but did not exceed those suggested for fish and poultry as recommended by Health Canada (Table 1, p>0.25; Hing, 1998). All other bowhead whale tissues, along with all fish samples, did not exceed any of the suggested ΣPCB guidelines (Table 1, p<0.01). Concentrations of ΣPCBs in the bearded seal blubber were statistically greater than the Health Canada ΣPCB threshold level for meat (p<0.01), whereas ΣPCBs in ringed seals exceeded both meat and poultry guidelines (p<0.02; both comparisons). As expected, ΣPCBs in beluga whale blubber exceeded all threshold levels, including fish (Table 2, p<0.004), whereas beluga maktaaq ΣPCB concentrations only exceeded meat and poultry guidelines (p<0.001). It should be noted that the maximum ΣPCB threshold levels were established for known or estimated consumption rates for the general Canadian population (Hing, 1998) and not those of indigenous peoples. Unfortunately, this information is not available for the subsistence communities in northern Alaska.

Tolerable daily consumption (or intake) limits (TDIL) for various marine mammal tissues and fish varied substantially among tissues and species (Table 3) and are likely better guidelines than those discussed above using tissue residue limits (i.e. threshold levels). The maximum allowable daily intake for bowhead whale blubber would be 67 g (or 469 g per week) over an entire human lifespan as established by ΣHCH concentrations. However, cetacean blubber is typically consumed with epidermis (collectively called "*maktak*" and "*maktaaq*" for bowhead and white whales, respectively) as part of a subsistence diet in northern Alaska. Thus, TDILs for bowhead whale maktak provides a more realistic exposure scenario to OCs than those values calculated from the consumption of blubber alone. The TDIL for maktak would be 687 g for HCB, 389 g for ΣCHL, 302 for ΣHCH, 697 g for ΣPCB, and approximately 25000 g for ΣDDT. The most restrictive TDIL for maktak (302 g per day, or 2114 g per week) indicates a consumer can intake more than 2 kg (approximately 4.4 lb) of maktak every week for their entire life and be below the critical level of exposure for these OCs. The mean TDILs calculated for other bowhead whale tissues were significantly greater than those determined for blubber due to the relatively lower concentrations of ΣOCs in other compartments and thus, can be safely consumed in larger amounts.

In the other biota analyzed, the most restrictive level of daily consumption was calculated to be 32 g and 78 g for white whale blubber and maktaaq, and 182 g and 200 g for ringed seal and bearded seal blubber, respectively, based on ΣCHL or ΣPCB concentrations. Consequently, an adult can safely consume 546 g (i.e. 1.20 lb) of maktaaq per week, every week for an entire lifetime. While white whale blubber is typically consumed as a part of maktaaq, seal blubber is rendered into oil and used as a dip for a variety of frozen and boiled meats and fish by Native Alaskans (Kassam, 2001) and, therefore, it is more difficult to provide "safe" consumption advice. The maximum TDIL was 31500 g for HCB in the fish fillets analyzed, whereas the tolerable consumption of burbot liver was more restrictive at approximately 1450 g per day (i.e. 10150 g or 22.4 lb per week). Given the relatively large amounts of fish and seal oil dip needed to surpass intake guidelines, these species should be considered safe to consume under the guidelines discussed.

It should be noted that the TDIL for bowhead whale tissues and other biota are subject to interpretation due to the discrepancy of ΣCHL TDI values between various regulatory agencies. The WHO PTDI value of 0.5 μg kg^{-1} d^{-1} used in this study was calculated by applying a 100-fold "safety factor" (to account for inter- and intra-species variability) from the chronic "no adverse effect level" (NOAEL) of 50 μg kg^{-1} using rats exposed to technical chlordane via dietary exposure (WHO, 1993). The same TDI value (or oral reference dose; RfD) is provided by the U.S. Environmental Protection Agency (EPA), which is based on applying a 1/300 uncertainty factor to a NOEAL value of 150 μg kg^{-1} d^{-1} derived from a laboratory experiment in which mice were orally exposed to ΣCHL for 104 weeks (Khasawinah and Grutsch, 1989; U.S. EPA, 1999). However, the Health Canada guideline value of 0.05 μg kg^{-1} d^{-1} for ΣCHL exposure is lower and more conservative (Health Canada, 1996); reflecting a high uncertainty factor (1000) compared to other jurisdictions. However, information on how this Health Canada dietary guideline value was established is not available. Nevertheless, the application of the Health Canada TDI value for ΣCHL would decrease the TDIL for bowhead whale tissues by one-order of magnitude (i.e. 14 g and 39 g of blubber and maktak, respectively). Based on the weight of evidence provided by the U.S. EPA and WHO, it is our opinion that the Health Canada guideline is overly protective and would place undue restriction on the consumption of the subsistence foods presented in this manuscript. Therefore, the lifetime exposure guideline of 0.05 μg kg^{-1} d^{-1} for ΣCHL proposed by Health Canada was not used for this analysis.

The ΣPCBs for store bought foods range of concentrations was 0.4 to 9.40 ng/g ww (Table 5) and of the wildlife tissues sampled 9 of 16 mean concentrations fell into this range (Tables 1 and 2). The range of concentrations for HCB (<0.01 to 22.5 ng/g ww) for store bought foods (Table 5) indicate HCB concentrations for 11 of 16 wildlife tissues sampled (Tables 1 and 2) occur within this range. Other comparisons show similar patterns as well, but the main point is that the store bought alternatives in many cases do not provide less contaminated alternatives.

PCDDs and "dioxin-like" OCs in bowhead whale blubber, liver

Relatively low concentrations of coplanar PCBs (i.e. non-*ortho* substituted congeners), mono-*ortho* Cl substituted PCB congeners, PCDD and PCDF isomers were detected in bowhead whale blubber and liver samples (Table 4) compared to other OCs. Overall, the profiles of PCDDs and other dioxin-like compounds in bowhead whale blubber are consistent with reports in other cetaceans (e.g. Gauthier et al., 1998; Jarman et al., 1996; Muir et al., 1996). The compound with the largest contribution to total TEQ values is the coplanar PCB congener, 3,3´,4,4´,5-pentaCB (CB-126), which comprised 33% and 72% of the total TEQ value in blubber and liver, respectively. The mono-*ortho* Cl substituted CB-118 and CB-156 were major contributors to the total TEQ (CB-118 blubber, 22%; liver, 6.0%; CB-156 blubber, 18%; liver, 10%) as compared to other congeners. While the mono-*ortho* Cl substituted PCB congeners CB-123 and CB-157 were not quantified in this study, the abundance of these congeners in arctic biota is minor (de Wit et al., 2003), and their subsequent contribution to the total TEQ is expected to be minimal.

