Annex Section (d) – Concentrations & Trends in the Environment

This annex contains data and references to support the information provided in Section (d) of the WCC Submission for Pentachlorobenzene (PeCB)

Extracted from Bailey, B., 2007. Pentachlorobenzene – Sources, environmental fate and risk characterisation, Euro Chlor Science Dossier (in press).

1 Concentrations and trends of PeCB in the environment

1.1 Atmosphere

During a project to monitor PeCB and other chemicals in the Canadian atmosphere to look for seasonal changes in 1988-1989, PeCB was detected in 133 out of 143 samples (Hoff et al. 1992). Its mean concentration was reported as <8.0 pg/m^3. Some PeCB was reported lost (volatilized) during summer sampling so that it was impossible to calculate a true mean.

Passive air samplers were deployed across North America for one year from 82° north (Alert, Canada) to 10° north (Monteverde, Costa Rica) in 2000-2001 to determine the long range transport and distribution of a variety of organochlorine compounds (Shen et al. 2005). The reported concentrations of PeCB were relatively constant across the continent with an annual average of 45 pg/m^3 with an apparent range of 17 to 136 pg/m^3. The corresponding annual average for HCB was 89 pg/m^3 with an apparent range of 49 to 131 pg/m^3. This agrees well with the average HCB concentration reported from the Integrated Atmospheric Deposition Network (IADN) above the North American Great Lakes in 2000, about 72 pg/m^3 (Buehler et al. 2004). This wide distribution of relatively constant PeCB atmospheric concentrations is consistent with a compound having a long atmospheric lifetime and release from a wide variety of processes. One parameter that apparently does influence the measured concentrations of PeCB (and HCB) is the altitude at a given location. Both in the work by Shen et al. and in a study using analysis of mosses in the Andean Mountains concentrations were reported to be higher at higher elevations (Grimalt et al. 2004).

A study of the influence of different emission sources on the mixtures of chloroorganics present in the atmosphere in Germany showed the chlorobenzenes, including PeCB, at higher concentrations near industrial or urban locations than at a rural reference site (Wenzel et al. 2006). Samples were collected July through September 1995 with a winter urban sample in February 1996. Reported concentrations of PeCB ranged from 5.7 to 28.6 pg/m^3 in the industrial and urban sites and 0.31 pg/m^3 at the rural reference site. Kaj and Palm reported atmospheric concentrations of PeCB in Southern Sweden in 2003 to average 0.033 ng/m^3, similar to the concentrations reported elsewhere (Kaj and Palm 2004).

1.2 Water

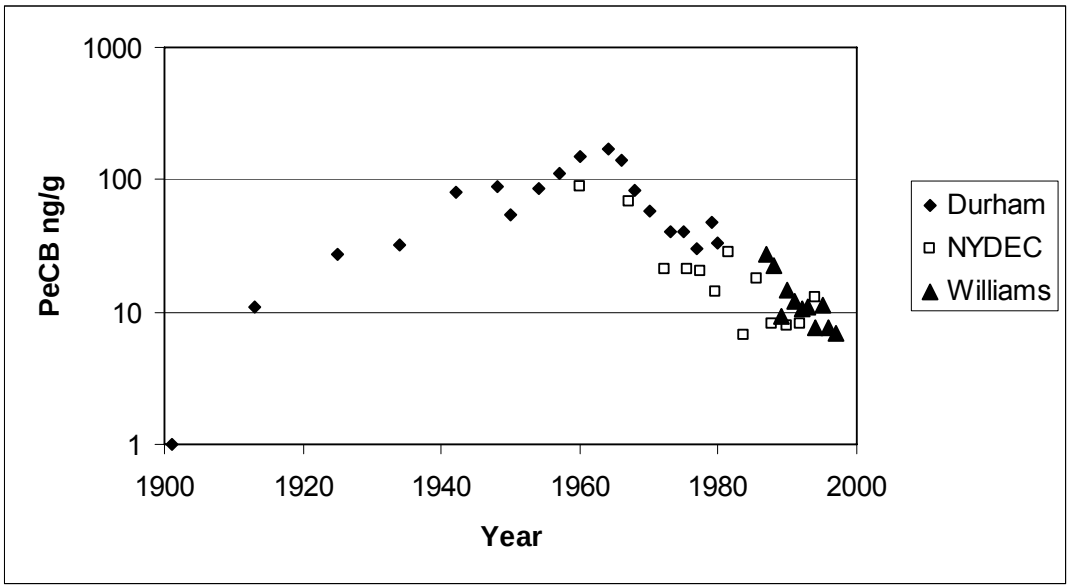
Concentrations of chemicals in the Niagara River were monitored for two years, 1981-1983 (Oliver and Nicol 1984). During this period reported concentrations of PeCB ranged from 0.34 to 6.4 ng/L with a mean of 1.3±1.0 ng/L. HCB concentrations ranged from 0.16 to 29 ng/L and the mean concentration was 1.1±2.9 ng/L. A more comprehensive monitoring program was started later which separated dissolved and particulate bound chemicals. Concentrations of PeCB at the mouth of the Niagara River where it flows into Lake Ontario have been monitored carefully during the period 1987-1997 showing annual mean total (dissolved plus particulate) concentrations dropping from 0.351 ng/L to 0.093 ng/L, a 75% reduction in the amount of PeCB entering Lake Ontario (Williams et al. 2000). PeCB mean concentrations at the head of the Niagara River were 0.024 to 0.015 ng/L over the same period. The estimated total concentration of 93 pg/L at the mouth of the Niagara River in 1996-1997 corresponds to a loading of 52 g per day to Lake Ontario (Williams et al. 2000). Most of this PeCB was not present at the head of the Niagara River but was added from various tributaries. Approximately 25% of this PeCB was present on the suspended solids. The concentrations of PeCB on the suspended solids are shown in Figure 4.1.

