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Organochlorine burdens in blood of ringed and bearded seals from north-western Svalbard

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Abstract

Ringed seal (*Phoca hispida*) and bearded seal (*Erignathus barbatus*) are the main prey of polar bears (*Ursus maritimus*), and information on organochlorines (OCs) in these pinniped species is important to understand the transport, fate and effects of persistent organic pollutants in the Arctic ecosystem. Thus, OCs were analysed in blood samples of bearded and ringed seals from the coastal ecosystem of the north-western Svalbard archipelago (Kongsfjorden, 78.55°N). The relative contribution of OCs could be ranked as follows: Ringed seal females: $\sum$PCB $>$ $\sum$DDT $>$ $\sum$CHL $>$ $\sum$HCH $>$ HCB $>$ Mirex. Ringed seal males: $\sum$PCB $\geqslant$ $\sum$DDT $>$ $\sum$CHL $>$ $\sum$HCH $\geqslant$ HCB $\geqslant$ Mirex. Bearded seal females: $\sum$PCB $>$ $\sum$HCH $\geqslant$ $\sum$CHL $>$ $\sum$DDT $>$ Mirex $>$ HCB. Bearded seal males: $\sum$PCB $>$ $\sum$DDT $\geqslant$ $\sum$CHL $>$ $\sum$HCH $>$ Mirex $\geqslant$ HCB. The concentrations of $\sum$PCB and $\sum$DDT were higher in ringed seals than in bearded seals, whereas $\sum$HCH was higher in bearded than in ringed seals. In ringed seal females and males $\sum$PCB was 337 ± 95 ng/g ($n = 6$) and 625 ± 443 ng/g ($n = 6$), whereas $\sum$DDT was 165 ± 47 ng/g ($n = 6$) and 621 ± 559 ng/g ($n = 6$), respectively. In bearded seal females and males, $\sum$PCB was 159 ± 132 ng/g ($n = 6$) and 248 ± 93 ng/g ($n = 5$), whereas $\sum$DDT was 46 ± 41 ng/g ($n = 6$) and 161 ± 71 ng/g ($n = 5$), respectively. The inter-species differences are caused by a higher trophic position of ringed seals in the Svalbard ecosystem compared to bearded seals. OC levels in ringed seals at Svalbard are similar to those reported from the North-American Arctic and in the lower range compared to previously reported data from Svalbard. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: PCB; DDT; Seals; Pinnipeds; Arctic; Pollution; Trophic level

1. Introduction

In the Arctic, only few known local sources of organochlorines (OCs) are present (de March et al., 1998). These contaminants are mainly transported from distant sources via atmosphere, from inflowing ocean currents, discharging rivers, continental runoff and from drifting sea ice (Oehme, 1991). Atmospheric transport followed by condensation seems to be the most important pathway of these semi-volatile OCs into the Arctic (Oehme et al., 1996).

OCs that enter the Arctic food web, are biomagnified (Hargrave et al., 1992). Since marine mammals have limited abilities to metabolise and excrete some OCs (Boon et al., 1992), concentrations in marine mammals may reach levels causing harmful effects. Recently, high concentrations of PCBs have been reported in polar bears (*Ursus maritimus*) from Svalbard. This could be linked to reported changes in retinol and thyroid hormone status,

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possible immunosuppression, and to indicative incidences of female hermaphrodism in polar bears (Bernhoft et al., 1997; Wiig et al., 1998; Bernhoft et al., 2000).

The ringed seal (*Phoca hispida*) and the bearded seal (*Erignathus barbatus*) are substantial food resources for polar bears (Stirling and Archibald, 1977). Since these two pinniped species are important intermediate links in the Arctic food chain, with the polar bear as the top predator, information about the presence of OCs in these two pinniped species is important to understand how OCs are transferred within the Arctic ecosystem.

During recent years, efforts have been made to apply the so-called non-destructive methods when assessing pollutant burdens or when studying the possible effects of pollutants in marine mammals (Jenssen et al., 1994; Jenssen, 1996; Fossi and Marsili, 1997). Studies have shown that blood concentrations of OCs expressed on lipid weight (lw) basis can be regarded as good estimates for levels in blubber (Boon et al., 1987; Reddy et al., 1998), allowing semiquantitative interspecies comparisons. The aim of the present study was to evaluate relative and absolute differences in the OC burden of blood samples from bearded and ringed seals from the coastal ecosystem of the north-western Svalbard archipelago.