The TCDD-TEQ concentrations were comparable to those reported in various commercially available food commodities with similar lipid content (Himberg, 1993; Dyke and Stratford, 2002; Schecter et al., 1997). For example, wet-weight TEQ concentrations of PCDD/Fs in various food items (e.g beef, pork, chicken, farm-raised fish, etc.) ranged from 0.03 to 2.90 pg g^{-1}. However, these TEQ concentrations in the commercial foods did not include coplanar PCBs, which may represent a significant contribution to the overall ΣTEQ value (Huwe, 2002).

Based on the TDI value of 10 pg kg^{-1} BW d^{-1} (Health Canada, 1996), and assuming a 70 kg adult consumer, the tolerable daily intake limit (TDIL) of dioxin-like compounds from the consumption of bowhead whale blubber and

liver was calculated to be 199 g (range: 141 to 348 g) and 2222 g (range: 1892 to 2390 g), respectively. As previously mentioned, bowhead whale blubber is typically consumed as maktak (i.e. blubber and epidermis) and therefore, actual exposure levels to contaminants via consumption of this traditional food item will be overestimated when only considering blubber concentrations. By comparing differences in ΣOC concentrations between these two food matrices (Table 1), the TCDD-TEQ concentration in maktak is likely 3× lower than blubber concentrations, thereby increasing the TDIL to approximately 600 g (i.e. 4.2 kg or approximately 9.2 lb per week) for this food item. Consequently, the risk to human health associated with exposure to PCDDs and "dioxin-like" compounds via bowhead whales is minimal considering the current toxicological information and contaminant data. Due to expense these analyses were not conducted for the store bought foods and data already exist from other studies mentioned.

Limitations and uncertainty

Careful interpretation of the dietary exposure values reported in this study is required. For example, the effect of food preparation on OC concentrations was not studied. Previous investigations have noted a reduction of ΣPCB and other OC concentrations in fish due to cooking (Kamrin and Fischer, 1999; Zabik et al., 1995). While the effect of rendering, fermentation, and other food preparation practices used by Native Alaskans (Kassam, 2001) on OC concentrations is unknown, the estimated daily intake values calculated from raw tissues in this study likely overestimate OC exposure from these subsistence dietary items when cooked. In addition, there are limitations in using TDI or PTDI guidelines to evaluate dietary exposure to anthropogenic compounds. As previously stated, these guidelines assume a life-long exposure and are developed using the NOAEL data from laboratory- or community-based exposure scenarios. These values were subsequently adjusted using conservative "safety" factors, typically by dividing the NOAEL by 100 or 1000, to compensate for interspecies differences between the test species and humans (Waltner-Toews and McEwen, 1994).

In addition, it should be emphasized that TDI/PTDI values are based on a lifetime of daily exposure. However, most wildlife and fish are hunted and consumed during select months of the year. For example, white whales in Wainwright, Alaska (USA) are generally hunted from June to July; whereas bowheads are hunted during two seasonal events in the Fall (September - October) and early Spring (April - May) at Barrow, Alaska (Kassam, 2001; Fuller and George, 1997). It should be noted that dietary surveys of these subsistence species are required to properly elucidate the extent of contaminant exposure via dietary intake. The TDIL values determined in this study only considered PCB/OC intake from each individual tissue/food item. Thus, dietary surveys are needed to consider contaminant intakes from all possible dietary sources, along with the seasonal nature of hunting practices, when evaluating which food items significantly contribute to PCB/OC exposure via an actual subsistence diet (e.g. Van Oostdam et al., 2003).

The obvious sociocultural and nutritional benefits of a subsistence diet to the residents of northern Alaska must be considered (see SC/56/E2). Preliminary information on the nutritional quality of bowhead whale tissues and other wildlife suggest that these subsistence dietary items are excellent sources of nutritionally essential minerals, fatty acids, and fat-soluble vitamins, such as vitamins A, D, and E (e.g. Blanchet et al., 2000; Kenny et al., 2003; Nobmann et al., 1992; Nobmann and Lanier, 2001; Van Oostdam et al., 2003; Woshner et al., 2001). The increasing prevalence of "Western" or modern diets, instead of traditional foods, is thought to have negative health consequences, in part due to the increased consumption of total fat, saturated fats and sucrose above recommended levels (Nobmann and Lanier, 2001;Van Oostdam et al., 2003). Upon considering the risks associated with exposure to contaminants relative to the known benefits of traditional foods, as well as the risks associated with eating poor replacement foods (e.g. Egeland et al., 1998; Kuhnlein and Chan, 2000), the consumption of bowhead whale tissues and other marine biota by Inuit of northern Alaska should be maintained and encouraged. By using the balanced approach nutrients and contaminants (Hansen, 2000), this information will allow individuals to decide for themselves which dietary habits best suits their lifestyle.

CONCLUSIONS

Persistent organochlorine contaminants were quantified in numerous tissues of the bowhead whale, store bought food, and other biota. In general, concentrations were relatively low in bowhead whales compared to other marine mammals and reflect the trophic status of this cetacean (Hoekstra et al., 2002a; Hoekstra et al., 2003b). Lipid content significantly influenced the concentrations of ΣOCs in bowhead whale tissues and accumulation profiles of ΣOC groups were generally homogeneous in bowhead whale tissues. ΣOC concentrations were used to evaluate the human consumption rates based on established exposure guidelines. Overall, the consumption of bowhead whale

tissues and other biota from northern Alaska is safe to consume at, or below, the levels calculated in this study. Many wildlife tissues had concentrations of OCs similar to the OCs concentrations found in local store bought food. Considering the "safety factors" applied to establish many of the TDILs, one could exceed the suggested intake levels by 100-fold the TDIL before achieving a "no observed effect" level and thus, allow for a rather large tolerable range of intake. Additional information on the dietary profile (e.g. rates of consumption, peak seasons of consumption) of traditional/country foods consumed by the subsistence communities of northern Alaska is required to more definitively address the potential human health risks resulting from chronic exposure to OCs from a subsistence-based diet and the level of nutrient intake.

