Persistent organic pollutants in Alaskan ringed seal (*Phoca hispida*) and walrus (*Odobenus rosmarus*) blubber†‡§

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Since 1987, the Alaska Marine Mammal Tissue Archival Project (AMMTAP) has collected tissues from 18 marine mammal species. Specimens are archived in the National Institute of Standards and Technology's National Biomonitoring Specimen Bank (NIST-NBSB). AMMTAP has collected blubber, liver and/or kidney specimens from a number of ringed seals (*Phoca hispida*) from the areas near Nome and Barrow, Alaska and walruses (*Odobenus rosmarus*) from several locations in the Bering Sea. Thirty-three ringed seal and 15 walrus blubber samples from the NIST-NBSB were analyzed for persistent organic pollutants (POPs). The compounds determined included PCBs (28 congeners or congener groups), DDT and related compounds, hexachlorobenzene (HCB), hexachlorocyclohexane isomers (HCHs), chlordanes, dieldrin, and mirex. POP concentrations in ringed seal blubber were significantly higher in Barrow than in Nome when statistically accounting for the interaction of age and gender; HCB, however, was not statistically different between the two locations. Unlike males, POP concentrations and age were not significantly correlated in females probably as a result of lactational loss. POP concentrations in walrus blubber were lower than in ringed seal blubber for $\sum$PCBs, chlordanes, and HCHs, but higher for dieldrin and mirex. POP concentrations in ringed seals and walrus from Alaska provide further evidence that the western Arctic tends to have lower or similar POP concentrations compared to the eastern Canadian Arctic.

Introduction

The ringed seal (*Phoca hispida*) is common in the Arctic with a circumpolar distribution. This species is generally associated with sea ice, using this habitat for resting, reproduction, and foraging, as well as for protection from predators. Ringed seals are the predominant prey of polar bears (*Ursus maritimus*) and important for subsistence users. The importance of the ringed seal in the arctic ecosystem has led the Arctic Monitoring and Assessment Program (AMAP) to suggest that the ringed seal be included as a target (indicator) species for arctic environmental monitoring.[1]

Ringed seal blubber samples have been collected from a variety of locations throughout the Arctic, including the White Sea in Russia, Baltic Sea, Svalbard, Greenland, and several locations in the Canadian Arctic and Alaska, and analyzed for persistent organic pollutants (Fig. 1).[2,3] Results from this work

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§ Disclaimer: Certain commercial equipment or instruments are identified in the paper to specify adequately the experimental procedures. Such identification does not imply recommendations or endorsement by the NIST nor does it imply that the equipment or instruments are the best available for the purpose.

John Kucklick was born in the United States, in 1960. He received his PhD in Marine Science from the University of South Carolina, USA in 1992, a Masters Degree in Marine Biology from the University of North Carolina at Wilmington in 1988, and a Bachelors of Science degree in Zoology from Miami University in Ohio, USA in 1983. In 1992 he joined the University of Maryland's Chesapeake Biological Laboratory as a post doctoral scientist. Since 1997 he has been a research biologist in the Analytical Chemistry Division of the National Institute of Standards and Technology. His current research interests are: environmental and marine chemistry, environmental fate, bioaccumulation, toxicology, and the analytical chemistry of organic pollutants.

