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DANCEA
Danish Cooperation for Environment in the Arctic
Ministry of Environment

Content

Introduction

In 1989 a conference on protection of the Arctic environment was held in Rovaniemi with participation of all eight circumpolar countries (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and USA). This was the start of the "Rovaniemi" process, continuing with the First Arctic Ministerial Conference in 1991, as an important step in the international cooperation for the protection of the Arctic, leading to the adoption of the Arctic Environmental Protection Strategy (AEPS).

Some of the objectives of the AEPS are:

- to protect the Arctic ecosystems, including humans
- to review regularly the state of the Arctic environment
- to identify, reduce and as a final goal, eliminate pollution.

Different work groups have been formed to implement the AEPS objectives. One of the initiatives is the Arctic Monitoring and Assessment Programme (AMAP).

The Arctic region represents one of the last frontiers of relative pristine nature but also an area vulnerable to pollution. However, results from AMAP's first phase (1994-1996) have shown that pollutants originating from anthropogenic activities at mid-latitudes are transported to the Arctic by atmospheric processes, ocean currents and rivers. Some of these pollutants accumulate in the Arctic environment.

AMAP's responsibilities are to monitor the levels and assess the effects of anthropogenic pollutants in all compartments of the Arctic environment (atmospheric, terrestrial, freshwater and marine environments, and human populations with respect to human health).

The work of AMAP has so far focused on three priority pollutants: persistent organic pollutants (POPs), heavy metals, and radioactivity. Each country has defined its own national implementation plan to meet the AMAP monitoring requirements.

Very few monitoring programmes existed in Greenland, when the international AMAP programme was adopted. To fulfil participation in the international AMAP programme Denmark initiated a national AMAP programme covering all the selected compartments and the priority pollutants in different parts of Greenland and in the Faroe Islands. The national AMAP programme has been funded by the Danish Environmental Protection Agency since 1994 as part of the environmental support program Dancea – Danish Cooperation for Environment in the Arctic.

The results from the first phase of the national AMAP programme were inter alia published in:
"AMAP Greenland 1994-1996" (Environmental Project No. 356, 1997).
"AMAP Greenland 1994-1996, Data Report" (Working Report No. 29, 1997).

AMAP's first scientific circumpolar assessment was published in: "AMAP Assessment Report: Arctic Pollution Issues" Oslo 1998.

The present report is one of four containing the results and assessment of data from the second phase (1997-2002) of the national AMAP programme in Greenland and the Faroe Islands. The four reports are compilations of a number of chapters written by different authors from several institutes. The four volumes are:

Vol. 1: Human Health.
Vol. 2: The Environment of Greenland.
Vol. 3: The Environment of the Faroe Islands.
Vol. 4: Data Report.

Besides these reports scientific international AMAP Assessment reports covering the circumpolar region are prepared.

Preface

The present report is part of the national contribution to the international Arctic Monitoring and Assessment Programme, AMAP, for its second phase 1997- 2002. The report is a collection of manuscripts written by project-teams which have been involved in describing the environment of the Faroe Islands during he entire 5 year period or during parts of it. Responsible for the collection of these manuscripts were the project-team at the Food and Environmental Agency who have been actively taking part in the AMAP program since 1997.

1 Atmospheric Mercury and Lead Accumulation Since 5420 14C yr BP at Myrarnar, Faroe Islands

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Summary and conclusions

Our findings suggest that the natural background flux of Hg to the Faroe Islands was always elevated, compared to continental bogs. Superimposed on these elevated natural fluxes, however, is a much greater Hg flux in recent samples (past two centuries) which is dominated by Hg from anthropogenic emissions. This interpretation is based on measurements of Hg concentrations, the Hg/Se ratios, Pb and stable Pb isotopes (^{204}Pb, ^{206}Pb, ^{207}Pb, and ^{208}Pb), and ^{210}Pb age dating. These conclusions, however, should be verified using at least one more peat core from another site on the Faroe Islands. For example, the peat core which we collected at Klovinmyren is certainly suitable to evaluate in more detail the pre-anthropogenic relationship between Hg, volcanic ash falls, and Se deposition since ca. 9,000 ^{14}C yr BP. Selenium shows great promise as a reference element for atmospheric Hg deposition in maritime locations, and in this context the geochemistry of Se in blanket peat bogs requires and deserves further study.

The large total mercury peak (498 ng Hg/g dry weight) at Myrarnar occurs between a depth of 5cm and 6cm. We can not explain this concentration by any geochemical mechanism or natural input. It is therefore our opinion that this is an anthropogenic signal. We will better be able to quantify the flux amounting from this signal with more detailed dating. Based on analysis of the Hg/selenium ration (a 17 time increase since the start of the industrial age), we expect that the mercury flux increased by the same amount. We cannot however, draw any conlusions at this time from our study as to whether the source of mercury is local, regional or from long transport.

Our data also suggest that Hg fluxes in other maritime locations such as NW Scotland and the Shetland Islands, warrant detailed investigation.

Finally, the long-term atmospheric deposition of natural Hg combined with the recent addition of Hg from anthropogenic sources may have lasting consequences for local ecosystems. The inventories and dynamics of Hg transformations in local soils and sediments also deserve attention.

1 Atmospheric Mercury and Lead Accumulation Since 5420 ^{14}C yr BP at Myrarnar, Faroe Islands

Concern has been expressed about the concentrations and chemical speciation of Hg in the food chain on the Faroe Islands, and the possible implications of these for human health. It is unclear how much of the present day Hg flux is from anthropogenic emissions, and how much from natural sources. The main goal of our study was to reconstruct a long-term record of atmospheric Hg accumulation, and to try to determine how much of the Hg flux is natural, and how much from anthropogenic sources.

A peat profile monolith ca. 15 x 15 x 75 cm was collected from a blanket bog at Myrarnar, on the Island of Streymoy, Faroe Islands. The core was cut into slices of 1 cm and analyzed for total concentrations of Hg and 19 additional major and trace elements, including Pb. Mercury concentrations were measured in solid samples using the Leco 254 Hg analyser which combusts the samples in an oxygen stream, traps the Hg onto gold, and measures Hg after thermal desorption using AAS. Lead and other trace elements, including Se, were measured in solid samples using non-destructive energy dispersive XRF. In addition, the isotopic composition of Pb, often used to fingerprint anthropogenic Pb sources, was measured in acid digests of selected samples using multicollector ICP-MS. A radiocarbon age date of the last sample of the core (ca. 75 cm) dates the profile at 5420 ^{14}C yr BP.

The vertical distribution of Hg at Myrarnar suggests that the surrounding rocks and soils have not contributed significantly to the Hg inventory of the peat core, but rather that Hg was supplied primarily, if not exclusively, by atmospheric deposition. The peat core contains abundant, visible grains of mineral matter, most likely emitted from Icelandic volcanoes which are often thought to be an important natural source of Hg. While some of the discrete volcanic events found in deeper peat layers appear to have affected the supply of Hg at some times in the pre-historical past, the pronounced peak of highly elevated Hg concentrations (up to 700 ng/g) is difficult to explain by natural emission sources alone. This peak is found at a depth of only 5 cm beneath the top of the peat core which suggests that it must be recent. The maximum Hg concentration in this core exceeds by a large margin the maximum concentrations of Hg found at all of our other study sites (Switzerland, Scotland, Shetland Islands, Denmark, southern and northern Canada, and Greenland). Measurements of Hg in selected peat samples from this core using an independent method (atomic fluorescence spectroscopy of acid digests) at the University of Maine provided identical concentrations. The high Hg concentrations at the surface of the peat bog, however, partly reflect the relatively slow peat accumulation rate (only 10 cm of peat has accumulated during the past two centuries). More important than the Hg concentrations, the **rate** of atmospheric Hg accumulation to this site requires quantification. This Hg flux, however, requires a detailed reconstruction of

the peat accumulation rates, and this will only be obtained once the high resolution age dating (^{14}C) has been completed.

The greatest Hg concentrations in the peat profile are found in the uppermost 10 cm which, according to the ^{210}Pb chronology, represents the past two centuries of peat accumulation. In an effort to quantify the *enrichment* of Hg, we have used Se as an reference element which is also supplied primarily from the atmosphere. Assuming that Se is supplied exclusively by natural atmospheric sources, is effectively retained in the peat column, and is residually enriched as the plant matter is slowly decomposed to peat, we use the Hg/Se ratio to try to distinguish natural from anthropogenic Hg. The Hg/Se ratio was found to be remarkably constant (0.08 ± 0.02, n=54) for nearly six thousand calendar years until it began a pronounced increase in the top 10 cm of the profile, reaching a maximum of 1.32 (17 times the longterm average value). Based on the ^{210}Pb chronology, this enrichment dates from the Industrial Period, and reached its maximum extent ca. AD 1935; this is consistent with the unpublished chronologies of Hg enrichment in peat bog profiles from Scotland and the Shetland Islands, and comparable with recently published chronologies from peat bogs in Denmark and southern Greenland.

The subsurface peat layer is also highly enriched in Fe (up to 9 % by weight), but the changes in Hg concentrations clearly preceed and predate the changes in Fe concentration. The porewaters are expected to have a pronounced concentration gradient with respect to Fe(II) which could drive the Fe accumulation (by oxidation to Fe(III) in the oxic surface layers), but the Hg concentration profile would be expected to drive Hg in the opposite direction. Thus, it is difficult to attribute the elevated Hg concentrations to chemical processes operating at the oxic/anoxic boundary. In addition, the vertical distribution of Pb EF (enrichment factor calculated using Ti as a conservative reference element) shows that Pb too, becomes enriched in the peat profile, below, and pre-dating, the changes in Fe concentrations. Thus, shapes of the Hg/Se and Pb EF profiles argue that the Hg and Pb concentration profiles reflect the chronology of atmospheric Hg and Pb deposition, and are not simply artefacts of chemical diagenesis.

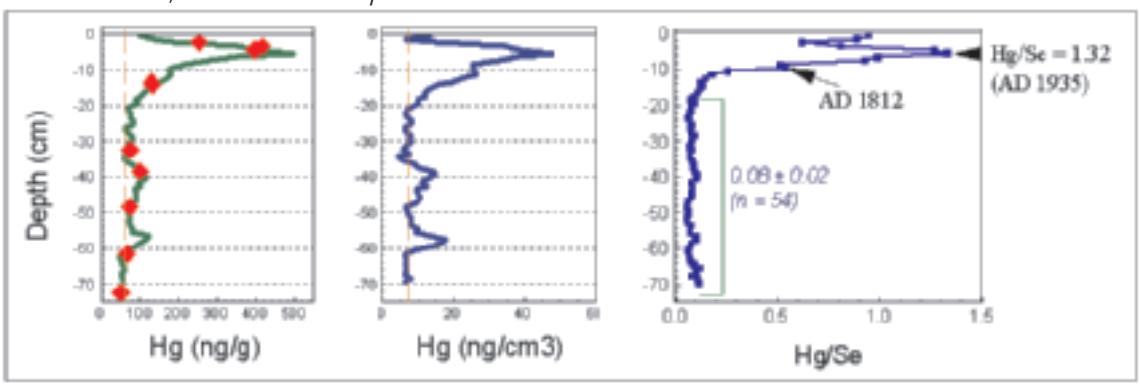
The isotopic composition of Pb in the peat profile supports this interpretation. In fact, the isotopic composition of Pb shows pronounced gradients which suggest that mixing by advection or diffusion have been negligible. Moreover, the minimum $^{206}Pb/^{207}Pb$ ratio (1.1349 ± 0.0029) is found in a peat sample dating from 1985. In fact, the variation in Pb isotope ratios with time (as revealed by the ^{210}Pb chronology) is consistent with the chronology of the introduction, phase-out, and gradual elimination of leaded gasoline in Europe.

Taken together, the data obtained thus far suggests that the "natural background" flux of Hg to the Faroe Islands may always have been greater that the "natural background" flux of Hg recorded by continental peat bogs such as the one in Switzerland described by Roos-Barraclough et al (2002). While part of this difference may be due to volcanic Hg emissions from Iceland, there are other possible explanations. Given the correlation between Hg and Br in the continental peat bog profile (Roos-Barraclough et al.,2002), and the recent observations of BrO formation at polar sunrise and its effects on atmospheric Hg fluxes in the Arctic, it may be that the higher Br concentrations in marine aerosols contribute to a more effective oxidation and scavenging of gaseous Hg. This latter hypothesis would help to explain why

the long-term rate of atmospheric Hg accumulation recorded by the peat bog profile at Myrarnar (6.1 to 7.8 micrograms/m2/yr) is very similar to a peat bog profile from the Shetland Islands (7.9 to 9.7 micrograms/m2/yr), and why these are much higher than in Switzerland (2.0 to 2.3 micrograms/m2/yr).

A detailed report of the geochemical studies of the peat core collected at Myrarnar is in preparation, and will be submitted to an international scientific journal for publication.

Figure 1.
Gravimetric and volumetric mercury concentrations and the mercury selenium ratio of the Myrarnar (NEO) peat core sampled in May 2000 (by M. Goodsite, and W. Shotyk), and archived at the Institute of Environmental Geochemistry, University of Heidelberg. Solid lines are mercury concentrations measured in whole, air dried bulk peat samples by N. Givelet, University of Berne, using the LECO AMA-254 mercury analyser. Diamonds are mercury concentrations measured in acid digests of sub-samples by Stephen Norton using atomic fluorescence spectroscopy at the Univ. of Maine. Selenium concentrations were measured by Andriy Cheburkin, in solid peat samples using the EMMA x-ray fluorescence analyser. Notice that the Hg/Se ratio in the sample dated 1935 (using 210-Pb)was 1.32. In contrast, the pre-industrial long term average value for Hg/Se in all of the samples below 20 cm, averages 0.08 +/- 0.02.



2 References

Roos-Barraclough, F., Martinez-Cortizas, A., Garcia-Rodeja, E., and Shotyk, W. (2002). A 14,500 year record of the accumulation of atmospheric mercury in peat: volcanic signals, anthropogenic influences, and a correlation to bromine accumulation. *Earth and Planetary Science Letters* 202(2):435-451.

2 Measurements of gaseous elemental mercury on the Faroe Islands

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Content

Summary and conclusions

Gaseous Elemental Mercury (GEM) has been measured on the Faroe Islands from May 2000 through March 2001. The measured data has been analysed together with basic meteorology, trajectories from the Atmospheric Chemistry and Deposition model (ACDEP model), and the modelled GEM concentrations from Danish Eulerian Hemispheric Model (DEHM). The models were subsequently used to determine the most likely source regions, which are associated with the measured concentrations. The air concentration time series shows periods with elevated mercury concentrations (>1.5 ngHg/m^3, the generally accepted global background average) which were attributed to two potential causes: local sources and long range transport. After a detailed analysis, it was determined that local sources were not responsible for the elevated levels observed, and it was further determined that the elevated levels were caused by long-range transport from Europe, most notably the UK. Explanations of concentrations lower than the global background average are discussed as well.

1 Measurements of gaseous elemental mercury on the Faroe Islands

1.1 Introduction

Mercury on the Faroe Islands is of both scientific and public concern due to the high concentrations in e.g. pilot whales and higher predators of fish, where up to 3 ppm Hg has been measured (AMAP, 1998). Furthermore, it has been shown that the present levels of mercury in sea animals have a negative effect also on the health of the local populations, when these animals are used as food supply (Grandjean et al. 1998). High concentrations of mercury have also been observed in peat cores taken on the Faroe Islands (Shotyk et al. 2001, see also Chap. 1). However, these levels cannot directly be linked to atmospheric concentrations or deposition, as the levels are not only a function of deposition but also bioaccumulation, the runoff area size and the geochemistry of the profile. It has also been discovered that trout from the Faroe Islands contain high levels of mercury (Larsen and Dam, 1999). In spite of strong indications of high mercury exposure to marine food chains and terrestrial ecosystems (implied by the core data), there has not been any study reported, which explains the sources responsible for the high mercury levels and/or how to mitigate the problem.
The aim of this study is to report a recently collected time series of atmospheric concentrations of gaseous elemental mercury (GEM) collected during roughly a one year period starting in May 2000, and to explore relationships between anthropogenic mercury source regions and deposition to the Faroe Islands. The results are compared with model calculations using the Danish Eulerian Hemispheric Model (DEHM) including scenario calculations. Furthermore trajectory calculations were carried out using the trajectory model developed for the Atmospheric Chemistry and Deposition model (ACDEP, Hertel et al. 1995).

1.2 Experimental

The measurements were performed with a Tekran Model 2537A Mercury Vapour Analyser equipped with an internal permeation source ensuring the stability of the instrument. GEM in ambient air is adsorbed on a gold trap and after sampling the adsorbed mercury is thermally desorbed and detected by Cold Vapour Atomic Fluorescence Spectrophotometry. The monitor is equipped with two gold traps, so continuous samples are taken with 5 minutes resolution, which for practical reasons were averaged to 1 hour mean values. Measurements were carried out based on the Standard Operating Procedure Manual for Total Gaseous Mercury Measurements for the Canadian Atmospheric Mercury Measurement Network (Steffen et al. 1999). The estimated uncertainty from manual calibration, collection efficiency etc. is estimated to 10 % (2 times standard deviation) for values above 1 ng/m^3. However, complications might significantly have effected the measurements in the Faroe Islands. The very high relative humidity (above 95%) may have

affected the measurements (Matthew Landis, Private communication, 2001, TEKRAN manual p. 2-1) and the high sea spray concentrations have previously been observed to effect the measurements of GEM (Ebinghaus et al. 2000).

Model calculations of the concentrations of GEM were carried out as well by the Danish Hemispheric Model (DEHM) that is a 3 dimensional eulerian model. The model is described in detail elsewhere (Kämäri et al., 1998; Christensen, 1997,1999 and Barrie et al. 2001).
In the current version the emissions of anthropogenic mercury are based on the new global inventory of mercury emissions for 1995 on a $1^{o}x1^{o}$ grid (Pacyna et. al., 2002, private communication), which includes emissions of Hg^{0}, reactive gaseous mercury and particulate mercury. There are not any re-emissions from land and oceans, instead a background concentration on 1.5 ng/m^{3} of Hg^{0} is used as initial concentrations and boundary conditions.
The chemical reaction scheme is based on Petersen et al. (1998) and includes 13 mercury species, 3 in the gas-phase (Hg^{0}, HgO and $HgCl_{2}$), 9 species in the aqueous-phase and 1 in particulate phase.
During the polar sunrise in the Arctic an additional fast oxidation rate of Hg^{0} to HgO is assumed. Inside the boundary layer over sea ice during sunny conditions it is assumed that there is an additional oxidation rate of ¼ $hour^{-1}$. The fast oxidation stops, when surface temperature exceeds $-4^{o}C$. The removals of Hg^{0} are due to the chemistry and the uptake by cloud water.
The dry deposition velocities of the reactive gaseous mercury species are based on the resistance method, where the surface resistance similar to HNO_{3} is used. Dry deposition velocities for RGM have been measured and reported from Barrow and are similar to those for HNO_{3} (Lindberg et al, 2002). The wet deposition of reactive and particulate mercury is parameterized by using a simple scavenging coefficients formulation with different in-cloud and below-cloud scavenging coefficients (see Christensen, 1997).

1.3 Site

The monitor was set up on the east part of Tórshavn, the capital on Faroe Islands, located 62^{o}01'N and 6^{o}47'W. This location is approximately 400 km north of Scotland, 600 km west of Norway and 500 km east of Iceland. The monitor was placed in a residential area. Because of this location, we tested the influence of possible local sources by examining the time series based on wind direction and concentration. Our results did not show any correlation between these quantities, both during quiescent periods and during episodes, thus allowing us to conclude that any local sources were insignificant.

1.4 Results

The results of the one year of measurements, i.e., from May 2000 to March 2001, of GEM are shown in figure 1.