2. Materials and methods

2.1. Field collection

Sampling was conducted in the Kongsfjorden area (78°55′N, 12°30′E), Svalbard, Norway, in May 1994 and 1996. Blood samples were collected from 12 adult ringed seals (six males and six females) and 11 adult bearded seals (five males and six females). Blood samples of about 50 ml were drawn from the epidural vein, and transferred into heparinised vacutainer tubes (Bechton Dickinson, B., Meyland Cedex, France) or polyethylene cryo-vials (NUNC A/S, Roskilde, Denmark) and then stored frozen (−20°C) until analyses. Unfortunately, no information on the age and body mass of the animals is available.

2.2. Analytical procedures

The samples were analysed according to methods described by Bernhoft et al. (1997). Because of the low lipid content of whole blood, some modifications to lipid determination were necessary, and these are outlined below. An aliquot of 10.5 ml of blood from each animal was weighed and homogenised (ultrasonic homogeniser 4710 series, Cole Parmer Instrument, Chicago, Ill, USA), the fat and fat-soluble pollutants (OCs) were extracted with cyclohexane and acetone, and the extract was cleaned using sulphuric acid. The extractable fat percentage was determined gravimetrically prior to acid clean-up by evaporating the whole samples to dryness on a sandbath at 40°C under a gentle flow of N_2-gas. The OCs were determined by comparison with corresponding individual standards using high resolution gas chromatography.

Internal standards (IS; PCB 29, 112 and 207) were added at the start of the extraction procedure, and compensates for loss through the entire sample preparation. PCB 29 covered α-HCH to PCB 47, PCB 112 covered PCB 74–183 and PCB 207 covered PCB 156–209. IS standard recovery was calculated automatically in all samples, including the ordinary recovery samples. Individual PCB congeners and chlordanes were obtained from Prompchem Gmbh, Germany. The CPM mixture containing pesticides and DDT compounds was supplied by Supelco, Bellefonte CA, USA.

A gas chromatograph (HRGC 5300 Mega Series, Carlo Erba) equipped with a split/splitless injector (splitless time 2 min, split ratio 1:20; Fisons AS 800 auto injector), an electron capture detector, and a capillary column of 60 m length (0.25 mm i.d.) coated with 0.25 μm of SPB 5 (Supelco, Bellefonte, PA, USA) was employed. The carrier gas was H_2 at a flow rate of 2 ml/min, and the make-up gas was 5% Ar/CH_4 at a flow rate of 30 ml/min. An identical GC with an SPB-1701 column (length 60 m, 0.25 mm i.d., film thickness 0.25 μm) was used to quantify PCB 47, 52, 156, 157 and 206 (IUPAC numbers). This column gave better separation and recovery for these congeners. The chromatographic data were transferred to a connected computer (Olivetti M290, Ivrea, Italy) equipped with Maxima 820 chromatography workstation (version 3.3, Millipore/Waters, Milford, USA) and the OCs were identified and quantified according to retention times and peak heights.

The whole blood samples from all animals were analysed for 33 PCB congeners (PCB 31, 28, 52, 47, 74, 66, 56, 101, 99, 87, 136, 110, 151, 149, 118, 114, 153, 105, 141, 137, 138, 187, 128, 156, 157, 180, 170, 199, 196, 189, 194, 206 and 209 (Ballschmiter and Zell, 1980), five DDT components and metabolites (*p,p′*-DDT, *o,p′*-DDT, *p,p′*-DDE, *p,p′*-DDD and *o,p′*-DDD), five chlordane compounds (*oxy*-chlordane, *trans*-chlordane, *cis*-chlordane, *trans*-nonachlor, *cis*-nonachlordane), 3 hexachlorocyclohexane isomers (α-HCH, β-HCH, γ-HCH), dodecachlorooctahydro-1,3,4-metheno-1H-cyclo-buta (cd) pentalene (Mirex) and hexachlorobenzene (HCB).

2.3. Analytical quality assurance

Relative recovery was calculated for each sample series by adding a known amount of a PCB standard (33 PCB) to four samples of sheep blood. Sheep blood was used because it was almost completely free of contaminants. This is a routine procedure at the laboratory. The acceptable recovery for a matrix with low fat content and low contaminant concentrations was set within 60–130%. To detect probable contamination by the injection system, solvent blanks were run through the entire analytical procedure for each sample series. To determine deviations from the calibration during the run of a lengthy series on GC, a standard solution was analysed as "an unknown" and quantified by the established calibration curve. Acceptable deviations had to be within ±10%. All recoveries, blanks and drift samples were within acceptable levels. The laboratory's in-house control sample of contaminated seal blubber is run in every series of samples, and for the year 1995, the variation coefficient between control samples at the laboratory ranged from 7% to 28% for different congeners, which is rendered acceptable.