PeCB has also been monitored in the St. Clair River (Chan 1993). Concentrations of PeCB in the St. Clair River were greater at the mouth than at the head, and the mean PeCB

concentration at the mouth dropped between 1988 and 1989. Both of these monitoring programs have continued but more recent data is not expected to be available until 2007 (Neilson 2006).

A survey of Great Lakes water to determine concentrations of chlorobenzenes in water and sediments was carried out April-November 1980 (Oliver and Nicol 1982). PeCB was not detected at some of the open water sites and mean

Figure 4.1. PeCB in Niagara Bar sediment and Niagara River suspended solids. Durham and NYDEC data are from sediment cores and Williams data is from suspended solids. Note logarithmic concentration scale.



concentrations of PeCB were reported to be 0.2 ppt (part per trillion) in Lake Ontario and 0.04 ppt in Lake Huron. Water samples collected in the spring of 1986 in the Canadian Great Lakes showed detectable PeCB in many samples (Stevens and Neilson 1989). None was detected in Lake Superior at a detection level of 0.007-0.011 ng/L. In Lake Huron PeCB was detected in 11% of the samples with an average concentration in those samples of 0.033 ng/L, and in Georgian Bay PeCB was detected in 29% of the samples at an average concentration of 0.019 ng/L. In the lower Great Lakes, concentrations were only a bit higher, 14% detected in Lake Erie with an average of 0.058 ng/L and in Lake Ontario 70% detected with an average PeCB concentration of 0.062 ng/L. Water sampling results in the mid to late 1990s were statistically treated to calculate the upper 90% confidence interval of compounds like PeCB which were only detected part of the time (Williams et al. 2001). Thus the upper 90% confidence interval reported for Lake Superior in 1997 was 0.024 ng/L PeCB; Lake Erie in 1998 was 0.02 ng/L; and Lake Ontario in 1998 PeCB was 0.05 ng/L.

Precipitation has been monitored on the Canadian side of the Great Lakes for contamination by organochlorine compounds, including PeCB (Chan et al. 2003). PeCB was detected in less than 50% of samples so that total amounts of these compounds could not be calculated. A study of PeCB in snow and ice from the Russian arctic reported only traces (Melnikov et al. 2003). In southeast Africa, on the shore of Lake Malawi, PeCB concentrations in precipitation samples collected in 1997 and 1998 ranged from 1 to 48 pg/L with an average of 10±14 pg/L (Karlsson et al. 2000).

A 1993 study of the distribution of chloroorganics in the North Pacific Ocean, the Bering and Chukchi Seas found PeCB in all samples (Strachan et al. 2001). PeCB concentrations were an average of 16 pg/L in the dissolved phase. Suspended solids represented just a small fraction of the total PeCB, adding 0.38 pg/L. Strachan et al. calculated that the flow of water northward into the Arctic Ocean carries 0.31-0.52 metric ton of PeCB per year.

Water and sediment in the Yangtse River near Nanjing were analyzed for organochlorines in 1998 (Jiang et al. 2000). The total PeCB concentrations were about 0.4 ng/L in the river water. An average of 57% of the PeCB was in the dissolved phase and on particulate matter less than 0.7 µm. The highest sediment concentration of PeCB at one location was 3 ng/g. Water from four rivers draining industrial regions in the U.K. were sampled weekly for two years to determine the chlorobenzenes contributed to the Humber estuary (Meharg et al. 2000). The flux of chlorobenzenes into the Humber was dominated by 1,2-dichlorobenzene, 56 kg/year, and 1,4-dichlorobenzene, 65 kg/year, with only 0.8 kg/year of PeCB discharged.

1.3 Sediments

Sediment cores from Lake Ontario near the mouth of the Niagara River reveal a history of PeCB loading to Lake Ontario which parallels that of the other chlorobenzenes and chlorinated chemicals. Figure 4.1 shows PeCB reached its peak concentration about 1960 followed by a substantial decline to about 10% of the peak by 1980 (Durham and Oliver 1983; NYDEC 1998) in this industrially impacted area. Concentrations of PeCB on suspended solids in the Niagara River flowing into Lake Ontario have continued to drop during the 1990s as shown by suspended solids analyses (Williams et al. 2000). It is interesting to note how well the PeCB concentrations on suspended solids agree with the concentrations in sediment cores. Note also that this more recent concentration trend is the same as observed in the earlier sediments.

Kaminsky et al. analyzed sediment samples collected from a number of sites in western Lake Ontario in October 1980 to trace the movement of contaminants from the Niagara River (Kaminsky et al. 1983). PeCB concentrations ranged from 2 ppb to 32 ppb. In another study the distributions of organochlorines in Lake Ontario sediments were studied to estimate total quantities which had accumulated in surface sediments as of 1981 (Oliver et al. 1989). At that time they estimated a total inventory of about 3 metric tons of PeCB in Lake Ontario surface sediments. Surface sediments in Lakes Erie, Huron, and St. Clair were analyzed for chlorobenzenes and other chlorinated chemicals in 1980 and 1982 (Oliver and Bourbonniere 1985). Mean PeCB concentrations in sediments in Southern Lake Huron were 1.5 ng/g, Lake St. Clair 5.8 ng/g, Western Lake Erie 2.9 ng/g, Central Lake Erie 1.0 ng/g, and Eastern Lake Erie 0.9 ng/g. The implication is that one source of PeCB was along the St. Clair River and perhaps another along the Detroit River.

