Fish	Area	ΣPCB 15	HCB	ΣHCH	ΣCHLOR
Freshwater species					
Burbot	Kola Peninsula, n=4	3.7 (2.4-5.7)	0.04 (<0.05-0.080)	0.18 (<0.05-0.36)	0-0.27[a]
	Taymir, west, n=6	4.8 (3.6-5.7)	0.095 (<0.05-0.18)	0.05-0.16[a]	<0.25
	Taymir, east, n=4	2.1 (1.8-2.3)	0.082 (<0.05-0.14)	0.05-0.25[a]	<0.25
Pike	Kola Peninsula, n=4	1.4 (1.2-1.7)	0.079 (0.070-0.10)	0.20 (0.13-0.21)	0-0.29[a]
	Chukotka, inland, n=6	2.3 (1.2-3.9)	0.072 (<0.05-0.25)	0.05-0.22[a]	<0.25
Perch	Pechora basin, n=3	0.6-1.6[a]	0.071 (0.050-0.090)	0.37 (0.19-0.66)	<0.25
Ide	Pechora basin, n=5	1.8 (1.4-2.1)	0.26 (0.18-0.38)	0.59 (0.51-0.74)	0.06-0.53[a]
Salmon species					
Whitefish	Kola Peninsula, n=4	2.3 (2.0-2.5)	0.074 (0.050-0.11)	0.42 (0.37-0.48)	0.14-0.32[a]
	Pechora basin, n=5	2.0 (1.6-2.5)	0.15 (<0.05-0.27)	0.20 (0.10-0.36)	0-0.63[a]
	Taymir, west, n=4	3.2 (2.3-6.2)	0.25 (0.20-0.32)	0.05-0.33[a]	0.23-0.58[a]
	Taymir, east, n=6	3.1 (2.1-3.7)	0.20 (0.15-0.25)	0.31 (0.21-0.37)	1.4 (0.96-2.1)
Arctic cisco	Taymir, west, n=4	3.7 (3.0-4.6)	0.062 (<0.05-0.17)	0.34 (0.17-0.50)	0.81 (0.42-1.3)
Broad Whitefish	Taymir, east, n=6	2.7 (1.6-3.8)	0.11 (0.090-0.17)	0.05-0.35[a]	0.91 (0.39-2.0)
	Chukotka, inland, n=2	1.4 (1.3-1.5)	0.075 (0.070-0.080)	0.26 (0.23-0.30)	0-0.28[a]
Inconnu	Chukotka, inland, n=2	1.4 (1.3-1.5)	0.094 (0.080-0.11)	0.05-0.47[a]	0-0.31[a]
Arctic grayling	Chukotka, cost, n=2	2.1 (2.0-2.2)	0.16 (0.15-0.17)	0.22 (0.19-0.24)	0.60 (0.50-0.71)

Table 5.21a. Concentrations (geometric mean and range; ng/g wet weight) of OCs in fish muscle in the Russian Arctic in 2001.
[a] More than half of concentrations were below the detection limit in at least 50% of the samples. In such cases, when lower and upper limits of the concentration interval were estimated, concentrations below the detection limits was set to zero or to the detection limit, respectively.

of all species are comparable. The high lipid concentration of burbot liver makes it a popular component of the diet of indigenous peoples.

(b) Heavy metals

Concentrations of HMs are similar in male and female fish of each species. Concentrations measured in the oldest fish groups are, on average, twice as high as in the corresponding youngest age group, whereas the mid-age/young-age group ratio is equal to 1.2. These values are consistent with ratios of mean ages in the groups, i.e., even for relatively old fishes, HM contamination levels are close to being proportional to age. Examples of Hg concentration dependence on fish age for those sites with the maximum number of sample age groups are given in Figure 5.21. Effective rates of HM accumulation in fish species are given in Table 5.20. For Pb they are comparable with those found in reindeer tissues, whilst for Hg and particularly Cd, rates are lower.

Concentrations of HMs in the liver of all species is higher than that in the muscle. The liver/muscle concentration ratios are similar for all species within a fish group and show no significant relationship to site. Geometric means of the liver/muscle concentration ratios for Hg, Pb and Cd in freshwater species are equal to 2.0, 2.8 and 4.8, respectively. For salmon species these values are somewhat higher (2.4, 8.6 and 7.5, respectively).

Levels and trends

(a) Organochlorines

OC concentrations in fish muscle are shown in Tables 5.21a and 5.21b. Concentrations of all OCs that were found at detectable levels are broadly similar for both salmon and freshwater groups, although slightly higher concentrations were found in salmon species. No pronounced geographic trend was found for any OC. All concentrations in muscle were below the corresponding MPCs established in Russia for freshwater fish (0.03 mg/kg for ΣHCH, and 0.3 mg/kg for ΣDDT) as well as those for sea fish. Most OC levels are comparable with those detected in reindeer. The only exception to this concerned concentrations of ΣDDT, which are several times higher in fish. Mean OC con-

Fish	Area	*p,p'*-DDE	*p,p'*-DDT	ΣDDT	Mirex
Freshwater species					
Burbot	Kola Peninsula, n=4	0.34 (0.07-0.93)	<0.05-0.70	0.07-0.26	<0.05-0.13
	Taymir, west, n=6	0.62 (0.42-0.89)	0.071 (<0.05-0.13)	0.66-1.4a	0.07 (<0.05-0.15)
	Taymir, east, n=4	<0.05-0.10[a]	0.089 (<0.05-0.20)	0.14-0.65a	<0.05
Pike	Kola Peninsula, n=4	0.39 (0.22-0.61)	0.28 (0.16-0.34)	0.38-1.2a	<0.05
	Chukotka, inland, n=6	<0.05	<0.05-0.20	0-0.64a	<0.05
Perch	Pechora basin, n=3	0.32 (0.19-0.75)	0.39 (0.36-0.48)	0.28 (0.67-1.5)	<0.05
Ide	Pechora basin, n=5	0.58 (0.33-0.96)	0.14 (0.10-0.20)	1.3 (0.83-2.0)	<0.05
Salmon species					
Whitefish	Kola Peninsula, n=4	1.1 (0.85-1.25)	0.31 (0.25-0.40)	1.9 (1.6-2.0)	<0.05
	Pechora basin, n=5	0.43 (0.30-0.70)	0.54 (0.35-0.70)	1.6 (1.4-1.9)	<0.05
	Taymir, west, n=4	0.85 (0.59-1.1)	0.33 (0.25-0.47)	2.2 (2.0-2.5)	<0.05
	Taymir, east, n=6	0.61 (0.52-1.0)	1.5 (1.0-2.0)	2.5 (1.7-3.3)	<0.05
Arctic cisco	Taymir, west, n=4	1.0 (0.62-2.0)	0.53 (0.35-0.75)	1.9 (1.1-3.2)	<0.05
Broad Whitefish	Taymir, east, n=6	0.44 (0.25-0.60)	0.59 (0.41-0.96)	1.3 (0.77-2.0)	<0.05
	Chukotka, inland, n=2	0.31 (0.22-0.43)	0.23 (0.17-0.30)	0.72 (0.68-0.76)	<0.05
Inconnu	Chukotka, inland, n=2	0.38 (0.35-0.41)	0.24 (0.20-0.29)	1.0 (0.9-1.1)	<0.05
Arctic grayling	Chukotka, cost, n=2	1.8 (1.3-2.5)	1.4 (1.0-1.8)	4.2 (3.9-4.6)	<0.05

Table 5.21b Concentrations (geometric mean and range; ng/g wet weight) of OCs in fish muscle in the Russian Arctic in 2001.
[a] More than half of concentrations were below the detection limit in at least 50% of the samples. In such cases, when lower and upper limits of the concentration interval were estimated, concentrations below the detection limits was set to zero or to the detection limit, respectively.

centrations in muscle of whitefish species from three lakes in the Canadian Arctic in 1993–1999 ranged from 4.7 to 24.7 ng/g for ΣPCB (102 congeners), from 0.32 to 2.66 ng/g for ΣHCH, from 1.7 to 9.0 ng/g for ΣCHLOR, and from 1.9 to 24.6 ng/g for ΣDDT (all – in ww) (CACAR, 2003). In comparison with the Canadian data, Figure 5.22, the upper limit of concentration ranges for whitefish species in the Russian North in 2001 coincides with the lower limit of the concentration ranges calculated for whitefish in Canada. The upper limits of concentration ranges for all OCs from the Canadian studies are several times higher than those seen in the Russian Arctic. In comparison with results from studies in northern Scandinavia, however, contamination levels in Russia are reasonably similar to concentrations measured in lake whitefish at three Norwegian sites in 1994 (0.5–1.6 ng/g for the sum of 6 PCB congeners; 0.10–0.12 ng/g for ΣHCH; 0.03–0.23 ng/g for ΣCHLOR; and 0.15-0.63 ng/g for ΣDDT), and also with concentrations measured in Arctic char in Finland (AMAP, 1998).

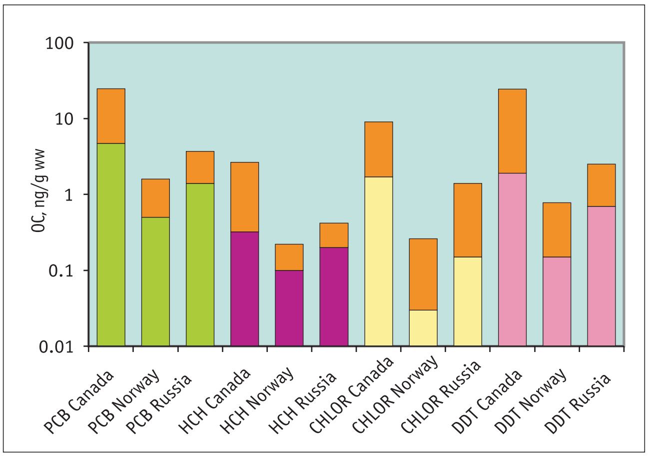


Figure 5.22 Comparison of mean OC concentrations in whitefish species in the Canadian Arctic (1993-1999), Norway (1994), and Russia (2001). The lower part of each column corresponds to the minimum mean concentration, and the total column height, to the maximum mean concentration. PCB=ΣPCB_{15}, HCH=ΣHCH, CHLOR=ΣCHLOR, DDT=ΣDDT

Samples of fish tissues were also analysed for other OCs, listed in Section 1.2.4. In the majority of samples, all other OCs were below detection limits. Only Heptaclor was found in few samples of burbot and whitefish liver and in broad whitefish muscle in concentrations close to the detection limit of 0.05 ng/g ww.

(b) PCDD/Fs

Concentrations of 2,3,7,8-substituted PCDD/Fs were analyzed in pooled fish muscle samples. Results are presented in Table 5.22 and Figure 5.12. PCDD/Fs in fish species follow a similar, but less pronounced, geographical distribution to that seen in reindeer. All concentrations are far below the maximum permissible levels associated with consumption of meat.

