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ORGANOCHLORINE CONTAMINANT LEVELS IN ESKIMO HARVESTED BOWHEAD WHALES OF ARCTIC ALASKA

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ABSTRACT: Organochlorine (OC) levels in liver and blubber of 20 bowhead whales (*Balaena mysticetus*) collected during the Eskimo subsistence harvest at Barrow (Alaska, USA) in 1992 and 1993 are presented. Liver sum DDT (lipid weight) was significantly greater in male whales than in females. Most of the organochlorines measured were at higher levels in longer (older) than in shorter (younger) males. For female bowhead whales, hexachlorobenzene and lipid levels decreased and other OC levels did not change significantly with increasing length. Most organochlorine contaminants have low concentrations in tissues of the bowhead whale compared to concentrations in tissues of other cetaceans, especially Odontocetes. Based on allowable daily intakes (ADI) levels established by the Canadian Northern Contaminants Program (Ottawa, Ontario, Canada) "safe" levels of blubber to consume were calculated. Chlordane levels in bowhead whale blubber results in the most restrictive consumption amount (50 g blubber/day). We expect no adverse effects related to these organochlorine contaminants to occur in bowhead whales or in consumers of their tissues. However, investigation of low level chronic exposure effects and a more rigorous assessment of histopathology, biomarkers, and immune status in the bowhead whale would be required to conclude "no effect" with more certainty.

Key words: *Balaena mysticetus*, blubber, bowhead whale, liver, organochlorines, subsistence.

INTRODUCTION

Eskimos (Inuit) of Alaska (USA) have hunted and consumed arctic wildlife and marine mammals, especially the bowhead whale (*Balaena mysticetus*), for many centuries (Stoker and Krupnik, 1993). The bowhead whale stock (Bering-Chukchi-Beaufort Sea stock or BCBS stock) discussed here was reduced by commercial whaling in the late 1800's and early 1900's (Shelden and Rugh, 1996), and is the largest remaining stock of this species. The population is estimated to be 8,200 (7,200 to 9,400, 95% confidence interval) and has an annual rate of increase of 3.2% (1.4% to 4.7%, 95% confidence interval) (Raftery and Zeh, 1998). The relative cultural and nutritional importance of wildlife to northern Alaska residents varies with time, season, and location (Hansen, 1990; Hansen et al., 1990), and these animals are not easily substituted with available food (i.e., store purchased) alternatives (Kinloch et al., 1992). Cetacean food products (i.e., subsistence) and associated exposure to organochlorine contaminants and risk to human consumers has been addressed for pilot whales (*Globicephala melaena*) (Simmonds et al., 1994) and arctic marine mammals (Kinloch et al., 1992; Dewailly et al., 1993; Simmonds and Johnston, 1994; Jensen et al., 1997). Many of these investigations have concluded that the benefits (nutritional, cultural, socioeconomic) of consuming these marine mammal products outweigh the potential risks (Kinloch et al., 1992; Wormworth, 1995). Wormworth (1995) and Kinloch et al. (1992) point out that the removal of "country foods" (i.e., subsistence) and associated nutrients (selenium, retinol, polyunsaturated fatty acids, etc.) and introduction of non-traditional foods are known to result in increased malnourishment, heart disease, diabetes, etc. in native communities. The loss of a known benefit is difficult to prescribe based on a uncertain potential risk (i.e., contaminants).

Anthropogenic activities, such as pesticide application, coal and oil combustion, metal smelting, sewage sludge, and nuclear weapons testing, result in releases of contaminants to soil, water, and air, and ultimately in varying degrees of global contamination of the human and wildlife food chains. For example, polychlorinated biphenyls (PCB's) were used worldwide in electrical transformers and capacitors, as flame retardants, as plasticizers in waxes, in paper manufacturing, and other uses. Other chlorinated organics were intentionally developed for release into the environment as pesticides (more than 30); including DDT and associated metabolites (o,p' and p,p' forms of DDD and DDE), chlorinated cyclodienes (chlordane, heptachlor, heptachlor epoxide, and dieldrin), chlorinated benzenes (hexachlorobenzene), and chlorinated cyclohexanes (lindane). Many OC's are known to be transported in the atmosphere (Hoff et al., 1992) and to interact with surface waters (Eriksson et al., 1989). They are also carried (adsorbed) on sediments and particles in water, as well as by migratory organisms in both freshwater and marine systems (O'Hara and Rice, 1996).