Muir et al. have determined the concentrations of PeCB in the sediment of a series of remote lakes in northern Canada (Muir et al. 1995). Sediment surface layer concentrations (representing a period of time approximately centered on 1979-1988) of PeCB in these northern lake sediments ranged from less than 0.01 to 0.73 ng/g sediment. Table 4.1 summarizes these results. The PeCB concentrations have been divided by the fraction of organic carbon (OC) in the sediments to allow comparison with regulatory limits. The sediment PeCB concentrations found in four Alaskan Arctic lakes sampled in 1991-1993 averaged 0.10 ±0.10 ng/g dry weight, approximately the same as the Canadian lakes described in Table 4.1 (Allen-Gil et al. 1997).

Table 4.1. Concentration of PeCB in remote Lake Sediments in Northern Canada (Muir et al. 1995).

Lake	PeCB ng/g	% OC	PeCB ng/g OC
Lake 375	0.28	13.4	2.1
Lake 382	<0.01	16.9	<0.06
Far Lake	0.21	9.4	2.2
Hawk Lake	0.32	13.5	2.4
Amituk Lake	0.73	1.2	61
Sophia Lake	0.01	3.0	0.33
Buchanan Lk	<0.01	1.3	<0.08
Hazen Lake	0.01	1.7	0.59

Chlorinated contaminants have been determined in the sediments and flood plain soils of the River Elbe watershed (Witter et al. 1998; Schwarzbauer et al. 2001). Two of three locations on the flood plain had concentrations of PeCB as high as 64 and 71 µg/kg (Witter et al. 1998).

The third site was reported to have only 1 µg/kg or less PeCB. Concentrations of PeCB appear to have peaked in the 1960s as shown by concentrations at different depths. Sediment samples collected in 1993 and 1994 in the Berlin area along the Spree and Havel Rivers also contained PeCB (Schwarzbauer et al. 2001). Most of the sampling locations had <10 µg/kg PeCB but the maximum concentration reported in the Havel River system was 76 µg/kg and in the Spree was17 µg/kg. Sediments from seven locations on the Elbe River downstream from Hamburg were analyzed for PeCB by three different methods (Eder et al. 1987). In general the PeCB concentrations reported ranged from 0.47 to 4.4 ng/g wet weight.

Sediment samples collected from the Lippe River, Germany, between 1999 and 2001 were analyzed for PeCB and other organics (Kronimus et al. 2004). PeCB was detected in many of the samples at concentrations ranging up to 6 ng/g from a location near its mouth at the Rhine River. There was considerable temporal variation with even the station showing the highest concentrations of PeCB reporting 1 ng/g at one sampling time. A survey of pollutants in sediments of the Ebro River reported PeCB in 25% of the samples with an LOD of 0.48 µg/kg (Lacorte et al. 2006). The mean PeCB concentration of detected samples was 1.17 µg/kg.

The concentration of PeCB in sediment from the Mulde Reservoir (Saxony, Germany) was determined in a study of chemical partitioning and mobilization under anoxic conditions (Zoumis et al. 2001). The reported concentration of PeCB was 0.4 µg/kg. In Ontario (Canada) the Sir Adam Beck Reservoir takes water from the Niagara River and after a relatively brief holding period returns it to the Niagara River through a power plant. In 1998 the sediment was sampled in several locations for determination of contaminant concentrations (Williams et al. 2003). The highest reported PeCB concentration was 0.4 ng/g at one location with only a trace at other locations.

Chlorobenzenes were determined in surface sediments collected off the coast of Taiwan in the vicinity of several sewage outfalls in 1996 (Lee et al. 2000). PeCB was detected at all but one of the 40 sampling stations at concentrations ranging up to 15.7 ng/g. These same locations were sampled a year later, 1997, to allow more statistical analysis to locate pollution sources (Lee et al. 2005). PeCB concentrations were similar in this second study and the authors did not report locations of any point sources for PeCB.

Low concentrations of PeCB, 0.01 to 0.06 µg/kg were reported in sediment from the industrially polluted Kishon River, Israel (Oren et al. 2006). As in many of the studies, concentrations of PeCB were correlated with the organic carbon content of the sediment. Surface sediments in Masan Bay, Korea, were analyzed in 1997 for chlorinated compounds (Hong et al. 2003). PeCB was detected in only a few samples at up to 0.28 ng/g.