ACKNOWLEDGEMENTS

The North Slope Borough Department of Wildlife Management (Barrow, AK, USA) initiated this study, and provided logistical and financial support. Additional funding was also provided by the US Department of Commerce via the National Oceanic and Atmospheric Administration Coastal Impact Assistance Award (No. NA170Z2054). The authors gratefully acknowledge the generous provision of bowhead whale samples by the Native hunters, whaling captains and crews (Barrow Whaling Captains Association, Barrow, AK) and co-operation of the Alaskan Eskimo Whaling Commission (Barrow, AK, USA), and white whale hunters of Point Lay, and Barrow, AK. Sample collection and logistics related to the shipment of samples to analytical laboratories were conducted by B. Akootchook, L. Dehn, J.C. George, C. Rosa, R. Suydam, S. Visalli, V. Woshner, and many others. We thank T. Rowles (Marine Mammal Health and Stranding Response Program, Washington, DC), S. Moore and M. Gosho (NOAA, Seattle, WA) for assistance in acquiring the necessary permits. Lori Verbrugge and S. Arnold (Environmental Public Health Program, State of Alaska Section of Epidemiology, Anchorage, AK) provided a valuable review of an earlier version of this manuscript. Analytical support from Axys Analytics (Sidney, BC, Canada), Angela Baitz, Mary Williamson, Xiaowa Wang, and Lisa Bradley (Environment Canada, Burlington, ON, Canada) was appreciated.

REFERENCES

Aguilar, A., Borrell, A., Pastor, T., 1999. Biological factors affecting variability of persistent pollutants levels in cetaceans. J. Cetacean Res. Manage. 1, 83-116.

Bagheri, H., Leonards, P.E.G., Ghijsen, R.T., Brinkman, U.A.T.H., 1993. Gas chromatography-negative ion chemical ionization mass spectrometry for the determination and identification of planar polychlorinated biphenyls in biological samples. Intern. J. Environ. Anal. Chem. 50, 257-268.

Becker, P.R., Wise, S.A., Koster, B.J., Zeisler, R., 1991. Alaska Marine Mammal Tissue Archival Project: Revised Collection Protocol. U.S. National Institute of Standards and Technology NIST Interagency Report 4529, U.S. Dept. of Commerce, National Institute of Standard and Technology, Gaithersburg, MD, USA.

Blanchet, C., Dewailly, É., Ayotte, P., Bruneau, S., Receveur, O., Holub, B.J., 2000. Contribution of selected traditional and market foods to the diet of Nunavik Inuit women. Can. J. Diet. Prac. Res. 61, 50-59.

Bruhn, R., Kannan, N., Petrick, G., Schulz-Bull, D.E., Duinker, J.C., 1995. CB pattern in the harbour porpoise: bioaccumulation, metabolism and evidence of cytochrome P450 IIB activity. Chemosphere 31, 3721-3732.

de Wit, C.A., Fisk, A.T., Hobbs, K.E., Muir, D.C.G., Kallenborn, R., Krahn, M.M., Norstrom, R.J., Skaare, J., 2004. Persistent organochlorine pollutants. In: de Wit, C.A., Fisk, A.T., Hobbs, K.E., Muir, D.C.G. (Eds.), Arctic Monitoring and Assessment Program (AMAP) II. Arctic Monitoring and Assessment Program, Oslo, Norway.

Dyke, P.H., Stratford, J., 2002. Changes to the TEF schemes can have significant impacts on regulation and management of PCDD/F and PCB. Chemosphere 47, 103-116.

Egeland, G.M., Feyk, L.A., Middaugh, J.P., 1998. The use of traditional foods in a healthy diet in Alaska: risks in perspective. State of Alaska Epidemiology Bulletin, Vol. 2 No. 1 (January).

Fuller, A.S. George, J.C., 1997. Evaluation of subsistence harvest data from the North Slope Borough 1993 census for eight North Slope villages: for the calendar year 1992. Department of Wildlife Management, Barrow, AK, USA.

Gauthier, J.M., Pelletier, É., Brochu, C., Moore, S., Metcalfe, C.D., Béland, P., 1998. Environmental contaminants in tissues of a neonate St. Lawrence beluga whale (*Delphinapterus leucas*). Mar. Pollut. Bull. 36, 102-108.

Health Canada, 1996. Values presently used by contaminants toxicology section. Food Directorate, Ottawa, ON, Canada.

Hebert, C.E., Keenleyside, K.A., 1995. To normalize or not to normalize? Fat is the question. Environ. Toxicol. Chem. 14, 801-807.

Himberg, K.K., 1993. Coplanar polychlorinated biphenyls in some Finnish food commodities. Chemosphere 27, 1235-1243.

Hing, M.C., 1998. A database for environmental contaminants in traditional foods in northern and arctic Canada: developments and applications. Food Add. Contam. 15, 127-134.

Hobbs, K.E., Muir, D.C.G., Michaud, R., Beland, P., Letcher, R.J., Norstrom, R.J., 2003. PCBs and organochlorine pesticides in blubber biopsies from free-ranging St. Lawrence River Estuary beluga whales (*Delphinapterus leucas*), 1994-1998. Environ. Pollut. 122, 291-302.

Hoekstra, P.F., Dehn, L.A., George, J.C., Solomon, K.R., Muir, D.C.G., O'Hara, T.M., 2002a. Trophic ecology of bowhead whales (*Balaena mysticetus*) compared with that of other arctic marine biota as interpreted from carbon-, nitrogen-, and sulfur-isotope signatures. Can. J. Zoo. 80, 223-231.

Hoekstra, P.F., O'Hara, T.M., Pallant, S.J., Muir, D.C.G., 2002b. Bioaccumulation of organochlorine contaminants in bowhead whales (*Balaena mysticetus*) from Barrow, Alaska. Arch. Environ. Contam. Toxicol. 42, 497-507.

Hoekstra, P.F., O'Hara, T.M., Teixeira, C., Backus, S., Fisk, A.T., Muir, D.C.G., 2002c. Spatial trends and bioaccumulation of organochlorine pollutants in marine zooplankton from the Alaskan and western Canadian Arctic. Environ. Toxicol. Chem. 21, 575-583.

Hoekstra, P.F., Letcher, R.J., O'Hara, T.M., Backus, S.M., Solomon, K.R., Muir, D.C.G., 2003a. Hydroxylated and methylsulfone-containing metabolites of polychlorinated biphenyls in the plasma and blubber of bowhead whales (*Balaena mysticetus*). Environ. Toxicol. Chem. 22, 2650-2658.

Hoekstra, P.F., O'Hara, T.M., Fisk, A.T., Borgå, K., Solomon, K.R., Muir, D.C.G., 2003b. Trophic transfer of persistent organochlorine contaminants (OCs) within an arctic marine food web from the southern Beaufort-Chukchi Seas. Environ. Pollut. 124, 509-522.

Huwe, J.K., 2002. Dioxins in food: a modern agricultural perspective. J. Agric. Food Chem. 50, 1739-1750.

Jarman, W.M., Norstrom, R.J., Muir, D.C.G., Rosenberg, B., Simon, M., Baird, R.W., 1996. Levels of organochlorine compounds, including PCDDs and PCDFs, in the blubber of cetaceans from the west coast of North America. Mar. Pollut. Bull. 32, 426-436.