Quantification was carried out within the linear range of the detector, this covered the range from the detection limit to 2–3 times the concentrations of the highest standards (50–100 ng/ml). The detection limit was set to be three times the background noise of the base line. The quantification limit was three times the detection limit. Limits of detection based on an average amount of whole blood samples of 10.5 ml were 0.002–0.008 ng/g (w.w.) for PCBs, 0.001–0.004 ng/g (w.w.) for DDTs and chlordanes, 0.001 ng/g (w.w.) for HCB and 0.003 ng/g (w.w.) for Mirex. Components with levels between the detection and the quantification limits were included in the sum values of the different classes of OCs. Components with levels below the limit of detection were included as half the detection level.

International reference material (CRM 349 and 350, ICES cod liver and mackerel oil) were analysed regularly. The laboratory participated in several intercalibration tests organised by WHO/UNEP (The World Health Organisation/United Nations Environmental Programme, 1982 and 1992) and at four steps of the ICES/IOC/OSPARCOM (International Council for Exploration of the Sea/International Oceanographic Commission/Oslo – Paris Commission) tests on PCBs in marine material. Furthermore, the laboratory is accredited as a testing laboratory for the substances in question according to the requirements of NS-EN 45001 (1989) and ISO/IEC Guide 25 (1990).

2.4. Statistical analysis

To compensate for the variations in the lipid content of the samples, concentrations are presented on a lw basis (Bignert et al., 1994). The statistical analyses were performed with the statistical programme SPSS (Release 7.0 for Windows 95, SPSS, Ill, USA). Non-parametric tests (Mann–Whitney *U*-tests and Spearman Rank correlation) were chosen due to known non-normal distribution of OCs in biological material (Weis and Muir, 1997). Lipid percent and concentrations and relative concentrations of the different classes of OCs and its single components were compared between females and males of the same species and between males, and females, respectively, of the two species. P-values $\leqslant 0.05$ were defined as statistical significant and values $0.05 < P \leqslant 0.1$ were considered as a significance limit (marginal difference). Only two-tailed P-values are presented. If not specified, the sample size (n) of ringed seal females and males, and bearded seal females and males are six, six, six and five, respectively. Z is defined as standard score, and is used to compute the level of significance in Mann–Whitney *U*-test.

3. Results

Lipid content and the concentrations of the different OCs in female and male ringed and bearded seals are given in Tables 1 and 2, respectively.

The extractable lipid content (%) from whole blood was significantly higher in ringed seals than in bearded seals. No significant differences were found between the sexes with respect to this parameter.

HCB, α-HCH, *oxy*-chlordane, *cis*-chlordane, *trans*-nonachlor, Mirex, p,p'-DDE, PCB 99, 118, 153, 105, 138, 128 and 180 were detected in all animals. In addition, β-HCH, γ-HCH, p,p'-DDT, PCB 31, 28, 52, 74, 66, 101, 110, 149, 114, 141, 187, 156 and 170 were detected in all ringed seals but only partly in bearded seals. Due to co-elution with unknown and/or known components, cis-nonachlor, trans-chlordane, o,p'-DDD, o,p'-DDT, PCB 56, 189, 206 and 209 were excluded from the further analyses.

3.1. OC-concentrations

Both sexes of ringed seals had significantly higher levels of lipid weight concentrations of HCB, $\sum$DDT and $\sum$PCB than both sexes of bearded seals (Table 3). Further, ringed seal females had marginally higher concentrations of $\sum$CHL than bearded seal females (Table 3). Only $\sum$HCH was higher in bearded seals than in ringed seals (Table 3, males vs males).

The concentrations (lw) of some classes of OCs differed between the sexes in bearded seals, HCB, $\sum$CHL, and $\sum$DDT were significantly higher in males than in females, and $\sum$PCB were marginally higher in males than in females (Table 3). In ringed seals, levels of $\sum$DDT tended to be higher in males than in females (Table 3). There were no intersexual differences for any of the other classes of OCs.