Levels of PCDD/Fs found in this study (0.03-0.2 WHO-TEQ/g) were of an order of magnitude lower than in fish muscle samples from the Grate Slave Lake in northern Canada in 1994/5 (0.6-1.1 WHO-TEQ/g; CACAR, 2003). PCDD/Fs concentrations in lake whitefish sampled in Norwegian lakes (1994) were even higher (5.3 ng I-TEQ/g). At four other sites in Scandinavian countries, however, PCDD/F levels in fish muscle were more comparable with those measured in the Russian North in 2001 (0.05-0.09 and 0.02-0.15 ng I-TEQ/g, respectively; AMAP, 1998).

Sample type	Area	pg WHO-TEQ/g ww	pg WHO-TEQ/g lipids	pg WHO-TEQ/pg*
		Freshwater species		
Pike	Kola Peninsula	0.089	14	0.12
Ide	Pechora basin	0.031	0.96	0.046
		Salmon species		
Whitefish	Kola Peninsula	0.13	13.8	0.120
	Pechora basin	0.060	1.5	0.077
	Taymir, west	0.027	1.6	0.063
	Taymir, east	0.050	2.4	0.130
Broad whitefish	Taymir, east	0.041	2.6	0.088
	Chukotka, inlanc	0.025	2.3	0.070

Table 5.22. Concentrations (expressed as TEQ) of PCDD/Fs in fish muscle the Russian Arctic in 2001.
* – ratio of PCDD/F concentration in pg WHO-TEQ/pg to that in pg/g

Fish	Area	NAP	NAP2M	FLE	PA	FLU
			Freshwater species			
Burbot	Kola Peninsula, n=4	105 (93-114)	25 (21-28)	5.5 (3.7-7.0)	14 (14-15)	4.2 (3.4-5.5)
	Taymir, west, n=6	77 (72-96)	37 (28-45)	5.1 (3.8-6.3)	11 (9.6-13)	3.1 (2.1-6.0)
	Taymir, east, n=4	67 (59-82)	53 (43-61)	5.4 (3.6-6.7)	14 (13-15)	4.9 (3.1-7.1)
Pike	Kola Peninsula, n=4	9.9 (8.1–12)	4.6 (4.0-6.6)	2.6 (2.1-3.8)	3.2 (1.6-4.9)	<0.5-1.2
	Chukotka, inland, n=6	52 (22-130)	24 (9.6-41)	4.3 (3.2-5.4)	10 (6.5-16)	3.3 (1.1-6.4)
Perch	Pechora basin, n=3	50 (28-67)	16 (12-16)	3.3 (2.0-4.5)	3.3 (1.2-5.6)	1.3 (1.1-1.5)
Ide	Pechora basin, n=5	37 (31-44)	6.2 (4.8-7.3)	2.0 (1.1-2.3)	2.7 (2.2-3.7)	0.95 (0.48-1.4)
			Salmon species			
Whitefish	Kola Peninsula, n=4	52 (42–61)	11 (8.6-15)	2.4 (1.9-3.0)	3.0 (2.4-3.9)	<0.5-1.3
	Pechora basin, n=5	55 (38-68)	18 (15-21)	<0.5-4.2	<0.5-5.6	<0.5-1.4
	Taymir, west, n=4	71 (69-73)	31 (22-41)	3.2 (2.6-4.4)	5.4 (4.5-6.1)	1.5 (1.3-1.9)
	Taymir, east, n=6	66 (43-80)	31 (21-39)	3.2 (1.8-5.4)	5.4 (3.6-7.8)	0.70 (<0.25-2.6)
Arctic cisco	Taymir, west, n=4	57 (45-66)	11 (7.5-16)	2.6 (1.2-4.5)	2.8 (1.8-4.2)	<0.5-1.1
Broad Whitefish	Taymir, east, n=6	26 (15-42)	16 (11-21)	4.8 (3.1-7.8)	3.0 (1.7-6.0)	<0.5-1.0
	Chukotka, inland, n=2	41 (37-48)	6.0 (4.8-7.4)	2.7 (2.5-2.9)	3.4 (3.0-3.9)	1.0 (1.0-1.0)
Inconnu	Chukotka, inland, n=2	39 (30-50)	17 (13-21)	4.1 (3.6-4.8)	4.0 (3.7-4.3)	1.0 (1.0-1.1)
Arctic grayling	Chukotka, cost, n=2	53 (44-64)	15 (12-18)	4.4 (4.3-4.5)	4.0 (3.6-4.5)	1.2 (1.0-1.4)

Table 5.23. Concentrations (geometric mean and range; ng/g ww) of PAHsa in muscle of fish species in the Russian Arctic.
[a] NAP = Naphthalene, NAP2M = 2-Methylnaphthalene, FLE = Fluorene, PA= Phenanthrene, FLU = Fluoranthene

(c) PAHs

The geometric means and ranges of PAH concentrations in the muscle of fish species in the Russian Arctic are given in Table 5.23. PAH levels in fish, in contrast to OCs, are higher than those in waterfowl, including the piscivores. The distribution of PAH between tissues is also very different from that of OCs. For example, the OC concentration in liver tissue in burbot can be several hundred times higher than that in muscle, while PAH levels in both of these tissues are comparable. No geographic trend in PAH levels in fish is apparent, although concentrations in pike from inland Chukotka are several times higher than those on the Kola Peninsula. However, for other fish species there are no noticeable differences between Chukotka and other regions.

(d) Brominated flame-retardants

Samples of fish tissues were analysed for 2,2',4,4'-tetrabromodiphenyl, 2,2',4,4',5-pentabromodiphenyl, 2,2',4,4'-tetrabromodiphenyl ether and 2,2',4,4',5-pentabromodiphenyl ether. In the majority of samples, concentrations were below the detection limit of 0.2 ng/g ww. Only 2,2',4,4'-tetrabromodiphenyl ether was found at higher levels in a few samples of fish liver (see Table 5.24).

(e) Heavy metals

No pronounced geographic trends are apparent in the levels of HMs in fish (see Table 5.25), although Hg concentrations measured on the Kola Peninsula are consistently higher than at other sites. Hg and Cd concentrations are generally comparable in all species at all sites, apart from relatively low Cd levels occurring in Arctic grayling. Pb levels are, as a rule, somewhat higher in freshwater species. All concentrations, with one exception, are significantly below the relevant MPCs (of 0.6 mg/kg for Hg, 0.2 mg/kg for Cd, and 1.0 mg/kg for Pb), established in Russia for predatory fish. The exception is Hg in whitefish from the Khatanga River, the concentration of which exceeds permissible limits by a factor of 1.5.

No significant difference was observed in Cd and Pb levels in caregonids in the Russian North between 1995 and 2001. Levels of Hg in these species in the Yenisey and Khatanga Rivers were higher in 2001 than in 1995, while Hg levels reported for whitefish caught in the Pechora River in 1995 (AMAP, 1998) are comparable with those measured in 2001. Hg levels in species in the Russian North are also consistent with results from the Canadian Arctic. Mean concentrations of Hg in whitefish species in Canadian lakes in 1996-2000 ranged from 0.03 to 0.35 µg/g (CARCAR, 2003), and those in Russian lakes and rivers in 2001 from 0.055 to 0.15 µg/g. These concentrations are also similar to those found in fish in northern Norway in 1995 (AMAP, 1998).

Area	Species	Number of samples analyzed	Number of samples with detectable levels	Concentration
Kola Peninsula	Whitefish	4	1	0.28
Kola Peninsula	Pike	4	2	0.23-0.31
Pechora basin	Perch	3	1	0.3
Pechora basin	Ide	4	1	0.23
Chukotka, inland	Pike	6	4	0.22-0.27
Chukotka, inland	Inconnu	2	2	0.34-0.42

Table 5.24. Concentrations (ng/g ww) of 2,2',4,4'-tetrabromodiphenyl ether in liver of fish in the Russian Arctic in 2001.

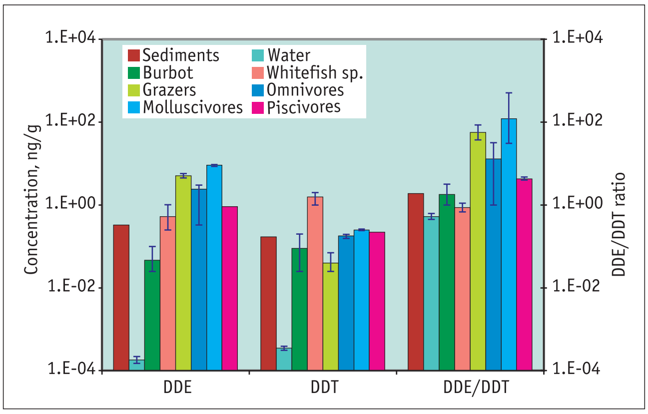


Figure 5.23. Absolute and relative levels of *p,p'*-DDE and *p,p'*-DDT in aquatic food chains in the Khatanga area. Geometric means and ranges of DDE and DDT levels in sediments are given on a dry weight basis, while levels in the muscle of birds and fish are on a wet weight basis. Ratios are shown with 95% confidence limits.

Fish	Area	Hg	Pb	Cd
Burbot	Kola Peninsula, n=4	0.16 (0.12-0.18)	0.045 (0.037-0.063)	0.032 (0.022-0.045)
	Taymir, west, n=6	0.11 (0.10-0.13)	0.15 (0.10-0.27)	0.032 (0.016-0.061)
	Taymir, east, n=4	0.089 (0.07-0.11)	0.033 (0.010-0.081)	0.046 (0.030-0.115)
Pike	Kola Peninsula, n=4	0.16 (0.13-0.18)	0.11 (0.09-0.14)	0.034 (0.028-0.039)
	Chukotka, inland, n=6	0.057 (0.024-0.12)	0.18 (0.12-0.25)	0.028 (0.015-0.029)
Perch	Pechora basin, n=3	0.096 (0.072-0.13)	0.16 (0.15-0.17)	0.034 (0.030-0.041)
Ide	Pechora basin, n=5	0.067 (0.054-0.082)	0.031 (0.027-0.034)	0.024 (0.018-0.031)
Whitefish	Kola Peninsula, n=4	0.15 (0.12-0.18)	0.037 (0.029-0.052)	0.035 (0.029-0.047)
	Pechora basin, n=5	0.055 (0.051-0.059)	0.015 (0.012-0.018)	0.020 (0.016-0.037)
	Taymir, west, n=4	0.078 (0.061-0.099)	0.037 (0.029-0.052)	0.022 (0.013-0.026)
	Taymir, east, n=6	0.15 (0.07-0.95)	0.017 (0.005-0.042)	0.014 (0.010-0.021)
Arctic cisco	Taymir, west, n=4	0.039 (0.025-0.052)	0.021 (0.018-0.024)	0.014 (0.011-0.016)
Broad Whitefish	Taymir, east, n=6	0.079 (0.055-0.12)	0.0087 (0.0047-0.015)	0.019 (0.006-0.058)
	Chukotka, inland, n=2	0.11 (0.07-0.14)	0.013 (0.010-0.018)	0.018 (0.010-0.032)
Inconnu	Chukotka, inland, n=2	0.032 (0.025-0.042)	0.092 (0.088-0.096)	0.11 (0.10-0.11)
Arctic grayling	Chukotka, cost, n=2	0.077 (0.065-0.090)	0.017 (0.013-0.021)	0.0035 (0.0030-0.0041)

Table 5.25. Concentrations (geometric mean and range; µg/g ww) concentrations of HMs in the freshwater fish muscle in the Russian Arctic in 2001.