Jensen, S., 1972. The PCB story. Ambio 1, 123-131.

Kassam, K.-A.S., 2001. Passing on the knowledge: mapping human ecology in Wainwright, Alaska. Arctic Institute of North America, University of Calgary, Calgary, AB, Canada.

Kamrin, M.A., Fischer, L.J., 1999. Current status of sport fish consumption advisories for PCBs in the Great Lakes. Regul. Toxicol. Pharmacol. 29, 175-181.

Kenny, D.E., O'Hara, T.M., Chen, T.C., Lu, Z., Tian, X., Holick, M.F., 2003. Evaluation of arctic zooplankton, fishes and marine mammals for vitamin D content. Zoo Biol. (in press).

Khasawinah, A.M., Grutsch, J.F., 1989. Chlordane: 24-month tumorigenicity and chronic toxicity test in mice. Regul. Toxicol. Pharmacol. 10, 244-254.

Krahn, M.M., Burrows, D.G., Stein, J.E., Becker, P.R., Schantz, M.M., Muir, D.C.G., O'Hara, T.M., Rowles, T., 2000. White whales (*Delphinapterus leucas*) from three Alaskan stocks: concentrations and patterns of persistent organochlorine contaminants in blubber. J. Cetacean Res. Manage. 1, 239-249.

Krahn, M.M., Herman, D.P., Ylitalo, G.M., Sloan, C.A., Burrows, D.G., Hobbs, R.C., Mahoney, B.A., Yanagida, G.K., Calambokidis, J., 2003. Blubber stratification in white whales and killer whales: variability in contaminant concentrations, fatty acid profiles, lipid percent and lipid class profiles that has implications for biopsy sampling. Paper SC/55/E3 presented to the International Whaling Commission (IWC) Scientific Committee, June 2003, 22pp.

Kucklick, J.R., Struntz, W.D.J., Becker, P.R., York, G.W., O'Hara, T.M., Bohonowych, J.E., 2002. Persistent organochlorine pollutants in ringed seals and polar bears collected from northern Alaska. Sci. Total Environ. 287, 45-59.

Kuhnlein, H.V., Chan, H.M., 2000. Environment and contaminants in traditional food systems of northern indigenous peoples. Annu. Rev. Nutr. 20, 595-626.

Lundgren, K., van Bavel, B., Tysklind, M., 2002. Development of a high-performance liquid chromatography carbon column based method for the fractionation of dioxin-like polychlorinated biphenyls. J. Chromatography A 962, 79-93.

Marsili, L., Focardi, S., 1997. Chlorinated hydrocarbon (HCB, DDTs and PCBs) levels in cetaceans stranded along the Italian coasts: an overview. Environ. Monit. Assess. 45, 129-180.

Muir, D.C.G., Braune, B., DeMarch, B., Norstrom, R., Wagemann, R., Lockhart, L., Hargrave, B., Bright, D., Addison, R., Payne, J., Reimer, K., 1999. Spatial and temporal trends and effects of contaminants in the Canadian Arctic marine ecosystem: a review. Sci. Total Environ. 230, 83-144.

Muir, D.C.G., Ford, C.A., Rosenberg, B., Norstrom, R.J., Simon, M., Béland, P., 1996. Persistent organochlorines in beluga whales (*Delphinapterus leucas*) from the St. Lawrence River estuary-I. Concentrations and patterns of specific PCBs, chlorinated pesticides and polychlorinated dibenzo-*p*-dioxins and dibenzofurans . Environ. Pollut. 93, 219-234.

Nobmann, E.D., Byers, T., Lanier, A.P., Hankin, J.H., Jackson, M.Y., 1992. The diet of Alaska Native adults: 1987 – 1988. Am. J. Clin. Nutr. 1024-1032.

Nobmann, E.D., Lanier, A.P., 2001. Dietary intake among Alaska native women resident of Anchorage, Alaska. Int. J. Circumpolar Health 60, 123-137.

O'Hara, T.M., Krahn, M.M., Boyd, D., Becker, P.R., Philo, L.M., 1999. Organochlorine contaminant levels in Eskimo harvested bowhead whales of arctic Alaska. J. Wildlife Dis. 35, 741-752.

O'Shea, T.J., 1999. Environmental contaminants and marine mammals. In: Reynolds, J.E. Rommel, S.A. (Eds.), Biology of Marine Mammals. Smithsonian Institution Press, Washington, DC, USA, pp 485-536.

Raftery, A.E., Zeh, J.E., 1998. Estimating bowhead whale population size and rate of increase from the 1993 census. J. Am. Stat. Assoc. 93, 1-13.

Rubin, C.H., Lanier, A., Socha, M., Brock, J.W., Kieszak, S., Zahm, S., 2001. Exposure to persistent organochlorines among Alaska Native women. Int. J Circumpolar. Health 60, 157-169.

Sandau, C.D., Ayotte, P., Dewailly, E., Duffe, J., Norstrom, R.J., 2000. Analysis of hydroxylated metabolites of PCBs (OH-PCBs) and other chlorinated phenolic compounds in whole blood from Canadian Inuit. Environ. Health Perspect. 108, 611-616.

Schecter, A., Cramer, P., Boggess, K., Stanley, J., Olson, R.J., 1997. Levels of dioxins, dibenzofurans, PCBs and DDE congeners in pooled food samples collected in 1995 at supermarkets across the United States. Chemosphere 34, 1437-1447.

Shelden, K.E.W., Rugh, D.J., 1996. The bowhead whale, *Balaena mysticetus*: its historic and current status. Mar. Fish. Rev. 57, 1-20.

Siddiqui, M.K.J., Nigam, U., Kaul, P.P., Seth, T.D., 2003. Bioaccumulation of HCH isomers in different tissues of young and old rats: a comparison. Bull. Environ. Contam. Toxicol. 56, 896-902.

Stoker, S.W., Krupnik, I.I., 1993. Subsistence whaling. In: Burns, J.J., Montague, J.J., Cowles, C.J. (Eds.), The bowhead whale. Allen Press, Lawrence, KS, pp 579-630.

U.S. EPA, (U.S. Environmental Protection Agency). 1994. Method 1613: Tetra- through octa-chlorinated dioxins and furans by isotope dilution HRGC/HRMS, Revision B. Washington, DC, USA.

U.S. EPA. 1999. Integrated risk information system (IRIS) – Chlordane. National Center for Environmental Assessment, Office of Research and Development, Washington, DC, USA (http://www.epa.gov/iris/search.htm). Accessed January 2004.