1.4 Soils

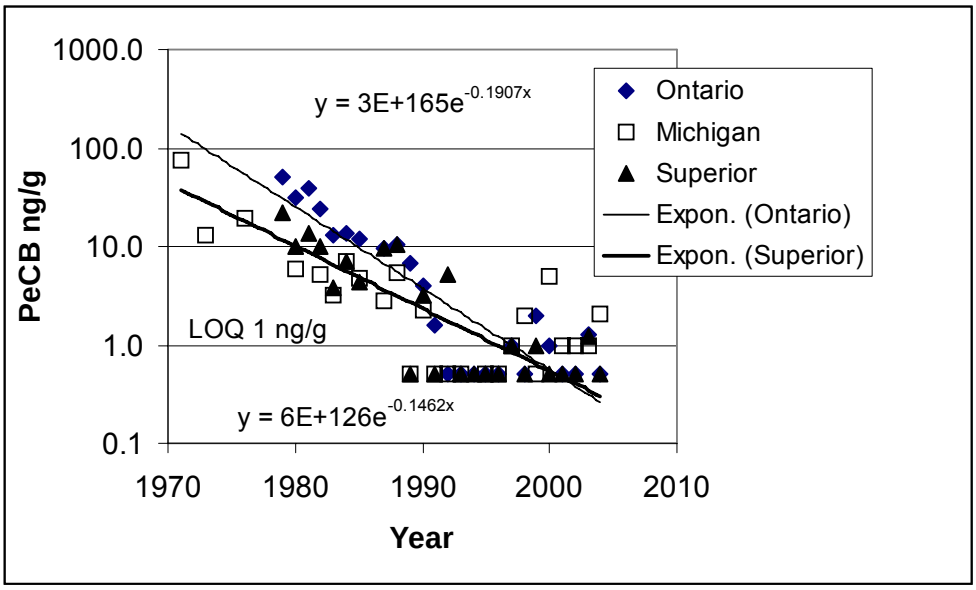
The concentrations of chlorobenzenes in surface soil at five sites in the Niagara Falls (USA) area were studied (Ding et al. 1992). The five sites were chosen to show if significant quantities of chlorobenzenes were migrating through the air from the Love Canal hazardous waste site or accumulating from contaminated water. The site near Love Canal was compared with nearby industrial sites and a suburban site 12 miles from the canal. PeCB was detected in soil samples from all the sites. Concentrations in individual soil samples ranged from non detect up to 1700 pg/g. The suburban site had a mean PeCB concentration of 480 pg/g with a range of 180 to 1200 pg/g. The conclusion was that the Love Canal hazardous waste site had not released excessive amounts of chlorobenzenes to the atmosphere which deposited in the region.

The European Reference Soil-Set was analyzed for a variety of chemical microcontaminants including PeCB (Gawlik et al. 2000). PeCB concentrations in the five soils ranged from 0.10 to 0.79 ng/g. Analysis of digested sewage sludges from five wastewater treatments near Vancouver (Canada) to determine their suitability for application to cropland did not detect PeCB at a detection level of <0.01 µg/g (Bright and Healey 2003).

1.5 Biota

PeCB has been monitored in Great Lakes herring gull eggs annually since the 1970s by the Canadian Wildlife Service. Concentrations at all herring gull colonies have dropped dramatically since then (Bishop et al. 1992; Petit et al. 1994; Pekarik et al. 1998; Jermyn-Gee et al. 2005; Havelka 2006). The exact extent of decrease varies at the different sites and the trend is partially obscured by the non-detected PeCB in many of the more recent samples. For example, the PeCB concentrations in herring gull eggs from Muggs Island/Leslie Spit near Toronto dropped from 50 ng/g in 1979 to non-detected at 1 ng/g by the mid 1990s, a 98% decrease. Figure 4.2 shows concentrations of PeCB in herring gull eggs at three representative sites on the Great Lakes. Herring gull eggs on Lake Superior probably reflect the background atmospheric concentration of PeCB because they are generally distant from most industrial activity. The trend lines indicate an average decrease in PeCB concentration of about 17% and 14% per year for the eggs from the shores of Lake Ontario and Lake Superior, respectively. Table 4.2 summarizes the decreases in PeCB concentrations from all the sampling sites. In the future it will not be possible to reliably evaluate trends because most of the PeCB concentrations are less than the limit of quantitation in the CWS herring gull egg program. A recent publication (Hebert and Weseloh 2006) adjusts the rates of decline in chemical concentrations for changes in the trophic position of the herring gulls in different colonies as a result of environmental changes. Because some herring gulls have moved down the food web as a result of eating more terrestrial food, the true decline in contaminant concentration may not be as great as indicated by the straight concentrations. For HCB this has the result of bringing the observed rate of decline in herring gull egg concentrations into closer agreement with the reported declines in atmospheric concentrations. There is no comparable data set for PeCB in the atmosphere.

Figure 4.2. Concentrations of PeCB in herring gull eggs from colonies on the shores of the Great Lakes. Note the logarithmic concentration scale. Concentrations less than the limit of quantitation (LOQ) have been plotted as 0.5 the LOQ. The trend lines for eggs from Lakes Superior and Ontario show the average rate of decrease in PeCB concentration.



Analyses of PeCB and other chloroorganics in Lake Ontario biota and environment collected 1981-1986 enabled determination of bioconcentration and biomagnification factors (Oliver and Niimi 1988). The concentrations of PeCB are listed in Table 4.3.

Table 4.2. Great Lakes herring gull colonies and rates of PeCB concentration decrease in herring gull eggs for the entire period of monitoring through 2004. See the CWS reports cited above for exact dates and monitoring sites.

Location	Rate Constant ($Year^{-1}$)	Percent Decrease ($Year^{-1}$)	Half-life (Years)
St Lawrence R., Strachan Island	-0.071	6.9	9.8
Lake Ontario, Snake Island - West Brothers Island	-0.144	13.4	4.8
Lake Ontario, Mugg's Island - Leslie Spit	-0.191	17.4	3.6
Hamilton Harbor	-0.112	10.6	6.2
Niagara River	-0.167	15.4	4.1
Lake Erie, Colbourne Light	-0.149	13.8	4.7
Lake Erie, Middle Island	-0.115	10.9	6.0
Detroit River, Fighting Island	-0.158	14.6	4.4
Lake Huron, Chantry Island	-0.107	10.1	6.5
Lake Huron, Channel Shelter I.	-0.173	15.9	4.0
Lake Huron, Double Island	-0.136	12.7	5.1
Lake Michigan, Gull Island	-0.111	10.5	6.2
Lake Michigan, Big Sister Island	-0.105	10.0	6.6
Lake Superior, Agawa Rock	-0.146	13.6	4.7
Lake Superior, Granite Island	-0.121	11.4	5.7