5.4.2. PTS transfer in the freshwater food chain

(a) Organochlorines

The major link in the contamination of many aquatic food chains by OCs, is their transfer from water to fish. As an example of *p,p'*-DDT and *p,p'*-DDE uptake patterns in freshwater aquatic food chains, Figure 5.23 shows levels of these contaminants in fish muscle and waterfowl from the Khatanga area of eastern Taymir, (the only site where all fish and bird groups were sampled).

The characteristic time for hexachlorobiphenyl (PCB-155) absorption/depuration, as determined by laboratory experiments on adult rainbow trout, is about 1 month (Gobas *et al.*, 1999). This indicates that steady state OC concentrations in fish are established within a period of months, even for OCs with a $\log K_{OW}$ value as high as 7. As shown, OC distribution between water and fish tissues can be quite accurately described by a simple adsorption/desorption model, with the water-to-fish transfer factor (TF_{WF}, mL/g ww of muscle) calculated as follows (Verhaar *et al.*, 1999):

$$TF_{WF} = (V_{LM}K_{OW}^{a1} + V_{WM})/(V_{LW}K_{OW}^{a2} + V_{WW}) \quad (5.5)$$

Where:

V_{LM} and V_{LW} are lipid fractions in the muscle of fish and in water, respectively;
V_{WM} and V_{WW} are water fractions in the muscle of fish and water, as a physical body respectively;
a1 and a2 are Collander coefficients, which compare the similarity of the lipid in a given compartment with octanol.

A typical value for dissolved organic matter (DOM) concentration in surface freshwater is about 10 mg/L whilst the normal lipid concentration in the muscle of fish is several percent. A typical value for the Collander coefficient for the organic matter of soil and sediments (a1) is 0.8 (Schwarzenbach *et al.*, 1993). A significantly smaller coefficient a2 might be expected, however, when experimental data are applied to equation 5.5 a similar value is obtained for both coefficients (Verhaar *et al.*, 1999). Therefore, for the purposes of this study, a value of 0.8 was used for both a1 and a2. Using these input parameters, equation 5.5 predicts almost constant transfer factors (TF_{WF} 1000 mL/g ww) for all hydrophobic substances with $\log K_{OW} > 6$. This is consistent with previously reported experimental TF_{WF} - K_{OW} dependences (Verhaar *et al.*, 1999). K_{OW} values selected by Pantolillo and Eganhouse (2001) were used for *p,p'*-DDT ($\log K_{OW} = 6.6$, the geometric mean of two selected K_{OW} values), and for *p,p'*-DDE ($\log K_{OW}$ 7.0), while the K_{OW} values of other OC's were taken from the publication by Mackay *et al.* (1992). For fish species harvested in Lake Lovozero, and from rivers in the study, most TF_{WF} values calculated for *p,p'*-DDT and *p,p'*-DDE, as well as for other OCs with detected levels and with $\log K_{OW} \geq 6$ are about 1000 mL/g ww, or somewhat higher.

The TF_{WF} values predicted for *p,p'*-DDE, with only one exception, overestimate experimental values, while those for *p,p'*-DDT underestimate values in most cases. This is unlikely to be the result of poor choice of K_{OW} values, because according to equation 5.5, when K_{OW} is sufficiently large, the accuracy of its value is not critical for freshwater, and the relative concentrations of all highly hydrophobic contaminants in fish and water are expected to be similar. However, the measured DDE/DDT ratio in fish is several times higher (see Figure 5.23 and Table 5.26a and 5.26b), probably indicating a faster rate of *p,p'*-DDT metabolism in fish tissues than predicted. In any event, the assumption seems reasonable for waterfowl, in which the DDE/DDT ratio is 1-2 orders of magnitudes higher than in water, sediments and fish. As the chemical and physical properties of *p,p'*-DDE and *p,p'*-DDT are quite similar, it is unrealistic to expect that the dramatic difference in their relative concentrations could have a non-metabolic explanation. Comparison with whitefish species provides further evidence of an enhanced rate of metabolic transformation of *p,p'*-DDT into *p,p'*-DDE in birds and/or in their food. Levels of *p,p'*-DDT and *p,p'*-DDE in whitefish are, respectively, higher and lower than in birds, whilst levels of the sum of *p,p'*-DDT and *p,p'*-DDE are comparable and consistent with the corresponding lipid concentrations. Despite feeding at the highest trophic level, piscivore tissues do not contain the highest levels of *p,p'*-DDT and *p,p'*-DDE, nor do they have the highest DDE/DDT ratio. Only DDE concentration is consistently higher in piscivore bird species than in fish, while other OC levels (such as *p,p'*-DDT) are comparable or even lower. From this it can be inferred that the fish-to-birds transfer factor is close to unity for OCs which do not undergo significant metabolic transformation in bird tissues.

Site	Water	Freshwater fish	Salmonid sp.
Kola Peninsula	0.23 (0.16-0.32)	2.6 (1.7-3.9)	3.40 (2.6-4.5)
Pechora basin	0.67 (0.45-1.0)	2.2 (1.4-3.4)	1.1 (0.74-1.6)
Taymir, west	2.4	4.1 (3.5-4.8)	3.4 (2.5-4.5)
Taymir, east	0.52 (0.45-0.62)	1.8 (1.0-3.2)	0.87 (0.68-1.1)
Chukotka inland	-	4.1 (3.9-4.3)	2.2 (1.4-3.2)

Table 5.26a. DDE/DDT ratios (geometric means and 95% confidence interval) in freshwater food chains.

Table 5.26b. DDE/DDT ratios (geometric means and 95% confidence interval) in freshwater food chains.

Site	Grazers	Omnivores	Molluscivores	Piscivores
Kola Peninsula	-	-	24 (6.9-80)	12.0
Pechora basin	-	2.1	-	1.7 (1.1-2.7)
Taymir, west	100 (59-180)	13 (5.1-34)	-	-
Taymir, east	56 (37-85)	13 (3.8-41)	120 (31-510)	4.3 (4.0-4.7)
Chukotka inland	4.2	1.2 (0.33-4.2)	3.2 (2.2-4.7)	-

Contaminants in water also constitute the basis for the most important food chain pathways that give rise to contaminants in waterfowl. All other conditions (such as forage composition, DOM concentration etc.) being equal, OC levels in birds are directly proportional to the level of contamination in water. This being so, it is possible for water-to-bird transfer factors to be calculated. These are comparable for all bird groups at all sites and equal 5700 and 980 mL/g ww for *p,p'*-DDE, and *p,p'*-DDT, respectively. Transfer factors for HCB and PCBs range from 460 mL/g ww (HCB, water- to- piscivores in eastern Taymir) to 67000 mL/g ww (PCB-153, water-to-molluscivores in western Taymir). The geometric means of transfer factors are in a good agreement with those predicted using equation 5.5 and equal 1200 mL/g ww for HCB, 1800 mL/g ww for PCB-153 and 4100 mL/g ww for PCB-28. The lower value obtained for PCB-153 when compared with that of PCB-28 may be due to the kinetic limitation of highly hydrophobic compound levels in bird tissues. Higher transfer factors for waterfowl when compared to fish are consistent with the bird/fish concentration ratio for PCDD/F of ~ 2.2, and with the approximately two times greater lipid concentration in the muscle of birds. All differences between waterfowl /fish concentration ratios for lipids and OCs are within a small (factor of two) variance, and there is close correlation between the ranges for OC ratios and those of lipids (see Figure 5.24).

(b) Heavy metals
Equillibrium levels of Hg, Pb and Cd in fish in laboratory experiments can normally be established in several weeks or months (WHO 1989a, 1989b, 1991, 1992, 1995). This indicates that, in the absence of sudden temporal or spatial changes in HM concentrations in environmental media or in the food supply, contamination levels in fish tissues would be expected to be relatively constant and in equilibrium with levels found in the environment.

An example of HM distribution patterns in an aquatic food chain are presented in Figure 5.25. Despite occupying a higher trophic level, HM contamination levels in piscivorous birds are comparable with those of fish. Water-to-fish and water-to-bird transfer factors for HMs vary within an order of magnitude. Values of water-to-fish transfer factors for Hg and Cd are similar for salmon species and for freshwater fish, while the water-to-fish transfer factor for Pb is several times higher for freshwater species. Geometric means of Hg and Cd TFWFs, calculated using pooled sets of data, are equal to 3300 and 570 mL/g ww, respectively. Geometric means of Pb TFWFs are equal to 280 mL/g ww for freshwater species and 60 mL/g ww for salmon species. Default values for Hg and Pb biomagnification in fish edible parts provided in the IAEA Handbook (IAEA, 1994) are consistent with values obtained in this study.

As shown in section 5.3.4, HM contamination levels are close to being directly proportional to fish age, even for relatively old fish. This indicates that HM elimination rates are low and that the biological half-lives for the 3 HMs considered are about 10 years. The elimination rates determined in this study are significantly slower than those measured in laboratory experiments, in which a state of equilibrium was normally reached within several weeks or months (WHO 1989a, 1989b, 1991, 1992, 1995). A possible explanation for this discrepancy is the relatively short duration of laboratory experiments. If this is the case, HMs could have accumulated primarily in tissues and organs that are capable of fast absorption and elimination of HMs. This hypothesis is supported by observations from laboratory experiments that the elimination rate decreases with time. The biological half-life of the remaining HM fraction may, therefore, be many years. This is the slowest stage of HM elimination and is, quite possibly, the controlling rate under natural conditions.

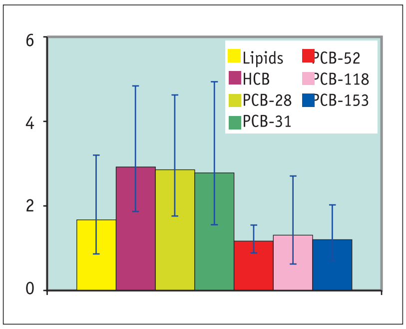


Figure 5.24.
Concentration ratios (geometric mean and 95% confidence limits) for OCs and lipid content in waterfowl/fish, for all sample sites.