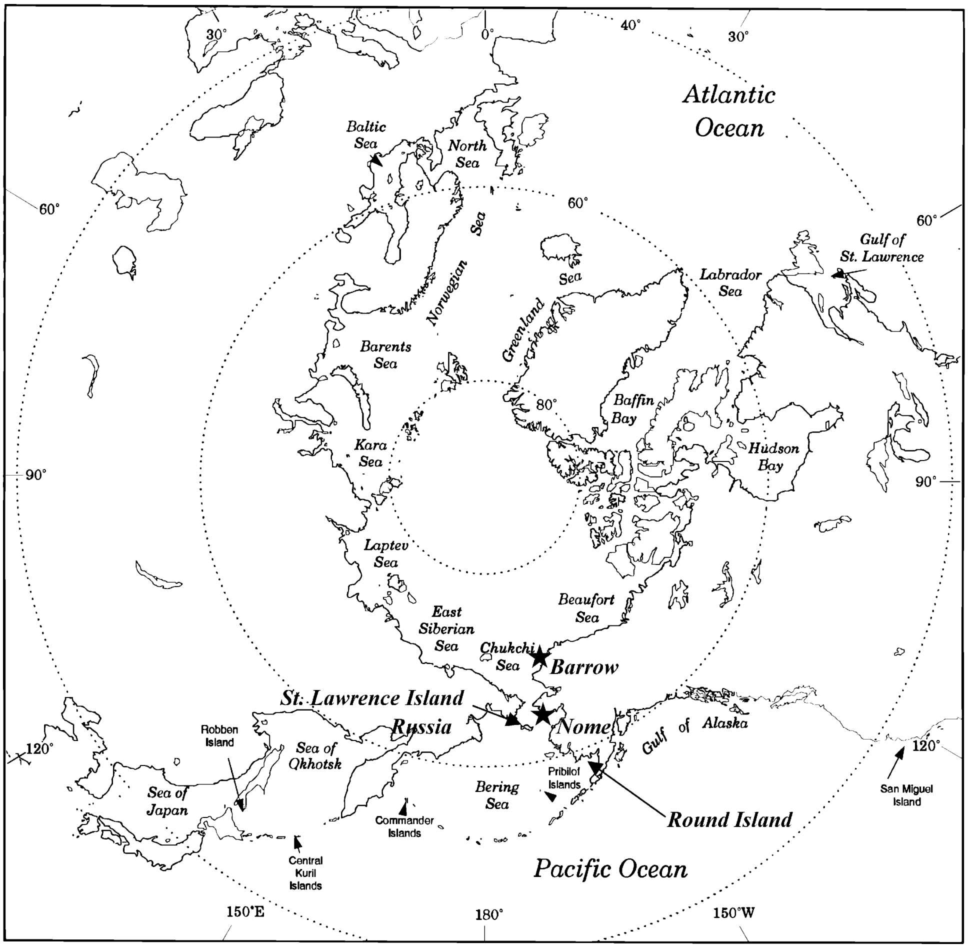

Fig. 1 The Arctic and surrounding regions.

showed a negative correlation between $\sum$DDTs (the sum of 4,4′-DDT, -DDE, and -DDD), $\sum PCB_{10}$ (the sum of PCBs 28, 31, 52, 101, 105, 118, 138, 153, 156, and 180), and *trans*-nonachlor blubber concentrations and the longitudes of the locations from where the samples were collected (*i.e.*, blubber concentrations decreased from east to west).[2] Conversely, the sum of hexachlorocyclohexanes ($\sum$HCH; the sum of α-, β-, and γ-HCH) concentrations increased with increasing longitude. Samples for this work originated from several locations ranging from the Russian central Arctic (Kara Sea, approximately 76° east longitude) to Resolute Bay in the eastern Canadian Arctic (approximately, 95° west longitude). The finding was consistent with that of Hoekstra *et al.* who found that persistent organic pollutant (POP) concentrations were lower in ringed seals collected from Barrow, Alaska, relative to the eastern Canadian Arctic.[4]

Unlike for ringed seals, little is known about geographical trends of POPs in walruses (*Odobenus rosmarus*). Data on POPs in walruses are mainly limited to three locations including Greenland, the eastern Canadian Arctic (Hudson Bay and the vicinity of Baffin Island), and the Bering Sea.[5–7] In general, concentrations of POPs in walruses are lower than seals as walruses feed primarily on benthic invertebrates. For example, male ringed seals collected from a region similar to that for the walruses had 2 to 4 times higher concentrations of PCB 153.[5] However, unusually high concentrations, up to 11 500 ng g^{-1}(8500 ng g^{-1} wet mass; mean (1 SD)) sum $\sum$PCBs (sum of 86 congeners) in male walruses (n = 9) have been observed from eastern Hudson Bay and have been attributed to seal predation by walruses.[5] In male walruses (n = 8) from the Bering Sea, the median $\sum$PCB (unspecified number of congeners) was 450 ng g^{-1} (390 ng g^{-1} wet mass) compared to 193 ng g^{-1} (53 ng g^{-1}) for non-seal eating walruses (n = 6) from northeastern Canadian Arctic (Igloolik).[5,7]