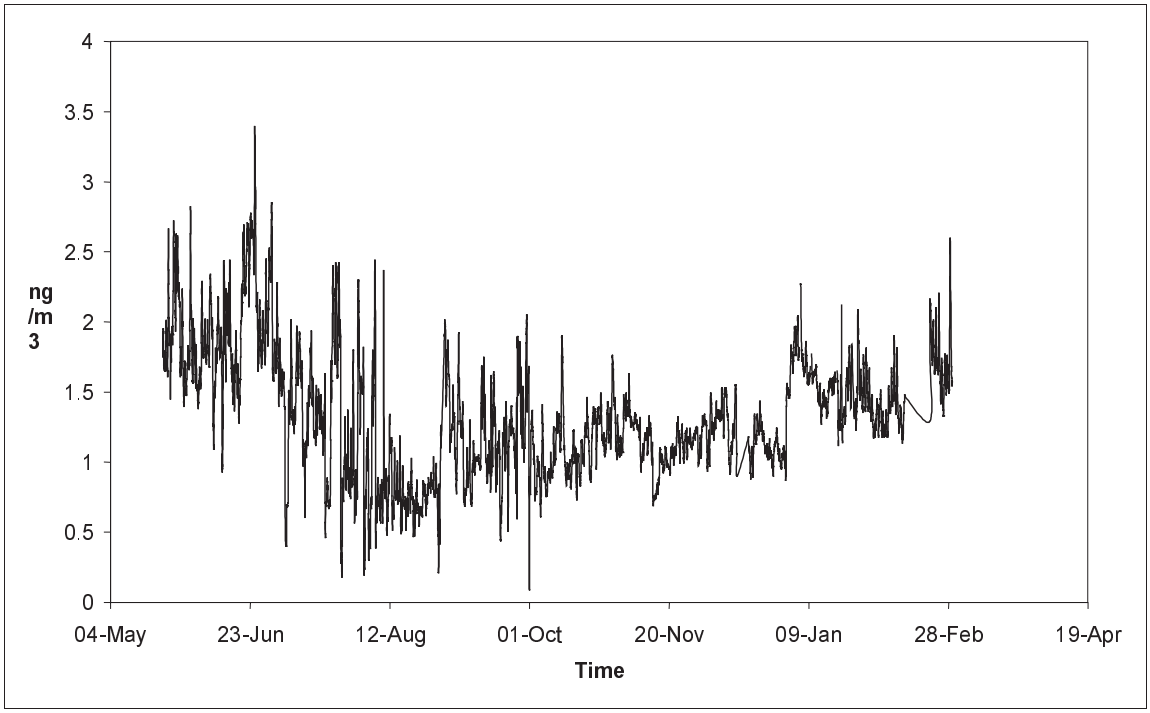

FIGURE 1. GEM CONCENTRATIONS AT FAROE ISLANDS FROM MAY 2000 TO MARCH 2001. VALUES ARE 1 HOUR AVERAGES.

The data varies between a general level of about 2 ng/m^3 in the beginning of the period (in May) with a decrease down to about 0.5 ng/m^3 in July, August with a slight increase to about 1.7 ng/m^3 in January and February. On top of this, some peaks are seen with values up to 3.4 ng/m^3, i.e., most notably in an episode from June 21 to 25. During this episode a low-pressure system above the British Islands forced air masses to be transported from Europe up to the Faroe Islands, with the UK being the most recent emission region loading the air mass. In the following period the dominant wind direction was from west (from the open Ocean), although there are also days where there were air mass trajectories originated from the UK. The concentration levels in the period of generally westerly winds varied between 0.8 to 1.3 ng/m^3. The daily mean temperature in the periods varied from 5.7 ^{0}C in May and June to 12.1 ^{0}C in August. The relative humidity was always close to 95%.
Through the rest of the year the concentrations slowly rise to a level of 1.7 ng/m^3 in January and February 2001.

The model calculations of daily average Hg^0 concentrations together with measured daily average GEM concentrations are shown in figure 2.

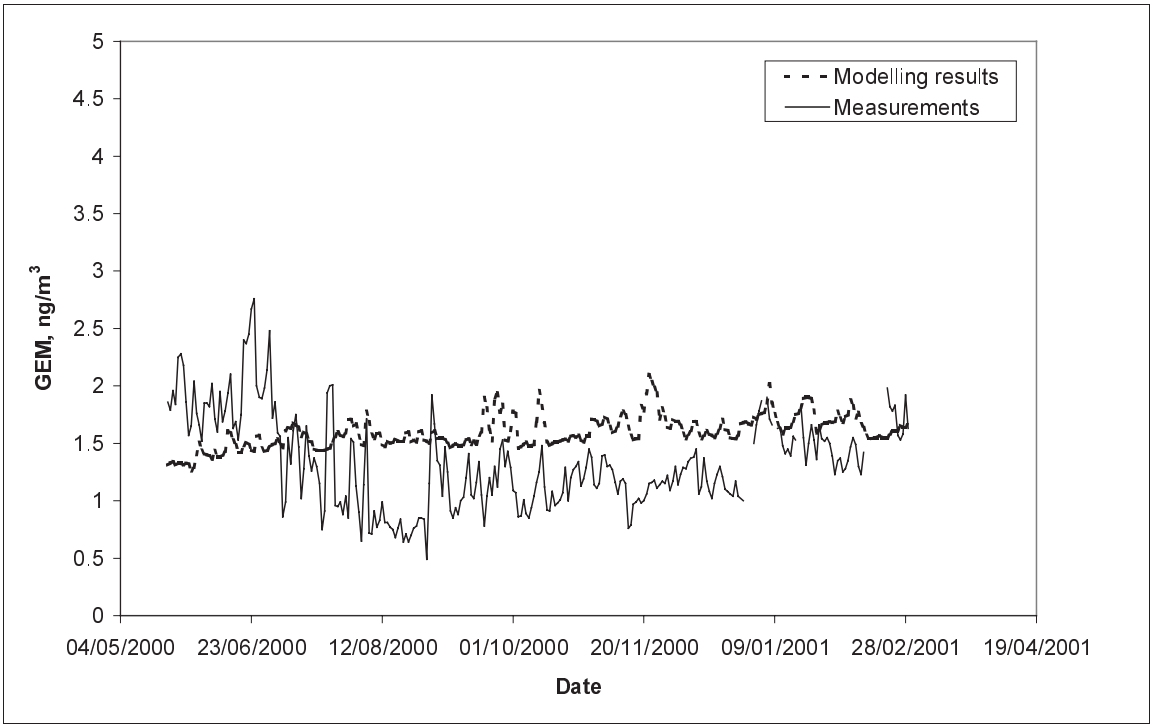

Figure 2. Comparison of daily mean GEM concentrations at Faroe Islands measured by a TEKRAN Hg analyser and Hg° obtained by DEHM.

The calculated concentrations are close to a constant level of 1.6 ng/m^3 throughout the one year period with only a minor decrease in April and May noted in both 2000 and 2001. The decrease is caused by mercury depletion episodes in the Arctic (MDE's) as documented in scenario calculations with (shown here) and without MDE, see also Chap. 3 Atmospheric Modelling.

1.5 Discussion

The measurements of GEM on the Faroe Islands are comparable in magnitude with the levels in 1999 from Mace Head on the west coast of Ireland (Ebinghaus et al. 2000) and with the values from Harwell an inland location in southern England in June 1995 to May 1996 (Lee et al. 2000). The average concentrations at the three localities are 1.68 ng/m^3 at Mace Head, 1.7 ng/m^3 at Harwell and 1.4 ng/m^3 on the Faroe Islands. The largest concentration levels at Harwell and at Mace Head are practically identical, with the concentrations on Faroe Islands somewhat smaller. It is generally believed that the background concentration of mercury in the Northern Hemisphere is about 1.5 ng/m^3 and fairly constant. The central question is of course if these measurements reflect the actual ambient concentrations or if they are lowered due to passivation of the gold trap.
Ebinghaus et al. mentioned passivation of the gold traps as a problem measuring at Mace Head caused by sea spray (the TEKRAN manual notes that low values are generally due to trap passivation too). A similar complication could be the reason for the relative low values at Faroe Islands. However Lee et al. reported similar low values at the inland station where sea spray should be of minor importance. If the low values are real they might be explained by marine air containing significant amounts of Clx and/or Brx that convert GEM to reactive gaseous mercury (RGM) by a mechanism similar to those observed in the high Arctic during polar spring (Schroeder et al. 1998, Berg et al. 2001, Brooks et al. 2002, Lindberg et al, 2002, Skov et al. 2001).

However, initiatives should be taken to ensure that passivation of sample gold cartridges do not occur in the future. Therefore all future GEM measurements should be carried out, by sampling through a heated line and through a soda-lime trap (recommended by Matthew S. Landis private communication, 2001 and the Canadian Catnet protocol).

The reason for the high concentrations of up to 3.5 ng/m^3 was examined. The high levels of GEM observed on Faroe Islands was suggested to originate from local anthropogenic sources but a questionnaire survey demonstrated that practically all mercury containing waste was collected and sent to Denmark for further treatment so this possibility can be ruled out. Alternatively, long range transport of GEM from the source regions on the British Isles and Europe could cause the episodic increase in the GEM concentrations. In fact the air masses in the episode from June 21 to 25 were calculated to arrive from British Isles and the European Continent bringing in air masses with generally elevated air pollution (Kemp et al. 1993), i.e. including mercury. Afterwards the wind was dominated by more westerly wind with resulting lower concentrations.

The model calculations gave a close to constant level of GEM throughout the period in accordance with the general belief that GEM has a long atmospheric lifetime of about 1 year (Lin and Pekhonen, 1999). If Clx and/or Brx are important sinks in the marine boundary layer then, this will shorten the lifetime of GEM, significantly creating a more varying time series of GEM in accordance with our observations.

1.6 Conclusion

The analysis of the concentrations of GEM at Faroe Islands shows that the levels are slightly lower than those observed at Harwell and at Mace Head. In short episodes, high concentrations were observed but the direct transport of GEM cannot explain the high levels observed in e.g. trout and peat since the transfer function for mercury from the atmosphere to the terrestrial system and further to the biosphere, is simply not known, but assumed to be primarily by wet depostion, upon conversion of GEM to RGM.
The highest GEM concentrations observed on the Faroe Islands can be explained by long-range transport from the British Isles and Europe. Whereas there is not any direct explanation of the low values, they might be explained by interference from humidity and/or sea spray. Therefore future measurements at coastal sites should be carried out through a heated line and through a soda lime trap. Comparison with the results from DEHM could not at present explain the GEM concentrations in Faroe Islands, but the model is under development, especially with respect to the chemical scheme.

Further atmospheric studies are needed in order to definitively answer the question of the high Hg levels measured in peat and in marine mammals near the Faroe Islands. In addition, if the low atmospheric concentrations observed on Faroe Islands are real then they indicate that GEM has a shorter lifetime within the marine boundary layer believed and thus deposition of atmospheric mercury to the marine system may be more important than previously believed.

2 Acknowledgements

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3 References

AMAP (1998): AMAP Assessment Report: Arctic Pollution Issues. *Arctic Monitoring and Assessment Programme (AMAP) P.O. Box 8100 Dep. N-0032 Oslo, Norway*. ISBN 82-7655-061-4.

L. A. Barrie, Y. Yi, U. Lohmann, W.R.Leaitch, P. Kasibhatla, G.-J. Roelofs, J. Wilson5, F. McGovern, C. Benkovitz, M.A. Meliere, K. Law, J. Prospero, M. Kritz, D.Bergmann, C. Bridgeman, M. Chin, J. Christensen, R. Easter, J. Feichter, A. Jeuken, E. Kjellstrom, D. Koch, C. Land, P. Rasch: (2001) A comparison of large scale atmospheric sulphate aerosol models (cosam): overview and highlights. *Tellus* **53B**, 615-645.

Berg, T. Batnicki, J. Munthe, J. Lattila, H. Hrehoruk, J. and Mazur, A. (2001) Atmospheric Mercury sprecies in the European Arctic:measuremnts and modelling. *Atm. Env.,* **35**, 2569-2582.

Brooks, S. Skov, H. Lindberg, S. Goodsite, M.E. Banic, C. Landis, M.S. Stevens, R.K. McConville, G. Near surface conversion and fluxes of gaseous elemental mercury to reactive gaseous mercury in the Arctic. Under preparation 2002.

Christensen, J. (1997) The Danish Eularian Hemispheric Model-A three-dimensional air pollution model used for the Arctic. *Atm. Env.*, **31**, No.24, pp.4169-4191.

Christensen, J. (1999): An overview of Modelling the Arctic mass budget of metals and sulphur: Emphasis on source apportionment of atmospheric burden and deposition. In: Modelling and sources: A workshop on Techniques and associated uncertainties in quantifying the origin and long-range transport of contaminants to the Arctic. Report and extended abstracts of the workshop, Bergen, 14-16 June 1999. AMAP report 99:4. see also http://www.amap.no/

Ebinghaus, R. Kock, H.-H. and Hempel, M. (2000) Bestimmung von Quecksilber in Umgebungsluft mit Hilfe von Zeitlich hochauflösenden On-line-Verfahren. *Gefahrstoffe – Reinhaltung der luft,* **60**, No. 5, pp 205-211.

Grandjean, P. Weihe, P. White, R.F and Debes, F (1998) Cognitive performance of children prenatally exposed to "safe" levels of methylmercury. *Env. Res.* Sec A. **77**, 165-172.

Hertel, O. Christensen, J. Runge, E. Asman, W.A.H. Berkowicz, R. Hovmand, M.F. and Hov, Ø. (1995) Development and testing of a new variable scale air pollution model - ACDEP. *Atm.* 29, 1267-1290.

Kämäri, J., P. Joki—Heiskala, J. Christensen, E. Degerman, J. Derome, R. Hoff and A.-M Kähkönen: Acidifying Pollutants, Arctic Haze, and Acidifications in the Arctic, Chapter 9 in: AMAP Assesment Report: Arctic Pollution Issues.

Arctic Monitoring and Assessment Programme (AMAP). S. Wilson, J. Murray and H. Huntington, Ed, 1998.

K. Kemp (1993) A multi-point receptor model for long-range transport over southern Scandinavia, *Atmospheric Environment*, **27A**, 823.

Larsen, R.B. and Dam, M. (1999). AMAP phase I report, The Faroe Islands. The Food and Environmental Agency, Faroe Islands, 1999:1, pp 43.

Lee, D.S., Dollard, G.J, Pepler, S: Gas-Phase Mercury in the Atmosphere of the United Kingdom, *Atm. Env.*, **32,** 5. pp. 855-864, 1998.

Lin C-J. and Pehkonen, S.O.: *The chemistry of atmospheric mercury*, *Atmospheric Environment,* **333** (1999) pp. 2067-2070.

Lindberg, S.E. Brooks, S. C-J. Lin, C-J. Scott, K.J. Landis, M.S. Stevens R.K. Goodsite, M and Richter, A. Dynamic Oxidation of Gaseous Mercury in the Arctic Troposphere at Polar Sunrise. *Environmental Science and Technology* (in press).

Petersen, G. Munthe, J. Pleijel, K. Bloxam, R. and Vinod Kumar, A.; A comprehensive eulerian modeling framework for airborne mercury species: development and testing of the tropospheric chemistry module (TCM). *Atm. Env.,* **32**. (1998) 829-843.

Schroeder and Munthe: *Atmospheric Mercury: An overview*. *Atmospheric Environment,* **32**, No.5, pp.809-822, 1998.

Shotyk, W. Goodsite, M.E. Roos-Barraclough, F. Givelet, N. and Knudsen, K. Millennium-scale records of atmospheric mercury deposition revealed by peat bogs on the Faroe Islands. Under preparation (2001).

Skov, H. Goodsite, M.E. and Christensen, J. Atmospheric mercury in Arctic, future challenges with respect to chemical kinetics. Oral presentation at The Second Informal Conference on Reaction Kinetics and Atmospheric Chemistry; NORFA and COGCI, Helsingør, Denmark, June, 2001.

Steffen, S. Schroeder, B. (1999) Standard Operating Procedures Manual for Total Gaseous Mercury Measurements CANADIAN ATMOSPHERIC MERCURY MEASUREMENT NETWORK (CAMNET) VERSION 4.0. Environment Canada Atmospheric Environment Service,4905 Dufferin Street, Toronto Ontario M3H 5T4.

3 Atmospheric Modelling

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Content

Summary and conclusions

The Danish Hemispheric Eulerian Model system has been used to model the atmospheric transport of sulphur, lead and mercury to the Faroe Islands.

When modelling sulphur (SO_X) and lead (Pb), the model was run from October 1990 to May 2001. The mean calculated concentrations of SO_X ($=SO_2 + SO_4^{2-}$) for the surface level and the total depositions are shown as are similar figures for Pb. The general pattern of both the SO_X and Pb is quite similar. The main pathway for the transport to Faroe Island is by directly transport from Europe.

The model have been compared with measurements many places in Europe and generally there is a very good agreement between the calculated values and the measured. For the Faroe Islands however, the model results have not been compared with actual measurements of SO_X and lead.

In the current version of DEHM the emissions of anthropogenic mercury are based on the new global inventory of mercury emissions for 1995 on a $1^{o}x1^{o}$ grid, which includes emissions of Hg^0, reactive gaseous mercury (RGM) and particulate mercury. There are no re-emissions from land and oceans, instead a background concentration on 1.5 ng/m^3 of Hg^0 are used as initial concentrations and boundary conditions.The mercury model has been run for October 1998 to December 2000. The model has been compared with measurements from Faroe Island. The results show that there is a poor agreement between the calculated and the observed concentrations of elemental mercury (Hg^0).

The total deposition of mercury is split up in three components: the contribution from the deposition of RGM, chemically made particulate mercury and directly emitted particulate mercury. It has been shown that the depletion phenomena is important for the deposition of mercury in the high Arctic areas at Greenland, while for Faroe Islands the depletion phenomena have only a minor influence on the mercury deposition. The deposition is increased by 8%. The deposition is a factor of two lower compared to the depositions in Denmark. The contribution from directly emitted particulate mercury is small (2%) at Faroe Islands. It is mainly the large atmospheric reservoir of elemental mercury, which contributes to the deposition, and which all global emissions both anthropogenic and natural contributes to.

1 Atmospheric Modelling

A model is a mathematical tool for the study of processes and mechanisms of complex system as f.ex. the atmosphere and the processes inside the atmosphere as transport of air pollution. This tool should therefore take into account all processes, which the transports depend on. The air pollution in the Arctic depends on the emissions from the sources, transport from the emissions area into the Arctic by the wind, dispersion of the pollution by diffusion, chemical transformations during the transport, removal of pollutants due to precipitation and deposition on the surface. An air pollution model for the Arctic must take into account all these physical and chemical processes. The different processes must be described very precisely to reduce the uncertainties in the model. It is only possible to handle such a model on a very powerful computer, because the processes and the interactions between the different processes are very complex.

There are several reasons why one should use a model. A model is a good tool for improving the understanding of the atmospheric pathways to the Arctic. The model can be used to estimate the contributions from the different sources in the Northern Hemisphere to the Arctic pollution, or a model can be used to quantify the importance of different processes as f.ex. mercury depletions importance for the transport of mercury into Arctic. Both examples are shown in the following sections.
The current state of atmospheric modelling of the pollution in the Arctic is highly developed. This is mainly caused by the development over the years of both 1) weather forecast models, which gives comprehensive knowledge about the physical processes in the atmosphere and provide reliable meteorological data for the models, and 2) the development of comprehensive regional transport chemistry models for the mid-latitudes with a detailed description of both the physical and chemical processes in the atmosphere.

The Danish Eulerian Hemispheric Model (DEHM) model has been used for this assessment. The DEHM model has earlier been used in 1. phase of AMAP (see Kämäri et al., 1998), and the model have been described in several papers, see e.g. Christensen (1997,1999). Barrie et al. (2001), Lohmann et al.(2001) and Roelofs et al. (2001). Model results from the DEHM will be shown in the following.

1.1 The DEHM modelling system

The system consists of two parts: a meteorological part based on the PSU/NCAR Mesoscale Model version 5 (MM5) modelling subsystem (see Grell et al, 1995) and an air pollution model part, the DEHM model. The MM5 model produces the final meteorological input for the DEHM model. Global meteorological data, used as input to the MM5 mesoscale modelling system, are obtained from the European Centre for Medium-range Weather Forecasts (ECMWF) on a 2.5°x2.5° grid with a time resolution of 12 hours. The whole system includes 2-way nesting capabilities, so it is possible to do finer (150 km $\rightarrow$ 50 km $\rightarrow$ 16.67 km, etc) model calculations over e.g. Greenland or Faroe Island. 23 years of meteorological data from 1979 to 2001

are available, but the MM5 model system for the mother domain has only been run for a period of 11 years from 1990 to 2001, while the model system with 1 nest have been run for the period 1995-2001 for Europe (50 km) and 1 month for Greenland (50 km) as demonstration .
In the used version the model has been run for only the hemispheric domain.