3.2. OC-patterns

As shown in Fig. 1, the relative contribution of the different groups of OCs could be ranked as follows: Ringed seal females: $\sum$PCB > $\sum$DDT > $\sum$CHL > $\sum$HCH > HCB > Mirex. Ringed seal males: $\sum$PCB $\geqslant$ $\sum$DDT > $\sum$CHL > $\sum$HCH $\geqslant$

Table 1
Lipid content (%) and concentrations of organochlorine compounds (ng/g) in blood samples from female ($n=6$) and male ringed seals ($n=6$) (*P. hispida*) from Kongsfjorden, Svalbard

Ringed seals						
Compund	Females			Males		
	Mean	S.D.	Median	Mean	S.D.	Median
Lipid %	0.65	0.13	0.62	0.75	0.15	0.74
HCB	17.01	6.68	15.07	14.49	4.37	15.46
α-HCH	44.55	38.92	37.13	32.17	19.41	29.56
β-HCH	5.32	1.30	5.65	5.95	1.45	5.79
γ-HCH	4.67	1.95	4.86	4.24	1.29	4.03
∑HCH	54.54	41.30	48.40	42.35	20.53	40.67
oxy-chlordane	47.23	11.41	50.30	109.16	75.33	76.22
cis-chlordane	20.52	12.89	17.10	34.55	25.58	23.86
trans-Nonachlor	45.95	44.08	26.17	43.25	24.72	34.91
∑CHL	113.68	62.50	97.92	186.96	122.27	139.44
mirex	11.34	6.00	8.83	11.52	4.33	10.09
p,p'-DDE	146.65	39.42	141.13	569.16	514.33	319.97
p,p'-DDD	1.36		1.36	8.16	3.58	7.24
p,p'-DDT	18.07	9.27	15.06	47.77	40.32	29.33
∑DDT	164.95	47.26	153.74	621.01	559.34	351.86
PCB 31	4.58	2.92	3.76	4.05	1.76	4.38
PCB 28	5.88	2.56	5.65	4.25	1.03	4.05
PCB 52	7.15	1.96	7.37	8.89	3.93	7.73
PCB 47	3.54	1.16	3.54	4.23	2.90	3.19
PCB 74	9.33	3.03	9.26	14.55	8.25	9.79
PCB 66	6.32	4.43	4.22	4.93	4.01	4.46
PCB 101	34.35	10.93	28.84	63.36	36.76	50.25
PCB 99	28.13	6.89	27.45	67.14	48.82	44.25
PCB 87	5.51	1.38	5.44	5.31	1.81	5.15
PCB 110	10.90	4.99	9.53	12.55	5.29	13.82
PCB 151	2.31	1.90	1.45	1.99	0.54	1.93
PCB 149	8.77	2.89	7.80	9.19	3.53	7.55
PCB 118	27.33	9.31	25.48	46.40	27.93	46.07
PCB 114	4.99	4.10	3.66	4.85	1.31	4.40
PCB 153	61.66	18.09	61.93	139.24	119.10	78.37
PCB 105	9.55	2.28	8.83	16.90	10.40	16.05
PCB 141	2.10	0.88	1.84	2.85	0.90	2.70
PCB 137	1.64	0.31	1.79	4.00	4.17	1.47
PCB 138	39.25	12.87	38.07	90.46	74.59	54.88
PCB 187	4.87	2.43	3.83	6.64	5.01	4.63
PCB 128	7.55	2.97	6.98	9.51	3.23	8.63
PCB 156	2.61	1.72	1.69	3.83	3.05	2.59
PCB 157	5.37		5.37	2.58	0.29	2.58
PCB 180	28.99	14.18	29.01	62.81	61.89	34.28
PCB 170	8.48	3.73	6.98	20.86	21.88	10.45
PCB 199	5.02	0.95	5.49	6.08	1.37	5.52
PCB 196	4.26	0.92	3.93	6.64	4.05	5.67
PCB 194	6.06	1.08	5.71	8.50	6.08	6.15
∑PCB	336.68	95.05	304.89	624.81	443.04	429.37

HCB ⩾ Mirex. Bearded seal females: ∑PCB > ∑HCH ⩾ ∑CHL > ∑DDT > Mirex > HCB. Bearded seal males: ∑PCB > ∑DDT ⩾ ∑CHL > ∑HCH > Mirex ⩾ HCB.

3.3. Class specific patterns

α-HCH was the major contributor to ∑HCH in both species. α-HCH/∑HCH was lower in ringed seals than

Table 2
Lipid content (%) and concentrations of organochlorine compounds (ng/g) in blood samples from female ($n = 6$) and male bearded seals ($n = 6$) (*E. barbatus*) from Kongsfjorden, Svalbard

