Chapter 5

PTS levels in biota and biomagnification in food chains

5.1. Sampling strategy

Environmental sampling and analysis within the framework of Activity 4 'Biomagnification in Arctic food chains' had two objectives:

- determination of current PTS levels in main biota species, particularly those which are a utilised as part of the traditional diet of the indigenous populations in the pilot areas covered by the project;
- evaluation of the extent to which biomagnification occurs, i.e., the measurement of PTS accumulation in terrestrial, freshwater, and marine food chains, in which humans represent the uppermost trophic level.

These two aims place somewhat different requirements on sampling, sample treatment, and analysis. For the first objective, in order to estimate PTS intake with food, it is necessary to obtain as reliable and representative data as possible on PTS levels in those species and tissues that are widely used as traditional food. For the second objective, it is necessary to determine the average levels of contamination in species representing a range of trophic levels (and in specific tissues of organisms at higher trophic levels), and from this information, evaluate the degree to which PTS are being accumulated and biomagnified in the various food chains that form the basis for food items in the traditional diet.

Figure 5.1. Location of the environmental sampling area on the Kola peninsula.

Figure 5.2. Location of the environmental sampling area in the lower Pechora basin.

To these ends, environmental sampling was carried out in six areas within the four main project regions, these areas being located around settlements with the highest indigenous populations. Bearing in mind that hunting and fishing grounds can be located at some distance from the actual settlements, and that migration of reindeer herds depends upon the season and weather conditions, field sampling was based on prior consultations with local indigenous peoples involved in traditional activities. The environmental sampling areas that were defined following these consultations are shown in Figures 5.1–5.4.

It is also important to note that the optimal season for environmental sampling differed between locations. It depends, not only on availability of the specified species, but on the hunting seasons, which may vary between different regions. In addition, sampling of certain species of biota, particularly those species which are obtained by hunting or fishing, had to be arranged in close collaboration with local hunters and fishers. This was important, not only to ensure efficiency in sampling related to these activities, but also from a legal point of view, since licences for the hunting of some species and for marine mammals in particular, can only be obtained by indigenous communities.

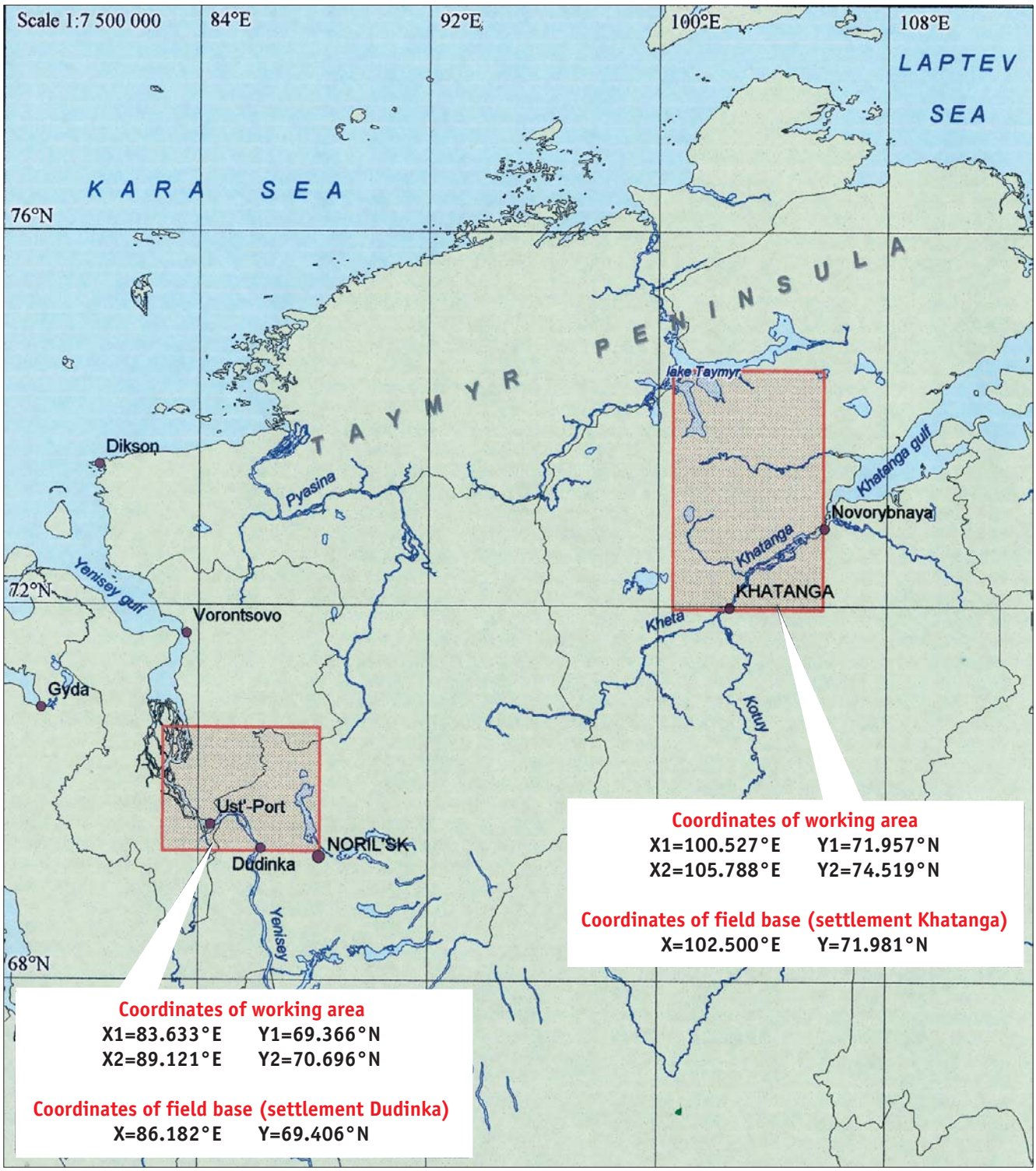


Figure 5.3. Location of the environmental sampling areas on the Taymir peninsula.

For these reasons, in addition to the main field sampling expeditions undertaken, additional field work in Chukotka was arranged in order to sample marine species (and particularly marine mammals) over the area shown in Figure 5.5.

The number and type of environmental samples were selected in accordance with the stated objectives of the activity. i.e., to study biomagnification in food chains and to measure PTS levels in traditional food sources of selected indigenous communities. Sampling of environmental media was designed to ensure that reliable data could be obtained for average concentrations of selected contaminants at the sample sites. For example, pooled water samples, which combined a number of replicated samples taken at different depths within the water column (e.g. sub-surface, middle and bottom), were utilized. A similar approach, i.e. using pooled samples, was employed for the lower trophic levels of food chains, and in particular for vegetation such as lichens, mosses, and mushrooms.

For biota species at higher trophic levels, specific organs and tissues known to be important with respect to PTS accumulation, were sampled. Tissue and organ

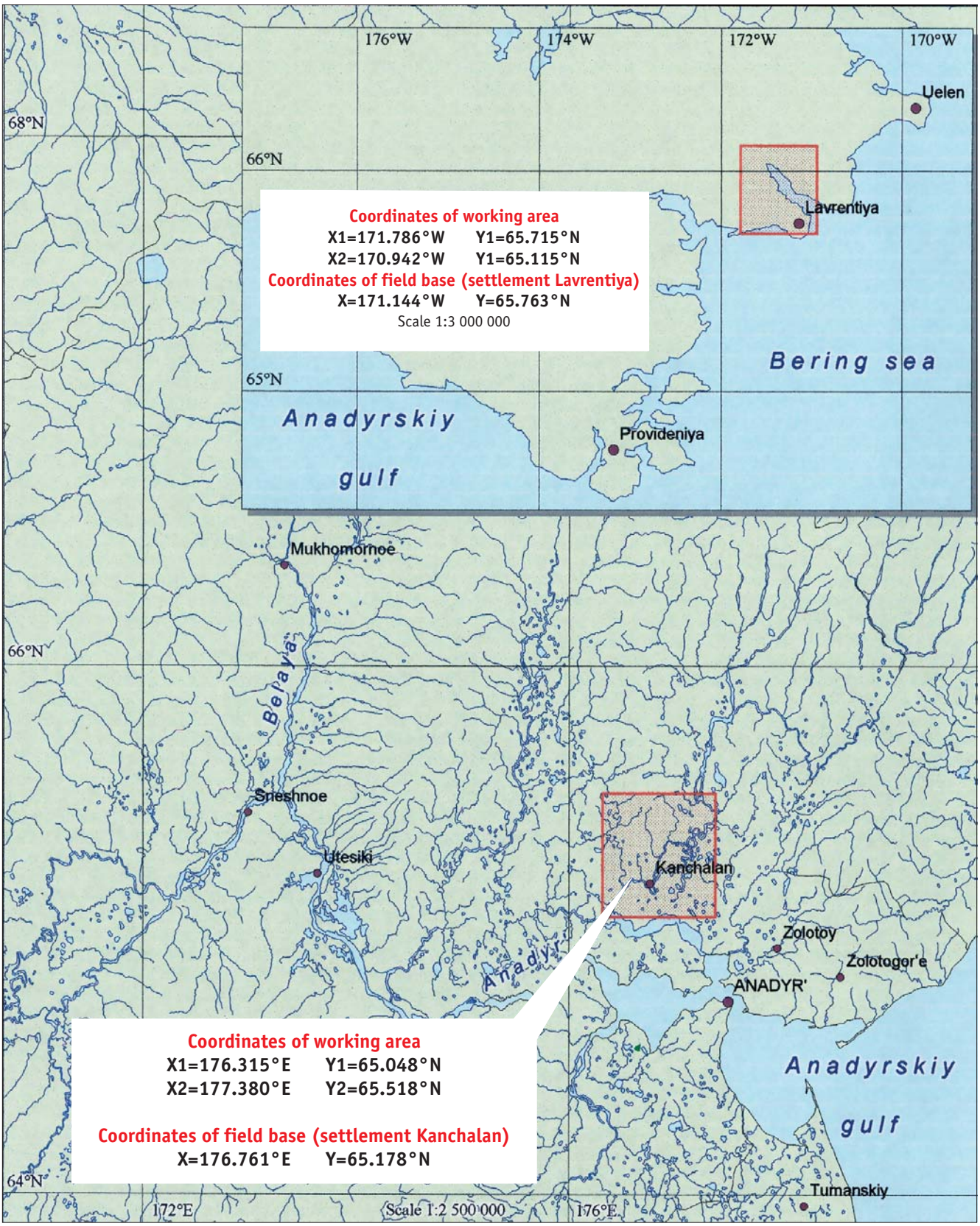


Figure 5.4. Location of the environmental sampling areas on the Chukotka peninsula.

samples from animals of the same sex and similar age groups were then pooled. An exception to this approach was made in the case of marine mammals, which feed at the top of (in some cases, long) marine food chains and can accumulate particularly high levels of lipophilic contaminants, including organochlorines, due to the high fat content in their bodies, and also high levels of methyl mercury. For these animals, samples were treated and analyzed individually and not pooled. All samples were frozen immediately after delivery to the field camp, and stored frozen until shipped to the laboratory. Samples pooling took place in the laboratory as a part of sample treatment prior to analysis.

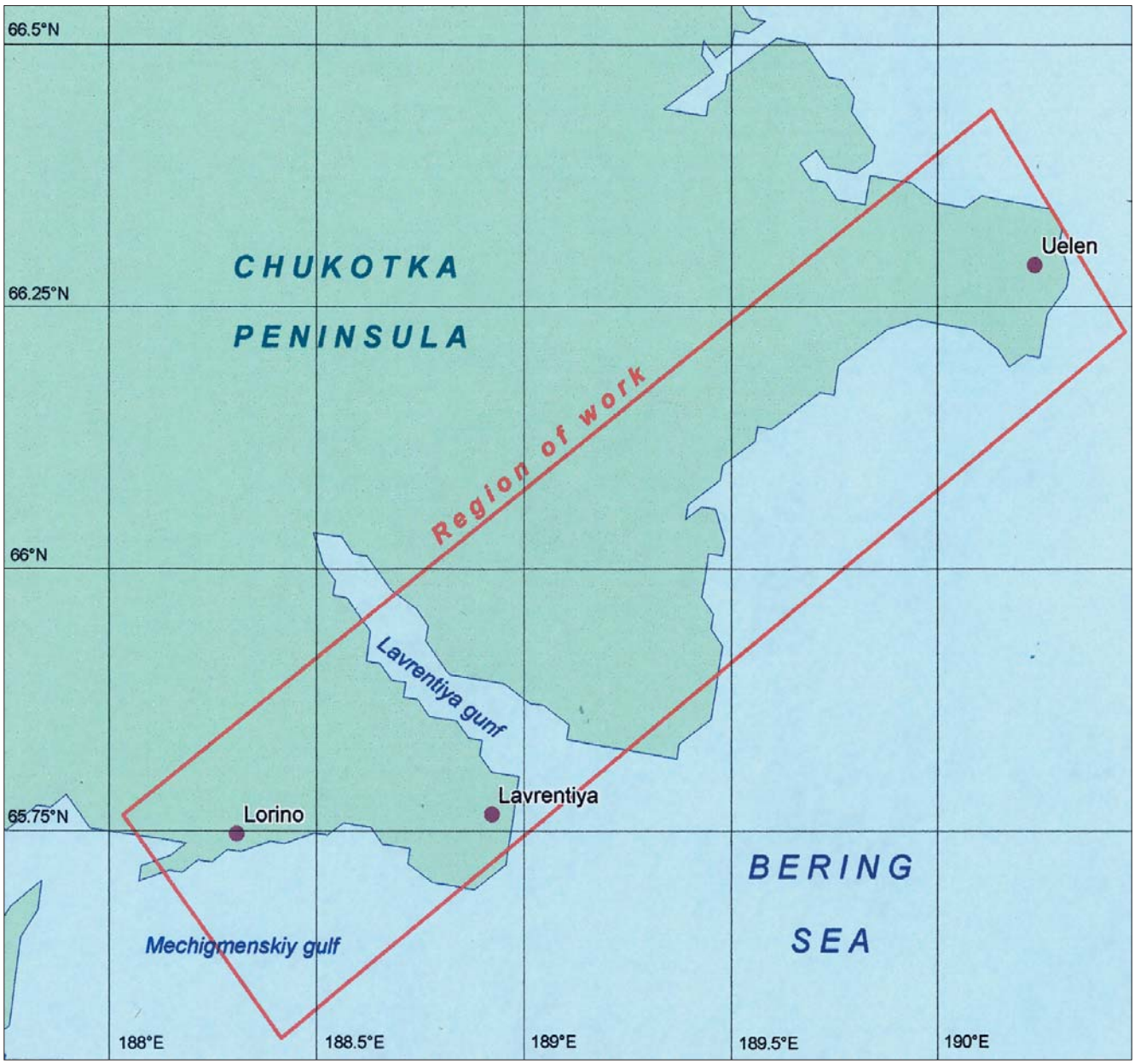


Figure 5.5. Location of the area in which marine food chain species were collected around the Chukotka peninsula.

Table 5.1 contains a list of environmental samples collected during field work, and a list of the pooled and individually analyzed samples of environmental media and biota is presented in Table 5.2.

5.2. Analytical methods and quality control

The analytical methods used for PTS determination in individual and pooled environmental and biotic samples were based on internationally recognized methodologies (ISO methods 8288:1986, 6468:1996, 5666:1983, 10382, 11048:1995, 10382, 19258, 14653-2; US EPA methods 200, 245.5, 245.6, 508, 525.1, 550, 608, 680, 8082, 8275a, 8290a, 8310a, PP-006; ASTM methods D 3534-85, D 3557-95, D 3559-96, D 5175-91, D 5412-93, D-5673-96, D5812-96; JAMP, 1999a and 1999b; NOAA, 1998; UNEP, 1993) also taking into account AMAP recommendations. Russian standard methodologies, as certified by the Russian State Standardization Committee (Gosstandart), were also used when appropriate (GOST 17.4.4.02-84, 26929-86, 26927-86, 26932-86, 26933-86, 7636-85, PND F 14.1:2:4.124-97, 14.2:4.74-96, 16.1.7-97, 16.1.4-97 14.2:4.70-96, RD 52.10.556-95, 52.18.180-89, 52.18.578-97, 52.44.590-97, 52.18.191-89, 52.44.592-97).

5.2.1. Quantitative determination of chlorinated and brominated organic compounds

Conventional extraction and clean-up procedures were utilised in the analytical treatment of samples. Extraction efficiency was checked by introducing internal standards (PCB-198 and dibromo-octafluorodiphenyl (DBOF)) prior to extraction.

Quantitative analysis of organochlorines (OC) was performed using gas chromatography (GC) with an electron capture detector (ECD). In addition, gas chromatography with mass spectroscopy (GC-MS) was employed for samples with an anomalous composition

Table 5.1.
List of environmental media and biotic samples obtained in the project study areas.

Environment	Sample (species)	Type (organ/ tissue)	Number of samples						
			Kola	Pechora	Taymir-Dudinka	Taymir-Khatanga	Chukotka-coastal/marine	Chukotka-Kanchalan	Total
Terrestrial	Soil	Upper layer	30	30	30	30	30	30	180
		Column	10	10	5	5	5	5	40
	Moss		20	20	20	20	20	20	120
	Lichen		20	20	20	20	20	20	120
	Berries	2 types	16 + 4	10 + 10	20 + 0	10 + 8 + 6	12 + 8	10	114
	Mushrooms	2 types	8 + 0	10 + 10	4 + 0	12 + 0	12 + 0	—	56
	Ptarmigan	Muscle	20	20	20	20	20	20	120
		Liver	20	20	20	20	20	20	120
	Water-fowl	Muscle	16	15	20	20	20	12	103
		Liver	16	15	20	20	20	12	103
	Hares	Muscle	10	15	15	14	—	15	69
		Liver	10	15	15	14	—	15	69
		Kidneys	10	15	15	14	—	15	69
	Reindeer	Muscle	10	15	10	10	10	10	65
		Liver	10	15	10	10	10	10	65
		Kidneys	10	15	10	10	10	10	65
Freshwater	Water		9	8	8	8	—	8	41
	Sediments		10	10	10	10	—	10	50
	Benthos		10	2	3	3	—	—	18
	Fish (3 species in each area)	Muscle	20 x 3	20 x 3	20 x 3	20 x 3	—	20 x 3	300
		Liver	20 x 3	20 x 3	20 x 3	20 x 3	—	20 x 3	300
Marine	Water		—	—	—	—	9	—	9
	Sediments		—	—	—	—	10	—	10
	Seaweed		—	—	—	—	20	—	20
	Fish (5 species)	Muscle	—	—	—	—	151	—	151
		Liver	—	—	—	—	151	—	151
	Ringed seal	Fat	—	—	—	—	14	—	14
		Muscle	—	—	—	—	14	—	14
		Liver	—	—	—	—	14	—	14
		Kidneys	—	—	—	—	14	—	14
	Other seal species	Fat	—	—	—	—	28	—	28
		Muscle	—	—	—	—	28	—	28
		Liver	—	—	—	—	28	—	28
		Kidneys	—	—	—	—	28	—	28
	Walrus	Fat	—	—	—	—	22	—	22
		Muscle	—	—	—	—	22	—	22
		Liver	—	—	—	—	22	—	22
		Kidneys	—	—	—	—	22	—	22
	Gray whale	Fat	—	—	—	—	8	—	8
		Muscle	—	—	—	—	8	—	8
		Liver	—	—	—	—	8	—	8
		Kidney	—	—	—	—	8	—	8
Total:			**389**	**420**	**395**	**404**	**846**	**362**	**2816**

or high concentrations of pollutants, to confirm the presence of the substances under consideration. Samples in which brominated biphenyls and brominated diphenyl ethers were detected in significant concentrations, were also subjected to additional GS-MS examination.