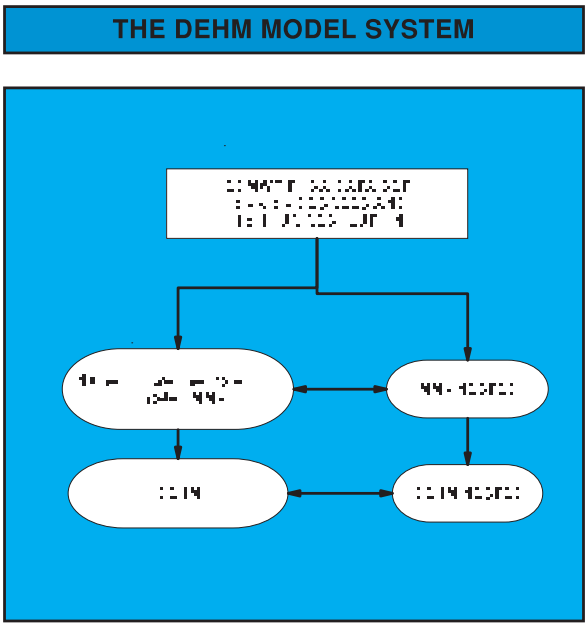

Figure 3. Overview of the DEHM model system.

The DEHM model is based on set of coupled full three-dimensional advection-diffusion equations, one equation for each specie. The horizontal mother domain of the model is defined on a regular 96x96 grid that covers most of the Northern Hemisphere with a grid resolution of 150 km × 150 km at 60°N. The vertical discretization is defined on an irregular grid with 20 layers up to ≈ 15km.
The vertical diffusion is parameterised by using a K_z profile for the surface layer based on the Monin-Obukhov similarity theory, and this K_z profile for the surface layer is extended to the whole boundary layer by using a simple extrapolation (see Christensen, 1997).

1.2 Modelling of Sulphur and Lead

In the basic version the emissions of anthropogenic sulphur are based on the global GEIA inventory of sulphur emissions, version 1A.1, for 1985 on a 1°x1° grid (see Benkowitz et al., 1996) and GEIA Global Lead Emissions Inventory, Version 1, for 1989 on a 1°x1° grid (see Pacyna et al, 1995). These emissions are redistributed to the grid used in the model. The EMEP emissions of sulphur (for Europe) for the years 1990-1997 are used for the part of the grid, which is equal the EMEP grid.
The sulphur chemistry is a simple linear function, where the oxidation rate of SO_2 to SO_4^{2-} depends on the latitude and the time in the year, while for lead there is no chemical transformations.
The dry deposition velocities of the species are based on the resistance method. The wet deposition is parameterized by using a simple scavenging ratio formulation with different in-cloud and below-cloud scavenging. The removal rates for Pb is equal to the rates for SO_4^{2-}.

The model has been run from October 1990 to May 2001. In figure 2 the mean concentrations of SO_X (=SO_2 +SO_4^{2-}) for the surface level and the total depositions are shown. The similar figures for Pb are given on figure 3. The general pattern of both the SO_X and Pb is quite similar. The main pathway for the transport to Faroe Island is directly transport from Europe.

The model have been compared with measurements many places and generally there is a very good agreement between the calculated and measured concentrations not only in the Arctic but also in Europe and North America, see Christensen (1997,1999), Barrie et al. (2001), Lohmann et al.(2001) and Roelofs et al. (2001). Therefore one should expect that even though the model results have not been compared with measurements of sulphur and lead from Faroe Island, the results can be used to assess the air pollution levels at the Faroe Island
In figure 4 and 5 there are given timeseries of calculated concentrations of SO_2, $SO_4^{=}$ and Pb. The concentrations are episodic for all three species. The maximum levels for SO_2 are approximately a factor 5 lower than levels for Denmark, factor 3 for sulphate and factor 7 lower for lead.

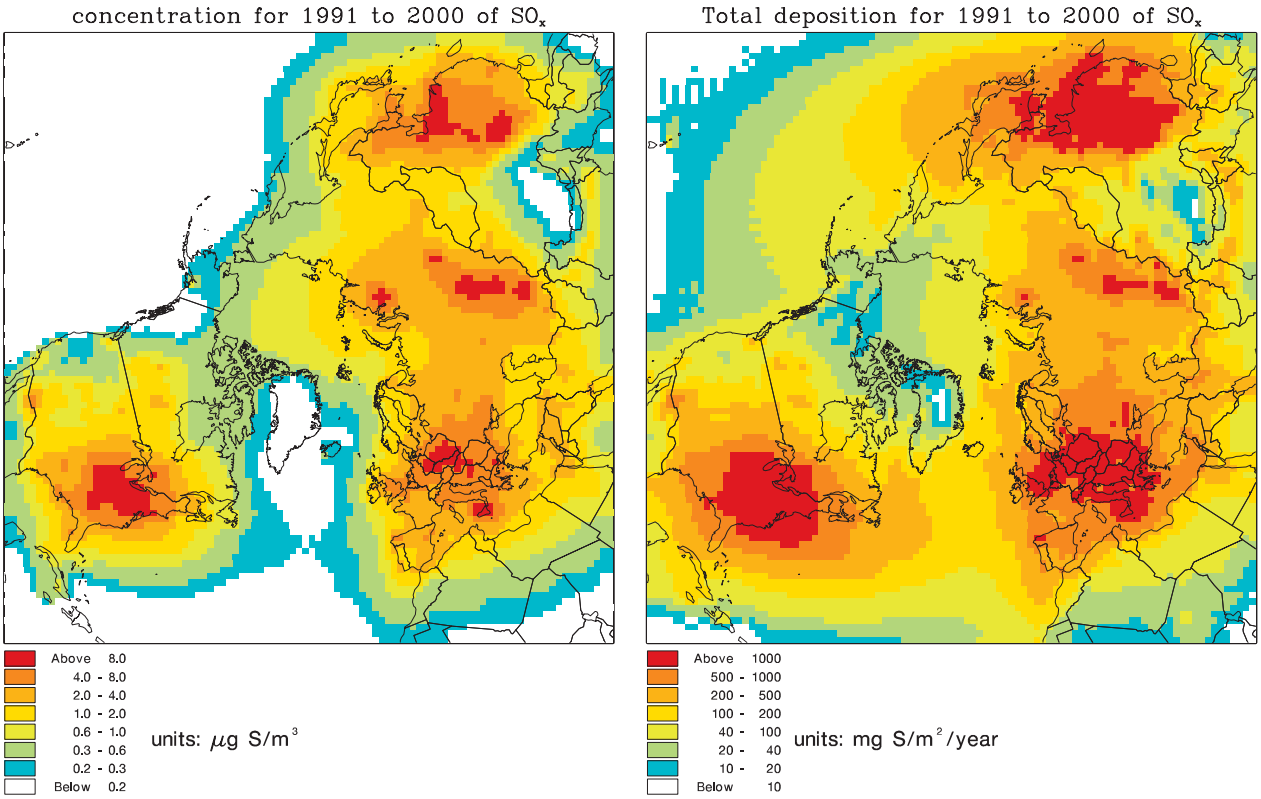

Figure 4. The mean concentrations for the surface layer of SOX in µg S/m3 (left) and the total deposition of SOX in mg S/m2/year (right)

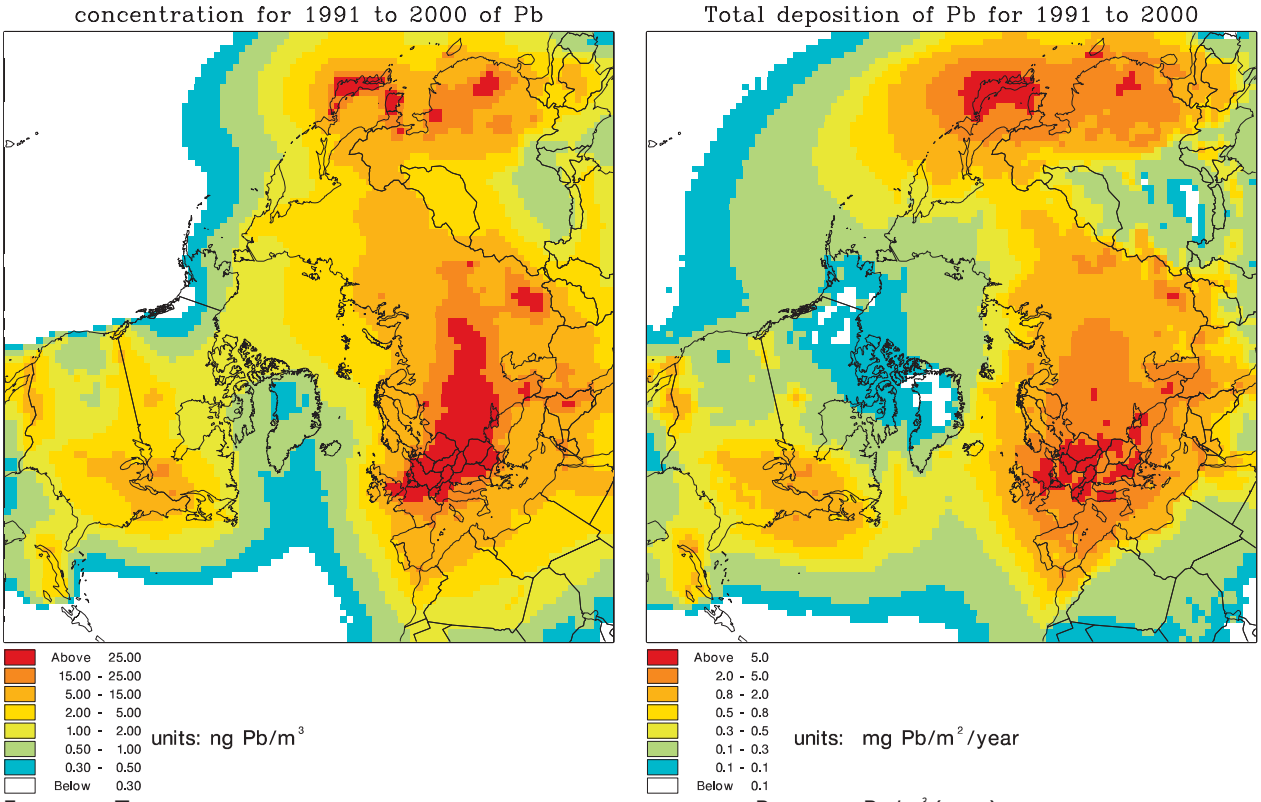

Figure 5. The mean concentrations for the surface layer of Pb in ng Pb/m^3 (left) and the total deposition of Pb in mg Pb/m^2/year (right).

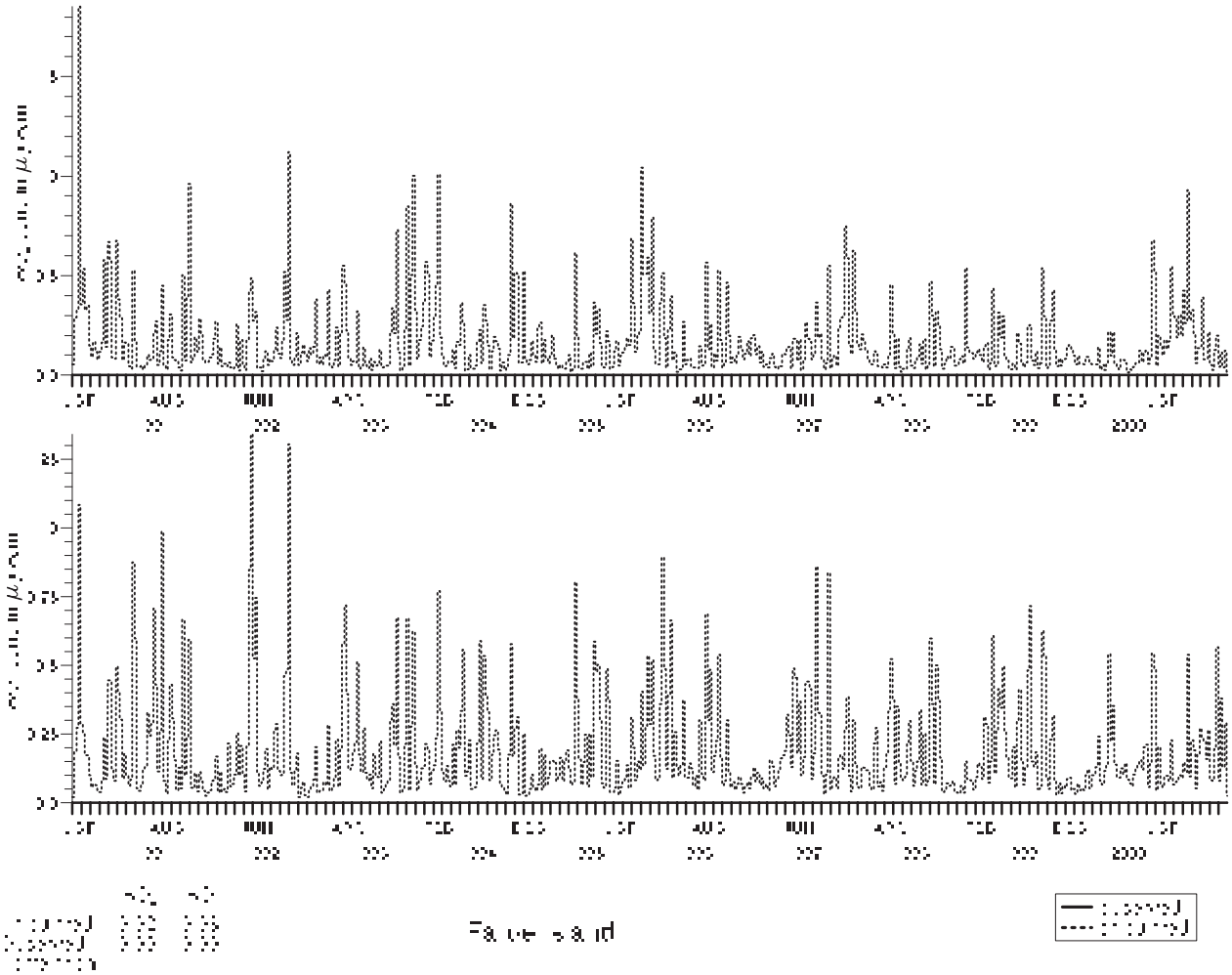

Figure 6. Timeseries of calculated weekly mean concentrations of SO_2 and SO_4= for Faroe Island

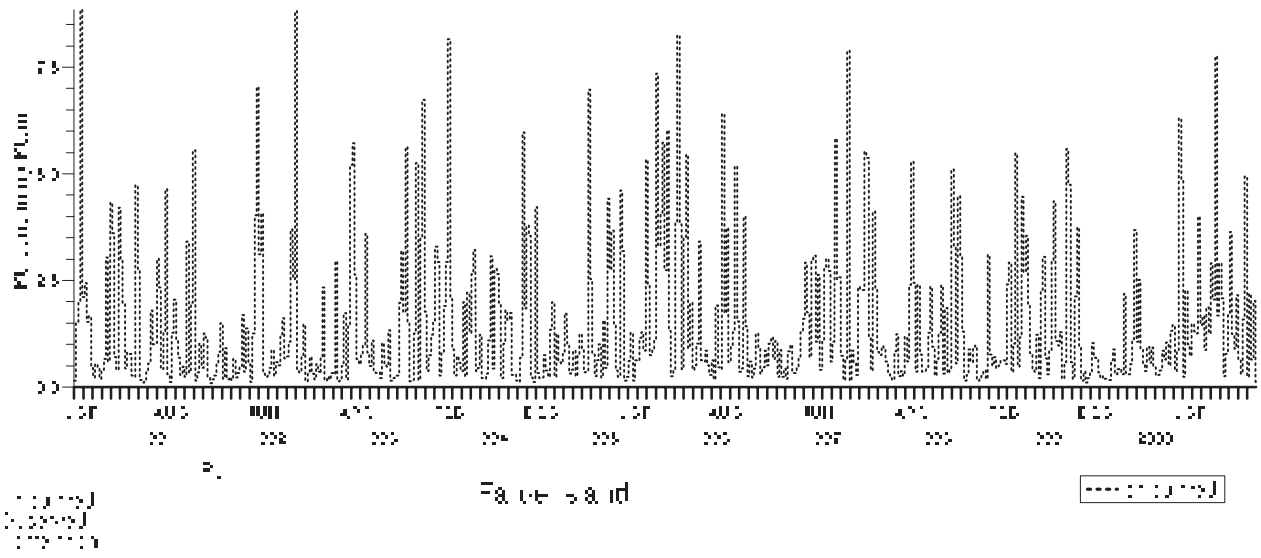

Figure 7. Timeserie of calculated weekly mean concentrations of Pb for Faroe Island

In figures 6 and 7 the vertical distributions of SO_x and Pb and the contribution from different anthropogenic sources to these vertical distributions for Faroe Island and Denmark are shown. The highest concentration levels for the total mean are a factor of 10 lower than the similar calculated mean concentrations for Denmark. The largest contribution to the atmospheric burden of sulphur for Faroe Island is coming from West European sources (up to 60 % in the lowest 1.5 km part of the atmosphere) and East Europe contributes with up to 20%. At higher levels it is mainly the North America sources, which contribute. Denmark have much larger contribution from East Europe (35 %) compared to Faroe Island. For lead it is mainly West Europe, which contributes to the concentration levels (up to 70%).

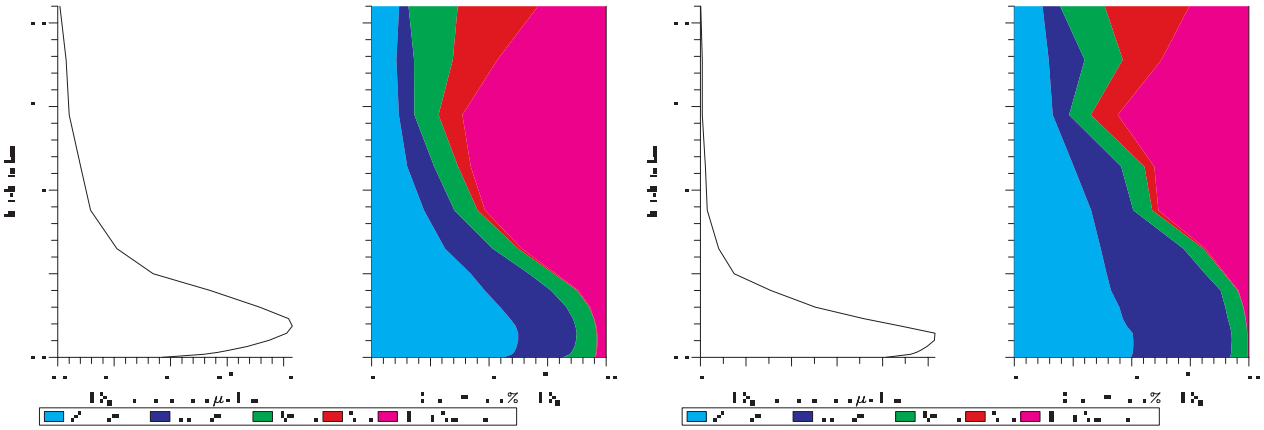

Figure 8. The vertical distribution of SOX and contributions from different sources to the vertical contributions for Faroe Island (left) and Denmark (right)

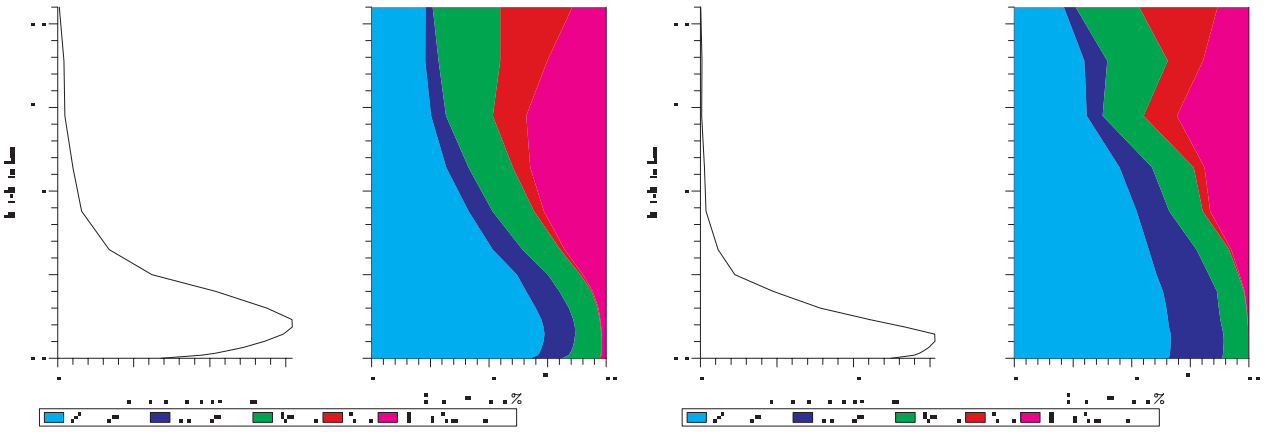

Figure 9. The vertical distribution of Pb and contributions from different sources to the vertical contributions for Faroe Island (left) and Denmark (right)

In figures 8 and 9 the total deposition and the contribution from different sources are shown for Faroe Island and Denmark. The deposition levels for both sulphur and lead are a factor 4 lower than the calculated deposition levels in Denmark. West Europe contributes with 58% to the total deposition of sulphur, East Europe with 23% and Russia with 11%. The similar numbers for lead are 70% from West Europe, 13% from East Europe and 14% from Russia.

