AMAP Faroe Islands Heavy Metals and POPs Core Programme 2009-2012

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Contents

1 Preface

The present report is part of the national contribution to the international Arctic Monitoring and Assessment Programme, AMAP, under the auspices of the Arctic Council. The report summarises the results of the core programme monitoring of heavy metals and persistent organic pollutants in terrestrial, freshwater and marine environments of the Faroe Islands. The monitoring is done according to guidelines adopted by AMAP, with adaptations that reflect the special Faroese pollution exposure issues and the experience gained from earlier work.

2 Úrtak

Hendan frágreiðingin tekur samanum úrslit, sum eru fingin í sambandi við eftiransing av dálkingarevnum í AMAP (Arctic Monitoring and Assessment Programme) kanningarsamstarvinum (sí eisini www.amap.no). Frágreiðingin fevnir um kanningar av tungmetalum og seint niðurbrótiligum lívrunnnum eiturevnum, POP, í feskvatni, á landi og í havumhvørvinum í Føroyum. Úrslitini eru partur av áhaldandi arbeiði, sum byrjaði í 1996 og hevur hildið áfram við skiftandi orku síðani tá.

Í Talvu 2.1 sæst hvørji sløg av sýnum eru kannað í AMAP tungmetal og POP kanningarskránni fyri Føroyar, og vera viðgjørd í hesi frágreiðing. Støðugir isotopar eru eisini við í talvuni. Talvan vísir eisini hvør vevnaður er kannaður, og hvørji dálkingarevni eru kannað.

Table 2.1 Yvirlit yvir kannaði sløg í 2009-2012

Slag	Innsavningar ár	Vevnaður	Kanning						
			Hg	Cd	Se	POPs	PBDE	PFCs	Støðugir isotopar
Grind (Pilot whale)	2009, 2010, 2011, 2012	Spik				+	+		
		Tvøst	+	+	+			+	+
		Livur	+	+	+			+	
		Nýra		+					
Toskur (Cod)	2008, 2009, 2010, 2011, 2012	Livur				+			
		Flak	+						+
Teisti (Black guillemot)	2009, 2011	Livur	+	+	+				
		Fjaðrar	+						
	2008, 2010, 2012	Egg	+			+			+
Bleikja (Arctic char)	2008, 2009, 2010, 2011, 2012	Flak	+		+	+			+
Seyður (Sheep)	2008, 2009, 2011	Livur	+	+	+			+	
		Tálg				+			
Hara (Mountain hare)	2008, 2010	Livur	+	+		+			

Afturat nýggju kanningarúrslitunum eru aðrar dátur, sum stuðla uppundir tulkingina av úrslitunum, við í frágreiðingini; bæði lívfrøðilig dáta fyri viðurskifti, sum kunnu elva til variatión í innihaldinum av dálkingarevnum, men eisini ein útvaldur partur av eldri dátum, sum eru við til at seta nýggju úrslitini í perspektiv. Hendan lýsingin av eldri dátum er gjørd í tann mun, har dátur hava verið lutfalsliga lætt atkomuligar, og er sostatt ikki gjørd miðvíst fyri øll sløg. Summi av hesum eldru úrslitunum eru fingin til vega í AMAP høpi, meðan onnur eru fingin til vega áður í sambandi við aðrar kanningar. Metingar av broytingum í konsentratiónum við tíðini eru ikki gjørdar sum ein innbygdur partur av kanningarætlanini, men verða gjørdar í sambandi við arbeiðið í altjóða AMAP serfrøðingabólkum, og verða tøkar í sambandi við tað arbeiði.

Talvurnar við kanningarúrslitini eru savnaðir í fílinum "AMAP Faroe Islands Heavy Metals and POPs Core Programme 2009-2012 Appendices" á www.us.fo.

3 Summary

The present report summarises monitoring data acquired in partial fulfilment of the circumpolar Arctic Monitoring and Assessment Programme, AMAP (www.amap.no). The contribution encompasses analyses of heavy metal and persistent organic pollutants (POPs) in freshwater, terrestrial and marine environments of the Faroe Islands. The monitoring results are part of an ongoing effort that began in 1996, and which has continued with varying intensity ever since.

The abiotic and biotic sample types included in the AMAP Faroe Islands Heavy Metals (HM) and POPs Core Programme presented in this report are shown in Table 3.1. Stable isotopes are included in the monitoring programme as indicators of placement in the food-web. The Table also specifies the various tissues and the contaminants that have been analysed.

Table 3.1 Overview of analysed species 2009-2012

Species	Sampling years	Matrix	Analysis						
			Hg	Cd	Se	POPs	PBDE	PFCs	Stable isotopes
Pilot whale	2009, 2010, 2011, 2012	Blubber				+	+		
		Muscle	+	+	+			+	+
		Liver	+	+	+			+	
		Kidney		+					
Cod	2008, 2009, 2010, 2011, 2012	Liver				+			
		Fillet	+						+
Black guillemot	2009, 2011	Liver	+	+	+				
		Feathers	+						
	2008, 2010, 2012	Eggs	+			+			+
Arctic char	2008, 2009, 2010, 2011, 2012	Fillet	+		+	+			+
Sheep	2008, 2009, 2011	Liver	+	+	+			+	
		Tallow				+			
Mountain hare	2008, 2010	Liver	+	+		+			

In addition to presenting the newly acquired analytical data, the report also contains information that assists in the overall interpretation of the results. The biological parameters that give rise to variability in the concentration of pollutants are discussed, and the most recent data are given perspective by presenting a suitable selection of previously acquired data. The older data were included as well because they were readily accessible, although the older data are not totally representative of all species. Some of the older data were acquired in the context of the AMAP Programme and some were acquired in connection with other earlier programmes.

The Tables with raw data are available in a separate file "AMAP Faroe Islands Heavy Metals and POPs Core Programme 2009-2012 Appendices" at www.us.fo.

4 Introduction

Monitoring of environmental contaminants according to the guidelines adopted by the AMAP programme began in the Faroe Islands in 1996. The monitoring has been adjusted and optimized where pertinent, and the resulting monitoring scheme is shown on the next page (Table 4.1).

The results in this report are from analyses in 2009-2012 and are part of the AMAP Phase III. The Faroe Islands has participated in the two previous phases of AMAP, and the results are reported in Larsen and Dam, 1999, Olsen *et al*., 2003, Hoydal *et al*., 2003, Hoydal and Dam, 2005 and Hoydal and Dam, 2009.

The metal analyses include mercury, cadmium and selenium. The POPs analysed include HCB, 14 single congeners of PCB and pesticides such as chlordanes, ß-HCH, DDT (in some instances both p,p- and o,p-isomers), mirex, five individual congeners (parlars) of toxaphene, and PBDE. In addition, stable isotope ratios of $^{15}N/^{14}N$ and $^{13}C/^{12}C$ have been analysed in four species. Finally PFCs have been analysed in sheep livers and Pilot whale muscle and livers.

Table 4.1 Overview of the monitoring series forming part of the AMAP Faroe Islands core Heavy Metals and POPs monitoring programme.

	Chemical parameters	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Pilot whales																				
blubber	PCB, pesticides, PBDE		v		v	v	v	v	v	v			v		v	v	v	v	v	v
muscle	Hg, Cd**, Se, Stable isotopes*, PFC		v		v	v	v	v	v	v		v	v		v	v	v	v	v	v
kidney	Cd				v	v	v	v				v	v		v	v	v	v	v	v
liver	Hg, Cd, Se, PFC						v	v		(v)		v	v		v	v	v	v	v	v
Black guillemot																				
eggs	PCB, pesticides, Hg, Stable isotopes*				v	v	v	v		v		v		v		v		v		v
liver	Hg, Cd, Se	v						v			v		v		v		v		v	
feathers	Hg	v						v			v		v		v		v		v	
Sculpin																				
liver	PCB, pesticides, Hg, Cd, Se,				v	v	v	v		v										
muscle	Stable isotopes*							v		v										
Cod																				
muscle	Hg		v			v	v		v	v	v	v	v	v	v	v	v	v	v	v
liver	PCB, pesticides		v			v	v		v	v	v	v	v	v	v	v	v	v	v	v
Arctic char																				
muscle	PCB, pesticides, Hg, Se, Stable isotopes*			(v)		v	v	v		v	v		v		v	v	v	v	v	v
Sheep																				
liver	Hg, Cd, PFC		v		v		v				v			v	v		v		v	
tallow	PCB, pesticides													v	v		v		v	
Hare		v		v		v			v											
liver	PCB, pesticides, Hg, Cd, Se		v		v		v			v		v		v		v				

*Analyses of selected stable isotopes of nitrogen and carbon began in 2002, but have not been done as frequently as, e.g., analyses for metals. See Chapter 9 for further details.
** Analysis of cadmium in muscle tissue of pilot whales was discontinued from 2010.

4.1 Analytical methods

Mercury and cadmium analyses were performed at the Food and Veterinary Agency of the Faroe Islands (FVA), and POPs and selenium analyses were performed at Centre de Toxicologie du Quebec (CTQ) in Canada, Alcontrol in Sweden and ALS in Norway. PBDE and PFC analyses were performed at the University of Örebro, Sweden. Stable isotopes of nitrogen and carbon were analysed at SINLAB, University of New Brunswick, Canada.

4.1.1 Metal analysis

At the FVA, cadmium was analysed with atom absorption spectrophotometry using either graphite furnace (Perkin Elmer 1100B) or flame (Perkin Elmer 2380) excitation, depending on the content of the examined material. Mercury was analysed with the Flow Injection Mercury System (FIMS) 400 (Mercury analysis system).

Quality assurance: Double determinations were performed. A certified reference material and a blank control sample were analysed in connection with each series. The certified reference material and the blank were digested in the same manner as the samples. A 4-point standard curve was always made. The FVA laboratory participates in regular intercalibration, for example, Quasimeme (Quality assurance of information for marine environmental monitoring in Europe). The FVA laboratory is accredited (DANAK) for mercury and cadmium analysis.

At CTQ, cadmium and selenium were analysed using ICP-MS after sample digestion with concentrated nitric acid. Mercury was analysed in the same digest, but by cold vapour atomic absorption spectrometry.

At ALS, selenium (in Hare 2010) was analysed using EPA method 200.7 and 200.8 (modified). Dry mass was determined at 105°C according to SS 028113. The sample was dried at 50°C, prior to dissolution in HNO_3 and H_2O_2 in a microwave oven.

4.1.2 POPs

POPs
When the term POPs is used, it is normally used as a common term for PCB, HCB and pesticides; PDBE is normally not included.

All samples for which POP results are presented in the present report, except for those of hares, were analysed for POPs by CTQ (see below).

Hare 2008 samples were analysed at Alcontrol, Linkøping Sweden, using HRGC/HRMS (PCB, DDTs and b-HCH). The method description is available in the files of the Environment Agency at US-6-003/08-40. Hexachlorobenzene determination was performed on a 5973 Gass Chromatograph-Mass Spectrometry (GC-MS) in EI mode on DB5 MS capillary column.

Hare 2010 and Sheep 2009 samples (also analysed at CTQ) were analysed at ALS. PCBs were analysed using US EPA 1668 method with HR double focussing reversed Nier-Johnsin geometry MS dual GC capillary columns. Chlorinated pesticides were analysed using method LMBG-00.00-34 (method DGF S19) EN 1528, part 1-4 /DDE, DDD, DDT), with GC/MSD or GC-ECD.

POPs analyses at CTQ
The CTQ laboratory is accredited under ISO 17025 by the Standards Council of Canada and participates in many national and international quality control programs including the Northern

Contaminants Program (NCP) of the Ministry of the Environment of Ontario, the External Quality Assessment Scheme QUASIMEME http://www.quasimeme.org/), as well as the German External Quality Assessment Scheme (G-EQUAS) for Biological Monitoring in Occupational and Environmental Medicine. The CTQ laboratory also participates in the Arctic Monitoring Assessment Program (AMAP).

Extraction and analysis by GC-MS

Tissue samples were analysed for the following compounds: PCBs 28, 52, 99, 101, 105, 118, 128, 138, 153, 156, 163, 170, 180, 183 and 187, hexachlorobenzene, β-HCH, α-chlordane, γ-chlordane, oxychlordane, cis-nonachlor, trans-nonachlor, mirex, o,p'-DDE, p,p'-DDE, o,p'-DDT, p,p'-DDT, parlar 26, parlar 32, parlar 50 and parlar 62. The sample weight used for the analyses was dependent on the nature of the matrix and the fat content and ranged from 0.025 g (whale blubber), 1.0 g (fish tissues, muscles, eggs and liver) to 4.0 g (subcutaneous fat). The tissue samples were enriched with internal standards (hexachlorobenzene-^{13}C6, α-HCH-^{13}C6, oxychlordane-^{13}C10, trans-nonachlor-^{13}C10, p,p'-DDE-^{13}C12, PCB 141-^{13}C12, PCB 153-^{13}C12, PCB 180-^{13}C12, parlar 26-^{13}C10 and parlar 50-^{13}C10), mixed with dichloromethane and chemically dried using sodium sulphate. The compounds were then extracted from the matrix by ultrasound sonification followed by filtration. A part of the organic solvent (10%) was used to determine the percentage of total lipids in the sample by gravimetry. The remaining fraction was concentrated by evaporation and subsequently purified using gel permeation chromatography (GPC) and cleaned-up on a Florisil column.

The extracts were analysed on a GC-MS with an Agilent 6890 Network gas chromatograph (GC), coupled with an Agilent 5973 Network mass spectrometer (MS) (Agilent Technologies, Mississauga, Ontario, Canada) and with an Electron Capture Detector (ECD). The GC was fitted to the MS with an Agilent 60 m DB-XLB column (0.25 mm i.d., 0.25 µm film thickness) and to the ECD with an Agilent 50 m Ultra-1 column (0.20 mm i.d., 0.33 µm film thickness). The ECD detector served mainly to quantify the PCB congeners 28 and 52, if the detection limit was not obtained with the mass detector, and to validate MS results. The measurement of ions generated, after negative chemical ionization (NCI) with methane (99.97 %) as the reagent gas, was performed in single ion monitoring (SIM). Samples (3 µL) were injected in the pulsed splitless mode. The temperature program was as follows: 2 min at 100°C followed by an increase to 200°C at a rate of 20°C min^{-1}, increase to 245°C at a rate of 1.5°C min^{-1} hold 10 minutes, increase to 280°C at a rate of 20°C min^{-1} hold 5 minutes and finally an increase to 330°C at a rate of 30°C min^{-1} hold 15 minutes. The total run time was 70.42 minutes.

Quantitation and method performance

The calibration was made with an extracted curve using corn oil. The linearity of the six-point curve was evaluated during the validation of the analytical method, but due to time considerations and to maintain a high throughput production, the quantitation was based on a single, extracted mid-point calibration. The concentration of the analytes was calculated with the ratio of peak areas relative to their labelled internal standards. Concentrations were reported per lipid weight (units of micrograms per kilogram) and the Limit Of Detection (LOD) for all compounds ranged from 0.1 to 10 µg/kg. For each sample, the LOD was adjusted relative to the weight of the sample and the lipid content, providing different LODs for each sample. For each of the analytes, the LOD was determined by first estimating the concentration equivalent to a signal-to-noise ratio of 3. We then measured 10 replicates of a sample with the analytes at a concentration from 4 to 10 times the estimated LOD. The calculated LOD became the value equivalent to thrice the standard deviation (SD) of those 10 replicates. The intra-day precision was between 1.7% and 8.3% and the inter-day was between 1.7% and 9.3%. Based on spiked levels (5 µg/kg in corn oil, n = 3), recovery was between 54% and 79% for all the analysed compounds.

The certified reference material used during the analyses was fish tissue (SRM-1947), containing all the analysed compounds, and was provided by the National Institute of Standards & Technology (NIST; Gaithersburg, MD, USA). The overall quality and accuracy of the analyses was monitored by regular participation in the Northern Contaminants Program (NCP) of the Ministry of the Environment of Ontario and the External Quality Assessment Scheme QUASIMEME.

The "Aroclor 1260" value reported in this report was calculated from individually quantified congeners, using a factor of calibration that was determined on a human tissue matrix. Thus, when

applying this Aroclor 1260 value, it is implicitly assumed that the metabolism/degradation of the various PCB congeners in the species considered is the same as in humans.

PBDEs
PolyBrominated Diphenyl Ethers (PBDEs) were analysed in pilot whale blubber samples at the University of Örebro, Sweden. The blubber samples were treated as described in Rotander *et al.*, 2011. Five to ten grams of blubber were homogenized in a mortar with anhydrous sodium sulphate and extracted with a mixture of n-hexane/toluene (1:1, v:v) using open column chromatography. Lipid content was determined gravimetrically. Sample cleanup was performed using three different columns in series, i.e., multilayer silica column, alumina oxide column and carbon column. All samples were analysed on a high resolution GC-MS system (Autospec Ultima; Waters Inc.) operating at >10,000 resolution using EI ionization at 35 eV. All measurements were performed in the selective ion recording mode (SIR), monitoring the two most abundant ions of the molecular bromine cluster. Quantification was performed using the internal standard method. Splitless injection was used to introduce 1 µl of the final extracts on the column (a DB-5MS column from J&W; 30 m x 250 µm i.d. x 0.25 µm film thickness). Detection levels were calculated at an S/N ratio of 3, corrected for recovery of the internal standard. The criteria for positive peak identification were an isotope ratio within ±15% of the theoretical value and a retention time match with that of the corresponding labelled compound. Recoveries were between 50-150 % for all samples.

PFC
PerFluorinated Compounds (PFC) were analysed in sheep liver and pilot whale muscle samples at the University of Örebro, Sweden. The analyses were done as described in Rotander *et al.*, 2012.

4.1.3 Stable isotopes

The ratio analyses of the two stable isotopes $^{15}N/^{14}N$ and $^{13}C/^{12}C$ were done at SINLAB. The samples were analysed for $d^{13}C$ and $d^{15}N$ using a Thermo-Finnigan Delta Plus isotope-ratio mass spectrometer (Bremen, Germany) interfaced with a Carlo Erba NC2500 Elemental Analyzer (Milan, Italy) via the Conflo II or Conflo III, respectively. This is a continuous flow system using helium as a carrier gas. Samples were converted to a gaseous state via combustion.

Four IAEA standards (N1, N2, CH6 and CH7), three elemental standards (acetanilide, cyclohexanone, and nicotinamide) and one internal standard (bovine liver) were used throughout each run to ensure high quality control.

5 Sampling

5.1 Black Guillemot (*Cepphus grylle*)

5.1.1 Black Guillemot eggs

Black guillemot eggs were sampled at two locations, Koltur and Skúvoy, in June 2008 and 2010, whereas sampling in 2012 was successful on Skúvoy only. One egg was sampled from each nest and the eggs were stored in a refrigerator (ca. +5°C) until further treatment.

The eggs were weighed and height and breadth were measured. The top of each egg was removed with a scalpel, or a hole was made in the top of each egg, and the contents were poured into a heat-treated glass (400ºC for four hours).

The yolk and white were mixed with a stainless steel fork, and subsamples were taken in polymethylpentene jars for POP analysis at CTQ in Canada. The remaining egg sample was analysed for Hg at the FVA. The samples were stored at -20ºC until shipment to the laboratories.

The eggshell thickness was measured with a micrometre calliper at three different places as near to the equator as possible with the membrane left on. The measured eggshell thicknesses are shown in Attachment 1.

5.1.2 Black Guillemot liver and feather

Young black guillemots (2K) were shot at Sveipur and Tindhólmur the 18th of April 2009, the 30th of April at Sveipur and the 11th of May at Tindhólmur in 2011. The full weight of each bird was recorded prior to dissection. The sex was recorded and the stomachs with their contents were taken for storage in the Environmental Specimen Bank (ESB) for potential future use. Livers were sampled and stored in heat-treated glass jars (400ºC for four hours) and frozen at -20ºC until analysis. The livers were analysed for Hg and Cd at the FVA and for Se at CTQ. Feather samples were taken (body contour feather under left wing) and analysed for Hg at the FVA.

Samples of kidney and muscle were stored in polyethylene bags at -20ºC and deposited in the ESB for potential future use. The polyethylene bags used for sample storage are invariably Minigrip®.

5.2 Cod (Gadus morhua)

Cod were sampled by the research vessel *Magnus Heinason* with trawl at the station "Mýlingsgrunnurin" north-east of the Faroe Islands in October 2008 (n= 23), September 2009 (n= 25), October 2010 (n= 24) and 2011 (n= 29). In October 2012, cod (n= 25) were sampled by *Gordrúgvin*.

The cod were frozen whole until sample preparation.

During the sample preparation, the cod were weighed and the fork length measured before the livers were extracted and stored in heat-treated glass jars at -20ºC until analysis. Samples were taken of muscle from the right side fillet and stored in heat-treated aluminium foil at -20ºC until analysis. The sex and maturity were determined from the gonads.

The majority of the cod from 2008, 2009, 2010, 2011 and 2012 were analysed as individual samples. From each year, two pooled samples were prepared with 5-8 individuals in each. The liver samples were analysed for POPs at CTQ. Muscle samples were analysed for Hg at the FVA and stable isotopes at SINLAB.