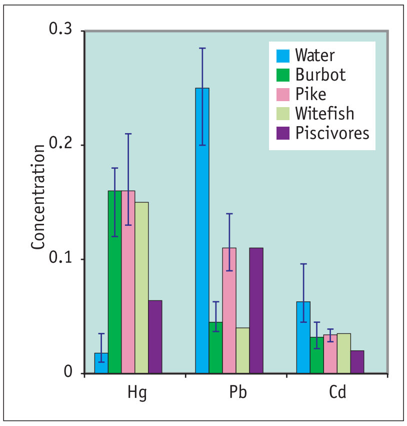


Figure 5.25.
The HM distribution pattern in water-fish-bird food chains on the Kola Peninsula in 2001. HM concentrations and their ranges in bird and fish muscle are in µg/g ww, while those in water are in µg/L.

5.5. Marine environment

5.5.1. PTSs in marine fish

Among marine fish species, only yellowfin sole flounder (*Limanda aspera*), harvested in the Bering Sea was sampled and analysed for PTSs content. However, for this analysis, some anadromous fish species such as smelt (*Osmerus eperlanus*), chum salmon (*Oncorhynchus keta*) and sea-run Arctic char (*Salvelinus alpinus*) were included in the group of sea fish, since they inhabit sea waters for a major part of year, migrating into river mouths only in the fall season for spawning.

(a) Organochlorines
As it is shown in Tables 5.27a and 5.27b, concentrations of OCs in muscle tissue of yellowfin sole are within the range of OC levels for anadromous fish. For concen-

Fish	Area, number of pooled samples (number of individual fish pooled)	ΣPCB_{15}	HCB	ΣHCH	ΣCHLOR
Chum salmon	Chukotka, coast, 4 (43)	2.3 (1.3-3.8)	0.26 (0.12-0.21)	0.62 (0.61 –0.63)	0.67 (0.55– 0.80)
Arctic char	Chukotka, coast, 8 (47)	6.5 (3.6–26.1)	0.31 (0.27-0.36)	0.27 (0.26-0.29)	1.3 (0.69–2.3)
Yellowfin sole	Chukotka, coast, 2 (20)	2.5 (2.45-2.55)	0.11 (0.11-0.12)	0.42 (0.39 - 0.46)	0.18 (<0.05-0.23)
Smelt	Chukotka, coast, 2 (25)	1.5 (1.0-2.5)	0.06 (<0.05-0.10)	0.16 (<0.05-0.22)	0.15 (0.14-0.16)

Table 5.27a.
Concentrations (geometric mean and range; ng/g wet weight) of OCs in muscle tissue of marine and anadromous fish in the Russian Arctic in 2001.

Fish	Area, number of pooled samples (number of individual fish pooled)	*p,p'*-DDE	*p,p'*-DDT	ΣDDT	Mirex
Chum salmon	Chukotka, coast, 4 (43)	0.68 (0.62-0.74)	0.53 (0.45-0.63)	1.9 (1.5-2.2)	<0.05
Arctic char	Chukotka, coast, 8 (47)	1.9 (0.84-4.1)	0.39 (0.19-0.79)	3.3 (1.6-6.5)	0.28 (0.23-0.33)
Yellowfin sole	Chukotka, coast, (20)	0.19 (0.16-0.23)	<0.05	0.41 (0.38– 0.45)	<0.05
Smelt	Chukotka, coast, 2 (25)	0.25 (0.23-0.26)	0.11 (0.10-0.13)	0.66 (0.59-0.75)	<0.05

Table 5.27b.
Concentrations (geometric mean and range; ng/g wet weight) of OCs in muscle tissue of marine and anadromous fish in the Russian Arctic in 2001.

trations of OCs found above detection limits, such as ΣPCB_{15}, ΣHCB, ΣHCH and ΣCHLOR, yellowfin sole muscle is approximately in the middle of the range of values for anadromous fish, although it had the lowest levels of DDT and its metabolites.

(b) Heavy metals
From Table 5.28, it can be seen that levels of Hg and Cd in yellowfin sole were, as for OCs, within the range of values for Hg and Cd found in anadromous fish, however, Pb concentrations in its flesh were higher than those in the anadromous fish group. Concentrations of all HM tested were well below guidelines concerning permissible levels of Hg, Pb and Cd in marine fish (0.4, 1.0 and 0.2 μg/g ww, respectively).

5.5.2. PTSs in marine mammals

5.5.2.1. Seal species

The seal family (*Phoca sp.*) in this study is represented by the ringed seal (*Phoca hispida*), the bearded seal (*Erignatus barbatus*) and the larga, or spotted seal (*Phoca largha*). Seals are the most abundant and widely distributed of the resident Arctic pinnipeds. Their diet consists of fish and crustaceans. Ringed seals have a broad circumpolar distribution and prefer annual, land-fast ice, but are also found near multiyear ice. Adults are believed to be relatively sedentary, but subadults can disperse over long distances. Ringed seals are a key component of the diet of the Inuit in northern Canada and Greenland, and of the Yupik and coastal Chukchi on the Chukotka Peninsula of Arctic Russia.

14 samples of ringed seal liver, kidney, muscle and blubber, together with 5 samples of bearded seal, and 22 samples of larga seal were collected from various communities located on the shores of Lavrentiya Bay in the Bering Sea, during the summer and fall periods of 2000 and 2002.

PTS concentration relationships to seal sex, age, and tissue type
As the age range of sampled animals among the seal species was very low (from 0.5 to 3.5 years), it was considered that neither age nor sex difference was likely to be particularly important in explaining variations in contaminant levels. Consequently, averages were calculated based on values obtained from both sexes and all ages.

Table 5.28.
Concentrations (geometric mean and range; g/g wet weight) of HMs in muscle tissue of marine and anadromous fish in the Russian Arctic in 2001.

Fish	Area, number of pooled samples (number of individual fish pooled)	Hg	Pb	Cd
Chum salmon	Chukotka, coast, 4 (43)	0.17 (0.15-0.18)	0.078 (0.070-0.086)	0.17 (0.14-0.20)
Arctic char	Chukotka, coast, 0 8 (47)	0.21 (0.15-0.28)	0.069 (0.067-0.072)	0.14 (0.12-0.15)
Yellowfin sole	Chukotka, coast, 0 2 (20)	0.053 (0.049-0.057)	0.132 (0.110-0.154)	0.032 (0.023-0.041)
Smelt	Chukotka, coast, 0 2 (25)	0.088 (0.078-0.098)	0.016 (0.014-0.018)	0.017 (0.015-0.020)

Table 5.29.
Concentrations (mean ± S.D. ng/g ww) of OCs in blubber of male and female seals harvested in the Russian Arctic (Chukotka), compared with data from northern Canada (CACAR, 1997).

OCs	Chukotka (coastal area)				Canada	
	Ringed seal		Larga seal		Ringed seal	
	male	female	male	female	male	female
ΣHCH	158±77	120.8±24.2	191.0±44.8	190±61	210±36.9	179±21.8
ΣDDT	86±33	72.0±28.4	232.3±95.7	208±72	703±890	359±166
ΣCHLOR	112±18	122±91	272.3±81.7	237±66	470±324	322±129
ΣCBz	15.0±2.7	16.2±2.7	37.1±14.3	23.6±8.6	36.1±7.1	37.6±9.4
Toxaphene	3.57±1.35	3.58±1.64	35.5±19.3	26.5±7.1	180±83.9	175±65.8
ΣPCBs	242±87	270±79	445±187	362±70	675±597	467±195

Seal species, number of samples	Organ or tissue	ΣPCB$_{15}$	HCB	ΣHCH	ΣCHLOR
Ringed Seal, (n=14)	Muscles	2.3 (1.5-2.9)	0.08 (<0.05-0.17)	0.94 (0.49-1.8)	0.38-1.2[a]
	Liver	2.5 (1.5-3.1)	0.09 (<0.05-0.22)	1.2 (0.8-1.5)	0.12-1.1[a]
	Kidney	2.2 (1.2-3.5)	<0.05-0.12a	0.81 (0.44-1.1)	0.36-1.1[a]
	Blubber	100 (70-154)	6.0 (4.2-9.4)	55 (36-74)	44 (21-92)
Larga Seal, (n=23)	Muscles	7.5 (5.7-10)	0.18 (0.05-0.48)	2.6 (1.4-4.2)	1.7 (0.87-3.9)
	Liver	2.9 (1.6-4.7)	0.22 (0.13-0.37)	1.3 (0.53-1.8)	0.69 (0.36-1.2)
	Kidney	1.8 (1.4-2.2)	0.18 (0.08-0.29)	0.69 (0.21-1.1)	0.46 (0.24-0.77)
	Blubber	123 (101-162)	9.5 (7.6-13)	52 (19-88)	35 (21-63)
Bearded Seal, (n=5)	Muscles	2.3 (2.2-2.4)	<0.05	<0.20	0.05-0.51[a]
	Liver	3.7 (3.4-4.0)	0.05 (0.06-0.09)	0.38 (0.32-0.44)	0.39-0.89[a]
	Kidney	4.9 (4.6-5.2)	0.09 (<0.05-0.13)	0.59 (0.51-0.68)	1.7 (1.6-1.8)
	Blubber	87 (79-95)	1.7 (1.0-2.6)	8.7 (7.0-11)	32 (30-35)

Table 5.30a. Concentrations (geometric mean and range; ng/g ww) of OCs in organ and tissues of seal species in the Russian Arctic.
[a] More than a half of concentrations measured were below the detection limit in at least one of the pooled samples.

In the ringed seal samples, PCBs, HCH, chlordanes, and DDT were the most prominent contaminants, while chlorobenzenes and toxaphene were present at lower concentrations. Average concentrations of PCB and chlordanes in females were higher than those in males, while mean levels of ΣHCH and ΣDDT in males exceeded those in females (Table 5.29). Mean concentrations of the sum of chlorobenzenes (ΣCBz) and toxaphene were very similar in both males and females.

In larga seals, PCBs, ΣCHLOR, ΣDDT, and ΣHCH were the main contaminants found, and average concentrations of all OCs tested were higher in males than in females.

Comparison of OC levels in the blubber of ringed seal harvested in the Canadian and Russian Arctic have shown that for all OCs under consideration, except for HCH, concentrations in the blubber of ringed seal from the Canadian Arctic, exceeded those in ringed seal from the Bering Sea. The most probable explanation for this is the difference in age between the two groups of seals, since seals hunted in the Bering Sea were no older than 3.5 years of age, whereas ringed seals from the Canadian North were 6 years or more in age.