Van den Berg, M., Birnbaum, L.S., Bosveld, A.T.C., Brunström, B., Cook, P., Feeley, M., Giesy, J.P., Hanberg, A., Hasegawa, R., Kennedy, S.W., Kubiak, T., Larsen, J.C., van Leeuwen, F.X.R., Liem, A.K.D., Nolt, C., Peterson, R.E., Poellinger, L., Safe, S.H., Schrenk, D., Tillit, D., Tysklind, M., Younes, M., Wærn, F., Zacharewski, T., 1998. Toxic equivalency factors (TEFs) for PCBs, PCDDs, PCDFs for humans and wildlife. Environ. Health Perspect. 106, 775-792.

Van Leeuwen, F.X.R., Younes, M., 1998. WHO revises the Tolerable Daily Intake (TDI) for dioxins. Organohalogen Compounds 38, 295-298.

Van Oostdam, J., Donaldson, S., Feeley, M., Tremblay, N., 2003. Human health. In: Canadian Arctic Contaminants Assessment Report II. Ministry of Public Works and Government Services Canada, Ottawa, ON, Canada, pp -127.

Waltner-Toews, D., McEwen, S.A., 1994. Chemical residues in foods of animal origin: overview and risk assessment. Prev. Vet. Med. 20, 161-178.

WHO (World Health Organization), 1993. Pesticide residues in food - 1994. Report of the joint meeting of the FAO panel of experts of pesticide residues in food and the environment and WHO toxicological and environmental core assessment groups. FAO Plant Production and Protection Paper 127.

Willett, K.L., Ulrich, E.M., Hites, R.A., 1998. Differential toxicity and environmental fates of hexachlorocyclohexane isomers. Environ. Sci. Technol. 32, 2197-2206.

Woshner, V.M., O'Hara, T.M., Bratton, G.R., Suydam, R.S., Beasley, V.R., 2001. Concentrations and interactions of selected essential and non-essential elements in bowhead and beluga whales of arctic Alaska. J. Wildlife Dis. 37, 693-710.

Zabik, M.E., Zabik, M.J., Booren, A.I.M., Nettles, M., Song, J.-H., Welch, R., Humphrey, H., 1995. Pesticides and total polychlorinated biphenyls in chinook salmon and carp harvested from the Great Lakes: effects of skin-on and skin-off processing and selected cooking methods. J. Agricult. Food Chem. 43, 993-1001.

Fig. 1: Sampling sites (●) of biota and anadromous fish at Pt. Lay (beluga only), Nuiqsut (arctic grayling, burbot, and broad whitefish only) and Barrow, Alaska, USA (1997 – 1999).

Fig. 2: The $\log_{10}$-adjusted relationship of ΣPCB concentrations (ng g^{-1}, wet weight) and lipid content of various bowhead whale tissues (n=5 for each tissue type). The solid line represents the 1st-order linear regression [$\log_{10}$ΣPCB = 0.07 + 1.15$\log_{10}$(lipid); r^2= 0.87; p<0.0001]. The quadratic (i.e. second-order) linear regression equation ($\log_{10}$ΣPCB = 0.22 + [0.57$\log_{10}$ (lipid)] + 0.31[$\log_{10}$ (lipid)]^2; r^2= 0.95; p<0.0001) for all points is represented by the dashed line.

Fig. 3: The mean (± 1 standard deviation, SD) proportion of ΣHCH to the total OC concentrations (top panel) and relative percentage of α– and β-HCH isomers (to ΣHCH) among various bowhead whale tissues and maktak (n=5, all groups). Graph bars designated with the same letters were not statistically different (GLM, Scheffé test, p<0.05).

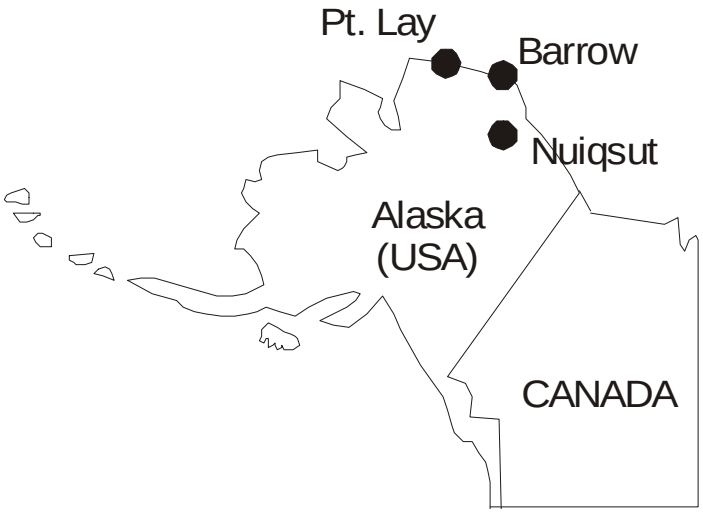

Fig. 1

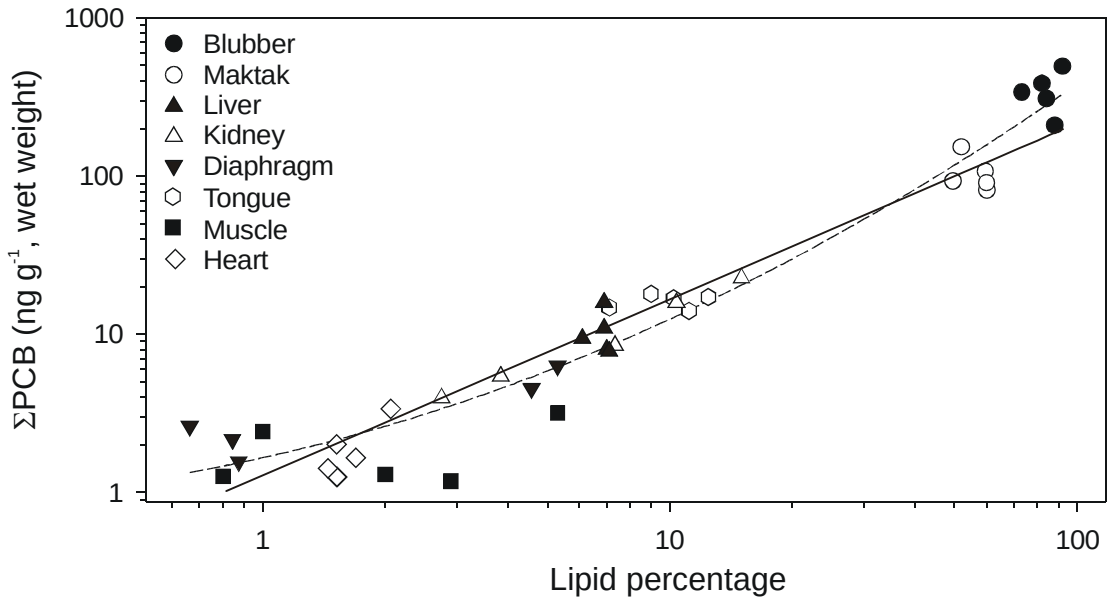
1000
100
10
1
ΣPCB (ng g-1, wet weight)
Blubber
Maktak
Liver
Kidney
Diaphragm
Tongue
Muscle
Heart
1
10
100
Lipid percentage