Atmospheric transport (on particles and in aerosols) and deposition during precipitation events (Bidleman et al., 1989; Gregor and Gummer, 1989) in the colder temperatures associated with the Arctic is a significant pathway. Many contaminants accumulate in the Arctic due to the relatively large surface areas of the sources and the relatively large area of the receiver (the Arctic). Transport of contaminants in the arctic food chain is unique (Barrie et al., 1992) and requires specific consideration. Halogenated organics are well known to be of low water solubility, high solubility in oils and organic solvents, accumulate in lipid, and have relatively long half lives in the body (Blus et al., 1996). These concerns have motivated the North Slope Borough and National Oceanic and Atmospheric Administration (NOAA) to examine contaminant levels and possible effects in the bowhead whale. The OC's have been implicated, in part, in many abnormalities of marine mammals, including some arctic species (Boon et al. 1992; Wiig et al., 1998). The OC's have been associated (in most cases weakly), with adverse health effects (carcinogenecity, teratogenecity, sterility, immunosuppression, organ specific toxicity) and designated as predisposing factors to mortality events that are ultimately caused by a pathogen or significant pathology (cancer, organ failure) in marine mammals (Martineau et al., 1988; Olsson et al., 1994; deSwart et al., 1994). Some OC's (DDT, lindane, etc.) have been implicated in affecting sexual or gonadal development, as early as *in utero* (Yamamoto et al., 1996). Although there is no cause-effect implied, true hemaphroditism has been documented in the St. Lawrence Estuary beluga whale (De Guise et al., 1994) and pseudohermaphroditism in the bowhead whale (Tarpley et al., 1995).

The OCs that were measured in bowhead whales for this study included polychlorinated biphenyls (sum of 17 PCB congeners), 1,1,1-trichloro-2,2-bis(p-chlorophenyl) ethane (DDT) and DDT metabolites (e.g., p,p' DDE), and other pesticides [e.g., chlordane, trans nonachlor, dieldrin, hexachlorobenzene (HCB), lindane, and heptachlor epoxide (HPE)]. We present data on OC levels in liver and blubber of bowhead whales and biological factors effecting tissue levels. Bowhead whale body length has been shown to increase with increasing age (based on aspartic acid racemization rates in the lens of the eye) and is used as an indicator of age in this study (George et al., 1999). In addition we will discuss the potential exposure to OC's of people who depend on this species for food, the Eskimos (Inuit) of Alaska.

MATERIALS AND METHODS

The bowhead whale samples (liver and blubber) were provided through the Eskimo (Inuit) harvest in Barrow, Alaska (71°17′N, 156°45′W) from a region 2 to 32 km offshore bordered by longitudes 157°00′W and 155°30′W under careful regulation of the Alaska Eskimo Whaling Commission (AEWC; Barrow, Alaska) in 1992 and 1993. These whales represent the Bering-Chukchi-Beaufort Seas (BCBS) Stock (Moore and Reeves, 1993; Shelden and Rugh, 1996). Whales are individually identified by year of harvest (1993 = 93), location (Barrow = B), and sequence in the harvest (6th of the year = 6), or 93B6, and all tissue samples are collected and tagged appropriately by the staff of the Department of Wildlife Management (Barrow, Alaska, USA). Gender and body length (fork to snout) are determined by the staff of the Department of Wildlife Management and recorded on data forms. Blubber and liver specimens were collected from bowhead whales in conjunction with the Alaska Marine Mammal Tissue Archival Project (AMMTAP; Gaithersburg, Maryland, USA) using collection protocols that were modifications of those used by AMMTAP (Becker et al., 1991). These modified procedures involved removal of tissue specimens during the butchering of the whales by the Eskimo hunters, placing these specimens in Teflon bags and returning them to the laboratory of the North Slope Borough Department of Wildlife Management (Barrow, Alaska) where the specimens were subsampled using previously cleaned titanium blade knives, placed in previously cleaned methylene chloride rinsed glass jars with Teflon lined lids, frozen in liquid nitrogen. Samples were maintained at liquid nitrogen vapor temperatures (−120 C) during shipment to the analytical laboratory at the Northwest Fisheries Science Center (Seattle, Washington, USA) where they were stored at −80 C until analyzed.