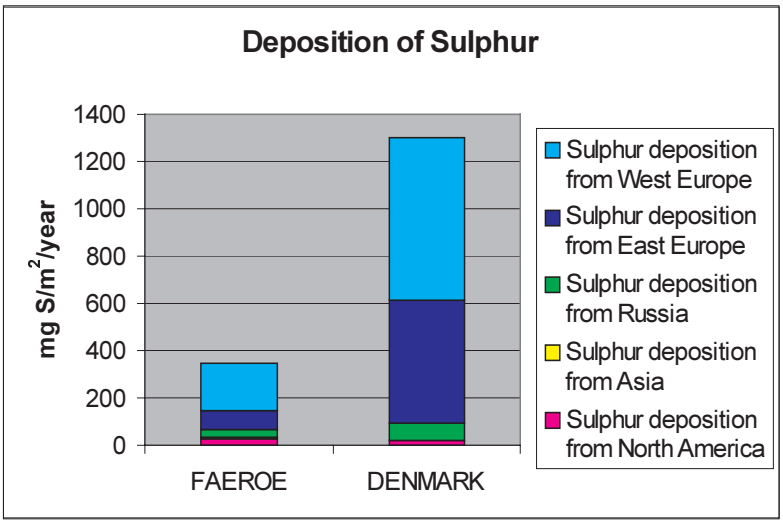

Figure 10. The contribution from different sources to the total deposition of sulphur for Faroe Island (left) and Denmark (right)

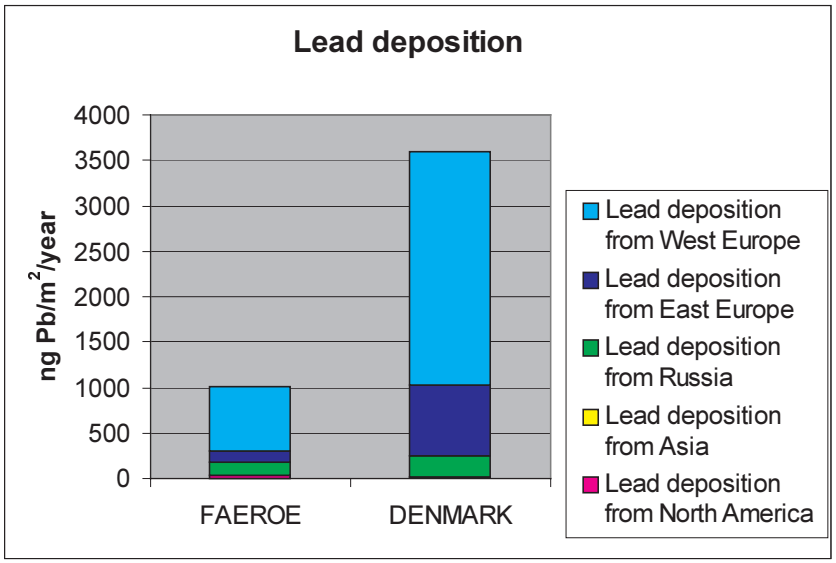

Figure 11. The contribution from different sources to the total deposition of Pb for Faroe Island (left) and Denmark (right)

1.3 Modelling of mercury

In general, activities aimed at modeling Hg are less developed, although major improvements in regional (European) and global modeling of Hg have been made. An example of a mercury model is the mercury version of the Danish Hemispheric Eulerian Model system (DEHM), which have been used to study the transport of mercury into the Arctic. The main reason for the development of the model was fulfill the Recommendation from the AMAP workshop: "Modelling and sources: A workshop on Techniques and associated uncertainties in quantifying the origin and long-range transport of contaminants to the Arctic. Bergen, 14-16 June 1999" to "Assess spring Hg and O_3 depletion using atmospheric model with high-resolution boundary layer. Therefore there has not been so much focus on the results for Faroe Island, but still the model results can be used for the assessment of the atmospheric mercury.

In the present mercury version of DEHM there are 13 mercury species, 3 in gas-phase (Hg^0, HgO and $HgCl_2$), 9 species in the aqueous-phase and 1 in particular phase.
In the current version the emissions of anthropogenic mercury are based on the new global inventory of mercury emissions for 1995 on a $1^{\circ}x1^{\circ}$ grid (Pacyna et. al., in prep), which includes emissions of Hg^0, reactive gaseous mercury (RGM) and particulate mercury. There are no re-emissions from land and oceans, instead a background concentration on 1.5 ng/m^3 of Hg^0 are used as initial concentrations and boundary conditions.
The chemistry is based on the scheme from the GKSS model (see Petersen et al, 1998). The mercury chemistry is depending on then concentrations of O_3, SO_2, Cl^- and Soot. Constant values of Cl^- and Soot concentrations are used, while O_3 and SO_2 concentrations are both obtained from the photochemical version of DEHM. During the polar sunrise in the Arctic an additional fast oxidation rate of Hg^0 to HgO is assumed: Inside the boundary layer over sea ice during sunny conditions it is assumed that there is an additional oxidation rate of ¼ $hour^{-1}$. The fast oxidation stops, when surface temperature exceeds $-4^{\circ}C$. The removals of Hg^0 are due to the chemistry and the uptake by cloud water.
The dry deposition velocities of the reactive gaseous mercury species are based on the resistance method, where the surface resistance similar to HNO_3 is used, which have a very high deposition velocity. The wet deposition of reactive and particulate mercury is parameterized by using a simple scavenging coefficients formulation with different in-cloud and below-cloud scavenging coefficients (see Christensen, 1997).

The mercury model has been run for October 1998 to December 2000. The model has been compared with measurements from Faroe Island. The results show that there is a poor agreement between the calculated and observed concentrations of elemental mercury (Hg^0), see Fig. 10 (see also the discussion in the chapter about measurements of mercury). For central Europe and in Sweden the model have been compared with measurements of both Hg^0 and particulate mercury with a much better agreement. At the figure there are also shown the calculated concentrations of reactive gaseous mercury (RGM) and particulate mercury. For Faroe Island the depletion phenomena have only a minor influence on the concentrations levels.

In figure 11, the total depositions of mercury for the years 1999 and 2000 are shown. This example shows the importance of the mercury depletion in the Arctic for the total deposition of mercury. The total deposition increases in the whole Arctic and the surrounding areas, and for the area north of the Polar Circle the total deposition of mercury increases from 89 to 208 tonnes pr. year due to the depletion according to the model runs. For the areas around Faroe Islands there is only a small increased deposition of mercury.

In figure 12 the total deposition of mercury in μg Hg/m^2/year for 8 different localities (6 in Greenland, Faroe Island and Denmark) are shown. The total deposition is split up in three components: the contribution from the deposition of RGM, chemical made particulate mercury and directly emitted particulate mercury. At the figure it is shown very clearly how important the depletion phenomena is for the deposition of mercury for the high Arctic areas at Greenland, while for Faroe Islands the depletion phenomena have only a minor influence on the mercury deposition. The deposition is increased by 8%. The deposition is a factor of two lower compared to the depositions in Denmark. The contribution from directly emitted particulate mercury is small (2%) at Faroe Islands. It is mainly the large atmospheric reservoir of elemental mercury, which contributes to the deposition, and which all global emissions both anthropogenic and natural contributes to.

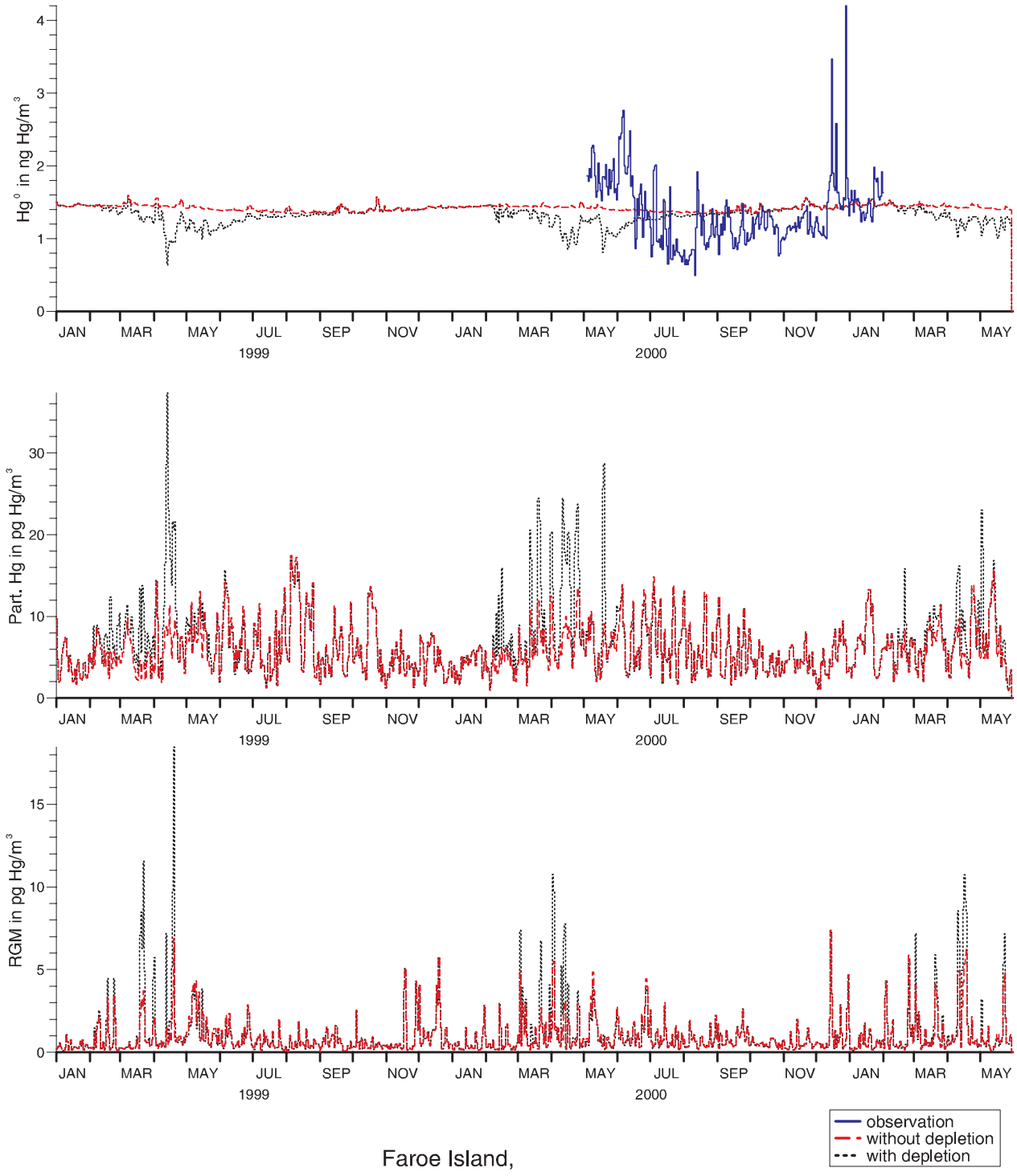

Figure 12. Comparisons between observed (blue curve) and calculated daily mean of Hgo with two model versions, one without depletion (red) and one with depletion (black) (top) , the total particulate mercury (middle) and total reactive gaseous mercury (bottom) for Faroe Island.

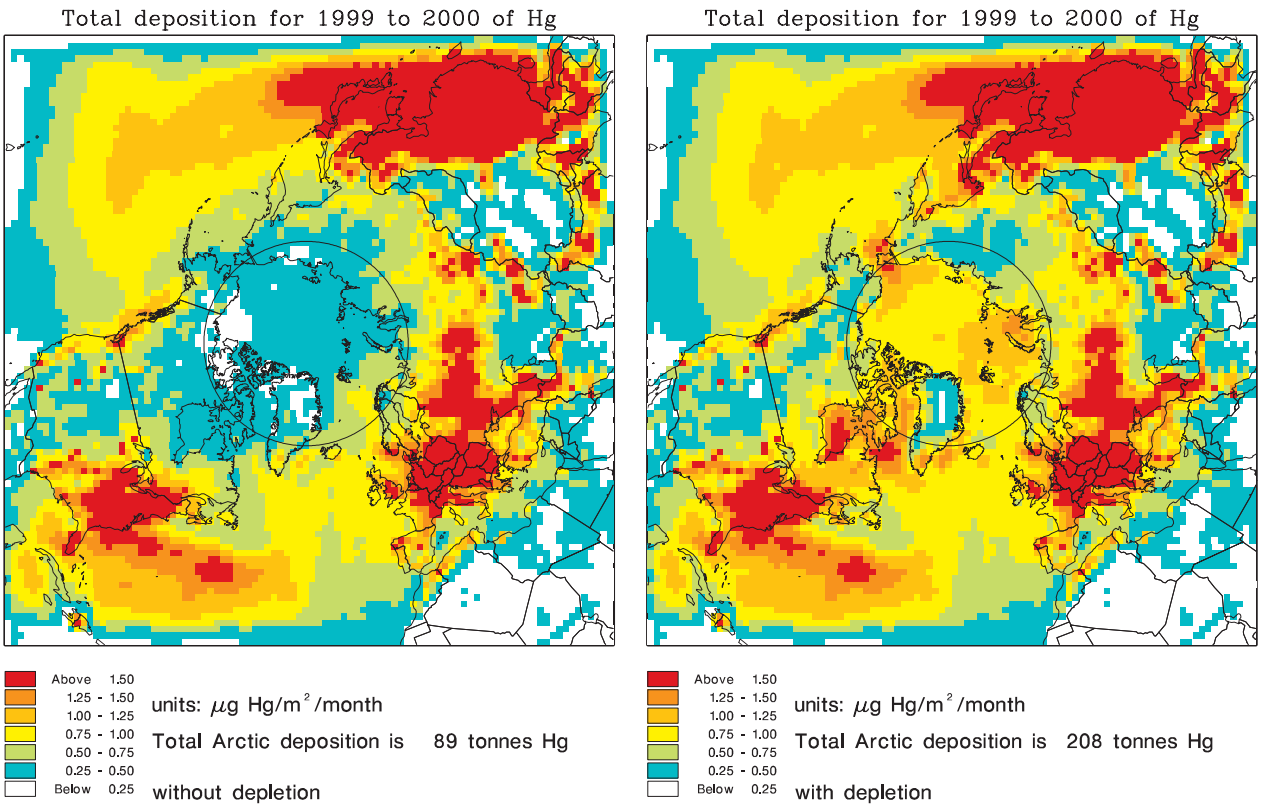

FIGURE 13. THE TOTAL DEPOSITION OF MERCURY WITHOUT ARCTIC MERCURY DEPLETION (LEFT) AND WITH (RIGHT) IN µG HG/M2/MONTH.

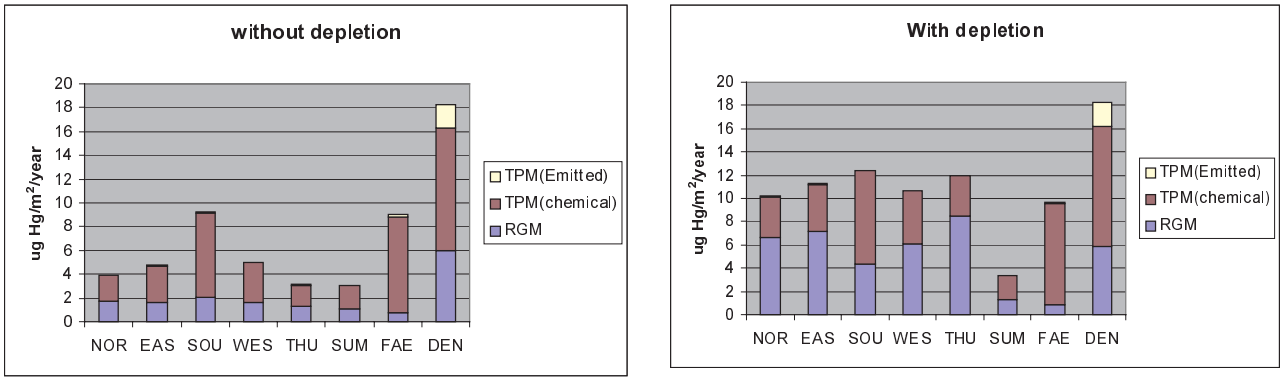

FIGURE 14. TOTAL DEPOSITION OF MERCURY IN µG HG/M2/YEAR SPLITTED UP IN DEPOSITION OF REACTIVE GASEOUS MERCURY, CHEMICAL MADE PARTICULATE MERCURY AND DIRECTLY EMITTED PARTICULATE MERCURY FOR TWO DIFFERENT MODEL RUNS: WITHOUT DEPLETION (LEFT) AND WITH DEPLETION (RIGHT), AND FOR 8 DIFFERENT LOCALITIES: STATION NORD (NOR), DANEBORG-SCORESBYSUND AREA (EAS), SOUTH GREENLAND (SOU), NUUK AREA (WES), THULE (THU), SUMMIT (SUM), FAROE ISLAND (FAE) AND DENMARK (DEN)

2 References

Benkowitz, C. M., T. Scholtz, J. Pacyna, L. Tarrasón, J. Dignon, E. Voldner, P. A. Spiro and T. E. Graedel (1996): Global Gridded Inventories of Anthropogenic Emissions of Sulphur and Nitrogen. *J. Geophys. Res.*, 101, 29239-29253.

Christensen, J. (1997): The Danish Eulerian Hemispheric Model - A Three Dimensional Air Pollution Model Used for the Arctic. *Atm. Env*, 31, 4169-4191.

Christensen, J. (1999): An overview of Modelling the Arctic mass budget of metals and sulphur: Emphasis on source apportionment of atmospheric burden and deposition. In: Modelling and sources: A workshop on Techniques and associated uncertainties in quantifying the origin and long-range transport of contaminants to the Arctic. Report and extended abstracts of the workshop, Bergen, 14-16 June 1999. AMAP report 99:4. see also http://www.amap.no/

Grell, G. A., Dudhia J. and Stauffer D. R., 1995: A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5). NCAR/TN-398+STR. NCAR Technical Note. June 1995, pp. 122. Mesoscale and Microscale Meteorology Division. National Center for Atmospheric Research. Boulder, Colorado.

Kämäri, J., P. Joki—Heiskala, J. Christensen, E. Degerman, J. Derome, R. Hoff and A.-M Kähkönen: Acidifying Pollutants, Arctic Haze, and Acidifications in the Arctic, Chapter 9 in: AMAP Assesment Report: Arctic Pollution Issues. Arctic Monitoring and Assessment Programme (AMAP). S. Wilson, J. Murray and H. Huntington, Ed, 1998.

Pacyna, Jozef M., M. Trevor Scholtz and Y-F. Li, (1995): Global Budgets of Trace Metal Sources, *Environmental Reviews*, 3, 145-159.

Pacyna, E.G., and J.M. Pacyna, Global emission of mercury from anthropogenic sources in 1995. *Water, Air, and Soil Pollution*, 137, pp.143-165, 2002.

Petersen, G. Munthe, J. Pleijel, K. Bloxam, R. and Vinod Kumar, A.; A comprehensive eulerian modeling framework for airborne mercury species: development and testing of the tropospheric chemistry module (TCM). *Atm. Env.,* 32. (1998) 829-843.

L. A. Barrie, Y. Yi, U. Lohmann, W.R.Leaitch, P. Kasibhatla, G.-J. Roelofs, J. Wilson5, F. McGovern, C. Benkovitz, M.A. Meliere, K. Law, J. Prospero, M. Kritz, D.Bergmann, C. Bridgeman, M. Chin, J. Christensen, R. Easter, J. Feichter, A. Jeuken, E. Kjellstrom, D. Koch, C. Land, P. Rasch: A comparison of large scale atmospheric sulphate aerosol models (cosam): overview and highlights. *Tellus*, 53B, pp 615-645, 2001.