Levels and trends

(a) Organochlorines

For the pooled data set of seal species, which included all ages and both sexes, geometric means were calculated (Tables 5.30a and 5.30b). No statistically significant differences were found between concentrations of OCs detectable in muscles, liver and kidney of ringed seal, but OC concentrations in blubber were about 50 times higher in comparison with other organs and tissues. Concentrations of OCs in muscles, liver, kidney and blubber of larga seal occured in the approximate ratio 1 : 0.3 : 0.2 : 15.

The highest level of muscle contamination by OCs was found in larga seal. Concentrations of all OCs in the muscle of other seal species were several times lower and close to those found in terrestrial mammals, waterfowl and fish. Concentrations of HCH and DDT and its metabolites in muscle, liver and kidney of seals were below corresponding guidelines established for consumption of seal meat in Russia (0.01 mg/kg for ΣHCH, and 0.03 mg/kg for ΣDDT). No significant difference was observed between concentrations of any OCs in other tissues of seals, with the exception of relatively low HCB and ΣHCH levels in the muscle and blubber of bearded seal. Like in fish muscle, levels of OCs in the blubber of seals were close to the lower margin of concentration ranges reported for seals from the Canadian Arctic in 1998-2001 (CACAR, 2003).

Results of a comparative assessment of OC contamination of ringed seal blubber in the Canadian and the Russian Arctic are shown in Figure 5.26. As can be seen from the Figure, concentrations of major OCs in the blubber of ringed seal in the Canadian Arctic meas-

Seal species, number of samples	Organ or tissue	*p,p'*-DDE	*p,p'*-DDT	ΣDDT	Mirex
Ringed Seal, (n=14)	Muscles	0.99 (0.56-1.7)	0.31 (0.15-0.64)	1.6 (0.92-2.3)	<0.05
	Liver	0.93 (0.60-1.3)	0.56 (0.29-0.93)	1.8 (1.4-2.5)	<0.05
	Kidney	0.67 (0.24-1.3)	0.30 (0.15-0.56)	1.3 (0.67-1.9)	<0.05
	Blubber	43 (14-80)	8.5 (4.3-14)	59 (24-102)	2.7 (1.6-4.7)
Larga Seal, (n=23)	Muscles	2.9 (1.3-5.5)	0.67 (0.30-1.3)	4.5 (2.7-7.1)	<0.05-0.19[a]
	Liver	1.2 (0.25-3.2)	0.21 (0.09-0.41)	2.1 (1.0-4.3)	<0.05
	Kidney	0.66 (0.36–0.97)	0.11 (0.03-0.35)	1.1 (0.56-1.5)	<0.05-0.10[a]
	Blubber	31 (12 –85)	14 (6.7-20)	55 (28-104)	1.7 (0.78-5.2)
Bearded seal, (n=5)	Muscles	0.28 (0.12-0.64)	0.82 (0.50-1.4)	1.3 (0.74-2.1)	<0.05
	Liver	1.3 (1.0-1.6)	0.28 (0.28-0.29)	2.0 (1.8-2.4)	0.12(0.12-0.13)
	Kidney	1.6 (1.1-2.2)	0.52 (0.47-0.58)	2.6 (2.2-3.2)	<0.05
	Blubber	35 (28-45)	8.6 (7.3-10)	49 (40-61)	1.1 (1.0-1.2)

Table 5.30b Concentrations (geometric mean and range; ng/g ww) of OCs in organ and tissues of seal species in the Russian Arctic.
[a] More than a half of concentrations measured were below the detection limit in at least one of the pooled samples.

Table 5.31.
Concentrations (ng/g ww) of of 2, 2', 4, 4'-tetrabromodiphenyl ether in seal species in the Russian Arctic in 2000-2002.

Species	Tissue	Number of samples analyzed	Number of samples with detectable levels	Concentration
Ringed seal	Blubber	6	1	0.51
Bearded seal	Blubber	2	1	1.9
Larga seal	Liver	10	1	0.23
Larga seal	Blubber	10	4	0.24-1.2

ured during the period 1989 to 2001 (CACAR, 1997; CACAR, 2003) were higher when compared with those measured in the Russian Arctic during the period 2000-2002.

(b) Brominated flame-retardants

Samples of tissues of marine mammals were analyzed for 2, 2', 4, 4'-tetrabromodiphenyl, 2, 2', 4, 4', 5-pentabromodiphenyl, 2, 2', 4, 4'-tetrabromodiphenyl ether and 2, 2', 4, 4', 5-pentabromodiphenyl ether. In most samples, these substances occurred below the detection limit of 0.2 ng/g. Only 2, 2', 4, 4'-tetrabromodiphenyl ether was found in few samples at higher levels (see Table 5.31).

(c) Heavy metals

Concentrations of HMs in seal species are shown in Table 5.32. The highest levels of contamination by Hg were found in the tissues of bearded and larga seal, and the lowest levels in ringed seal. Lead and Cd concentrations were similar in all seals. Hg concentrations in the muscle of seal species were significantly higher when compared with those in terrestrial mammals, birds, and fish. Lead levels in seals were somewhat lower than those in birds and terrestrial animals, while Cd concentrations in all mammals, birds, and fish were comparable. All Pb concentrations in the muscle, liver and kidney of seals were below corresponding guidelines established for human consumption of meat, liver, and kidney in Russia (0.5, 0.6, and 1.0 mg/kg, respectively). However, all Hg and most Cd concentrations in seals significantly exceeded corresponding guidelines (Table 5.33).

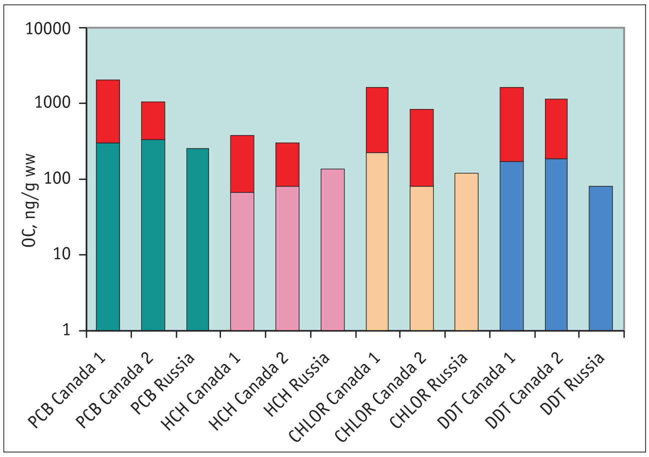


Figure 5.26. Comparison of mean OC concentrations in ringed seal blubber in the Canadian Arctic (Canada 1: 1989-1994, Canada 2: 1998-2001) and Russia (2000-2002). The lower part of each column corresponds to the minimum mean concentration, and the total column height, to the maximum mean concentration. PCB=ΣPCB (sum of 15 congeners in Russia; sum of more than 100 congeners in Canada), HCH=ΣHCH, CHLOR=ΣCHLOR, DDT=ΣDDT.

As seen in Table 5.32, the organ showing the greatest degree of contamination by Hg, in all seal species, was liver, followed by muscle tissue, and kidney. With respect to Cd, the most contaminated organ was kid-

Table 5.32.
Concentrations (geometric mean and range; µg/g ww) of HMs in tissues and organs of seals in the Russian Arctic in 2000-2002.

Species	Tissue	Hg	Pb	Cd
Ringed seal, (n = 14)	Muscle	0.48 (0.089-1.63)	0.042 (0.007-0.1)	0.047 (0.006–0.56)
	Liver	2.49 (0.41-8.36)	0.09 (0.067-0.155)	3.81 (0.15-18.65)
	Kidney	2.26 (0.83-10.0)	0.079 (0.054-0.124)	15.81 (1.53-50.13)
	Blubber	0.03 (0.002-1.59)	0.064 (0.014-0.686)	0.027 (0.006-0.52)
Bearded seal, (n = 5)	Muscle	1.25 (0.88-2.14)	0.038 (0.021-0.065)	0.030 (0.011-0.062)
	Liver	9.25 (3.71-37.4)	0.109 (0.065-0.186)	2.07 (1.28-3.62)
	Kidney	3.71 (1.71-8.32)	0.077 (0.064-0.11)	5.83 (3.31-11.49)
	Blubber	0.013 (0.003-0.37)	0.025 (0.022-0.03)	0.015 (0.004-0.024)
Larga seal, (n = 23)	Muscle	1.11 (0.14-3.28)	0.045 (0.024-0.070)	0.034 (0.005-0.136)
	Liver	5.64 (1.14-27.0)	0.091 (0.061-0.168)	1.71 (0.18-8.35)
	Kidney	2.78 (0.86-9.53)	0.058 (0.023-0.148)	6.24 (1.42-20.9)
	Blubber	0.022 (0.01-0.046)	0.055 (0.012-0.397)	0.017 (0.006-0.048)

Table 5.33.
Amount by which concentrations of Hg and Cd measured in tissues and organs of seal species harvested in the Russian Arctic exceed guidelines for consumption of meat, liver, and kidney products.

Seal species	Tissue, organ	Hg		Cd	
		Guideline (mg/kg)	Amount by which measured levels exceed guidelines (factor)	Guideline (mg/kg)	Amount by which measured levels exceed guidelines (factor)
Ringed seal	Muscle	0.03	16	0.05	-
	Liver	0.1	24.9	0.3	12.7
	Kidney	0.2	11.3	1.0	15.8
Bearded seal	Muscle	0.03	41.7	0.05	-
	Liver	0.1	92.5	0.3	7
	Kidney	0.2	18.5	1.0	5.8
Larga seal	Muscle	0.03	37	0.05	-
	Liver	0.1	56.4	0.3	5.7
	Kidney	0.2	13.9	1.0	6.2

Sex, number of samples	Organ or tissue	ΣPCB$_{15}$	HCB	ΣHCH	ΣCHLOR
Males (n = 11)	Muscle	1.3 (0.5-2.9)	0.04 (<0.05-0.08)	0.88 (0.18-3.35)	0.16 (0.15-0.25)
	Liver	3.8 (1.9-7.1)	0.03 (<0.05-0.08)	3.78 (1.7-5.77)	0.26 (0.15-0.41)
	Kidney	1.6 (1.1-3.6)	0.07 (<0.05-0.27)	1.81 (1.23-3.37)	0.22 (0.15-0.47)
	Blubber	84.4 (46-135)	0.25 (<0.05-1.9)	82.4 (38.6-196.9)	5.23 (2.4-12.1)
Females (n = 11)	Muscle	0.95 (0.4-3.4)	0.06 (<0.05-0.09)	0.85 (0.3-3.89)	0.18 (0.15-0.28)
	Liver	3.2 (1.8-7.2)	0.04 (<0.05-0.29)	2.15 (0.98-5.13)	0.24 (0.15-0.34)
	Kidney	1.6 (1.0-2.4)	0.05 (<0.05-0.12)	1.34 (0.54-2.1)	0.19 (0.18-0.21)
	Blubber	66.8 (34-116)	0.12 (<0.05-0.77)	106.9 (40.3-262)	5.59 (2.9-11.8)

Table 5.34a.
Concentrations (geometric mean and range; ng/g ww) of OCs in tissues and organs of male and female walrus in the Russian Arctic in 2002.