The present study aims to provide additional information on ringed seals in the western Arctic as well as new information on walruses collected from the Bering Sea. This study makes use of samples collected and archived by the Alaska Marine Mammal Tissue Archival Project (AMMTAP)[8,9] for inclusion in the National Institute of Standards and Technology's National Biomonitoring Specimen Bank (NIST-NBSB). Samples were collected with the cooperation of Alaskan Native organizations and subsistence hunters. As of 2005, AMMTAP has sampled the blubber, liver, and/or kidney of 115 ringed seals from areas near Nome and Barrow, Alaska. Thirty-three ringed seal and fifteen walrus blubber samples from the NIST-NBSB have been

Table 1 Information on ringed seal blubber samples used in this study

NIST NBSB identifier	Location	Year collected	Gender	Age/year	Blubber thickness/cm	Lipid, mass fraction (%)
RGSL-2	Barrow	1988	Female	0.5	2.5	81.3
RGSL-5	Barrow	1988	Female	1	2.7	82.1
RGSL-6	Barrow	1988	Female	0.5	2.8	82.2
RGSL-10	Barrow	1988	Female	2	3.0	78.5
RGSL-23	Barrow	1991	Female	5.5	2.3	78.0
RGSL-28	Barrow	1991	Female	9	2.5	81.5
RGSL-48	Barrow	1996	Female	7	2.0	79.4
RGSL-54	Barrow	1996	Female	6	1.8	84.9
RGSL-55	Barrow	1996	Female	5	2.0	85.3
RGSL-25	Barrow	1991	Female	1.5	2.4	84.3
RGSL-37	Barrow	1994	Male	1	3.2	88.3
RGSL-47	Barrow	1996	Male	7	3.5	83.2
RGSL-50	Barrow	1996	Male	6	2.9	87.0
RGSL-51	Barrow	1996	Male	7	2.8	85.9
RGSL-52	Barrow	1996	Male	5	2.9	84.6
RGSL-53	Barrow	1996	Male	6	1.9	88.3
RGSL-49	Barrow	1996	Male	7	1.9	84.5
RGSL-12	Nome	1989	Female	2	3.5	74.0
RGSL-15	Nome	1989	Female	0.5	3.3	85.5
RGSL-17	Nome	1991	Female	NA[a]	7.0	89.5
RGSL-18	Nome	1991	Female	1	2.0	90.9
RGSL-35	Nome	1994	Female	NA	3.5	87.5
RGSL-36	Nome	1994	Female	NA	3.8	85.8
RGSL-48	Nome	1997	Female	NA	4.4	86.3
RGSL-56	Nome	1997	Female	4	2.0	90.0
RGSL-11	Nome	1989	Male	1	4.0	86.7
RGSL-14	Nome	1989	Male	1	3.0	84.2
RGSL-16	Nome	1991	Male	0.5	4.0	87.6
RGSL-29	Nome	1993	Male	1	3.4	90.0
RGSL-30	Nome	1993	Male	NA	6.0	87.0
RGSL-31	Nome	1993	Male	1.5	4.0	91.0
RGSL-33	Nome	1994	Male	NA	4.0	85.1
RGSL-34	Nome	1994	Male	NA	2.5	86.5

[a] Not available.

analyzed for POPs by NIST, and/or the National Oceanic and Atmospheric Administration (NOAA).

Experimental

The ringed seal blubber samples used in this study were from 10 female and 7 male seals from Barrow, Alaska and 8 male and 8 female seals from Nome, Alaska collected from 1988–1997 during native subsistence hunts (Fig. 1 and Table 1). While the collection spans ten years, previous studies did not find significant temporal trends of POPs during this period in ringed seals.[10,11] Walrus blubber samples were collected during native subsistence hunts from several locations in Alaska including Round Island, Saint Lawrence Island, and from coastal waters around the Seward Peninsula (Table 2). Samples were collected, shipped, and stored using stringent protocols designed for samples to be included in the NIST-NBSB.[12] Prior to analysis, samples were cryohomogenized