5.3 Long-finned pilot whale (*Globicephala melas*)

Pilot whale samples are collected in connection with the traditional whale hunt. The sampling takes place after the killing and prior to the meat distribution. At this time, the whales are cut open by an abdominal cut, to facilitate cooling. The samples of blubber and muscle are taken at the ventral and caudal side of these abdominal cuts. Pieces of blubber, muscle, liver and kidney were sampled and placed in polyethylene bags and stored at -20ºC until subsampling and shipment for analysis. As part of the sampling, the length of the whale in cm and/or the size in *skinn* (a special Faroese unit for measuring the size of the whale based on an assessment of the mass fit for human consumption) and the sex may be determined, otherwise, these data will be available from the authorities on site.

Pilot whale samples were collected in 2009, 2010, 2011 and 2012, but not in 2008. Pilot whale samples analysed as part of the AMAP Core Programme in 2001 and later are shown in Table 5.1. The number and size of the analysed pilot whales are shown in
Table 5.2.

Table 5.1 Number of pilot whale samples analysed in the AMAP Core Programmes of the Faroe Islands in 2001-2012

Location	Date of hunt	Number of samples analysed			
		Muscle	Blubber	Liver	Kidney
Miðvágur	06.07.01	25	25	20	20
Tórshavn	03.09.02	25	25	20	20
Hvalvík	30.08.03	25	25	-	-
Bøur	04.06.04	23	23	-	-
Hvannasund	28.08.06	15	15	8	8
Leynar	06.09.06	10	10	7	7
Tórshavn	03.07.07	11	11	9	9
Gøta	13.07.07	14	14	6	6
Hvannasund	05.01.09	13	38	8	8
Hvalvík	23.05.09	24	29	7	7
Vestmanna	24.06.10	17	17	7	7
Tórshavn	02.07.10	8	8	8	8
Vestmanna	09.02.11	13	13	6	6
Vestmanna	02.09.11	11	11	9	9
Klaksvík	10.07.12	10	10	9	9
Hvannasund	09.08.12	15	15	6	6
Total		259	289	130	130

The muscle and liver samples were analysed for Hg and Cd at the FVA in the Faroe Islands and for Se at CTQ in Canada. Muscle Cd analyses were discontinued after 2010.

The kidney samples were analysed for Cd at the FVA in the Faroe Islands.

The blubber samples were analysed for POPs at CTQ and for PBDE and PFC at the University in Örebro, Sweden. During the preparation of the blubber samples, the outer part of the blubber that had

been in contact with the wrapping was removed. The blubber samples were transferred to polymethylpentene jars and kept frozen until analysis.

5.3.1 Defining groups

Following studies by Desportes *et al.* (1993) and Martin & Rothery (1993), pilot whales are divided into the following groups with regard to sex and sexual maturity:

Juvenile females: All females < 375 cm
Adult females: All females ≥ 375 cm
Juvenile males: All males < 494 cm
Adult males: All males ≥ 494 cm

Since 2006, muscle and blubber have been sampled from preferably young individuals, whereas liver and kidney have been sampled from preferably older (large) individuals. This sampling strategy was different from the one used in previous years and was chosen following statistical analyses of time series (Dam and Riget, 2006), which established a higher probability of detecting directional trends in younger (immature) whales than in older individuals. Thus, it was decided to adapt the monitoring so that pilot whale muscle and blubber samples were analysed with the purpose of detecting possible time-trends, whereas liver and kidney samples were analysed with the objective of detecting negative biological effects of pollutants.

Table 5.2 Number and size of the analysed pilot whales.

	Age and sex group										
Year	Date		Juveniles			Adult females			Adult males		
			skinn	length	n	skinn	length	n	skinn	length	n
2009	05.01.09	Min	4	220	13	9	440		19	535	
		Max	12	430	(M=6,	13	460	4	25	572	4
		Mean	7.1	314	F=7)	12	451		22	557	
	23.05.09	Min	2	-	12	10	-		16	-	
		Max	10	-	(M=9,	14	-	4	21	-	3
		Mean	5.2	-	F=3)	11.8	-		18	-	
2010	24.06.10	Min	2	275	17	7	410		11	508	
		Max	9	450	(M=10,	8	442	4	12	520	3
		Mean	5.3	373	F=7)	7.5	424		11.3	514	
	02.07.10	Min	3	265	8	9	405		14	535	
		Max	10	455	(M=5,	10	445	6	14	545	2
		Mean	5.5	350.3	F=3)	9.2	434		14	540	
2011	09.02.11	Min	1	220	13*	6	387		14	526	
		Max	8	437	(M=7,	9	420	4*	15	526	2*
		Mean	3.7	324	F=6)	7.9	406		14.5	526	
	02.09.11	Min	1	158	14	7	420		-	-	
		Max	9	435	(M=9,	8	438	4	-	-	-
		Mean	4.8	332.6	F=5)	7.3	425.8		-	-	
2012	10.07.12	Min	3	260	10	7	380		-	-	
		Max	12	485	(M=8,	9	440	9	-	-	-
		Mean	6.3	355	F=2)	8.2	406.1		-	-	
	09.08.12	Min	3	277	15	6	411		14	411	
		Max	13	459	(M=7,	8	437	4	14	533	2
		Mean	5.6	345.6	F=8)	7.3	427.5		14	472	

5.4 Mountain Hare (*Lepus timidus*)

The hares were shot at the locations Signabøhagi and Norðradalur during November and December 2006, 2008 and 2010. The lengths and weights of the hares were recorded, as well as the length of one foot and the skulls. Liver, intestinal fat and pieces of muscle were sampled. Livers were stored in heat-treated glass jars (400ºC for 4 hours), intestinal fat in polymethylpentene jars and muscle in polyethylene bags.

The livers were analysed for Hg and Cd at the FVA and the livers from 2006 and 2008 were analysed for POPs at Alcontrol, whereas 2010 samples were analysed for POPs and Se at ALS. The analyses were made on individual samples. The samples of muscle and intestinal fat were stored at -20ºC and stored in the ESB for potential later use.

5.5 Arctic char (Salvelinus alpinus)

Arctic char were caught by angling in the lake á Mýrunum by members of the anglers association "Føroya Sílaveiðufelagið in June and July in 2009, 2010, 2011 and 2012 with permission from the Veterinary Department of the FVA. The fish were wrapped in plastic bags and frozen at -20ºC until further treatment. Before and after fishing, the fishing tackle was disinfected with the commercial disinfectant VirkonS.

The length and weight of each fish was recorded. Muscle samples were taken from the right side fillet and analysed for Hg at the FVA and for Se and POPs at CTQ. The otoliths were sampled and age determined by the Natural History Museum of Kópavogur in Iceland.

The livers were placed in heat-treated glass or polymethylpentene jars and stored in ESB at ca. -20ºC for potential future studies.

5.6 Sheep (Ovis aries)

The livers and tallow were sampled during slaughtering season (October) in 2008, 2009 and 2011 from female sheep and lambs that had been grazing in Norðradalur. The samples were kept frozen until further treatment.

The sheep from 2008 were analysed as four, pooled samples, two with respectively three and four female sheep each and two with respectively six and seven samples from lambs. The sheep from 2009 and 2011 were analysed as four pooled samples, two with five female sheep each and two with five lambs.

The livers were homogenized in a liquidizer and analysed for Se at CTQ, Hg and Cd at FVA and PFOS (2008 and 2009 samples) at the university in Örebro. Tallow samples from 2008, 2009 and 2011 were analysed for POPs at CTQ. Sheep tallow 2009 samples were also analysed at ALS, and thus were analysed in duplicate at two different laboratories.

6 Heavy metal results

6.1 Black guillemot

6.1.1 Black guillemot eggs

A summary of Hg in black guillemot eggs is given in Table 6.1.

Table 6.1 Summary of Hg in black guillemot eggs in 2008, 2010 and 2012.

Skúvoy				
Year		2008	2010	2012
n*		10	10	10
Hg, mg/kg	Min	0.387	0.459	0.498
	Max	0.985	1.030	0.777
	Median	0.695	0.784	0.615
	Mean	0.677	0.760	0.628
	SD	0.159	0.187	0.076
Koltur				
Year		2008	2010	2012**
n		10	10	
Hg, mg/kg	Min	0.365	0.378	-
	Max	1.330	0.869	-
	Median	0.562	0.537	-
	Mean	0.635	0.557	-
	SD	0.283	0.189	-

*n is number of samples.
**Sampling was unsuccessful in Koltur in 2012.

The mean concentration of Hg is higher in black guillemot eggs from Skúvoy than from Koltur in both 2008 and 2010 (Table 6.1). One of the eggs sampled in Koltur in 2008 had the highest concentration of Hg measured to date in black guillemot eggs from the Faroe Islands.

As seen in Figure 6.1, the mean concentrations of Hg in black guillemot eggs from Skúvoy were higher in 2006-2012 than in the years prior to 2004. The highest mean since the regular analysis of black guillemot eggs from the Faroe Islands started in 1999 was found in the samples from Skúvoy in 2010.

Statistical analyses using PIA (windows version 2011.12.26 abi) of the Hg in black guillemot eggs from Skúvoy show a 6.1% yearly increasing trend (with a 95% confidence interval of 1.9, 10%). This trend is statistically significant ($p<0.011$; i.e., a true change, assuming the assumptions of the regression analysis are fulfilled). The Koltur egg Hg data does not show a similar significantly increasing trend.

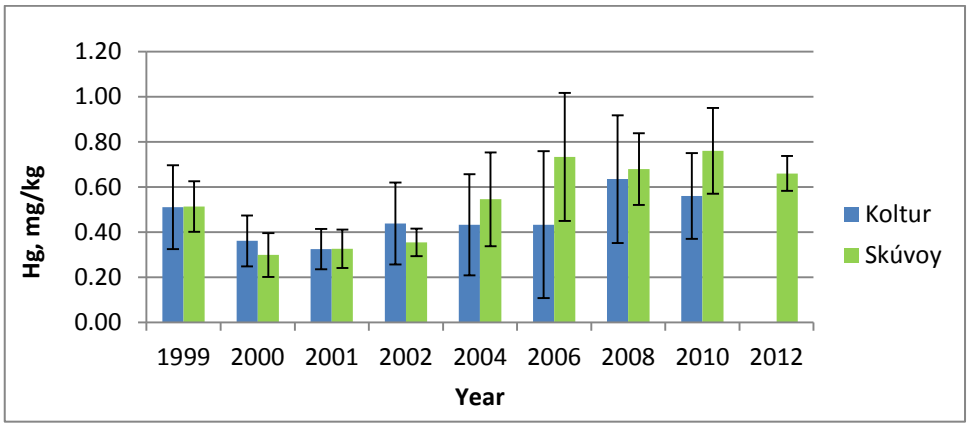

Figure 6.1 Hg in black guillemot eggs from Koltur and Skúvoy from 1999-2012.

6.1.2 Black guillemot liver

The concentration of heavy metals in black guillemot liver was analysed in birds shot for scientific purposes near Sveipur and Tindhólmur, 8 females and 9 males in April 2009 and 9 females and 8 males in April-May 2011. Summary results of Hg, Cd and Se are given in Table 6.2 and Figure 6.2; individual results are given in Attachment 2.

Table 6.2 Hg, Cd and Se concentration in black guillemot liver 2009 and 2011.

Year	n		Hg, mg/kg	Cd, mg/kg	Se, mg/kg
2009	17	Min	0.78	0.24	1.50
		Max	4.66	0.74	2.80
		Mean	1.39	0.50	1.9
		SD	0.92	0.14	0.29
2011	17	Min	0.83	0.41	1.7
		Max	1.87	1.38	3.80
		Mean	1.27	0.74	2.2
		SD	0.335	0.24	0.49

The level of heavy metals in black guillemot livers seem to be unchanged from 2007 to 2011 (Figure 6.2). When comparing male and female birds separately (Figure 6.3), the Hg concentration seems to be higher in males than in females, whereas a similar difference is not seen with the Cd concentration (Figure 6.4). The apparent sex dependence of the Hg concentration could be associated with diet, for instance, if male black guillemots have a greater preference for fish over their female counterparts, or it could be associated with local differences between the two sampling areas - like fish availability - because the Tindhólmur samples tended to be dominated by males, whereas the Sveipur samples tended to be dominated by females.

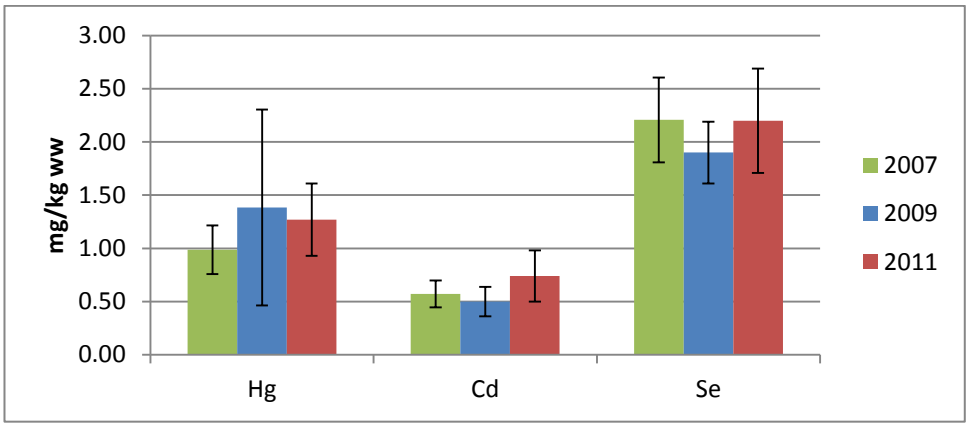

Figure 6.2 Heavy metals in black guillemot liver from 2007-2011.

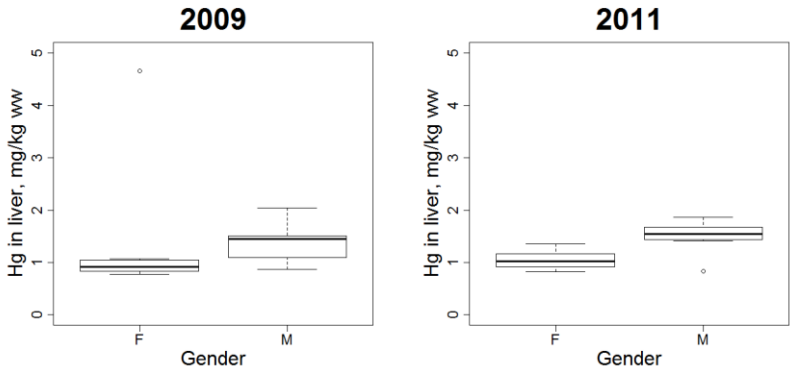

Figure 6.3 Box plot of Hg in black guillemot liver from 2009 and 2011. F: females, M: males.

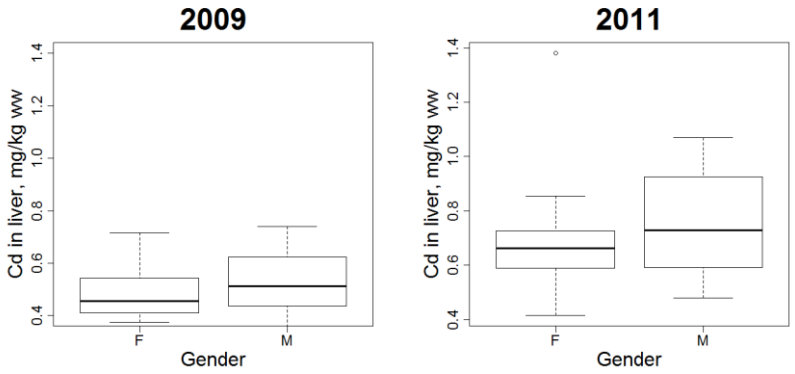

Figure 6.4 Box plot of Cd in black guillemot liver from 2009 and 2011. F: females, M: males.

6.1.3 Black guillemot feathers

The feathers of black guillemots sampled in 2009 and 2011 were analysed for Hg. A summary of the results is shown in Table 6.3. Individual results are shown in Attachment 2.

Table 6.3 Hg in black guillemot feathers from 2009 and 2011

Year	n		Hg, mg/kg
2009	17	Min Max Mean SD	1.64 19.8 4.55 4.13
2011	17	Min Max Mean SD	1.04 4.78 3.18 0.95

The Hg concentration in black guillemot feathers was higher in 2009 than in previous years and in 2011. Figure 6.5 is a box plot of the Hg concentration in black guillemot feathers for the various gender groups.

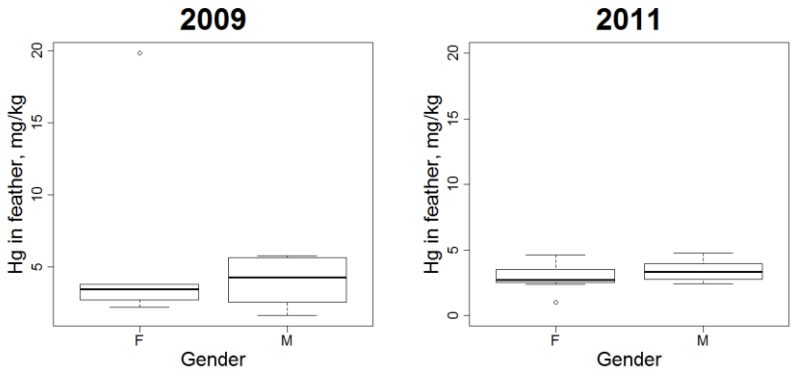

Figure 6.5 Hg in black guillemot feathers from 2009 and 2011. F: females, M: males.

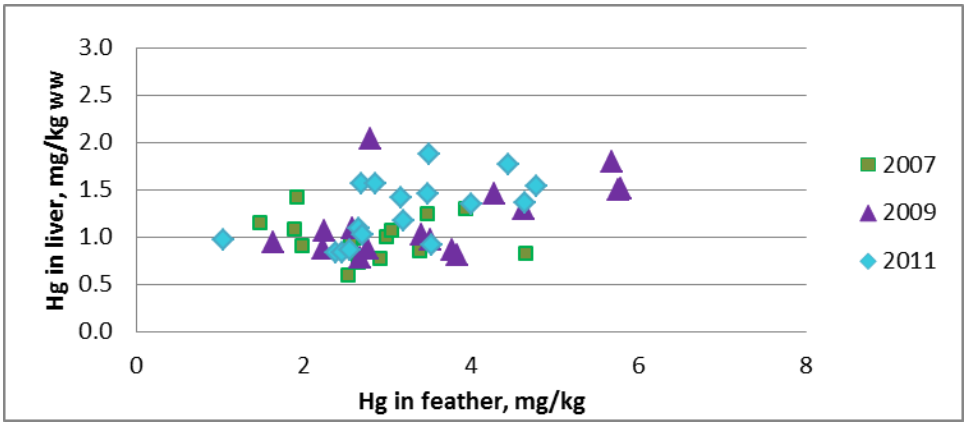

Figure 6.6 Correlation between Hg in livers and feathers of black guillemot from 2007, 2009 and 2011. Data from 2007 were taken from Hoydal, K. and Dam, M. 2009.

The Hg concentrations in livers and feathers are not correlated (Figure 6.6). One outlier for a black guillemot from 2009 is removed. The concentrations of Hg in the liver and feather for this individual were 4.66 mg/kg ww and 19.8 mg/kg ww, respectively. These relatively high Hg concentrations in the 2009 data are included in box plots Figure 6.3 and Figure 6.5.

The birds from 2009 and 2011 were shot in April-May and were young birds hatched the previous summer. The concentration of Hg in the feathers reflects the concentration of readily bioavailable Hg in the blood and thus, mainly the Hg taken with food during the period of feather growth. On the other hand, the concentration of Hg in the liver is the result of accumulation, biotransformation and depletion processes and gives, as such, a more time-integrated view of the Hg status of the ambient environment.

6.2 Cod

Cod muscle samples from 2008, 2009, 2010, 2011, and 2012 were analysed for Hg and a summary of the results is shown in

Table 6.4. Individual results and data on biological parameters are given in Attachment

Table 6.4 Hg in cod muscle, mg/kg ww

Year	n		Length, cm	Dry matter %	Hg, mg/kg
2008	23*	Min	41.4	19.3	0.019
		Max	57.6	22.8	0.023
		Mean	51.4	21.0	0.021
		SD	3.47	0.70	0.001
2009	25**	Min	41	19.9	0.020
		Max	59	21.8	0.060
		Mean	50.6	21.02	0.035
		SD	4.22	0.61	0.011
2010	24***	Min	44	17.5	0.043
		Max	61	21	0.076
		Mean	52.0	20	0.060
		SD	4.8	0.90	0.011
2011	29*'	Min	41.5	19.4	0.039
		Max	57	20.7	0.082
		Mean	46.5	20.1	0.062
		SD	3.05	0.38	0.012
2012	25**	Min	43.5	19.6	0.031
		Max	53.5	21.6	0.088
		Mean	49.9	20.5	0.058
		SD	2.54	0.71	0.021

*Analysed as 13 individual samples and two pooled samples with 5 individuals in each. **Analysed as 13 individual samples and two pooled samples with 6 individuals in each. ***Analysed as 13 individual samples and two pooled samples with respectively 5 and 6 individuals in each. *' Analysed as 13 individual samples and two pooled samples with 8 individuals in each.

The mean Hg concentration in cod muscle was around 0.06 mg/kg ww in 2010, 2011 and 2012. This is higher than the two previous years when the mean was 0.021 mg/kg and 0.035 mg/kg in 2008 and 2009, respectively.