Sex, number of samples	Organ or tissue	*p,p'*-DDE	*p,p'*-DDT	ΣDDT
Males (n = 11)	Muscle	0.046 (<0.05-0.14)	0.047 (<0.05-0.13)	0.24 (0.15-0.46)
	Liver	0.079 (<0.05-0.25)	0.11 (<0.05-0.39)	0.51 (0.27-0.79)
	Kidney	0.059 (<0.05-0.19)	0.11 (<0.05-1.06)	0.33 (0.18-1.71)
	Blubber	5.64 (1.41-37.9)	2.0 (0.39-4.91)	11.97 (4.33-50.94)
Females (n = 11)	Muscle	0.055 (<0.05-0.11)	0.045 (<0.05-0.19)	0.24 (0.18-0.39)
	Liver	0.07 (<0.05-0.11)	0.07 (<0.05-0.21)	0.39 (0.21-0.60)
	Kidney	0.043 (<0.05-0.09)	0.13 (0.06-0.23)	0.34 (0.24-0.47)
	Blubber	3.32 (1.24-18.9)	2.05 (0.71-6.8)	9.82 (4.22-38.11)

Table 5.34b.
Concentrations (geometric mean and range; ng/g ww) of OCs in tissues and organs of male and female walrus in the Russian Arctic in 2002.

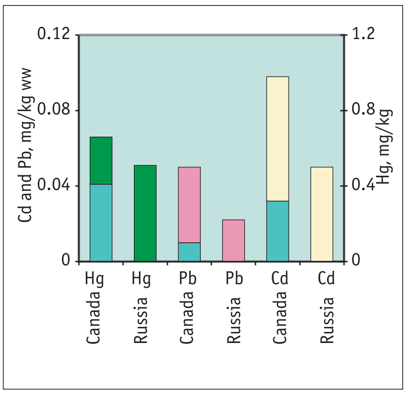
ney, followed by liver. Concentrations of Cd in muscle tissue in seal species were below guideline levels.

The ranges of all HM concentrations in muscle, liver and kidney of seals were consistent with concentrations determined in 1998-2001 in ringed seal in the Canadian Arctic (CACAR, 2003). However, HM concentrations in ringed seal from Canada are somewhat lower than those determined in ringed seal in the Russian Arctic, this despite the fact that the were reported on the dry weight basis. HM concentrations in ringed seal muscle in the Russian Arctic fall almost in the middle of concentration ranges determined in Canada in 1987-1994 (CACAR, 1997; see Figure 5.27).

5.5.2.2. Walrus

Walrus (*Odobenus rosmarus*) are long-lived benthic feeders and, as such, are an important indicator species for the bioaccumulation of contaminants in benthic marine food webs. Although they have an important role in the traditional hunts and diets of indigenous peoples, relatively little is known about contaminant levels in walrus. Some individuals, however, are known to feed at higher trophic levels and include ringed seal in their diet, and as a result have much higher contaminant concentrations in their tissues (AMAP, 1998; CACAR, 2003). Walrus tissues and organs, including 22 samples each of liver, kidney, muscle, and blubber, were collected in the summer and fall of 2002 from coastal communities of the Chukotka Peninsula.

Figure 5.27.
Comparison of mean HM concentrations in ringed seal muscle in the Canadian Arctic (1987-1994) and Russia (2000-2002). The lower part of each column corresponds to the minimum mean concentration, and the total column height, to the maximum mean concentration.



PTS concentrations relationship to walrus sex, age and tissue type

The age distribution of male walrus sampled was as follows: 3 individuals aged 1.5 years, 2 individuals aged 3.5 years, 2 individuals aged 4.5 years, and 4 individuals aged 5.5 years. Female walrus sampled showed greater variability in age distribution and were represented by 1 walrus aged 0.5 years, 4 individuals aged 2.5 years, 3 individuals aged 3.5 years, and 1 individual each of 4.5, 5.5 and 6.5 years.

As the mean age difference between male and female walrus was relatively small (3.8 years vs 3.4 years, respectively), average PTS levels in walrus tissues and organs were calculated without distinguishing between age groups. Tables 5.34a, 5.34b show OC concentrations as measured in different organs and tissues of male and female animals.

Sex, number of samples	Organ or tissue	Hg	Pb	Cd
Males (n = 11)	Muscle	0.046 (0.028-0.072)	0.043 (0.03-0.117)	0.014 (0.005-0.03)
	Liver	1.73 (0.58-3.56)	0.059 (0.034-0.133)	2.16 (0.634-6.962)
	Kidney	0.29 (0.18-0.48)	0.049 (0.017-0.104)	13.71 (2.55-27.13)
	Blubber	0.01 (0.006-0.018)	0.049 (0.022-0.154)	0.010 (0.005-0.025)
Females (n = 11)	Muscle	0.038 (0.012-0.057)	0.050 (0.028-0.114)	0.019 (0.006-0.05)
	Liver	1.59 (0.29-4.01)	0.059 (0.031-0.134)	2.72 (0.40-6.231)
	Kidney	0.26 (0.14-0.40)	0.050 (0.028-0.138)	14.46 (2.51-29.4)
	Blubber	0.011 (0.006-0.022)	0.057 (0.022-0.472)	0.010 (0.006-0.026)

Table 5.35.
Concentrations (geometric mean and range; μg/g wet weight) of HMs in tissues and organs of male and female walrus in the Russian Arctic in 2002.

Table 5.36a.
Concentrations (geometric mean and range; ng/g ww) of OCs in tissues and organs of walrus in the Russian Arctic in 2002.

Organ or tissue	ΣPCB_{15}	HCB	ΣHCH	ΣCHLOR
Muscle	1.1 (0.4-3.4)	0.05 (<0.05-0.09)	0.86 (0.18-3.89)	0.17 (0.15-0.28)
Liver	3.5 (1.8-7.2)	0.04 (<0.05-0.29)	2.85 (0.98-5.77)	0.25 (0.15-0.41)
Kidney	1.6 (1.1-3.6)	0.06 (<0.05-0.27)	1.56 (0.54-3.37)	0.21 (0.15-0.47)
Blubber	75.1 (34-135)	0.17 (<0.05-1.9)	93.9 (38.6-262)	5.4 (2.4-12.1)

Table 5.36b.
Concentrations (geometric mean and range; ng/g ww) of OCs in tissues and organs of walrus in the Russian Arctic in 2002.

Organ or tissue	*p,p'*-DDE	*p,p'*-DDT	ΣDDT
Muscle	0.050 (<0.05-0.14)	0.046 (<0.05-0.19)	0.24 (0.15-0.46)
Liver	0.074 (<0.05-0.25)	0.09 (<0.05-0.39)	0.45 (0.21-0.79)
Kidney	0.050 (<0.05-0.19)	0.12 (<0.05-1.06)	0.33 (0.18-1.71)
Blubber	4.33 (1.24-37.9)	2.03 (0.39-6.8)	10.85 (4.22-50.94)

Table 5.37.
Concentrations (geometric mean and range; µg/g wet weight) of HMs in tissues and organs of walrus in the Russian Arctic in 2002.

Organ or tissue	Hg	Pb	Cd
Muscle	0.042 (0.012-0.072)	0.046 (0.028-0.117)	0.017 (0.005-0.05)
Liver	1.66 (0.29-4.01)	0.059 (0.031-0.134)	2.43 (0.40-6.962)
Kidney	0.27 (0.14-0.48)	0.050 (0.017-0.138)	14.08 (2.51-29.4)
Blubber	0.011 (0.006-0.022)	0.053 (0.022-0.472)	0.010 (0.005-0.026)

The distribution of HM concentrations in walrus tissues and organs for each sex is shown in Table 5.35. Levels of Hg in the muscle, liver, and kidney of male walrus were slightly higher than in females, but concentrations of Pb and Cd in females, in contrast to Hg, exceeded those in males.

Levels and trends

(a) Organochlorines

For the pooled data set, geometric means were calculated including all ages and both sexes of walrus (Tables 5.36a and 5.36b). No statistically significant differences were found between concentrations of HCB, chlordane-related compounds, or ΣDDT in the muscle, liver and kidney of walrus; however, ΣPCB_{15} concentrations in blubber were approximately 68, 47, and 21 times higher when compared to the muscle, kidney and liver, respectively. Concentrations of ΣHCH in the muscle, kidney, liver, and blubber of walrus were found in the ratio of 1 : 1.8 : 3.3 : 109; levels of ΣCHLOR in these organs and tissues occurred in the ratio of 1 : 1.2 : 1.5 : 32; and ΣDDT levels in muscle, kidney, liver, and blubber were found in the ratio of 1 : 1.4 : 1.9 : 45.

Concentrations of HCH and DDT measured in muscle tissue and the blubber of walrus were compared with existing Russian guidelines for HCH and DDT compounds, in both the meat of marine mammals (including walrus), and in animal fat. The levels of HCH and DDT measured in walrus muscle were found to be, respectively, 12 and 35 times, lower than the corresponding guidelines values (of 10 and 30 ng/g ww). The levels of summed HCH isomers in the blubber of walrus, measured at 93.9 ng/g ww and were approximately 2.1 times lower than the guideline value of 200 ng/g ww.

(b) Heavy metals

Concentrations of heavy metals in walrus organs and tissues are shown in Table 5.37. Levels of Hg were highest in the liver, 42-fold greater than those in muscle, and 6-fold greater than those in kidney. Concentrations of Cd were highest in kidney and exceeded those in muscles by a factor of nearly 700, and those in liver by a factor of approximately 6.

Concentrations of Cd in the liver and kidney of walrus were 8- and 14-times higher, respectively, than the human consumption guideline values for Cd in internal organs, established in the Russian Federation. Levels of Hg in muscle, liver, and kidney of walrus were, respectively, 1.4-, 16.6- and 1.3-times higher than the associated human consumption guidelines values. Although high, these levels of exceedance of guideline values are less than those noted for seal species.

5.5.2.3. Grey whale

Grey whales (*Eschrichtius gibbosus*), taken from the Bering Sea by indigenous hunters of the coastal communities of Chukotka were sampled. The sampled whales included 2 females, with a mean age of 3 years, 3 females with the mean age of 7.3 years, and 2 males with a mean age of 6.5 years.