Quantitative determination was made using an absolute calibration method, using target components and the (DBOF) internal standard that was added to the sample before its analysis.

Routine analyses were performed using a measurement system consisting of a *Fisons Mega-2* chromatograph with *ECD800* detector, and a chromatographic data processing system consisting of a *Multichrome-1.4* and *Kristall-2000M* chromatograph with electron capture detector, an automated sampler, and the chromatographic data processing software, *Chromatec Analytic 1.21.*

Analysis of chlorinated compounds by mass-spectrometry was carried out using a *Fisons 8060* gas chromatograph and an *MD800* mass spectrometer operating in the electron shock mode (70 eV). For brominated compounds, the comparable system comprised a *Carlo-Erba 8060* gas chromatograph and *MD800* mass spectrometer as above. Operational control of the above systems, recording of mass-spectra, and their subsequent processing was undertaken using the *MassLab1.3* software package, and the National Institute of Science and Technology (NIST) library of organochlorine compounds.

A measurement system consisting of a *Carlo Erba 8035* chromatograph, and an *Autospec-Ultima (VG)* high resolution mass-spectrometer, operating in electron impact mode (36 eV) and with a resolution of ≥10.000, was used for isomer-specific analysis of polychlorinated dibenzo-p-dioxin and dibenzofurans (PCDD/Fs), brominated compounds and

Table 5.2.
List of pooled or individually analyzed samples of environmental media and biota.

Environment	Sample (species)	Type (organ/ tissue)	Number of samples						
			Kola	Pechora	Taymir-Dudinka	Taymir-Khatanga	Chukotka-coastal/ marine	Chukotka-Kanchalan	Total
Terrestrial	Soil		5	1	1	2	1	1	11
	Moss		3	1	2	2	1	2	11
	Lichen		4	1	2	2	1	2	12
	Berries	2 types	2	2	1	2	2	2	11
	Mushrooms	2 types	1	2	1	1	1	—	6
	Ptarmigan	Muscle	2	2	2	2	2	2	12
		Liver	2	2	2	2	2	2	12
	Water-fowl	Muscle	4	4	5	7	3	8	31
		Liver	4	4	5	7	3	8	31
	Hares	Muscle	2	2	2	2	—	2	10
		Liver	2	2	2	2	—	2	10
		Kidneys	2	2	2	2	—	2	10
	Reindeer	Muscle	6	6	5	4	2	2	25
		Liver	6	6	5	4	2	2	25
		Kidneys	6	6	5	4	2	2	25
Freshwater	Water		4	3	2	2	—	1	12
	Sediments		1	1	1	1	—	1	5
	Fish (3 species in each area)	Muscle	12	13	14	16	—	10	65
		Liver	12	13	14	16	—	10	65
Marine	Water		—	—	—	—	3	—	3
	Sediments		—	—	—	—	1	—	1
	Seaweed		—	—	—	—	2	—	2
	Fish (5 species)	Muscle	—	—	—	—	18	—	18
		Liver	—	—	—	—	18	—	18
	Ringed seal	Fat	—	—	—	—	14	—	14
		Muscle	—	—	—	—	14	—	14
		Liver	—	—	—	—	14	—	14
		Kidneys	—	—	—	—	14	—	14
	Other seal species	Fat	—	—	—	—	28	—	28
		Muscle	—	—	—	—	28	—	28
		Liver	—	—	—	—	28	—	28
		Kidneys	—	—	—	—	28	—	28
	Walrus	Fat	—	—	—	—	22	—	22
		Muscle	—	—	—	—	22	—	22
		Liver	—	—	—	—	22	—	22
		Kidneys	—	—	—	—	22	—	22
	Gray whale	Fat	—	—	—	—	8	—	8
		Muscle	—	—	—	—	8	—	8
		Liver	—	—	—	—	8	—	8
		Kidney	—	—	—	—	8	—	8
Total:			80	73	73	80	352	61	719

toxaphenes. Separation of isomers was carried out in a 60 m non-polar *DB-5MS J&W Scientific* column.

All standard solutions of organochlorine pesticides and PCBs used for calibration were produced by Ultra Scientific (USA) and certified by ISO9001. Standards for toxaphenes, brominated diphenyl ethers, and brominated biphenyls were produced by St. Petersburg University.

5.2.2. Quantitative determination of heavy metals

Measurements of mercury were carried out using a (Russian) *Kvant-Z-ETA* atomic absorption spectrophotometer (analogous to the Western *Varian AA-8000* system), operating with a *GRG-106* mercury generator in automatic mode, using Zeeman background correction.

Mercury in samples was reduced to its metal state using tin dichloride, and then transferred in an argon gas flow ('Cold Vapor' method) to a graphite furnace, the internal surface of which was covered with a fine palladium layer to ensure mercury retention in the furnace. The detection limit for mercury in the solutions under consideration was 0.001 µg/L, with a relative error of 20% at this level of concentration.

Measurements of lead and cadmium were carried out using a *Kvant-Z-ETA* atomic absorption spectrophotometer, with electrochemical atomization of the sample, using Zeeman background correction and a constant aliquot volume of 5 µL of sample solution. Prior to any measurements, a palladium modifier (at a concentration of 20 µg/L (Pd)) was added to the samples.

5.2.3. Quantitative determination of polyaromatic hydrocarbons (PAHs)

Determination of PAHs in all samples involved liquid extraction, followed by clean-up of extracts to remove substances that could cause interference during analysis. Octafluoronaphthalene (OFN) was introduced as an internal standard to check the extraction efficiency of PAHs.

PAH analytical determination was made using High Resolution Liquid Chromatography (HRLC), with target components registered by diode-matrix and fluorescent detectors connected in series. Quantification of PAH levels was made by absolute calibration, using standard solutions of target components and a control based on the internal standard (OFN) solution, which was added to the sample before its analysis. Analysis was performed using a measurement system consisting of an *HP1090M* chromatograph with a standard diode-matrix component, a *Spectraphysics* fluorescent detector with programmed excitation wavelength, and Hewlett-Packard hardware/software processing system for chromatographic data.

	Water	Bottom sediments	Soil	Vegetation	Reindeer	Hares	Birds	Fish	Marine mammals	Total
Heavy metals (HM)										
Analysis of blank samples	1	1	1	1	2	1	2	5	4	**18**
Analysis of replicate samples	1	1	3	1	2	1	2	5	4	**19**
Analysis of standard solutions	—	1	—	—						**1**
Analysis of samples with addition of target components					2	1	2	6	4	**15**
Polycyclic aromatic hydrocarbons (PAHs)										
Analysis of blank samples	1	1	1	1	2	1	2	5	4	**18**
Analysis of replicate samples	1	1	3	1	2	1	2	5	4	**19**
Analysis of standard solutions	—	1	—	—						**1**
Analysis of samples with addition of target components					2	1	2	6	4	**15**
Organochlorines: polychlorinated biphenyls (PCBs)										
Analysis of blank samples	1	1	1	1	2	1	2	5	4	**18**
Analysis of replicate samples	1	1	3	1	2	1	2	5	4	**19**
Analysis of standard solutions	—	1	—	—						**1**
Analysis of samples with addition of target components					2	1	2	6	4	**15**
Chlorobenzenes, polybrominated biphenyl and diphenyl ethers, polychlorinated camphenes (PCCs)										
Analysis of blank samples	1	1	1	1	2	1	2	5	4	**18**
Analysis of replicate samples	1	1	3	1	2	1	2	5	4	**19**
Analysis of standard solutions	—	1	—	—						**1**
Analysis of samples with addition of target components					2	1	2	6	4	**15**
Organochlorines: HCHs, DDTs, cyclodienes										
Analysis of blank samples	1	1	1	1	2	1	2	5	4	**18**
Analysis of replicate samples	1	1	3	1	2	1	2	5	4	**19**
Analysis of standard solutions	—	1	—	—						**1**
Analysis of samples with addition of target components					2	1	2	6	4	**15**
Chlorinated dibenzodioxins and dibenzofurans										
Analysis of blank samples						1		1		1		
Analysis of replicate samples						0		0		0		
Analysis of standard solutions										
Analysis of samples with addition of target components						1		1		1		

Table 5.3. Quality control analyses performed as part of the analysis of environmental and biotic samples.

Table 5.4.
Comparison of concentrations of brominated compounds in environmental and biotic samples obtained by routine GC, and by high resolution GC-MS methods. TeBD=tetra brominated diphenyl, PeBD=pentabrominated diphenyl, TeBDE=tetrabrominated diphenyl ether, PeBDE=pentabrominated diphenyl ether.

Samples	Routine GC method				High resolution GC-MS method			
	TeBD	PeBD	TeBDE	PeBDE	TeBD	PeBD	TeBDE	PeBDE
Bottom sediments, pg/g dw	< 200	< 200	< 200	< 200	< 2	< 2	3.1 - 24.1	1.0 - 3.0
Soil, pg/g dw	< 200	< 200	< 200	< 200	< 2	< 2	1.5 - 5.4	1.2 - 2.7
Mosses, pg/g dw	< 200	< 200	< 200	< 200	< 2	< 2	7.2 - 11.9	6.2 - 10.9
Lichens, pg/g dw	< 200	< 200	< 200	< 200	< 2	< 2	20.7 - 29.4	5.1 - 10.2
Berries, pg/g ww	< 200	< 200	< 200	< 200	< 2	< 2	3.2 - 21.8	1.0 - 9.5
Reindeer kidney, pg/g ww	< 200	< 200	< 200	< 200	< 2	< 2	136.2 - 233.3	5.1 - 7.1
Hare liver, pg/g ww	< 200	< 200	< 200	< 200	< 2	< 2	123.1 - 258.9	3.1 - 6.5
Fish liver, pg/g ww	< 200	< 200	420	< 200	6.7	< 2	620.2	8.9

All standard solutions for PAHs used for calibration were produced by Ultra Scientific (USA) and certified by ISO9001. The octafluoronaphthalene standard was produced by St. Petersburg University.

5.2.4. Quality control

Analytical quality control and quality assurance involved the execution of a full programme of work including analyses of blank samples, standard solutions, replicate samples, samples spiked with target components, and analysis of samples of different matrix compositions containing known levels of the determined components (Table 5.3). In addition, laboratories involved in the work participated in international intercalibration exercises within the framework of the 'QUASIMEME' Programme, and the AMAP Ring Test on analysis of POPs in human blood samples.

Under an arrangement made through the AMAP Secretariat, the laboratory responsible for analysis of environmental and biotic samples participated in the first stages of Rounds 22, 24 and 25 of the laboratory performance studies organized by 'QUASIMEME'. These concerned the analysis of bottom sediments and biota samples for levels of PAHs, OCs and HMs (Rounds 22 and 24), and the analysis of samples of sea and estuarine waters for OCs, HM and mercury (Round 25).

Calibration standards used were the Russian State Certified Standards and certified standards produced in other countries (by ULTRA Scientific, Wellington Laboratories, etc.). Previously analyzed samples, spiked with specific components at levels approximately 2-4 times greater than those detected during their original analysis, were employed as matrix samples containing known levels of the determined components. In addition, residual material from test samples distributed as part of the 'QUASIMEME' laboratory performance studies, with known composition and published 'assigned' concentration values, were also used as control samples.

As concentrations of toxaphenes, brominated diphenyl ethers and brominated biphenyls in most pooled samples were found to be very low (below the levels of reliable determination for these compounds using routine methods), 40 samples (6 bottom sediment, 6 soil, 6 lichen, 6 berry, 3 reindeer kidney, 4 hare liver, and 3 fish liver samples) were sent for control analysis using high resolution GC-MS (*Carlo Erba 8010/Autospec Ultima V6* system, described above) (Table 5.4). The control analyses confirmed the validity of the data obtained using the routine methods.

5.2.5. Processing and presentation of analytical results

Results of analyses were grouped according to sampling site and sample types. Concentrations of individual compounds within related groups of substances were summed to provide a total value for the group. For purposes of calculation, where results were below the detection limit, a value of half the detection limit was used if this did not contribute more than 20% of the summed value; otherwise no sum was calculated.

Sums were calculated for the following groups of substances:
ΣHCH: the sum of α-, β- and γ-isomers of HCH.
ΣDDT: the sum of *o,p'*- and *p,p'*-DDT, -DDE, -DDD.
ΣCHLOR: the sum of *cis*- and *trans*-chlordane and *cis*- and *trans*-nonachlor.
ΣPCB_{15}: the sum of 15 PCB congeners (#28, #31, #52, #99, #101, #105, #118, #128, #138, #153, #156, #170, #180, #183, and #187).
ΣPCB_{7}: the sum of 7 PCB congeners (#28, #52, #101, #118, #138, #153, and #180); calculated to allow comparison with data obtained in the Russian North in 1994/1995.
Toxaphene: the sum of Parlar-26, Parlar-50, and Parlar-62.
ΣPCDD/F: the sum of all 2,3,7,8-substituted congeners of dibenzo-*p*-dioxin and dibenzofuran.

Environmental contaminants commonly exhibit a log-normal frequency distribution in their concentration values (WHO, 1983). A log-normal distribution was therefore assumed to apply for concentrations of a particular contaminant (and concentration ratios) within any given sample type collected at a particular site. In most cases, therefore, data are reported as the geometric mean concentration (or ratio) and the associated standard deviation. Arithmetic mean concentrations and standard deviations were only calculated when concentration variability was low (i.e. where the standard deviation was less than 30% of the mean for most contaminants). This latter calculation, however, facilitated comparison with results from other studies, where PTS concentrations are commonly reported in terms of mean values and their standard deviations.

Sample type	Area	ΣPCB$_{15}$	ΣPCB$_7$	ΣHCB	ΣHCH
Lichens	Kola Peninsula, n=4	3.9±0.3	2.8±0.2	0.5 (0.1-0.9)[a]	0.53±0.17
	Pechora basin, n=1	3.2	2.3	1.25	0.74
	Taymir, west, n=2	3.5±0.3	2.5±0.2	0.5±0.1	1.4±0.5
	Taymir, east, n=2	3.5±0.6	2.5±0.4	1.0±0.2	1.6±0.4
	Chukotka, inland, n=2	3.4±0.5	2.2±0.2	0.4±0.1	0.89±0.08
	Chukotka, coast, n=1	3.9	2.5	0.15	0.76
Mosses	Kola Peninsula, n=3	12.6±0.1	9.1±0.1	0.2(0.1-0.45)[a]	0.8±0.2
	Pechora basin, n=1	7.7	6.2	0.95	1.4
	Taymir, west, n=2	11.8±1.8	9.0±1.2	1.0±0.3	2.3±0.5
	Taymir, east, n=2	10.3±0.5	7.7±0.1	0.7±0.1	1.9±0.2
	Chukotka, inland, n=2	13.1±1.0	9.6±0.5	0.5±0.2	0.69±0.04
	Chukotka, coast, n=1	13.1±1.0	10.5	0.24	0.5
Berries	Kola Peninsula, n=2	1.2 – 1.8[a]	1.1±0.2	0.18±0.04	0– 0.4[a]
	Pechora basin, n=2	1.4 – 1.8[a]	1.3±0.1	0.25±0.05	0.1 – 0.5[a]
	Taymir, west, n=1	4.4	3.25	0.21	0– 0.40[a]
	Taymir, east, n=2	1.5 – 3.0[a]	1.2±0.1	0.18±0.01	0– 0.5[a]
	Chukotka, inland, n=2	1.1 – 2.1[a]	1.1±0.1	0.19±0.08	0– 0.6[a]
	Chukotka, coast, n=2	1.0 – 1.5[a]	1.0±0.1	<0.1-0.15[a]	0– 0.40[a]
Mushrooms	Kola Peninsula, n=1	0.5 – 1.7[a]	0.4 – 0.9[a]	0.11	0– 0.4[a]
	Pechora basin, n=2	0.7 – 2.0[a]	1.0±0.2	0.20±0.05	0.1 – 0.5[a]
	Taymir, west, n=1	1.4 – 2.3[a]	1.2	0.14	0.1 – 0.4[a]
	Taymir, east, n=1	0.9 – 1.8[a]	0.88	0.14	0– 0.4[a]
	Chukotka, coast, n=1	0.5 – 1.7[a]	0.2 – 0.7[a]	0.05	0– 0.4[a]

Table 5.5a.
Concentrations (mean and standard deviation, or range; ng/g dw) of OCs in vegetation in the Russian Arctic in 2001.
[a] A range is given when the standard deviation is greater than 50% of the mean, or the concentration in one of the samples is below the detection limit. When lower and upper limits of the concentration interval were estimated for summed concentrations, any individual values that were below the detection limit were either set to zero or to the detection limit (see Section 5.2.5).
n = number of pooled samples analyzed.

5.3. Results – Terrestrial environment

5.3.1. PTSs in plants and mushrooms

The following species were collected and analysed for PTSs:
Lichens – *Cetraria cuculata, Cetraria islandica, Cladina rangiferina, Cladina alpica, Cladina stellaris, Cladina mitis*;
Bryophytes – *Polytrichum commune, Pleurozium schreberi*;
Mosses – *Dicranum sp., Sphagnum balticum, Hylocomium splendens*;
Berries – low-bush cranberry (*Vaccinium vitis-idaea*), cloudberry (*Rubus chamaemorus*), bilberry (*Vaccinium myrtillus*), blueberry (*Vaccinium uliginosum*), crowberry (*Empetrum nigrum*);
Mushrooms – orange-cap boletus (*Leccinum aurantiacum*), brown-cap boletus (*Leccinum scabrum*), mossiness mushroom (*Xerocomus sp.*).

The number of individual samples of each vegetation type collected at a given site and used in the preparation of a pooled sample was usually 10, but ranged between 4 and 20 (see Table 5.1). Vegetation was analysed for all PTS listed in Section 1.2.4.