A survey of Great Lakes fish caught during the late 1970s found PeCB only in fish from Lake Ontario and the Ashtabula River, Ohio, and its tributary (Kuehl et al. 1981). More recently the US National Study of Chemical Residues in Fish (Kuehl et al. 1994) detected PeCB at about 22% of the 388 sites nationwide, with the highest concentrations near chemical manufacturing plants. Pereira et al. and Burkhard et al. reported PeCB along with other halogenated organics in biota and sediments from the lower Calcasieu River and the Bayou d'Inde, Louisiana (Pereira et al. 1988; Burkhard et al. 1997). A 1993 study of contaminants in brown bullhead fish from the Detroit River, Michigan found PeCB along with much higher concentrations of PCBs and other chloroorganics in this industrially impacted river (Leadley et al. 1998). Mean concentrations of PeCB were 13.0, 29.4 and 16.1 μg/kg wet weight in the fish from Amherstburg Channel (east side), Trenton Channel (west side) and Peche Island at the head of the river, respectively.

Table 4.3. Concentrations of PeCB in Lake Ontario biota and environment (Oliver and Niimi 1988).

Species, units	PeCB
Water, pg/L	72±15
Bottom sediments, ng/g dry wt.	33±14
Suspended sediments, ng/g dry wt.	13±3.9
Plankton, ng/g wet wt.	0.6±0.3
Mysids, ng/g wet wt.	8.4±6.5
Amphipods, ng/g wet wt.	5.0±3.7
Oligochaetes, ng/g wet wt.	0.8±0.3
Sculpin, ng/g wet wt.	2.6
Alewive, ng/g wet wt.	n.d.
Small smelts, ng/g wet wt.	n.d.
Large Smelts, ng/g wet wt.	2.1
Fish (large salmonids), ng/g wet wt.	5.0±3.1

Zebra mussels and eel in the Rhine and Meuse Rivers in 1994 were analyzed for a wide variety of chemicals and metals (Hendriks et al. 1998). PeCB concentrations in zebra mussels from the Rhine, Meuse, and Ysselmeer were 0.49, 0.27, 0.50 μg/kg wet weight, respectively. PeCB in eel from the Rhine, Meuse, and Hollands Diep were 15, 2.9, and 7.7 μg/kg wet weight, respectively. A survey of chemicals in fish from the Ebro River in Spain detected PeCB in 14 out of 18 samples with an LOD of 0.30 μg/kg. The mean concentration of PeCB was 1.10 μg/kg with a range of 0.32 to 3.31 μg/kg (Lacorte et al. 2006).

A quantity of PeCB, estimated at 59 kg, mixed in 5400 kg of PCB heat transfer fluid was released in the Gulf of St. Lawrence after a barge sank in 1970 (King et al. 2003). The barge was raised in 1996 at which time it was discovered that much of the heat transfer fluid had leaked into the environment. Snow crab digestive glands were monitored for their PeCB content and showed a rapid decline over the five year period at the sampling point right where the barge had rested. Concentrations were 150 ng/g wet weight in 1996, 12 ng/g wet weight in 1997, 3.6 ng/g wet weight in 1998, 3,6 ng/g wet weight in 1999, 3.1 ng/g wet weight in 2000. The other sampling sites, one or more miles distant, showed no increased concentrations over what is apparently the PeCB background concentration in that region, even in 1996.

A study of organochlorines in fin whale blubber collected in 1971 and 1972 from the Newfoundland area showed mean concentrations of PeCB of 0.96 and 0.01 ng/g lipid for females and males, respectively (Hobbs et al. 2001). From Nova Scotia the concentrations were 0.23 ng/g lipid and non detected for females and males, respectively. Because HCB was still in wide use in agriculture at that time, the corresponding concentrations of HCB were 244 and 333 ng/g lipid for females and males from Newfoundland and 217 and 221 ng/g lipid for females and males from Nova Scotia. Blubber biopsies from St. Lawrence Estuary beluga whales in 1994-1998 showed PeCB concentrations ranging widely from 1.56 ng/g lipid to 1510 ng/g with a geometric mean of 24.5 in females (Hobbs et al. 2003). In males the range was similar, 1.5-1500 ng/g lipid with a geometric mean of 144 ng/g.

A study of PeCB in fish from four Alaskan arctic lakes found mean concentrations (ng/g wet weight) of PeCB of 1.42±1.82 in grayling liver, 0.06±0.08 in grayling muscle, 0.48±0.35 in lake trout liver and 1.21±3.66 in lake trout muscle (Allen-Gil et al. 1997). A terrestrial top predator, the arctic fox has been studied for accumulation of chlorinated chemicals (Hoekstra et al. 2003). Samples were collected at three sites: Arviat on Hudson Bay, Canada, Holman, Northern Territory, Canada and Barrow, Alaska. About 20 animals at each site were collected during 1999-2001 at some distance from human habitation to minimize effects of garbage scavenging. The PeCB concentrations found in arctic foxes were: Arviat, muscle, 0.61±0.12; Holman, muscle, 0.29±0.06; Holman, liver, 0.57±0.11; Barrow, muscle, 0.55±0.20; Barrow, liver, 0.73±0.17.