PTS concentration relationships to whale sex, age and tissue type

Most OCs, except for HCH, were found in lower concentrations in female whales than in males, possibly due to the elimination of these lipophilic compounds during lactation. No significant trend in OC concentration levels with age was found in male grey whale, but a substantial decrease in OC concentration in females occurred after six years of age, which corresponds to the age at which first parturition takes place. For example, the average concentration of PCB congeners in the blubber of grey whale females of 3 years was 135 ng/g ww, whilst in female of 7.3 years, ΣPCBs averaged 87.5 ng/g ww (Table 5.38). The levels of the main OCs in the liver, kidney and blubber of females aged 3 years, exceeded those in females aged 7.3 years 1.4- to 1.8-fold. This is consistent with the influence of parturition and lactation, which are associated with the elimination of contaminants from maternal whales. An

Tissue, organ	Sex, mean age (years), and number of samples	ΣPCB$_{15}$	HCB	Toxaphene	ΣHCH	ΣDDT	ΣCHLOR
Liver	Female, 3 (n = 2)	4.64 3.85-5.59	1.12 0.79-1.58	1.17 0.64-2.13	5.73 6.62-5.84	3.11 2.44-3.96	1.94 1.57-2.39
	Female, 7.3 (n = 3)	2.58 1.59-3.47	0.35 0.33-0.39	0.63 0.49-0.76	3.27 2.48-4.54	1.50 0.79-2.94	0.98 0.68-1.44
	Male, 6.5 (n = 2)	2.78 2.35-3.28	0.57	2.65 2.48-2.83	5.23 5.12-5.41	1.82 1.78-1.86	1.08 0.99-1.19
Muscle	Female, 3 (n = 2)	3.04 2.06-4.49	0.19 0.18-0.21	0.37 0.27-0.50	1.83 1.62-2.06	2.03 1.52-2.72	1.18 1.01-1.38
	Female, 7.3 (n = 3)	2.17 0.69-16.58	0.30 0.06-3.10	0.21 0.14-0.30	1.42 0.46-13.53	3.69 0.71-20.11	1.77 0.38-6.77
	Male, 6.5 (n = 2)	1.13 0.65-1.98	0.09 0.07-0.11	0.53 0.47-0.60	0.71 0.42-1.19	0.80 0.41-1.56	0.55 0.33-0.93
Kidney	Female, 3 (n = 2)	1.69 1.59-1.80	0.58 0.44-0.76	0.26 0.16-0.44	2.03 1.81-2.27	0.96 0.88-1.05	0.62 0.59-0.65
	Female, 7.3 (n=3)	1.08 0.86-1.27	0.51 0.33-0.67	0.22 0.20-0.25	0.86 0.54-1.68	0.59 0.40-0.84	0.36 0.30-0.47
	Male, 6.5 (n=2)	1.19 0.99-1.43	0.81 0.71-0.93	0.47 0.44-0.51	1.56 1.52-1.60	0.48 0.41-0.56	0.29 0.27-0.31
Blubber	Female, 3 (n = 2)	135.1 113.3-161.2	105.8 79.9-140.0	37.1 21.8-63.0	149.7 124.1-180.7	91.1 76.0-109.3	50.8 42.8-60.2
	Female, 7.3 (n = 3)	87.5 36.4-194.6	40.7 26.9-62.8	24.0 19.2-39.1	65.2 36.4-93.0	46.6 18.6-109.2	24.8 12.2-45.6
	Male, 6.5 (n = 2)	231.9 223.3-240.9	164.2 142.0-190.0	63.3 56.0-71.6	145.4 126.8-166.7	150.1 146.7-153.5	71.4 70.1-72.7

Table 5.38. Concentrations (geometric mean and range; ng/g ww) of OCs in tissues and organs of grey whale in the Russian Arctic, by age and sex.

exception to this is seen in muscle tissue, in which levels of DDT, HCB, and chlordane-related compounds were higher in females of over 7 years than in females of 3 years. It is important to note however, that the statistical significance of most age-related differences in concentrations of PTS from the limited dataset available is rather low.

As can be seen from Table 5.39, Hg levels varied according to age and sex, with higher levels observed in males, followed by females of 7.3 years, and lowest levels in females of 3 years of age. Concentrations of Pb and Cd did not follow the same pattern; for Pb, the highest levels were found in older females, followed by males, with lowest levels in females of 3 years of age.

Levels and trends

(a) Organochlorines

For the pooled data set, which included all ages and both sexes, geometric means were calculated for PTS concentrations in grey whale. From Table 5.40 it can be seen that the highest concentrations of all OCs tested were found in the whale blubber. For the other organs and tissues, levels of ΣPCB$_{15}$, toxaphene, ΣHCH, ΣDDT, and ΣCHLOR were highest in liver, although higher in kidney than in liver in the case of HCB.

Tissue, organ	Sex, mean age (years), and number of samples	Hg	Pb	Cd
Muscle	Female, 3 (n = 2)	0.015 0.012-0.019	0.039 0.028-0.056	<0.005
	Female, 7.3 (n = 3)	0.065 0.044-0.089	0.075 0.071 –0.083	0.009 0.006-0.012
	Male, 6.5 (n = 2)	0.070 0.051-0.096	0.042 0.037-0.047	<0.005-0.005[a]
Liver	Female, 3 (n = 2)	0.041 0.026-0.066	0.046 0.038-0.057	0.363 0.352-0.375
	Female, 7.3 (n = 3)	0.158 0.118 –0.197	0.102 0.054-0.225	1.320 0.834-1.748
	Male, 6.5 (n = 2)	0.179 0.12-0.268	0.060 0.05-0.072	0.742 0.666-0.828
Kidney	Female, 3 (n = 2)	0.026 0.02-0.033	0.034 0.031-0.038	0.545 0.455-0.652
	Female, 7.3 (n = 3)	0.085 0.067-0.102	0.039 0.034-0.042	3.268 2.707-4.692
	Male, 6.5 (n = 2)	0.101 0.08-0.128	0.039 0.036-0.042	2.752 2.7-2.805
Blubber	Female, 3 (n = 2)	0.012 0.011-0.013	0.029 0.027-0.032	0.008 0.007-0.009
	Female, 7.3 (n = 3)	0.015 0.015-0.016	0.058 0.054-0.066	0.012 0.011-0.012
	Male, 6.5 (n = 2)	0.017 0.014-0.021	0.043 0.038-0.049	0.011 0.01-0.012

Table 5.39. Concentrations (geometric mean and range; µg/g ww) of HMs in tissues and organs of grey whale in the Russian Arctic, by age and sex.
[a] Range given, as one of the sampled whales had concentrations below the detection limit.

Tissue, organ	ΣPCB$_{15}$	HCB	Toxaphene	ΣHCH	ΣDDT	ΣCHLOR
Liver	3.12 1.59-5.59	0.56 0.33-1.58	1.13 0.49 –2.83	4.38 2.45-5.84	1.95 0.79-3.96	1.23 0.69-2.39
Muscle	1.98 0.65-16.58	0.19 0.06-3.1	0.32 0.14-0.6	1.18 0.37-13.63	2.01 0.41-20.11	1.13 0.33-6.75
Kidney	1.25 0.86-1.8	0.60 0.33-0.93	0.29 0.16-0.51	1.30 0.54-2.27	0.64 0.4-1.05	0.39 0.27-0.65
Blubber	130.9 36.37-240.9	79.65 26.9-190.0	36.66 17.69-71.58	104.0 36.36-180.67	78.16 18.6-153.55	41.43 12.22-73.16

Table 5.40. Concentrations (geometric mean and range; ng/g ww) of OCs in tissues and organs of grey whale in the Russian Arctic.

Tissue, organ	Hg	Pb	Cd
Muscle	0.044 0.012-0.096	0.053 0.028-0.083	<0.005- 0.012[a]
Liver	0.112 0.026-0.268	0.070 0.038-0.225	0.775 0.352-1.748
Kidney	0.065 0.02-0.128	0.035 0.027-0.042	1.865 0.455-4.692
Blubber	0.015 0.011-0.021	0.044 0.027-0.066	0.010 0.007-0.012

Table 5.41 Concentrations (geometric mean and range; µg/g ww) of HMs in tissues and organs of grey whale in the Russian Arctic.
[a] Range given as more than a half of concentrations were below the detection limit in at least one of the samples contributing to the mean.

Mammal	pg TEQ-WHO/g w.w.	pg TEQ-WHO/g lipids	pg TEQ-WHO/pg*
	Muscle		
Ringed seal	0.10	1.9	0.10
Bearded seal	0.10	4.4	0.10
Larga seal	0.19	4.4	0.10
Grey whale	0.11	15.9	0.13
	Blubber		
Ringed seal	1.10	1.11	0.11
Bearded seal	0.97	1.12	0.065
Larga seal	1.25	1.51	0.15
Grey whale	0.74	1.74	0.068

Table 5.42. Concentrations (expressed as TEQ) of PCDD/Fs in marine mammals harvested in the Russian Arctic in 2000-2002.
* – ratio of PCDD/F concentration in pg WHO-TEQ/g to that in pg/g

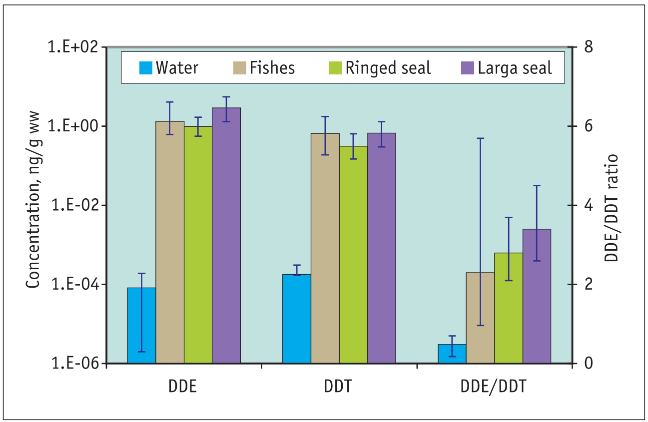


Figure 5.28. Absolute and relative levels of p,p'-DDE and p,p'-DDT in the marine food chain in the Lavrentiya Bay. Geometric means and ranges are shown for DDE and DDT concentrations in muscle tissue, water concentrations are in g/L. Ratios are shown with 95% confidence limits.

The observed concentrations of HCH and DDT in the organs and tissues of grey whale were below the human consumption guidelines values established in Russia for these contaminants. For example, levels of ΣHCH in muscle and blubber were approximately a factor of 8.5 and 2, respectively, lower than the corresponding guideline values (10 ng/g ww for meat, and 200 ng/g ww for animal fat). Observed concentrations of ΣDDT in muscle were two orders of magnitude lower than the guideline value (200 ng/g ww) for human consumption of meat of marine mammals.

(b) Heavy metals

Concentrations of HMs in grey whale are presented in Table 5.41. Levels of Hg and Pb in the liver of grey whale were high compared to concentrations of these metals in other organs and tissues. Hg concentrations in blubber, muscle, kidney, and liver were measured in the ratio 1 : 2.9 : 4.3 : 7.5, while levels of Pb in kidney, blubber, muscle, and liver were found in the ratio of 1 : 1.2 : 1.5 : 2.0.