Hg in cod muscle from the Faroe Islands has been analysed for several years, although for many of these years the analyses have been done on salt fish rather than on fresh fish. Taking a closer look at the data acquired since 1994, when monitoring of cod as an indicator of environmental pollution status began, up to the most recent available data for 2012, reveals that the Hg concentration in cod from the Faroe Shelf area (mainly Mýlingsgrunnur) has increased. The data series show a 7.1% yearly increasing trend ($p < 0.001$, PIA windows version 2011.12.26 abi). This is in contrast to earlier analyses, when analyses of cod data from the Faroe Islands using data from the 1970s until 2005

showed a decreasing Hg trend (Dam and Riget, 2006; AMAP 2007). Note that the trend remains significant also when including data from 1997 and onwards only, and thus excluding the unusually low Hg concentrations recorded in the 1994 samples (Figure 6.7).

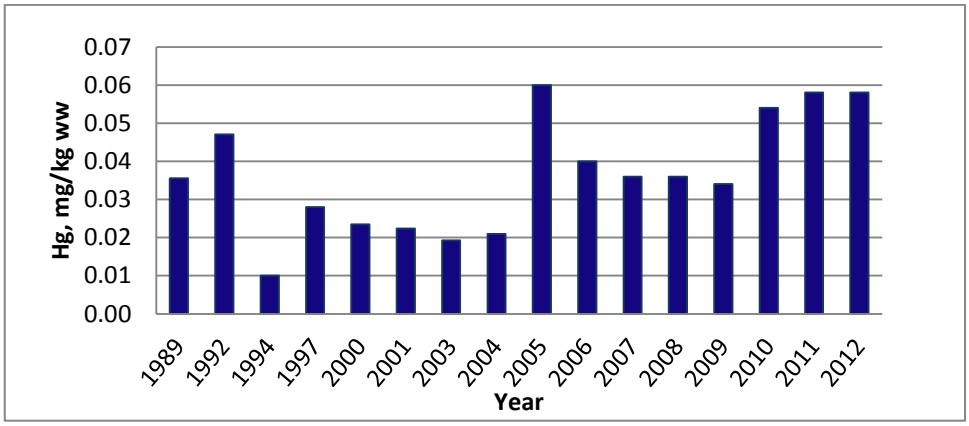

Figure 6.7 Hg in cod (fork-length 40-61 cm) muscle from the Faroe Shelf. Note that no annual samples until 2000 and onwards.
1989-2007 data: from previous analyses of cod from the Faroe Islands (Dam and Hoydal, 2005; 2007; 2009).
2008-2012 data: current work.

6.3 Pilot whale

Pilot whales sampled in 2009 to 2012 were analysed for Hg, Cd and Se in muscle and liver, and for Cd in kidney. The results of heavy metal analyses in the various tissues are shown below and complete dataset is provided in Attachment 4.

6.3.1 Muscle

A summary of the results of the heavy metals and Se analyses in juvenile pilot whale muscle is given in Table 6.5.

The concentrations of Hg in juvenile pilot whale muscle samples from the present, as well as previous studies from 1994 onwards, are shown in (Figure 6.8). The level of Hg appears to be unchanged since the mid 1990s, and no trend is discernible (PIA windows version 2011.12.26 abi).

It is well known that Hg increases with age in pilot whales due to accumulation. Age is not a parameter that is easily measured in pilot whales; for the young individuals, length may be seen as a proxy for age (Bloch *et al.*, 1993b). Figure 6.9 displays the relationship between whale length and muscle Hg concentration in juvenile pilot whale samples from 1997 onwards.

The annual mean length of the analysed juvenile whales (Figure 6.10 and
Table 5.2) mainly ranges from 300 to 350 cm, with an increasing tendency. This increase could arise from differences in the ratio of males to females, as an increased ratio of juvenile males would pull the average length up. Males are sorted into the juvenile group up to a body length that is approximately 120 cm longer than the limit for juvenile females. However, taking the length differences at face value, and calculating the anticipated increase in Hg occurring from the regression of muscle Hg vs. body length curve (0.71mg/(kg*m)) (Figure 6.9), it is seen that the yearly Hg increase (0.0037 mg/kg*year, Figure 6.8) is actually less than what could be expected from the increased length (0.015 mg/(kg*year), calculated from regression analysis Figure 6.9 and 6.10).

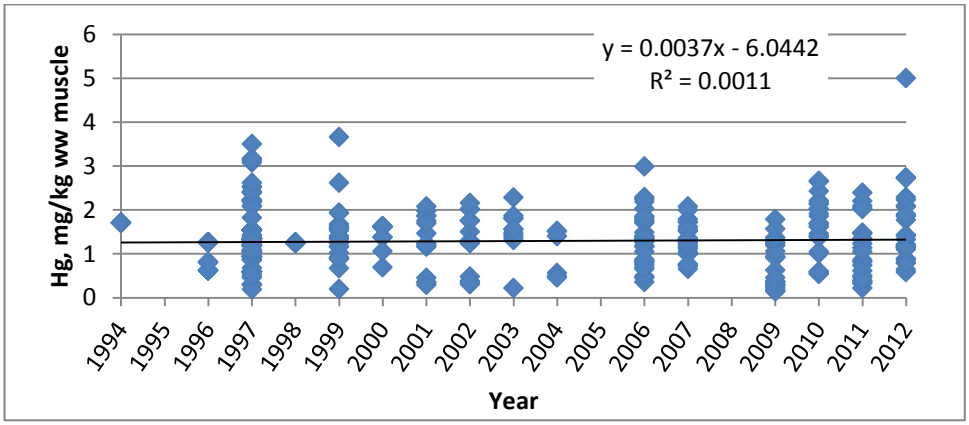

Figure 6.8 Hg in muscle tissue from juvenile pilot whales.

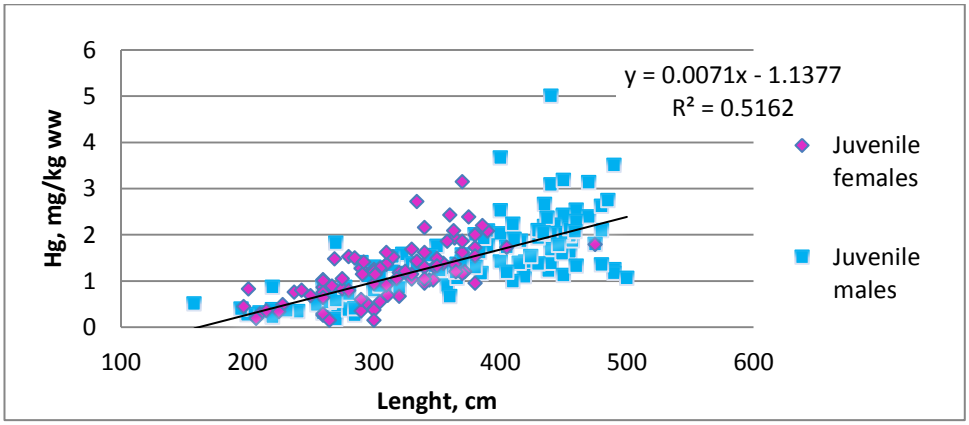

Figure 6.9 Hg versus length for juvenile pilot whales from 1997-2012 for years where Hg and length have been measured. The linear regression line shown is the best fit to the juvenile male data, and this fits as well with the female data, except in the upper reaches.

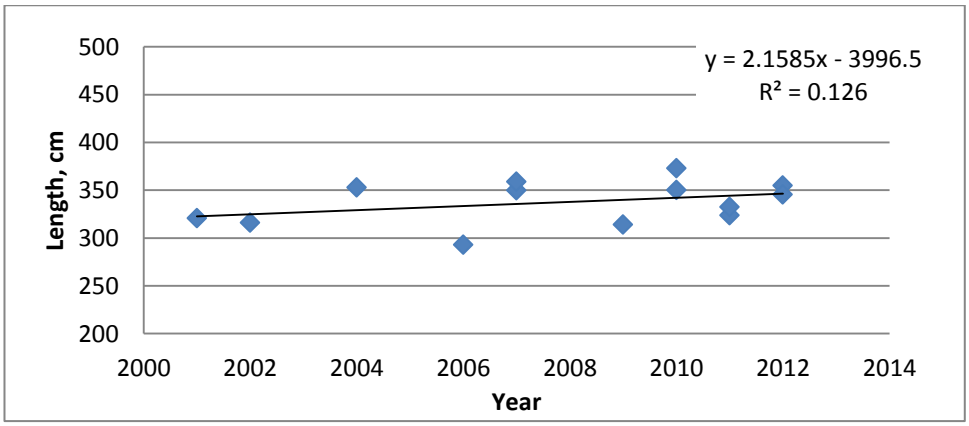

Figure 6.10 Mean length of the analysed juvenile pilot whales. In 2003, and in one of the schools from 2006, whale length was not recorded.

Table 6.5 Heavy metals in muscle tissue from juvenile pilot whales. Number and size of the analysed whales are given in Table 5.2.

Year	Date		Dry weight %	Hg mg/kg ww	Cd mg/kg ww	Se mg/kg ww
2009	05.01.09	Min	27	0.15	0.008	0.5
		Max	32	1.37	0.035	1.3
		Mean	29.7	0.70	0.02	0.69
		SD	1.55	0.49	0.01	0.21
	23.05.09	Min	26	0.29	0.002	
		Max	33	1.79	0.13	
		Mean	28.2	0.89		
		SD	1.8	0.55		
2010	24.06.10	Min	27.4	0.59	0.007	0.71
		Max	31.5	2.7	0.06	1.6
		Mean	29.2	1.7	0.03	1.04
		SD	1.3	0.5	0.02	0.286
	02.07.10	Min	-	0.54	0.016	0.57
		Max	-	2.13	0.040	0.88
		Mean	-	1.35	0.027	0.73
		SD	-	0.69	0.008	0.104
2011	09.02.11	Min	26	0.22	-	0.44
		Max	35	2.36	-	2.9
		Mean	30.8	0.88	-	0.99
		SD	2.8	0.62	-	0.68
	02.09.11	Min	27	0.39	-	0.51
		Max	34	2.39	-	1.2
		Mean	30.5	1.51	-	0.79
		SD	2.3	0.70	-	0.21
2012	10.07.12	Min	28	0.58	-	0.75
		Max	30	5.0	-	1.7
		Mean	29	1.75	-	1.14
		SD	0.82	1.38	-	0.30
	09.08.12	Min	27	0.79	-	0.68
		Max	49	2.72	-	2.2
		Mean	31.3	1.53	-	1.16
		SD	5.10	0.53	-	0.37

6.3.2 Liver

Adult individuals were selected for analyses of metals in liver tissue, see Table 5.2. The results of the heavy metal and Se analyses in liver are shown in Table 6.6 and Figure 6.11.

Table 6.6 Heavy metals in pilot whale liver from 2009 to 2012 (mg/kg ww).

Year	Date	n		Dry weight %	Hg	Cd	Se
2009	05.01.09	8 (M=4 , F=4)	Min	26	36.5	13.8	13
			Max	29	139	39	57
			Mean	27.6	76.1	21.6	28.6
			SD	0.9	39.2	9.6	15.07
	23.05.09	7 (M=3 , F= 4)	Min	26	22.3	11.9	7.8
			Max	28	88.3	53.9	38
			Mean	27	54.5	27.4	20.9
			SD	0.82	27.5	10.9	10.9
2010	24.06.10	7 (M=3 , F= 4)	Min	-	91.1	23.7	27
			Max	-	282	52.7	89
			Mean	-	180	33.4	60.42
			SD	-	77.3	9.9	23.75
	02.07.10	8 (M= 2, F= 6)	Min	-	45	8.7	13
			Max	-	236	33.2	62
			Mean	-	122.6	22.5	37.5
			SD	-	79.2	7.9	17.68
2011	09.02.11	6 (M= 2, F= 4)	Min	-	30.9	12.6	9.5
			Max	-	197	29.6	68
			Mean	-	93.3	20.9	34.2
			SD	-	70	6.5	24.7
	02.09.11	9 (M= 3, F= 6)	Min	-	33.2	22.3	10
			Max	-	188	77.8	84
			Mean	-	74.8	32.4	28.1
			SD	-	54.5	18.8	25.1
2012	10.07.12	9 (M= 0, F= 9)	Min	-	43.8	17.2	19
			Max	-	214	64.1	110
			Mean	-	104.8	33.7	49
			SD	-	70.5	16.5	35
	09.08.12	6 (M= 2, F= 4)	Min	-	87.7	25.7	31
			Max	-	290	78.5	130
			Mean	-	160	47.2	68.8
			SD	-	80	19.0	36.1

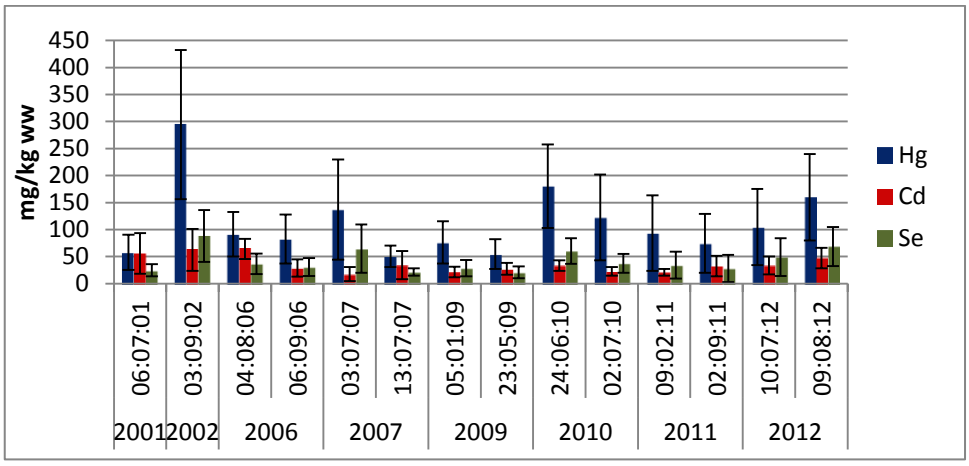

Figure 6.11 Heavy metals in pilot whale liver samples from 6th of July 2001 to 9th of August 2012.

The absolute concentration of liver Cd, as well as the between-year variability in liver Cd concentrations, are smaller than for liver Hg (Figure 6.11). However, the liver is not the organ that primarily accumulates Cd; the highest concentrations of Cd are found in the kidneys (see following section).

Se is known to have a protective effect against Hg toxicity and comparing the concentrations of Hg and Se shows a correlation between these (Figure 6.12). On average, the median liver Hg concentration was 81 mg/kg, and the molar ratio between Se and Hg in these liver samples was 0.90± 0.23, with 66% (n=40) of the sampled individuals (n=61) having a Se/Hg molar ratio <1.0. The minimum Se/Hg molar ratio found in these individuals was 0.49, in a female whose liver Hg concentration was 98.4 mg/kg ww. In the individual having the highest liver Hg concentration among these sampled whales, a female whose liver concentration was quantified to 290 mg/kg Hg, the Se/Hg molar ratio was 1.1.

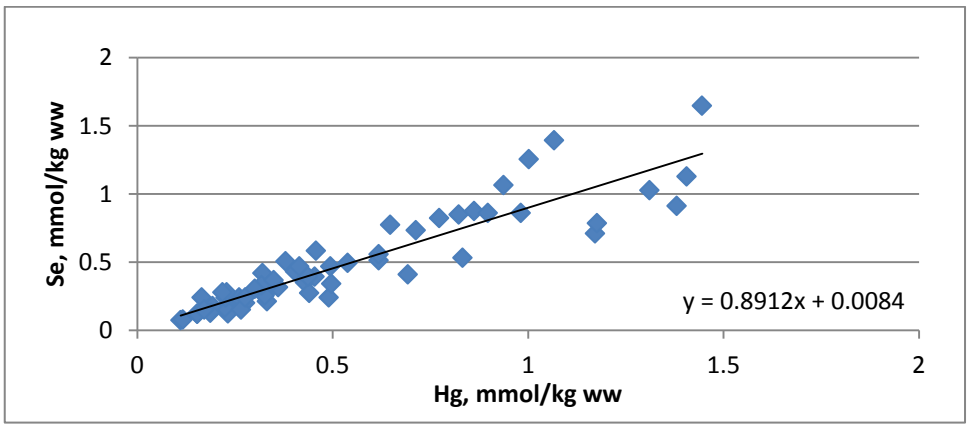

Figure 6.12 Correlation between Se and Hg in pilot whale liver samples taken in the period 2009 to 2012, n=61.

A liver Hg level of 60 mg/kg ww has been suggested as a threshold for marine mammals (Law, 1996). Forty individuals, which corresponds to 66% of the pilot whales analysed in this work, exceeded this suggested threshold, above which adverse effects may be observed.

Similarly, a range from 20 mg/kg to 200 mg/kg Cd in liver has been suggested to be the threshold for potential organ dysfunction in marine mammals (Law, 1996). Forty-six of the analysed individuals, or 75%, had liver Cd concentrations higher than 20 mg/kg.

6.3.3 Kidney

Kidney samples from 60 adult pilot whales were analysed for Cd. The results are shown in Table 6.7. The Cd concentrations show large variations among the different schools, the highest mean is seen in the school from 09.08.12 at 99.5 mg/kg.

The threshold for potential kidney dysfunction in marine mammals due to Cd contamination may be in the range of 200-400 mg/kg ww (Law, 1996). The maximum kidney Cd concentration measured in these 60 individuals was 123 mg/kg, thus none fell within this suggested limit range.

Table 6.7 Cd in pilot whale kidney (mg/kg ww).

Year	Date	n		Cd
2009	05.01.09	8 (M=4, F=4)	Min Max Mean SD	43.9 106 84.9 19.7
	23.05.09	7 (M=3, F=4)	Min Max Mean SD	46.4 103 72.1 19.9
2010	24.06.10	7 (M=3, F=4)	Min Max Mean SD	23.7 52.7 33.4 9.9
	02.07.10	8 (M=2, F=6)	Min Max Mean SD	8.72 33.2 21.54 7.86
2011	09.02.11	9 (M=6, F=3)	Min Max Mean SD	29.6 78.8 48.9 23.1
	02.09.11	6 (M=2, F=4)	Min Max Mean SD	45.6 93.8 64.78 13.9
2012	10.07.12	9 (M=0, F=9)	Min Max Mean SD	41.5 123 74.3 31.0
	09.08.12	6 (M=2, F=4)	Min Max Mean SD	55.4 121 99.5 20.0

6.4 Mountain Hare

In 2008, 15 hares shot in Signabø (n=9) and Norðradalur (n=6) were taken for analyses. In 2010, 17 hares shot in Signabø (n=8) and Norðradalur (n=9) were analysed. The hares were analysed for the heavy metals Hg and Cd and the results are shown in Table 6.8. Details on the individuals are provided in Attachment 6.

Table 6.8 Hg and Cd in hare liver from 2008 and 2010.

Year	n		Hg, mg/kg	Cd, mg/kg	Se, mg/kg
2008	15	Min	0.03	0.06	-
		Max	0.13	0.54	-
		Mean	0.07	0.21	-
		SD	0.03	0.12	-
2010	17	Min	0.01	0.02	1.43
		Max	0.44	0.23	2.57
		Mean	0.11	0.12	2.13
		SD	0.14	0.06	0.38

Figure 6.13 shows the individual results of Hg versus Cd in hare livers in samples from 2008 and 2010.

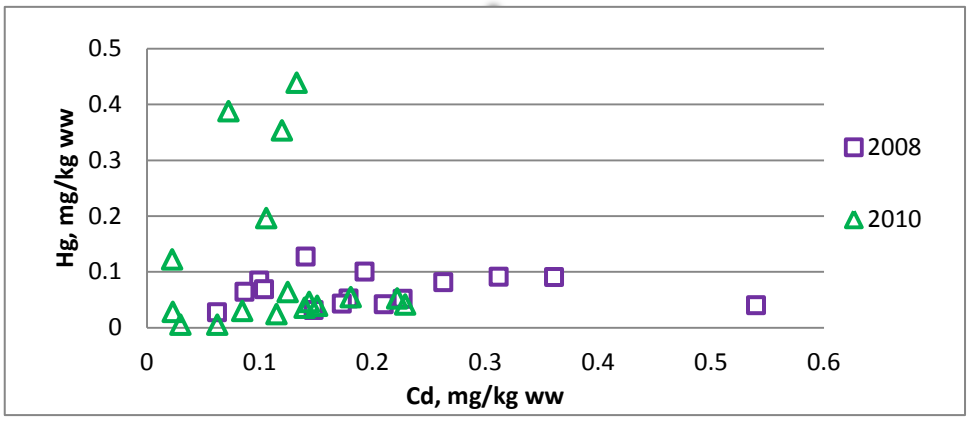

Figure 6.13 Hg versus Cd in hare liver from 2008 and 2010.