The polar bear has been studied as another top predator whose diet allows for accumulation of persistent chemicals. A wide ranging study of bears from Alaska, Canada, East Greenland and Svalbard sampled between 1996 and 2002 looked for geographical variations in chemical concentrations (Verreault et al. 2005). Unfortunately for this purpose the data was reported in terms of HCB and the sum of PeCB, HCB and 1,2,3,4-tetrachorobenzene (TeCB). Thus only the sum of PeCB and TeCB can be calculated which can be interpreted as an upper bound on the PeCB concentration. HCB constituted about 75% of the sum of these three chlorobenzenes. Table 4.4 shows the reported concentrations and the sum of TeCB and PeCB. Concentrations of chlorobenzenes were relatively uniform between these polar bear populations spread over about half of the arctic.

Body burdens and concentrations of chlorobenzenes in polar bears of different ages have been studied before and after their seasonal fasts (Polischuk et al. 2002). Polischuk et al. reported that none of the chlorobenzenes included in their summation (1,2,4,5-TeCB, PeCB, and HCB) were excreted or metabolized during the fast so that concentrations increase as fat was metabolized. They also reported that nursing polar bear cubs received increased amounts of chlorobenzenes so that the concentration of chlorobenzenes in cubs is greater than that in adult bears.

Table 4.4. Concentrations of chlorobenzenes in polar bear lipid from adipose tissue, geometric mean in ng/g lipid (range) (Verreault et al. 2005).

Location	ΣCBz	HCB	PeCB+TeCB calculated
Alaska (males)	113 (70.4-181)	84.5 (35.1-157)	28.5
Alaska (females)	118 (70.0-277)	85.7 (41.7-230)	32.3
Amundsen Gulf	113 (71.1-190)	75.5 (43.9-146)	37.5
W. Hudson Bay	97.5 (55.9-257)	75.3 (39.3-229)	22.2
Foxe Basin/Gulf of Boothia	127 (73.4-329)	87.3 (46.3-305)	39.7
Lancaster Sound/Jones Sound	148 (111-186)	107 (74.9-146)	41
N. Baffin Island	191 (108-656)	152 (76.7-620)	39
S. Baffin Island	111 (42.0-275)	87.1 (33.2-249)	23.9
E. Greenland	79.1 (36.5-323)	60.0 (25.5-311)	19.1
Svalbard	105 (49.0-248)	90.4 (37.9-229)	14.6

Chlorobenzenes and other organochlorine compounds have been determined in a variety of Greenland biota collected in 1998-2001 (Vorkamp et al. 2004). As above, only the concentrations of HCB and the sum of 1,2,3,4-TeCB, PeCB and HCB are reported so that the sum of TeCB and PeCB have been determined by difference. As shown in Table 4.5, the concentration of PeCB+TeCB in lipid is much less than that of HCB in most cases. The concentration of PeCB+TeCB is very small in most tissues when they are adjusted for the lipid content of the tissues. In most species the chlorobenzenes concentration in lipid is about the same in the different tissues.

Table 4.5. Median concentrations and ranges of chlorobenzenes concentrations in Greenland biota in ng/g lipid weight (Vorkamp et al. 2004). The percentage of lipid in tissues was used to calculate the wet weight concentration of PeCB+TeCB, the potential PeCB dose to predators from consumption of prey.

Species	Tissue	% Lipid	ΣCBz, ng/g lw	HCB, ng/g lw	PeCB+TeCB, ng/g lw	PeCB+TeCB, ng/g ww
Ptarmigan	Liver	6.7	6.6 (4.3-29)	2.9 (2.1-5.1)	3.7	0.248
	Muscle	3.8	5.4 (3.5-9.6)	3.6 (3.5-6.8)	1.8	0.068
Hare	Liver	4.0	170 (120-330)	170 (120-330)	0	0.000
	Muscle	3.1	12 (3.1-56)	9.9 (3.0-40)	2.1	0.065
	Kidney	36	17 (15-170)	17 (15-170)	0	0.000
Lamb	Liver	9.1	4.8 (1.8-16)	4.6 (1.7-16)	0.2	0.018
	Muscle	8.8	1.5 (0.65-4.4)	1.2 (0.53-3.6)	0.3	0.026
	Kidney	3.9	5.4 (3.1-12)	4.8 (2.9-11	0.6	0.023
	Blubber	91	0.24 (0.11-0.48)	0.21 (0.089-0.41)	0.03	0.027
Caribou	Liver	7.3	6.3 (3.9-7.6	6.2 (3.9-7.4)	0.1	0.007
	Muscle	1.5	9.1 (7.0-10)	8.7 (6.8-9.5)	0.4	0.006
	Kidney	3.4	3.8 (2.3-5.6)	3.7 (2.2-5.4)	0.1	0.003
	Blubber	64	7.5 (3.8-9.6)	7.3 (3.7-9.3)	0.2	0.128
Muskox	Liver	9.8	150 (46-190)	150 (45-190)	0	0.000
	Muscle	2.0	620 (23-1100)	620 (23-1100)	0	0.000
	Kidney	3.1	180 (4.9-460)	180 (4.3-460)	0	0.000
	Blubber	89.8	0.79 (0.29-7.7)	0.46 (0.13-6.2)	0.33	0.296
Arctic char	Muscle	1.1	29 (18-75)	28 (18-48)	1	0.011
(From three	Muscle	1.5	52 (37-110)	49 (36-88)	3	0.045
Locations)	Muscle	2.8	28 (19-53)	25 (17-48)	3	0.084
Shrimp	Muscle	0.95	75 (41-110)	15 (12-19)	60	0.570
Snow crab	Liver	4.0	49 (27-66)	40 (21-53)	9	0.360
	Muscle	0.72	63 (38-86)	45 (25-55)	18	0.130
Iceland scallop	Muscle	0.40	1.8 (0.80-3.3)	0.44 (n.d.-1.2)	1.36	0.005
Atlantic cod	Liver	58	30 (28-33)	27 (25-30)	3	1.740
	Muscle	0.68	38 (18-71)	33 (16-49)	5	0.034
Redfish	Muscle	1.8	38 (20-45)	34 (19-39)	4	0.072
Atlantic salmon	Muscle	9.2	16 (14-24)	13 (11-18)	3	0.276
Greenland halibut	Liver	39	48 (39-730)	42 (34-710)	6	2.340
	Muscle	10	51 (24-62)	44 (19-54)	7	0.700
Wolffish	Liver	21	38 (27-58)	34 (24-53)	4	0.840
	Muscle	1.7	42 (26-60)	37 (23-54)	5	0.085
Capelin	Muscle	1.7	51 (37-79)	47 (35-73)	4	0.068
Shorthorn sculpin	Liver	17	60 (45-110)	52(39-94)	8	1.360
Shorthorn sculpin	Liver	23	53 (39-110)	44 (34-91)	9	2.070
Shorthorn sculpin	Liver	15	16 (10-37)	14 (8.7-32)	2	0.300
Shorthorn sculpin	Liver	10	17 (13-26)	14(12-22)	3	0.300