Levels and trends

(a) Organochlorines

Concentrations of organochlorines (OCs) in vegetation that significantly exceeded detection limits are shown in Tables 5.5a and 5.5b. Data for those OCs which occurred at concentrations below the detection limit in most samples are not presented. The level of HCB was above the detection limit in all samples of plants and mushrooms. ΣPCB$_{15}$ and ΣPCB$_7$, ΣDDT and ΣHCH were detectable in all samples of lichens and mosses and ΣPCB$_7$ and ΣDDT also in most of the berry

Sample type	Area	*p,p'*-DDE	*p,p'*-DDT	ΣDDT	Mirex
Lichens	Kola Peninsula, n=4	0.24±0.07	0.4±0.1	1.0±0.3	<0.1
	Pechora basin, n=1	0.75	0.80	2.2	0.52
	Taymir, west, n=2	1.2±0.6	1.3±0.3	3.1±0.3	0.18±0.03
	Taymir, east, n=2	0.71±0.13	0.9±0.3	2.9±0.8	<0.1 – 0.3[a]
	Chukotka, inland, n=2	0.30±0.03	0.62±0.12	1.39±0.03	<0.1
	Chukotka, coast, n=1	0.24	0.67	1.2	<0.1
Mosses	Kola Peninsula, n=3	0.3±0.1	0.4±0.1	1.3±0.1	0.15±0.06
	Pechora basin, n=1	0.72	0.77	2.3	0.44
	Taymir, west, n=2	<0.05 – 1.1[a]	1.1±0.3	2.6±0.5	0.5±0.2
	Taymir, east, n=2	0.7±0.1	0.9±0.2	3.0±0.2	0.20±0.02
	Chukotka, inland, n=2	0.3±0.1	0.60±0.03	1.4±0.1	<0.1
	Chukotka, coast, n=1	0.20	0.39	1.0	<0.1
Berries	Kola Peninsula, n=2	<0.1-0.12	1.09±0.04	1.59±0.02	<0.1
	Pechora basin, n=2	<0.1	0.17±0.06	0.1-0.7[a]	<0.1
	Taymir, west, n=1	0.15	0.28	1.1	<0.1
	Taymir, east, n=2	<0.1-0.13	0.1-0.9[a]	0.1–1.5[a]	<0.1
	Chukotka, inland, n=2	0.13±0.03	0.13±0.03	0.1 –0.7[a]	<0.1
	Chukotka, coast, n=2	<0.1-0.1	<0.1-0.1	0.1 –0.6[a]	<0.1
Mushrooms	Kola Peninsula, n=1	0 – 0.12[a]	0.28	0.4 – 0.8[a]	<0.1
	Pechora basin, n=2	<0.1	<0.1	0– 0.6[a]	<0.1
	Taymir, west, n=1	0.1	0.18	0.5 – 0.8[a]	<0.1
	Taymir, east, n=1	<0.1	0.18	0.3 – 0.7[a]	<0.1
	Chukotka, coast, n=1	<0.1	<0.1	0– 0.6[a]	<0.1

Table 5.5b.
Concentrations (mean and standard deviation, or range; ng/g dw) of OCs in vegetation in the Russian Arctic in 2001.
[a] A range is given when the standard deviation is greater than 50% of the mean, or the concentration in one of the samples is below the detection limit. When lower and upper limits of the concentration interval were estimated for summed concentrations, any individual values that were below the detection limit were either set to zero or to the detection limit (see Section 5.2.5).
n = number of pooled samples analyzed.

and mushroom samples. The ΣPCB_7 value, when multiplied by two, can be used to provide an estimate of the total PCB concentration in mosses and, most likely, also in other plants (AMAP, 1998). Of the DDT group, only *p,p'*-DDT occurs in detectable concentration in all berry and most mushroom samples. ΣDDT concentration in berries and mushrooms were therefore estimated using the ratio of *p,p'*-DDT/ΣDDT found in lichens and mosses (0.39±0.07). This probably provides a conservative estimate as, at the three sites where ΣDDT in berries could be calculated directly, this ratio was equivalent to 0.5±0.2.

Concentrations of HCB, HCH, and DDT in mosses are comparable to those in lichens, while PCB levels are 2-4 times higher in mosses at all sites. Concentrations of these substances in berries and mushrooms are several times lower than those found in mosses and lichens.

Levels of HCB, HCH, and DDT follow a similar geographical trend, with highest levels found at the two locations on the Taymir Peninsula, and in the lower Pechora basin. In contrast, no geographical trend in PCB levels was observed. With only one exception (berries from Dudinka), all differences in PCB concentrations between the sites could be explained by analytical variability.

PCB levels in the Arctic have been found to be generally decreasing over time. Over the last few years, however, the rate of decrease has been small and levels have remained relatively constant (AMAP, 2002). In accordance with this tendency, mean ΣPCB_7 concentrations measured in 2001 in samples of lichens collected near Khatanga, in eastern Taymir (2.5 ng/g) and at Chukotka (2.2 and 2.5 ng/g) were slightly lower than those determined in these areas in 1995 (3.2 and 3.82 ng/g, respectively) (AMAP, 1998). In contrast, the ΣPCB_7 concentration for lichens from the Pechora basin in 1995 was below the detection limit, while 2.3 ng/g was found in 2001. An unexpected increase was also observed in the ΣPCB_7 concentration in mosses, which in 1994/1995 in the Russian North ranged from 0 to 3.6 ng/g (0–02.4 ng/g on the Taymir Peninsula; and below the detection limit in the Pechora basin). The ΣPCB_7 concentration in mosses in 2001 is significantly higher (10.3–013.9 ng/g).

The PCB congener patterns seen in lichens differ significantly from those occurring in most of the common technical mixtures used in Western countries. In Western products, PCB-138 and 153 dominate, while in the environment of Russian Arctic, PCB-28 makes the greatest contribution to the summed value in samples from all sites. However, relative levels of the congeners PCB-28, 52, 118, 138, 153 and 180 found in remote Arctic areas of North America also differ from those found in American technical mixtures (Wilcke and Amelung, 2000) and are close to those found in the Russian Arctic. Therefore, the PCB composition patterns provided in Figure 5.6 could also be a result of the fractionation of congeners during long-range transport.

Concentrations of ΣCBz (sum of HCB and pentachlorobenzene (PeCBz), not shown in tables) measured in plants in this study, in 2001, are distinctly higher than levels previously reported for the Russian North (see Figure 5.7). In August 1995, on the Taymir Peninsula, concentrations of 0.25 and 0.4 ng/g of ΣCBz were found in lichens and mosses, respectively (AMAP, 1998). Mean concentrations of ΣCBz in lichens and mosses obtained during the current study at two sites on the Taymir Peninsula, were 0.64±0.16 and 1.3±0.3 ng/g, and 0.9±0.1 and 1.4±0.2 ng/g, respectively. Concentration of ΣCBz in 3 samples of lichen collected near Khatanga in 1995 (AMAP, 1998) ranged from 0.16 to 0.66 ng/g, while concentrations of 1.2-1.5 ng/g ΣCBz were found at Khatanga in 2001 (see Figure 5.7). In the Pechora basin, mean ΣCBz concentrations in lichens and mosses in 1994/1995 ranged from 0 (i.e., below the detection limit) to 0.08 ng/g (AMAP, 1998), whilst in 2001 values of 0.2–1.0 ng/g were found. Thus, a comparison of the data obtained in 1994/1995 and in 2001, indicates that the concentration of chlorinated benzenes in lichens and mosses (and by inference in air) in the Russian North has shown a tendency to increase during recent years.

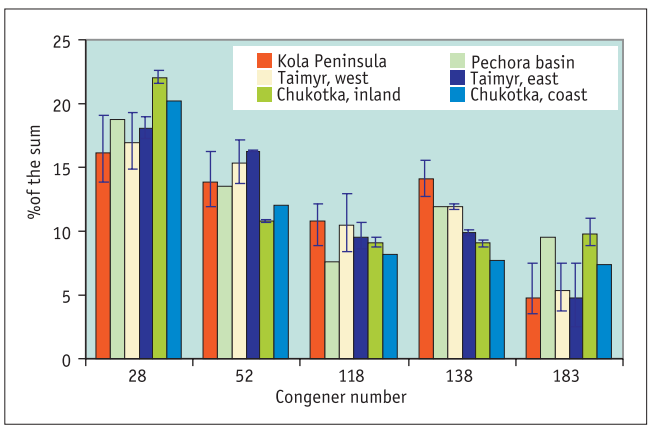


Figure 5.6. PCB congener contributions to ΣPCB_{15} levels in lichen in the Russian Arctic in 2001. The congeners shown are the main contributors within each homologue group.

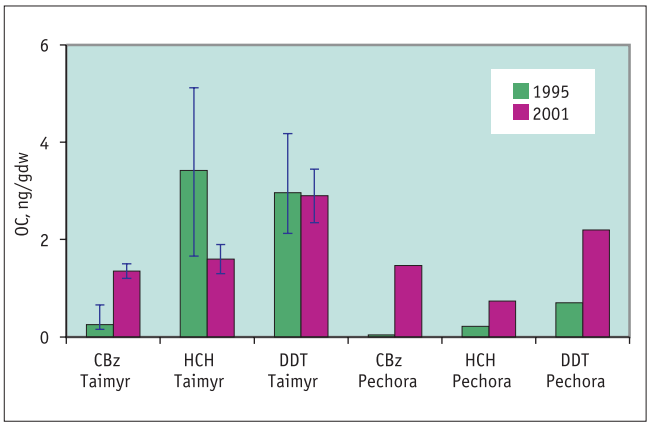


Figure 5.7. Mean values and ranges of OC concentrations measured in lichen in Eastern Taymir and the Pechora Basin in 1995 and in 2001. Values for Eastern Taymir were derived from the analysis of three samples in 1995, and two samples in 2001. CBz = sum of HCB and PeCBz, DDT=ΣDDT.

Sample type	Area	NAP	ACNLE	BIPN	NAP2M	FLE	ACNE	PA
Lichens	Kola Peninsula, n=4	179 (124-258)	1.3 (<0.5–7.9)	1.5 (<0.5–10)	45 (33-65)	12 (5.8-22)	1.2 (<0.5–5.7)	75 (33-142)
	Pechora basin, n=1	188	10.0	13.1	30	5.3	<0.5	237
	Taymir, west, n=2	177 (164-192)	8.5 (7.1-10.2)	7.4 (5.3-10.3)	29 (21-40)	9.8 (8.2-11.6)	<0.5	31 (26-38)
	Taymir, east, n=2	315 (262-378)	9.2 (6.8-12.5)	39 (33-45)	73 (59-91)	18 (15-21)	4.7 (3.5-6.3)	123 (105-144)
	Chukotka, inland, n=2	79 (63-100)	<0.5	<0.5	13 (11–14)	8.7 (6.8-11)	<0.5	65 (61-70)
	Chukotka, coast, n=1	505	7.9	<0.5	71	21	8.7	129
Mosses	Kola Peninsula, n=3	174 (86-432)	17 (13-21)	37 (28-50)	60 (48-78)	26 (20-35)	6 (4.2-9.8)	141 (110–166)
	Pechora basin, n=1	335	16	<0.5	91	13	<0.5	131
	Taymir, west, n=2	626 (512-765)	23 (16-35)	116 (102-132)	64 (54-75)	19 (19 –20)	6.5 (5.8-7.4)	66
	Taymir, east, n=2	275 (261-290)	11 (8.8-15)	35 (30-40)	208 (177-245)	13 (8.9-18)	<0.5	64
	Chukotka, inland, n=2	123 (112-134)	26 (24-28)	15 (13-17)	20 (19-21)	8.5 (7.8-9.2)	<0.5	61
	Chukotka, coast, n=1	144	<0.5	<0.5	28	27	5.0	136

Table 5.6a. Concentrations (geometric means and ranges; ng/g dw) of PAHs[a] in vegetation in the Russian Arctic in 2001.
[a] NAP = Naphthalene, ACNLE = Acenaphthylene, BIPN = Biphenyl, NAP2M = 2-Methylnaphthalene, FLE = Fluorene, ACNE = Acenaphthene, PA= Phenanthrene.

The mean ΣHCH concentration in 3 samples of lichens collected near Khatanga in 1995 (AMAP, 1998) was twice as high as those measured in the current study in the same area (3.42 and 1.6 ng/g, respectively). In contrast, ΣHCH concentrations in lichens and mosses in the Pechora basin in 1995 ranged from 0.17 to 0.38 ng/g, whilst concentrations of 0.74–1.4 ng/g were found in this area in 2001. Despite the difference in values, these results are unlikely to be indicative of a trend, as there is known to be a high degree of spatial variability in levels of contamination from HCH across the Russian North. In 1994/1995, the concentration of ΣHCH, as a function of sampling site, varied within two orders of magnitude, even for samples taken in the same area (AMAP, 1998).

No temporal trend in ΣDDT concentrations in lichens and mosses was evident in the Russian North. The mean concentration of ΣDDT in 3 samples of lichens collected near Khatanga in 1995 (AMAP, 1998) was almost the same as that found in 2001 (2.96 and 2.9 ng/g, respectively). The range of ΣDDT concentrations (0.7–3 ng/g) determined in lichens and mosses in five other areas in the Russian North in 1994/1995 (AMAP, 1998) is consistent with data obtained from the current study (1.0–3.1 ng/g). Concentrations of ΣDDT, ΣHCH, and ΣCBz found in lichens in the Russian Arctic in 2001 are all comparable with those found in the Canadian Arctic in 1993/4. PCB concentrations in Canada in 1993/4 were several times lower, while toxaphene levels were significantly higher, than those measured in Russia in 2001 (AMAP, 1998).

Mirex has not been used in the fSU/Russia. However, it does occur at detectable concentrations in some samples of lichens and mosses, presumably as a result of long-range atmospheric transport from remote sources. The geographical distribution pattern of Mirex is similar to that of ΣDDT, ΣHCH and HCB. In the most highly contaminated areas (the Pechora basin and the Taymir peninsula), Mirex concentration in lichens and mosses ranged from 0.2 to 0.5 ng/g. However, in the majority of samples collected in less contaminated areas (on the Kola peninsula, and Chukotka), Mirex concentrations were below the detection limit of 0.1 ng/g. The similarity between the spatial distribution observed for ΣDDT, ΣHCH, and HCB, and that of Mirex indicates that trans-boundary transport is at least an important source, and most likely the main source of contamination in the Russian Arctic for these compounds.

Samples of plants and mushrooms were also analyzed for other OCs listed in Section 1.2.4, with the exception of PCDD/Fs. Of these substances, only heptachlor was detected in some samples of lichen and mosses, in concentrations ranging from 0.1 to 0.3 ng/g. As all of these samples were collected in the Pechora basin and the Taymir peninsula, the spatial pattern of heptachlor distribution appears, at least qualitatively, similar to that of Mirex, ΣDDT, ΣHCH, and HCB.

Sample type	Area	ANT	FLU	PYR	BAA	CHR	BBF	BKF
Lichens	Kola Peninsula, n=4	2.0 (1.3-3.3)	41 (21-70)	18 (12-28)	1.2 (0.7-2.4)	16 (11-21)	14 (9.7-19)	3.7 (2.4-6.1)
	Pechora basin, n=1	2.3	14	2.7	1.0	18.2	4.0	1.6
	Taymir, west, n=2	1.6 (1.1-2.3)	7.6 (5.7-10.1)	6.2 (5.4-7.1)	0.7 (0.5-1.0)	12 (9.2-16)	2.5 (2.1-3.1)	1.0 (0.8 –1.2)
	Taymir, east, n=2	11 (9.0-12)	115 (85-152)	69 (54-88)	5.2 (3.6-7.3)	16 (12-20)	31 (27-35)	9.0 (6.6-12)
	Chukotka, inland, n=2	1.1 (0.8-1.4)	10 (8.8 –11)	7.4 (7.0-7.7)	0.6 (0.5-0.8)	3.8 (3.3-4.5)	2.6 (2.2-3.0)	1.1 (1.0-1.1)
	Chukotka, coast, n=1	2.8	27	13	1.5	9.6	2.3	2.2
Mosses	Kola Peninsula, n=3	1.3 (1.0-2.1)	18 (14-22)	15 (14-17)	2.8 (2.2-3.2)	12 (8.6-16)	6.8 (4.3-5.8)	4.8 (1.7-9.4)
	Pechora basin, n=1	1.7	13	10.4	1.3	17	6.1	3.1
	Taymir, west, n=2	3.9 (3.8-4.0)	12 (11-13)	18 (15-22)	1.0 (0.8-1.2)	6.2 (5.7-6.8)	2.3 (2.0-2.7)	1.2 (1.0-1.3)
	Taymir, east, n=2	9.3	45	47	6.5	21	20	11
	Chukotka, inland, n=2	0.7 (0.6-0.8)	9.2 (8.6-9.9)	5.6 (4.1-1.7)	0.5 (0.4-0.7)	12 (12-13)	3.0 (2.9-3.1)	1.0 (0.8-1.2)
	Chukotka, coast, n=1	2.4	12	16	1.1	17	10.4	4.3

Table 5.6b. Concentrations (geometric means and ranges; ng/g dw) of PAHs[a] in vegetation in the Russian Arctic in 2001.
[a] ANT= Anthracene, FLU = Fluoranthene, PYR = Pyrene, BAA = Benz[*a*]anthracene, CHR = Chrysene, BBF = Benzo[*b*]fluoranthene, BKF = Benzo[*k*]fluoranthene.

(b) PAHs

Geometric means and ranges of concentrations of PAHs in lichen and mosses are provided in Tables 5.6a and 5.6b. PAH composition is similar at all sites, with naphthalene, 2-methylnaphthalene and phenanthrene contributing 70-90% of the value of ΣPAH in both lichen and mosses. The highest concentrations, and especially those of heavier PAHs, are normally found near Khatanga. Lichens and mosses were also analyzed for benzo[*e*]pyrene, benzo[*a*]pyrene, perylene, dibenz[*ah*]anthracene, indeno[1,2,3-*cd*] pyrene and benzo[*ghi*] perylene. In the most cases, concentrations of these compounds were below the detection limit of 0.5 ng/g. Perylene, indeno[1,2,3-*cd*]pyrene and benzo[*ghi*] perylene were, however, found in concentrations which ranged from 1 to 10 ng/g in several samples, primarily from the Kola and Taymir peninsulas. A notable exception was the concentration of benzo[*ghi*]perylene found in mosses from Eastern Taymir, which was as high as 30 ng/g.

Naphthalene levels determined in berries and mushrooms are normally several times lower than those found in lichen and mosses. The difference in concentrations occurring between the two groups of plants increases with the molecular weight of the substance in question, and for the heaviest PAHs can be as much as two orders of magnitude. This may indicate that the greater efficiency of lichens and mosses for interception of gaseous and particulate PAHs from the air is partially offset by the ability of plants and mushrooms to take up PAHs with $\log K_{ow} < 4$ from the soil and translocate them to the aboveground parts of the plant (McLachlan, 1996).

(c) Brominated flame-retardants

Vegetation samples 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 all samples these substances were below the detection limit of 0.2 ng/g dw.

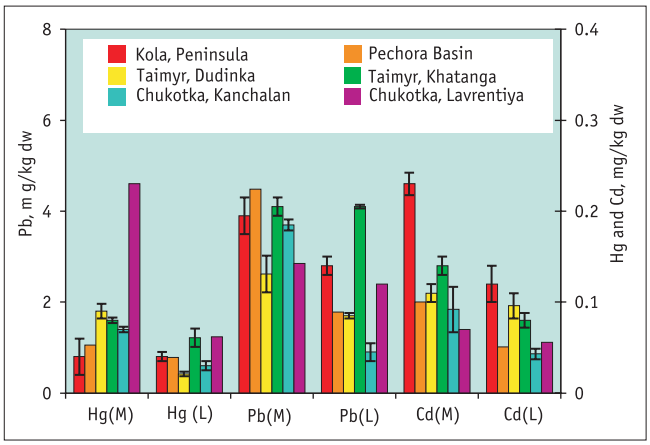


Figure 5.8. Concentrations of HMs in lichen (L) and mosses (M) in the Russian Arctic in 2001.