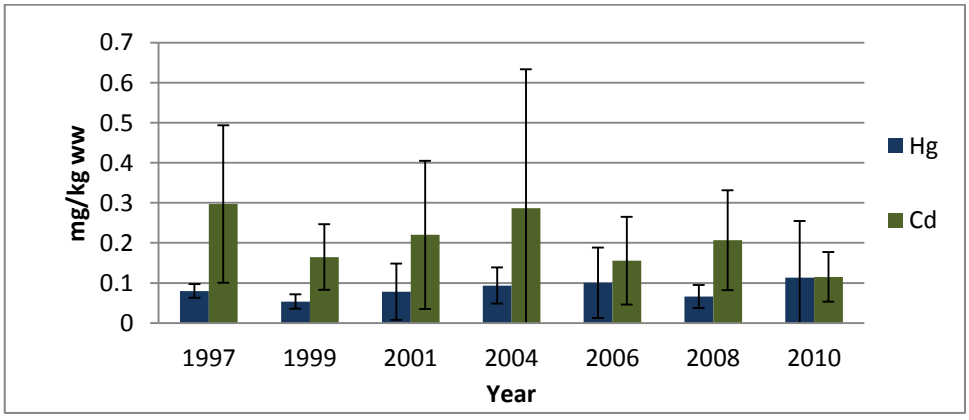

Figure 6.14 Hg and Cd in hare liver samples taken from 1997 to 2010.

The sampled hares accumulated more Cd than Hg. The average Hg and Cd levels recorded for the various years are shown in Figure 6.14. The levels vary between years, but do not show a directional trend. Since 2001, the hares have been sampled from the locations Signabøhagi and Heimihagi, Norðradalur. No significant difference was found between year or location (ANOVA p>0.05).

6.5 Arctic char

Arctic char muscle was analysed for Hg and Se. Summary results of heavy metals in Arctic char are shown in Table 6.9 and individual results are found in Attachment 7.

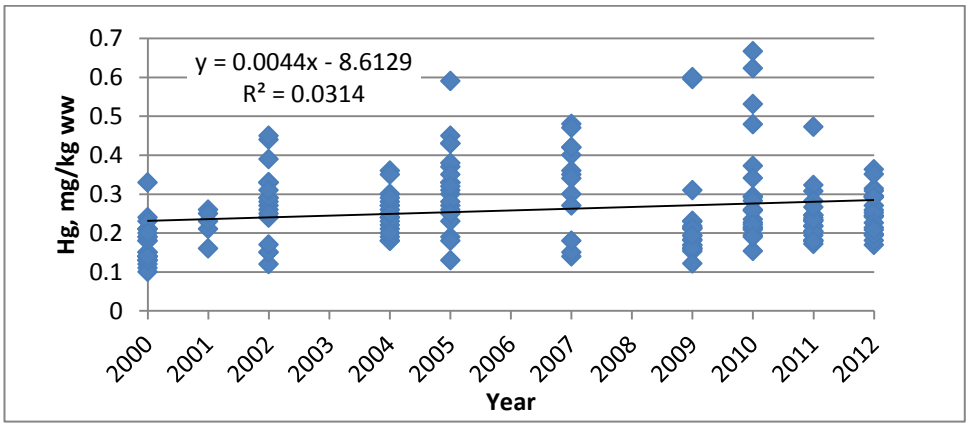

Figure 6.15 Muscle Hg in Arctic char from the lake á Mýrunum.

Table 6.9 Hg and Se concentration in Arctic char muscle from 2009-2012.

Year	n		Length, cm	Weight, g	Age, years	Dry matter %	Hg, mg/kg	Se, mg/kg
2009	20	Min	25	192	4	15	0.16	1.2
		Max	37	480	12	26	0.6	1.7
		Mean	32.3	353.8	7.1	23.1	0.21	1.57
		SD	3.13	62.5	1.9	2.7	0.13	0.13
2010	20	Min	29	282	5	-	0.15	1.4
		Max	38.5	450	12	-	0.67	1.7
		Mean	33.0	337.0	8.05	-	0.31	1.58
		SD	2.9	48.4	1.9	-	0.15	0.1
2011	20	Min	28	191	5	20	0.17	1.5
		Max	35	343	10	26	0.47	2
		Mean	30.8	272.4	7.3	22.5	0.24	1.7
		SD	2.0	44.8	1.26	1.67	0.07	0.12
2012	20	Min	24.5	146	5	17	0.17	1.4
		Max	32	242	9	23	0.36	1.9
		Mean	28	193.5	6.63	20.5	0.26	1.62
		SD	2.0	25.9	1.12	3.01	0.1	0.25

The yearly mean muscle Hg concentration varied from 0.21 mg/kg to 0.31 mg/kg. Hg concentrations measured in Arctic char muscle, since monitoring began in the lake á Mýrunum in 2000, are presented in Figure 6.15.

Hg appears to be increasing in the recent years, but a closer look at the analysed samples discloses that fish length is also decreasing, see Figure 6.16. The fish fork length in the period 2000-2007 was quite stable and had a period mean of 36.7 cm, whereas the mean fork length in the 2009-2012 period, at 30.7, was shorter.

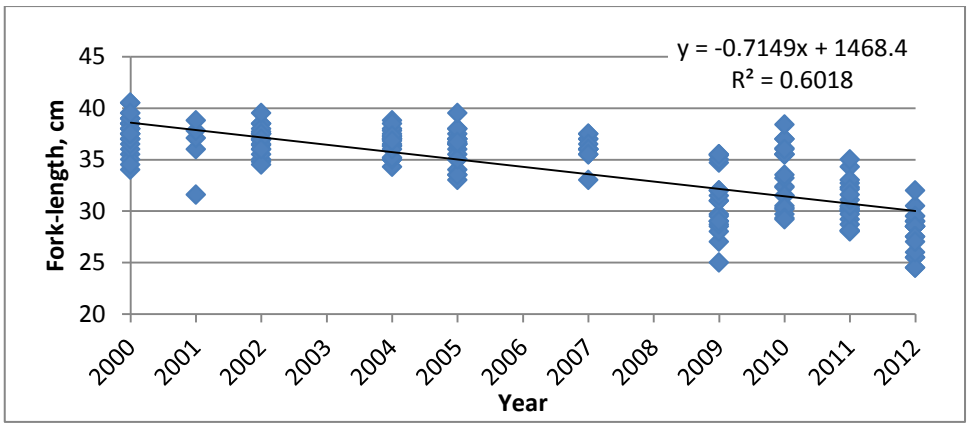

Figure 6.16 Fork length of Arctic char from Lake á Mýrunum.

Correlation analysis of yearly samples of muscle Hg (log-transformed) vs. fish length indicated that the Hg concentration was significantly correlated to fish length, although with some variation in regression slope and intercept between years. Thus, the annual mean muscle Hg measured for the consecutive years 2009-2012 was adjusted to an average length of 36.7 cm, with the increment corresponding to what would have been measured if the fish sample for that particular year was the same as in the 2000-2007 period. Analysing the resulting data for time-trend using the PIA software, showed a 7.2% yearly increasing trend ($p<0.001$).

Figure 6.17 shows Arctic char age versus length. Fish length was significantly correlated with age in two out of four years, in 2010 and 2011 with $p=0.001$ and 0.004, respectively, as well as for all fish combined, $p=0.000$ ($n=78$).

Fish length is, however, more easily measured than fish age. Considering all samples from the period 2000-2012, each year separately, there are 10 years of samples (sampling was unsuccessful in 2003, 2006 and 2008) where length was known for every individual; age was unknown only for 2004 samples. It was discovered that for seven of the yearly samples age and length were both significantly and positively correlated to muscle Hg (see Figure 6.18). Performing the same analyses on Fulton condition index versus muscle Hg showed that muscle Hg was invariably, in 10 out of 10 cases, significantly and negatively correlated to the condition index (see Figure 6.19). Condition index was calculated as 100 times the round weight in grams divided by the cube of fork length in centimetres.

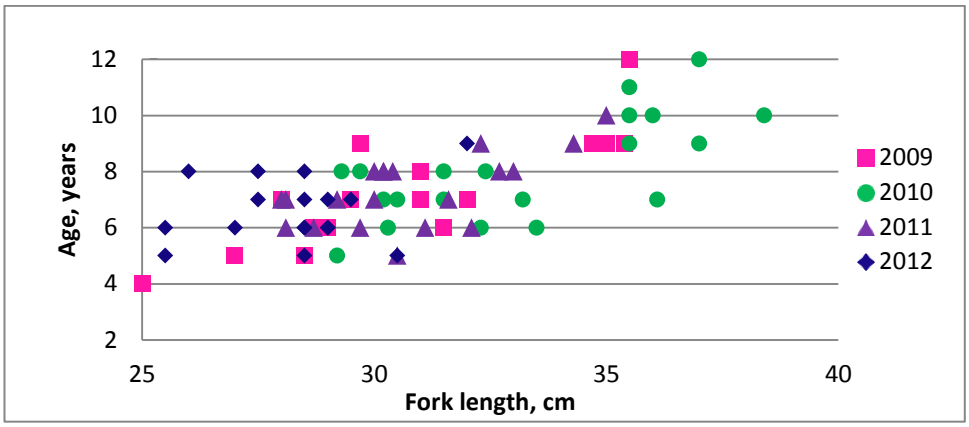

Figure 6.17 Arctic char fork length as a function of age in fish caught in June-July 2009, 2010, 2011 and 2012.

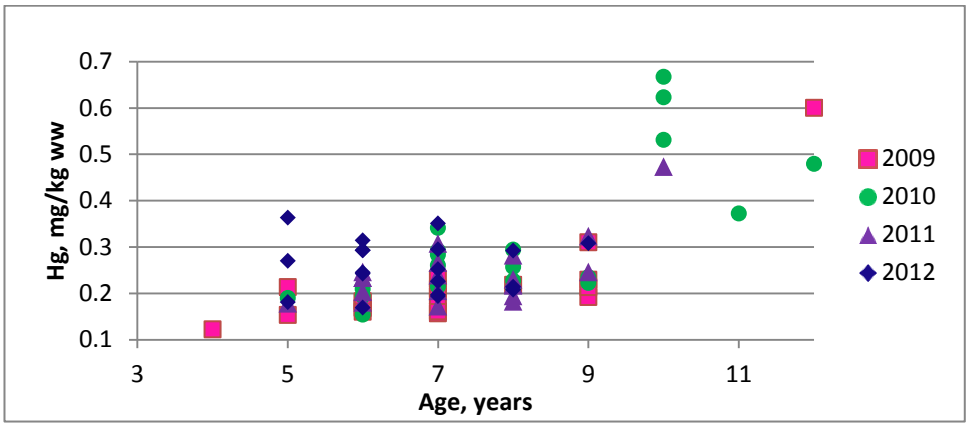

Figure 6.18 Arctic char muscle Hg concentration versus fish age.

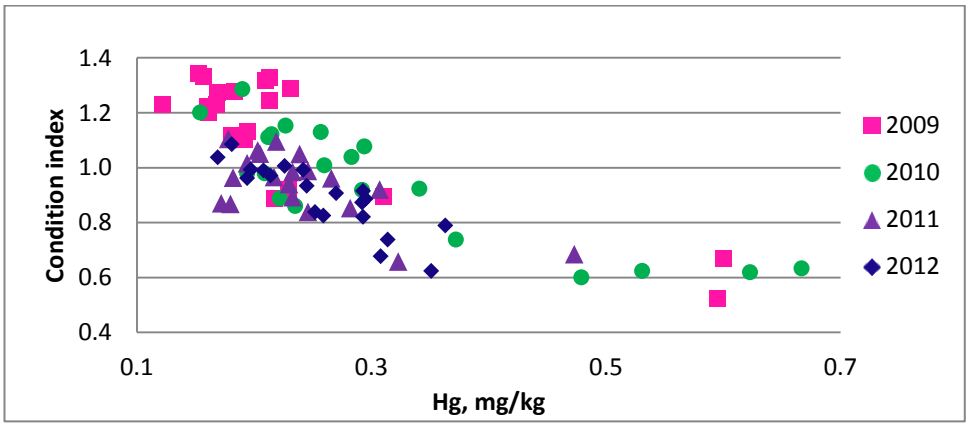

Figure 6.19 Arctic char condition index versus muscle Hg.

The Se concentration in muscle appears to be rather constant, with minimum concentration at 1.2 mg/kg and maximum at 2.0 mg/kg in the 80 individuals analysed in 2009-2012. This is also mirrored in the relative standard deviation, which varies from 6% to 8% in the respective years for muscle Se

concentrations, while the relative standard deviation in mean concomitant Hg concentrations varies from 21% to 56%. The small variability in Se concentrations discourages correlation analyses. To the extent that one could say there exists a correlation between muscle Hg and Se, it is invariably negative (Figure 6.20), meaning that Se does not increase with increasing Hg concentration. In five of the ten yearly sample batches, this negative correlation was statistically significant, based on a Spearman rank correlation test.

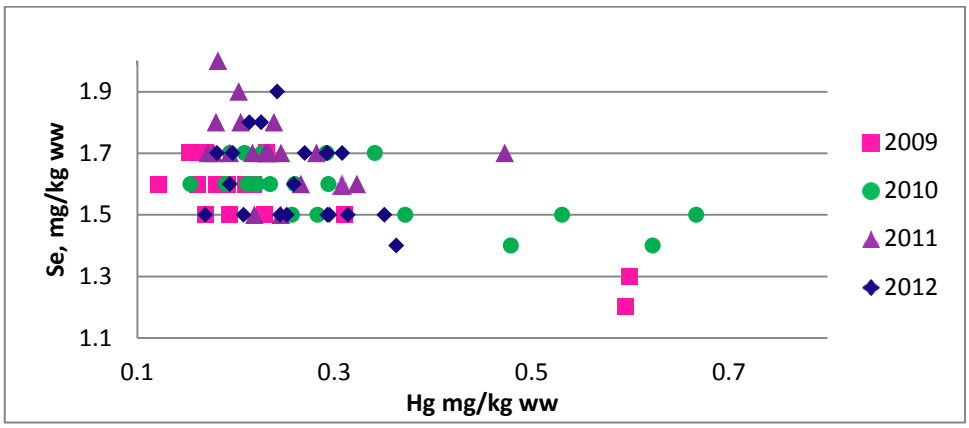

Figure 6.20 Arctic char muscle Hg versus muscle Se.

6.6 Sheep

Livers from adult females and juveniles were analysed for Cd, Hg and Se. The results of heavy metal analyses on the pooled samples are shown in Table 6.10. In Figure 6.21 it is seen that the Cd results in adult females have higher values than the juveniles. Little difference is seen in the Hg and Se results, as shown in Figure 6.22 and 6.23. Additional data are given in Attachment 7.

Table 6.10 Hg, Cd and Se concentration in lamb and ewe (juvenile and adult female) liver samples.

Year	n	maturity	Sample ID	Dry matter %	Cd, µg/kg	Hg, µg/kg	Se, mg/kg
2008	3	Adult females	Oa-2008-1	-	55.4	15	0.39
	4		Oa-2008-2	-	131	11.8	0.43
	7	Juveniles	Oa-2081-3	-	18.4	<10	0.46
	6		Oa-2008-4	-	19.1	11.9	0.51
2009	5	Adult females	Oa-2009-11	-	84.6	<10	0.42
	5		Oa-2009-12	-	111	<10	0.41
	5	Juveniles	Oa-2009-13	-	20.7	10.3	0.45
	5		Oa-2009-14	-	19.1	12.4	0.41
2011	5	Adult females	Oa-2011-10	33	104	29.9	0.46
	5		Oa-2011-11	32	86.2	<10	0.41
	5	Juveniles	Oa-2011-8	30	12.9	<10	0.34
	5		Oa-2011-9	31	16.1	<10	0.31

*Detection limit for Hg was 10 µg/kg. In statistical analysis values below detection limit were replaced by half the value of the detection limit.

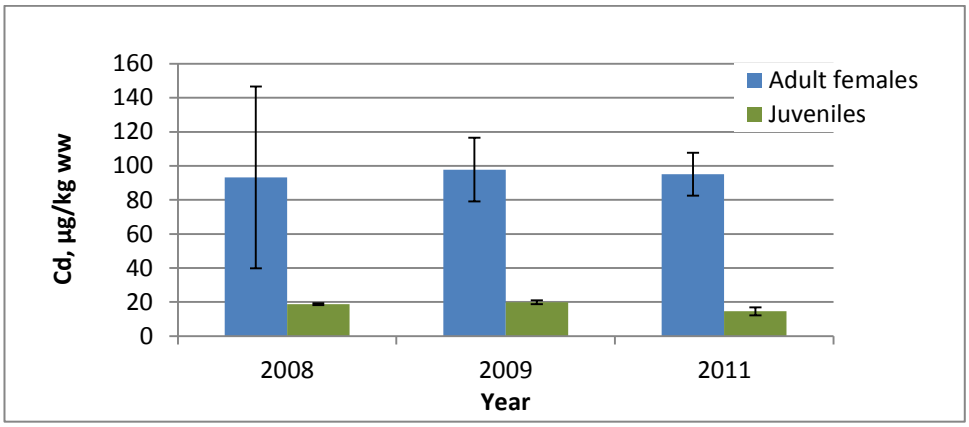

Figure 6.21 Cd in sheep liver from 2008, 2009 and 2011. Cd was not detected in several of the samples (see Table 6.10), thus half of the detection limit was used in the calculation for these samples.

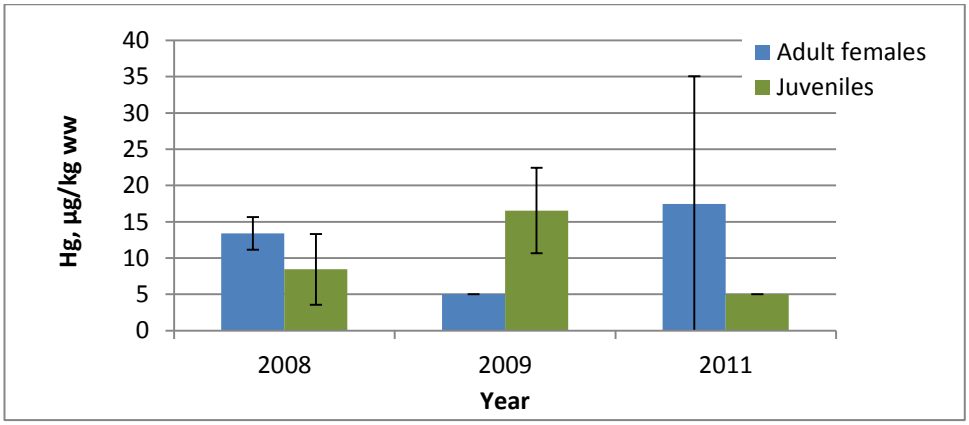

Figure 6.22 Adult female and juvenile liver Hg concentrations.

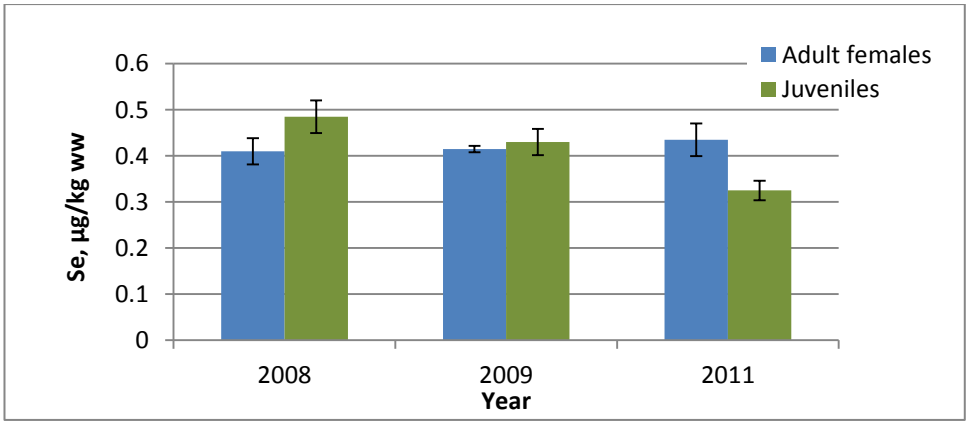

Figure 6.23 Adult female and juvenile liver Se concentrations.

7 POP results

7.1 Black guillemot eggs

Black guillemot eggs sampled on the islands of Koltur and Skúvoy in 2008, 2010 and 2012 were analysed for POPs, as in 1999, 2000, 2001 (Hoydal *et al.*, 2003), 2004 (Hoydal and Dam, 2005) and 2002, 2006 (Hoydal and Dam, 2009). Summary data are shown below (Table 7.1); individual results are available in Attachment 1. Summary of chosen pollutants are given in Table 7.2 and 7.3.

Table 7.1 PCB in black guillemot eggs (µg/kg of lipids).

Year	Location	n		Aroclor 1260 (mg/kg of lipids)	CB 153	PCB 6* or PCB 5**
2008	Koltur	10	Min	2300	320	701
			Max	5500	790	1685
			Mean	3470	501	1062
			SD	1004	145.6	308
	Skúvoy	9	Min	2300	330	695
			Max	3900	540	1162
			Mean	2822	401	846
			SD	563	80.2	167
2010	Koltur	10	Min	1600	230	441
			Max	4000	570	1116
			Mean	2455	363	701
			SD	789	109.1	247
	Skúvoy	10	Min	1600	240	453
			Max	4000	580	1125
			Mean	2655	383	726
			SD	870	108.9	219
2012	Skúvoy	10	Min	1600	230	441
			Max	3300	470	924.5
			Mean	2430	352	674.7
			SD	570	81.6	157

*PCB 6 is calculated as the sum of PCB 28, 101, 118, 138, 153 and 180, since CB 52 was not included in the calculation for 2008 and 2010 data. For other congeners, half of the detection limit was used in the calculation of PCB 6. ** In samples from 2012, neither CB 28 nor CB 52 was detected in any of the black guillemot eggs, therefore PCB 5.