Table 2 Information on walrus blubber samples used in this study

NIST NBSB identifier	Location	Year collected	Gender	Age/year	Blubber thickness/cm	Lipid, mass fraction (%)
WLRS-001	Norton Sound	1993	Male	12 to 15	2.5	72.1
WLRS-002	Nome	1993	Male	8 to 10	2.5	77.5
WLRS-003	Nome	1994	Male	19	5.0	55.7
WLRS-004	Nome	1994	Male	21	3.3	74.9
WLRS-005	Nome	1994	Male	18	3.0	79.2
WLRS-006	West of Gambell[a]	1995	Female	8	NA[b]	82.0
WLRS-007	West of Gambell	1995	Female	8 to 10	8.0	81.6
WLRS-008	West of Gambell	1995	Female	5 to 6	6.0	79.4
WLRS-010	NE of Gambell	1995	Female	Calf	NA	64.3
WLRS-013	Gambell	1996	Female	Adult	3.9	84.5
WLRS-014	St. Lawrence Island	1996	Female	6 to 9	6.8	79.3
WLRS-016	Round Island	1996	Male	16 to 25	6.3	74.4
WLRS-017	Round Island	1996	Male	16 to 25	NA	62.6
WLRS-018	Round Island	1996	Male	16 to 25	3.3	39.7
WLRS-020	Round Island	1996	Na	*ca.* 15	17	69.0

[a] Western end of St. Lawrence Island. [b] Not available.

according to Zeisler *et al.*[13] then stored at −80 °C or below. Ringed seal ages were estimated by enumerating the number of front claw growth rings, and walrus ages were determined from stained, sectioned teeth.

Sample analysis of ringed seals was done jointly by NIST and NOAA. NOAA and NIST jointly analyzed 17 of the samples for POPs; 8 were analyzed by NIST only and 8 by NOAA only. All walrus blubber samples were analyzed for POPs by NIST only. POPs were measured by gas chromatography with electron capture detection using techniques described in detail elsewhere.[14–16] Briefly, samples were extracted using Soxhlet or pressurized fluid extraction, fat was removed by size exclusion chromatography, and the extracts were further purified using Florisil or NH_2 open column and liquid chromatography techniques, respectively. Analyte values were averaged if determined by multiple laboratories. NIST and NOAA have participated in NIST sponsored interlaboratory comparison exercises for organohalogen compounds in marine mammal tissues for nearly 20 years.[17] In addition, Standard Reference Material (SRM) 1945 Organics in Whale Blubber was run with each batch of samples at both laboratories as a control material. Measurements made by the two laboratories using this material were in excellent agreement: $r^2 = 0.97$, slope = 0.95 and residuals for all compounds were <20%.

Several POPs classes were summed prior to statistical analysis. The sum of hexachlorocyclohexanes (∑HCH) was the sum of α-, β-, and γ-HCH; the sum chlordane (∑chlordane) was the sum of *cis*- and *trans*-chlordane, *cis*- and *trans*-nonachlor, heptachlor epoxide, and oxychlordane; the sum of polychlorinated biphenyls ($\sum PCB_{28}$) was the sum of 28 PCB congeners or congener groups that were measured by both laboratories; the sum of DDT (∑DDT) was the sum of 4,4′- and 2,4′-DDT, DDE, and DDD. POP data were log transformed prior to statistical analysis. The importance of variables contributing to POP variance was assessed by backwards stepwise regression including age, collection year, gender, location, and blubber thickness and their interaction terms as independent variables. For ringed seals, location and the interaction between age and gender were the only two variables significantly contributing to POP variability. However, sample collection date, while removed from the model was approaching significance suggesting a weak trend in POP concentration with sample collection year. POP concentrations of ringed seals collected from Nome and Barrow, Alaska were compared using an analysis of covariance (ANCOVA) controlling for the age/gender interaction term. For walruses, none of the variables measured significantly contributed to contaminant variability.