(d) Heavy metals

The heavy metals, mercury (Hg), lead (Pb) and cadmium (Cd) were detected in all samples of lichens, mosses and mushrooms (see Figure 5.8 and Table 5.7). In the majority of berry samples, Hg and Cd were below the detection limits (0.001 and 0.005 µg/g, respectively), while the Pb level was detectable in all samples. Pb concentrations ranged from 2.6 to 4.5 µg/g in mosses, from 0.9 to 4.1 µg/g in lichens, from 0.04 to 0.1 µg/g in mushrooms and from 0.01 to 0.05 µg/g in berries. Concentrations of Hg and Cd in samples of lichens and mosses ranged from 0.01 to 0.2 µg/g. No pronounced spatial trend was observed in HM contamination of lichens and mosses (see Figure 5.8). The relatively high Hg concentration in mosses collected at Chukotka is, very likely, due to a single anomalous sample, and was not confirmed by data for lichen from the same location. The only notable spatial tendency was a slight decreasing gradient in Cd concentrations from the Kola Peninsula towards Chukotka.

Table 5.7.
Concentrations (mean and standard deviations; µg/g dw) of HMs in vegetation in the Russian Arctic in 2001.
[a] Range is given when the standard deviation is greater than 50% of the mean, or the concentration in one of samples is below the detection limit.
[b] Concentration detected in both samples.

Sample type	Area	Hg	Pb	Cd
Lichens	Kola Peninsula, n=4	0.04±0.01	2.80±0.25	0.12±0.02
	Pechora basin, n=1	0.039	1.78	0.051
	Taymir, west, n=2	0.021±0.003	1.7±0.2	0.096±0.014
	Taymir, east, n=2	0.061±0.002	4.1±0.2	0.080±0.008
	Chukotka, inland, n=2	0.03±0.01	0.9±0.5	0.043±0.006
	Chukotka, coast, n=1	0.062	2.4	0.056
Mosses	Kola Peninsula, n=3	0.04±0.02	3.9±0.1	0.23±0.02
	Pechora basin, n=1	0.053	4.5	0.10
	Taymir, west, n=2	0.089±0.008	2.62±0.05	0.11±0.02
	Taymir, east, n=2	0.089±0.008	4.1±0.2	0.14±0.01
	Chukotka, inland, n=2	0.071±0.003	3.70±0.06	0.092±0.006
	Chukotka, coast, n=1	0.23	2.8	0.069
Berries	Kola Peninsula, n=2	<0.001	0.018±0.001	<0.005
	Pechora basin, n=2	<0.001	0.016±0.003	<0.005
	Taymir, west, n=1	<0.001	0.012	<0.005
	Taymir, east, n=2	<0.001	0.025±0.005	<0.005
	Chukotka, inland, n=2	<0.001	0.029±0.011	<0.005
	Chukotka, coast, n=2	<0.001	0.008 - 0.050[a]	0.008[b]
Mushrooms	Kola Peninsula, n=1	0.018	0.041	0.082
	Pechora basin, n=2	0.010±0.001	0.022 - 0.058[a]	0.086±0.026
	Taymir, west, n=1	0.041	0.072	0.072
	Taymir, east, n=1	0.023	0.097	0.060
	Chukotka, coast, n=1	0.007	0.072	0.032

Comparison between data obtained in 1995 (AMAP, 1998) and 2001, indicates that an increase in the Hg deposition rate in Chukotka may have taken place during this period. Hg levels in lichens and mosses in 1995 (0.02 and 0.03 µg/g, respectively) were several times lower than those found in 2001 (0.06 and 0.15 µg/g, respectively). A similar temporal trend in Hg concentration in lichen is observed on the Taymir Peninsula (0.01 µg/g in 1995, and 0.06 µg/g in 2001).

For the other HMs and sample sites, changes over time are less significant, with the exception of a decrease by an order of magnitude (from 0.9 to 0.06 µg/g) in Cd concentration in lichen from Chukotka. However, over the same period, an increase in Cd levels in mosses was also observed in this area. Given the similar pathways for Cd uptake in mosses and lichen, these results suggest that the above-mentioned differences in HM concentrations occurring between 1995 and 2001 are most likely a reflection of normal intersample variability. Similar to the majority of OCs, HM concentrations measured in lichen and mosses in Russia in 2001 are consistent with concentration ranges obtained in the Canadian Arctic in 1993/4.

5.3.2. PTS in reindeer

Samples of reindeer (*Rangifer tarandus*) tissues were collected at all 6 sites in the four regions. The number of individual tissue/organ samples collected at a given site and combined in the preparation of pooled samples was 2-3 in most cases, but ranged from 1 to 6 (see Table 5.2). Pooled samples were prepared from tissue samples of animals of the same sex and with an age difference of less than 2 years. The ages of animals ranged from 1 to 8 years, and equal numbers of animals of each sex were sampled at all sites, except for Western Taymir, where tissue samples from 3 male and 2 female reindeer were collected. Samples were grouped according to sex, (female and male), age group (1-3 years and 4-8 years), and tissue type (liver, kidney, or muscle). Reindeer muscle, liver and kidney were analysed for all PTS listed in Section 1.2.4.

PTS concentration relationships with reindeer sex, age, and tissue type

(a) Organochlorines

Concentration dependence on animal sex, age, and tissue type was investigated for OCs that exhibited concentrations above detection limits in most cases (*p,p'*-DDT, *p,p'*-DDE, PCB-118, PCB-153 and HCB).

Ratios of (geometric mean) concentrations of various OCs between male and female reindeer were in the range 1.1 to 1.3, and were found to be independent of site, age group, and tissue type. The difference between these values and unity had very low statistical significance and therefore mean concentrations were calculated using data for both sexes.

Similarly, differences in OC concentrations between the two age groups, and between different tissue types were not statistically significant, the ratios for 'old/young' reindeer groups ranging from 0.8 to 1.3 (1.1–1.3 for *p,p'*-DDT, *p,p'*-DDE, PCB-118 and PCB-153 and 0.8 for HCB).

The geometric mean of the liver/muscle lipid concentration ratios, from the data collected in this study, was 1.5. Based on this value, somewhat higher concentrations of OCs might be expected in liver tissue when compared with muscle. However, the geometric means of both the liver/muscle and kidney/muscle concentration ratios for all of the OCs investigated were close to unity and independent of site.

From these results, it was decided to calculate mean concentrations based on data from both age groups; values for OCs in muscle tissue only are presented in Tables 5.8a and 5.8b.

Area	ΣPCB_{15}	HCB	ΣHCH
Kola Peninsula, n=6	1.7 (1.2-2.47)	0.27 (0.13-0.45)	0.47 (0.2-0.9)
Pechora basin, n=6	2.2 (1.7-2.7)	0.18 (0.14-0.35)	0.54 (0.28-2.49)
Taymir, west, n=5	1.4 (1.1-2.0)	0.09 (<0.05-0.30)	0.42 (0.24-0.91)
Taymir, east, n=4	1.3 (0.59-4.3)	0.12 (<0.05-0.29)	0.55 (0.31-0.91)
Chukotka, inland, n=2	2.8 (1.9-4.0)	0.24 (0.21-0.28)	0.47 (0.42-0.53)
Chukotka, coast, n=2	1.3 (1.2-1.3)	0.06 (0.06-0.06)	1.18 (1.16-1.20)

Table 5.8a. Concentrations (geometric mean and range; ng/g ww) of OCs in muscle of reindeer in the Russian Arctic in 2001.

Area	*p,p'*-DDE	*p,p'*-DDT	ΣDDT
Kola Peninsula, n=6	0.11(<0.05-0.24)	0.17(0.10-0.28)	0.49(0.25-0.63)
Pechora basin, n=6	0.11(<0.05-0.22)	0.28(0.13-1.1)	0.59(0.37-1.3)
Taymir, west, n=5	0.10(<0.05-0.17)	0.24(0.18-0.46)	0.51(0.28-0.69)
Taymir, east, n=4	0.10(<0.05-0.17)	0.21(0.12-0.33)	0.56(0.50-0.64)
Chukotka, inland, n=2	1.2(0.96-1.4)	0.88(0.51-1.5)	2.65(2.07-3.4)
Chukotka, coast, n=2	0.19(0.19-0.20)	0.13(0.13-0.13)	0.44(0.43-0.45)

Table 5.8b. Concentrations (geometric mean and range; ng/g ww) of OCs in muscle of reindeer in the Russian Arctic in 2001.

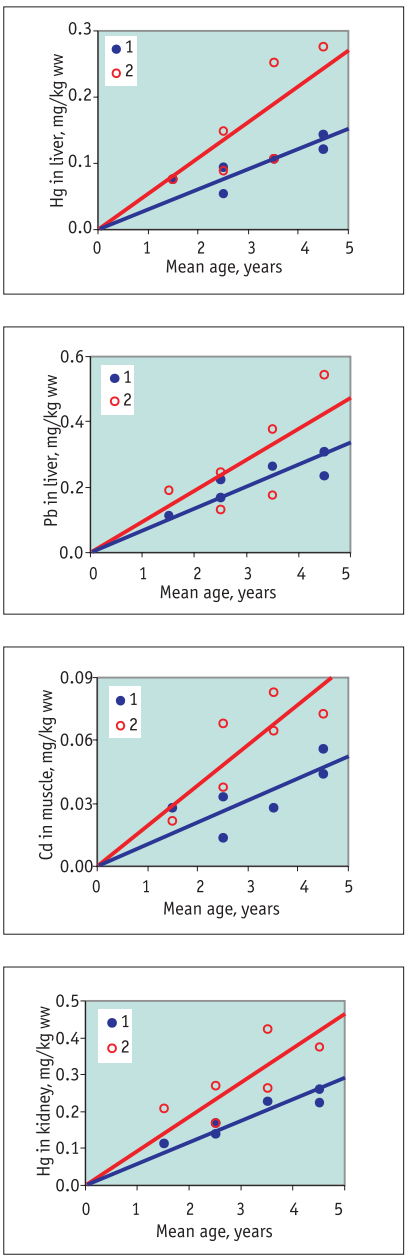
(b) Heavy metals

As for OCs, the concentrations of HMs in reindeer tissues do not show any significant sex dependence. However, a slight, but consistent increase in concentrations does occur with increasing age of the animals sampled. Concentration ratios between the two age groups (3 years and under, and over 3 years) are similar for all HMs, sites, and tissue types; the geometric means of the age ratios, calculated for almost 30 samples, equal to 1.8, 1.7 and 1.9 for Hg, Pb, and Cd, respectively. Figure 5.9 shows examples of age depend-

ency of HM concentrations in reindeer tissues for the two locations where samples included the greatest range of age groups. Similar relationships between concentrations and age are observed in samples from other sites. In all reindeer tissues, HM concentrations increase in direct proportion to the age of the animal sampled. This implies that the effective rate of HM accumulation in various tissues, expressed in µg/g per year, is independent of age, at least in the sampled mean age interval of 1.5–7.5 years. The only reasonably clear deviation from direct proportionality is the relatively low level of muscle contamination, primarily for Hg, seen in the youngest animals of 1.5–2.5 years of age. This possibly indicates that a steady state liver/kidney concentration ratio is established quite rapidly, whilst a steady state distribution of HM between the liver and muscle may require several years to develop.

The HM distribution between reindeer tissues, appears similar for both age groups and sexes. Only for Hg are liver/muscle and kidney/muscle ratios about 3 times higher for younger animals. Relative concentrations of HMs in the muscle, liver and kidney appear, respectively, in the ratios of 1:5:5 for Pb, 1:11:33 for Cd and 1:11:42 for Hg in reindeer over 3 years of age, and 1:31:136 for Hg in younger reindeer (figures are based on the geometric means of the ratios for pooled samples). The degree of variability between liver/muscle and liver/kidney concentration ratios for HMs within a herd is greatest for Hg. The level of variability between reindeer herds is similar. The liver/muscle concentration ratios are slightly lower than those calculated for Swedish herds, but the difference was not statistically significant (see Figure 5.10). As the distribution of HMs between tissues is herd specific, the age concentration ratios for HMs are relatively constant, and concentration variability within a herd is quite low, mean concentrations of Hg, Pb and Cd were calculated separately for all three tissue types and are shown only for the oldest age group. The calculation of separate mean concentrations for each age group does not significantly improve the representativeness of the results, because the variability found in concentrations of HMs within a herd is low.

Figure 5.9.
Relationships between HM concentration in reindeer tissues and age, for the Kola peninsula (1) and the Pechora basin (2).



Levels and trends

(a) Organochlorines

Concentrations of OCs reliably detected in reindeer muscle are given in Tables 5.8a and 5.8b. Levels of PCB, HCB, HCH and DDT vary within fairly narrow ranges and do not follow any pronounced spatial trend, although somewhat higher levels of PCB, HCB, and DDT are found in inland Chukotka (see Figure 5.11).

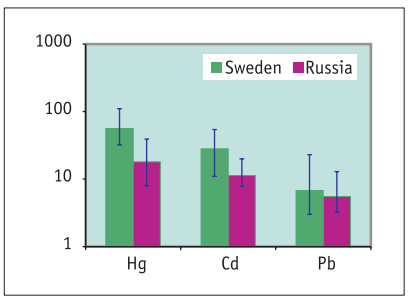


Figure 5.10.
Geometric means and ranges of HM liver/muscle concentration ratios in Swedish and Russian reindeers. The Swedish data were for 10 herds (AMAP, 1998) and the Russian data for 6 herds.

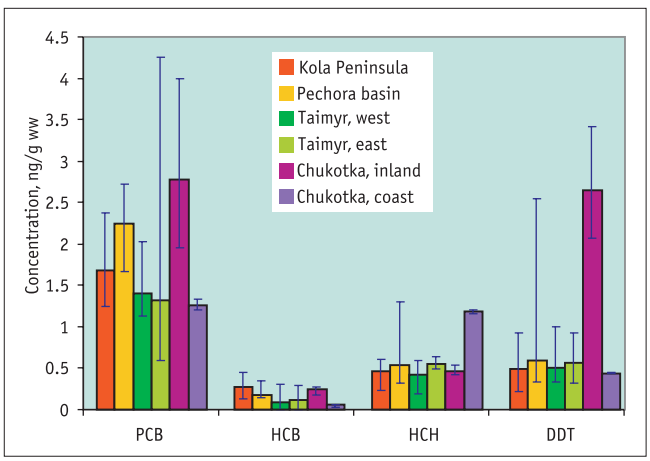


Figure 5.11. Geometric means and ranges of OC concentrations in reindeer muscle in the Russian Arctic in 2001. PCB= ΣPCB_{15}, HCH=ΣHCH, DDT=ΣDDT.

OCs in reindeer show no correlation with the spatial trends found for OC contamination in lichen. All concentrations are far below the maximum permissible concentrations (MPC) for OCs in meat, established by the Russian Ministry of Health; the MPC of 0.1 mg/kg for ΣHCH and ΣDDT, given in Chapter 3, is equivalent to 100 ng/g. Concentrations for all OCs measured in reindeer liver in 2001 coincide with the lower end of corresponding ranges obtained for the Russian North in 1994/1995 (AMAP, 1998) Values are also in reasonably good agreement with data on reindeer muscle OC contamination reported from Canada and Norway (AMAP, 1998). For example, the following concentrations of OCs were found in muscle samples from two Canadian reindeer herds: 1 ng/g for ΣHCH, 1-2 ng/g for ΣDDT and 2-10 ng/g for ΣPCB. The ranges of the geometric means for OC concentrations determined in Russia in 2001 were 0.4-1.2 ng/g for ΣHCH; 0.4 - 2.6 ng/g for ΣDDT; and 1.3-2.8 ng/g for ΣPCB. The Canadian data for summed PCB concentrations included more PCB congeners than did the Russian 2001 data. The agreement between the Canadian and Russian reindeer data is similar to that seen in the data concerning OCs measured in lichen and mosses in Russia in 2001, and in Canada in 1994.

Area	pg WHO-TEQ/g ww	pg WHO-TEQ/g lipids	pg WHO-TEQ/pg*
Muscle			
Kola Peninsula	0.98	20	0.20
Pechora basin	0.10	2.2	0.13
Taymir, west	0.031	1.3	0.11
Taymir, east	0.083	0.75	0.17
Chukotka, inland	0.066	4.3	0.10
Chukotka, coast	0.053	2.6	0.059
Liver			
Kola Peninsula	6.5	105	0.22
Pechora basin	2.4	38	0.20
Taymir, west	0.71	18.2	0.24
Taymir, east	0.49	8.0	0.23
Chukotka, inland	0.22	5.1	0.12
Chukotka, coast	0.24	4.2	0.21

Table 5.9. Concentrations (expressed as TEQ) of PCDD/Fs in reindeer tissues the Russian Arctic in 2001.
* – ratio of PCDD/F concentration in pg WHO-TEQ/g to that in pg/g

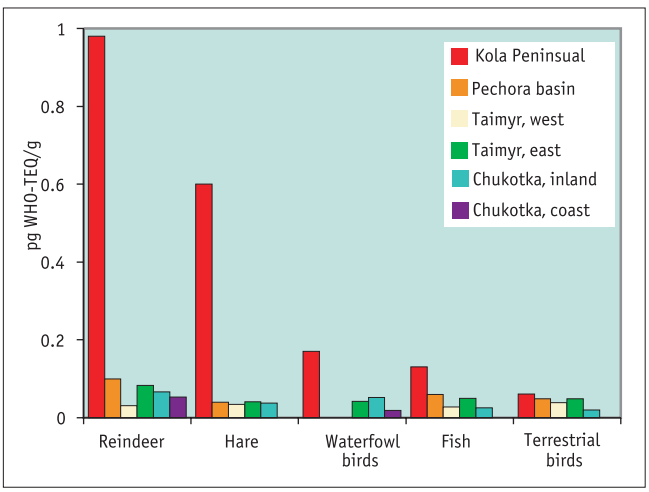


Figure 5.12. Levels of PCDD/Fs in muscle of reindeer, hare, waterfowl (molluscivores), fish (whitefish species), and terrestrial birds (browsers) in the Russian Arctic in 2001.

Samples of reindeer tissue were also analyzed for the other OCs listed in Section 1.2.4. In the majority of samples, all of these additional OCs exhibited levels below the detection limit. Only Mirex and some of the cyclodienes were found in concentrations close to the detection limit (about 0.1 ng/g), and then only in a few samples. This is again consistent with results of previous studies carried out in Canada and in the Russian North in 1995 (AMAP, 1998).

(b) PCDD/Fs

Concentrations of 2,3,7,8-substituted PCDD/Fs were analyzed using pooled samples of reindeer tissue. The results are presented in Table 5.9.

PCDD/F levels in reindeer in the Russian Arctic follow a distinct spatial distribution, that is reflected in other terrestrial mammals, birds, and fish (see Figure 5.12). The highest PCDD/F levels are found at the Kola Peninsula, where they are an order of magnitude greater than those found at other sites. After correction for tissue lipid content, residual differences still remain in PCDD/F concentrations between the various tissues types. In contrast to other OCs, PCDD/F levels occurring in the liver of reindeer are, on average, 7 times higher than those in the muscle. Maximum contamination levels were found in liver tissue from the Kola Peninsula (6.5 pg WHO-TEQ/g) and from the Pechora basin (2.4 pg WHO-TEQ/g). The liver concentrations associated with these TEQ values, and also those in muscle of reindeer from the Kola Peninsula, exceed the maximum permissible level for meat, established by the Russian Ministry of Health, which is 0.9 ng/g. All other concentrations measured were below this level.