Blubber and liver samples were analyzed for OCs and percent lipid following standard methods and quality assurance protocols (Krahn, 1988; Sloan, 1993) with slight modifications for the lipid-rich tissue of marine mammals. Briefly, samples of thawed tissue (1.0 to 3.0 g) were extracted, macerated with sodium sulfate and methylene chloride and then the methylene chloride extract was filtered through a column of silica gel and alumina (Spectrum, 100–200 mesh, 60 Angs, New Brunswick, New Jersey, USA and alumina JT Baker, Inc. 50–200 micrometer particle size, Phillipsburg, New Jersey, USA) and concentrated for further cleanup. Size exclusion chromatography with high performance liquid chromatography (HPLC pump 8800, Spectra Physics, San Jose California, USA with autosampler 231/401 Gilson Co., Middleton, Wisconsin, USA, and Envirosep ABC SEC column 350 × 21.2mm, Phenomenex, Inc., Torrance, California, USA) was used to separate lipids and other biogenic material from a fraction containing the OC's. The OC fraction was analyzed by capillary column gas chromatography (GC) equipped with an electron capture detector (ECD) (Hewlett-Packard 5890 series II GC/ECD, Hewlett-Packard, Avondale, Pennsylvania, USA). Identification of selected individual OC's was confirmed using GC-mass spectrometry (Hewlett-Packard 5890 Series II GC/MSD, Hewlett-Packard, Avondale, Pennsylvania, USA). The OC's are reported here (1) "sum PCB's" which refers to the two times the sum of concentrations of chlorinated biphenyl congeners 18, 28, 44, 52, 66, 101, 105, 118, 128, 138, 153, 170, 180, 187, 195, 206, and 209, a method to estimate total PCB concentrations from concentrations of these 17 congeners, and (2) "sum DDT's" is the sum of concentrations of o,p'-DDD, p,p'-DDD, o,p'-DDE, p,p'-DDE, o,p'-DDT, and p,p'-DDT (Sloan et al. 1993).

Quality assurance procedures for the analysis of OC's included the use of a standard reference material (SRM) from National Institute of Standards and Technology (SRM1945 Whale Blubber Homogenate), method blanks, solvent blanks, certified calibration standards (Accustandard, Inc. New Haven, Connecticut, USA), internal (surrogate) standards (UltraScientific Inc., North Kingston, Rhode Island, USA), and replicate samples (Krahn, 1988; Sloan et al. 1993). The quality assurance results for all analyses (calibrations, method blanks, SRM's; replicates, recoveries of the surrogate standard in samples) met the quality assurance criteria established for our laboratory.

Summary statistics and regression analyses were calculated using Microsoft Excel (7.0) for Windows 97 (Microsoft Corporation, Santa Rosa, California, USA). An adjustment to the *P* value used to determine significance is required when multiple comparisons are made and a Bonferroni adjustment for some multiple comparisons was used. Samples with no detectable OC levels were not used to calculate any statistics and will bias some means to slightly higher levels as these unknown "low" levels were not determined or estimated (i.e., one half the detection level). However, we did make comparisons based on "detectable" versus "not detectable" for female and male whales using a Fisher's Exact Test.

Calculations for tolerable consumption levels of blubber were determined based on allowable daily intake (ADI) levels recommended by the Contaminants Toxicology Section (Food Directorate, Health Canada, Ottawa, Ontario, Canada) as described in Jensen et al. (1997). We assumed an average body weight of 70 kg for a human consumer. ADI (μg/kg/day) × 70 kg = allowable daily dose (μg, adult) which is divided by mean tissue level [convert ppb to μg/g wet weight (ww) by dividing by 1,000] of the contaminant to give

TABLE 1. Mean and median levels for lipid content (%) and organochlorines detected (ppb, lipid weight) in blubber and liver of bowhead whales from Alaska.

Statistic	% lipid	HCB[a]	lindane	HPE[b]	cis-chlordane	trans-non[c]	dieldrin	oxy-chlordane	p,p′ DDE[d]	p,p′ DDT[d]	sum DDTs[e]	sum PCBs[f]
Blubber												
Mean	75.3	117.8	31.2	35.6	24.2	47.6	149.2	25.9	41.0	19.5	172.0	458.5
Median	75.5	115.0	27.0	31.5	21.5	42.5	140.0	22.0	33.0	18.0	150.0	385.0
SD[g]	8.0	38.6	13.4	16.1	11.4	18.6	67.6	16.0	20.8	6.5	76.2	237.2
n[h]	26	26	25	26	26	26	26	26	26	26	26	26
Liver												
Mean	4.7	178.3	34.0	24.1	14.4	32.3	77.7	17.6	25.4	65.3	119.8	979.8
Median	4.9	175.0	30.0	20.0	13.0	34.0	79.0	13.0	21.5	21.0	102.5	550.0
SD[g]	1.0	57.7	16.1	9.5	5.7	10.3	30.4	13.3	10.8	79.6	68.6	1,520.8
n[h]	20	20	16	17	17	20	20	14	20	7	20	11

[a] hexachlorobenzene (HCB).
[b] heptachlor epoxide (HPE).
[c] trans nonachlor (trans-non).
[d] p,p′ DDT and p,p′ DDE are specific DDT isomers.
[e] sum DDTs = 1,1,1-trichloro-2,2-bis(p-chlorophenyl) ethane and other isomers.
[f] sum PCBs = polychlorinated biphenyls.
[g] standard deviation.
[h] The total number of samples analyzed per category is equal to the % lipid (n), if a lower n is listed the difference represents the number of samples below the detection level (approximately 10–56 ng/g).

the allowable amount of blubber that can be consumed in grams per day.