Table 3 Concentrations (ng g^{-1} wet mass) of persistent organic pollutants in ringed seal and walrus blubber. Values are the geometric mean (mean) and standard deviation (SD). $\sum PCB_{10}$ is the sum of chlorobiphenyl (CB) congeners 28, 31, 52, 101, 105, 118, 138, 153, 156, and 180 and are the same congeners summed in Muir *et al.*[2] to obtain ∑PCB

	Ringed seals								Walruses			
	Barrow				Nome							
	Female (*n* = 10)		Male (*n* = 7)		Female (*n* = 8)		Male (*n* = 8)		Female (*n* = 6)		Male (*n* = 8)	
Compound	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
∑TriCB	25	4.4	24	15	12	6.4	11	2.4	6.9	11	1.8	0.3
∑TetraCB	54	22	59	28	34	12	16	7.7	2.7	3.1	1.1	0.2
∑PentaCB	220	74	240	92	110	37	120	17	10	8.5	11	4.4
∑HexaCB	240	47	300	150	130	47	130	44	44	25	27	27
∑HeptaCB	65	22	77	45	32	15	21	10	4.6	2.0	3.1	1.5
∑Octa-decaCB	2.8	4.2	3.6	2.1	4.0	5.8	<0.3	—	2.0	1.7	1.0	0.8
$\sum PCB_{28}$	620	120	710	320	330	110	300	71	77	41	47	32
$\sum PCB_{10}$	430	77	500	240	220	79	220	55	60	28	39	31
HCB	26	15	12	3.7	17	6.2	20	13	<1	—	<1	—
α-HCH	240	240	210	130	130	81	170	100	13	10	34	14
β-HCH	54	12	66	44	42	25	44	13	65	47	69	63
γ-HCH	10	7.3	14	14	7.5	4.6	4.2	3.1	1.9	0.9	4.2	1.3
∑HCH	410	250	300	200	180	96	220	110	81	56	110	73
cis-Chlordane	7.1	11	8.4	12	5.1	4.8	2.9	6.0	<1	—	<1	—
trans-Chlordane	2.6	0.9	3.7	1.8	2.3	1.5	2.0	1.2	2.3	0.8	1.1	0.1
Oxychlordane	170	66	230	180	99	38	71	50	83	52	37	31
cis-Nonachlor	11	13	14	16	7.1	4.9	3.9	3.5	<1	—	<1	—
trans-Nonachlor	130	190	260	410	79	83	58	44	3.0	1.6	3.2	1.1
Nonachlor III	54	23	81	98	23	9.0	26	17	—	—	—	—
Heptachlor epoxide	45	25	73	79	34	15	27	13	10	5.9	11	5.2
∑Chlordane	400	230	660	670	270	140	200	110	88	53	42	31
2,4′-DDD	<3	—	3.3	0.3	<3	—	<3	—	<2	—	<2	—
2,4′-DDE	5.7	0.2	2.4	2.4	<2	—	<2	—	<2	—	<2	—
2,4′-DDT	4.8	3.1	9.3	5.4	4.3	4.9	2.0	1.4	<2	—	<2	—
4,4′-DDD	10	11	5.8	2.8	5.7	3.9	4.7	5.0	2.7	0.1	1.5	0.1
4,4′-DDE	320	92	440	250	170	77	160	62	4.5	3.6	4.2	1.0
4,4′-DDT	62	66	46	28	21	10	15	17	<2	—	<2	—
∑DDT	410	150	510	280	200	94	180	75	5.0	3.7	5.2	1.2
Dieldrin	34	20	35	27	19	8.0	17	25	45	23	48	34
Mirex	8.2	5.1	11	10	6.6	4.0	3.0	1.3	17	8.7	5.7	3.0

Table 4 The geometric mean and range (ng g^{-1} wet mass) of selected persistent organic pollutants in ringed seals. Values from Grise Fjord, Arctic Bay, Eureka, and Resolute are given in Muir *et al.*;[2] additional samples from Barrow are from Hoekstra *et al.*[4] $\sum PCB_{10}$ is the sum of PCB congeners 28, 31, 52, 101, 105, 118, 138, 153, 156, and 180; $\sum$DDT is the sum of 4,4′-DDD, -DDE, and -DDT; $\sum$HCH is the sum of α-, β-, and γ-HCH