Three congeners (2,3,7,8-TeCDD, 1,2,3,7,8-PeCDD, and 2,3,4,7,8-PeCDF) contribute more than half (and up to 85%) of the total WHO-TEQ in the majority of samples. The average contribution of 2,3,4,7,8-PeCDF, and the most toxic of the dioxins to the total TEQs are similar in waterfowl, terrestrial birds, fish and marine mammals (4.4% and 4.7%, respectively). In terrestrial animals, the average contribution of 2,3,4,7,8-PeCDF is significantly higher, whilst the contribution from the most toxic dioxins is almost the same (13% and 4.2%, respectively). For this reason, the ratio of concentration in pg WHO-TEQ to weight concentration for terrestrial animals is also higher.

(c) PAH

Reindeer tissue was analyzed for the same PAH set as vegetation. The geometric means and ranges of PAH concentrations determined in reindeer muscle in the Russian Arctic in 2001 are shown in Tables 5.10a and 5.10b. Results obtained from two sites in Chukotka were treated as one data set, due to the similarity of contamination levels and the small number of samples analyzed. PAH concentrations in liver were, on average, 3-5 times higher than those in muscle, while concentrations found in kidney and muscle are comparable.

Area	NAP	NAP2M	FLE	PA
Kola Peninsula, n=6	21(12-32)	3.5(<2-11)	<0.5-5.1	16(3.6-83)
Pechora basin, n=6	14(2.1-29)	3.2(<2-6.7)	2.1(<0.5-8.5)	13(1.6-36)
Taymir, west, n=5	19(12-28)	5.5(3.1-13)	<0.5-9.8	19(8.7-77)
Taymir, east, n=5	8.1(<2-30)	5.5(2.1-14)	<0.5-6.6	12(2.9-49)
Chukotka, n=4	21(6.8-40)	18(11-23)	6.8(4.5-13)	11(8.6-13)

Table 5.10a. Concentrations (geometric mean and range; ng/g ww) of PAHs[a] in reindeer muscle in the Russian Arctic in 2001.
[a] NAP = Naphthalene, NAP2M = 2-Methylnaphthalene, FLE = Fluorene, PA = Phenanthrene.

Area	ANT	FLU	PYR	BAA
Kola Peninsula, n=6	<0.5-1.4	<0.5-1.1	2.2(<0.5-8.8)	0.6(<0.5-2.6)
Pechora basin, n=6	<0.5-2.3	<0.5-1.6	2.5(<0.5-14)	1.0(<0.3-4.2)
Taymir, west, n=5	<0.5-2.2	1.0(<0.5-5.7)	2.8(<0.5-15)	<0.5-2.1
Taymir, east, n=5	<0.5-2.8	<0.5-1.3	<0.5-8.6	<0.3-1.7
Chukotka, n=4	0.8(0.6-1.3)	2.9(1.7-4.0)	0.7(<0.5-1)	<0.3

Table 5.10b. Concentrations (geometric mean and range; ng/g ww) of PAHs[a] in reindeer muscle in the Russian Arctic in 2001.
[a] ANT = Anthracene, FLU = Fluoranthene, PYR = Pyrene, CHR = Chrysene

As for OCs, no trend in spatial distribution was found. The PAH composition pattern in reindeer tissues reflects that found in lichen. Naphthalene, 2-methylnaphthalene and phenanthrene contribute well over half of the ΣPAH value. Reindeer tissues were also analyzed for the other PAH listed in Section 5.3.1.(b). In the majority of samples these PAHs were below the corresponding detection limits (0.5–2 ng/g) or, in a few samples of liver tissue, were only slightly above detection limits.

(d) Brominated flame-retardants

Samples of reindeer tissues 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 all samples these occurred at levels below the detection limit of 0.2 ng/g ww.

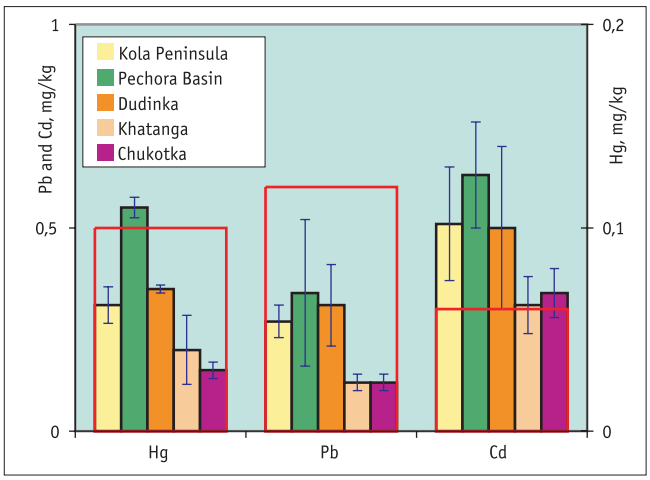


Figure 5.13. Means and ranges of HM concentrations in reindeer liver (wet weight) in the Russian Arctic in 2001. Red lines indicate the maximum permissible concentrations allowed by food safety standards.

(e) Heavy metals

Concentrations of HMs in reindeer tissues are shown in Table 5.11 and Figure 5.13. Levels of Pb are below the corresponding MPCs in all tissues, although the difference in the case of liver is quite small. Cadmium and Hg levels in all tissues, and at all sites, except for Hg in tissues from Chukotka, are either close to or exceed corresponding MPCs. The greatest disparity between observed levels of the metals under the scope and MPCs occurred in kidney tissue from the Pechora basin, which exceeded the MPC by two and a half times.

The spatial distribution of HM concentrations in reindeer liver tissue is shown in Figure. 5.13. HM levels in other tissues follow a similar pattern. As for OCs, there is no pronounced correlation with the spatial distribution of HMs in lichen. For all HMs, however, the least contaminated areas are inland Chukotka and the east Taymir (Khatanga) regions. As mentioned above, the HM concentration relationship with reindeer age is almost directly proportional, at least for the first few years of the animals' life. The coefficients for this rela-

Table 5.11. Concentrations (mean and standard deviation; g/g ww) of HMs in tissues of reindeer (>3 years of age) in the Russian Arctic in 2001.
[a] Hg level in one sample was close to the detection limit (0.001 ng/g ww), and below the detection limit in another.
[b] Hg level in both samples was close to the detection limit.
[c] Concentration range.

Tissue	Area	Hg	Pb	Cd
Muscle	Kola Peninsula, n=3	0.010±0.002	0.05±0.02	0.043±0.014
	Pechora basin, n=3	0.015±0.005	0.09±0.02	0.074±0.009
	Taymir, west, n=2	0.014±0.002	0.09±0.01	0.061±0.01
	Taymir, east, n=2	0.0005-0.001[a, c]	0.012-0.035[c]	0.016±0.002
	Chukotka, inland, n=2	0.001[b]	0.013±0.002	0.026±0.005
Liver	Kola Peninsula, n=3	0.062±0.009	0.27±0.04	0.51±0.14
	Pechora basin, n=3	0.11±0.05	0.37±0.18	0.63±0.13
	Taymir, west, n=2	0.07±0.02	0.33±0.10	0.50±0.20
	Taymir, east, n=2	0.039±0.017	0.14±0.02	0.31±0.07
	Chukotka, inland, n=2	0.030±0.004	0.16±0.02	0.34±0.06
Kidney	Kola Peninsula, n=3	0.24±0.02	0.21±0.05	2.0±0.9
	Pechora basin, n=3	0.36±0.08	0.34±0.16	2.5±0.9
	Taymir, west, n=2	0.33±0.06	0.31±0.15	2.1±1.3
	Taymir, east, n=2	0.12±0.01	0.12±0.02	2.1±1.3
	Chukotka, inland, n=2	0.15±0.03	0.12±0.02	0.78±0.07

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).

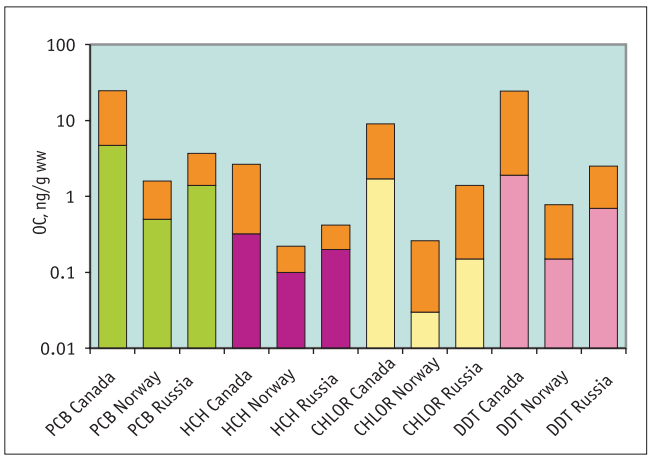


Figure 5.22 Comparison of mean OC concentrations in whitefish species in the Canadian Arctic (1993-1999), Norway (1994), and Russia (2001). The lower part of each column corresponds to the minimum mean concentration, and the total column height, to the maximum mean concentration. PCB=ΣPCB_{15}, HCH=ΣHCH,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

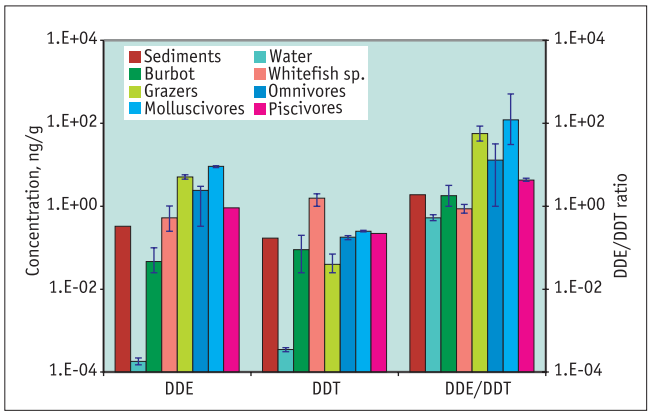


Figure 5.23. Absolute and relative levels of *p,p'*-DDE and *p,p'*-DDT in aquatic food chains in the Khatanga area. Geometric means and ranges of DDE and DDT levels in sediments are given on a dry weight basis, while levels in the muscle of birds and fish are on a wet weight basis. Ratios are shown with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

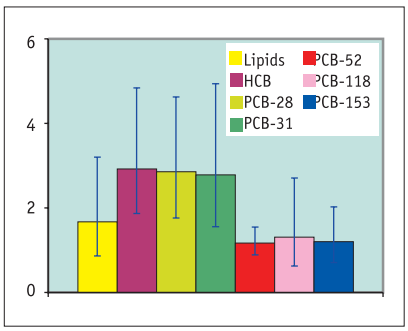


Figure 5.24.
Concentration ratios (geometric mean and 95% confidence limits) for OCs and lipid content in waterfowl/ fish, for all sample sites.

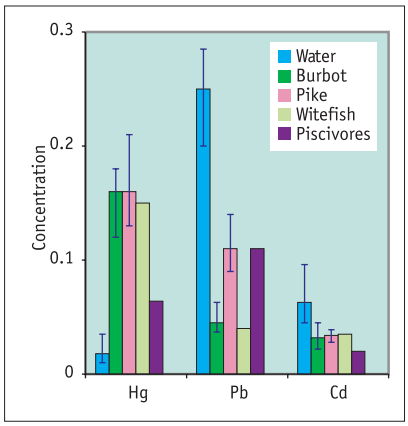


Figure 5.25.
The HM distribution pattern in water-fish-bird food chains on the Kola Peninsula in 2001. HM concentrations and their ranges in bird and fish muscle are in µg/g ww, while those in water are in µg/L.

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.

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.

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 5.28. 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.

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

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).

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

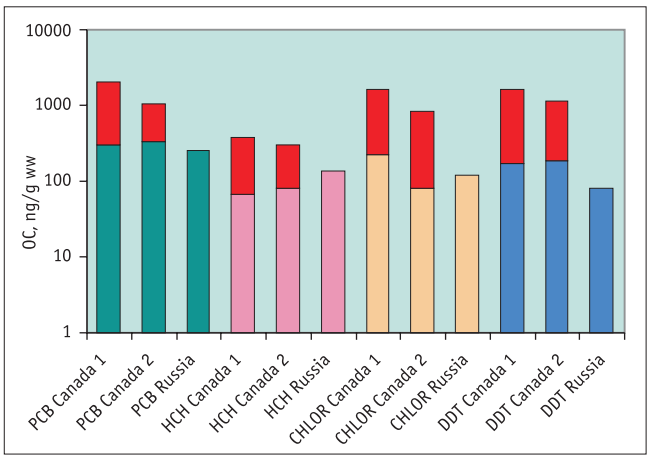


Figure 5.26. Comparison of mean OC concentrations in ringed seal blubber in the Canadian Arctic (Canada 1: 1989-1994, Canada 2: 1998-2001) and Russia (2000-2002). The lower part of each column corresponds to the minimum mean concentration, and the total column height, to the maximum mean concentration.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

(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).

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.

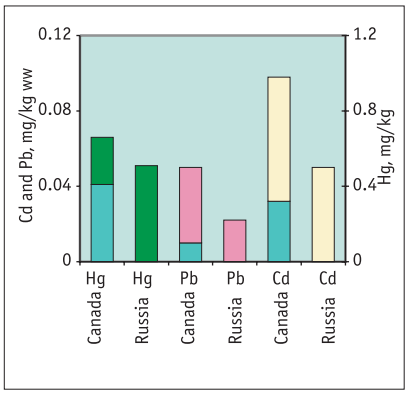


Figure 5.27. Comparison of mean HM concentrations in ringed seal muscle in the Canadian Arctic (1987-1994) and Russia (2000-2002). The lower part of each column corresponds to the minimum mean concentration, and the total column height, to the maximum mean concentration.

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.

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.

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	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

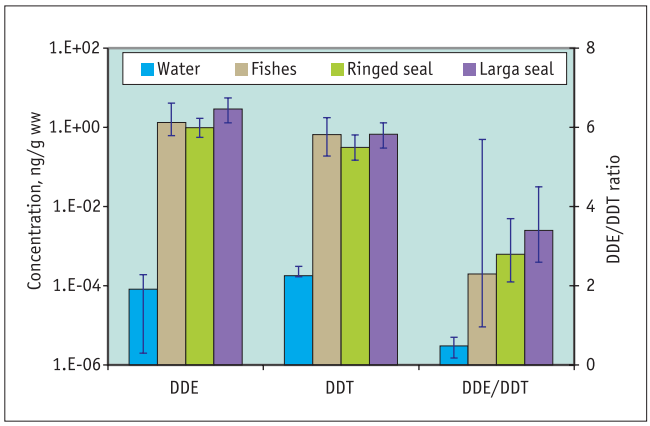


Figure 5.28. Absolute and relative levels of p,p'-DDE and p,p'-DDT in the marine food chain in the Lavrentiya Bay. Geometric means and ranges are shown for DDE and DDT concentrations in muscle tissue, water concentrations are in g/L. Ratios are shown with 95% confidence limits.

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 cor-

responding 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.

Area	Muscle	Liver	Kindey
		Hg	
Kola Peninsula, n=6	0.0018 (0.0010-0.0033)	0.016 (0.012-0.021)	0.062 (0.056-0.068)
Pechora basin, n=6	0.0035 (0.0024-0.051)	0.035 (0.019-0.033)	0.096 (0.075-0.12)
Taymir, west, n=5	0.0015 (0.0006-0.0036)	0.012 (0.011-0.015)	0.058 (0.039-0.086)
Taymir, east, n=4	—	0.0089 (0.0054-0.015)	0.033 (0.018-0.062)
Chukotka, coast, n=2	—	0.020 (0.008-0.051)	0.11 (0.047-0.23)
		Pb	
Kola Peninsula, n=6	0.013 (0.009-0.021)	0.071 (0.060-0.083)	0.057 (0.045-0.070)
Pechora basin, n=6	0.021 (0.018-0.026)	0.088 (0.062-0.12)	0.076 (0.059-0.098)
Taymir, west, n=5	0.017 (0.013-0.021)	0.056 (0.033-0.093)	0.048 (0.030-0.079)
Taymir, east, n=4	0.0052 (0.0029-0.010)	0.034 (0.021-0.051)	0.034 (0.019-0.060)
Chukotka, coast, n=2	0.0059 (0.0033-0.011)	0.095 (0.054-0.017)	0.067 (0.044-0.10)
		Cd	
Kola Peninsula, n=6	0.011 (0.0073-0.015)	0.13 (0.12-0.15)	0.40 (0.28-0.56)
Pechora basin, n=6	0.019 (0.015-0.023)	0.16 (0.14-0.18)	0.52 (0.37-0.73)
Taymir, west, n=5	0.011 (0.0078-0.016)	0.093 (0.050-0.17)	0.28 (0.18-0.043)
Taymir, east, n=4	0.0043 (0.0022-0.0083)	0.081 (0.043-0.015)	0.24 (0.14-0.42)
Chukotka, coast, n=2	0.014 (0.0083-0.024)	0.20 (0.14-0.28)	0.43 (0.22-0.82)

Table 5.12. Geometric means and 95% confidence interval of effective rates of accumulation of heavy metals in reindeer tissues (µg/g ww per year).

tionship are given in Table 5.12, and these can be considered as the effective rates of accumulation of metals in reindeer tissues. The lowest values normally occur in the Taymir Peninsula, however, the values do not differ by more than a factor of 3 and the differences are therefore of no great significance.

Concentrations of Cd and Hg in muscle tissue sampled in 2001 are very close to those found in 1994/1995 in the Russian North (AMAP, 1998), while levels of Pb in muscle are an order of magnitude lower than those reported earlier. In comparison with 1995 values, liver/muscle concentration ratios calculated in 2001 are significantly higher for all HMs, and are similar to those measured in other regions of the Arctic (AMAP, 1998). Levels of all HMs are similar to, or slightly lower than those determined in the Canadian Arctic in 1998-2001 (CACAR, 2003). However, as concentrations of HM in Canadian reindeer are reported on a dry weight basis, direct comparison is not possible; on a dry wt basis, absolute values are typically up to an order of magnitude greater.

5.3.3. PTS in the Arctic hare

Tissues of Arctic hare (*Lepidus timidus*) were sampled at all sites, except for coastal Chukotka. The number of single samples of each tissue, collected at a given site and used in the preparation of pooled samples, ranged from 4 to 10 (see Table 5.1). Equal numbers of male and female animals, all younger than 3 years, were sampled at each site. The muscle, liver and kidney of hare were analyzed for all PTS listed in Section 1.2.4.

PTS concentration relationships with hare sex and tissue type

(a) Organochlorines

Only a few OCs (HCB, *p,p'*-DDT, *p,p'*-DDE, PCB-118, PCB-138 and PCB-153) were detectable at all sites and in the majority of samples. No significant concentration relationship to either sex or tissue type was identified for these OCs in hare.

(b) Heavy metals

HMs occur in detectable concentrations in all samples, except for Hg in muscle tissue. Calculated male/female concentration ratios for Hg, Pb, and Cd do not differ significantly from unity and are neither site nor tissue specific. Mean concentrations for HMs were, therefore, calculated using data for both sexes. The distribution of the three HMs between tissues is similar for both sexes, and approximates that found in reindeer. Relative levels of contaminants in muscle, liver and kidney are in the ratio of 1:11:5 for Pb and 1:26:160 for Cd (based on geometric means of ratios for pooled samples).