U. Lohmann, W.R. Leaitch, K. Law, L. Barrie, Y. Yi, D. Bergman, C, Bridgeman, M. Chin, J. Christensen, R. Easter, J. Feichter, A. Jeuken, E. Kjellstrom, D. Koch, C. Land, P. Rasch, G.-J Roelof: Vertical distributions of sulphurspecies simulated by large scale atmospheric models in cosam: Comparison with observations. *Tellus*, **53B**, pp 646-672, 2001

G.J. Roelofs, P. Kasibhatla, L. Barrie, D. Bergmann, C, Bridgeman, M. Chin, J. Christensen, R. Easter, J. Feichter, A. Jeuken, E. Kjellström, D. Koch, C. Land, U. Lohmann, P. Rasch: Analysis of regional budgets of sulfur species modelled for the COSAM exercise. *Tellus*, **53B**, pp 673-694, 2001

4 Radionuclides

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Content

Summary and conclusions

Radioactivity measurements have been carried out for samples collected in 1999 and 2000. The samples are from marine as well as terrestrial environment, including freshwater lakes. The average Caesium (^{137}Cs) aktivitet in seawater are around 1.6 Bq/m^3 for both 1999 and 2000, with a declining trend from 1999 to 2000 in Tórshavn/Hoyvík and Kirkjubøur. The average ^{137}Cs/^{90}Sr concentration ratio from the measurements is 1.49, which corresponds to the global fallout ratio. Results for ^{137}Cs concentrations in marine biota are presented, all showing low values, with cod having the relative highest value of around 0.2 Bq/kg fresh weight.
Geografical variations of ^{137}Cs activity are seen for soil and grass samples. Also in cows milk geographical variations are seen resulting in significantly higher levels in ^{137}Cs activity in cows milk at the southern location than at the two northern locations.

Due to the expected transport time of Technetium (^{99}Tc) to Faroese waters of 12-15 years, the results presented are therefore not related to the latest releases from Sellafield, but mainly to discharges in the 1970s and to global fallout from nuclear weapons tests.

1 Radioactivity in Faroese environment. Measurements from 1999 and 2000

Radioactivity measurements have been carried out for samples collected in 1999 and 2000. The samples are from marine as well as terrestrial environment, including freshwater lakes. The analytical metods are as described in Aarkrog et al. 1997 and Chen et al. 1994. In some cases, ^{40}K measured by gamma-spectrometry has been expressed as the equivalent amount of potassium. One gramme of potassium holds 30.65 Bq of the natural gammaemitter ^{40}K.

1.1 Marine environment

The collection of samples covers biota as well as seawater. The measurements for seawater are presented in Table 1. The average ^{137}Cs concentrations in seawater are around 1.6 Bq/m^3 for both 1999 and 2000, with a declining trend from 1999 to 2000 in Tórshavn/Hoyvík and Kirkjubøur. The average $^{137}Cs/^{90}Sr$ concentration ratio from the measurements is 1.49, which corresponds to the global fallout ratio.

The peak release of ^{99}Tc from Sellafield in 1995 has raised environmental and political awareness of this particular radionuclide. The radionuclide is transported from the Irish Sea to Faroese waters by ocean currents, having an expected transport time to Faroese waters of 12-15 years (Dahlgaard 1995). The results presented in Table 1 for ^{99}Tc are therefore not related to the latest releases from Sellafield, but mainly to discharges in the 1970s and to global fallout from nuclear weapons tests.

Comparing ^{137}Cs and ^{99}Tc activities in Fucus shown in Table 2 with activities in seawater in Table 1 show a concentration factor for ^{137}Cs from seawater to Fucus of 209-274 Bq kg^{-1} dry / Bq L^{-1}, or L kg^{-1}. The similar number for ^{99}Tc is 60000-83000.

Table 2. Cs-137 in fucus vesiculosus sampled in the Faroe Islands 1999

Location	Position		Sampling date	^{137}Cs Bq/kg dry	SD %	^{99}Tc Bq/kg dry	SD %
	N	W					
Kalbaksbotnur	62°03'	06°50'	8Dec1999	0.569	27.3	1.98	3.3
Kirkjubøur	61°57'	06°47'	8 Dec1999	0.458	32.6	1.17	4.7
Tórshavn	62°02'	06°45'	7 Dec1999	0.380	29.4	1.65	3.5

Results for ^{137}Cs concentrations in other marine biota can be found in Table 3, all showing low values, with cod having the relative highest value of around 0.2 Bq/kg fresh weight. Table 4 show measured ^{137}Cs activity concentrations in pilot whale meat, sampled on three locations in 1999.

Table 1. Measured activity concentrations in surface seawater sampled in the Faroe Islands in 1999 and 2000

Location	Position		Sampling	Salinity	^{137}Cs	Counting	^{90}Sr	Counting	^{99}Tc	Counting
	N	W	date	‰	Bq m^{-3}	St. dev.%	Bq m^{-3}	St. dev.%	Bq m^{-3}	St. dev.%
Kirkjubøur	61°57'	06°47'	Sep 1999	34.81	1.67	16.8	0.98	2.3	0.0195	23.1
Kirkjubøur	61°57'	06°47'	19 Oct 2000	35.68	1.60	14.4	1.13	4.9		
Tórshavn/Hoyvík	62°02'	06°45'	Sep 1999	34.75	1.82	14.1	1.18	6.3	0.0199	23.1
Tórshavn/Hoyvík	62°02'	06°45'	2 Nov 2000	35.19	1.75	16.0	1.06	3.0	0.0179	16.5
Kollafjørður	62°07'	06°55'	2 Nov 2000	35.06	1.72	15.3	1.53	2.7	0.0141	22.4

Table 3. Cs-137 in sea animals sampled in 1999

Species	Sampling location	Position		Sampling date	^{137}Cs Bq kg^{-1} fresh	Counting St. dev.%
		N	W			
Sculpin total	Toftir	62°06'	06°45'	17 Sep	0.0495	Detection limit
Cod fillet	Faroes	62°00'	06°45'	March	0.1820	4.0
Cod fillet	Faroes	62°00'	06°45'	August	0.2504	4.6
Haddock fillet	Faroes	62°00'	06°45'	March	0.0957	8.3
Common Mussel soft part	Kalbak	62°03'	06°50'	7 Dec	0.0521	31.5
Shrimps soft part. 406-408 m depth	Faroes	63°18.9'	10°09.7'	6 May	0.1140	16.1
Shrimps soft part. 414-424 m depth	Faroes	63°22.6'	10°27.6'	9 May	0.0945	20.1
Shrimps soft part. 401-403 m depth	Faroes	63°16.3'	10°44.2'	12 May	0.1023	18.6

Table 4. Measurements for pilot whale meat collected in the Faroe Islands in 1999

	Position			^{137}Cs		^{40}K	
Location	N	W	Sampling date	Bq kg^{-1} fresh	St. dev. %	Bq kg^{-1} fresh	St. dev. %
Miðvágur	62°03'	7°10'	July	0.153	10.7	95.9	0.5
Klaksvík	62°14'	6°36'	July	0.229	5.1	64.7	0.5
Vestmanna	62°09'	7°10'	Sept.	0.317	9.2	86.1	1.0

1.2 Freshwater lakes

Measurements of water from three freshwater lakes in 1999 are presented in Table 5. The ^{137}Cs/^{90}Sr ratio is 0.89, 0.80 and 0.77 in Eiðisvatn, Toftavatn and Leynavatn, respectively.

Table 5. Measurements of water sampled from three freshwater lakes in September 1999.

Location	Position		Cs-137		Sr-90		Ca
	N	W	Bq m^{-3}	St. Dev; %	Bq m^{-3}	St. Dev; %	g m^{-3}
Eiðisvatn	62°18.0'	07°07.1'	1.80	6.6	2.02	1.71	29.90
Toftavatn	62°05.7'	06°42.9'	4.17	2.7	5.22	1.46	21.94
Leynavatn	62°07.7'	07°01.2'	1.26	9.5	1.64	1.79	27.16

1.3 Soil

More extensive analyses have been carried out for soil samples, collected at two locations in the central part of the country. The results are presented in Tables 6 and 7. The most significant variation with soil depth is observed for ^{137}Cs, where most of the radionuclide is retained in the uppermost 10cm. The ^{137}Cs activity at Toftavatn is about a factor two higher than in Hvalvík, where the results are around the values that should be expected in 1999 (Joensen, 1999).

Table 6. Soil samples collected at Toftavatn in the Faroe Islands 6 September 1999

	^{137}Cs			^{226}Ra			^{232}Th			^{239,240}Pu			^{238}Pu		
Depth in cm	Bq kg^{-1} dry	Bq m^{-2}	StD %	Bq kg^{-1} dry	Bq m^{-2}	StD %	Bq kg^{-1} dry	Bq m^{-2}	StD %	Bq kg^{-1} dry	Bq m^{-2}	StD %	Bq kg^{-1} dry	Bq m^{-2}	StD %
0-10	78.44	9178	0.8	2.56	300	22.3	5.47	640	19.1	1.770	207.1	5.9	0.0567	6.63	14.9
10-20	12.71	1780	2.0	3.37	471	7.7	3.90	547	13.1						
20-30	2.39	305	6.9	3.39	433	6.9	3.78	482	12.4						
30-40	1.20	166	15.5	3.11	430	8.5	3.93	543	15.1						

Table 7. Soil samples collected at Hvalvík in the Faroe Islands 17 July 1999

	^{137}Cs			^{226}Ra			^{232}Th			^{239,240}Pu			^{238}Pu		
Depth in cm	Bq kg^{-1} dry	Bq m^{-2}	StD %	Bq kg^{-1} dry	Bq m^{-2}	StD %	Bq kg^{-1} dry	Bq m^{-2}	StD %	Bq kg^{-1} dry	Bq m^{-2}	SD %	Bq kg^{-1} dry	Bq m^{-2}	StD %
0-10	80.29	4809	0.6	3.07	184	8.8	3.55	213	15.5	2.090	125.2	5.6	0.0839	5.026	10.4
10-20	9.64	454	2.1	2.68	126	8.3	3.12	147	15.6						

1.4 Grass

Results of measurements for mixed grass from three locations in 1999 are presented in Table 8. There is a significant geographical variation in the ^{137}Cs activities as well as in the concentration of ^{40}K. High values of ^{137}Cs tend to correlate to low values of K, although it is not obvious to make this conclusion from Table 8.

Table 8. Measurements for grass collected in the Faroe Islands in 1999

	Position			^{137}Cs		^{40}K	
Location	N	W	Sampling date	Bq kg^{-1} dry	St. dev. %	Bq kg^{-1} dry	St. dev. %
Hvalba	61° 59'	06° 51'	2 August	4.11	16.8	388	3.4
Skáli	62° 09'	06° 47'	21 July	27.36	7.1	470	7.1
Kollafjørður	62° 07'	06° 55'	5 October	2.54	6.1	29.30	0.7

1.5 Moss

Moss has been collected on one location in 1999. The measurements are presented in Table 9. There is no information about the moss species, and it is not possible to give a satisfying explanation about the difference in the two ^{137}Cs values.

Table 9. Measurements for moss collected near the lake Toftavatn in the Faroe Islands 7 September 1999

	Position		^{137}Cs			^{40}K		
Species	N	W	Bq kg^{-1} fresh	Bq kg^{-1} dry	St. dev. %	Bq kg^{-1} fresh	Bq kg^{-1} dry	St. dev. %
Moss	62° 05.7	06° 42.9'	87.2	91.9	2.5	63	67	25.6
Moss	62° 05.7	06° 42.9'	270.5	300.2	1.5	77	86	29.7

1.6 Potatoes

The ^{137}Cs activity concentration in potatoes from 1999 is in the range 1.07-1.51 Bq/kg fresh weight, and 0.28-0.35 (Bq ^{137}Cs)·(g K)$^{-1}$.

Table 10. Measurements for potatoes collected in the Faroe Islands in 1999

		^{137}Cs		K	
Location	Sampling date	Bq kg^{-1} fresh	St. dev. %	g kg^{-1} fresh	St. dev. %
Klaksvík	November	1.07	5.2	3.71	1.2
Vestmanna	November	1.51	2.7	4.31	0.8
Kollafjørður	November	1.25	1.6	3.67	0.5

1.7 Cow milk

Cow milk has been collected from three locations, monthly in the first quarter of 1999. The highest ^{137}Cs activity concentration is found at the southernmost location, Tvøroyri, where the levels are significantly higher than at the two northern locations. This may possibly be related to a higher deposition from the Chernobyl accident in the southern part of the country, but this is still to be confirmed. The ^{137}Cs/K ratio is in the range 98-778 (Bq ^{137}Cs)·(g K)$^{-1}$.

Table 11. Measurements for cow milk collected in the Faroe Islands in 1999

		^{137}Cs		K	
Location	Month	Bq m^{-3}	St. dev. %	kg m^{-3}	St. dev. %
Tórshavn	January	375.1	5.1	1.674	1.1
Tórshavn	February	463.5	2.3	1.642	0.6
Tórshavn	March	427.6	2.1	1.642	0.5
Klaksvík	January	187.6	8.1	1.922	0.9
Klaksvík	February	203.2	4.6	1.751	0.6
Klaksvík	March	275.1	3.5	1.602	0.6
Tvøroyri	January	1110.6	1.2	1.581	0.6
Tvøroyri	February	866.0	2.3	1.598	0.9
Tvøroyri	March	1173.6	1.1	1.509	0.6

1.8 Lamb meat

Lamb meat has been collected at the time of slaughter in October 1999 from Bøur and Sandur. The measurements are presented in Table 12. The ^{137}Cs activity concentration range is 3.67-6.54 Bq/kg fresh weight, and 0.85-1.49 (Bq ^{137}Cs)·(g K)$^{-1}$.

Table 12. Measurements for lamb meat in the Faroe Islands in 1999

	Position			^{137}Cs		K	
Location	N	W	Sampling date	Bq kg^{-1} fresh	St. dev. %	g kg^{-1} fresh	St. dev. %
Bøur	62°05'	07°22'	2 October	6.54	0.9	4.40	1.1
Bøur	62°05'	07°22'	2 October	3.67	1.6	4.33	0.9
Sandur	61°50'	06°49'	22 October	4.77	1.0	3.74	0.7
Sandur	61°50'	06°49'	22 October	4.97	0.8	3.99	0.6

2 References

Aarkrog, A., P. Aastrup, G. Asmund, P. Bjerregaard, D. Boertmann, L. Carlsen, J. Christensen, M. Cleemann, R. Dietz, A. Fromberg, E. Storr-Hansen, N. Zeuthen Heidam, P. Johansen, H. Larsen, G. Beyer Paulsen, H. Petersen, K. Pilegaard, M. E. Poulsen, G. Pritzl, F. Riget, H. Skov, H. Spliid, H. Weihe & W. Wåhlin. 1997. AMAP Greenland 1994-1996. *Environmental Project* **356:** 792pp. Ministry of Environment and Energy, Copenhagen.

Chen, Q. J., Dahlgaard, H. & Nielsen, S. P. (1994). Determination of Tc-99 in Sea Water at Ultra Low Levels. *Analytica Chimica Acta*, 285, 177-180.

Joensen, H. P.: Long-Term Variation of Radiocaesium in the Foodchain of Lamb in the Faroe Islands. *Journal of Environmental Radioactivity* 46 (1999), p. 345-360.

Dahlgaard, H. (1995). Transfer of European coastal pollution to the Arctic: Radioactive tracers. *Marine Pollution Bulletin* 31, 3-7.

5 AMAP Faroe Islands 1997 – 1998

Arctic Monitoring and Assessment Program (AMAP)

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Content

Summary and conclusions

The Faroe Islands have participated in the Arctic Monitoring and Assessment Programme (AMAP) and this report presents results of the samples collected in the period: 1997-1998.
There have been made some analysis of different species and the levels of contaminants can be found in the report. Species from both the marine, terrestrial, and freshwater environments are included, with the main emphasis on the marine environment.

The following species were analysed from the marine environment:

- Blue mussel *Mytilus edulis*
- Queen scallop *Clamys opercularis*
- Cod *Gadus morhua*
- Fulmar *Fulmarus glacialis*
- Grey seal *Halichoerus grypus*
- Pilot whale *Globicephala melas*

The following species were analysed from the terrestrial and freshwater environments:

- Moss *Racomitrium lanuginosum*
- Lichen *Cladonia mitis*
- Sheep *Ovis aries*
- Brown trout *Salmo trutta*
- Arctic char *Salvelinus alpinus*

The different species were analysed for the parameters shown in tables 0.1 and 0.2.

Table 0.1 Overview of the marine programme

Species	Tissue	Heavy metals	Organic Pollutants				Radio-activity	Dw[1)]	Lc[2)]
		Cd, Cu, Pb, Hg	PCB, HCB, HCH, DDT	PAH	Chlordanes	Toxaphenes	^{137}Cs		
Blue mussel	Soft tissue	+	+	+				+	+
Queen scallop	Soft tissue	+	+	+			+	+	+
Fulmar (*pullus*)	Liver	+	+	+				+	+
	Lipid		+	+					+
	Muscle						+		
Fulmar (immature)	Liver	+						+	
	Lipid		+					+	+
	Muscle	+						+	
Fulmar (adults)	Liver	+						+	
	Lipid		+					+	+
	Muscle	+						+	
Cod	Liver	+(-Hg)	+	+	+	+			+
	Muscle	Hg					+	+	
Seal	Liver	+							
	Lipid		+	+	+	+			+
	Muscle	Hg					+	+	
Pilot whale	Lipid		+	+	+	+			+
	Muscle	Cd, Hg					+	+	

[1)]Dw: Dry weight determination
[2)]Lc: Lipid content

Table 0.2 Overview of the terrestrial and freshwater programmes

Species	Tissue	Heavy metals	Organic Pollutants				Radio-activity	Dw[1)]	Lc[2)]
		Cd, Cu, Pb, Hg	PCB, HCB, HCH, DDT	PAH	Chlordanes	Toxaphenes	^{137}Cs		
Moss		+ Al, Se, Zn, Cr, As, V, Ni, Fe					+	+	
Lichen		+ Al, Se, Zn, Cr, As, V, Ni, Fe					+	+	
Sheep (adults)	Liver	+	PCB		+			+	+
	Lipid		PCB		+				+
	Muscle	+					+	+	
Lamb	Liver	+	PCB		+			+	+
	Lipid		PCB		+			+	
Trout	Liver	+(-Hg)	+	+	+	+			+
	Muscle	Hg					+	+	
Arctic char	Liver		+						+
	Muscle	Hg						+	

[1)]Dw: Dry weight determination
[2)]Lc: Lipid content

1 Introduction

The first phase of the circumpolar Arctic Monitoring and Assessment Programme was initiated in 1993 - without participation from the Faroe Islands. In 1995 the Danish Ministry of Foreign Affairs and the Faroese Government decided that the Faroes should be included in the AMAP area, as suggested by the AMAP steering committee.

AMAP first part, 1993 to 1997, was subdivided into five compartments:

- Human health
- Marine biosystem
- Terrestrial biosystem
- Atmosphere
- Radioactivity

Leading countries were assigned to follow up on the data collection and the programme progress in the various compartments. Denmark was leading country in the Human health compartment. Major parts of the work on studying effects of environmental toxins on especially children have been performed in the Faroes parallel to the AMAP programme. The exposure data of Faroese mothers and their children have been submitted to AMAP, and have constituted the Human health part of the Faroese AMAP participation.

The present report, summarises the findings of a project that was undertaken by the Food and Environmental Agency of the Faroes in 1997. The main focus of the project has been the marine environment, but some biota from the terrestrial and freshwater compartments have also been included. The emphasis has been on providing the chemical data, and these are presented here, in this context two species, the fulmar and Arctic char, have got a more detailed study, where the data are treated and compared with other countries. Also, one effect study has been done as part of this AMAP programme, this was to uncover and describe the occurrence of imposex in dogwhelks. This project was published separately, in "Levels and effects of organotin compounds in the Faroese coastal zone," Følsvik *et al.,* Fróðskaparrit 1998, Føroya Fróðskaparfelag, (in English).