	Grise Fjord		Arctic Bay		Eureka		Resolute		Barrow (ref. 4)		Barrow (this study)		Nome (this study)	
Longitude/°	82.5		85		88		94.5		156.5		156.5		165	
Gender	F	M	F	M	F	M	F	M	F	M	F	M	F	M
n	4	4	6	8	10	8	10	10	6	14	11	6	8	8
HCB	10	13	25	28	87	104	43	41	11	16	26	12	17	20
	9–13	7–30	17–30	22–52	39–200	35–200	13–69	28–77	5–28	6–50	11–51	7–17	11–28	7–50
trans-Nonachlor	54	149	86	330	140	160	110	95	66	62	126	230	79	58
	44–64	94–220	50–150	87–1100	20–370	25–820	35–220	55–190	8–330	15–200	37–650	76–1080	318–250	16–140
$\sum$HCH	72	75	219	260	260	300	310	400	120	110	410	300	180	220
	46–88	56–89	136–330	138–510	133–430	160–600	150–660	260–580	65–230	1–410	200–990	150–590	94–390	160–370
$\sum$DDT	40	1140	190	910	640	970	340	350	100	120	400	490	200	180
	150–430	420–3000	140–240	210–6900	400–1300	510–1500	160–510	140–750	15–400	18–260	270–650	180–870	110–370	66–320
$\sum PCB_{10}$	170	670	180	612	530	1000	330	400	180	240	420	500	220	220
	140–430	290–1400	140–240	210–2500	280–820	670–2000	210–530	220–620	85–570	81–680	330–540	230–820	140–380	170–210

Results and discussion

Ringed seals

Summed POP concentrations for the Nome and Barrow ringed seals are presented in Table 3 and the concentrations of individual compounds are given in the supplementary information. All concentrations are reported on a wet mass basis unless otherwise specified. Overall, $\sum PCB_{28}$ concentrations were greater than $\sum$chlordanes with $\sum$chlordanes greater than $\sum$DDT, followed by $\sum$HCH. The exception was male ringed seals from Nome, where $\sum PCB_{28} > \sum HCH > \sum$chlordanes $> \sum$DDTs (Table 3). Dieldrin and mirex, while detected in all blubber samples, were present at concentrations generally lower than most other organochlorines. PCBs were dominated by the hexa- and hepta-chloro PCB isomers which comprised an average of 74% (4%) of the $\sum PCB_{28}$. The variation in male POP concentrations was generally higher than in females, as was previously observed in ringed seals.[2,3] Age and POP concentrations were significantly correlated in males for mirex, $\sum$HCH, $\sum$chlordane, $\sum$DDT and $\sum PCB_{28}$, but not for HCB. POP concentrations and age were not significantly correlated in females, which was likely to be due to the loss of lipophilic contaminants through lactation and parturition.[18]

The POP concentrations observed in the Barrow ringed seals were comparable to western Arctic values based on a recent compilation of ringed seal data from around the Arctic (Table 4). For example, the geometric mean of $\sum$DDT in female seals from Resolute Bay was 340 ng g^{-1} (the range was 163 ng g^{-1} to 540 ng g^{-1})[2] *versus* 424 ng g^{-1} in the Barrow female seals (the range was 266 ng g^{-1} to 652 ng g^{-1}) and 179 ng g^{-1} (the range was 94 ng g^{-1} to 387 ng g^{-1}) in the Nome female seals. For the locations given in Table 4, POP concentrations in Barrow seals appeared most similar to those in Resolute Bay, while Nome seals were more comparable to those from Grise Fjord, with the exception of $\sum$HCHs which were 2.7 times higher in the Nome seals. Interestingly, more recent data (1999–2000) on ringed seals samples from Barrow[4] show much lower levels than in this study suggesting a temporal difference (Table 4).

Studies of ringed seals have generally found significant correlations between age and blubber thickness for many classes of POPs. For example Muir *et al.*[2] found significant correlations between the age of male ringed seals and the sum of 10 PCB congeners ($\sum PCB_{10}$), $\sum$DDT, *trans*-nonachlor, concentrations, but not $\sum$HCH concentrations. No relationship was seen in females which is a result of the transfer of POPs from lactation.[19] Weak relationships between blubber thickness were also observed for some POPs, however none of the relationships was significant. For the Nome and Barrow seals, POP concentrations were significantly correlated ($p < 0.05$) with age in male seals for mirex, $\sum$HCH, $\sum$chlordane, $\sum$DDT, and $\sum PCB_{28}$, but not for HCB or dieldrin. POP concentrations and age were not significantly correlated in females.