Levels and trends

(a) Organochlorines

The levels of OCs that were generally above detection limits in tissues of hare (HCB, *p,p'*-DDT, *p,p'*-DDE, PCB-118 and PCB-153) did not follow any geographical trend. Geometric means of OC concentrations range from 0.06 ng/g ww (*p,p'*-DDT, *p,p'*-DDE) to 0.12 ng/g ww (HCB). Concentrations of PCB-138, PCB-180, as well as α- and γ- HCH occur at similar levels at several sites. In a few samples, some of the other OCs (PCBs, Mirex, and cyclodienes) were found in concentrations close to the detection limit. Concentrations of all detectable OCs in hare tissues are 2-4 times lower than those in reindeer, and are far below the limit values for these substances established in Russia.

Area	pg WHO-TEQ/g ww	pg WHO-TEQ/g lipids	pg WHO-TEQ/pg*
		Muscle	
Kola Peninsula	0.60	29	0.18
Pechora basin	0.043	2.7	0.15
Taymir, west	0.034	1.4	0.084
Taymir, east	0.041	3.5	0.18
Chukotka, inland	0.037	1.8	0.14
		Liver	
Chukotka, inland	0.10	2.5	0.082

Table 5.13. Concentrations (expressed as TEQ) of PCDD/Fs in hares in the Russian Arctic in 2001.
* – ratio of PCDD/F concentration in pg WHO-TEQ/g to that in pg/g

(b) PCDD/Fs
Concentrations of 2,3,7,8-substituted PCDD/Fs were analyzed in pooled samples of hare tissues collected at each site. Results are presented in Table 5.13 and Figure 5.12. PCDDFs in hare tissues follow the same spatioal distribution pattern as for reindeer. All concentrations are at levels below the (maximum) permissible level for meat.

(c) PAH
Hare tissues were analyzed for the same PAH set as were reindeer tissues. In contrast to OCs, most PAH concentration levels in hare are either comparable with those in reindeer or are higher. Only phenanthrene concentrations in hare muscle are, for most sites, found to be several time lower than those in reindeer.

(d) Brominated flame-retardants
Samples of hare tissue 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 all samples, concentrations of these substances were below the detection limit of 0.2 ng/g ww.

(e) Heavy metals
HM concentrations measured in hare tissues are given in Table 5.14. Concentrations are usually several times lower than those found in reindeer, with the exception of Cd in kidney tissue, for which levels in hare and reindeer are comparable. Spatial distribution patterns observed for all three HMs are similar to those for reindeer. The lowest concentrations occur in Chukotka and eastern Taymir. Concentrations of HMs in hare tissues measured in this study are similar to those reported for hares in Finland in 1995 (AMAP, 1998). Differences in levels between the data from Finland in 1995 and Russia in 2001 are relatively small (within a factor of two), with the exception of Pb in muscle, which is 4.4 times higher in the Russian North.

5.3.4. PTS in birds

Waterfowl and terrestrial game birds harvested by indigenous peoples in the Russian Arctic for the project, were analyzed for all contaminants listed in Section 1.2.4. Samples tissues of the following groups of birds were collected:

- Grazers (geese that graze mainly on aquatic and terrestrial vegetation): bean goose (*Anser fabalis*), white-fronted goose (*Anser albifrons*), goldeneye duck (*Bucephala clangula*) and ptarmigan (*Lagopus sp.*);
- Omnivores (surface-feeding ducks with a varied diet consisting mainly of aquatic vegetation): pintail (*Anas acuta*), wigeon (*Anas penelope*), and teal (*Anas crecca*);
- Molluscivores (diving ducks feeding mainly on invertebrates): eider (*Somateria mollissima*), and long-tailed duck or oldsquaw (*Clangula hyemalis*);
- Piscivores (diving ducks feeding mainly on fish): scaup (*Aythya marila*), merganser (*Mergus sp.*), scoter (*Melanitta sp*).

For most sites, equal numbers of male and female birds of each groupwere harvested. Exceptions were: omnivores (1 male pintail) and piscivores (1 female scoter) in eastern Taymir; grazers (1 female goose) at inland Chukotka; and molluscivores (1 male eider) at coastal Chukotka.

PTS concentration relationships with bird sex
No significant concentration dependence on sex was identified for any of the detectable OCs, for Hg and Cd in all bird groups, and for Pb in waterfowl. Pb concentrations in the muscle tissue of male browsers were consistently about twice as high as those measured in females at all six sites; the male/female ratios ranging from 1.7 to 2.6, with a geometric mean of 2.1 for the six values. Since the male/female ratios for Pb in browsers are not particularly high, the ratio is independent of site, and the same sample pattern for sexes was followed at all sites (50% male and 50% female), all geometric means, including those for Pb concentrations in browsers, were calculated using data for both sexes

Levels and trends

(a) Organochlorines
Concentrations of OCs in birds are shown in Tables 5.15a and 5.15b and Figures 5.14 and 5.15. The lowest contamination levels are found in the muscle tissue of browsers. The only OC that was repeatedly detected in these birds was *p,p'*-DDE. Levels of ΣPCB_{15} in browsers

Table 5.14.
Concentrations (mean and standard deviation; µg/g ww, n=2) of HMs in tissues of the Arctic hare (< 3 years of age) in the Russian Arctic in 2001.
[a] The range (in brackets) is given where the standard deviation is larger than 50% of the mean.

Tissue	Area	Hg	Pb	Cd
Muscle	Kola Peninsula	<0.001	0.005 (<0.001–0.008)[a]	0.010±0.002
	Pechora basin	<0.001	0.012±0.001	0.016±0.004
	Taymir, west	<0.001	0.012±0.004	0.014±0.003
	Taymir, east	<0.001	0.022 (<0.001-0.042)[a]	0.007±0.001
	Chukotka, inland	<0.001	0.031 (<0.001-0.059)[a]	0.007±0.001
Liver	Kola Peninsula	0.007 (0.002-0.017)[a]	0.12±0.02	0.29±0.11
	Pechora basin	0.020±0.002	0.19±0.03	0.36 (0.20-0.52)[a]
	Taymir, west	0.021±0.002	0.18±0.04	0.40±0.11
	Taymir, east	0.010±0.004	0.10±0.03	0.19±0.06
	Chukotka, inland	0.020±0.006	0.087±0.013	0.21±0.06
Kindey	Kola Peninsula	0.066±0.008	0.048±0.013	2.0±0.9
	Pechora basin	0.11±0.02	0.072±0.023	2.5±1.1
	Taymir, west	0.098±0.021	0.078±0.022	2.2±0.9
	Taymir, east	0.053±0.008	0.038±0.008	1.0±0.3
	Chukotka, inland	0.051±0.004	0.045±0.019	1.04±0.08

Bird group	Area	ΣPCB$_{15}$	HCB	ΣHCH	ΣCHLOR
Browsers	Kola Peninsula, n=2	1.52 (1.49-1.56)	0.10 (0.05-0.20)	0-0.46[a]	0-0.21[a]
	Pechora basin, n=2	0.6-2.0[a]	<0.05	<0.20	<0.20
	Taymir, west, n=2	0.6-1.1[b]	<0.05-0.20	0.07-0.41[a]	<0.20
	Taymir, east, n=2	0.6-1.1[b]	<0.05-0.14	0.19 (0.14-0.27)	0-0.21[a]
	Chukotka, inland, n=2	1.46 (1.20-1.77)	<0.05-0.35	<0.20	0-0.24[a]
	Chukotka, coast, n=2	0.6-1.1[b]	<0.05-0.34	0.10-0.23[a]	<0.20
Grazers	Taymir, west, n=2	2.81 (2.07-3.82)	0.06 (0.05-0.08)	0.18-0.28[a]	<0.20
	Taymir, east, n=2	2.87 (2.58-3.21)	0.10 (0.07-0.15)	0.12-0. 28[a]	<0.20
	Chukotka, inland, n=1	1.14	0.17	<0.20	<0.20
Omnivores	Pechora basin, n=4	2.30 (1.62-3.34)	0.16 (0.07-0.37)	0-0.89[a]	0-0.57[a]
	Taymir, west, n=3	2.88 (2.32-3.45)	0.22 (0.13-0.36)	0-0.43[a]	0.08-0.39[a]
	Taymir, east, n=2	3.44 (2.54-4.66)	0.36 (0.17-0.76)	0.50 (0.26 - 0.97)	0.16 (0.11-0.23)
	Chukotka, inland, n=3	3.20 (2.23-4.47)	0.28 (0.15-0.54)	0.41 (0.24-0.76)	0.10-0.50
Molluscivores	Kola Peninsula, n=2	3.88 (2.57 –5.86)	0.39 (0.25-0.62)	0.52 (0.39 –0.71)	0.33 (0.28-0.40)
	Taymir, east, n=2	13.6 (10.7-17.2)	1.36 (1.22-1.50)	2.21 (1.78-2.64)	2.67 (2.01-3.55)
	Chukotka, inland, n=2	4.09 (3.32-5.04)	0.43 (0.29-0.56)	1.71 (1.28-2.13)	0.64 (0.52-1.00)
	Chukotka, coast, n=3	3.47 (2.81-4.01)	0.32 (0.15-0.36)	0.60 (0.40-0.80)[b]	0.47 (0.37-0.61)[b]
Piscivores	Kola Peninsula, n=2	4.07 (3.63-4.65)	0.42 (0.32-0.55)	<0.20	0-0.21[a]
	Taymir, east, n=1	3.88	0.12	0.32	0.31
	Chukotka, inland, n=2	1.71 (1.68-1.74)	0.23 (0.18-0.30)	<0.20	<0.20

Table 5.15a. Concentrations (geometric mean and range; ng/g ww) of OCs in the muscle of birds in the Russian Arctic in 2001.
[a] In at least one sample, more than half of the concentrations were below the detection limit. Concentrations below the detection limit were set to zero or to the detection limit when determining lower and upper limits of concentration ranges.
[b] The range is given only for oldsquaw (n=2). Concentrations in eider were below the detection limit.

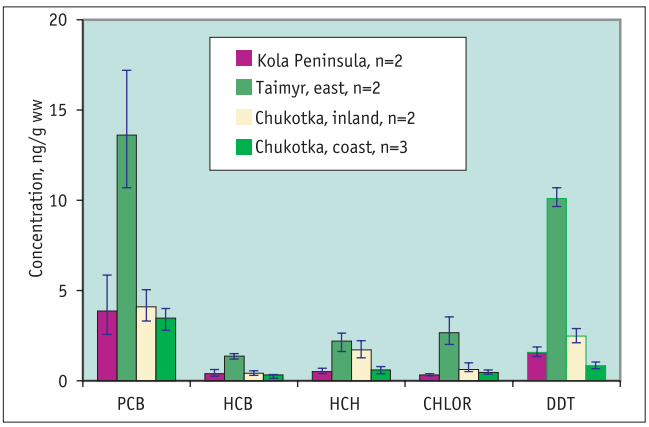


Figure 5.14. Geometric means and ranges of OC concentrations in molluscivores. PCB=ΣPCB$_{15}$, HCH=ΣHCH, CHLOR=ΣCHLOR, and DDT=ΣDDT.

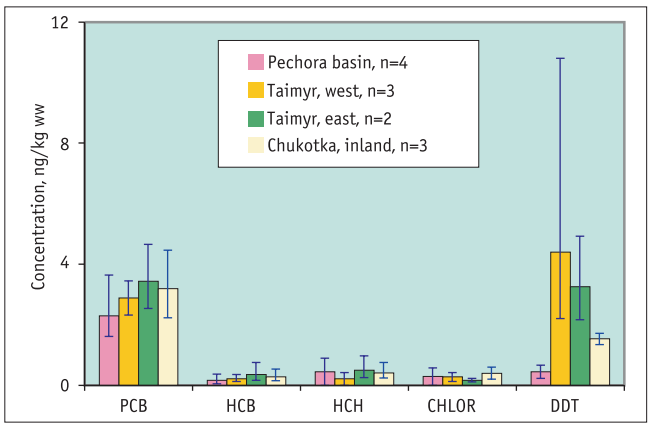


Figure 5.15. Geometric means and ranges of OC concentrations in omnivores. PCB=ΣPCB$_{15}$, HCH=ΣHCH, CHLOR=ΣCHLOR, and DDT=ΣDDT.

Bird group	Area	*p,p'*-DDE	*p,p'*-DDT	ΣDDT	Mirex
Browsers	Kola Peninsula, n=2	0.23 (0.22-0.25)	<0.05-0.56	0.48-0.91[a]	<0.05
	Pechora basin, n=2	0.24 (0.16-0.36)	<0.05-0.26	0.42-0.65[a]	<0.05
	Taymir, west, n=2	0.19 (0.16-0.23)	<0.05-0.30	0.29-0.68[a]	<0.05
	Taymir, east, n=2	0.24 (0.20-0.29)	<0.05-0.25	0.45-0.95[a]	<0.05
	Chukotka, inland, n=2	0.18 (0.14-0.18)	<0.05-0.24	0.14-0.62[a]	<0.05
	Chukotka, coast, n=2	<0.05-0.05	0.22 (0.19-0.26)	0.31-0.52[a]	<0.05
Grazers	Taymir, west, n=2	3.88 (3.25-4.63)	<0.05	3.45-5.09[a]	0.09 (0.06-0.15)
	Taymir, east, n=2	5.09 (4.52-5.74)	<0.05 - 0.07	5.67-6.12[a]	0.12 (0.07-0.21)
	Chukotka, inland, n=1	0.35	<0.05	0.56	<0.05
Omnivores	Pechora basin, n=4	0.34 (0.23-0.41)	<0.05	0.23-0.67[a]	0.14 (0.13-0.16)[c]
	Taymir, west, n=3	3.47 (1.29-10.1)	0.26 (0.21-0.40)	4.40 (2.11-10.8)	<0.05-0.09
	Taymir, east, n=2	2.43 (1.31-4.50)	0.18 (0.08-0.42)	3.26 (2.17-4.92)	<0.05
	Chukotka, inland, n=3	0.51 (0.26-1.16)	0.29 (0.14-0.49)	1.54 (1.35-1.72)	<0.05
Molluscivores	Kola Peninsula, n=2	1.21 (0.94-1.55)	0.14 (0.11-0.18)	1.59 (1.34-1.89)	<0.05
	Taymir, east, n=2	9.09 (8.56-9.56)	0.25 (0.24-0.26)	10.1 (9.66-10.7)	0.08 (0.08-0.09)
	Chukotka, inland, n=2	1.04 (0.79-1.36)	0.30 (0.23-0.38)	2.47 (2.12-2.90)	<0.05
	Chukotka, coast, n=3	0.35 (0.26-0.50)	0.23 (0.21-0.26)	0.83 (0.67-1.04)[b]	<0.05
Piscivores	Kola Peninsula, n=2	1.26 (1.19-1.33)	0.05 - 0.11	1.25-1.59[a]	0.11 (0.10-0.11)
	Taymir, east, n=1	0.92	0.22	1.44	<0.05
	Chukotka, inland, n=2	0.30 (0.22-0.40)	<0.05	0.31-0.74[a]	0.06 (0.05-0.08)

Table 5.15b. Concentrations (geometric mean and range; ng/g ww) of OCs in the muscle of birds in the Russian Arctic in 2001.
[a] In at least one sample, more than half of the concentrations were below the detection limit. Concentrations below the detection limit were set to zero or to the detection limit when determining lower and upper limits of concentration ranges.
[b] The range is given only for oldsquaw (n = 2). Concentrations in eider were below the detection limit.
[c] The geometric mean and range is given only for pintail (n = 2). Concentrations in mallard are below the detection limit.

were about 1 ng/g ww, about 2-3 times higher than ΣDDT at all sites. Other OCs occurred at concentrations below or close to the detection limit in all samples. As for OCs in reindeer, there was no evident geographical trend for OCs in terrestrial birds.

OC levels in waterfowl are up to an order of magnitude greater that those in browsers. Clear maximum concentrations of all OCs in molluscivores are found in eastern Taymir, near Khatanga. In other bird groups, OC levels at this site are comparable to those found at other sites. Maximum concentrations range from 0.08 ng/g ww for Mirex, and 1-3 ng/g ww for HCB, ΣCHLOR, and ΣHCH, to about 10 ng/g ww for ΣDDT and ΣPCB_{15}. Similar patterns of OC concentrations are seen in other waterfowl at all sites. Concentrations of *p,p'*-DDE found at all sites, are significantly higher than those found in reindeer muscle, while concentrations of other OCs are comparable with those in reindeer. The lowest concentrations occur, as a rule, at sites in Chukotka. Contamination levels in most cases, decrease in the following order: molluscivores > omnivores > piscivores > grazers. All OC concentrations in birds are far below the (maximum) permissible levels for bird meat established in Russia.

(b) PCDD/Fs

Concentrations of 2,3,7,8-substituted PCDD/Fs were analyzed in pooled samples of bird muscle tissue collected from each site. Results are presented in Table 5.16 and Figure 5.12. PCDD/F concentrations in birds follow the same geographic distribution pattern as they do in reindeer, although the spatial differences are less pronounced in birds. All concentrations occur at levels which are far below the maximum permissible levels for these substances in meat.