Species	Tissue	% Lipid	ΣCBz, ng/g lw	HCB, ng/g lw	PeCB+TeCB, ng/g lw	PeCB+TeCB, ng/g ww
Common eider	Liver	5.0	81 (45-89)	71 (38-75)	10	0.500
	Muscle	3.5	60 (42-110)	50 (36-90)	10	0.350
King eider	Liver	5.3	65 (49-130)	56 (42-110)	9	0.477
	Muscle	3.5	73 (52-120)	62 (45-100)	11	0.385
Kittiwake	Liver	5.7	13 (9.4-30)	2.2 (1.0-6.3)	10.8	0.616
	Muscle	14	20 (9.6-71)	3.6 (0.57-44)	16.4	2.296
Thick-billed murre	Liver	5.5	110(77-170)	97 (69-150)	13	0.715
	Muscle	3.6	89 (46-360)	76 (41-320)	13	0.468
Ringed seal	Liver	5.4	20 (13-34)	12 (8.9-17)	8	0.432
	Muscle	12	20 (9.4-71)	13 (6.7-29)	7	0.840
	Blubber	97	16 (1.1-60)	9.3 (0.65-27)	6.7	6.499
Ringed seal	Liver	5.3	11 (7.0-22)	5.2 (4.1-16)	5.8	0.307
(Second	Muscle	3.2	11 (6.9-43)	7.6 (5.2-14)	3.4	0.109
Location)	Kidney	3.8	10 (4.7-18)	5.4 (2.7-11)	4.6	0.175
	Blubber	92	14 (8.6-39)	7.9 (5.0-13)	6.1	5.612
Harp seal	Liver	6.2	78 (21-250)	72 (13-250)	6	0.372
	Muscle	1.7	58 (15-140)	48 (12-120)	10	0.170
	Kidney	3.0	21 (12-52)	19 (9.5-48)	2	0.060
	Blubber	87	71 (14-120)	66 (11-110)	5	4.350
Minke whale	Liver	5.8	170 (150-250)	170 (150-250)	0	0.000
	Muscle	1.2	120 (71-240)	120 (71-240)	0	0.000
	Kidney	3.4	120 (52-250)	120 (52-250)	0	0.000
	Blubber	18	n.a.	160 (15-610)	n.a.	
Beluga	Liver	6.3	210 (40-410)	190 (34-380)	20	1.260
	Muscle	1.8	370 (210-570)	350 (190-510)	20	0.360
	Kidney	3.2	250 (31-360)	230 (26-310)	20	0.640
	Skin	3.6	160 (16-320)	150 (15-310	10	0.360
	Blubber	88	260 (27-690)	250 (21-550)	10	8.800
Narwhal	Liver	4.7	430 (290-810)	420 (280-780)	10	0.470
	Muscle	2.2	450 (50-800)	440 (45-770)	10	0.220
	Kidney	2.5	400 (180-470)	390 (170-450)	10	0.250
	Skin	3.5	310 (250-410)	300 (240-390)	10	0.350
	Blubber	87	490 (390-830)	470 (370-790)	20	17.400

An extensive study of organochlorine compounds in seals from the east and west sides of the Northwater Polnya between Canada and Greenland looked for influences of diet (Fisk et al. 2002). Tissue samples from the ringed seals were collected by Inuit hunters during the spring of 1998. Fisk et al. reported 8.4±1.1 ng/g wet weight in females and 7.3±1.9 ng/g PeCB in males from the west side, Grise Fiord. On the east side, Qanaq, females contained 5.0±0.5 and males 7.0±1.5 ng/g wet weight of PeCB.

A study of organochlorine concentrations in seal blubber, fishes and invertebrates from the White Sea in Northwestern Russia found PeCB along with other compounds (Muir et al. 2003). The mean concentrations of PeCB in the different species are shown in Table 4.6. Harp seal pups collected in 1992 and 1998 were analyzed to look for trends in contamination. The mean concentration (± standard deviation of the 10 samples) of PeCB in 1992 was 11±2.0 ng/g lipid weight. In 1998 the concentration of PeCB was 5.0±1.8 ng/g lipid weight. Apparently, the concentrations of PeCB dropped by approximately 50% over the period of 1992 to 1998 as did concentrations of nearly all the other organochlorines measured.