Bearded seals						
Compund	Females			Males		
	Mean	S.D.	Median	Mean	S.D.	Median
Lipid %	0.39	0.13	0.38	0.39	0.12	0.39
HCB	4.74	2.55	4.32	9.34	1.24	9.85
α-HCH	63.22	46.01	54.32	76.20	20.50	71.34
β-HCH	2.59		2.59	2.88	0.64	2.55
γ-HCH	3.06	0.78	2.78	2.27	0.40	2.46
∑HCH	66.70	46.38	57.15	79.29	18.53	73.90
oxy-chlordane	15.26	14.97	9.76	37.58	6.38	36.17
cis-chlordane	8.49	5.13	6.12	18.04	5.41	15.29
trans-Nonachlor	33.85	22.48	24.99	77.23	18.19	71.36
∑CHL	57.60	42.30	40.31	132.85	29.04	119.78
mirex	12.85	3.83	12.86	10.44	3.43	9.23
p,p′-DDE	44.00	37.62	24.99	155.99	70.35	133.82
p,p′-DDD	n.d.			n.d.		
p,p′-DDT	4.69	3.80	2.59	6.43	2.85	6.13
∑DDT	46.34	41.02	26.08	161.13	71.21	137.43
PCB 31	n.d.			n.d.		
PCB 28	n.d.			3.37	1.50	2.55
PCB 52	3.50	2.65	3.50	3.54	1.52	3.54
PCB 47	n.d.			n.d.		
PCB 74	4.78	3.73	2.87	6.45	2.56	7.39
PCB 66	n.d.			4.27	0.93	4.27
PCB 101	5.11	4.04	4.03	8.24	1.41	7.65
PCB 99	15.28	14.88	10.57	21.79	6.30	20.39
PCB 87	4.32	1.50	4.32	n.d.		
PCB 110	n.d.			n.d.		
PCB 151	n.d.			n.d.		
PCB 149	4.03	3.52	2.40	5.03	0.30	5.10
PCB 118	15.96	15.00	10.57	30.70	15.57	28.03
PCB 114	2.73	0.37	2.64	n.d.		
PCB 153	32.06	33.88	17.66	60.40	29.22	50.63
PCB 105	3.54	2.75	2.64	7.37	4.15	7.39
PCB 141	2.21	0.51	2.40	2.79	0.55	2.55
PCB 137	3.18	1.18	2.59	3.04	1.05	2.55
PCB 138	20.06	21.57	10.26	40.22	19.56	34.36
PCB 187	0.86		0.86	2.80	1.06	2.55
PCB 128	7.03	3.40	5.55	9.60	2.55	9.04
PCB 156	3.57	1.37	3.57	2.85	0.54	2.85
PCB 157	5.19		5.19	n.d.		
PCB 180	26.48	27.38	15.23	26.70	13.68	20.38
PCB 170	12.20	8.48	8.13	9.39	3.14	9.85
PCB 199	6.32	1.97	5.28	6.41	1.44	6.53
PCB 196	5.19		5.19	n.d.		
PCB 194	6.37	2.58	6.58	6.10	2.28	5.10
∑PCB	159.14	131.70	105.25	247.58	93.02	203.87

in bearded seals (Table 4). In males, both β-HCH/∑HCH and γ-HCH/∑HCH were higher in ringed seals than in bearded seals (Table 4). The only inter-sex difference found was a higher γ-HCH/∑HCH ratio in males of bearded seal compared to females ($Z = -2.01$, $p = 0.044$).

∑DDT consisted mainly of p,p'-DDE in both species but p,p'-DDE contributed significantly more to ∑DDT

Table 3
Levels of significance with respect to differences in concentrations of groups organochlorine compounds in blood between ringed (*P. hispida*) and bearded seals (*E. barbatus*)

Compound	Ringed females vs bearded females		Ringed males vs bearded males		Ringed males vs ringed females		Bearded males vs bearded females	
	$\|Z\|$	p	$\|Z\|$	p	$\|Z\|$	p	$\|Z\|$	p
Lipid%	2.40	0.016	2.56	0.011				
HCB	2.88	0.004	2.01	0.045			2.56	0.011
$\sum$HCH			2.37	0.018				
$\sum$CHL	1.92	0.055					2.19	0.028
$\sum$DDT	2.56	0.011	2.19	0.028	1.92	0.055	2.37	0.018
$\sum$PCB	2.24	0.025	2.01	0.045			1.83	0.068

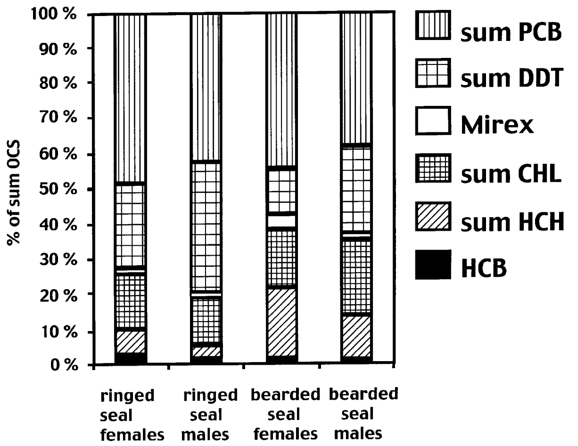

Fig. 1. Relative contribution of the different classes of OCs to $\sum$OCs in blood of ringed (*P. hispida*) and bearded seals (*E. barbatus*) from Kongsfjorden, Svalbard.