Table 7.2 Toxaphene and p,p'-DDE in black guillemot eggs (µg/kg of lipids).

Year	Location	n		% Lipids	Parlar no. 26	Parlar no. 32	Parlar no. 50	Parlar no. 62	p,p'-DDE
2008	Koltur	10	Min	5.9	9.4	2	9	5.1	180
			Max	13	27	6.7	79	24	790
			Mean	9.8	18.1	4.75	60.7	15.9	387
			SD	2.1	5.6	1.3	15.3	5.7	201
	Skúvoy	9	Min	8.3	15	2.4	49	10	140
			Max	12	23	4.9	83	19	290
			Mean	8.3	18	3.7	62.4	14.9	203
			SD	8.3	3.1	0.8	12.9	2.4	61
2010	Koltur	10	Min	8.3	9.6	2.6	35	7.7	120
			Max	11	19	5.8	65	15	300
			Mean	9.6	14.7	4.1	51.3	12.0	199
			SD	0.9	3.2	1.0	12.4	2.7	67
	Skúvoy	10	Min	9.4	12	2.4	43	10	110
			Max	13	30	4.4	100	25	250
			Mean	11.4	20	3.1	63.4	14.2	175
			SD	1.4	5.8	0.62	19.1	4.9	46
2012	Skúvoy	10	Min	8.1	9.9	0.8	38	8.9	89
			Max	11	20	3.6	63	15	200
			Mean	9.49	14.2	2.3	48.6	12.2	154.9
			SD	0.8	3.0	0.9	10.2	2.5	32.3

Table 7.3 Organochlorine pesticides in black guillemot eggs (µg/kg of lipids).

Year	Location	n		ß-HCH	alpha-chlordane*	cis-nonachlor	hexa-chloro-benzene	mirex	oxychlordane	trans nonachlor
2008	Koltur	10	Min	9.9	0.35	15	96	25	22	5
			Max	19	1	39	160	56	50	15
			Mean	14.4	0.57	26.1	130.6	34.8	35.8	9.3
			SD	3.3	0.33	6.9	19.3	10.1	8.2	3.1
	Skúvoy	9	Min	11	0.45	19	92	26	23	6.2
			Max	18	0.75	31	200	42	48	19
			Mean	14.8	0.45	24.1	124.5	32	32.7	10
			SD	3.0	0.45	5.3	37.5	5.7	9.1	3.9
2010	Koltur	10	Min	10	low	12	100	17	19	5.2
			Max	20		26	190	46	34	13
			Mean	16.3		18.5	143.6	27	25.2	8
			SD	3.1		4.3	25.8	8.9	5.0	2.1
	Skúvoy	10	Min	11	low	14	84	20	18	6.4
			Max	25		27	200	45	39	23
			Mean	16.5		21.5	129.5	30.4	28.4	11.5
			SD	4.3		4.7	30.8	7.8	7.3	4.9
2012	Skúvoy	10	Min	10	<0.8	12	99	25	15	5.9
			Max	19	1	24	180	49	28	14
			Mean	16	<1	18.6	143.4	37.4	20.2	8.4
			SD	2.9	na	4.0	24.9	9.4	3.9	2.6

* For calculation purposes, results reported as lower than the detection limit were assumed to be equal to 0.5*DL, except for the 2012 batch, where all but one sample were below the detection limit.

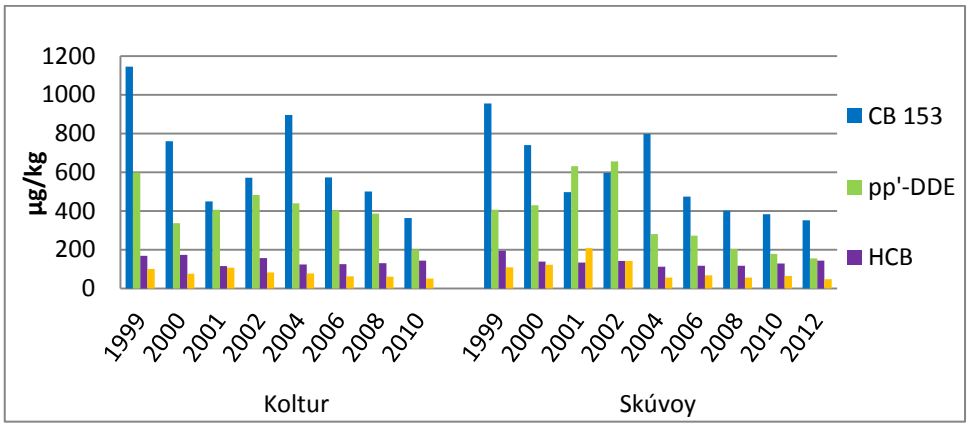

Figure 7.1 POPs in black guillemot eggs from 1999 to 2012.

The PCB data as CB 153 in black guillemot eggs from Skúvoy (Figure 7.1) show a 6.5% yearly decreasing trend ($p<0.004$; PIAW 2011). A similar decrease (-6.6 %) both for CB 153 and p,p'-DDE was noted in the eggs from Koltur. Sampling from Koltur in 2012 was not successful, thus the data series stops temporarily with the 2010 data. The decreasing trend for Koltur was not significant.

7.2 Cod

The cod livers from 2008, 2009, 2010, 2011 and 2012 were analysed for POPs and the mean results are shown in Table 7.4 to Table 7.6 and Figure 7.2. PCB results are shown as Aroclor 1260, CB 153 and PCB 6. The individual POP results are given in Attachment 4. Selected pollutants are shown in Figure 7.

Table 7.4 PCB in in cod liver (µg/kg of lipids).

Year	n		Aroclor 1260	CB 153	PCB 6*
2008	23	Min	97	12	30.9
		Max	190	25	56.9
		Mean	127.13	16.25	39.4
		SD	28.33	3.6	8.11
2009	25	Min	100	13	31.8
		Max	430	61	124
		Mean	176	23.33	53.4
		SD	85.09	12.4	23.9
2010	24	Min	260	31	78.3
		Max	1700	220	486
		Mean	618.1	79.6	185.2
		SD	463.7	59.8	144.3
2011	29	Min	240	32	70.9
		Max	2700	340	735
		Mean	715.3	96.5	204.7
		SD	645.7	81.6	175.6
2012	25	Min	130	17	37.5
		Max	880	110	233.5
		Mean	247	32.3	70.4
		SD	183.8	22.6	48.1

* PCB 6 is calculated as the sum of PCB 28, 101, 118, 138, 153 and 180. Since CB 52 was not detected in any of the cod samples and, since the detection limits are high, CB 52 was not included in the calculation. For other congeners (CB 28), half of the detection limit was used in the calculation of PCB 6, when results were reported as not detected.

Table 7.5 Toxaphen and DDT in cod liver (µg/kg of lipids).

Year	n		% Lipids	Parlar no. 26 (T2)	Parlar no. 32*	Parlar no. 50 (T12)	Parlar no. 62 (T20)	p,p'-DDE	p,p'-DDT
2008	23	Min	41	7.8	<0.1	17	3.4	26	1.7
		Max	62	60.0	1.5	120	15.0	220	36.0
		Mean	53.3	14.3	0.8	28.5	5.8	56.9	4.9
		SD	7.15	12.94	0.47	25.8	3.14	52.7	8.64
2009	25	Min	35	8.8	0.56	17	3.9	18	1.9
		Max	67	19	1.3	37	11	53	4.8
		Mean	54.5	11.3	0.93	22.7	6.97	26.9	2.96
		SD	8.13	3.09	0.53	6.16	2.36	9.57	0.84
2010	24	Min	32	8.6	<0.2	13.0	3.3	25	<0.5
		Max	65	20.0	1.3	43.0	14.0	87	3.7
		Mean	51.6	12.2	0.6	24.3	6.3	38.8	1.8
		SD	9.98	4.04	0.39	9.38	3.31	14.94	1.18
2011	29	Min	10	11	0.25	15	1.5	46	1.9
		Max	56	44	0.42	83	7.6	340	11
		Mean	30.9	18.6	0.34	29.7	3.7	103.3	4.0
		SD	12.9	9.3	0.06	16.5	1.94	79.5	2.4
2012	25	Min	21	6.3	0.44	12	2.6	16	1.2
		Max	65	47.0	0.73	80	12	110	7.6
		Mean	53.3	16.45	0.59	29.9	6.11	36.13	3.22
		SD	11.53	10.25	0.21	17.9	3.17	24.50	1.76

*When results were reported as not detected, half of the detection limit was used in the calculation of the mean.

Table 7.6 Organochlorine pesticides in cod liver (µg/kg of lipids).

Year	n		ß-HCH*	alpha-chlor-dane	gamma-chlor-dane	cis-nona-chlor	hexa-chloro-benzene	mirex	oxy-chlor-dane	trans-nona-chlor
2008	23	Min	0.58	5.2	0.64	4.0	13	0.88	2.6	9.3
		Max	3.5	51.0	5.9	46.0	70.0	8.1	14.0	120
		Mean	1.7	10.3	1.3	8.9	37.3	2.2	5.1	21.4
		SD	0.95	11.4	1.29	10.4	21.1	1.70	2.8	27.5
2009	25	Min	0.51	4.1	0.34	3.7	9	0.7	2.6	7.7
		Max	0.65	9.1	1.3	9.3	21	3.8	7.3	23
		Mean	0.58	5.44	0.66	5.09	12.6	1.44	3.8	11.9
		SD	0.04	1.38	0.25	1.53	3.63	0.85	1.3	4.0
2010	24	Min	<0.5	4.1	0.6	4.4	11.0	1.1	2.2	10.0
		Max	1.50	13.0	1.9	9.3	48.0	4.9	10.0	28.0
		Mean	0.89	7.6	1.0	6.0	28.4	1.9	4.8	14.9
		SD	0.32	2.48	0.40	1.62	11.8	0.9	2.0	5.2
2011	29	Min	<0.5	3.5	0.33	6.4	14	3.7	4.1	13
		Max	<3	18.5	1.45	34	24	17.5	14	80
		Mean	-	7.6	0.65	13.2	17.4	7.33	7.7	31.4
		SD	-	4.2	0.31	8.11	2.6	4.3	3.1	19.4
2012	25	Min	0.57	2.8	0.27	3.0	16	0.87	1.3	8.9
		Max	0.65	14	1.0	23	59	5.4	21	51
		Mean	0.61	6.5	0.58	8.19	26.4	2.22	6.93	18.53
		SD	0.03	3.26	0.24	4.9	11.86	1.02	4.44	10.64

*When results were reported as not detected, half of the detection limit was used in the calculation of the mean.

Analysis for some POPs in cod from the Faroe Shelf has been carried out since 1994 (Figure 7.3). The overall trend seems to be decreasing, although with large annual variation. Statistical analyses (PIA, using power= 80% and alpha =5%) gives no clear picture, but concentration trends vary randomly. The only exception is CB 153, which increases significantly with an 11% increasing trend ($p<0.019$) in cod sampled on Mýlingsgrunnur (i.e., the samples from 1997 and onwards).

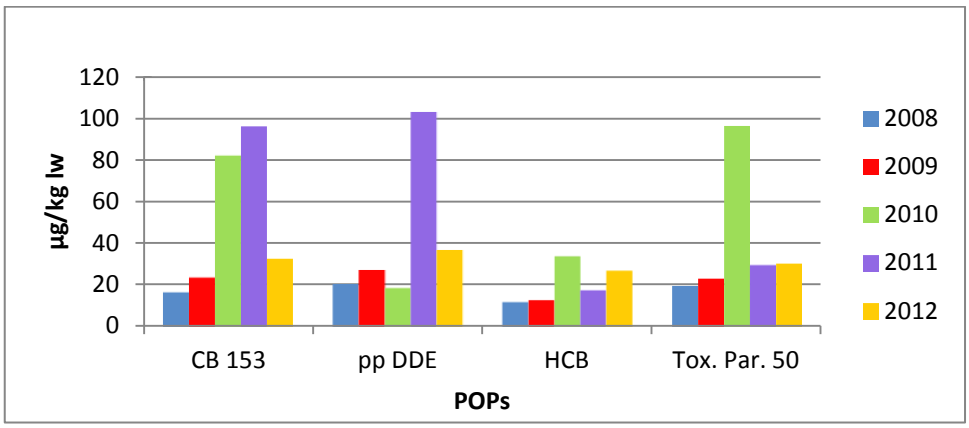

Figure 7.2 Selected POPs in cod liver from 2008, 2009, 2010, 2011 and 2012.

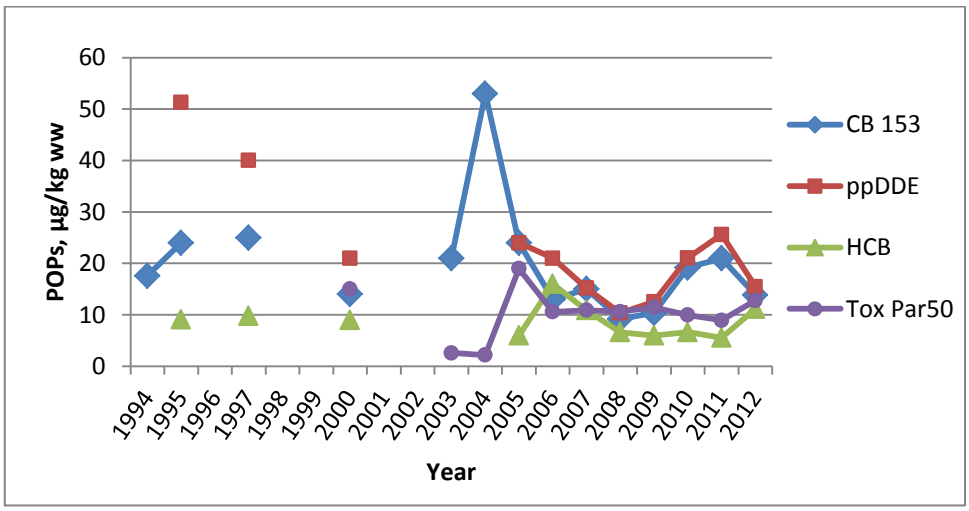

Figure 7.3 Median concentrations [µg/kg ww] of selected POPs in cod liver from 1994 to 2012. The livers from 1997 were analysed as two pooled samples, and the livers from 1994 as one pooled sample.

7.3 Pilot whale

In pilot whales, as with other mammals, parameters like age and sex are important when assessing POP concentration. The age of pilot whales may be determined by analysis of the teeth, however, the age is correlated to length until they reach maturity (Bloch *et al.*, 1993b), which makes the juvenile whales the group of choice for analysis of possible trends in POPs concentrations. Thus, blubber from juvenile pilot whales was analysed for PCBs, DDTs, toxaphenes and other organochlorine pesticides.

A summary of the results is given below, and the individual data and results are given in Attachment 4.

7.3.1 PCB

The mean results of PCBs as Aroclor, CB 153 and PCB 7 are shown in Table 7.7. All the analysed PCB congeners are shown as individual results in Attachment 4.

Table 7.7 PCB in blubber from juvenile pilot whales from 2009 to 2012 (µg/kg of lipids).

Year	Date	n*		Lipids %	Aroclor 1260	CB 153	PCB 7***
2009	05.01.09	19 (M=9, F=10)	Min	43	4500	500	1593
			Max	93	23000	2700	7680
			Mean	71.8	12778	1399	4415
			SD	15.3	5391	622	1748
	23.05.09	12 (M=9, F=3)	Min	67	7200	780	2508
			Max	94	50000	5500	16900
			Mean	78.3	16842	1839	6074
			SD	9.1	12402	1379	4290
2010	24.06.10	17 (M=10, F=7)	Min	37	11000	1200	3952
			Max	83	33000	3700	11203
			Mean	77.2	18970.6	2144.1	6452.4
			SD	10.7	6992.1	782.2	2213.7
	02.07.10	8 (M=5, F=3)	Min	53	11000	1200	3898
			Max	84	31000	3400	10200
			Mean	76.63	17750	1937.5	5982.1
			SD	69.8	159	621.6	247.5
2011	09.02.11	13 (M=7,F=6)	Min	63	8900	990	3201
			Max	84	46000	5000	16199
			Mean	75.6	22730.8	2495.4	7664.7
			SD	6.4	12978.9	1372.4	4438.9
	02.09.11	12 (M=9,F=3)	Min	56	7700	900	2325
			Max	82	26000	2800	8348
			Mean	70.4	17372.7	1904.6	5590.6
			SD	7.7	6616.1	690.1	2135.1
2012	10.07.12**	10 (M=8, F=2)	Min	60	8100	950	2793
			Max	80	29000	3200	9591
			Mean	71.3	18510	2115	6218
			SD	7.27	6899.4	752.1	2307.45
	09.08.12	15 (M=7, F=8)	Min	48	3200	380	
			Max	80	43000	5000	
			Mean	69	19207	2200.7	
			SD	10.1	13177	1505	

*M: males; F: females

**CB 52 was not detected in one of the blubber samples from Klaksvík 10.07.12, thus half of the detection limit was used in the calculation of PCB 7 for this sample.

*** PCB 7 is calculated as the sum of CB 28, 52, 101, 118, 138, 153 and 180.

Figure 7.4 shows mean PCB 7 concentrations in juvenile pilot whale samples from 2001 to 2012. The shown data indicates a decresing trend for PCB 7 in juvenile pilot whale blubber.

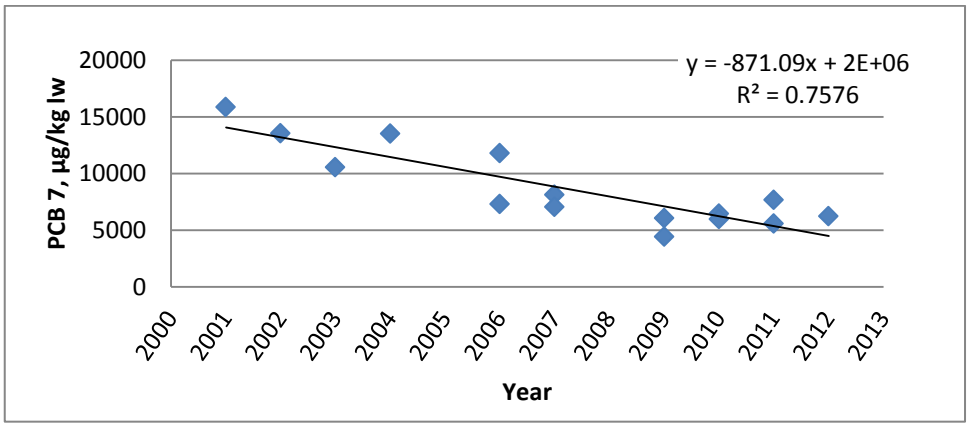

Figure 7.4 PCB 7 in juvenile pilot whale blubber from 2001 to 2012.

7.3.2 DDT

DDT was analysed in blubber of juvenile and adult pilot whales from 2001 to 2004, and only in juveniles from 2006 and 2012. In 2001, 2002 and 2006, all 6 isomers and metabolites of DDT were analysed, whereas in 2003, 2004 and 2007, 2009, 2010, 2011 and 2012 only p,p'-DDE and p,p'-DDT were analysed. The mean results of p,p'-DDE and p,p'-DDT for the groups that have been analysed for all isomers and metabolites are shown in Table 7.8 and Figure 7.5. All individual values are shown in Attachment 4.

Figure 7.5 shows the mean values of p,p'-DDE and p,p'-DDT in the analysed juvenile pilot whales from 2001 to 2012. p,p'-DDE is found at the highest concentrations, followed by p,p'-DDT. In previous years, all six isomeres (p,p'-DDT, p,p'-DDE, p,p'-DDD, o,p'-DDT, o,p'-DDE and o,p'-DDD) were reported. Due to the fact that p,p'-DDE and p,p'-DDT make up by far the largest part of sum DDTs, the other four isomers are not considered in this report.

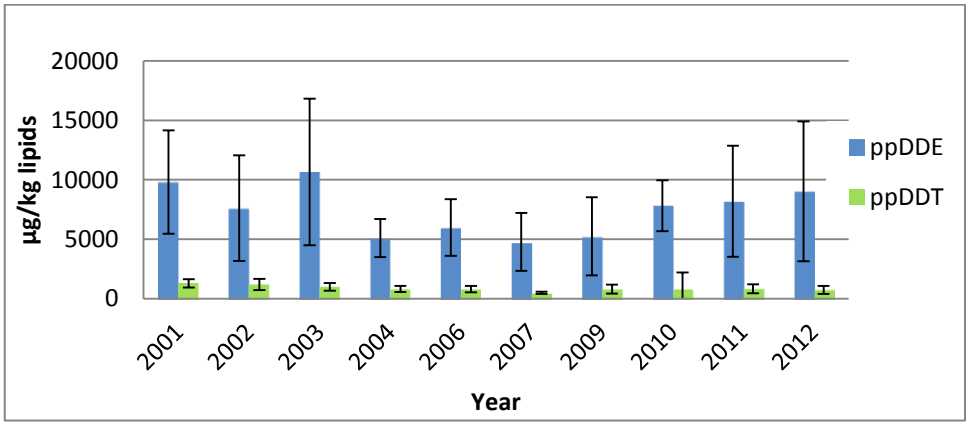

Figure 7.5 p,p'-DDE and p,p'-DDT in juvenile pilot whale blubber samples from 2001-2012, in µg/kg of lipids.