RESULTS

Mean and median levels of organochlorines (ppb, lipid weight) are presented in Table 1 for bowhead liver and blubber for all whales and by gender in Tables 2 and 3. Student t-test results indicate that sum DDT (lipid weight) in liver was significantly greater in male whales than female ($P = 0.046$). Eight of nine female whales had no detectable p,p'-DDT in liver whereas six of 11 males had detectable levels. Detectable levels were found in liver of three of nine females and eight of 11 males for sum PCB, and four of nine females and ten of 11 males for oxychlordane (Table 2, 3). A Fisher's Exact Test comparing detected to not detected levels concluded no significant difference for p,p'-DDT and sum PCB ($P = 0.058$ and 0.095, respectively); and a significant difference for oxychlordane ($P = 0.038$) for female and male whales (lipid weight, Tables 2, 3). There was no difference observed between lipid content for liver or blubber for males versus females.

The regression analyses of organochlorine levels (lipid weight) versus whale length are presented in Table 4. For females, only one organochlorine (HCB) and lipid content (%) showed a significant negative relationship (coefficient < 0, $P < 0.05$) versus increasing whale length. For males, most (7 of 11) organochlorines showed a positive significant relationship (coefficient > 0, $P < 0.05$) with length and includes cis-chlordane, trans nonachlor, dieldrin, p,p'-DDE, p,p'-DDT, sum DDT, and sum PCB (Table 4). However, the r^2 values indicate the linear fit is not ideal. Using a more conservative comparison ($P \leq 0.005$), a Bonferroni adjustment, none of the regression analyses would be considered significant.

The mean and median levels for the organochlorines as wet weight (ww) is presented in Table 5 and by gender in Tables 6 and 7. The wet weight levels are important for determining human exposure, as tissue consumed is estimated on a wet

TABLE 2. Mean and median levels for lipid content (%) and organochlorines detected (ppb, lipid weight) in blubber of bowhead whales from Alaska by gender.

Statistic	% lipid	HCB[a]	lindane	HPE[b]	cis-chlor-dane	trans-non[c]	dieldrin	oxy chlor-dane	p,p′ DDE[d]	p,p′ DDT[d]	sum DDTs[e]	sum PCBs[f]
Blubber Female Only												
Mean	75.0	118.2	34.8	37.9	25.8	49.8	144.6	28.9	41.3	18.2	173.1	492.5
Median	74.5	105.0	26.0	30.5	22.5	42.0	130.0	27.0	33.0	18.0	150.0	435.0
SD[g]	5.4	53.6	18.8	21.9	13.7	23.7	82.3	15.7	24.5	5.0	88.3	234.8
n[h]	12	12	11	12	12	12	12	12	12	12	12	12
Blubber Male Only												
Mean	75.6	117.4	28.4	33.6	22.8	45.8	153.1	23.3	40.7	20.6	171.1	429.3
Median	78.0	120.0	28.0	32.0	19.5	42.5	150.0	13.5	32.5	18.0	145.0	290.0
SD[g]	9.9	20.7	6.4	9.3	9.2	13.6	55.1	16.3	18.1	7.5	67.7	244.0
n[h]	14	14	14	14	14	14	14	14	14	14	14	14

[a] hexachlorobenzene (HCB).
[b] heptachlor epoxide (HPE).
[c] trans nonachlor (trans-non).
[d] p,p′ DDT and p,p′ DDE are specific DDT isomers.
[e] sum DDTs = 1,1,1-trichloro-2,2-bis(p-chlorophenyl) ethane and other isomers.
[f] sum PCBs = polychlorinated biphenyls.
[g] standard deviation.
[h] The total number of samples analyzed per category is equal to the % lipid (n), if a lower n is listed the difference represents the number of samples below the detection level (approximately 10–56 ng/g).

TABLE 3. Mean and median levels for lipid content (%) and organochlorines detected (ppb, lipid weight) in liver of bowhead whales from Alaska by gender.

Statistic	% lipid	HCB[a]	lindane	HPE[b]	cis-chlor-dane	trans-non[c]	dieldrin	oxy chlor-dane	p,p′ DDE[d]	p,p′ DDT[d]	sum DDTs[e]	sum PCBs[f]
Liver Female Only												
Mean	4.5	187.2	37	26.7	16.3	30.0	74.1	13.3	25.6	10.0	91.2[i]	580.0
Median	4.7	183.6	38.0	20.0	16.3	27.0	69.6	13.3	19.5	10.0	81.0	605.0
SD[g]	1.0	72.4	15.2	13.9	8.1	13.1	40.1	3.3	13.7	—	53.4	288.3
n[h]	9	9	5	7	6	9	9	4	9	1	9	3
Liver Male Only												
Mean	4.9	171.0	32.6	22.3	13.4	34.2	80.6	19.3	25.2	74.5	143.2[i]	1,129.8
Median	4.9	170.0	25.0	21.0	12.0	36.0	83.0	12.0	23.0	47.5	140.0	475.0
SD[g]	1.0	44.6	17.0	4.8	4.0	7.5	21.4	15.5	8.4	83.0	73.0	1,785.0
n[h]	11	11	11	10	11	11	11	10	11	6	11	8