In addition to or in replacement of, the biological indicator species that were described in the internationally adopted AMAP guidelines, some species have been included to support the assertion of the exposure data needed in the Human health assessment. These are typically part of the traditional food and are under suspicion of being important as transport routes for environmental pollutants. However, except from the results of the pollutant analyses on these species, this report does not cover the work done in the Human health area. That part is covered through the participation of the Department of Occupational and Public Health in the Faroe Islands. Excluded in this report is also any work done by institutions outside the Faroes in pursuit of the same common AMAP task.

There are other projects undertaken by the Food and Environmental Agency that could be of relevance in the context of AMAP studies, these are listed in groups 1 to 5 below. The results of the first two are presently available as draft versions in Danish with English summaries. The project listed third is under preparation and will be available later this year. The inventories covering heavy metals and POPs are available as unpublished material from the Food and Environment Agency.

1. "Measurements of environmental toxins in a selection of indicator species from the Faroese marine environment"

2. "What is the diet of black guillemot, common eider and shag in the Faroes, and what is the concentration of pollutants in these birds?"

3. "Integrated ecological monitoring in the coastal zone; environmental pollutants"

4. Inventories of results of heavy metal and organic pollutant analyses on Faroese material were made in 1995. A selection of the most recent of these data were published in "Føroya Umhvørvi í tølum 1997".

5. Integrated ecological monitoring in a terrestrial ecosystem. "Norðuri á Fossum"; a report on the establishment of the reference station for the terrestrial monitoring programme is available from the Food and Environmental Agency.

The projects numbered 1 to 3 above are relevant to the marine compartment, project number 5 is relevant to the terrestrial biosystem and to a certain extent to the atmosphere part. The report mentioned under project number 4, is a combination of data representing the state of the environment in the marine, the terrestrial and the freshwater ecosystems.

Brief outline of projects 1 to 3

Generally, the guidelines valid for AMAP have been followed also in these projects, with respect to selection of tissues for analyses, in the choice of pollutants analysed, in the quality of performance demanded from the contracted laboratories, as well as in the analysis of pooled samples consisting of sub-samples from a certain number of individuals. However, the aim of these projects have been more extended towards shedding some light on the extent of and the cause for, natural, seasonal variations in addition to the assessment of the overall level of contaminants in the species. In AMAP the detection of trends in distribution (spatial trends) was one of the major issues, whereas the individual variations at the various locations were not offered special attention. Another deviation from the AMAP guidelines which is general for the projects outlined here, is that the analysis of copper has been included and that of selenium has been omitted.

"Measurements of environmental toxins in a selection of indicator species from the Faroese marine environment".
Project period: 1995 – 1997.

The selection of indicator species analysed in this project were:

- kelp *Laminaria hyperborea*
- blue mussel *Mytilus edulis*
- starfish *Asteria rubens*
- dab *Limanda limanda*
- long rough dab *Hippoglossoides platessoides*
- common eider *Somateria molissima*

As a whole, the concentrations of environmental toxins were low and comparable to those found in similar species in Spitsbergen and Greenland. The concentrations were generally somewhat higher during springtime than in the autumn, though this was not always seen, an exception is for instance the PCB concentrations in common eider.

Table 1.1. PCB and DDE in indicator species from the Faroese marine environment.

species	Location	tissue	Number of ind.	PCB 7 mg/kg lipid	relative	DDE mg/kg lipid	relative
blue mussel	Svínáir	Soft parts	210	0,20	1	0,12	1
dab	Kirkjubøur	Liver	60	0,20	1	0,10	1
long rough dab	62°53´N - 09°06´W	Liver	55	0,31	2	0,21	2
common eider adults	Kaldbak	Liver	30	0,94	5	0,42	4

PCB 7 = CB 28, CB 52, CB 101, CB 118, CB 153, CB 138 and CB 180. DDE = *p,p´*-DDE

"What is the diet of black guillemot, common eider and shag in the Faroes, and what is the concentration of pollutants in these birds?"
Project period: 1995 – 1997.

These birds have certain common features, they are

-sea birds, which
-stay in the Faroe Islands throughout the year, and
-are confined to the coastal zone all year round.

The study comprising 142 black guillemots *Cepphus grylle*, 106 common eiders *Somateria molissima*, and 40 shags *Phalacrocorax aristotelis*, showed that:

- The highest pollution load was found in shags, as was indeed expected. The black guillemots came next, and the lowest levels were found in the common eiders. The last statement must however be modified to allow for the very high levels of copper that was found in the liver of common eiders. But this copper content has also been found in Spitsbergen and is thought to stem from food sources or the metabolism in these birds and is thus, at least so far, not to be considered as stemming from pollution.

- The concentrations of organochlorines in the Faroese birds are very similar to those found in Spitsbergen and Greenland, and are lower than what is found closer to more densely populated and industrialised areas in Europe.

- The relative contribution of the three dominant PCB congeners, IUPAC nos 138, 153 and 180, was fairly constant among birds of different age and sex classes, and between the three bird species.

Common eiders, 10 females and 5 males shot in April 1996, all adults, were analysed separately for heavy metal concentrations in the liver. In addition, livers from 8 females from August 1996 and the 5 males from April were analysed separately for POP including toxaphene. These birds were chosen because the analysis of the pooled samples had identified these groups as the ones with the highest contaminant burdens among the females and males, respectively.

The results in the sub-sample of 15 eiders from April, proved that there are dramatic differences in copper concentrations, with the lowest result 7 mg/kg w.w. and the highest 1049 mg/kg w.w. Cadmium concentrations varied from 1 to 8 mg/kg w.w. and lead from 0,02 to 1,0 mg/kg w.w. liver. There were also marked differences in organochlorine concentrations with the lowest PCB 7 concentration equal to 0,7 mg/kg lipid and the highest 4,0 mg/kg lipid, the lowest concentration was found in a 3K+ male, and the highest in a female. The concentration of *p,p'*-DDT was very similar for the two groups, with a mean equal to 7 µg/kg lipid for the females and males. The geometric mean concentrations of *p,p'*-DDE were on the other hand almost twice as high in the female group as in that of the males, equal to 517 µg/kg lipid in the former and 283 µg/kg lipid in the latter.

The results also showed that there is not a direct correlation between the doses of the various pesticides or organochlorines; for instance the two bird with the highest *p,p´*-DDE concentrations (both females) had the lowest PCB burden among the females.

Table 1.2. Overview over pooled sample results for the three bird species. All the results are presented in wet weight.

Geo. mean values	Common eider	Black guillemot	Shag
POPS IN µG/KG			
matrix	adults, 1996	adults, 1995/96	adults, 1996
Number of individual	35	56	7
lipids, weight %	2,40	4,06 (3,39 - 4,94)	4,9 (4,4 - 5,5)
PCB 7, µg /kg	19 (12 – 37)	37,7 (17 - 94,2)	116,2 (111,5 - 121,2)
p,p´-DDE	9,41 6,1 - 16,6	11,7 (7,4 - 30,6)	37 (36,5 - 37,5)
HCB	0,97 (0,6 - 1,4)	2,82 (1,7 - 7,9)	3,6 (3,1 - 4,1)
METALS IN MG/KG			
matrix	adults, 1996	adults and juveniles 1995/96	adults and juveniles, 1996
Number of individual	35	88	40
dry weight g/100g	29,6 (28,5 - 30,3)	31,5 (29,8 - 33,1)	29,3 (27,1 - 30,7)
lead	0,04 (0,02 - 0,11)	<0,03* (<0,02 - 0,21)	<0,02 (<0,02)
mercury	0,23 (0,06 - 0,68)	0,74 (0,38 - 0,97)	0,41 (0,12 - 0,76)
cadmium	3,8 (2,73 - 5,26)	1,13 (0,69 - 1,73)	0,43 (0,15 - 1,21)

* the results given as <0,02 (the usual detection limit) were set to be equal to the detection limit during the calculation of the geometric mean values. The results are therefore given here as less than this geometric mean.

The last project which is relevant to mention in this context, is the method development programme with participation from Iceland, Faroe Islands and Norway, where the main aim was to describe the effects of lifecycle processes on the levels of environmental toxins for biota in the coastal zone.

"Integrated ecological monitoring in the coastal zone; environmental pollutants".
Project period: 1995 – 1998.

The selection of species in this programme was:
- kelp *Laminaria hyperborea*
- blue mussel *Mytilus edulis*
- limpet *Patella vulgata*
- dab *Limanda limanda*
- black guillemot *Cepphus grylle*

In addition to these primary indicator species which were submitted to a more comprehensive analysis, both with respect to biological and chemical parameters, some analyses were also made on the following species:
- ❖ sea urchin *Echinus esculentus*
- ❖ grey topshell *Gibbula cineraria*
- ❖ banded chink shell *Lacuna divericata (L. vincta)*

The parameters that were recorded differed among the species. However, in general terms attempts were always made to describe the parameters for all species, that is the lengths and sizes, that are either known to or are at least thought to affect the level of pollutants. In cases where diet studies were feasible, they were also made.

The project as such is in the completing phase, but a new phase comprising a more pronounced biological effects compartment is in preparation, and will probably be launched in 2000 as a Nordic co-operation project.

"Integrated ecological monitoring in a terrestrial ecosystem. "
Project period: 1996 – continuing.

The reference station, Norðuri á Fossum, was established according to the programme guidelines of the Long Range Transboundary Air Pollution protocol of UN/ECE. The activities on the site are not of the intensive type, as defined in the programme guidelines, but are more comprehensive than the biological type.
The international programme was established to meet the needs for a systematic, integrated monitoring that would enable a thorough description of the magnitude and the development of the acid rain complex. Thus parameters like sulphate and nitrogen containing species were and remain the main focus. The ongoing activities at the Faroese reference station are;

- chemical analysis on precipitation (three times a year)
- chemical and bacteriological analysis of runoff water (parallel to the analyses on precipitation)
- chemical analysis on soil, in three segments of the soil profile
- temperature monitoring (hourly, at surface and in soil at depths –10 and –30 cm)

In addition to these activities carried out by the Food and Environmental Agency, other institutions are involved in the project, they are

- The Botanical Department of the Faroese Museum of Natural History, which has described the vegetation in the area as part of this project.
- The Geological Department of the Faroese Museum of Natural History, which is responsible for the soil profile description.

Further, the State Engineer, LVF, has continuous runoff monitoring from the site. This means that the site as such is very well defined hydrologically, and this was really the main attraction of the area when the reference station was chosen in 1996.
The electricity company, SEV, also has strong interests in the area; the runoff water from the site is used as input in the electricity production in Vestmanna. Therefore precipitation in the area is of interest to the company, which therefore does precipitation monitoring in the area in co-operation with Denmark Meteorological Institute.

2 Chemical analysis

2.1 Pre-treatment

Prior to analysing the various tissue samples pooled samples were made. Only sheep liver has been analysed on an individual basis. The pooled samples were homogenised with a Warning blender in a glass vessel with a stainless steel knife. Following homogenisation the most of the samples were stored in heat-treated glass jars.

2.2 Heat-treatment

We were advised that the best containers for samples are glass jars with screw caps, with a sheet of aluminium foil placed under the lid. The jars as well as the aluminium foil, were heated to 400°C and kept at this temperature for 4 hours. The lids were not given the heat treatment, but the samples were never in direct contacts with these.

2.3 Heavy metals and dry-weight percentage

All metal analyses and determinations of dry-weight percentage were carried out at the Food and Environmental Agency in the Faroe Islands. Exempt from this were samples of moss and lichen which were analysed in Finland.

Copper, cadmium and lead were analysed with atom absorption on either graphite (Perkin Elmer 1100B) or flame (Perkin Elmer 2380) depending on the content of the examined material. Hg was analysed on a Perkin Elmer 2380 + MHS 10 (Mercury Hydrid System). The determination of the dry-weight percentage was based on the loss of mass after 10 to 20 hours at 105°C.

Quality assurance: Double determinations were performed. A certified reference material and a blank sample were analysed in connection with each series. The certified reference material and the blank were destroyed in the same manner as the samples. A 4-point standard curve was always made. The laboratory participates in regular intercalibration, for example Quasimemes (quality assurance of information for marine environmental monitoring in Europe).
In connection with performing the analyses the laboratory was accredited to the following analyses: mercury, lead, cadmium and dry-weight. Later the laboratory has also been accredited to copper.

The metal analysis on moss and lichen were carried out at the Geological Survey of Finland. The samples were destroyed with nitric acid in a microwave oven. The concentrations of Al, Cd, Cr, Cu, Fe, Ni, Pb, Se and Zn were determined by ICP-MS (Inductively Coupled Plasma – Mass Spectroscopy). Hg was determined by HAAS. The laboratory is accredited to carry out all of the above metal analyses.

2.4 Radioactivity

The analyses were done by the Faculty of Science and Technology in the Faroe Islands. Cesium-137 was measured with radiation spectroscopy with a lead shielded Ge-detector. The software, OMNIGAM from EG&G Ortec, was used to calculate the cesium-137 activity. The samples were placed in boxes on top of the detector. The diameter of the boxes was equal to that of the detector.

2.5 PCB, pesticides, toxaphene, chlordane, PAH and lipid determinations

Blue mussels, queen scallops and fulmars were analysed by NIVA (Norwegian Institute for Water Research), which is accredited to PCB and pesticide determinations. First the samples were homogenised at the Food and Environmental Agency in the Faroe Islands. The homogenised samples were stored in heat-treated jars, frozen and sent to NIVA. NIVA freeze-dried the homogenised samples and added CB-53 as internal standard. The samples were extracted in two relays with a mixture of cyclohexan and acetone by means of ultrasound disintegration. Then the samples were centrifuged. The centrifugate was evaporated to dryness for lipid determination. Parts of the lipids were weighed out and dissolved in cyclohexane. The sample was purified/saponified with concentrated sulphuric acid. The extract was evaporated to the desired volume in heat-treated jars. The quantitative determination of PCB and pesticides was carried out on a gas chromatograph with a 50 m capillary column and an electro capture detector (GC-ECD). An 8-point standard curve was used for the quantification and all PCB and pesticide concentrations were within the limits of the standard curve.

The quality of the analysis results was secured by analysing known standards for every ten samples and by analysing a certified reference material, which was processed in the same manner as the samples, at regular intervals. Blind samples were also analysed regularly. A deviation interval of plus/minus 10% on the PCB analyses is realistic for the laboratory.

To determine PAH the sample was processed with a modified vesion of Grimmer and Bøhnke's method[1]. Following homogenisation internal standards were added and the sample was saponified by boiling with KOH/methanol. PAH was extracted from the solution by cyclohexane extraction. The extract was then washed with methanol:water before further purification with dimethyl formamid, water partitioning and chromatography on a silica gel column. PAH was analysed on a gas chromatograph connected to a mass selective detector (GC-MS). The identifications are based on retention time and/or significant ions. Quantification takes place by means of the internal standards.

Quality assurance: The analysis methods are controlled by analysing reference material for sediments and blue mussels with certified concentrations for PAH. The gas chromatograph is regularly recalibrated and is in addition frequently controlled by analysing standards.

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1 Grimmer, G and Bøhnke H.: "Polycyclic Aromatic Hydrocarbon Profile Analysis of High-Protein Foods, Oils and Fats by Gas Chromatography". J. of the AOAC, 58 no. 4, 725-733 (1975).

Cod liver, trout liver, pilot whale blubber and seal blubber were analysed for PCB and PAH at RIVO-DLO (Netherlands' Institute for Fisheries Research). RIVO-DLO is accredited to analyse PCB, chlordane, toxaphene, pesticides, PAH and lipid content. PCB and pesticides were determined by means of GC-ECD and toxaphene and chlordanes were quantified by means of a GC and a mass spectrophotometer with a negative chemical ionisation. HPLC (High pressure liquid chromatography) was used to determine PAH. The quality of the analyses was secured by participating in intercalibrations and by regular analysis on certified reference material, in addition control was made by blanks and recovery.

Sheep liver and lipids were analysed at Le Centre de Toxicologie du Québec, CTQ, in Canada.
The entire sample was homogenised to a uniform consistency with a laboratory homogeniser (Virtix). Aliquots of tissue (1 g for fat or 4 g for liver and lamb) where homogenized with a mechanical homogeniser (Polytron) in the presence of methylene chloride, 3 g of anhydrous sodium sulfate and 10 ng of the internal standard, CB no. 198.

Determination of lipid content: 10 ml of the methylene chloride extract is pipetted into a tared aluminium cup, which is allowed to concentrate to dryness in a ventilated oven at 30°C.
The sample was then defatted using gel permeation chromatography (GPC), and evaporated to ~1 ml. The extract was cleaned up by column chromatography on Florisil deactivated (0.5%). PCBs, toxaphene and organochlorinated pesticides were eluted with 10 ml of hexane/methylene chloride (75:25). The eluent was reduced to ~1 ml on a "Speed-Vac" evaporator. This volume was taken to 100 µl by its sequential transfer to a 0.2 ml vial and by evaporation with the aid of a jet of nitrogen at 40 °C.
PCBs and organochlorinated pesticides were analyses on an HP-5890 gas chromatograph equipped with dual capillary columns split-splitless injector and dual ^{63}Ni electron capture detectors.
Depending on the lipid content and the available quantity of tissues, quantification limits varied in adipose tissues from 0,3 to 0,9 µg/kg and in liver and lamb/bird tissues from 3 to 14 µg/kg.

For each batch of samples two standards are used. The first standard is used to check column performance and detector sensitivity and it is a non-extracted verification standard in hexane containing PCB congeners and organochlorinated pesticides at 5 µg/kg. The other standard is a calibration standard extracted in hexane containing PCB congeners and organochlorinated pesticides at 5 µg/kg. This standard is used to calculate the relative response factors for all the compounds.
One method blank and one reference control (cod liver oil) was analysed per batch of samples. A contamination which exceeds by 10% of the desired detection limit for any of the product invalidates the results for the batch concerned. The normal quality protocol includes duplicate analyses on 10% of the samples.
Peaks were identified by their relative retention times (RRT) obtained on the two columns, using a computer programme developed at CTQ. The identification window was 0.001.

Precision:

- For PCB congeners: 5 to 21%.
- For organochlorinated pesticides: 6 to 16%.
- For Aroclor 1260: 6,4%.

The method for converting congener data to Aroclor 1260 is empirical. It is based on results obtained from the analysis of human blood plasmas in which quantification were done using both an Aroclor 1260 standard and single congener standards[2]. The best fit between the single congener results and the PCB as Arochlor 1260 results was found using the sum of congeners 138 and 153 multiplied by a factor. This factor was close to 5 and this is also similar to that in the original technical product[3].

2.5.1 Definition of some abbreviations

In some tables, PCB results are shown as the "Seven Dutch" or PCB 7. The Seven Dutch is the sum of the concentrations of the PCB congeners, IUPAC nos. CB 28, CB 52, CB 101, CB 118, CB 138, CB 153.
Among other abbreviations used in the report are HCBD = hexachloro-butadiene, QCB = pentachlorobenzene, and HCB = hexachlorobenzene.

[2] J.-P. Weber, CTQ, personal comm.
[3] B. Luckas, W. Vetter, P. Fisher, G. Heidemann and G. Plötz, Chemosphere 21 (1990) 13-18.

Marine environment

Blue mussel *Mytilus edulis*

Queen scallop *Clamys opercularis*

Cod *Gadus morhua*

Fulmar *Fulmarus glacialis*

Grey seal *Halichoerus grypus*

Pilot whale *Globicephala melas*

3 Blue mussel (*Mytilus edulis*)

3.1 Sampling

Blue mussels were sampled in Kaldbak in November 1997. The mussels were found close to the mouth of Týggjará near a fish farm. A total of 57 mussels were collected.

3.2 Pre-treatment

The blue mussels were left in sea water overnight. The height and length of each mussel were measured before they were cut open and drained for a minimum of 5 minutes. The soft tissue was used for the pooled sample. The homogenised sample was stored in heat-treated jars.

Table 3.1 shows shell index and length of the blue mussels to indicate their size. The shell index is found by dividing the length of the mussel with the height (modified after R Seed.[4]).

Table 3.1. Length and shell index of blue mussels

	Shell index	Length
Mean	2,3	3,7 cm
Min.	1,9	3,0 cm
Max.	2,7	4,6 cm

3.3 Results

3.3.1 Heavy metals

Table 3.2 contains an overview of the lead, cadmium, copper and mercury contents of blue mussels.

Table 3.2 Heavy metals in blue mussels (mg/kg wet weight)

Parameters	Blue mussel
Number in pooled sample [pcs]	57
Dry weight [g/100g]	19,9
Pb	0,27
Cd	0,17
Cu	5,00
Hg	0,03

[4] R. Seed , "Factors influencing shell shape in the mussel *Mytilus edulis",* Rep. J. Mar. Biol. Ass. U.K. (1968) 48, pp. 561-584

3.3.2 Persistent organic pollutants

The PCB and pesticide contents of blue mussels are shown in tables 3.3 and 3.4.