Table 7.8 DDT in blubber from juvenile pilot whales from 2009-2012 (µg/kg of lipids)

		Age and sex group		Juveniles		
Year	Date	n*		p,p'-DDE	p,p'-DDT	sumDDT**
2009	05.01.09	19 (M=9, F=10)	Min	1500	310	-
			Max	7700	1200	-
			Mean	4295	668	-
			SD	1829	290	-
	23.05.09	12 (M=9, F=3)	Min	2600	480	-
			Max	19000	2000	-
			Mean	6183	938	-
			SD	4738	483	-
2010	24.06.10	17 (M=10, F=7)	Min	5000	440	-
			Max	19000	1700	-
			Mean	9511.8	883.8	-
			SD	4031	331.9	-
	02.07.10	8 (M=5, F=3)	Min	3700	520	-
			Max	9800	930	-
			Mean	6112.5	692.5	-
			SD	247.5	2506	-
2011	09.02.11	13 (M=7,F=6)	Min	3900	570	-
			Max	22000	2400	-
			Mean	10342	1118.5	-
			SD	6567	537.4	-
	02.09.11	12 (M=9,F=3)	Min	2400	230	-
			Max	10000	990	-
			Mean	6036.4	540.5	-
			SD	2755	221.1	-
2012	10.07.12	10 (M=8, F=2)	Min	2200	290	-
			Max	15000	1200	-
			Mean	8590	781	-
			SD	4144	272.3	-
	09.08.12	15 (M=7, F=8)	Min	960	130	-
			Max	26000	1300	-
			Mean	9470.7	695.3	-
			SD	7620	406.6	-

*F: females; M: males

**Sum of p,p'-DDT, p,p'-DDE, p,p'-DDD, o,p'-DDT, o,p'-DDE and o,p'-DDD

7.3.3 Toxaphene

The mean results of toxaphene in pilot whale blubber are shown in Table 7.9. Toxaphene averages are shown in Figure 7.6. Individual results are found in Attachment 4.

Table 7.9 Toxaphene in blubber of juvenile pilot whales (µg/kg of lipids).

		Age and sex group		Juveniles			
Year	Date	n*		Par. no. 26	Par. no. 32**	Par. no. 50	Par. no. 62
2009	05.01.09	19 (M=9, F=10)	Min	350	0.5	680	130
			Max	1900	9.2	2700	640
			Mean	1032	4.16	1611	340
			SD	430	3.62	618	160
	23.05.09	12 (M=9, F=3)	Min	610	6.1	920	190
			Max	3600	26	5000	1300
			Mean	1432	13.1	2213	497
			SD	1004	11.2	1512	322
2010	24.06.10	17 (M=10, F=7)	Min	730	3.8	970	160
			Max	2500	12	3800	860
			Mean	1215	6.8	1789	322
			SD	455	2.5	757	201
	02.07.10	8 (M=5, F=3)	Min	730	4	1100	190
			Max	1900	8.5	2600	570
			Mean	1173	6.1	1775	354
			SD	478	1.6	587	147
2011	09.02.11	13 (M=7, F=6)	Min	710	3.8	1100	270
			Max	3500	21	5000	1400
			Mean	1585	11.9	2350	636.9
			SD	974	5.4	1214	302
	02.09.11	12 (M=9, F=3)	Min	310	4.3	510	120
			Max	1600	9.8	2700	550
			Mean	895	6	1456	303.2
			SD	362	2.6	601	141.4
2012	10.07.12	10 (M=8, F=2)	Min	250	4.2	460	170
			Max	1800	15	2600	560
			Mean	1052	7.8	1526	344
			SD	477	3.5	633	138.2
	09.08.12	15 (M=7, F=8)	Min	110	<4	210	80
			Max	2100	10	2900	520
			Mean	1029	3.7**	1447	290
			SD	697	2.6**	898	143

*F: females; M: males

**Par. No. 32 was not detected in 13 out of 15 blubber samples from Hvannasund 09.08.12, half of the detection limit was used in the calculations of the mean and the standard deviation for these samples.

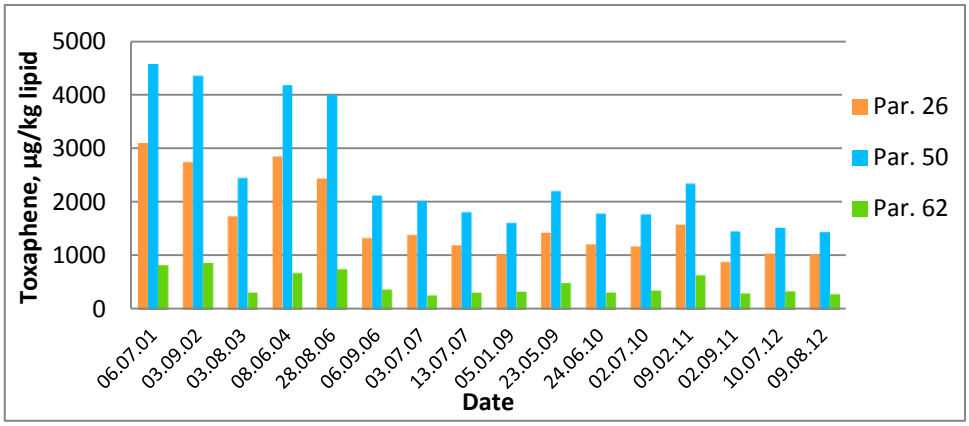

Figure 7.6 Toxaphene parlar 26, 50 and 62 in pilot whale blubber from 2001 to 2012, in µg/kg of lipids.

7.3.4 Chlordanes and other pesticides

Mean values of the analysed chlordanes and other organochlorinated pesticides are shown in Table 7.10. Individual results are found in Attachment 4.

Table 7.10 Chlordanes and other organochlorine pesticides in blubber from juvenile pilot whales (µg/kg of lipids).

	Age and sex group			Juveniles							
Year	Date	n*		ß-HCH	alpha-chlor-dane	gamma-chlor-dane	cis-nona-chlor	trans-nona-chlor	hexa-chloro-benzene	mirex	oxy-chlor-dane
2009	05.01.09	19 (M=9, F=10)	Min	11	120	3	160	440	180	25	76
			Max	53	390	16	580	2000	780	100	410
			Mean	30	225	8.1	375	1236	417	65	247
			SD	12	84	3.6	123	452	173	20	92
	23.05.09	12 (M=9, F=3)	Min	15	120	4.7	250	840	170	52	150
			Max	120	660	23	1000	4200	1300	160	1000
			Mean	47	319	12.4	499	1798	583	85	420
			SD	36	206	6.9	282	1116	428	32	319
2010	24.06.10	17 (M=10, F=7)	Min	19	120	3.8	280	1000	210	92	170
			Max	63	490	17	860	3000	770	250	580
			Mean	33	228	6.8	468	1679	387	153	289
			SD	11.9	108	3.6	156	539	162	42.6	106
	02.07.10	8 (M=5, F=3)	Min	22	120	2.7	330	940	260	63	200
			Max	56	280	10	630	2000	870	130	590
			Mean	36.3	193	4.8	448	1326	519	92	344
			SD	13.5	63	2.5	134	415	225	24	159
2011	09.02.11	13 (M=7, F=6)	Min	18	85	3.8	280	600	230	51	140
			Max	130	450	21	1200	4300	2700	200	1400
			Mean	47.5	246.9	10.2	586.9	1618	804.6	122.2	466.9
			SD	32.3	112.2	5.2	327.7	987.5	668.5	43.0	385.0
	02.09.11	12 (M=9, F=3)	Min	7.1	60	3.7	150	530	72	46.5	64
			Max	44	340	13	690	2300	530	170	350
			Mean	24.9	173.2	6.8	370.5	1348	316.5	101.0	203.9
			SD	10.1	78.0	3.1	156.0	619.5	166.4	38.0	81.4
2012	10.07.12	10 (M=8, F=2)	Min	7	77	4.7	140	520	160	91	49
			Max	60	410	15	830	2900	970	260	420
			Mean	32.2	220.7	8.1	485.0	1782	510.0	150.1	260.9
			SD	16.7	105.8	3.8	209.2	783.5	256.6	51.5	126.7
	09.08.12	15 (M=7, F=8)	Min	18	36	6.1	70	230	45	72	23
			Max	59	360	10	900	3800	710	200	620
			Mean	35.3	177.6	8.2	464.7	1718	322.7	121.1	248.5
			SD	14.5	105.1	1.4	295.4	1166	194.3	42.0	181.0

*M: males; F: females

The chlordanes and the other organochlorine pesticides in this section that were found in highest concentrations were cis-nonachlor, trans-nonachlor and hexachlorobenzene, see Figure 7.7. For one of the schools (09.02.11), the max value for oxy-chlordane exceeds the max value for cis-nonachlor; this is not the case for any of the average values.

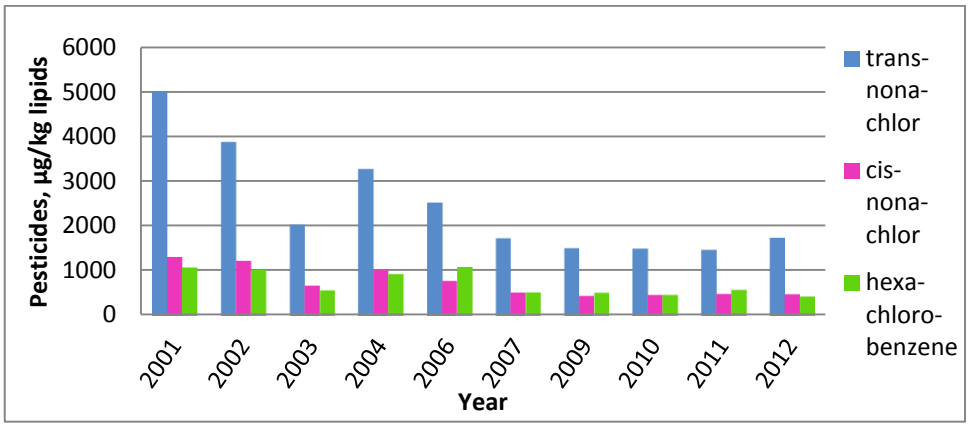

Figure 7.7 Selected pesticides analysed in blubber of juvenile pilot whales, in µg/kg of lipids.

7.3.5 PBDE

PBDE nos. 28, 47, 66, 100, 99, 85, 154, 153, 138 and 183 were analysed in blubber samples from juvenile male pilot whales from 2010, 2011 and 2012, five individuals from each year, to add to a time-trend series established previously (Rotander *et al.*, 2011). PBDE were detected in all samples and the individual concentrations are presented in Attachment 4. BDE 47 was the dominant BDE-congener in recent samples, as in earlier ones (Figure 7.8), making up, on average, 54% of the sum PBDE.

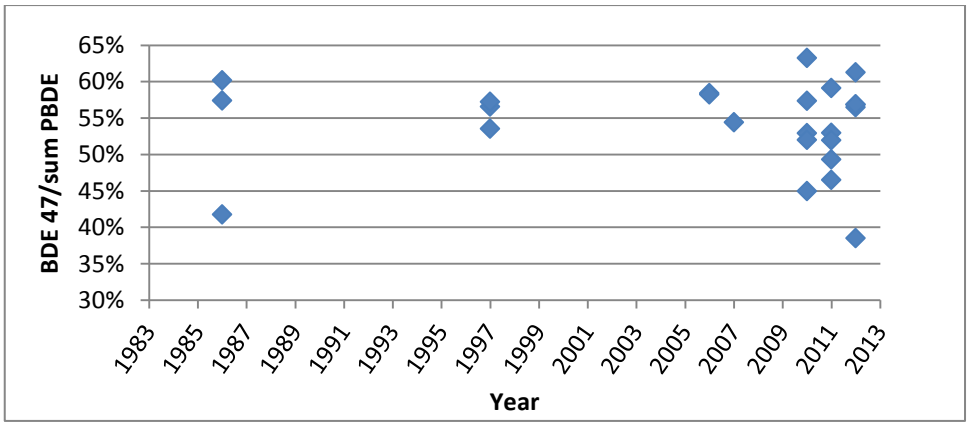

Figure 7.8 The ratio of BDE 47 to sum PBDE in samples of juvenile male pilot whale blubber from 1986 to 2012. Note, that the analyses in 2010 - 2012 were done on individual whales, whereas the earlier samples were done on pools of from five to eight whales in each. Data from 1986 - 2007 were adapted from Rotander *et al.*, 2011.

The decision to base the analyses on juvenile males only was due to the fact that age and sex influences PDBE concentrations, as with other POPs. In the present case, a weak negative correlation was found between the sum PDBE concentration in the 15 samples from 2010-2012 and whale length (Figure 7.9), which may be relevant to consider in the context of interpreting the variation in concentrations between years (Figure 7.10). The variation in mean length among the samples was 396 cm in one sample from 2006 to 420 cm in one from 1997. Using the regression slope (although not statistically significant) would imply that 18 ng/g should be added to the sample in 1997 with a mean length of 420 cm (which indeed had the lowest PBDE concentration among the three pools from that

year, at 569 ng/g lw blubber). That would, however, not change the overall picture, which is one of a marked decrease of PBDE in pilot whale blubber since the turn of the millennium.

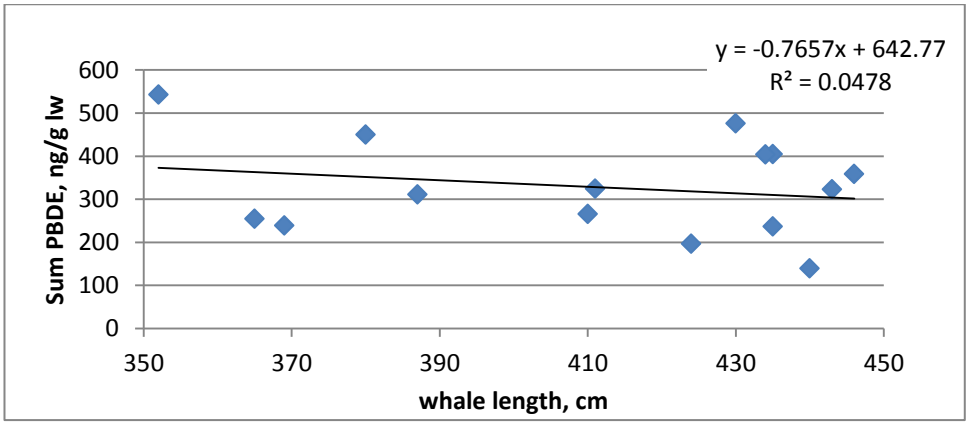

Figure 7.9 A weak negative correlation was seen between juvenile male pilot whale length and sum PBDE in blubber.

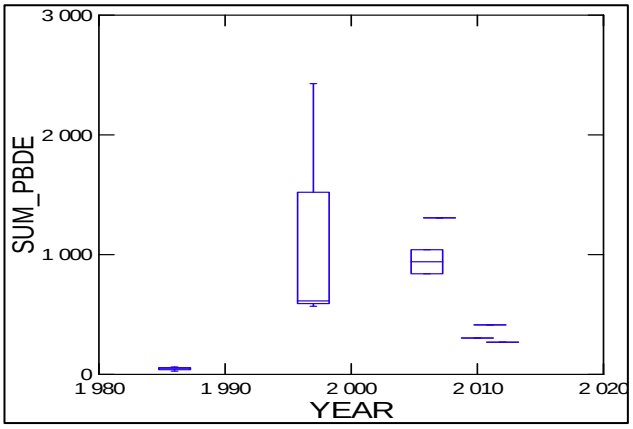

Figure 7.10 Sum PBDE in juvenile male pilot whale blubber samples, in ng/g lw. Data from 1986 to 2007 are from Rotander *et al.*, 2011. Data from 2010 to 2012 have been pooled in order to make these comparable to data from 1986 to 2007 where the analyses were made on pooled samples as opposed to the present analyses, which were made on individual samples.

7.3.6 Discussion of the POP and PBDE results in pilot whales

POPs have been analysed in both juvenile and adult pilot whales until 2004, but only in juveniles in 2006, 2007, 2009, 2010, 2011 and 2012. Juvenile pilot whales have shown to be more suitable for detecting a trend in the Hg concentration (Dam and Riget, 2006), probably partly due to the more simple length to age relationship, which enables comparison between years for predefined whale size groups.

The POPs analysed in pilot whales generally show the same trends; the levels in juveniles and adult males appear to be decreasing, whereas the level in adult females is increasing. The level in females is generally found to be lower than in males as well as juveniles. This is due to the excretion of accumulated lipid soluble compounds to the offspring with lactation. The apparent decrease in the

POP levels of juveniles and adult males would be in line with similar observations - although not for the same species – in, for instance, the Baltic sea.

The increase in adult females at the same time is, however, puzzling, but could be connected to changes in the breeding behaviour of the whales, such as lower birth frequency, which would lead to less excretion and thus higher accumulation in adult females. More investigations, for instance to shed light on possible changes in population demographics, are needed before such conclusions can be made.

In comparison to previous studies, the levels of all PBDEs have decreased significantly, Figure 7.9 and 7.10 (Rotander *et al*, 2011), a likely effect of the bans restricting the use of most commercially available PBDE mixtures. The decrease in the levels of BDE 85 is stronger than the other congeners. This might result from the use of HRGC/HRMS, which is more selective, and thus a co-eluting substance possibly contributing to the earlier established concentrations no longer adds to the determined concentration.

7.4 Mountain hare

The 16, 15 and 17 hares from 2006, 2008 and 2010, respectively, were analysed individually. The samples were analysed for seven PCBs, DDTs, HCB and β-HCH. A subsection of the results is shown below in Table 7.11 to Table 7.13, and the complete dataset is given in Attachment 6.

Table 7.11 POPs in hare liver from 2006 (ng/g ww).

ID	Sample ID	CB 153	PCB 7*	p,p'-DDE	p,p'-DDT	SUM DDT**	hexachloro-benzene	ß-HCH
Lt-0066	Lt-0066	0.0036	0.009	<0.1	<0.1	0.2	0.55	<0.1
Lt-0067	Lt-0067	0.0062	0.01	<0.1	<0.1	0.2	0.63	<0.1
Lt-0068	Lt-0068	0.09	0.11	<0.1	<0.1	0.2	0.57	<0.1
Lt-0070	Lt-0070	0.0039	0.012	<0.1	<0.1	0.2	0.62	<0.1
Lt-0071	Lt-0071	0.0058	0.0032	<0.1	<0.1	0.2	0.45	<0.1
Lt-0072	Lt-0072	0.0031	0.018	<0.1	<0.1	0.2	0.53	<0.1
Lt-0073	Lt-0073	0.0058	0.018	<0.1	<0.1	0.2	0.57	<0.1
Lt-0074	Lt-0074	0.004	0.012	<0.1	<0.1	0.2	0.24	<0.1
Lt-0075	Lt-0075	0.0066	0.02	<0.1	<0.1	0.2	0.23	<0.1
Lt-0076	Lt-0076	4.1	19.3	<0.1	<0.1	0.2	0.73	<0.1
Lt-0077	Lt-0077	0.016	0.12	<0.1	0.18	0.33	0.95	<0.1
Lt-0078	Lt-0078	0.011	0.03	<0.1	<0.1	0.2	0.40	<0.1
Lt-0079	Lt-0079	0.004	0.0067	<0.1	<0.1	0.2	0.23	<0.1
Lt-0080	Lt-0080	0.0033	0.0073	<0.1	0.3	0.53	0.44	<0.1
Lt-0081	Lt-0081	0.018	0.052	<0.1	<0.1	0.2	0.41	<0.1
Lt-0082	Lt-0082	0.006	0.052	<0.1	<0.1	0.2	0.68	<0.1
	Mean	0.27	1.24			0.22	0.51	
	Mean LB			0	0.03	0.04		0
	Mean UB			0.1	0.12	0.40		0.1

* PCB 7 is calculated as the sum of PCB 28, 52, 101, 118, 138, 153 and 180.
**Sum DDT: p,p'-DDT + o,p'-DDT + p,p'-DDE + p,p'-DDD. When values reported as lower than the detection limit were used in calculations of sum DDT, half of the detection limit was used.
LB: Lower bound values. Not detected values have been set to be 0 in calculations.
UB: Upper bound values. Not detected values have been set to be the equal to the detection limit in calculations.

Table 7.12 POPs in hare liver from 2008 (ng/g ww).