Fig. 2

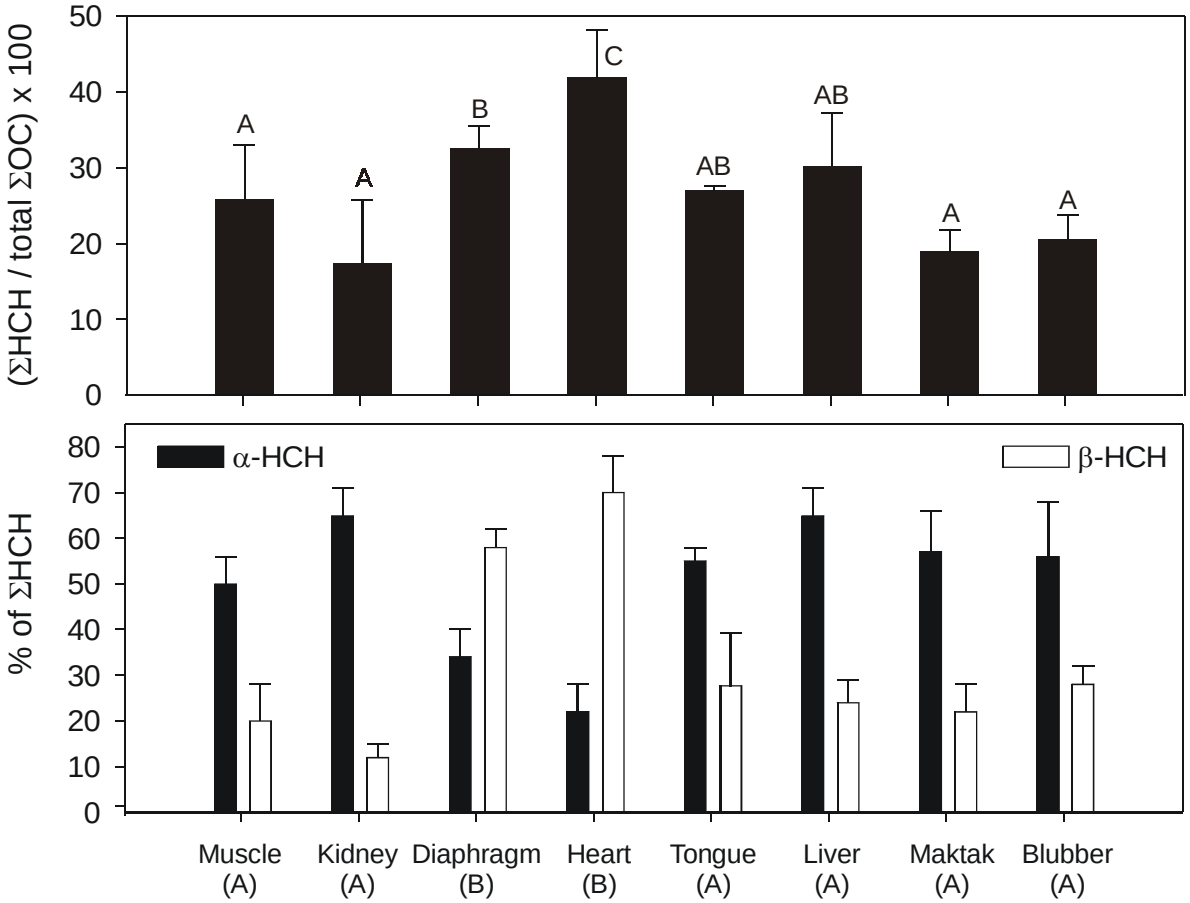
(ΣHCH / total ΣOC) x 100
50
40
30
20
10
0
A
A
B
C
AB
AB
A
A
% of ΣHCH
80
70
60
50
40
30
20
10
0
α-HCH
β-HCH
Muscle (A)
Kidney (A)
Diaphragm (B)
Heart (B)
Tongue (A)
Liver (A)
Maktak (A)
Blubber (A)

Fig. 3

Table 1: Mean (± 1 standard deviation), median, and range of lipid content (%) and sum (Σ) concentrations of persistent organochlorine contaminant classes and HCB (ng g^{-1}, wet weight) in bowhead whale (*Balaena mysticetus*) tissues and uncooked maktak from Alaska (1997 – 1999).

Tissue	Statistic	% Lipid	HCB	ΣCHL	ΣDDT	ΣHCH	ΣPCB
Blubber	Mean±SD	83.7±11.0	100±24	255±122	377±343	297±126	354±211
(*n*=5)	Median	83.0	112	239	258	273	313
	Range	62.3–99.3	73.0–273	94.5–701	118–1925	92.2–763	153–1305
Maktak	Mean±SD	56.1±5.0	30.5±5.24	95.3±27.1	57.3±11.6	65.7±16.9	105±28.2
(*n*=5)	Median	59.5	28.1	90.6	54.9	59.6	93.1
	Range	49.5–60.0	26.0–39.1	69.4–136	48.1–77.1	50.1–87.4	81.8–153
Kidney	Mean±SD	8.00±5.76	5.50±3.06	7.82±4.72	6.37±4.20	7.20±5.37	12.0±8.91
(*n*=5)	Median	7.11	5.70	7.90	5.98	6.21	10.6
	Range	2.75–15.0	2.49–8.13	3.10–12.4	2.24–11.4	2.05–14.3	3.97–22.7
Liver	Mean±SD	6.58±1.70	3.17±1.77	5.48±2.22	3.72±1.54	9.45±2.22	9.10±4.13
(*n*=5)	Median	6.89	3.66	5.70	3.69	9.14	9.04
	Range	3.36–10.4	1.73–9.35	2.30–10.6	1.35–6.72	6.25–13.82	1.66–16.5
Muscle	Mean±SD	2.39±1.85	1.60±0.96	2.32±1.17	1.71±1.01	2.74±1.68	1.87±0.90
(*n*=5)	Median	1.96	1.16	1.63	2.15	1.86	1.30
	Range	0.80–5.34	0.69–3.02	1.20–3.69	0.59–2.81	1.41–5.48	1.18–3.19
Heart	Mean±SD	1.65±0.25	1.31±0.51	1.53±0.92	0.25±0.18	3.50±0.99	1.95±0.85
(*n*=5)	Median	1.52	1.14	1.02	0.26	3.14	1.66
	Range	1.45–2.05	0.98–2.21	0.99–3.13	0.03–0.46	2.39–4.88	1.26–3.38
Diaphragm	Mean±SD	2.39±2.19	1.96±1.26	2.69±2.06	1.59±1.04	4.47±2.51	3.43±1.94
(*n*=5)	Median	0.87	1.33	1.56	0.96	3.06	2.62
	Range	0.66–4.98	0.90–3.82	1.03–5.46	0.74–2.93	2.38–7.26	1.57–6.28
Tongue	Mean±SD	10.2±2.3	8.58±1.54	18.4±3.76	15.8±4.67	22.0±3.76	15.7±1.57
(*n*=5)	Median	10.7	7.93	19.7	17.2	23.3	15.8
	Range	7.11–12.4	7.60–10.9	12.9–21.4	9.13–19.8	16.5–24.9	14.1–17.3