To further investigate the effects of age, blubber thickness, gender and location on POP concentrations, backwards stepwise regression was used on the log transformed concentrations. Based on this, only the interaction between age/gender and location significantly contributed to contaminant variance. When controlling for the age/gender interaction term, Barrow seals had significantly (ANCOVA, $p < 0.05$) higher concentrations of $\sum PCB_{28}$, $\sum$chlordanes,$\sum$DDT, dieldrin, and mirex than Nome seals. HCB concentrations, however, were not significantly different between the two locations.

Ratios of POPs may indicate regional sources or transport patterns.[20] Nome is 10° longitude farther west and 7° latitude farther south than Barrow, hence the POP ratios in Nome may indicate a stronger influence of the current sources originating from Asia or India. The ratios of β-HCH/$\sum$HCH, 4,4′-DDT/4,4′-DDE and PCB 52/PCB 180 are shown in Fig. 2. Russian PCB mixtures differ substantially from the North American PCB formulations[21] therefore the ratio of PCB 52/PCB 180 was calculated because the ratio of these two congeners is much higher in the Russian PCB formulation "Soval" than in PCB mixtures manufactured in North America.[21] The β-HCH/$\sum$HCH was higher in Nome seals relative to Barrow seals but not significantly so (*t*-test, $p = 0.07$). Similar to the β-HCH/$\sum$HCH ratio, the ratios of 4,4′-DDT/4,4′-DDE and PCB 52/PCB 180 were also higher in the Nome seals, but the

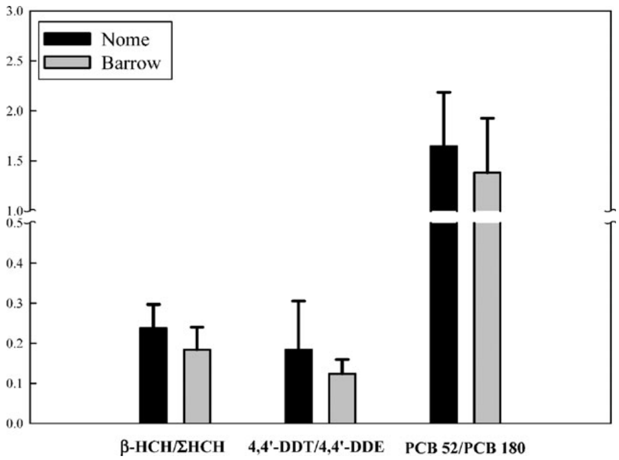

Fig. 2 Ratios of selected POPs in Nome and Barrow ringed seal blubber samples. Errors bars are 1 SD of the mean.

difference was not significant (*t*-test, $p = 0.051$ and $p = 0.27$, respectively). These results suggest that there could have been more recent sources and/or relatively greater amounts of HCH and DDT entering the Bering Sea environment when these samples were collected. However, additional samples should be analyzed before making this conclusion.

Walruses

Concentrations of POPs in walrus blubber are shown in Table 3. Concentrations of POPs were generally lower than in ringed seal blubber from Nome or Barrow except for dieldrin and mirex (Table 3). Concentrations were not significantly affected by age or gender as seen in other studies.[6] The lack of a significant difference between males and females is somewhat surprising; however this may be due to the relatively young females that were sampled, which ranged in age from a calf to 8 to 10 years old. It is possible that the females sampled had not calved hence had not reduced their POP burdens through maternal transfer. Previous studies of walrus reproduction rates indicate that female walruses begin to reproduce from roughly 6 to 10 years of age with the maximum reproduction rate occurring from 11 to 15 years of age.[22] Other studies of marine mammals have also found that males and immature females do not have statistically different POP concentrations.[23]