ID	Sample ID	CB 153	PCB 7*	p,p'-DDE	p,p'-DDT	SUM DDT**	hexachloro-benzene	ß-HCH
Lt-0083	Lt-0083	0.0083	0.003	<0.1	<0.1	0.2	0.9	<0.1
Lt-0084	Lt-0084	0.017	0.037	<0.1	0.11	0.26	0.98	<0.1
Lt-0085	Lt-0085	0.01	0.0294	<0.1	<0.1	0.2	1.15	<0.1
Lt-0086	Lt-0086	0.013	0.039	<0.1	<0.1	0.2	1.1	<0.1
Lt-0087	Lt-0087	4.9	24.7	<0.1	<0.1	0.2	0.48	<0.1
Lt-0088	Lt-0088	0.0064	0.02	<0.1	<0.1	0.2	0.71	<0.1
Lt-0089	Lt-0089	0.013	0.031	<0.1	<0.1	0.26	0.39	<0.1
Lt-0090	Lt-0090	0.011	0.039	<0.1	0.54	0.69	0.73	<0.1
Lt-0091	Lt-0091	0.004	0.027	<0.1	<0.1	0.2	0.34	<0.1
Lt-0092	Lt-0092	0.017	0.04	<0.1	0.25	0.4	0.36	<0.1
Lt-0093	Lt-0093	0.0021	0.017	<0.1	<0.1	0.2	0.26	<0.1
Lt-0094	Lt-0094	<2	10.4	<0.1	<0.1	0.2	0.65	<0.1
Lt-0095	Lt-0095	7.7	33.2	<0.1	<0.1	0.2	0.2	<0.1
Lt-0096	Lt-0096	2.7	14.2	<0.1	<0.1	0.2	0.71	<0.1
Lt-0097	Lt-0097	0.0024	0.0012	<0.1	<0.1	0.2	0.53	<0.1
	Mean		5.52			0.25	0.63	
	Mean LB	1.03		0	0.06	0.07		0
	Mean UB	1.16		0.1	0.14	0.44		0.1

* PCB 7 is calculated as the sum of PCB 28, 52, 101, 118, 138, 153 and 180.
**Sum DDT: p,p'-DDT + o,p'-DDT + p,p'-DDE + p,p'-DDD. When values reported as lower than the detection limit were used in calculations of sum DDT, half of the detection limit was used.
LB: Lower bound values. Not detected values have been set to be 0 in calculations.
UB: Upper bound values. Not detected values have been set to be the equal to the detection limit in calculations.

Table 7.13 POPs in hare liver from 2010 (ng/g ww).

ID	Sample ID	CB 153	PCB 7*	p,p'-DDE	p,p'-DDT	SUM DDT**	hexachloro-benzene	ß-HCH
Lt-0098	Lt-0098	<0.220	n.d	<5	<5	n.d	<2	<5
Lt-0099	Lt-0099	<0.140	n.d	<5	<5	n.d	<2	<5
Lt-0100	Lt-0100	<0.220	n.d	<5	<5	n.d	<2	<5
Lt-0101	Lt-0101	<0.180	n.d	<5	<5	n.d	<2	<5
Lt-0102	Lt-0102	<0.160	n.d	<5	<5	n.d	<2	<5
Lt-0103	Lt-0103	<0.220	n.d	<5	<5	n.d	<2	<5
Lt-0104	Lt-0104	<0.220	n.d	<5	<5	n.d	<2	<5
Lt-0105	Lt-0105	<0.300	n.d	<5	<5	n.d	<2	<5
Lt-0106	Lt-0106	<0.140	n.d	<5	<5	n.d	<2	<5
Lt-0107	Lt-0107	<0.220	n.d.	<5	<5	n.d.	<2	<5
Lt-0108	Lt-0108	<0.240	n.d.	<5	<5	n.d.	<2	<5
Lt-0109	Lt-0109	<0.280	n.d.	<5	<5	n.d.	<2	<5
Lt-0110	Lt-0110	<0.210	n.d.	<5	<5	n.d.	<2	<5
Lt-0111	Lt-0111	<0.200	n.d.	<5	<5	n.d.	<2	<5
Lt-0113	Lt-0113	<0.200	n.d.	<5	<5	n.d.	<2	<5
Lt-0114	Lt-0114	<0.230	n.d.	<5	<5	n.d.	<2	<5
Lt-0115	Lt-0115	<0.270	n.d.	<5	<5	n.d.	<2	<5
	Mean							
	Mean LB	0		0	0		0	0
	Mean UB	0.215		5	5		2	5

* PCB 7 is calculated as the sum of PCB 28, 52, 101, 118, 138, 153 and 180.
**Sum DDT: p,p'-DDT + o,p'-DDT + p,p'-DDE + p,p'-DDD. When values reported as lower than the detection limit were used in calculations of sum DDT, half of the detection limit was used.
LB: Lower bound values. Not detected values have been set to be 0 in calculations.
UB: Upper bound values. Not detected values have been set to be the equal to the detection limit in calculations.

The levels of DDTs and β-HCH were normally below detection limits. CBs 101, 118, 138 and 153 were detected in most samples from 2006 and 2008, but not in samples from 2010, which were analysed at another laboratory with higher detection limits.
In 2001 and 2004, the median HCB concentration was 0.49 ng/g ww and 0.39 ng/g ww, respectively. For the calculation of the median value for 2004 one outliar of 4.5 ng/g ww was excluded. The median HCB concentration in 2006 was 0.51 ng/g ww, and in 2008 the median HCB concentration was 0.63 ng/g ww, thus there appears to be a slight increase in the period 2004-2008. In 2010, HCB was not detected at 2 ng/g ww liver.

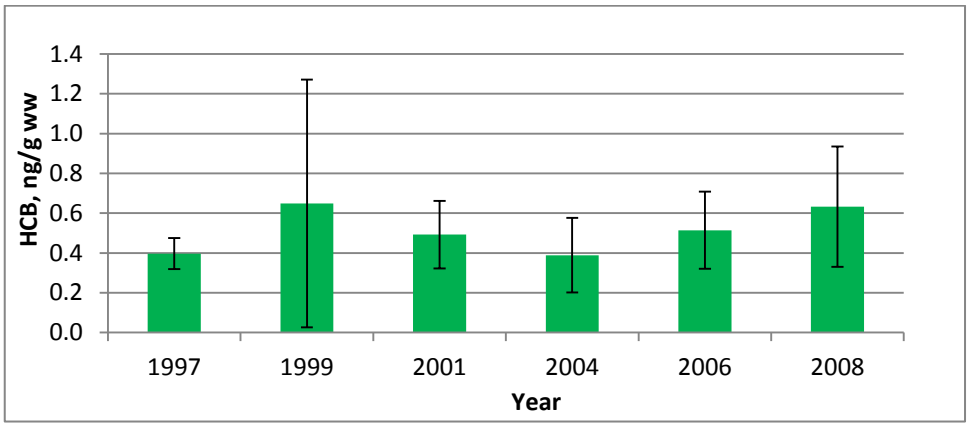

Figure 7.11 HCB in hare liver from1997-2008. The data from 1997-2004 are re-calculated from lipid weight to wet weight.

7.5 Arctic char

Arctic char from 2007, 2009, 2010, 2011 and 2012 were analysed for POPs and the mean results are shown in Table 7.14 and Table 7.15. Individual results are given in Attachment 7. All the POP analyses and most of the lipid analyses were done by CTQ, and in addition some samples were re-analysed for lipid content at Eurofins Steins Lab.

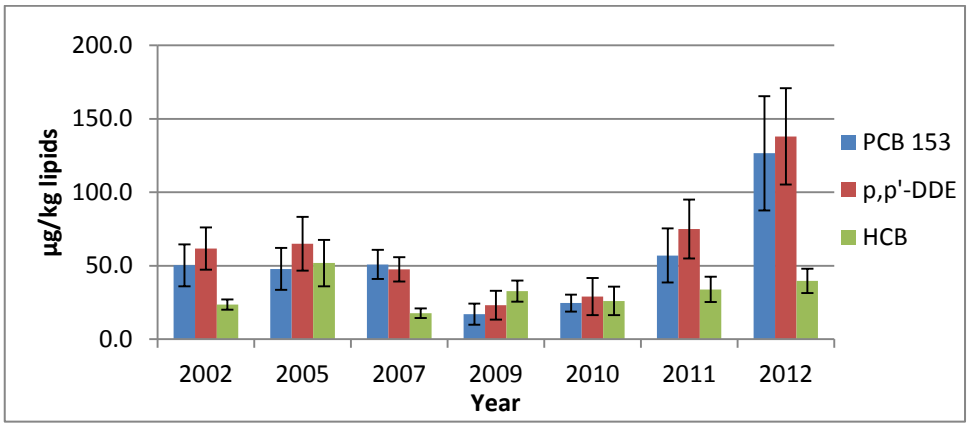

Figure 7.12 CB-153, pp'-DDE and HCB in Arctic char muscle, in µg/kg of lipids, shown as mean levels and standard deviations.

Table 7.14 PCB in Arctic char muscle (µg/kg of lipids). 2009, 2010, 2011 and 2012 data were corrected for lipid content partly as determined in re-analyses.

Year	n		Lipids %	Aroclor 1260 µg /kg of lipids	CB 153 µg/kg of lipids	PCB 6* µg/kg of lipids
2007	13	Min	0.8	79.0	79.0	27.8
		Max	2.5	670	670	197.0
		Mean	1.4	445	445	140.4
		SD	0.6	168	168	50.0
2009	20	Min	0.3	27.8	2.8	9.3
		Max	1.79	590	70	208
		Mean	0.80	149.8	17.1	63.5
		SD	0.39	120.8	14.4	45.2
2010	20	Min	0.36	75.4	8.5	24.2
		Max	1.18	480	55	172
		Mean	0.67	216.7	24.6	80.6
		SD	0.24	102.2	11.5	39.9
2011	20	Min	0.3	104.9	12.2	43.7
		Max	0.82	1200	140	400
		Mean	0.49	497.0	57.0	174.6
		SD	0.20	327.6	36.9	100.8
2012	20	Min	0.1	144.3	17.5	58.0
		Max	0.97	2400	300	779
		Mean	0.28	1029.9	126.5	362.8
		SD	0.26	626.0	77.6	200.9

* PCB 6 is calculated as the sum of PCB 28, 101, 118, 138, 153 and 180. CB 52 was not detected in any sample and, as the detection limits were high, CB 52 was not included in the calculation of Sum PCB. For other congeners, when results were reported as below the detection limit, half of the detection limit was used in the calculation.

Table 7.15 Organochlorine pesticides in Arctic char muscle (µg/kg of lipids). Corrected for lipid re-analyses as in Table 7.14

Year	n		p,p'– DDE	alpha-chlordane*	cis-nonachlor*	hexachloro benzene	Mirex*	oxychlordane*	trans-nonachlor*	Parlar no. 26*	Parlar no. 50*
2007	13	Min	13.0	2.30	1.40	9.7	1.10	2.10	3.50	1.9	5.2
		Max	79.0	7.00	7.00	35.0	2.70	4.50	17.0	6.6	18.0
		Mean	47.5	4.19	3.96	17.7	2.07	3.11	9.08	4.13	10.1
		SD	16.4	1.62	1.55	6.6	0.55	0.80	3.8	1.59	4.6
2009	20	Min	4.76	0.68	0.68	4.1	0.68	0.68	1.36	0.68	1.74
		Max	90	13	11	51	5	11	26	16	36
		Mean	23.1	4.52	2.73	32.7	1.93	3.62	6.78	5.2	12.1
		SD	19.5	2.98	2.51	14.3	1.21	2.34	5.6	3.7	7.8
2010	20	Min	2.97	0.85	0.85	2.5	0.85	0.85	1.0	0.85	2.12
		Max	79	9.4	7.7	54	3.5	8.5	19	9.8	25
		Mean	29.0	4.28	2.94	26.0	1.94	4.09	8.02	4.7	11.6
		SD	25.4	2.98	2.1	19.5	0.87	2.95	5.6	3.4	8.5
2011	20	Min	24.4	1.22	1.22	8.54	1.22	0.025	1.22	1.22	1.22
		Max	160	13	10	56	4.5	4.5	26.0	16	35.0
		Mean	75.1	5.02	4.67	33.9	3.07	3.01	13.09	6.2	13.2
		SD	40.1	3.37	2.89	17.3	1.19	1.40	7.2	4.6	10.9
2012	20	Min	20.62	1.37	1.37	3.43	1.37	0.025	1.37	1.37	1.37
		Max	230.0	12	16.0	58.0	10	10	41.0	14.0	35.0
		Mean	138.1	7.37	7.94	39.8	6.14	6.07	23.0	7.80	17.66
		SD	65.6	3.54	4.32	16.6	3.41	3.52	11.8	4.00	9.86

*Some individual results were lower than the detection limit. When analytical data reported as lower than the detection limit were used in calculations of the mean value, half of the detection limit was used.

POPs in Arctic char appeared to be at the same level from 2002 to 2007, with the exception of hexachlorobenzene which was at the same level in 2002 and 2007 but significantly higher in 2005 (Figure 7.12).

In the 2012 Arctic char samples, both PCB 153 and p,p'-DDE, were significantly higher than in the previous years. Hexachlorobenzene was more or less stable from 2007 to 2011, but in 2012 the concentration increased towards the 2005 level. p,p'-DDE and PCB 153 occured at approximately twice the concentration in 2012 than in previous years.

Several of the samples from 2009 to 2012 have been re-analysed for lipid content due to a very low lipid concentration in the Arctic char muscle. The low lipid concentration could confer uncertainty in the results presented here for 2012, but this would also be the case for the 2011 samples, and cannot explain the higher PCB and p,p'-DDE concentrations in 2012 than in 2011. It is more likely that the explanation for the elevated 2012 concentrations shall be found in other factors like fish age, fish feed and possibly in climate conditions.

In Figure 7.13 three boxplots are presented. The first panel shows the Fulton condition index, and although the median condition index was somewhat lower in 2012 than in 2011, the fish length and age (middle panel in Figure 7.13 and Table 6.9) and muscle lipid content (Table 7.14) in 2011 and 2012 were similar, and thus cannot account for a doubling in POPs concentrations. Also, the tendency for a lower d15N enrichment as seen in the right panel in Figure 7.13 would imply that fish sampled in 2012 were feeding at a slightly lower trophic level than fish sampled in 2010 and 2011. The enrichement of d15N is normally regarded as an indicator of trophic level, in such a way that a shift in approx. 3-4‰ of d15N would be equivalent to a one-tier shift. The present data do not support a hypothesis of increasing POPs concentration with higher d15N enrichement. On the contrary- in the eight years for which both stable isoptopes data and PCB data were available for this population, only in two (2007 and 2010) were d15N significanty correlated to CB153 and then with an inverse relation, such that an increase in d15N would correlate to a decrease in CB153.

A closer look at the data from 2000 to 2012 indicates that there was a statistically significant (least squares regression, $p < 0.05$) negative relationship between the Fulton condition index and CB 153 concentration from 2000 to 2007, but not in the period 2009 to 2012. In samples from 2007 to 2012, fish age was normally not correlated to CB 153 either, and this is well in line with the observed trend.

It appears that the explanation for the increase in POPs concentration must be sought in ecosystem factors not accounted for in the simplistic models used above, like for instance those which take heed of climate. The Office of Public Works (*Landsverk*) operates a weather station placed within a few kilometers and at similar elevation as the lake á Mýranar, and some climate data are available for this site. The data reveal that there was heavy precipitation in the period between the 2011and 2012 Arctic char samplings events, with a 2011 annual sum precipitation of 3226 mm and 2189 mm in 2012. Unfortunately, precipitation data for this site is not available for earlier years, and a possible link between POPs in fish and precipitation remains a possibility which cannot be further elucidated without access to more data.

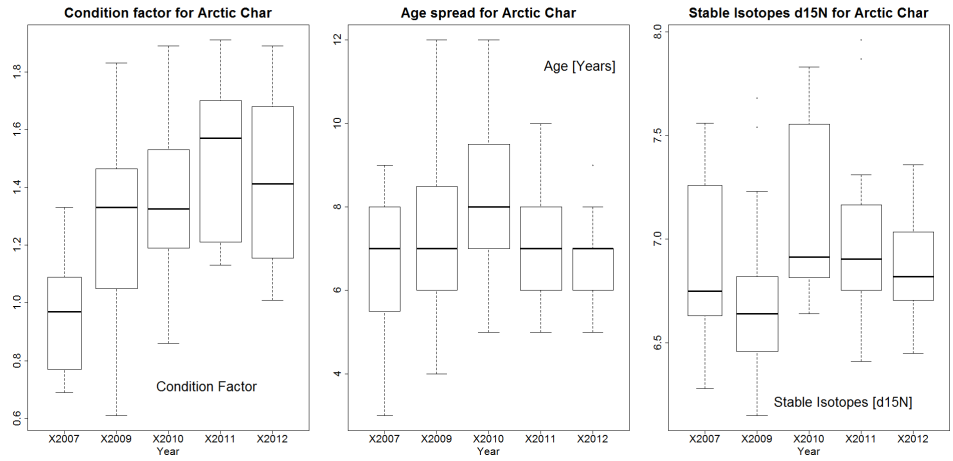

Figure 7.13 These boxplots show the Arctic char 2007-2012 samples condition index, fish age and fish muscle stable isotopes (d15N) enrichment.

7.6 Sheep

Sheep, both ewes and lambs, were analysed for POPs in pooled samples from 2008, 2009 and 2011, see Appendix 5. In 2008 and 2009, for samples analysed at CTQ, PCBs other than CB 153 and 180 could not be detected in any sample, at detection limits around 0.4-0.5 µg/kg of lipids. CB 153 was detected at concentrations from 0.5 to 1.3 µg/kg of lipids, and CB 180 was detected in one sample at 0.46 µg/kg of lipids. In sheep samples from 2011, the same overall picture as in 2008 and 2009 samples was seen for three of the four pooled samples; although one sample (Oa-2011-10) stood out with a hundredfold higher PCB concentration (then as Aroclor 1260). Since this same sample did not contain elevated concentrations of pesticides, it is likely that the sheep in this pool had been grazing in the vicinity of PCB-contaminated soil. Apart from HCB, chlorinated pesticides were generally not detected in sheep samples at detection limits defined in the Tables in Appendix 5.

When analysing the same 2009 samples at another laboratory, CB 153 results from CTQ were generally confirmed, but at somewhat higher concentrations, with 16% higher concentrations at ALS than at CTQ (when comparing calculated freshweight-based data for the two datasets). In addition to PCB, the ALS laboratory also analysed a range of pesticides: pentachlorbenzene*, hexachlorbenzene*, alpha, beta and gamma-HCH, aldrin, dieldrin, endrin, isodrin*, telodrin, heptachlor, cis-and trans-heptachlorepoxide, the six isomers of DDT, alpha-endosulphan, hexachlorobutadien and hexachloroethan; none of these were detected at 0.005 mg/kg tallow, except the compounds marked with an asterisk above, which were not detected at 0.002 mg/kg tallow. Interestingly, this is one of very few datasets describing the concentration of pesticides like dieldrin and aldrin, for which the Codex Alimentarius MRL for meat from mammals, excluding marine mammals, is 0.2 mg/kg lw.

That HCB could not be detected at 0.02 µg/kg is somewhat in disagreement with the results from CTQ. At CTQ HCB in the same samples was reported to be between 3 and 5 µg/kg tallow (calculated from lipid-based data, and measured lipid %, see Appendix), which equates to more than a 100% discrepancy in analysis outcomes from the two laboratories. The concentration of HCB is, however, low and close to the detection limit for analyses at ALS, apparently, when the concentration is close to the detection limit, there is a tendency for the concentration to be underestimated.

8 PFC results

8.1 Pilot whale

In an earlier study, a partial time series for PFC in pilot whale liver samples from the Faroe Islands was established. The results indicated that PFOS had peaked at the turn of the millennium, whereas longer C-chain homologues continued to increase until 2006 (Dam *et al*., 2011). In order to evaluate the existence of a possible trend in more detail, it was decided to prolong the time series and fill in any gaps. To do so, however, it was necessary to analyse muscle tissue rather than liver tissue, because muscle samples were available for more years than liver samples, and a denser time series could thus be established. Pilot whale muscle from 33 juvenile males sampled in the period 1986 to 2010 was analysed for thirteen different perfluorinated carbon compounds, PFCs. The analysed compounds were perfluorinated C-4, C-6, C-8 sulphonates, perfluorinated C-6,7,8,9,10,11, 12, 13 and 14 carboxylic acids. The full dataset is given in Attachment 4. PFOS were detected in every sample, and PFUnDA in 25, whereas PFNA, PFDA and PFDoDA were detected in ca. every third sample. PFOS occurred in highest concentration. The next highest concentrations were found for PFUnDA. Plots of the time trends of PFOS and PFUnDA in pilot whale muscle are shown in Figure 8.1 and Figure 8.2. The PFOS data series show no linear trend (PIAW), but the PFUnDA data series show a 5.6% yearly increasing trend ($p < .001$; PIAW). For the statistical analyses of PFUnDA, the analyses results (n= 4) reported as less than the DL were deleted.

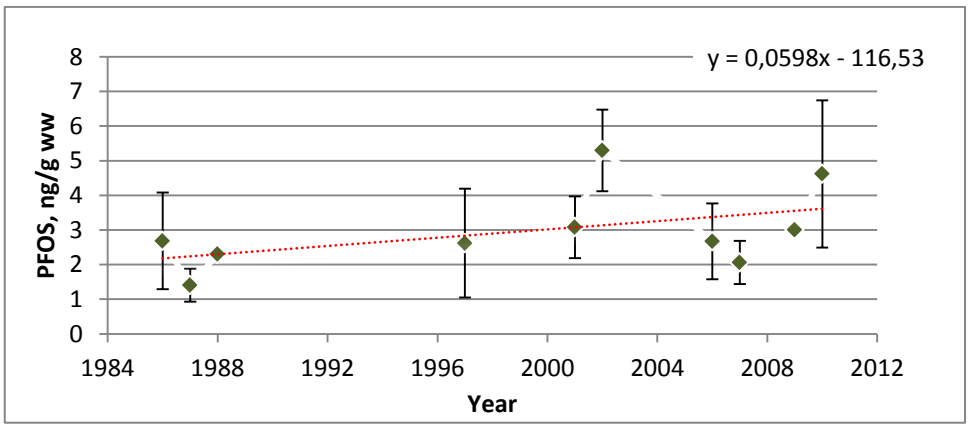

Figure 8.1: PFOS in juvenile male pilot whale muscle, in ng/g ww.