[a] hexachlorobenzene (HCB).
[b] heptachlor epoxide (HPE).
[c] trans nonachlor (trans-non).
[d] p,p′ DDT and p,p′ DDE are specific DDT isomers.
[e] sum DDTs = 1,1,1-trichloro-2,2-bis(p-chlorophenyl) ethane and other isomers.
[f] sum PCBs = polychlorinated biphenyls.
[g] standard deviation.
[h] The total number of samples analyzed per category is equal to the % lipid (n), if a lower n is listed the difference represents the number of samples below the detection level (approximately 10–56 ng/g).
[i] Significantly different based on Students t-test ($P = 0.046$).

TABLE 4. Regression analyses (r^2, coefficient with 95% confidence level [ppb lipid weight/cm of length] and P value) of organochlorine contaminant levels (ppb lipid weight) and percent (%) lipid versus body length (cm) for significant relationships ($P < 0.05$) for male and female bowhead whales from Alaska.

Analyte	Female r^2	Coefficient (ppb/cm, 95% range)	P value	Male r^2	Coefficient (ppb/cm, 95% range)	P value
Lipid (%)	0.45	−0.01 (−0.02 to −0.003)	0.017	0.09	−0.01 (−0.04 to 0.01)	0.289
hexachlorobenzene	0.35	−0.12 (−0.23 to −0.005)	0.043	0.003	0.004 (−0.05 to 0.06)	0.82
cis-chlordane	0.13	−0.02 (−0.05 to 0.01)	0.246	0.41	0.02 (0.006 to 0.04)	0.013
trans nonachlor	0.14	−0.03 (−0.09 to 0.03)	0.236	0.29	0.03 (0.0004 to 0.06)	0.048
dieldrin	0.20	−0.14 (−0.33 to 0.06)	0.144	0.31	0.13 (0.008 to 0.25)	0.039
p,p′ DDE[a]	0.09	−0.03 (−0.09 to 0.03)	0.331	0.32	0.04 (0.004 to 0.08)	0.035
p,p′ DDT[a]	0.07	−0.005 (−0.02 to 0.008)	0.420	0.34	0.02 (0.03 to 0.002)	0.028
sum DDT	0.11	−0.11 (−0.32 to 0.11)	0.299	0.37	0.17 (0.03 to 0.31)	0.021
sum PCB	0.05	−0.19 (−0.78 to 0.41)	0.501	0.31	0.57 (0.03 to 1.10)	0.039

[a] p,p′ DDT and p,p′ DDE are specific DDT isomers.

weight basis. Maximum threshold for PCB levels for human consumption range from 0.2 μg/g ww (meat), 0.5 μg/g ww (poultry), to 2.0 μg/g ww (fish) as recommended by Health Canada (Hing, 1998). Jensen et al. (1997) indicated that daily intakes (ADI, μg/kg/day) should not exceed 20 for sum DDT, 0.3 for HCH, 1.0 for sum PCB, 0.05 for chlordanes, 0.1 for heptachlor, 0.1 for dieldrin, and 0.27 for HCB. We deter-

TABLE 5. Mean and median levels (ppb, wet weight) of organochlorines detected in blubber and liver of bowhead whales from Alaska.

Statistic	HCB[a]	lindane	HPE[b]	cis-chlordane	trans-non[c]	dieldrin	oxy chlordane	p,p′ DDE[d]	p,p′ DDT[d]	sum DDTs[e]	sum PCBs[f]
All Blubber											
Mean	88.7	23.8	27.2	18.5	36.3	113.7	19.9	31.1	14.7	130.1	350.2
Median	80.5	22.0	25.0	16.0	31.5	105	16	24.5	14.0	110.0	280.0
SD[g]	33.9	11.7	14.0	10.0	16.3	57.5	13.6	17.3	5.3	65.2	202.2
n	26	25	26	26	26	26	26	26	26	26	26
All Liver											
Mean	8.1	1.5	1.1	0.7	1.5	3.6	0.8	1.2	2.5	5.3	34.4
Median	8.5	1.6	1.0	0.7	1.3	3.5	0.7	1.0	1.1	5.3	23.1
SD[g]	2.4	0.6	0.4	0.3	0.6	1.4	0.7	0.5	2.3	2.5	36.5
n	20	16	17	17	20	20	14	20	7	20	11

[a] hexachlorobenzene (HCB).
[b] heptachlor epoxide (HPE).
[c] trans nonachlor (trans-non).
[d] p,p′ DDT and p,p′ DDE are specific DDT isomers.
[e] sum DDTs = 1,1,1-trichloro-2,2-bis(p-chlorophenyl) ethane and other isomers.
[f] sum PCBs = polychlorinated biphenyls.
[g] standard deviation.