(c) PAH

Bird tissues were analyzed for the same PAH set as reindeer. Geometric means and ranges of PAH concentrations found in bird muscles in the Russian Arctic in 2001 are given in Table 5.17. Concentrations of 2-methylnaphthalene and fluorene in waterfowl are several times higher, whilst concentrations of phenanthrene and pyrene are several times lower than those found in browsers. Naphthalene and fluoranthene occur in the two bird groups in comparable concentrations. Those PAHs not included in Table 5.17, were found in concentrations close to their detection limits, and then only in few samples of waterfowl. In contrast, chrysene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, benzo[*ghi*]perylene, and biphenyl were detectable in most of the browser muscle samples in concentrations

Species	Area	pg WHO-TEQ/g ww	pg WHO-TEQ/g lipids	pg WHO-TEQ/pg*
Browsers				
Lagopus sp.	Kola Peninsula	0.061	3.1	0.095
	Pechora basin	0.049	2.8	0.130
	Taymir, west	0.038	1.8	0.100
	Taymir, east	0.049	2.2	0.079
	Chukotka, inland	0.020	0.87	0.13
	Chukotka, coast	0.018	1.2	0.16
Molluscivores				
Bucephala clangula	Kola Peninsula	0.17	5.3	0.17
Clangula hyemalis	Taymir, east	0.042	1.9	0.13
	Chukotka, inland	0.052	1.9	0.24
	Chukotka, coast	0.019	0.53	0.078
Omnivores				
Anas acuta	Pechora basin	0.026	1.0	0.093
	Taymir, west	0.11	4.6	0.14

Table 5.16. Concentrations (expressed as TEQ) of PCDD/Fs in bird muscles in the Russian Arctic in 2001.
* – ratio of PCDD/F concentration in pg WHO-TEQ/g to that in pg/g

Bird group	Area	NAP	NAP2M	FLE	PA	FLU	PYR
Browsers	Kola Peninsula, n=2	31 22-43)	7.9 (7.1-8.7)	0.61(0.58-0.65)	21 (18-25)	1.4 (1.2-1.6)	4.3 (3.1-6.1)
	Pechora basin, n=2	35 (19-62)	8.1 (5.2-13)	0.83(0.78-0.88)	25 (16-38)	1.6 (1.3-1.9)	5.2 (5.0-5.6)
	Taymir, west, n=2	28 (23-33)	6.6 (3.5-13)	<0.5-0.89	25 (17-38)	1.5 (1.1-2.0)	4.5 (4.5-4.6)
	Taymir, east, n=2	20 (16-24)	6.2 (2.5-15)	<0.5-1.3	26 (13-52)	1.0 (0.5-1.7)	4.3 (4.1-4.6)
	Chukotka, inland, n=2	35 (30-41)	5.8 (4.2-7.9)	<0.5	37 (16-86)	1.3 (0.84-1.9)	6.1 (4.8-7.8)
	Chukotka, coast, n=2	25 (16-38)	4.7 (3.5-6.2)	<0.5	22 (22-22)	0.75 (0.54-1.0)	5.3 (4.5-6.3)
Grazers	Taymir, west, n=2	6.7 (6.7-7.3)	14 (12-16)	3.7 (3.1-4.5)	5.8 (5.4-6.3)	1.0 (1.0-1.0)	<0.5
	Taymir, east, n=2	9.3 (3.5-25)	21 (19-22)	3.1 (2.8-3.5)	8.3 (6.9-10)	<0.5-0.6	<0.5
	Chukotka, inland, n=1	36	27	4.6	9.2	1.0	<0.5
Omnivores	Pechora basin, n=4	28 (22-40)	14 (4.4-45)	<0.5-5.2	6.8 (4.2-10)	1.2 (1.0-1.4)	<0.5-1.2
	Taymir, west, n=3	12 (5.1-36)	19 (11-25)	2.6 (2.2-3.4)	8.9 (4.4-17)	1.1 (1.0-1.2)	<0.5-1.1
	Taymir, east, n=2	44 (26-73)	22 (15-32)	<0.5-2.0	5.6 (4.5-6.8)	1.4 (1.2-1.6)	<0.5-1.0
	Chukotka, inland, n=3	25 (20-37)	6.7 (4.1-8.9)	2.7 (2.1 –3.5)	5.2 (4.6-6.2)	2.3 (1.9-2.6)	<0.5-1.4
Molluscivores	Kola Peninsula, n=2	24 (22-26)	10 (6.4-16)	1.6 (1.3-2.0)	5.5 (5.3-5.7)	1.9 (1.8-2.1)	1.1 (1.0-1.2)
	Taymir, east, n=2	25 (21-31)	24 (21–28)	3.4 (2.4 – 4.9)	7.3 (7.1-7.6)	<0.5-1.1	<0.5
	Chukotka, inland, n=2	17 (16-18)	7.0 (5.3-9.3)	<0.5 – 1.2	3.7 (3.0-4.7)	1.3 (0.93-1.7)	<0.5
	Chukotka, coast, n=3	7.0 (2.0-14)	11 (7.1-20)	2.8 (2.2 –3.8)	4.3 (2.4-8.4)	1.1 (<0.5-2.7)	1.0 (<0.5-2.2)
Piscivores	Kola Peninsula, n=2	20 (13-31)	19 (14-27)	4.9 (4.3-5.5)	7.7 (6.1-9.6)	0.90 (0.81-1.0)	<0.5
	Taymir, east, n=1	28	14	3.4	6.0	2.3	1.1
	Chukotka, inland, n=2	29 (25-34)	38 (29-50)	4.5 (4.5-4.5)	8.1 (7.5-8.7)	0.79 (0.63-1.0)	<0.5

Table 5.17. Concentrations (geometric mean and range; ng/g ww) of PAHs a in muscle of birds in the Russian Arctic in 2001.
[a] NAP = Naphthalene, NAP2M = 2-Methylnaphthalene, FLE = Fluorene, PA= Phenanthrene, FLU = Fluoranthene, PYR = Pyrene

Bird group	Area	Hg	Pb	Cd
Browsers	Kola Peninsula, n=2	<0.001	0.14 (0.10-0.22)	0.056 (0.042-0.074)
	Pechora basin, n=2	<0.001	0.20 (0.14-0.29)	0.067 (0.063-0.072)
	Taymir, west, n=2	<0.001	0.24 (0.16-0.37)	0.091 (0.061-0.13)
	Taymir, east, n=2	<0.001	0.11 (0.07-0.18)	0.049 (0.045-0.053)
	Chukotka, inland, n=2	<0.001	0.09 (0.07-0.12)	0.047 (0.036-0.061)
	Chukotka, coast, n=2	<0.001	0.11 (0.08-0.18)	0.050 (0.038-0.066)
Grazers	Taymir, west, n=2	0.012 (0.011-0.013)	0.057 (0.054-0.060)	0.006 (0.004-0.008)
	Taymir, east, n=2	0.006 (0.006-0.006)	0.09 (0.07-0.11)	0.010 (0.005-0.021)
	Chukotka, inland, n=1	0.010	-[a]	0.028
Omnivores	Pechora basin, n=4	0.062 (0.035-0.12)	0.13 (0.11-0.17)[a]	0.012 (0.005-0.036)
	Taymir, west, n=3	0.037 (0.019-0.10)	0.31 (0.27-0.35)	0.034 (0.031-0.037)
	Taymir, east, n=2	0.065 (0.059-0.071)	0.067 (0.047-0.095)	0.004 (0.003-0.005)
	Chukotka, inland, n=3	0.019 (0.012-0.043)	0.43 (0.15-1.2)	0.013 (0.008-0.019)
Molluscivores	Kola Peninsula, n=2	0.10 (0.10-0.11)	0.52[a]	0.030 (0.011-0.085)
	Taymir, east, n=2	0.073 (0.063-0.085)	0.35 (0.22-0.57)	0.069 (0.050-0.096)
	Chukotka, inland, n=2	0.027 (0.026-0.029)	0.23 (0.22-0.24)	0.015 (0.013-0.018)
	Chukotka, coast, n=3	0.055 (0.050-0.064)	0.12 (0.08-0.18)	0.020 (0.017-0.032)
Piscivores	Kola Peninsula, n=2	0.064 (0.046-0.090)	0.11 (0.10-0.12)	0.020 (0.019-0.021)
	Taymir, east, n=1	0.034	0.21	0.003
	Chukotka, inland, n=2	0.080 (0.073-0.086)	0.21[a]	0.012 (0.011-0.013)

Table 5.18. Concentrations (geometric mean and range; µg/g ww) of HMs in muscle of birds in the Russian Arctic in 2001.
[a] Data for one sample which was contaminated by lead shot was discarded. Pb concentrations in contaminated samples range from 0.5 to 11 µg/g wet weight.

from 0.5 to 5 ng/g ww. Levels of all PAHs in browsers, with the exception of fluorene, were about twice as high as those found in reindeer. No noticeable geographic trend was observed for any of the PAHs. For these substances, the variability between samples was always comparable with the variability between sites.

(d) Brominated flame-retardants

Samples of bird tissues 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 all samples, these substances were found at concentrations below the detection limit of 0.2 ng/g ww.

(e) Heavy metals

In most of the waterfowl samples, levels of Hg exceeded the MPC for this metal, and only in browsers were Hg concentrations below the detection limit at all sites (see Figure 5.16). Levels of Pb and Cd in terrestrial birds and waterfowl are comparable (see Table 5.18). No pronounced geographic trend was observed for any of the HMs in any bird group. Concentration differences occurring between any two sites, for a given HM and bird group, were not statistically significant, despite inter-sample variability being quite low at almost all sites. The only notable exception to this, was the concentration of Cd measured in omnivores and piscivores in eastern Taymir, which was found to be significantly lower than at other sites. Concentrations of Pb and Cd in birds were normally below maximum permissible levels for these metals (0.5 and 0.05 mg/kg, respectively), and only in few samples were concentrations found to be higher (up to twice the MPC level).

5.3.5. PTS transfer in the terrestrial food chain

For the estimation of soil-to-lichen and water-to-fish transfer coefficients, pooled samples of soil were collected at all 6 sites. The number of pooled samples ranged from 1 to 5, and the number of single samples

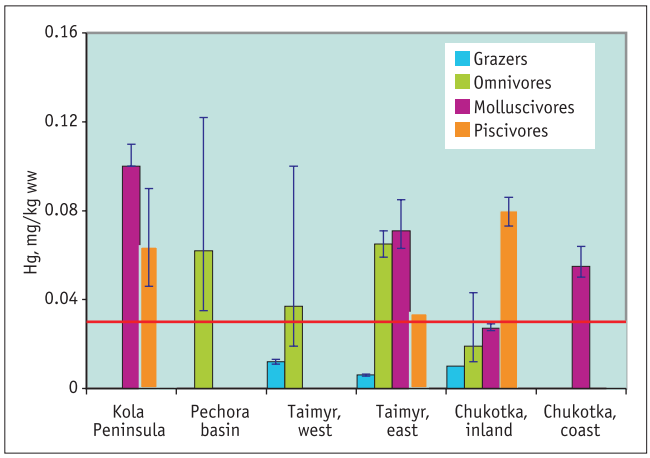


Figure 5.16. Geometric means and ranges of Hg concentrations in muscle of waterfowl in the Russian Arctic in 2001. The red line indicate the maximum permissible concentrations of Hg allowed by food safety standards. The number of values used for calculating means varied between 1 and 4.

used in the preparation of pooled samples ranged from 3 to 9 (see Table 5.1). Most of the soils sampled were of peat litter.

(a) Organochlorines

It is well known that POPs that are present in abiotic media (soil, water and air) can be taken up by living organisms, and subsequently transferred within food chains. In most cases, intake via the diet is the major pathway for human POP exposure. In a steady state system, POPs are distributed throughout the environment according to the fugacity capacities of the various environmental compartments. For POPs, fugacity capacities are proportional to the lipid concentration in a given biological compartment (Sharpe and Mackay, 2000; McLachlan, 1996). In this section, the partitioning of OCs between abiotic media and the tissues of terrestrial organisms in the Russian Arctic is considered, mainly using data on *p,p'*-DDT and *p,p'*-DDE levels. These two OCs, are convenient reference compounds, being detectable in most biotic and abiot-

ic samples collected. In addition, the ratio of *p,p'*-DDE to *p,p'*-DDT levels in soil is widely used to estimate the age of the contamination and can, therefore, serve as an indicator of the relative rate of *p,p'*-DDT metabolic transformation in organisms. Most other OCs follow similar patterns of uptake and transport in food chains that have been studied.

The soil-lichen-reindeer food chain is one of the most important in the Arctic. An example of levels of *p,p'*-DDT and *p,p'*-DDE in this chain are given for Khatanga in eastern Taymir in Figure 5.17. Geometric means of soil-to-lichen transfer factors (concentration ratios) for both *p,p'*-DDT and *p,p'*-DDE are equal to 2.9 ranging from 0.7 (for *p,p'*-DDT on the Kola Peninsula) to 15 (for *p,p'*-DDE in western Taymir). The soil-to-lichen transfer factors for other OCs show a similar degree of variability and similar geometric means (1.1 for PCB-28 and PCB-153, 1.9 for HCB, and 2.5 for HCH isomers). High levels of within site variability in the ratios are most probably explained by a relatively high variability of *p,p'*-DDT and *p,p'*-DDE concentrations in soils. Variability in OC concentrations at a particular site is significantly less in lichens and mosses than soils. Lichens and mosses uptake pollutants primarily from the air, which, in the absence of local sources of pollutants, has relatively uniform contamination levels.

Even though lichens do not take up OCs directly from the soil, soil-to-lichen transfer coefficients can still be calculated, is based on the fact that, in the air of remote areas, OC levels are proportional to those in soil, especially surface soil. Proportionality of OC levels between soils and lichens can, therefore, also be expected. Uptake from the air is the main route by which POPs contaminate, not only mosses and lichens, but also other plants; as POPs are highly lipophilic compounds and, once adsorbed on the root surfaces, they tend not to be translocated to the aboveground parts of plants (McLachlan, 1996). Concentrations of OCs in air were not measured in the current study, therefore, only relative air-to-plant transfer factors (based on interspecies concentration ratios) could be calculated. Using such ratios, once the OC concentration has been measured in one particular plant species at a given site, the concentration in any other species can be estimated using the corresponding species/ species concentration ratio.

This approach relies on the similarity of the uptake mechanism for POPs in different plant species. The predominant pathway for uptake of POPs by plants is dry gaseous deposition from the atmosphere (Paterson *et al.*, 1994; McLachlan, 1996). The POP concentration in plants (C_P) can be related to that in air (C_A) by the following equation:

$$C_P = L \cdot K_{OA} \cdot C_A \qquad (5.1)$$

where:

L is the lipid fraction in the plant tissue (volume/volume);

K_{OA} – is the octanol-air partition coefficient (the ratio of volume concentrations when at equilibrium).

Taking into account of the relatively low variability in lipid content in plant tissues, Equation 5.1 indicates that POP concentration ratios between two species can be considered as being independent of site. If the kinetic limitations of uptake and depuration are ignored, it could also be expected that the same ratio value would apply for all POPs. A comparison of the concentrations of all OCs (excluding PCB) in lichens and mosses supports these assumptions (see Figure 5.18). From Figure 5.18, it is evident that OC concentrations in lichens show a clear relationship to those in mosses. The best correlation is seen for DDT metabolites, probably because these contaminants are present at higher concentrations and there is a lower detection error. The lichen/moss concentration ratio for POPs, obtained using linear regression analysis, is equal to 0.97. In other words, POPs concentrations in lichen can be used as a direct estimate of the POP concentrations in mosses in the study area, and vice versa.

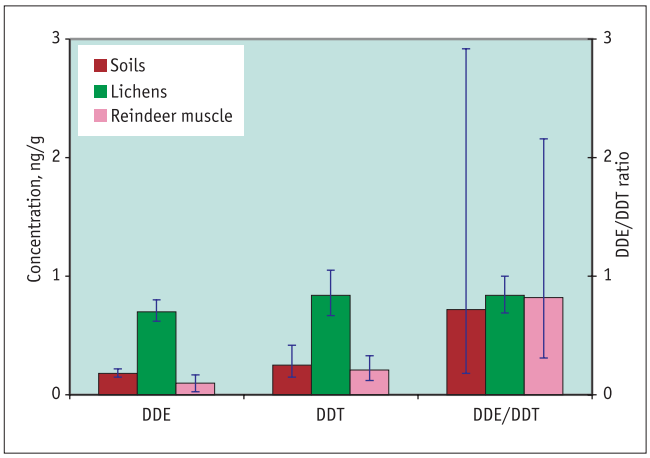


Figure 5.17. Absolute and relative levels of *p,p'*-DDE and *p,p'*-DDT for the soil-lichen-reindeer food chain in the Khatanga area. Geometric means and ranges of DDE and DDT levels in soil and lichen are provided on a dry weight basis, while levels in reindeer muscle are on a wet weight basis; 95% confidence limits are shown for ratios.

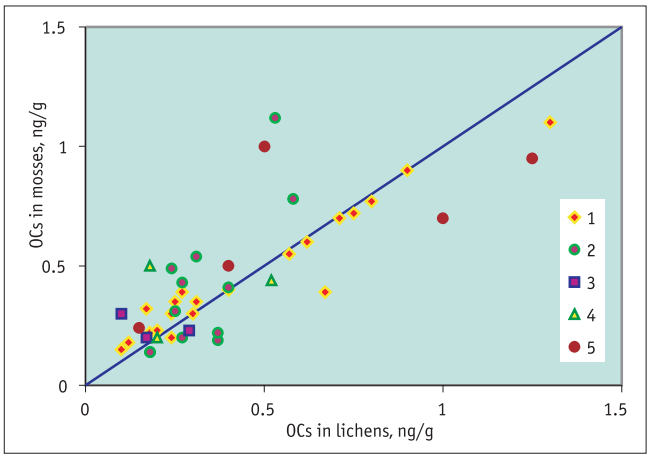


Figure 5.18. The relationship between OC concentrations in mosses and lichen (dry weight) in the northern Russia. 1 – DDT and its metabolites, 2 – HCH isomers, 3 – Heptachlor, 4 – Mirex, 5 – HCB.

Berries and mushrooms are both components of the human diet in the Russian North. Assessment of their contribution to human OC exposure in the Arctic requires data on contamination levels. As the available data set for berry and mushroom contamination in the Arctic is much more limited than that for lichen and mosses, the calculated lichen/berry and lichen/mushroom concentration ratios are useful. Sufficiently reliable data for calculation of the berry/lichen concentration ratio were obtained only for *p,p'*-DDT and HCB (although data for the Kola Peninsula site where an anomalously high *p,p'*-DDT level was measured were excluded). The berry/lichen concentration ratio for *p,p'*-DDT was found to be practically the same as that for HCB. The geometric mean of the nine ratios calculated, using data on both *p,p'*-DDT and HCB, is equal to 0.27.

Lichen-to-reindeer transfer factors (TF_{LR}) were also of the same value (0.3, based on wet wt. and dry wt. concentrations, respectively) for both *p,p'*-DDT and *p,p'*-DDE. They ranged from 0.1 (for *p,p'*-DDE in western Taymir) to 1.8 (for *p,p'*-DDE in Chukotka). In the Canadian Arctic, in 1993, this factor was found to range from one to values in the tens (based on lipid wt. and dry wt. concentrations, respectively) for different OCs (CACAR, 1997). The geometric mean of lipid content measured in reindeer muscle in the current study was about 5%. Using this value to convert the transfer factors based on wet wt. concentrations to their lipid wt. equivalents yields values that are close to those reported for Canada. TF_{LR}s for other OCs that were found at concentrations above detection limits in the current study are of similar values to those determined for *p,p'*-DDT and *p,p'*-DDE (0.2 for PCB-28, 0.8 for PCB-153, 0.5 for α- and γ-HCH, and 0.3 for HCB, based on wet wt. and dry wt. concentrations, respectively).

All transfer factors obtained for *p,p'*-DDT and *p,p'*-DDE in the soil-lichen-reindeer chain agree reasonably well with the values expected on the basis of corresponding concentration ratios for lipids. This result is reasonable since POP concentrations in the soil surface and in plants will generally be at close to equilibrium with POP concentrations in the air, and will reflect the lipid contents of the soil and plants (McLachlan, 1996). Relatively large deviations from equilibrium are observed only for concentrations of POPs which have a very high molecular weight, but even then, these deviations are similar in both plants and soils. POP absorption and depuration by mammals is significantly slower than that by plants. For example, the depuration half-life for PCDD in the human body can be as long as several years (Masuda, 2001). However, given relatively stable levels of air contamination, POP concentrations in mammal tissues and in vegetation used for food should, in general, be comparable, after correction for lipid content (McLachlan, 1996). For example, cow milk/fodder fugacity quotients measured in Germany were, with a few exceptions, close to unity for HCB, PCBs, and PCDD/Fs (McLachlan, 1996). This indicates that a steady state partitioning of OCs between feed and cow tissues takes place. Data obtained in the current study indicated that OC distribution between soil, lichen, and reindeer tissues was also close to a steady state. The observed lack of dependence of OC concentrations in reindeer tissues on animal age, and also the similarity of values calculated for OC concentration and lipid content ratios for reindeer/hare and reindeer/birds also support this conclusion (see Figure 5.19). All differences found between reindeer/hare and reindeer/bird concentration ratios for lipids and any of the OCs were small and within a factor of two, and OC ratio ranges agreed closely with those for lipids.