In addition, a pilot study on the correlation between PFCs in pilot whale muscle vs. liver samples was conducted on six individuals (Attachment 4). The results showed the concentration of PFCs in liver to be ca. 23 times higher than in muscle, with a relative standard deviation in liver of 22% and in muscle of 13%. The four PFCs occurring in highest concentrations were PFOS > PFUnDA > PFTrDA > PFDoDA, in both muscle and liver samples. However, the concentration of these compounds between liver and muscle tissue were not correlated.

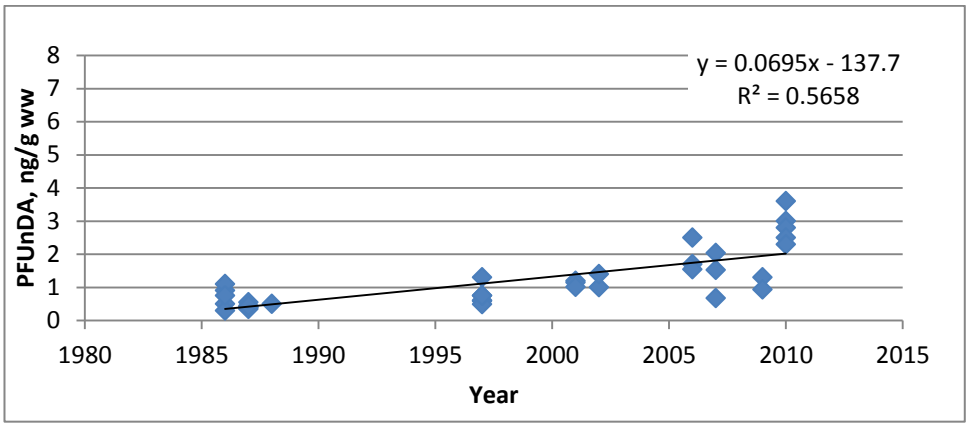

Figure 8.2 PFUnDA in juvenile male pilot whale muscle, in ng/g ww. In drawing the figure, analyses results reported as "less than" the DL, have been assumed to be equal to that DL. The DLs were in the range 0.3 to 0.75 ng/g ww.

In pilot whale muscle, the ratio between PFOS and PFOA was 30/4 ng/g ww, i.e., 7-8 fold higher concentration of PFOS than PFOA, while in liver samples the ratio was 58.3/0.2 ng/g ww, i.e., 290 times higher concentrations in liver than in muscle. Note that this is only based on six whales, and must therefore be viewed with caution. The concentration of PFOS decreased in the newest samples, while the PFOA remained stable or increased slightly, thus the PFOS/PFOA ratio has decreased. In muscle samples, the concentrations and ratios are more stable. This could support the hypothesis that PFOS availability has decreased, but could also be due to the fact that contamination concentrations vary among schools of pilot whales.

8.2 Sheep

Sheep liver samples from 2008 and 2009 were analysed for PFAS (Attachment 5). Pooled samples of ewes and lambs were analysed, and the PFOS concentrations were in the range of 0.9-1.3 ng/g ww liver, with no apparent difference between age groups. The four PFCs occurring in highest concentrations were PFOS ≈ PFUnDA > PFDA ≈ PFNA, whereas the other nine PFCs were either not quantified (PFBuS, PFHxA) or not detectable at 0.2 to 0.75 ng/g ww liver. In Figure 8.3 are given different PFCs; no trend can be obtained due to the few number of samples.

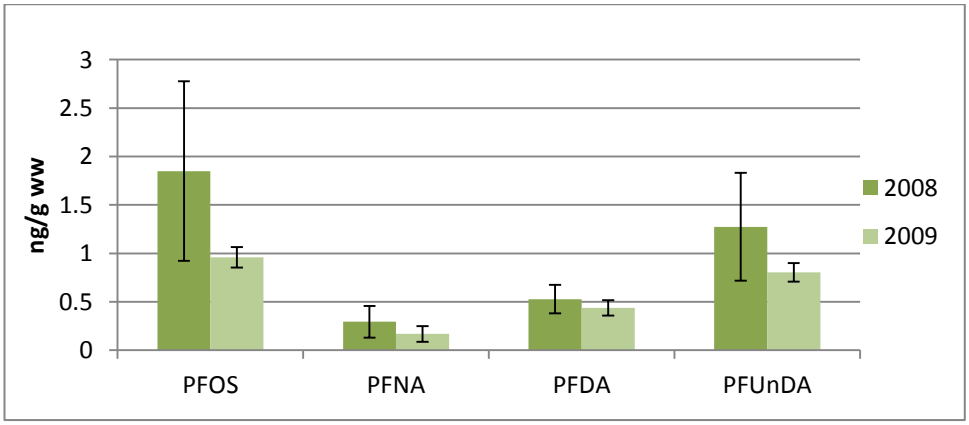

Figure 8.3 Mean levels (ng/g ww) and standard deviations of PFOS, PFNA, PFDA and PFUnDA in sheep liver.

9 Stable isotopes

The ratios of heavier to lighter isotopes of nitrogen and carbon can be used to examine the trophic relationship in food webs (Hobson and Welch, 1992). The heavier isotopes are enriched in animal tissue relative to diet, with the enrichment factors between tissue and diet being about 1‰ for the ^{13}C isotope and 3‰ for the ^{15}N isotope (Sagerup *et al*., 2002; Fry, 1988). In the following, the isotope numbers are written in normal font numbers.

Tissue samples of pilot whale muscle, Arctic char muscle and black guillemot eggs were analysed for the fraction of stable isotopes of nitrogen (15N/14N) and carbon (13C/12C) at SINLAB in Canada.

The enrichment of the heavier isotopes is described by d15N and d13C, respectively, which are calculated as follows:

$dX = [(R_{sample}/R_{standard}) - 1] *1000$

where X is 13C or 15N and R is the corresponding ratio 13C/12C or 15N/14N in the sample and in the standard, respectively. The standard materials used are described in Chapter 4.1.3.

9.1.1 Results

The lipid level in the samples was highly variable. This has an influence on the C/N ratio as 13C is discriminated against during lipid synthesis, leading to higher C/N ratio and lower d13C level when the lipid content is high. To avoid lipid discrimination towards d13C, normalization of d13C (d') was carried out using estimated lipid content (L) according to the formula from McConnaughy & McRoy, 1979.

$L = 93/[1+(0.246C/N-0.775)^{-1}]$

$d' = d+D[-0.207+3.90/(1+287/L)]$

where L is % lipid, C/N is the carbon to nitrogen ratio in muscle and D is the depletion of 12C (‰) relative to protein and assigned a value of 6‰ (Sagerup *et al*., 2002; McConnaughy & McRoy, 1979).

The d15N values versus normalised d13C' are shown in Figure 9.1 to Figure 9.4, and summary data for the analysed species are given in Table 9.1 to Table 9.3. Table 9.4 gives a summary of pollutants chosen for correlation analyses to stable isotopes.

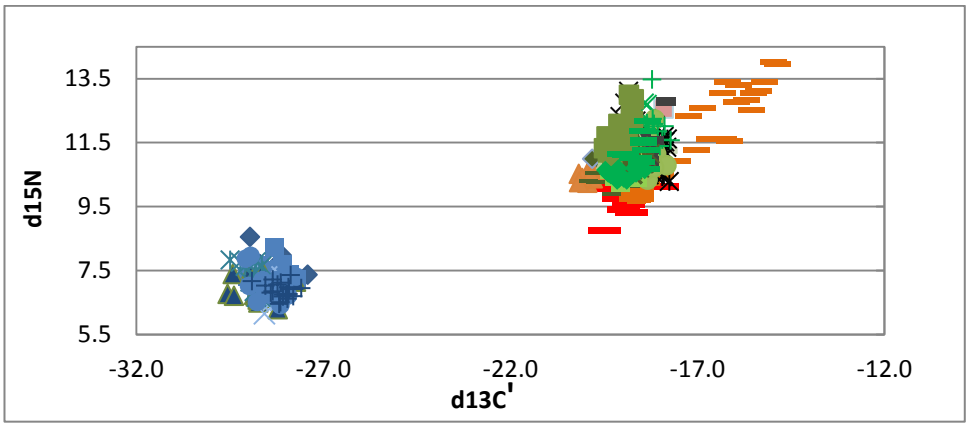

Figure 9.1 d15N versus d13C' (normalised) in Arctic char muscle, black guillemot eggs and pilot whale muscle. Arctic char legends are blue, black guillemot legends are orange and pilot whale legends are green.

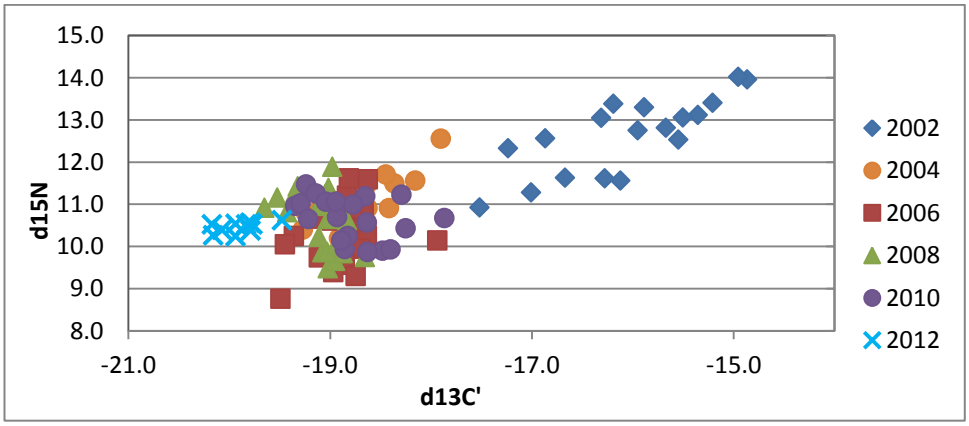

Figure 9.2 d15N versus d13C' (normalised) in black guillemot eggs collected in 2002, 2004, 2006, 2008, 2010 and 2012.

Table 9.1 Stable isotopes in black guillemot eggs.

Year	n	d13C'				d15N			
		Min	Max	Mean	SD	Min	Max	Mean	SD
2002	17	-17.52	-14.87	-16.06	0.75	10.93	14.02	12.63	0.88
2004	17	-19.27	-17.90	-18.71	0.81	10.19	12.55	11.07	0.82
2006	20	-19.49	-17.94	-18.87	0.32	8.76	11.61	10.39	0.74
2008	20	-19.65	-18.65	-19.09	0.23	9.48	11.89	10.62	0.68
2010	20	-19.35	-17.87	-18.79	0.38	9.87	11.47	10.66	0.50
2012	10	-20.17	-19.48	-19.89	0.20	10.24	10.62	10.46	0.12

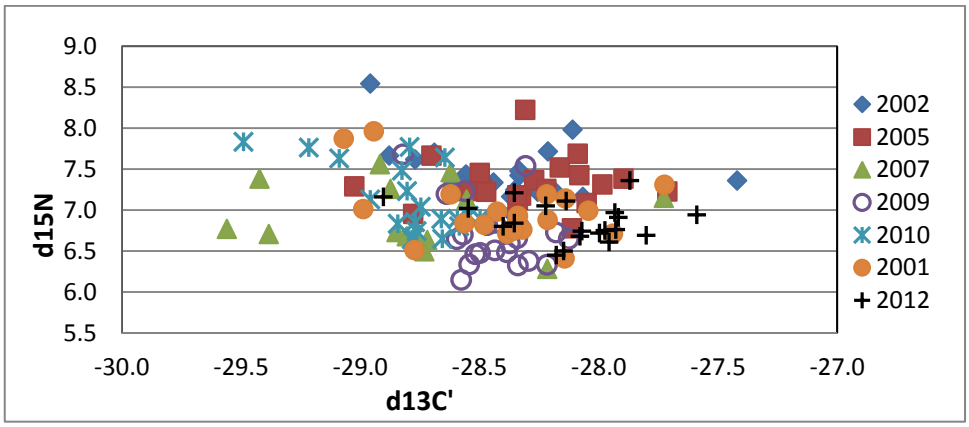

Figure 9.3 d15N versus d13C' (normalised) in muscle from Arctic char caught in 2002, 2006, 2008, 2010 and 2012.

Table 9.2 Stable isotopes in Arctic char muscle.

Year	n	d13C'				d15N			
		Min	Max	Mean	SD	Min	Max	Mean	SD
2002	20	-28.96	-27.42	-28.39	0.3192	6.82	8.54	7.41	0.378
2005	20	-29.02	-27.71	-28.30	0.3017	6.78	8.22	7.32	0.288
2007	13	-29.56	-27.73	-28.79	0.4571	6.28	7.56	6.92	0.384
2009	20	-28.82	-28.12	-28.44	0.1639	6.15	7.68	6.70	0.394
2010	20	-29.49	-27.50	-28.80	0.2319	6.64	7.83	7.11	0.404
2011	20	-29.07	-27.72	-28.40	0.3408	6.41	7.96	6.99	0.377
2012	20	-28.90	-27.59	-28.12	0.2852	6.45	7.36	6.86	0.233

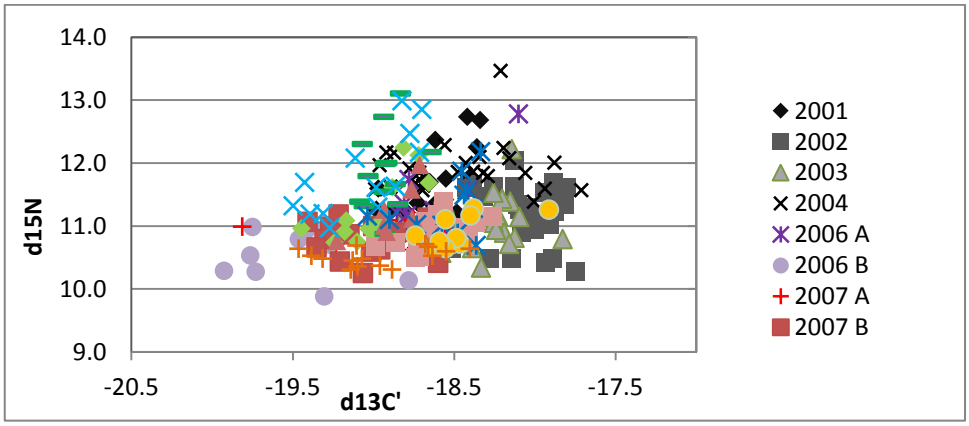

Figure 9.4 d15N versus d13C' (normalised) in muscle from pilot whale caught in 2001, 2002, 2003, 2004, 2006, 2007, 2009, 2010, 2011 and 2012. Letters A and B denote different schools.

Table 9.3 Stable isotopes in pilot whale muscle

Year	n	d13C'				d15N			
		Min	Max	Mean	SD	Min	Max	Mean	SD
2001	25	-18.98	-18.34	-18.64	0.1690	10.62	12.73	11.42	0.5435
2002	24	-18.51	-17.75	-18.06	0.2027	10.28	12.04	11.19	0.4768
2003	25	-19.29	-17.83	-18.42	0.3062	10.34	12.22	11.05	0.3440
2004	25	-18.99	-17.71	-18.46	0.3590	11.39	13.47	11.92	0.3865
2006 A	15	-18.93	-18.10	-19.45	0.1930	10.83	12.78	11.26	0.4629
2006 B	10	-19.92	-18.78	-19.45	0.3086	9.88	10.98	10.57	0.3559
2007 A	11	-19.81	-18.56	-18.89	0.3439	10.72	11.10	10.89	0.1224
2007 B	13	-19.41	-18.60	-19.07	0.2366	10.25	11.18	10.78	0.2782
2009 A	12	-19.45	-18.66	-19.01	0.2098	10.74	12.25	11.21	0.5047
2009 B	13	-19.08	-18.64	-18.93	0.1157	10.87	13.10	11.86	0.5910
2010 A	17	-18.99	-18.26	-18.60	0.1782	10.49	11.39	10.87	0.2360
2010 B	8	-19.22	-18.71	-18.87	0.1612	10.76	11.97	11.20	0.3739
2011 A	13	-19.50	-18.70	-19.06	0.2753	10.97	12.99	11.81	0.6301
2011 B	11	-19.04	-18.33	-18.55	0.2232	10.69	12.18	11.30	0.4233
2012 A	10	-18.74	-17.91	-18.47	0.2118	10.65	11.28	10.93	0.2376
2012 B	15	-19.46	-18.40	-18.96	0.3092	10.31	10.71	10.52	0.1335

Table 9.4 Mean values and correlation coefficients for isotopes and selected pollutants from black guillemot eggs.

Year	n	Annual mean values					
		d15N	d13C'	p.p'DDE	PCB153	Hg	Aroclor
2002	17	12.69	-16.06	554.12	582.35	0.4	4335.29
2004	17	11.07	-18.71	374.41	855.71	0.48	5947.06
2006	20	10.39	-18.87	338	524	0.58	3910
2008	20	10.62	-19.09	300	453.68	0.65	3163.16
2010	20	10.66	-18.79	187	371.5	0.66	2545
2012	10	10.46	-19.89	156.27	357.27		2463.64
Spearman and Pearson correlation to d15N (all years)							
	r_s		0.48	0.38	0.32	0.05	0.36
	r_p		0.78	0.29	0.16	-0.06	0.18
Spearman and Pearson correlation between annual averages (aa) of d15N and pollutants (all years)							
	$r_{s\ aa}$		0.83	0.60	0.54	-0.7	0.54
	$r_{p\ aa}$		0.95	0.84	0.35	-0.85	0.40

9.1.2 Discussion

Previous studies, such as Hussey *et al*. (2014), have shown a clear relationship between changes in d15N and changes in trophic position. Thus, a correlation between enrichment of d15N and concentration of biomagnifying pollutants should be expected since isotope levels are considered to be good indicators of trophic position.

Sculpin (*Myoxocephalus scorpius*) were analysed at an earlier stage in the AMAP Faroe Islands Programme, and the average enrichment of d15N in muscle tissue from this species (from 2004; n = 24) was found to be 14.56‰, with a range from 13.16‰ to 16.05‰ (Hoydal and Dam, 2005). In the recently analysed tissue from pilot whale, black guillemot and Arctic char, the latter species clearly differed from the first two (Figure 9.1). The enrichment of d15N in muscle tissue in Arctic char was 7.05‰ on average for the period 2002-2012, with a mean range of 6.7±0.4‰ in 2009 to 7.4±0.4‰ in 2002 (Table 9.2). The enrichment of d15N in pilot whale and black guillemot eggs was markedly higher than in Arctic char (Figure 9.1). Pilot whales and black guillemot eggs were rather similar,

except that the black guillemot eggs appeared to have a larger range of both d13C' and d15N enrichment compared to pilot whales.

The increase in d15N was highly correlated to that of d13C' when all datasets from the three species pilot whale, black guillemot and Arctic char were considered simultaneously (Spearman rank correlation, two-tailed, r_s = 0.75, p<0.005). When the increments in d15N vs. d13C' were considered for each species separately, a correlation was found in the black guillemot eggs data (Spearman rank correlation, two-tailed, r_s = 0.45, p<0.01), but no correlation was seen in the datasets for Arctic char muscle (Spearman rank correlation, two-tailed, r_s = -0.14, p>0.1), and there was a low/small correlation in pilot whale muscle data (Spearman rank correlation, two-tailed, r_s = 0.24; 0.05 < p <0.1).

There is a clear time trend in the d15N enrichment for black guillemot eggs; Figure 9.2 shows a decreasing trend. The decreased d15N enrichment observed in recent years indicates a dietary shift towards a lower trophic level. The occurrence of a reduction in PCB concentration over a given time period (Figure 7.1) could thus be the result of a shift in the food items taken. Correlation analyses, however, do not support such a trophic shift as the sole explanation for the observed decrease in PCB concentration in black guillemot eggs, as there was no significant correlation between d15N and CB 153 (used as a proxy for PCB).

When considering black guillemots eggs (Table 9.4), the correlation between normalized d13C' and d15N was found to be very high. The high correlation value indicates a significant linear relationship between the two (Pearson rank correlation, two-tailed, r_p = 0.78; p <<0.01, rejecting the null hypothesis). The linear relationship between d13C' and d15N particularily in the 2002 samples can be observed in Figure 9.2. Furthermore, the relationship between isotopes and persistent pollutants was investigated. Generally, for all the persistent pollutants investigated no significant correlation was seen between stable isotopes enrichment and pollutant level (Table 9.4).

Reducing the number of points to only including the average of annual averages for correlation analysis improved the correlation to d15N for all pollutants (Table 9.4). This improvement suggests that other factors regarding a change in pollution levels are reduced, and that the trophic position becomes more important. More realistically, this is probably caused by the reduction of data points in the analysis.

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