Table 2: Mean (± 1 standard deviation), median, and range of lipid content (%) and sum (Σ) concentrations of persistent organochlorine contaminant classes and HCB (ng g^{-1}, wet weight) in various marine mammals and fish from Alaska (1997 – 1999).

Species	Tissue	Statistic	% Lipid	HCB	ΣCHL	ΣDDT	ΣHCH	ΣPCB
Beluga whale	Blubber	Mean±SD	84.8±8.15	239±91.4	816±84.0	1979±954	212±161	2730±1024
(*Delphinapterus leucas*)	*n*=20	Median	84.0	233	792	2120	175	2680
		Range	71.4–100	55.8–487	135–1936	254–4210	86.7–865	620–5248
	Maktaaq	Mean±SD	44.2±9.60	76.3±21.5	520±226	324±95.3	66.7±23.1	962±264

	n=5	Median	48.3	77.9	453	305	64.9	898
		Range	28.3–53.3	39.2-106	258-922	194–483	43.3–97.0	619–1390
Ringed seal	Blubber	Mean±SD	82.2±13.6	17.3±11.7	488±400	269±198	203±127	691±526
(*Phoca hispida*)	*n*=20	Median	86.1	12.3	400	230	141	495
		Range	54.7–100	4.95–49.5	68.8–1484	28.6–818	37.2–1068	124–2114
Bearded seal	Blubber	Mean±SD	79.5±3.96	6.65±0.55	188±19.4	156±21.2	89.3±36.4	293±30.9
(*Erignathus barbatus*)	*n*=7	Median	84.4	7.52	217	138	64.8	270
		Range	60.7–90.0	3.92–8.32	123–245	111–267	25.1–300	196–411
Pink salmon	Fillet	Mean±SD	6.34±0.26	1.45±0.52	1.32±0.27	1.83±0.27	1.36±0.58	2.63±3.50
(*Oncorhynchus gorbuscha*)	*n*=7	Median	6.46	2.10	1.18	1.63	1.58	2.89
		Range	5.21–7.10	1.10–3.25	0.54–2.05	0.98–2.11	0.92–2.15	0.57–5.86
Arctic char	Fillet	Mean±SD	4.54±1.79	1.44±0.53	1.35±1.10	1.62±0.38	1.81±0.88	2.34±0.95
(*Salvelinus alpinus*)	*n*=5	Median	3.64	1.23	1.29	1.48	1.65	2.54
		Range	2.36–7.32	0.63–1.81	0.18–2.17	1.18–2.15	1.06–2.25	0.89–3.15
Broad whitefish	Fillet	Mean±SD	4.19±1.04	0.47±0.18	0.49±0.46	0.14±0.28	0.22±0.09	2.89±2.84
(*Coregonus nasus*)	*n*=19	Median	3.98	0.42	0.39	0.06	0.22	1.64
		Range	2.60–6.01	0.25–0.91	0.10–2.21	0.02–1.20	0.06–0.40	0.16–10.5
Arctic grayling	Fillet	Mean±SD	4.45±2.70	4.83±2.59	1.28±0.90	1.32±0.72	0.26±0.29	2.13±1.71
(*Thymallus arcticus*)	*n*=2	Median	–	–	–	–	–	–
		Range	2.54,6.36	3.00,6.67	0.64,1.91	0.81,1.83	0.06,0.47	0.92,3.34
Burbot	Liver	Mean±SD	40.6±8.93	9.74±2.70	25.2±14.7	16.2±5.89	4.41±1.58	47.3±17.7
(*Lota lota*)	*n*=15	Median	38.9	9.96	22.7	15.8	4.55	47.2
		Range	31.4–62.8	3.31–13.8	3.74–63.4	3.88–27.4	1.60–6.79	15.7–81.9

Table 3: The mean (±1 standard deviation, SD) tolerable daily intake limits (TDIL; equation 2) for various subsistence dietary items based on dietary exposure guidelines [a,b] and wet weight concentrations of persistent organochlorine contaminants listed in Tables 1 and 2.

		Tolerable Daily Intake Limits (in grams)				
Species	Tissue	HCB	ΣCHL	ΣDDT	ΣHCH	ΣPCB
	TDI (µg/kg/d)	0.3[a]	0.5[b]	20[a]	0.3[a]	1.0[a]
Bowhead whale	Blubber	184±80	149±43	4680±1940	67±15	218±72
	Maktak	687±99	389±100	25000±4270	302±73	697±152
	Tongue	2390±352	1974±494	96800±38100	980±197	4480±448
	Liver	2930±1563	7594±2823	>500000	2185±411	7200±1877
	Kidney	5130±3050	6270±4078	>325000	4800±3890	9510±6950
	Muscle	16200±8600	18453±8476	>500000	9730±4470	43800±17100
	Diaphragm	21600±14400	20663±12650	>500000	5960±2680	26100±13900
	Heart	25300±8050	27800±11935	>500000	6400±1310	40500±15600
Beluga whale	Blubber	97±63	43±40	1316±1196	122±44	32±21
	Maktaaq	276±106	80±33	4727±1435	358±127	78±22
Ringed seal	Blubber	1924±1010	182±176	13300±11700	212±147	203±144
Bearded seal	Blubber	3000±328	200±22	9788±1060	436±113	254±25
Fish[c]	Fillet	31500±20800	90646±86740	>500000	89300±87500	64700±88000
Burbot	Liver	2250±468	1795±712	80330±19100	4940±2250	1450±390

[a] Health Canada (1996); [b] U.S. EPA (1999) and WHO (1993); [c] TDIL values calculated from pooled fish data (except burbot)

Table 4: Mean (± 1 standard deviation) concentration (pg g^{-1}, wet weight) and toxic equivalent (TEQ) values for polychlorinated dibenzo-*p*-dioxins (PCDDs), dibenzofurans (PCDFs), and "dioxin-like" polychlorinated biphenyl (PCB) congeners in bowhead whale blubber and liver (n=5).