in bearded seals than in ringed seals (Table 4). Conversely, the p,p'-DDT contributed significantly more to $\sum$DDT in ringed seals than in bearded seals (Table 4). In ringed seal females and males the median (range) p,p'-DDE/DDT ratio was 0.90 (0.86–0.93) and 0.92 (0.90–0.93), respectively, whereas in bearded seal females and males it was 0.98 (0.90–1.00) and 0.97 (0.94–0.99), respectively.

With respect to PCBs, the mono-ortho-biphenyl PCB 118, and the di-ortho-biphenyls PCB 101, 99, 153, 138 and 180 made up 65–70% of $\sum$PCB lw in both species. However, in bearded seals, the contribution of PCB 101 was lower, and that of PCB 170 higher than in ringed seals.

To compare the distribution pattern of PCBs between the species and sexes, the concentrations of all congeners were expressed relative to PCB 153 (Fig. 2). PCB 153 was regarded as a relevant reference component because it was present in all samples well above the quantification limit and because it is one of the most persistent PCBs (Boon et al., 1992). The normalised values of PCB 101, 99, 128, 180, 199 and 194 differed significantly between the two species (Fig. 2, Table 5). The relative values of PCB 101 were significantly higher in ringed seals than in bearded seals. In addition, PCB 99 was significantly higher in males of ringed seal compared to male bearded seal male. PCB 128, 180 and 199 were significantly higher in females of bearded seals compared to females of ringed seals. Furthermore, PCB 194 was significantly higher in males of bearded seals than in males of ringed seals.

When comparing the two sexes, the relative values (lw) of congeners PCB 149, 187 and 94 were significantly higher in ringed seal females than in males. In bearded seals, PCB 128 and 180 were significantly more abundant in females than in males (Table 5).

4. Discussion

Factors such as the animals' nutritional condition, age and sex, as well as the tissue chosen for analysis, will

Table 4
Levels of significance with respect to differences in relative concentrations of some organochlorine groups in blood between ringed (*P. hispida*) and bearded seals (*E. barbatus*)

Compund	Ringed females vs bearded females		Ringed males vs bearded males	
	$\|Z\|$	p	$\|Z\|$	p
α-HCH/$\sum$HCH	2.75	0.006	1.92	0.055
β-HCH/$\sum$HCH			2.75	0.006
γ-HCH/$\sum$HCH			2.75	0.006
p,p'-DDE/$\sum$DDT	2.41	0.016	2.74	0.006
p,p'-DDT/$\sum$DDT	2.41	0.016	2.74	0.006

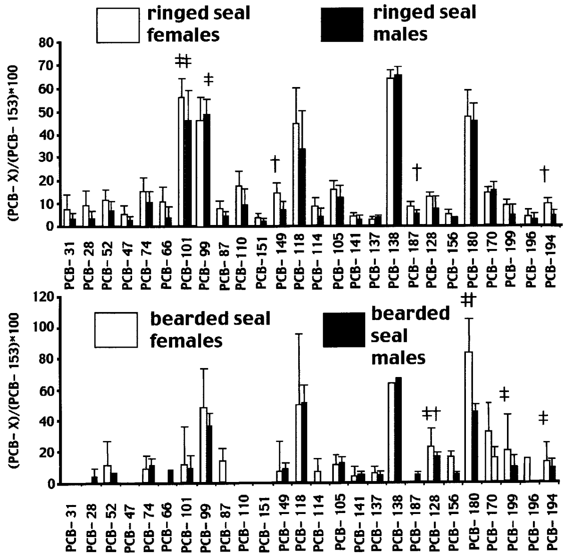

Fig. 2. PCB congeners relative to PCB 153 in blood of ringed (*P. hispida*) and bearded seals (*E. barbatus*) from Kongsfjorden, Svalbard. Ratios are presented as mean and standard deviation. † annoates significant differences between sexes. ‡ annoates significant differences between species (same sex). The sample size is 6 in both sexes of ringed seals, except for PCB-47 which was only detected in two females. In bearded seal females the sample size is 6, except for PCB 196 which was detected in only one female, and for PCB-52, -87 and -156 which were detected in two females. In bearded seal males, the sample size is 5, except for PCB-52, -66, and -156 which only were detected in two males. See Table 5 for exact levels of significance between the groups.

affect the concentration of OCs reported in different studies. Comparison of exposure levels between studies should therefore be carried out with care. However, studies indicate that concentrations of ∑DDT and ∑PCB in blood can be regarded as rough estimates of blubber concentrations (Boon et al., 1987; Reddy et al., 1998). Thus, as indicated in Table 6, the concentrations of OCs in whole blood of ringed and bearded seals seem to be similar to levels reported in the North-American Arctic. However, compared to the concentrations previously reported in blubber of these species at Svalbard, they are in the lower range (Table 6).