Table 4.6. Mean concentrations of PeCB in seal blubber, fish and invertebrates from the White Sea, Russia (Muir et al. 2003).

	PeCB
Bearded seal blubber	0.9 ng/g lipid

Harp seal (adult) blubber	12 ng/g lipid
Ringed seal (juvenile) blubber	2.5 ng/g lipid
Ringed seal female blubber	2.9 ng/g lipid
Ringed seal male blubber	2.1 ng/g lipid
Navaga whole fish	5.06 ng/g wet wt.
Bullrout whole fish	0.01 ng/g wet wt.
White Sea cod muscle	0.01 ng/g wet wt.
White Sea herring whole fish	3.77 ng/g wet wt.
Smelt whole fish	3.81 ng/g wet wt.
Isopod	0.04 ng/g wet wt.
Zooplankton	0.07 ng/g wet wt.
Spider crab	0.08 ng/g wet wt.
Whelk	<0.01 ng/g wet wt.

Samples of cod liver and halibut liver from near Adak Island in the Aluetian Chain of islands, Alaska were analyzed for organochlorine compounds (Arend et al. 2001). The PeCB liver concentrations were 1.4, 0.8 and 1.4 µg/kg lipid for Sweeper Cove cod, Kuluk Bay cod and Kuluk Bay halibut, respectively. A study of organochlorine compounds in bowhead whales from Barrow, Alaska found mean PeCB concentrations of 0.3±0.01 ng/g wet weight in liver and 0.8±0.1 ng/g in blubber (Hoekstra et al. 2002).

PeCB has also been detected in Antarctic biota (Corsolini et al. 2006). Corsolini et al. report the concentrations of PeCB to be 0.05 ng/g in krill, 0.08 ng/g in emerald rockcod muscle, 0.09 ng/g in rockcod whole body and 0.68 ng/g in adelie penguin eggs.

1.6 Comparison of environmental concentrations with emission and fate

One potential concern is the risk of missing a significant source which could result in an unexpected exposure of humans or the environment to PeCB. One way of checking for unknown sources is by back calculating the expected emissions from measured environmental concentrations using a model. This predicted emission rate can be compared with reported emissions. Obviously the uncertainties in concentration measurements, estimated emissions and models need to be remembered when interpreting the results which can only give a rough indication at best.

In the modeling above, section 2.3, illustrating the movement of PeCB in the environment, PeCB can accumulate in the soil but the majority, 80%, is degraded in the atmosphere. Thus, on a global basis atmospheric degradation is expected to be important. Thus a very simple model can be used to look for glaring inconsistencies.

Consider the northern hemisphere as a continuous stirred pot reactor. The volume of the atmosphere can be calculated from its depth, 8000 m (Weast 1983) and the area of the northern hemisphere, 255 million km^2. If the concentration of PeCB in the atmosphere is 45 pg/m^3, then the total amount of PeCB in the atmosphere can be calculated:

NH atmosphere $(255 \times 10^6\ km^2)*(8000\ m)*(10^6\ m^2/km^2) = 2.04 \times 10^{18}\ m^3$

PeCB $(45 \times 10^{-12}\ g/m^3)*(2.04 \times 10^{18}\ m^3) = 91{,}800{,}000$ g PeCB

The globally, seasonally, diurnally averaged atmospheric half-life of 370 days is equivalent to a first order reaction rate of 0.69 y^{-1}, see Section 2.1 above. Thus the amount of PeCB that needs to be added to the atmosphere to maintain a concentration of 45 pg/m^3 is:

$0.69\ y^{-1} * 91{,}800$ kg = 63,200 kg/y.

This is about the same as found in the "bottom-up" inventory based on sources reported in the literature, section 3. This calculated number of 63,000 kg/y ignores any degradation of PeCB dissolved in water, sorbed to soil or sediments or exported irreversibly to polar regions and across the equator. Inclusion of the additional fates for PeCB as done by the EMEP environmental model (Vulykh et al. 2005) would increase the amount needed to maintain the atmospheric concentration. It is important to be aware of the uncertainties involved in all aspects of these calculations, PeCB emissions, modeling simplifications and environmental concentrations. The surprisingly close agreement between the calculated emissions and the calculated total degraded suggests that there are no major hidden emission sources which are dramatically affecting environmental concentrations of PeCB.

Because only atmospheric degradation has been considered, it is conservative in that the inclusion of additional degradation processes will increase the overall degradation rate. Because only published sources of emissions of PeCB in the environment have been included there could be additional sources which have not been considered. The assumed atmospheric PeCB concentration is based on only one study (Shen et al. 2005), and it is generally consistent with the higher concentrations reported from some of the other studies of PeCB in the atmosphere.

1.7 PeCB in the Environment – Summary

- PeCB has been observed at low concentrations essentially everywhere in the environment that has been carefully analyzed.
- Polar bear adipose tissue had the highest reported concentrations of PeCB+TeCB with an average concentration of 30 ng/g lipid.
- Among the highest reported PeCB concentrations in prey organisms is about 5 ng/g wet weight in the blubber of Arctic seals.
- PeCB concentrations in herring gull eggs on the shore of Lake Superior, Canada have dropped by over 90% since the 1970s.
- Concentrations of PeCB have dropped by over 90% since the 1960s in sediments near the industrially impacted Niagara Falls area of the US and Canada.
- PeCB concentrations in sediments from remote lakes in northern Canada averaged 0.20 ng/g compared to about 8 ng/g off the mouth of the Niagara River in Lake Ontario.

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