TABLE 6. Mean and median levels (ppb, wet weight) of organochlorines detected in blubber of bowhead whales of Alaska by gender.

Statistic	HCB[a]	lindane	HPE[b]	cis-chlor-dane	trans-non[c]	dieldrin	oxy chlor-dane	p,p′ DDE[d]	p,p′ DDT[d]	sum DDTs[e]	sum PCBs[f]
Blubber Female Only											
Mean	90.3	26.7	29.0	19.8	38.1	110.1	22.3	31.4	13.8	131.3	376.7
Median	77.5	19.0	23.5	16.0	30.0	91.5	19.0	24.0	13.5	110.0	320.0
SD[g]	47.1	16.2	18.8	12.2	21.1	69.6	13.9	20.6	4.6	77.5	208.2
n	12	11	12	12	12	12	12	12	12	12	12
Blubber Male Only											
Mean	87.3	21.5	25.6	17.4	34.7	116.7	17.9	30.8	15.6	129.0	327.4
Median	82.5	22.0	25.0	15.0	34.0	110.0	10.5	26.0	14.5	115.0	215.0
SD[g]	18.2	6.0	8.5	7.9	11.5	47.2	13.5	14.8	5.8	55.5	201.9
n	14	14	14	14	14	14	14	14	14	14	14

[a] hexachlorobenzene (HCB).
[b] heptachlor epoxide (HPE).
[c] trans nonachlor (trans-non).
[d] p,p′ DDT and p,p′ DDE are specific DDT isomers.
[e] sum DDTs = 1,1,1-trichloro-2,2-bis(p-chlorophenyl) ethane and other isomers.
[f] sum PCBs = polychlorinated biphenyls.
[g] standard deviation.

mined daily consumption limits, based on mean weight levels in bowhead whale blubber and the assumption that the average consumer weighs 70 kg, to calculate the daily total exposure [ADI (μg/kg/day) × 70 kg = dose (μg/day)]. This dose is then divided by the mean μg/g ww determined in bowhead blubber (ppb ww/1,000). The maximum allowable bowhead whale blubber intake (g, ww) per day would then be 10,769 g for sum DDT, 882 g for HCH, 200 g for sum PCB, 47 g for chlordanes, 257 g for heptachlor, 62 g for dieldrin, and 210 g for HCB. Therefore,

TABLE 7. Mean and median levels (ppb, wet weight) of organochlorines detected in liver of bowhead whales from Alaska by gender.

Statistic	HCB[a]	lindane	HPE[b]	cis-chlor-dane	trans-non[c]	dieldrin	oxy chlor-dane	p,p′ DDE[d]	p,p′ DDT[d]	sum DDTs[e]	sum PCBs[f]
Liver Female Only											
Mean	7.9	1.7	1.1	0.7	1.3	3.2	0.5	1.1	0.3	3.9	20.8
Median	8.0	2.0	1.0	0.7	1.0	3.0	0.6	0.9	0.31	3.5	19.0
SD[g]	2.5	0.7	0.4	0.3	0.5	1.3	0.2	0.5		2.0	8.8
n	9	5	7	6	9	9	4	9	1	9	3
Liver Male Only											
Mean	8.2	1.5	1.1	0.7	1.7	4.0	0.9	1.2	2.9	6.5	39.5
Median	9.0	1.1	1.0	0.7	2.0	4.0	0.7	1.0	2.2	6.3	24.8
SD[g]	2.5	0.6	0.3	0.2	0.6	1.4	0.8	0.5	2.3	2.4	42.1
n	11	11	10	11	11	11	10	11	6	11	8

[a] hexachlorobenzene (HCB).
[b] heptachlor epoxide (HPE).
[c] trans nonachlor (trans-non).
[d] p,p′ DDT and p,p′ DDE are specific DDT isomers.
[e] sum DDTs = 1,1,1-trichloro-2,2-bis(p-chlorophenyl) ethane and other isomers.
[f] sum PCBs = polychlorinated biphenyls.
[g] standard deviation.

the most restrictive intake would be 47 g per day based on chlordanes.