Compound	Concentration (pg g^{-1} w.w.)		TEF[a]	TEQ (pg g^{-1} w.w.)	
	Blubber	Liver		Blubber	Liver
PCDDs					
1,2,3,4,6,7,8-heptaCDD	ND[b]	0.35 ± 0.18	0.01	—	0.003 ± 0.002
OCDD	ND	1.60 ± 0.42	0.0001	—	0.002 ± 0.001
ΣPCDDs	—	1.95 ± 0.39	—	—	0.004 ± 0.002
PCDFs	ND	ND	—	—	—
Non-ortho Cl substituted PCBs					
3,3′,4,4′-tetraCB (CB-77)	8.75 ± 4.27	5.50 ± 1.73	0.0001	0.0009 ± 0.0001	0.0006 ± 0.0002
3,4,4′,5-tetraCB (CB-81)	4.95 ± 3.99	ND	0.0001	0.0005 ± 0.0004	—
3,3′,4,4′,5-pentaCB (CB-126)	11.52 ± 4.55	2.28 ± 0.58	0.1	1.152 ± 0.455	0.228 ± 0.058
3,3′,4,4′,5,5′-hexaCB (CB-169)	9.42 ± 4.52	1.49 ± 0.73	0.01	0.094 ± 0.045	0.015 ± 0.007
Σno-PCBs	39.8 ± 16.1	9.27 ± 2.72	—	1.24 ± 0.438	0.243 ± 0.065
Mono-ortho Cl substituted PCBs					
2,3,3′,4,4′-pentaCB (CB-105)	2418 ± 1175	86.5 ± 40.9	0.0001	0.242 ± 0.118	0.008 ± 0.004
2,3,4,4′,5-pentaCB (CB-114)	1200 ± 763	18.5 ± 15.3	0.0005	0.600 ± 0.381	0.009 ± 0.007
2,3′,4,4′,5-pentaCB (CB-118)	7870 ± 4170	197 ± 106	0.0001	0.787 ± 0.417	0.019 ± 0.011
2,3,3′,4,4′,5-hexaCB (CB-156)	1298 ± 1200	85.2 ± 22.6	0.0005	0.649 ± 0.601	0.031 ± 0.023
2,3′,4,4′,5,5′-hexaCB (CB-167)	479 ± 393	7.0 ± 5.0	0.00001	0.005 ± 0.004	0.001 ± 0.001
2,3,3′,4,4′,5,5′-heptaCB (CB-189)	304 ± 230	ND	0.0001	0.030 ± 0.023	—
Σmo-PCBs	13500 ± 7420	376 ± 200	—	2.31 ± 1.43	0.071 ± 0.010
ΣTEQ:				3.52 ± 1.12	0.315 ± 0.031
ΣTEQ Range:				(2.01 – 4.95)	(0.293 – 0.370)

[a] Toxic equivalency factors (TEFs) for PCDD/F, non- and mono-*ortho* substituted PCB congeners from van den Berg et al. (1998); [b] Not detected at concentrations greater than method detection limits (MDL).

Table 5: Sum (Σ) concentrations (ng/g; wet weight) of hexachlorobenzene (HCB) and various classes of persistent organochlorine contaminants in selected store-bought foods.

Food Item	No. of Pools	% Lipid	HCB	ΣCHL	ΣDDT	ΣHCH	ΣPCB	ΣPCB_{10}
Terrestrial Biota								
Boneless Pork Loin Chop	1	0.7	<0.01	0.01	0.03	<0.01	2.48	0.28
Beef Shank	1	2.6	0.10	0.22	0.98	<0.01	0.96	0.21
Beef Tongue	1	12.1	0.61	0.46	2.09	0.07	2.14	0.81
Reindeer Steak	1	2.5	0.93	0.03	0.03	0.26	2.03	0.25
Reindeer Steak Marrow	1	58.8	22.5	0.32	0.15	1.22	7.85	2.86
Cornish Game Hen	2	0.7, 0.7	<0.01, <0.01	0.08, 0.01	0.12, 0.01	0.03, 0.06	2.77, 3.81	0.51, 0.28
Chicken Egg Yolk	1	23.8	0.01	2.74	0.15	<0.01	7.77	0.21
Aquatic Biota								
Milkfish	1	5.6	0.03	0.07	0.40	0.19	2.64	0.72
Smoke Salmon Strips	1	2.1	0.35	1.01	0.92	0.53	2.72	0.66
Sardines	1	19.9	0.02	0.27	0.86	0.03	9.40	2.22
Honeycombed Tripe	1	1.9	0.02	0.04	0.43	0.02	1.15	0.32
Canned Salmon	1	4.0	0.37	0.56	1.19	0.69	4.77	0.96
Imitation Crab Flakes	1	0.8	0.01	0.04	0.12	0.02	0.40	0.06
Lobster Tail	1	0.5	<0.01	0.03	0.01	<0.01	0.83	0.09

ΣCHL=sum of chlordane technical products *cis*- and *trans*-chlordane, *cis*- and *trans*-nonachlor, and oxychlordane; ΣDDT = sum of *o,p′*- and *p,p′*-substituted DDT, DDE, and DDD; ΣHCH = sum of α–, β–, and γ-HCH isomers; ΣPCB = sum of PCB congeners CB-4/10, 5/8, 6, 7/9, 12/13, 15/17, 16, 18, 19, 21/33/53, 22, 24/27, 25, 26, 28, 29/54, 31, 32, 40, 41/71, 42, 43, 44, 45, 46, 47/48, 49, 50, 51, 52, 55, 56/60, 59, 63, 64, 66/95, 70, 74, 76/98, 82, 83, 84/92, 81, 85, 87, 91, 97, 99, 100, 101, 105, 107/147, 110, 114, 118, 119, 128, 129/178, 130/176, 132, 133/149, 135, 136, 137, 138, 141/179, 143, 144, 145, 151, 153, 156, 158, 163, 167, 170/190, 172, 173/202, 174, 171, 175, 177, 182, 183, 185, 187, 197, 180, 189, 193, 191, 194, 195, 196/203, 198, 199, 201, 205, 206, 207, 208, and CB-209; ΣPCB = sum of PCB congeners CB-28, 31, 52, 101, 105, 118, 138, 153, 156 and CB-180 (IUPAC designation).