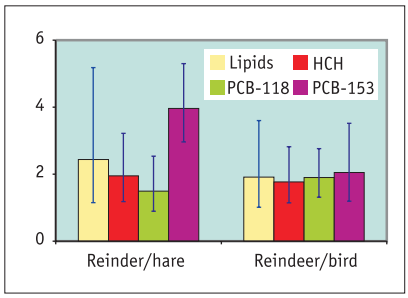


Figure 5.19.
Concentration ratios (geometric mean and 95% confidence limits) for OCs and lipid content in reindeer/hare and reindeer/birds, for all sample sites.

The DDE/DDT ratio in soils immediately following application of DDT pesticide is normally about 0.1 or less (Harner *et al.*, 1999). As a result of the microbiological transformation of *p,p'*-DDT into *p,p'*-DDE, and other metabolites, this ratio increases with time. In temperate zones, the DDE/DDT ratio in soils 30 years after the last pesticide application ranges from 0.7 to 2 (Harner *et al.*, 1999). Ratios in the Russian Arctic are, as a rule, at the lower end of this range (see Table 5.19a). This may indicate that fresh use of DDT is still contributing to contamination of the Russian Arctic. However, lower ratio values can be also explained by the slower rate of metabolic processes which occur in Arctic soils.

Metabolic transformation of *p,p'*-DDT also takes place in higher organisms (WHO, 1982) and the DDE/DDT ratio in their tissues can serve as an indicator of the relative rate of *p,p'*-DDT transformation in different species. DDE/DDT ratios in terrestrial food chains in the Russian Arctic are provided in Figure 5.17 and Tables 5.19a and 5.19b. No statistically significant differences were observed between the ratio values, either in soils, lichens, or reindeer tissues, or, between the 6 sites (see Table 5.19a and 5.19b). This indicates that the *p,p'*-DDT transformation rate in reindeer tissues is comparable with that in soils and lichens. The ratio values for terrestrial birds are, as a rule, somewhat higher than in reindeer (see Table 5.19a), probably due to a faster rate of metabolic *p,p'*-DDT transformation in birds.

(b) Heavy metals

Some HMs, such as copper (Cu) and zinc (Zn) are essential elements for both plants and animals and as such, their levels in tissues are under homeostatic control (Yagodin *et al.*, 1989; Speidel and Agnew, 1982).

Table 5.19a.
DDE/DDT ratios (geometric means and 95% confidence interval) in terrestrial food chains.
n. d. – not detected

Site	Soil	Lichens	Browsers	
			Muscle	Liver
Kola Peninsula	0.35 (0.26-0.49)	0.60 (0.49-0.73)	0.39	4.2 (0.84-21)
Pechora basin	0.53 (0.4-0.69)	0.28	3 (0.14-65)	2.2 (0.69-3.2)
Taymir, west	0.54 (0.46-0.63)	0.87 (0.28-2.78)	0.77	1.4 (1.30-1.6)
Taymir, east	0.72 (0.18-2.9)	0.84 (0.69-1.0)	3.1 (0.22-41)	2.1 (0.63-7.4)
Chukotka inland	2.4	0.49 (0.33-0.74)	0.75	0.76 (0.76-0.77)
Chukotka, coast	0.48	0.44	0.19	n.d.
All sites	0.52 (0.48-0.71)	0.64 (0.54-0.74)	1.2 (0.14-10)	1.9 (0.6-5.7)

Non-essential elements, such as Hg and Cd, do not appear to be well-regulated by living organisms. Thus, tissue concentrations of Hg and Cd proportional to environmental (or food) contamination levels can be expected. The use of transfer factors is based on this assumption. However, deviations from direct proportionality do occur, and quite often are more pronounced at higher levels of exposure, especially for Pb (WHO 1989a, 1989b, 1991, 1992, 1995). A possible explanation for this is that HMs in high concentrations are toxic for all organisms and their transfer through cell membranes may be limited when tissue contamination exceeds some critical level. In addition, Pb content in tissue is probably under at least some degree of homeostatic regulation, since it belongs to a group of so-called 'conditionally essential elements' (Yagodin *et al.*, 1989; Speidel and Agnew, 1982). As a result, the HM transfer coefficient for a particular link in a food chain depends not only upon environmental conditions, but also upon the HM concentration in abiotic media (or food). It follows that use of HM transfer coefficient values obtained at low exposure levels, for tissue concentration assessment at high exposure levels, can lead to an overestimation of the concentration of that HM.

Another important condition for the applicability of the transfer factor approach, is the absence of kinetic limitations. The biological half-life of HMs in mammals is difficult to estimate (WHO 1989a, 1989b, 1991, 1992, 1995). The biological half-life of Hg and Pb in blood and the soft tissues of mammals normally ranges from several weeks to several months. However, significantly slower Hg and Pb elimination rates have also been reported. For example, the half-life of Hg in brain tissue and of Pb in bone ranges from years to decades, and for a mammal to eliminate 50% of absorbed Cd can take as long time as 30 years. Based on these elimination rates, HM food-to-mammal transfer factors can be expected to show a significant degree of dependence on mammal age.

As for OCs, the soil-lichen-reindeer food chain is one of the most important pathways for human exposure to HMs in the Arctic. Lichen is able to assimilate mineral substances from any material to which it adheres. However, the similar pattern of HM concentration ratios in lichens, mosses and soils (Hg: Cd: Pb in the ratio of 2:3:95) indicates that mosses, as well as lichen, take up most of their HM burden from the air, apparently from windblown soil and dust. Geometric mean values of lichen/moss concentration ratios ranged from 0.5 to 0.6 for all three HMs. This ratio can be considered indicative of the greater ability of mosses to intercept particles. The geometric mean for the lichen/moss concentration ratio, calculated using the pooled set of data for all three metals was equal to 0.56.

An example of HM concentration patterns for the soil-lichen-reindeer food chain is given in Figure 5.20.

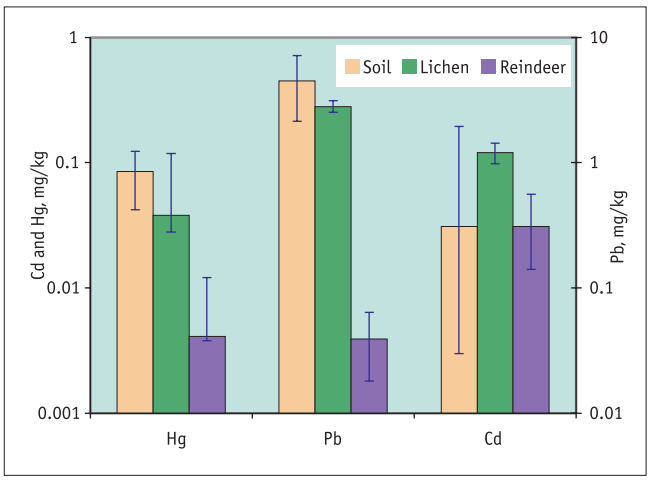


Figure 5.20. HM distribution patterns in the soil-lichen-reindeer food chain on the Kola Peninsula in 2001. Concentrations of HMs in soil and lichen and their ranges are given on the dry weight basis, while those for reindeer muscle are provided on the wet weight basis.

Table 5.19b.
DDE/DDT ratios (geometric means and 95% confidence interval) in terrestrial food chains.
n. d. – not detected

Site	Reindeer		
	Muscle	Liver	Kidney
Kola Peninsula	0.63 (0.38-1.1)	1.3 (0.67-2.4)	0.93 (0.54-1.6)
Pechora basin	0.39 (0.21-0.73)	1.2 (0.75-1.8)	0.83 (0.53-1.3)
Taymir, west	0.55 (0.35-0.85)	0.47 (0.23-0.96)	0.72 (0.58-0.88)
Taymir, east	0.82 (0.31-2.16)	0.38 (0.12-1.2)	0.41 (0.13-1.3)
Chukotka inland	1.33 (0.67-2.6)	0.5	n.d.
Chukotka, coast	1.5 (1.43-1.58)	0.49 (0.46-0.51)	n.d.
All sites	0.65 (0.48-0.89)	0.76 (0.54-1.1)	0.73 (0.55-0.96)

Soil-to-lichen transfer coefficients for Hg and Pb are similar (the geometric mean equal to 0.6, ranging from 0.3 to 1.3 based on dry wt. concentrations). The geometric mean for Cd was about twice as high (1.3), but the difference is of low statistical significance. Soil-to-lichen transfer factors for HMs are several times lower than those for OCs. This is consistent with the hypothesis that soil dust interception is the main pathway of HM uptake by lichens, whilst organic chemicals, in addition to this mechanism, are also absorbed through dry gaseous deposition. Uptake of HMs from soil by mushrooms is more strongly affected by the chemical state of the metal. Geometric mean values of soil-to-mushroom transfer factors (based on dry weight concentrations) ranged from 0.12 and 0.25 for Pb and Hg, respectively, to 1.5 for Cd. The geometric mean of the soil-to-berry transfer factor for Pb (0.006) is two orders of magnitude lower than that calculated for lichens.

Significant differences between Pb and Hg and Cd also occur in the transfer of HMs from lichen to reindeer tissues. Geometric means of lichen-to-reindeer transfer factors for Hg and Cd are similar (0.4 and 0.5, respectively) and an order of magnitude higher than that calculated for Pb (0.03). All transfer factors as a function of herd, vary within an order of magnitude. This variability can be partially explained by differences in the mean age of animals sampled. The age dependence of a pollutant concentration in an animal tissues can be described by the following simple model:

$$\frac{dC}{dt} = r_i - k_e C \qquad (5.2)$$

Where:

C is the pollutant concentration in the animal, ng/g ww;
r_i is the pollutant accumulation rate, ng/g ww per year;
k_e is the pollutant elimination rate constant, per year;
t is the animal age, years.

Assuming that the intake rate is constant, this can be expressed as:

$$C = \frac{r_i}{k_e}(1 - e^{-kt}) \qquad (5.3)$$

When $k_e t$ is small (i.e., elimination is slow), equation 5.4 can be simplified and the concentration dependence on age becomes directly proportional:

$$C = r_i t \qquad (5.4)$$

As was shown in section 5.3.2, HM levels in reindeer are directly proportional to age. This means that the elimination rate is quite slow ($k_e t$ is small) during at least the first few years of life, and effective rates of HM accumulation in reindeer tissue (see Table 5.12) provide an estimate of r_i. Values for the elimination rate (k_e) can be estimated by applying equation 5.3 to experimental data. Because of the small number of age groups and narrow age intervals recorded, the accuracy of such estimates using data obtained in this study is low. However, it is clear that the elimination half-life for all three HMs is at least several years, and could be in the order of 10 years.

Using a typical rate of lichen consumption by reindeer (i.e. 40 g dw/kg live weight per day; White *et al.*, 1999) and HM concentrations from Table 5.7, the total annual uptake of HMs from lichen by reindeer can be calculated. Based on geometric means, this yields values of 0.51, 29, and 1.0 mg/kg live weight per year for uptake of Hg, Pb and Cd, respectively. Comparison of these values with effective deposition rates from Table 5.12 indicate that less than 0.1% of Pb from consumed lichens is transferred into the muscle, while the effectiveness of Hg and Cd transfer to muscle is up to an order of magnitude greater, with values of 0.4% and 1.0%, respectively.

5.4. Freshwater environment

5.4.1. PTS in fish

Fish were obtained from Lake Lovozero (Kola Peninsula), the Pechora River, the Yenisey River (western Taymir), the Khatanga River (eastern Taymir), and the Kanchalan River (inland Chukotka). Fish age ranged from 5 to 14 years. The number of individual samples of tissue collected at a given location for use in the preparation of pooled samples ranged from 1 to 13 (see Table 5.1). The following fish species were sampled:

- pike (*Esox lucius*)
- burbot (*Lota lota*)
- perch (*Perca fluviatilis*)
- ide (*Leuciscus idus*)
- whitefish (*Coregonus lavaretus*)
- Arctic cisco (*Coregonus autumnalis*)
- broad whitefish (*Cerogonus nasus*)
- Arctic char (*Salvelinus alpinus*)
- inconnu (*Stenodus leucichthys nelma*)
- grayling (*Thymallus thymallus*)

Fish muscle and liver tissues were analyzed for all PTS listed in Section 1.2.4. Results of analysis were divided into groups according to sex (male or female), age (either two or three classes), and tissue type (muscle or liver). Age differences within groups ranged from 1 to 2 years. The difference between the mean ages of fish in the oldest and youngest groups was always less than a factor of two.

PTS concentration relationships to fish sex, age and tissue type

(a) Organochlorines

Male/female concentration ratios of OCs that could be reliably quantified (*p,p'*-DDT, *p,p'*-DDE, PCB-138, PCB-153, and HCB) were calculated using data from

fish of the same age groups. No statistically significant difference was found between the geometric mean of the ratios and unity, for any OCs or any species. Calculated age ratios (for middle/young and old/young age groups) are, with a few exceptions, slightly higher than unity and range from 0.8 to 2.8. However, in all cases, the standard deviation was comparable to, or larger than the mean ratio value. Taking into account the relatively small number of values included in the average, this implies that the statistical significance of any observed age dependency is very low, and that data for all age groups can be combined in the calculation of geometric mean OC concentrations. The geometric means of OC liver/muscle concentration ratios are close to unity for salmon species and range from 2 to 5 for pike, perch and ide. The highest absolute and relative concentrations of all OCs from all sites were found in burbot liver samples. In the liver of both male and female burbot, fished from Yenisey River, OC concentrations were as high as 580 ng/g for ΣPCB_{15}, 470 ng/g for ΣDDT, and 39 ng/g for ΣCHLOR. Levels of OCs in the liver of other fish species were much lower. In contrast, OC concentrations in burbot muscle were very close to those in other species. The liver/muscle concentration ratio for burbot varied from site to site within two orders of magnitude. The geometric mean for detected OCs in burbot ranges from 50 to 160. These observations are explained by the fact that the lipid content of burbot liver is significantly higher than that of the other species studied, whilst lipid levels in the muscle

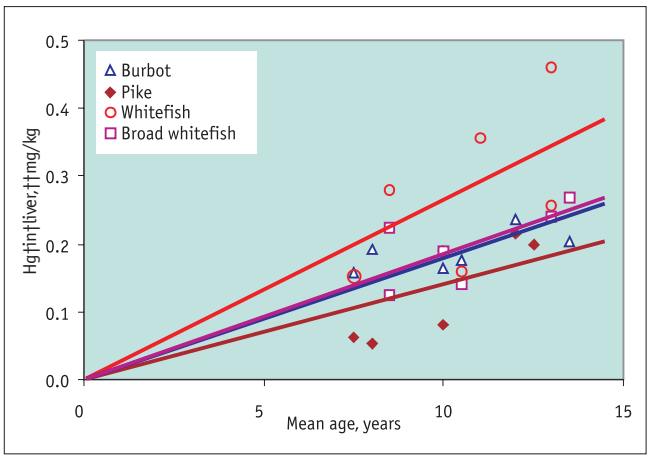


Figure 5.21. Hg concentration in fish liver as a function of the fish age in northern Russia in 2001.

Table 5.20. Geometric means and 95% confidence interval of effective rates of accumulation of heavy metals in fish tissues (μg/g ww per year).

Fish	Area	Muscle	Liver
		Hg	
Burbot	Kola Peninsula, n=4	0.018 (0.013-0.024)	0.043 (0.037-0.049)
	Taymir, west, n=6	0.011 (0.0088-0.013)	0.019 (0.016-0.021)
	Taymir, east, n=4	0.010 (0.072-0.14)	0.020 (0.014-0.029)
Pike	Kola Peninsula, n=4	0.017 (0.013-0.023)	0.035 (0.031-0.039)
	Chukotka, inland, n=6	0.0058 (0.0039-0.088)	0.012 (0.0080-0.017)
Perch	Pechora basin, n=3	0.012 (0.011-0.013)	0.025 (0.020-0.031)
Ide	Pechora basin, n=5	0.0069 (0.0053-0.089)	0.013 (0.011-0.016)
Whitefish	Kola Peninsula, n=4	0.014 (0.013-0.015)	0.043 (0.034-0.054)
	Pechora basin, n=5	0.0053 (0.0046-0.0060)	0.013 (0.011-0.014)
	Taymir, west, n=4	0.0069 (0.0048-0.010)	0.017 (0.014-0.020)
	Taymir, east, n=6	0.014 (0.0066-0.030)	0.025 (0.019-0.033)
Arctic cisco	Taymir, west, n=4	0.0039 (0.0030-0.0052)	0.011 (0.010-0.013)
Broad Whitefish	Taymir, east, n=6	0.0075 (0.0066-0.086)	0.018 (0.015-0.022)
Inconnu	Chukotka, inland, n=2	0.0031 (0.0028-0.0036)	0.014 (0.089-0.022)
		Pb	
Burbot	Kola Peninsula, n=4	0.0051 (0.0040-0.0064)	0.019 (0.014-0.0025)
	Taymir, west, n=6	0.015 (0.011-0.022)	0.025 (0.021-0.030)
	Taymir, east, n=4	0.0037 0.0017-0.0081)	0.010 (0.0054-0.017)
Pike	Kola Peninsula, n=4	0.012 (0.0099-0.015)	0.046 (0.040-0.052)
	Chukotka, inland, n=6	0.018 (0.016-0.021)	0.044 (0.037-0.052)
Perch	Pechora basin, n=3	0.020 (0.016-0.026)	0.057 (0.044-0.074)
Ide	Pechora basin, n=5	0.0031 (0.0027-0.0036)	0.013 (0.011-0.016)
Whitefish	Kola Peninsula, n=4	0.0014 (0.0010-0.0019)	0.013 (0.012-0.015)
	Pechora basin, n=5	0.0014 (0.0012-0.0017)	0.016 (0.013-0.020)
	Taymir, west, n=4	0.0033 (0.0028-0.038)	0.022 (0.018-0.028)
	Taymir, east, n=6	0.0016 (0.0009-0.0030)	0.021 (0.018-0.025)
Arctic cisco	Taymir, west, n=4	0.0021 (0.0020-0.0023)	0.012 (0.0081-0.017)
Broad Whitefish	Taymir, east, n=6	0.00083 (0.0006-0.0011)	0.021 (0.018-0.025)
Inconnu	Chukotka, inland, n=2	0.0089 90.0067-0.012)	0.028 (0.021-0.38)
		Cd	
Burbot	Kola Peninsula, n=4	0.0037 (0.0029-0.0045)	0.024 (0.019-0.030)
	Taymir, west, n=6	0.0032 (0.0022-0.0045)	0.019 (0.015-0.026)
	Taymir, east, n=4	0.0052 (0.0026-0.010)	0.011 (0.010-0.0014)
Pike	Kola Peninsula, n=4	0.037 (0.0032-0.0042)	0.021 (0.015-0.028)
	Chukotka, inland, n=6	0.0028 (0.022-0.0036)	0.0084 (0.0075-0.0095)
Perch	Pechora basin, n=3	0.0043 (0.0034-0.0053)	0.018 (0.015-0.022)
Ide	Pechora basin, n=5	0.0026 (0.0020-0.0032)	0.023 (0.020-0.028)
Whitefish	Kola Peninsula, n=4	0.0032 (0.0027-0.0038)	0.024 (0.021-0.028)
	Pechora basin, n=5	0.0020 (0.0015-0.0025)	0.015 (0.012-0.019)
	Taymir, west, n=4	0.0019 (0.0014-0.0027)	0.0080 (0.0073-0.0088)
	Taymir, east, n=6	0.0018 (0.0012-0.0027)	0.017 (0.013-0.023)