Table 3.3 PCB in blue mussels (µg/kg wet weight)

Parameters	Blue mussel
Number in pooled sample [pcs]	57
Lipid content [weight %]	1,97
CB 28	<0,1
CB 52	0,1
CB 101	0,2
CB 118	0,2
CB 153	0,7
CB 105	0,2
CB 138	0,4
CB 156	<0,2
CB 180	0,3
CB 209	<0,2
Sum PCB	2,1
Seven Dutch	1,9

Table 3.4 Pesticides in blue mussels (µg/kg wet weight)

Parameters	Blue mussel
Number in pooled sample [pcs]	57
Lipid content [weight %]	1,97
Pentachlorobenzene	<0,1
Hexachlorobenzene	<0,1
α-HCH	<0,1
γ-HCH	0,1
Oxychlordane	<0,1
p,p'-DDE	0,7
p,p'-DDD	0,2
p,p'-DDT	0,4

3.3.3 Polycyclic aromatic hydrocarbons

The PAH content of blue mussels is shown in table 3.5.

Table 3.5 PAH in blue mussels (µg/kg wet weight)

Parameters	Blue mussel
Number in pooled sample [pcs]	57
Naphthalene	<0,5
2-Methyl-Naphthalene	0,8
1-Methyl-Naphthalene	0,7
Biphenyl	<0,5
2,6-Dimethylnaphthalene	7,9
Acenaphthylene	0,9
Acenaphthene	0,6
2,3,5-Trimethylnaphthalene	<0,5
Fluorene	2
Phenanthrene	11
Antracene	1,3
Fluoranthene	9,6
Pyrene	8,1
Benz(a)anthracene*	1,2
Chrysene/Triphenylene	3,3
Benzo(b)fluoranthene*	2,7
Benzo(jk)fluoranthene*	<0,5
Benzo(e)pyrene	3,5
Benzo(a)pyrene*	<0,5
Perylene	0,5
Indeno(123cd)pyrene*	0,5
Dibenz(ah)anthracene*	<0,5
Benzo (ghi)perylene	0,9
Sum PAH	55,5
Sum KPAH (*)	4,4
Sum KPAH as % of sum PAH	7,9
Dry weight g/100g	19,7

*Indicates potential carcinogen properties for humans according to IARC (1987). The asterisk marked compounds are listed in IARC's categories 2A or 2B (likely or potential carcinogens)

4 Queen scallop (*Chlamys opercularis*)

4.1 Sampling

Queen scallops were taken by a scallop fishing vessel at Húsagrynnan, a bank north east of Nólsoy. The main sampling took place in September 1997 when 56 scallops were collected at position 62°06'00N 6°28'51W (Queen scallop 1) and 50 were collected at position 62°04'30N 6°37'70W (Queen scallop 2). As there was not sufficient material for the radioactivity measurements, another 50 scallops were collected north east of Nólsoy in November 1997.

The queen scallops were landed on the day they were caught. They were stored at <-18°C in polyethylene bags until sample pre-treatment.

4.2 Pre-treatment

The samples were cut from semi-thawed scallops. The length of the shells was measured on 20-25 scallops. The mean length and the length of the biggest and smallest individual scallops from this sub-sample are given in table 4.1.

Table 4.1. Queen scallop shell length

Parameters	Queen scallop 1	Queen scallop 2	Queen scallop 3
Date	September 1997	September 1997	February 1998
Position	62°04'30N 6°37'70W	62°06'00N 6°28'51W	NE of Nólsoy
Mean length [cm]	6,2	6,3	6,1
Min [cm]	5,5	5,5	5,5
Max [cm]	7,5	7,3	6,8

20 intact queen scallops were weighed. The muscles were used for the analyses. They were cut from the shells with a scalpel. The small membrane which covers the muscle was removed to avoid sand in the sample.

The muscles were homogenised to pooled samples and stored in heat-treated jars at <-18°C until analysis.

4.3.1 Heavy metals

The heavy metal contents of scallops 1 and 2 were determined (table 4.2).

Table 4.2 Heavy metals in queen scallops (mg/kg wet weight)

Parameters	Queen scallop 1	Queen scallop 2
Number in pooled sample [pcs]	56	50
Dry weight [g/100g]	23,1	22,5
Cd	0,42	0,42
Cu	0,67	0,49
Hg	<0,02	<0,02
Pb	0,093	0,036

4.3.2 Persistent organic pollutants

The PCB content of queen scallops 1 and 2 is shown in table 4.3 and the pesticide content is shown in table 4.4.

Table 4.3 PCB in queen scallops (µg/kg wet weight)

Parameters	Queen scallop 1	Queen scallop 2
Number in pooled sample [pcs]	56	50
Lipid content [weight %]	0,06	0,03
CB 28	<0,1	<0,1
CB 52	<0,1	<0,1
CB 101	<0,1	0,4
CB 118	<0,1	0,2
CB 153	0,1	0,1
CB 105	0,1	0,3
CB 138	<0,1	0,4
CB 156	<0,1	<0,1
CB 180	0,2	<0,1
PCB 209	<0,1	<0,1
Sum PCB	0,4	1,4
Seven Dutch	0,3	1,1

Table 4.4 Pesticides in queen scallops (µg/kg wet weight)

Parameters	Queen scallop 1	Queen scallop 2
Number in pooled sample [pcs]	56	50
Lipid content [weight %]	0,06	0,03
Pentachlorobenzene	<0,1	<0,1
Hexachlorobenzene	<0,1	<0,1
α-HCH	<0,1	<0,1
γ-HCH	0,1	<0,1
Oxychlordane	<0,1	<0,1
p,p'-DDE	0,2	<0,1
p,p'-DDD	0,3	<0,1
p,p'-DDT	<0,1	<0,1

4.3.3 Polycyclic aromatic hydrocarbons

The PAH content of queen scallops is shown in table 4.5.

Table 4.5 PAH in queen scallops (µg/kg wet weight)

Parameters	Queen scallop 1	Queen scallop 2
Number in pooled sample [pcs]	56	50
Naphthalene	<0,5	<0,5
2-Methyl-Naphthalene	<0,5	<0,5
1-Methyl-Naphthalene	<0,5	<0,5
Biphenyl	<0,5	<0,5
2,6-Dimethylnaphthalene	0,5	0,5
Acenaphthylene	<0,5	<0,5
Acenaphthene	<0,5	<0,5
2,3,5-Trimethylnaphthalene	<0,5	<0,5
Fluorene	<0,5	<0,5
Phenanthrene	<0,5	<0,5
Antracene	<0,5	<0,5
Fluoranthene	<0,5	<0,5
Pyrene	<0,5	<0,5
Benz(a)anthracene*	<0,5	<0,5
Chrysene/Triphenylene	<0,5	<0,5
Benzo(b)fluoranthene*	<0,5	<0,5
Benzo(jk)fluoranthene*	<0,5	<0,5
Benzo(e)pyrene	<0,5	<0,5
Benzo(a)pyrene*	<0,5	<0,5
Perylene	<0,5	<0,5
Indeno(123cd)pyrene*	<0,5	<0,5
Dibenz(ah)anthracene*	<0,5	<0,5
Benzo(ghi)perylene	<0,5	<0,5
Sum PAH	0,5	0,5
Sum KPAH (*)		
Sum KPAH as % of sum PAH		
Dry weight g/100g	23,4	22,8

* Indicates potential carcinogen properties for humans according to IARC (1987). The asterisk marked compounds are listed in IARC's categories 2A or 2B (likely or potential carcinogens)

5 Fulmar (*Fulmarus glacialis*)

Two separate studies were made on fulmar in AMAP context, and they are presented separate below as *study 1* and *study 2*.

Study 1

5.1 Sampling

Fulmars form part of the traditional Faroese diet and large numbers of both young fulmars and adults are taken each year for consumption. At the end of August and the beginning of September the young fulmars leave their nests, which are built on steep mountain sides and sit on the surface of the sea until they have lost sufficient weight to be able to fly. The birds are caught by nets while they lie on the surface of the sea.

In September 1997, 15 young fulmars were caught in the vicinity of the village of Vestmanna and 25 were caught north east of Nólsoy. The birds were skinned and frozen in plastic bags awaiting sample pre-treatment.

5.2 Pre-treatment

The young fulmars were weighed individually without feathers and intestines. The weight of the individual liver was registered.

The right liver lobes were used for the pooled sample (approx. 5-11 grams). Samples of subcutaneous fat were also taken. No subcutaneous fat was found in three of the birds caught near Vestmanna. The samples were homogenised and stored in heat-treated glass jars at <-18°C until analysis.

Muscle samples for the radioactivity measurements were taken from the bird legs. The samples were stored in plastic bags at <-18°C until analysis.

5.3 Results

5.3.1 Heavy metals

The lead, copper, cadmium and mercury contents of the fulmar livers are shown in table 5.1.

Table 5.1. Heavy metals in young fulmars (mg/kg wet weight)

Parameters	Vestmanna	Nólsoy
Matrix	Liver	Liver
Number in pooled sample [pcs]	15	25
Dry weight [g/100g]	29,2	29,1
Cd	0,40	0,38
Cu	13,7	9,76
Hg	0,11	0,19
Pb	<0,15	<0,15

5.3.2 Persistent organic pollutants

The PCB and pesticide contents in the liver and lipids of the young fulmars are shown in tables 5.2 and 5.3.

Table 5.2. PCB in young fulmars (µg/kg wet weight)

Parameters	Vestmanna		Nólsoy	
Matrix	Liver	Subcutaneous fat	Liver	Subcutaneous fat
Number in pooled sample [pcs]	15	12	25	25
Lipid content [weight %]	6,25	87,5	6,46	86,9
CB 28	1,3	8,5	0,5	10,2
CB 52	0,2	3,7	0,2	3,6
CB 101	1,4	17,4	0,6	14,0
CB 118	33,6	181	7,5	147
CB 153	90,8	426	19,0	375
CB 105	11,3	57,1	2,7	49,9
CB 138	49,3	258	10,8	217
CB 156	6,6	37,1	1,3	29,5
CB 180	38,3	195	8,0	162
CB 209	1,9	3,8	1,0	4,1
Sum PCB	234,7	1187,6	51,6	1012,3
Seven Dutch	214,9	1089,6	46,6	928,8

Table 5.3. Pesticides in young fulmars (µg/kg wet weight)

Parameters	Vestmanna		Nólsoy	
Matrix	Liver	Subcutaneous fat	Liver	Subcutaneous fat
Number in pooled sample [pcs]	15	12	25	25
Lipid content [weight %]	6,25	87,5	6,46	86,9
Pentachlorobenzene	0,6	7,1	0,1	5,6
Hexachlorobenzene	17,7	132	5,6	105
α-HCH	0,2	5,2	0,1	4,5
γ-HCH	0,3	2,0	0,2	2,5
Oxychlordane	1,8	3,8	0,5	4,4
p,p'-DDE	102	1540	22,0	508
p,p'-DDD	11,0	46,5	1,5	19,2
p,p'-DDT	28,0	373	7,1	214

5.3.3 Polycyclic aromatic hydrocarbons

The PAH content of the young fulmars is given in the following table.

Table 5.4. PAH in the liver of young fulmars (µg/kg wet weight)

Parameters/Place	Vestmanna	Nólsoy
Number in pooled sample [pcs]	15	25
Naphthalene	2,9	0,7
2-Methyl-Naphthalene	1,9	<0,5
1-Methyl-Naphthalene	1,6	<0,5
Biphenyl	<0,5	<0,5
2,6-Dimethylnaphthalene	<0,5	0,6
Acenaphthylene	<0,5	<0,5
Acenaphthene	<0,5	<0,5
2,3,5-Trimethylnaphthalene	<0,5	<0,5
Fluorene	<0,5	<0,5
Phenanthrene	1,2	<0,5
Antracene	0,5	<0,5
Fluoranthene	<0,5	<0,5
Pyrene	<0,5	<0,5
Benz(a)anthracene*	<0,5	<0,5
Chrysene/Triphenylene	<0,5	<0,5
Benzo(b)fluoranthene*	<0,5	<0,5
Benzo(jk)fluoranthene*	<0,5	<0,5
Benzo(e)pyrene	0,8	<0,5
Benzo(a)pyrene*	<0,5	<0,5
Perylene	<0,5	<0,5
Indeno(123cd)pyrene*	<0,5	<0,5
Dibenz(ah)anthracene*	<0,5	<0,5
Benzo (ghi)perylene	<0,5	<0,5
Sum PAH	8,9	1,3
Sum KPAH *		
Sum KPAH as % of sum PAH		
Dry weight g/100g	28,7	28,1

* Indicates potential carcinogen properties for humans according to IARC (1987). The asterisk marked compounds are listed in IARC's categories 2A or 2B (likely or potential carcinogens).

Study 2

5.4 Introduction

Analyses carried out at the National Environmental Research Institute in Denmark in 1989 (Cederberg, 1998) revealed high concentrations of PCB in fat from Faroese fulmars. These studies were recently re-read to evaluate the intake of environmental toxins in the Faroese diet both that which follows consumption of sea birds and the intake which stems from the marine mammal part of the diet. Details on the material analysed in 1989 have unfortunately been lost in the course of the years, even the number of birds analysed is unknown but recollections indicate "a few birds". The results of the 1989 analyses[5] were 21,9 mg/kg PCB (as Aroclor 1260) in fulmar fat and 1,55 mg/kg in fulmar eggs, the concentrations of *p,p´*-DDE in these samples were 8,09 and 0,372 mg/kg in fat and eggs, respectively. These concentrations are so high that even though there are large uncertainties in both the characteristics of the material analysed and in the interpretation of the PCB results given as Aroclor equivalents compared to the present day custom as concentrations of single-congeners content, it still poses the question of whether in fact fulmars are a source of the POPs (persistent organic pollutants) as important as pilot whale blubber, at least to frequent consumers of fulmar.

Apart from being a possible threat to public health, it is disturbing that so high PCB concentrations were identified in sea birds which primarily are stationary in the Faroe Islands and thus find their food in the Faroese coastal areas.

The fulmar is a typical scavenger; it eats what it finds and as it is a poor diver it often lies in the wake of fishing boats to catch the fish guts which are thrown out (Jensen, 1998). These scavenger eating habits have been the main reason why fulmars have not been included in Faroese environmental surveys, because the bird which is used as indicator organism must have a well-defined food choice so that any changes will reflect an actual change in the environmental toxin content and not only a change in eating habit.

As mentioned above however, the fulmar is interesting when evaluating the environmental toxin content in the Faroese diet, especially because the quantity of *pullus* (*nátaungar*[6]) which are caught every year is considerable. The number of *pullus* taken for consumption has been estimated to be 150,000 birds (Olsen, 1998). In study 1 in this chapter, PCB and pesticide analyses were carried out on *pullus*. The results of that study did not cause any particular concern. However, the fact that the PCB content of a hardly fledged *pullus* corresponds to that of an old cormorant, indicates that there might be reason to pursue this subject, especially because the content of non-degradable substances tends to increase with age. Thus it became probable that the content of these substances in adult fulmar in general and not only as odd examples, could prove to be in the range defined by Cederberg's PCB-results (1989) which must be considered alarming in a food safety context.

[5] The 1989 result table also contains data on DDT, dieldrin, α-, β- and γ-HCH, HCB as well as heptachlorepoxide.
[6] *Nátaungar* are young fulmars which have left their nests, but which are too heavy to fly.

5.5 Material and methods

5.5.1 Collection and pre-treatment

The collection of fulmars both immature and adult birds, took place in Nólsoy in 1998. Later they were analysed for heavy metals such as mercury and cadmium and for organochlorinated environmental toxins. The results for the *pullus* caught in 1997 (study 1 in this chapter) are shown in comparison. They were caught in Vestmanna (15 birds) and to the north east of and on the island of Nólsoy (25 birds). A total of 65 birds were analysed, including the 40 *pullus* from the earlier study. In 1998 the birds were caught in the traditional way, that is the birds were caught on the cliffs with *fleygingarstong* (a rod with a net at the end, analogous to a landing-net). The young, unfledged birds from the 1997 study were caught directly from the surface of the sea. This type of catching only takes place over a period of approx. two weeks each year when the *pullus* are too heavy to fly. As can be imagined there is a lot of fat on these *pullus*, it is however difficult to say exactly how much without preceding studies, but a rough estimate is in the range of 100 g per bird. A study of how much fat there is in fulmars in various age groups is ongoing[7].

Fulmars are notorious for carrying microbes (*Chlamydia psittaci)* which can cause the feared psittacosis, *havhestasjúka*. Consequently certain precautions are normally taken when handling these birds. Fifty years ago there were several outbreaks of psittacosis, the disease proved to be particularly serious for pregnant women. Therefore, it became common practise that only men handled the fulmars until they were ready to cook and non-infectious; that is plucked or skinned and salted (Joensen, 1998). The fact however, that also other sea birds around the Faroe Islands of which some have been processed at the Food and Environmental Agency in large numbers, carry these infections (Olsen, 1998), and the studying of the Chief Medical Officer's statistics of psittacosis outbreaks (Joensen, 1997), have not commanded that special precautions should be taken when handling fulmars. Pre-treatment and sampling, therefore, took place following the hygiene directions issued by the Chief Medical Officer on how to handle fulmars without risk, available at the pharmacy in Tórshavn.

The whole bird was weighed. Then some body feathers were plucked from the back in the area just between the wings when they are extended (see section 7.5.3). The plumage was opened with a longitudinal cut under the left wing and the bird skinned. Subcutaneous fat was taken from above the breastbone, under the wings and by the thighbones. Then the left pectoral muscle was taken for tissue banking, and the bird was opened to the abdominal cavity. The sex and reproduction history of the bird were determined and the size of the ovary or testicles was registered. Then the liver was cut out and the proventrickle together with 2/3 of the gullet as well as the gizzard, the small hard "muscle stomach" which holds food components which are hard to digest such as shell parts, otoliths and plastic parts, were removed and stored for subsequent studies.

Tissue samples from liver and subcutaneous fat were taken from each individual. In addition, some grams of fat around the intestine, called intestinal fat, were taken from the fat birds. The largest fat deposits were in

[7] A project at the Food and Environmental Agency financed by the Arctic Environment Programme.

particular found in the immature birds. The older birds had a thinner layer of subcutaneous fat and often no visible intestinal fat. The material was sorted in four groups consisting of adult females and males and immature females and males, respectively. The females were sorted based on the appearance of the oviduct. The males were sorted by the largest testicle so that males with a left testicle measuring 10 mm or more lengthways were registered as adults. Regarding a possible *Bursus fabriosus*, the applied sampling method did not allow a routine study of whether it was present or not. This gland is used as an indicator in age determination of birds together with other indicators such as the colour of the plumage, the appearance of the reproduction organ, brood spot on the breast etc.

Pooled samples were made so that a part of the liver from each adult male was analysed as one sample and the subcutaneous fat from these birds was also analysed as one. Correspondingly, pooled samples were made of liver and subcutaneous fat from the adult female birds and of the immature females and males. In addition, pooled samples were made of intestinal fat from the immature males and females to get an impression of whether the organochlorine contents of the two types of fat deposits were identical.

5.5.2 Analysis

Pooled samples of muscle and liver were analysed for the heavy metals mercury (Hg), copper (Cu), lead (Pb) and cadmium (Cd) at the Food and Environmental Agency. The Cd and Pb analyses were carried out by thermal AAS, Cu by flame AAS and Hg was analysed by hydrid AAS. Details on the analyses are found in the Danish Standards manuals; Hg (AAS mod. AOAC (90) 947s264, mod. DIN), Cd (GAAS mod. DS 2210, 2211, DS/EN ISO 5), Pb (GAAS mod. DS 2210, 2211) and Cu (FAAS mod. DS 259, 263). Dry weight was determined by mod. NMKL no 23.

The organochlorines and the lipid content in the liver as well as the lipid tissue were analysed at the Norwegian Institute for Water Research by GC-ECD[8]. Here organochlorines cover: a selection of single PCB (polychlorinated biphenyl) congeners; CBs 28, 52, 101, 105,118, 138, 153, 156, 180 and 209. In addition *p,p´*-DDT, *p,p´*-DDE and *p,p´*-DDD, as well as γ- HCH (lindane), α- HCH (hexachlorohexane), HCB (hexachlorobenzene), QCB (pentachlorobenzene) and OCS (octachlorostyrene) were analysed. PCB 7 is the calculated sum of the measured concentrations of the following congeners: CBs 28, 52, 101, 118, 138, 153 and 180.