Among the six different groups of OCs analysed in ringed and bearded seals, the dominating OC contaminants were PCBs, DDTs, CHLs and HCHs. This pattern is previously reported in ringed seals from the Canadian high Arctic, Greenland and the Kara Sea (Muir et al., 1992; Nakata et al., 1997, Cleeman et al., 2000b). Mirex represented only a small part of ∑OC, which is consistent with corresponding data from the Canadian Arctic (Cameron et al., 1997).

The most abundant PCB congeners in ringed and bearded seals were those containing five to seven Cl atoms. Mono-ortho and di-ortho congeners contributed up to 65–70% to ∑PCB. p,p'-DDE was the main DDT-related compound in both species. This is in agreement with other studies of marine mammals in the northern hemisphere (Muir et al., 1988). The p,p'-DDE/∑DDT ratios in bearded and ringed seals ranged from 0.86 to 1.00. As expected, this shows that there are no local sources of DDT entering the Kongsfjorden ecosystem.

α-HCH was the main contributor to ∑HCH in both ringed and bearded seals. α-HCH is a major component in technical mixtures and has a higher vapour pressure than the other isomers (Kucklick et al., 1991) and is thus transported to remote areas to a greater extent. It can be concluded that the OC pattern clearly shows that there are few or no local sources of OC contamination in the Kongsfjorden ecosystem.

Bearded seals are first level predators in the Arctic ecosystem, primarily feeding on benthic organisms (Hjelseth et al., 1999), while ringed seals are second level predators feeding mainly on a more lipid rich diet consisting of Arctic cod (*Boreogadus saida*) and pelagic crustaceans (Weslawski et al., 1994). It has been shown that strong relationships exist between the trophic position of Arctic marine organisms and their body bur-

Table 5
Levels of significance with respect to differences in relative concentrations of some PCB congeners in blood between ringed (*P. hispida*) and bearded seals (*E. barbatus*)

Compound	Ringed females vs bearded females		Ringed males vs bearded males		Ringed males vs ringed females		Bearded males vs bearded females	
	$\|Z\|$	p	$\|Z\|$	p	$\|Z\|$	p	$\|Z\|$	p
101/153	2.01	0.045	2.75	0.006				
99/153			2.01	0.045				
149/153					2.19	0.028		
187/153					2.09	0.037		
128/153	2.73	0.006					2.02	0.044
180/153	2.88	0.004					2.78	0.006
199/153	2.56	0.011						
194/153			2.56	0.011	2.81	0.005		

Table 6
Organochlorines in ringed seals (*P. hispida*) and bearded seals (*E. barbatus*) from Svalbard, Norway

Location	Mnd.	Year	Tissue	*N*	Sex	Organochlorine concentration (ng/g lw) range or mean									References
						HCB	α-HCH	∑HCH	∑CHL	*pp*′-DDE	∑DDT	mirex	PCB-153	∑PCB	
Ringed seals (P. hispida)															
West coast of Svalbard	x	1980	Blubber	1	x						5000			10 000	Andersson et al. (1988)
Hornsund	September/ October	1984	Blubber	5	x	9–16	54–140	60–154		330–470	510–750			490–820	Carlberg and Bøler (1985)
Kongsfjorden	March/ April	1986	Blubber	4	M	10–35	86–165			596–2081			176–598		Oehme et al. (1988, 1990)
Kongsfjorden	March/ April	1986	Blubber	3	F	15–34	106–198			632–2266			211–617		–
Kongsfjorden	March/ April	1986	Blubber	7	x	10–35		139.5			1657			1270–5050	Oehme et al. (1990)
Kongsfjorden/ Tempelfjorden	March/ April	1990	Blubber	5	M					880–3790				942–3460	Daelemans et al. (1993)
Kongsfjorden/ Tempelfjorden	March/ April	1990	Blubber	4	F					332–1305				539–1208	–
Kongsfjorden	March/ April	1990	Blubber (I)[a]	4	M					2400				2800	Severinsen et al. (1995)
Kongsfjorden	March/ April	1990	Blubber (O)[b]	4	M					3400				4500	–
Kongsfjorden	March/ April	1990	Blubber (I)[a]	4	F					750				1400	–
Kongsfjorden	March/ April	1990	Blubber (O)[b]	4	F					950				1500	–
Kongsfjorden	May	1996	Blubber	7	M								496–896		Wolkers et al. (1998)
Kongsfjorden	May	1996	Blubber	7	F								477–365		–
Kongsfjorden	May	1994/ 1996	Whole blood	6	M	9–21	12–56	21–65	85–407	169–1276	182–1395	8–19	50–325	258–1300	Present study
Kongsfjorden	May	1994/ 1996	Whole blood	6	F	11–29	12–111	18–123	59–237	103–199	111–225	6–21	41–87	233–468	–
Bearded seals (E. barbatus)															
Hornsund	September/ October	1984	Blubber	2[c]	x	9–11	35–43	37–46		720–740	930–960			1100	Carlberg and Bøler (1985)
Kongsfjorden	May	1994/ 1996	Whole blood	5	M	7–10	56–111	62–111	102–170	97–272	97–277	7–16	38–111	171–405	Present study
Kongsfjorden	May	1994/ 1996	Whole blood	6	F	2–9	5–141	8–146	31–141	23–118	23–128	8–18	12–100	83–422	–