DISCUSSION

Marine mammals of the Arctic are long lived and develop large lipid or fat depots, and many occupy high trophic levels in this lipid-dependent food web. These biological factors are key to the entry and magnification of persistent and lipophilic xenobiotics. This sets the stage for bioaccumulation where chemicals can biomagnify (increased levels in the predator versus the prey), thus, making the trophic level of a species critical to its respective exposure; the biomagnification factor (BMF) = concentration of X in predator/concentration of X in prey. Among the marine mammals, species that feed on a low trophic level (i.e., bowhead whale and walrus that consume invertebrates) tend to have a lower exposure and subsequently a low tissue burden, than do those species that feed on a middle level (i.e., ice seals, beluga and narwhal whales that consume fish) and have moderate tissue levels of contaminants. Finally, those species that consume fish-eating marine mammals (i.e., polar bear that consume ringed seals) tend to have the highest exposures. Bowhead whales feed almost exclusively on copepods, euphausiids, and amphipods (Lowry, 1993) which is consistent with relatively low levels of OC's. However, an understanding of organochlorine (OC) contaminants in bowhead whale is important because this species is endangered and is harvested and consumed by Alaskan and Russian natives.

Mean levels of sum PCB in bowhead whale blubber were 0.35 ppm ww and 4.5 ppm lipid weight in our study compared to 0.21 ppm ww in bowhead whale blubber in an earlier study (McFall et al., 1986) indicating rather low levels as compared to other marine mammals. Previous reports of OC's in Mysticetes have indicated one to two orders of magnitude lower levels as compared to Odontocetes (Borell, 1993; O'Shea and Brownell, 1994; O'Hara and Rice, 1996). For example, other Mysticetes (e.g., fin whale (*Balaenoptera physalus*) and sei whale (*B. borealis*)) have blubber PCB levels of 1.26 and 0.46 ppm (lipid weight), respectively (Borell, 1993). In comparison, Odontocetes like long-finned pilot whales (*Globicephala melaena*), white sided dolphins (*Laganorhynchus acutus*), and sperm whales (*Physeter macrocephalus*) have levels of 49.0, 43.0, and 11.0 ppm (lipid weight), respectively (Borell, 1993).

Except for sum DDT's and dieldrin, the mean levels of other OC's in blubber in our study were relatively low compared to other marine mammals and similar to bowhead whale blubber levels reported by McFall et al. (1986). The mean sum DDT's 0.13 ppm ww and dieldrin 0.11 ppm ww were higher in our study. McFall et al. (1986) reported relatively low mean levels for the following OC's in blubber, sum DDT's 0.032 ppm ww, chlordane 0.007 ppm ww, dieldrin 0.017 ppm ww, hepatachlor epoxide 0.008 ppm ww, and lindane 0.009 ppm ww. In our study, some OC's were roughly double compared to levels reported in McFall et al. (1986) including oxychlordane 0.02 ppm ww, hepatachlor epoxide 0.027 ppm ww, and lindane 0.024 ppm ww. These apparent differences must be interpreted very carefully as lipid content, age, gender, analytical variability, and nearly a decade difference in sampling could explain the variation in the concentrations. These comparisons, however, are important for detecting trends in contamination over time in the Arctic.

Pollutant levels in marine mammals are known to be affected by diet, body size, body composition, nutritive (body) condition, disease, age, and reproductive stage (immature, mature, gestation, lactation). These factors must be taken into account when designing monitoring programs, experiments, interpreting data, and comparing populations or species. For the bowhead whale in our study, the tissue levels of some OC's, including DDT's, increased with increasing size (age) in males, whereas similar measurements in females either showed no change or a decrease with increasing size. Positive age correlations for sum PCB and sum DDT were found in females but not in males for beluga whales of the St. Lawrence River Estuary (Muir et al., 1996a), just the opposite of our results for the bowhead whales. However, other studies of cetaceans have shown that total PCB's are significantly higher in males than in females and are age dependent (Addison et al., 1986; Muir et al., 1988; Boon et al., 1992), thus supporting our results. In most cases, lactation and the neonate (due to fetal accumulation) are important excretion mechanisms for OC's for the sexually mature and active female. More importantly this mechanism of excretion results in high levels of exposure *in utero* and during lactation at a critical phase for the development of organ systems (CNS, reproductive, immune etc.) of the neonate. Persistent OC's are lower in mature females, compared to males, for polar bear, seals (ringed and fur), and beluga and narwhal whale (Muir et al. 1992a, b). In general, the body burden or tissue concentrations increase with age for both sexes, until onset of sexual maturity and activity and then a difference based on gender is usually detected (Boon et al., 1992). In most cases (with exception of highly contaminated areas), males continue to accumulate OC as they age, whereas females plateau or decrease (Boon et al., 1992). Lipid content is important to determine because, particularly in emaciated or lactating individuals, lipid mobilization may be coupled with increased blubber water content and this may affect OC levels. Collection of these biological data and the actual lipid types and levels is important for the interpretation of the toxicological results.