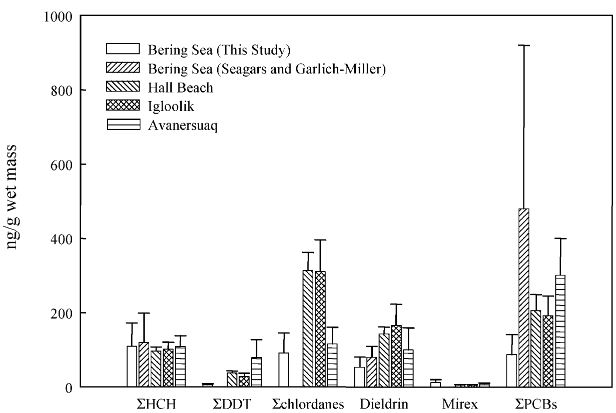

Fig. 3 Concentrations of selected POPs in walruses from eastern Greenland (Avanersuaq), the eastern Canadian Arctic (Igloolik and Hall Beach) and the Bering Sea (this study and Seagars and Garlich-Miller[7]). Values are the arithmetic mean and 1 SD. ∑PCBs are the sum of 86 congeners for Hall Beach, Iglooklik, and Avanersuq.[5,6] The number of congeners summed to derive ∑PCB in Seagars and Garlich-Miller was not specified. ∑HCH and ∑DDT is as specified in the text.

The relative order of the major POP groups in walruses (average of both males and females) was different than that observed in the ringed seals with $\sum$HCH > $\sum PCB_{28}$ > $\sum$chlordanes > $\sum$DDTs. Total PCBs and 4,4′-DDE were especially low compared to ringed seals. This possibly results from reliance on a benthic food web (walruses) *versus* an ice/pelagic-based food web (ringed seals), or walruses may be better able to metabolize and eliminate these compounds compared to ringed seals. Further evidence of good biotransformation ability is the relatively high concentration of oxychlordane, the major chlordane metabolite in walrus *versus* ringed seals. In walruses 92% of the chlordane was in the form of oxychlordane *versus* 40% in ringed seals and 62% observed previously in polar bears.[9] The ratio of oxychlordane to $\sum$chlordane in this study is much higher than observed previously in walruses (28% to 41%) from the eastern Canadian Arctic.[6] The reason for the difference in oxychlordane to $\sum$chlordane ratios between the walruses in this study (Pacific walruses) and those from the eastern Canadian Arctic (Atlantic walruses) is unknown.

POP concentrations in male walruses from another study in the Bering Sea and other locations in the Arctic are shown in Fig. 3. Only values from male walruses were used due to the assumed reproductive effects on POP concentrations in females (excretion of POPs to calves *via* lactation).[23] Male and female walruses from the present study were averaged since POP concentrations were not statistically different. $\sum$HCH and mirex concentrations among the different studies were tightly clustered with mirex concentrations ranging from 5 ng g^{-1} (1.7 ng g^{-1}) in Igloolik walruses to 12 ng g^{-1} (8.4 ng g^{-1}) in walruses from the Bering Sea; $\sum$HCH concentrations ranged from 97 ng g^{-1} (11 ng g^{-1}) to 120 ng g^{-1} (79 ng g^{-1}) in Bering Sea walruses, more consistent than found in ringed seals from similar locations. The reason for this difference is not known but may again be related to reliance on a benthic food web for walruses and an ice-based/pelagic food web for ringed seals. $\sum$DDTs, dieldrin, and $\sum$chlordanes were higher in walruses from locations other than the Bering Sea, consistent with the trend seen in ringed seals. $\sum PCB_{28}$ concentrations in the walruses sampled in the present study were found to be lower than those from other investigations. The overall trend of lower PCBs in the eastern Arctic relative to the western Arctic is consistent with that observed by Muir *et al.* for ringed seals.[2]

Conclusion

POP concentrations in ringed seals and walruses from Alaska provide further evidence that the western Arctic tends to have lower or similar POP concentrations compared to the eastern Canadian Arctic for most POPs. POP levels in ringed seals from around Barrow were more similar to those in the

Canadian Arctic than in seals from Nome. The Nome animals had statistically lower concentrations for the compounds examined except for HCB, which was similar in seals from the two areas. Further analysis of ringed seals should be conducted using more recent samples to look for temporal trends and the presence of compounds of emerging interest such as flame retardants and substituted fluorinated alkanes. The higher β-HCH/∑HCH and 4,4′-DDT/4,4-DDE ratios in Nome compared to Barrow suggest that Asia continues to be a source of these POPs in Alaskan waters. More recent samples should be examined to see if this still is the case. POP concentrations in walruses, in agreement with other work on non-seal eating walruses, were much lower than ringed seals reflecting the walruses's reliance on a lower trophic level benthic food web. POP patterns in walruses suggest a better ability to metabolize POPs, especially chlordanes, than ringed seals.

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