[a] (I) – Inner part of blubber sample.
[b] (O) – outer part of blubber sample taken from the back.
[c] One was found dead.

dens of ∑PCB and ∑DDT (Hargrave et al., 1992; de March et al., 1998). Thus, the higher concentrations (lw) of these OC-groups in ringed seals can be explained by the higher trophic position that ringed seals occupy in the food web compared to bearded seals.

HCHs were the only group of OCs which were present in higher concentrations in bearded seals than in ringed seals. Even though the difference only was noticeable in males, it is consistent with reports that HCH-concentrations seem to decrease as a function of trophic level (Hargrave et al., 1992). Furthermore, the higher β-HCH/∑HCH found in male ringed seals compared to male bearded seals is consistent with reports that the contribution of β-HCH increases as a function of trophic level (Borgaa et al., 1997).

There were also differences in the relative composition of some PCB-congeners between the two species. Compared to bearded seals, ringed seals had higher relative concentrations of the pentachloro substituted PCBs 101 and 99, and lower relative concentrations of the hexachloro substituted PCB 128, 180, 199, and 194. It has been shown that in Arctic cod, which constitutes a substantial part of the prey of ringed seals, PCB 101 constitutes a relatively high proportion of ∑PCB as compared to in mussels (Cleemann et al., 2000a), which is the main prey of bearded seals. On the contrary, the relative concentration of PCB 180 is higher in mussels than in the Polar cod (Cleemann et al., 2000a). The differences in the relative composition of these PCB-congeners between the two seal species are therefore probably primarily related to the composition of OCs in their prey.

In bearded seals, concentrations of most OCs were significantly higher in males than in females. This is in agreement with results from previous studies on seals (Addison and Smith, 1974), and is attributed to the females′ ability to excrete OCs via their lipid rich milk (Addison and Brodie, 1977, 1987). However, for the ringed seal samples, no significant inter-sex differences were found for any OCs. This is in accordance with results reported by Wolkers et al. (1998) but in contrast to reports from other studies of this species (Addison and Smith, 1974; Cameron et al., 1997). As suggested by Wolkers et al. (1998), it is possible that our results are related to that ringed seals feed during lactation.

In males of both species, the ∑DDT/∑OC was higher than in females (see Fig. 1). This is in agreement with previous findings in grey seals, harp seals (*Phoca groenlandica*) and hooded seals (*Cystophora cristata*) (Addison and Brodie, 1977, 1987; Espeland et al., 1997), and is probably due to a larger maternal transfer of DDT to the pup compared to PCBs as the other major OC-group. Females of both species which had high contribution of some highly chlorinated and persistent PCB congeners (hexa- to octa-chlorinated; PCB 149, 187 and 194 in ringed seals; PCB 128 and 180 in bearded seals; Fig. 2). This is probably linked to a selective barrier against transfer of persistent PCBs from blood to the mammary gland (Addison and Brodie, 1987).

In conclusion, levels of the OCs reported in ringed and bearded seals were in the lower range of previously reported concentrations in these species at Svalbard. The higher concentration of most OCs in ringed seals compared to bearded seals are caused by a higher trophic position of ringed seals in the Svalbard ecosystem compared to bearded seals. The observed inter-sex differences is most likely related to excretion of OCs to offspring via milk.

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