Diet can change body burden levels but in some cases can require a long period of time due to the very long half-life of these compounds. For example, harbor seals on a "clean" diet for 8 months only decreased body burdens slightly, whereas the group on the contaminated diet (levels were 7 times that of the control diet) doubled their body burdens (Boon et al., 1992). We cannot assess individual bowhead whale differences in diet in this study but we have initiated a study to compare seasonal differences in diet with respect to contaminant levels and other tissue constituents (i.e., lipids).

The blubber of the bowhead whale was assessed as a source of OC's to human consumers based on ADI (Jensen et al., 1997) from the Canadian Northern Contaminants Program and tissue levels (Hing, 1998). The mean and median PCB levels found in bowhead whale blubber exceed the levels for meat by about 75%, but do not exceed fish and poultry PCB levels suggested for consumption. The maximum threshold levels for human consumption range from 0.2 ppm ww (meat), 0.5 ppm ww (poultry), to 2.0 ppm ww (fish) for PCB's as recommended by Health Canada (Hing, 1998). However, these maximum threshold tissue levels are determined based on known or good estimates of consumption rates for the general population which is not known for bowhead blubber consumers. Bowhead whale liver is much lower in sum PCB's and is not typically consumed. The sum of the average chlordanes (oxychlordane, cis-chlordane, trans-nonachlor) detected in blubber equals 101.9 ppb ww (10.19 μg/100 g ww portion) which is much less than walrus (204.5 μg/100 g ww) and narwhal (213.8 μg/g ww) blubber, and slightly lower than ringed seal (33.0 μg/100 g ww) reported by the Canadian Northern Contaminants Program (Jensen et al., 1997). The same program determined sum DDT to be 141.9, 272.6, and 32.7 μg/100g ww for walrus, narwhal, and ringed seal blubber (Jensen et al., 1997) and the bowhead blubber level in this study was 130.1 ppb ww or 13.01 μg/100g ww and is much lower in comparison to these other marine mammals. The same program determined sum PCB to be 337.1, 320.5, and 36.4 μg/100 g for walrus, narwhal, and ringed seal blubber (Jensen et al., 1997) and the bowhead blubber level in this study was 350.2 ppb ww or 35.02 μg/100 g ww and is much lower in comparison to the walrus and narwhal, but similar to ringed seal. It needs to be stressed that the ADI is for a life long exposure and a significant safety factor has been applied, making these very safe and conservative estimates. Jensen et al. (1997) describe the derivation of the ADI as first determining the no observed adverse effect level (NOAEL) for a chemical from epidemiological or laboratory based studies then dividing this "no effect level" by 100 (a factor of 10 each for assuming humans to be more sensitive than laboratory animals, and for variability within the human population), these intake levels are then divided over the human lifespan. These levels of intake are then thought to be without appreciable risk. The use of 100 g portions is more meaningful to consumers versus other measures (i.e., μg/g, ppb, μg/g lipid, etc.). This assessment of bowhead whale blubber assumes a 70 kg consumer and does not specifically address fetal or neonatal exposure as this would require measures of OC's in cord blood, milk, etc. and not direct intake of blubber.

The levels of chlordanes detected and estimated level of exposure would pose the most restrictive consumption rate at approximately 50 g of blubber per day. However, based on DDT levels, one could consume nearly 11 kg per day. Consumers must consider that they likely do not currently eat bowhead whale blubber daily, and safety factors are used to develop these suggested consumption levels. Consumption rates for the multiple significant sources of OC's (fish, other marine mammals, etc.) would be required to best assess human risk, but is beyond the scope of this paper. In addition, we do not know how chemicals present in food interact in the diet. Furthermore, the cultural, nutritional, and spiritual benefits for the consumer must be considered. Other investigations of contaminants in Inuit food have concluded the known benefits outweigh the potential risk of adverse effects due to contaminants (Kinloch et al., 1992; Wormworth, 1995). Based on our current state of knowledge we do not suggest any changes in consumption of bowhead whale blubber.

In conclusion, persistent organic pollutants resulting from anthropogenic activities are found in tissues of bowhead whales. The levels of persistent organochlorine contaminants in this large baleen whale are low compared to Odontocetes. Levels in males tended to accumulate with increasing length (age). No marked differences were observed in mean OC concentration between males and females, except DDT was at a greater mean level in males. The results are consistent with depletion of chemical stores during parturition and lactation as females showed no increase in tissue levels with length. Mean OC levels were used to determine suggested human consumption rates of blubber based on recommended ADI. Our findings suggest that, based on current knowledge of effects of OC's, bowhead whale blubber should be considered relatively safe to consume at or below the levels of consumption calculated. However, investigation of low level chronic exposure effects and a more rigorous assessment of histopathology, biomarkers, and immune status of the bowhead whale would be required to conclude "no effect" with more certainty.

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