Concentrations of Hg measured in muscle tissue of grey whale exceeded the human consumption guideline values for Hg in meat by almost 1.5 times. Cd levels in liver were 2.5-fold the guideline value for Cd in internal organs (0.3 µg/g ww), and Cd concentrations in kidney exceeded the associated guideline value (1.0 µg/g ww) by almost 1.9 times.

5.5.3. PCDDs/Fs in marine mammals

Concentrations of 2,3,7,8-substituted PCDDs/Fs were analyzed in samples of marine mammals collected from the coastal survey site off the Chukotka Peninsula. Results are presented in Table 5.42.

PCDDs/Fs levels in the blubber of marine mammals from the Bering Sea measured in 2001 (0.6-1.0 pg I-TEQ/g) were an order of magnitude lower than levels in ringed seals from the Barents Sea in measured in 1987 (6-26 pg I-TEQ/g; AMAP, 1998). This difference is, however, consistent with spatial trends observed for other non-mammalian marine species, presented above.

5.5.4. PTS transfer in the marine food chain

(a) Organochlorines

Levels of *p,p'*-DDT and *p,p'*-DDE, and the DDE/DDT ratio in the water-fish-seal food chain are shown in Figure 5.28. The water-to-fish transfer factors for *p,p'*-DDT and *p,p'*-DDE in the marine food chain are significantly higher than those calculated for the freshwater environment in the Russian Arctic (14000 and 2500 mL/g ww of muscle, respectively). These results may be explained by the lower DOM concentration in sea water, normally, an order of magnitude lower than in freshwater. However, TFWF values for other OCs are similar, around 1000 mL/g ww in both freshwater and marine systems. The high TFWF value for DDE is possibly a result of accelerated transformation from DDT to DDE in marine fish or invertebrates.

Concentrations of OCs found in fish and seals muscles are comparable, which is consistent with the similar lipid content in their muscles. Slightly higher contamination levels occur in larger seals, and slightly lower contamination in ringed seals, compared with other species, however, all differences are of fairly low statistical significance. Similar patterns between species and values for the fish-to-seal transfer coefficient are observed for other OCs and marine mammals. The geometric mean of the fish-to-seal transfer coefficient, calculated using data on all OCs found at detectable levels is equal to 0.5 for ringed seals and 1.4 for larga seals. DDE/DDT ratios in fish and seals are also comparable and are several times higher than the ratio in water. Comparison of OC levels with corresponding lipid concentrations, indicates that OC distribution in the marine environment, as for the terrestrial and freshwater environment, is close to being in a state of equilibrium. However, the difference is clearly seen while comparing OCs in fish and blubber of marine mammals, which is consistent with high lipid difference.

(b) Heavy metals

HM water-to-fish transfer factors (i.e., the ratios of the geometric mean of concentrations) for chum salmon and Arctic char are similar in value. The geometric means of the TFWFs of both species equal 9400, 340 and 2900 mL/g ww for Hg, Pb and Cd, respectively. These are somewhat higher than transfer factors calculated for the freshwater environment, the probable reason being that anadromous fish species absorb HMs from both fresh and sea waters, and that HM levels are normally lower in seawater than in freshwater. HM concentrations in marine fish species (flounder and smelt) are comparable with those in seals and walrus (i.e., TF values are close to unity). The single exception to this is seen for Hg concentrations in seals, which are 7-18 times higher than those in fish.

5.6. Conclusions

Levels

- Concentrations of PCDD/Fs in reindeer muscle from the Kola Peninsula, exceed maximum permissible levels in meat by approximately 10%. Concentrations of ΣHCH and ΣDDT in all tissues of the mammals, birds and fish sampled in the Russian Arctic are far below the corresponding maximum permissible concentrations established by the Russian Ministry of Health. Only in some marine mammal species are concentrations of OC's found to be close to these permissible levels, in some samples.
- Concentrations of PCDD/Fs in muscle tissue are highest in reindeer and lowest in terrestrial birds, however the range is not large and well within an order of magnitude. Other OCs occur in comparable concentrations in marine mammals, salmon species, and waterfowl. In terrestrial mammals and birds, concentrations are, as a rule, several times lower than in other species and are generally highest in reindeer.
- At all sites, Pb concentration in reindeer tissues are at least several times lower than the corresponding maximum permissible concentrations. Cd and Hg levels for all tissues and sites, with the exception of Hg in Chukotka, are either close to the corresponding maximum permissible concentrations or slightly exceed them. The greatest difference between measured and guideline levels is seen in the Pechora basin, where Cd concentration in reindeer kidney are 2.5 times higher than the permissible level. Levels of Pb and Hg in muscle tissue of hares and terrestrial birds are significantly below the corresponding maximum permissible concentrations, while the Cd level in birds is close to, or slightly higher than the maximum permissible concentration.
- Concentrations of Pb and Cd in waterfowl are normally below permissible levels and only in few samples attain a maximum level that exceeds the permissible level by a factor of up to two. Concentrations of Hg in molluscivorous, omnivorous, and piscivorous birds are consistently close to the permissible level, and in most samples actually exceed it, by a maximum of up to 4 times. All concentrations in fish muscle are below the corresponding maximum permissible concentrations established in Russia for fish, with only one exception; this being Hg in whitefish from the Khatanga River, for which concentrations are 1.5 times the permissible level.
- All Hg and most Cd concentrations in seals are significantly higher than the corresponding maximum permissible concentrations. The greatest difference between measured and guideline values is for Hg concentrations in seal muscle, which exceed permissible concentrations by as much as 100 times. All Pb concentrations measured in muscle, liver, and kidney of seals occur at levels below the corresponding maximum permissible concentrations.
- The level of contamination in male animals is normally slightly higher than that measured in females, but in most cases the difference is not statistically significant. The single exception found was for Pb in browsers, where concentrations in male browsers are consistently twice as high as those in females at all 6 sites.
- Concentrations of both OCs and HMs are, as a rule, higher in older animals. However, the greatest differences observed in this study between older and younger age groups is within a factor of two. This was particularly the case for fish species, where the range in the age groups was relatively small. The most pronounced concentration relationship to age was observed for HMs in reindeer. For the first few years of life, this relationship is close to being directly proportional, with the rate of HM elimination calculated as being around 10 years for all 3 metals studied.
- Contamination levels in the liver and kidney are normally higher than those in muscle, especially for HMs. The liver/muscle concentration ratio for Hg in reindeer, and for OCs in burbot, and also the kidney/muscle ratio for Cd in marine mammals can be up to between two and three orders of magnitude. The highest OC concentrations found in this study occur in the liver of burbot, fished from the Yenisey River (580 ng/g ww of ΣPCB_{15}, 470 ng/g ww of ΣDDT, and 39 ng/g ww of ΣCHLOR).
- Levels of brominated flame-retardants are below the detection limit of 0.2 ng/g ww in all samples of soil, vegetation, terrestrial mammals, and birds. However, in a few samples of fish and seal liver, as well as in seal blubber, 2,2',4,4'-tetrabromodipheny ether was found in concentrations ranging from 0.2 to 1.9 ng/g ww.

Trends

- PCDD/F levels in the tissues of reindeer and hare from the Kola Peninsula are an order of magnitude higher than those found at other sites. Concentrations of PCDD/Fs in birds and fish follow similar, but less pronounced, trends.
- No significant spatial trend in concentrations of OCs, other than for PCDD/Fs in terrestrial mammals, birds, and fish, was identified in the Russian Arctic in 2001. Only OC concentrations found in molluscivorous birds show a distinct maximum in eastern Taymir.
- OC levels measured in reindeer are in reasonably good agreement with levels previously reported for Russian, Canadian, and Norwegian Arctic areas. This is consistent with the finding that levels of lichen contamination in Arctic Canada and Russia are comparable.
- OC levels in fish in the Russian Arctic, are at the lower end of corresponding concentration ranges for OCs in fish in the Canadian Arctic, and are similar to those measured at three locations in Norway in 1994.
- As seen for OC concentrations in fish, OC levels in the blubber of seals in the Russian Arctic are found to be close to the lower end of concentration ranges obtained for seals in the Canadian Arctic in 1998-2001.
- Fish muscle from the Grate Slave Lake in northern Canada in 1994/5, contained PCDD/Fs at levels an order of magnitude higher than those determined in samples from Russia in this study. In contrast, PCDD/Fs levels measured in the muscle of freshwater fish at four Scandinavian Arctic sites are close to those found in the Russian North in 2001.
- Concentrations of HMs in terrestrial mammals and birds are lowest in inland Chukotka and in eastern Taymir. However, differences between these and the other studied locations in northern Russia are within a factor of 3.
- Levels of HMs in fish and waterfowl do not follow a pronounced spatial trend.
- Levels of HMs in reindeer tissues determined in recent studies in the Canadian Arctic are, as a rule, somewhat higher than those measured in the Russian Arctic.
- Concentrations of Hg in whitefish species in the Russian Arctic in 2001 are close to those found in the Canadian Arctic in 1996-2000, and in northern Norway in 1995.
- HM concentrations in the muscle, liver, and kidney of seals in the Russian Arctic in 2001 generally occur within ranges similar to those found in ringed seal in the Canadian Arctic in 1998-2001.
- No significant temporal trend in contamination levels in any of the sampled biological species, for either OCs or HMs, is evident when the results of this study are compared with those of previous studies. However, the consistent level of concentrations, and, at some sites, significantly higher concentrations of HCH and Hg in mosses and lichen in 2001, indicates that it is possible that some increase in depositions of these contaminants has taken place in the Russian North during the past few years.

Biomagnification

- OC concentration distribution patterns in both terrestrial and aquatic food chains in the Russian Arctic are similar to those of lipids. This indicates that OCs in Arctic ecosystems, are close to an equilibrium state distribution.
- Concentrations of OCs in lichens reflect those in mosses, with lichen/mosses concentration ratio for OCs close to unity. Concentration of OCs in lichen can therefore provide a direct estimate of the concentration in mosses at a given site, and vice versa.
- The OC lichen-to-reindeer transfer factor obtained in this study is equal to 0.3 (ww muscle to dw lichen) and is consistent with factors previously determined in the Canadian Arctic.
- The OC water-to-fish transfer factors (TFWFs) obtained in this study are in a reasonably good agreement with those predicted using octanol-water partition coefficients.
- Values of Hg and Cd water-to-fish transfer factors are similar for both freshwater and marine fish groups, while the transfer factor for Pb is several times higher for freshwater species. Geometric means of Hg and Cd TFWFs, calculated using pooled sets of data, are 3300 and 570 mL/g ww, respectively. The geometric mean of Pb TFWFs is 280 mL/g ww for freshwater species, and 60 mL/g ww for marine species. Transfer factor values for Hg and Pb are in a good agreement with corresponding default values previously published by the IAEA.