Sample treatment and the various steps in the organochlorine determination are in summary:
The homogenised samples are freeze dried, CB-53 is added as internal standard, extracted in two relays with cyclohexane:acetone by means of ultrasound disintegration. Following centrifuging, the centrifugate is evaporated to dryness for lipid determination. A partial quantity of the fat is then weighed out and dissolved in cyclohexane and then cleaned/saponified with concentrated sulphuric acid. The extract is evaporated to the desired volume in heat-treated jars. Then a quantitative analysis of PCB and pesticides is carried out by GC with 50 m capillary column and Electro Capture Detector (ECD). The quantification is based on an 8-point standard curve, and all the concentrations shall be found within the upper and lower

[8] GC-ECD: gas chromatography with electron capture detection.

limits of the curve. Quality assurance of the analyses implies a regular analysis of known standards (once for every ten samples) and analysis of certified reference material processed in the same manner as the samples. Blind samples are also analysed regularly. A deviation interval of plus/minus 10% on the PCB analyses is realistic for the laboratory.

5.5.3 Tissue sample bank

When the necessary quantities for the chemical analysis had been taken, surplus material was taken for environmental sample banking, put in heat treated jars and placed in the freezer at minimum -20°C. In addition to liver, muscle and lipid samples the kidneys and some body feathers were also placed in the tissue bank. The stomachs with content were removed as described earlier in this section and frozen.

5.6 Results

5.6.1 Metals

Table 5.5 shows the results of the metal analyses. The mean values for liver and muscle from the immature and adult fulmars, which were analysed in connection with this study are shown in table 5.6 together with corresponding results for the unfledged birds which were analysed in 1997 (study 1 in this chapter). Lead was not measurable in the fulmars, except in one sample of liver tissue from immature females. This group also had the highest mercury content in the liver, but not in the muscle. Generally, the analysed fulmars have a high cadmium content, especially in the liver.

Table 5.5. Metal concentrations in fulmar (mg/kg wet weight).

	Numbers of individual in pooled samples	Matrix	Dry matter (g/100g)	Hg	Cd	Pb	Cu
Adult males	9	Liver	31,2	2,89	9,32	<0,02	4,44
Adult females	6	Liver	30,4	2,22	9,83	<0,02	3,49
Immature males	5	Liver	30,4	2,39	6,28	<0,02	4,15
Immature females	5	Liver	30,4	3,14	8,77	0,024	3,49
Adult males	9	Muscle	27,8	0,44	0,41	<0,02	3,49
Adult females	6	Muscle	29,5	0,31	0,41	<0,02	3,81
Immature males	5	Muscle	28,3	0,32	0,22	<0,02	3,35
Immature females	5	Muscle	28,8	0,26	0,24	<0,02	3,74

Table 5.6. Metal concentrations in fulmar (mg/kg wet weight).

	Number of birds in pooled samples	Matrix	Dry matter (g/100g)	Hg	Cd	Pb	Cu
Immature and adults fulmars 1998	25	Liver	30,60	2,66	8,55	0,02	3,89
min			30,4	2,22	6,28	<0,02	3,49
max			31,2	3,14	9,83	0,02	4,44
Pullus 1997*	40	Liver	29,15	0,15	0,39	<0,15	11,73
min			29,1	0,11	0,38	<0,15	9,76
max			29,2	0,19	0,4	<0,15	13,7
Upper limits for consumption *(value of concern)**		Liver		*0,1*	0,5		
Immature and adults fulmars 1998	25	Muscle	28,60	0,33	0,32	<0,02	3,60
min			27,8	0,26	0,22	<0,02	3,35
max			29,5	0,44	0,41	<0,02	3,81
Pullus 1997*	40	Muscle	na	na	na	na	na
min			na	na	na	na	na
max							
Upper limits for consumption *(value of concern)**		Muscle		*0,05*	0,1		

*: Lovtidende A, 1985-hæfte 69
na: not analysed

5.6.2 Organochlorines

The results of the PCB analyses are shown in table 5.7, the analysis results from the unfledged *pullus* in 1997 are shown for comparison. The results of the pesticide analyses are shown in table5.8, also with the results for the *pullus* from 1997.
The results in table 5.7 shows that the three congeners CBs 153, 138 and 180 are predominant in fulmars. The PCB analysis procedure is optimalised to identify specific congeners, and these are selected to cover the "essential" congeners. Consequently the entire spectrum of congeners is not analysed in this type of standard analysis package bought from a commercial laboratory. Research laboratories or special agreements can give a total analysis of all detectable PCB congeners. The Food and Environmental Agency has bought total analyses of PCB in pilot whale blubber and they showed the same pattern, the three congeners CBs 153, 138 and 180 constituted approx. 1/3 of the sum of the concentration of all 61 detectable congeners! If only a selection of the congeners is studied, PCB 7 or the so-called "seven dutch" CB 28, 52, 101, 118, 138, 153 and 180, the above mentioned three congeners constitute approx. 65% of PCB 7 in the pilot whale blubber. In the fulmars caught in 1998 these three congeners constitute 86% of PCB 7, the content in the *pullus* from 1997 was a little lower, 81%. The comparability with other Faroese sea birds in an equivalent study (Dam, 1998) is striking, these three congeners also constituted 86% of PCB 7 in black guillemot and common eider. The share in shag was a little lower, 83%, but that is probably due to the large share of immature birds in the shag material. These three PCB congeners are

molecules which contain 6 and 7 chlorine atoms[9] and are among the higher chlorinated PCB congeners which are most persistent. As a result there is an accumulation of these congeners in nature, even though the original commercial product maybe only contained a small share of the higher chlorinated persistent congeners. In addition to measuring the concentrations of *p,p'*-DDT and the metabolites *p,p'*-DDE and *p,p'*-DDD it is often found informative to evaluate the ratio between DDE and DDT in the sample matrix in relation to the ratio present in the pesticide. The original pesticide, "technical DDT" contained approx. 77% of *p,p'*-DDT and 15% of *o,p'*-DDT, and only traces of *p,p'*-DDE and *p,p'*-DDD together with the *o,p'*-isomers of these (WHO, 1989). In the current relation, when only considering the *p,p'*-isomers, the *p,p'*-DDE constitutes 85% and 82% in liver and lipid tissues, respectively, while *p,p'*-DDT only constitutes 10% and 15% in the same tissue. Consequently, it can be concluded that this pollution of DDT in fulmars is of an earlier date or has passed through several levels in the food chain before reaching birds.

Table 5.7. PCB in fulmar (µg/kg wet weight)

Year of sampling		N	PCB 7, mg/kg lipid	Matrix	DM g/ 100g	Lipid, %	PCB 7	CB 28	CB 52	CB 101	CB 118	CB 153	CB 105	CB 138	CB 156	CB 180	CB 209
1998	Adult males	9	18,2	Liver	31,6	5,2	947	2,2	0,5	2,3	107	404	26	172	27	259	12
	Adult females	6	8,5	Liver	30,2	5,1	435,6	1,7	0,8	1,1	58	194	14	77	13	103	2,2
	Immature Males	5	10,0	Liver	30,8	4,7	468,5	1,4	0,3	0,8	70	204	19	101	14	91	6,5
	Immature females	5	6,6	Liver	30,4	4	265,8	1,3	0,8	0,7	36	119	9,5	53	7,5	55	4,6
1997	Pullus Vestmanna	15	3,4	Liver	29,2	6,25	214,9	1,3	0,2	1,4	33,6	90,8	11,3	49,3	6,6	38,3	1,9
	Pullus	25	0,7	Liver	29,1	6,46	46,6	0,5	0,2	0,6	7,5	19	2,7	10,8	1,3	8	1
1998	Adult males	9	26,8	Subcut. fat	84	79,2	21244	60	3	53	2896	8073	705	4417	727	5742	124
	Adult females	6	16,3	Subcut. fat	86,2	81,4	13304	45	10	32	1616	6321	386	2034	394	3246	59
	Immature males	5	20,8	Subcut. fat	90,1	87,3	18174	51	3	51	2656	8422	671	3628	510	3363	87
	Immature females	4	13,1	Subcut. fat	89,7	85,3	11155	39	1	104	1509	5165	354	2045	311	2292	68
1997	Pullus Vestmanna	12	1,2	Subcut. fat	87,5	87,5	1089,6	8,5	3,7	17,4	181	426	57,1	258	37,1	195	3,8
	Pullus	25	1,1	Subcut. fat	86,9	86,9	928,8	10,2	3,6	14	147	375	49,9	217	29,5	162	4,1
1998	Immature males	5	16,4	Int. fat	91,9	90	14736	46	10	47	2189	6945	537	2888	404	2611	53
	Immature females	4	9,0	Int. fat	94,9	92,5	8317	38	3	47	1193	3792	280	1534	234	1710	43

Subcut. fat: subcutaneous fat
Int. fat: intestinal fat
N = Number of birds in pooled samples

[9] CB 153 and 138 are hexachlorobiphenyls and CB 180 is a heptachlorobiphenyl.

Table 5.8. Pesticides in fulmar (µg/kg wet weight)

	Number of birds in pooled samples	matrix	Penta-chloro-benzen	Hexa-chloro-benzen	alpha-Hexa-chloro-hexane	gamma-Hexa-chloro-hexane	Octa-chlor-styrene	p,p-DDE	p,p-DDD	p,p-DDT	Sum p,p-DDT
Adult males	9	Liver	0,5	27	<0,1	0,3	4,5	694	39	23	756
Adult females	6	Liver	0,6	24	0,1	0,3	3,3	274	16	13	303
Immature males	5	Liver	0,5	18	<0,1	0,5	3,6	254	14	9	277
Immature females	5	Liver	0,3	14	<0,1	<0,1	2,7	206	15	9	230
Pullus Vestmanna´97	15	Liver	0,6	17,7	0,2	0,3	1,8	102	11	28	141
Pullus Nolsoy´97	25	Liver	0,1	5,6	0,1	0,2	0,5	22	1,5	7	31
Adult males	9	Subcut. fat	18	612	7	1,0	37	6641	354	1439	8434
Adult females	6	Subcut. fat	18	513	5	<1	27	6260	163	861	7284
Immature males	5	Subcut. fat	17	478	6	1,0	30	7037	211	908	8156
Immature females	4	Subcut. fat	16	420	5	<1	26	7215	238	996	8449
Pullus Vestmanna´97	12	Subcut. fat	7,1	132	5,2	2,0	3,8	1540	46,5	373	1960
Pullus Nolsoy´97	25	Subcut. fat	5,6	105	4,5	2,5	4,4	508	19,2	214	741
Immature males	5	Intest. fat	18	480	6	1,0	23	6230	173	749	7152
Immature females	4	Intest. fat	17	427	5	<1	20	6093	180	857	7130

Subcut. fat: subcutaneous fat
Intest. fat: intestinal fat

5.7 Evaluation

5.7.1 Age dependence

There seems to be a general tendency for increased concentrations of organochlorinated, lipid-soluble environmental toxins with age, but a balance seems to be established in birds which have lived for some years, and the concentrations then appear to reach a plateau. Such a sequence can partially be explained by a change in the bird's diet so that the intake of organochlorines is reduced, another possibility is that the bird's immune system and ability to metabolically transform and excrete organochlorines increases with age. There are however other factors of massive influence, this is particularly distinct in the relationship between the organochlorinated substances in the unfledged birds (*pullus*) caught in 1997 (tables 5.7, 5.8 and 5.9) where the difference in the liver concentration of the two groups, the one

from Vestmanna and the other from Nólsoy, was approx. a factor 4. Whether this difference is due to different diets for fulmars on the western and eastern side of the Faroe Islands as suggested by Jensen (1998) is a possibility that is left open and which only can be determined by further studies. There are however certain elements which should be considered in this context and these are related to tissue characteristics.

5.8 Tissue comparisons

If the environmental toxin concentration is expressed on a lipid basis, the content of organochlorines is relatively similar in the adult fulmars and the immature[10] individuals. The difference is particularly small if the comparison is made between organochlorines in the subcutaneous fat. The POPs content in the liver of adult birds is on the other hand higher than in the immature individuals, especially in the male adults. A comparison between the various tissues shows that the organochlorine content is decreasing in the order: subcutaneous fat > intestinal fat > liver, not only due to the variation of the lipid content in the various tissues, as the lipid percentage is as high in intestinal fat as in subcutaneous fat, but also as a result of the various functions of the various tissues. In this context the liver may be seen as an active transforming/excreting organ whereas the fat is passive storage for as long as it lasts. It is well known that intestinal fat is of a more transient nature than the subcutaneous fat reserves. Intestinal fat is therefore a younger tissue which better reflectes the current diet status, and consequently has not stored organochlorines for as long as the subcutaneous fat has. It may also be of consequence that it is the mobilisation period, that is the time it takes to dissolve the organochlorines from the fat, which is the limiting factor in the excretion process (WHO, 1993).
There was, as earlier mentioned, markedly higher POPs concentrations in liver from *pullus* sampled in Vestmanna in 1997 than in those from Nólsoy the same year, whereas the concentrations in the subcutaneous fat samples were more similar. Earlier studies indicate that the liver concentration is a representative[11] of the present more than the subcutaneous fat concentration is, and the more homogeneous lipid tissue concentrations in the two groups indicate that the high liver concentrations in the Vestmanna birds are either due to a recent intake of food with a high environmental toxin content, or that the lipid tissue has been reduced and the organochlorines which subsequently became "homeless" were redistributed to the remaining tissue, among these the liver. Nutritional status was not evaluated when samples were taken from the two groups of *pullus*, and based on the lipid percentage in the liver, the birds appear to be in similar condition. But the fact that 3 out of 15 birds from Vestmanna had no subcutaneous fat remaining on the carcass after the skinning and that lack of fat was not observed in any of the 25 birds from Nólsoy suggests that there can be a difference. The carcass weight of *pullus* from Vestmanna in 1997 was also lower than in the birds from Nólsoy, the first group had a mean/median weight of 387g/426g while the *pullus* from Nólsoy in 1997 were 456g/455g. Consequently the above mentioned possibilities of differences in food choice and availability seem to be supported

[10] In this connection immature means not activily reproducing, *i.e.* the bird can be up to 8 years old.
[11] CB 153 dosed to rats showed that the highest concentrations were first identified in muscle and liver tissue, but at the end of the exposure period the lipid tissue had the higest concentrations (Muehleback and Bickel, 1981).

and may thus be part of the explanation of the differences observed but the reduced body weight may also be a matter of differences in time elapsed since hatching when the birds were caught.

Analyses of fulmars from Prince Leopold Island in 1975 demonstrated a certain reduction in DDE and Sum PCB contents in the order egg >liver from *pullus* > adult liver (Nettleship and Peakall, 1987). This rather bizarre pattern does not correspond with the results of the present material in which there is a marked increasing tendency in the reversed order regarding PCB and DDE contents in liver. The difference between adult and immature birds decreases on the other hand regarding POPs concentrations in the subcutaneous fat, while the difference to the unfledged birds remains marked, with the exception of the liver concentrations in *pullus* from Vestmanna in 1997, which have the highest concentration of *p,p*'-DDT.

Table 5.9. PCB, pesticides and metals contents in fulmar from different location

Location	Year	n	age	matrix	lipid %	***α-HCH µg/kg lipid	CB 153 µg/kg lipid	p,p´-DDE, µg/kg lipid	Sum DDTs µg/kg lipid	Dieldrin µg/kg lipid	Hg mg/kg ww	Cd mg/kg ww	*Ref.*
St.Kilda, (UK)○	1977	5	?	liver							8,38	13,97	*Osborn et al., 1979*
Svalbard, west$	1980	10	?	liver	5**		4.571	12.600					*Norheim & Kjos-Hanssen, 1984*
Svalbard, west	1980	10	?	liver							2,10	17,00	*Norheim, 1987*
Svalbard, west$	1980	7	?	fat	85**		9.916	25.882					*Norheim & Kjos-Hanssen, 1984*
Greenland Thule	1984	14	Juvenile + adult	liver							1,86	16,26	*Nielsen & Dietz, 1989*
Greenland	1984-86	17	Juvenile + adult	liver							2,22	10,47	*Nielsen & Dietz, 1989*
Faroe Island$	1989	?	?	subcut fat	85**	21,2	3.435	9.518	10.007	105			*Cederberg, 1989*
Svalbard, Ny-Ålesund○	1991	5	?	liver							1,39	20,92	*Savinova & Gabrielsen, 1994*
Bjørnøya○	1991	5	?	liver							0,56	10,43	*Savinova & Gabrielsen, 1994*
Arctic Canada*$	1993	15	Eggs	white & yolk	11,9	40,3	676		4.118	108	0,32		*Muir et al., 1996*
Karaocean Russia $	1995	4	?	liver	5?	7,6	9.003	2.840					*AMAP, 1998*
Nólsoy, Faroe Island	1997	25	Pullus	liver	6,5	1,5	294	341	474		0,19	0,38	*Study 1 in this chapter*
Vestmanna, Faroe Island	1997	15	Pullus	liver	6,3	3,2	1.453	1.632	2.256		0,11	0,4	*Study 1 in this chapter*
Nólsoy, Faroe Island	1997	25	Pullus	subcut fat	86,9	5,2	432	585	853				*Study 1 in this chapter*

Location	Year	n	age	matrix	lipid %	***α-HCH µg/kg lipid	CB 153 µg/kg lipid	p,p´-DDE, µg/kg lipid	Sum DDTs µg/kg lipid	Dieldrin µg/kg lipid	Hg mg/kg ww	Cd mg/kg ww	*Ref.*
Vestmanna, Faroe Island	1997	15	Pullus	subcut fat	87,5	5,9	1.245	1.760	2.239				*Study 1 in this chapter*
Nólsoy, Faroe Island	1998	15	Adult	liver	5,2	nd	5.806	9.398	10.282		2,56	9,58	*This work.*
Nólsoy, Faroe Island	1998	15	Adult	subcut fat	80,3	7,5	8.963	8.033	9.787				*This work*
Nólsoy, Faroe Island	1998	9	Im-mature	int. fat	91,3	6,0	5.883	6.752	7.826				*This work*
Nólsoy, Faroe Island	1998	10	Im-mature	liver	4,4	nd	3.713	5.287	5.828		2,77	7,53	*This work*
Nólsoy, Faroe Island	1998	9	Im-mature	subcut fat	86,3	6,4	7.872	8.257	9.621				*This work*

$: when converting from Sum PCB we used factor 1/7, and when converting from Sum PCB (Aroclor) we used factor 1/7,5

○: when converting from results based on dry weight, we assumed a dry matter content corresponding to 28,5%

*: Prince Leopold Island

**: lipid % default lipid content in liver was set to 5% and in subcut. fat to 85%

***: results from Faroe Island (1989) and Canada is the sum of α, β, and γ isomers, (but for the Faroese samples only the α isomer was detectable

5.8.1 Comparison with fulmars in other countries

The perhaps most remarkable finding regarding the metal content of fulmars is the high cadmium concentrations in the liver. It is difficult to find comparable results from other countries as there has been little interest in fulmars in an environmental toxin context, but results from Greenland show a similar mercury content and a rather higher cadmium content, especially in birds from the northernmost part, in Thule (Nielsen and Dietz, 1989). Results from Shetland/the Orkney Islands and Scotland (Thomson *et al.*, 1992) in which fulmar feathers from both museum collections and recent days were analysed for mercury, showed a median of 4 to 4,5 mg/kg in the older material and 1,4 and 2,9 mg/kg feather in the newer material. Feathers from the present material were not analysed, but analyses of feather and liver from other sea birds (kittiwake, guillemot and Brunnicks guillemot) show that the mercury concentration in body feathers for the three species varies between 50 and 75% of that of the liver when the latter is expressed on a dry weight basis (Wenzel and Gabrielsen, 1995). This ratio should suggest a concentration of between 6 mg/kg dry weight and 9 mg/kg dry weight liver in the Scottish fulmars from the museum collections and lower in the newer material. The content in Faroese fulmars on a corresponding weight basis is in the range of 7,3 to 10.3 mg/kg/dry weight, that is in the same range as the older Scottish fulmars. Thomson *et al.* (1992) substantiate the mercury reduction in the Scottish and Shetlandic/Orkney Islands fulmars with a change

of diet (to fish, from whale!), a factor which without doubt will have decisive influence on the environmental toxin content. There are fewer data for organochlorines, but some examples are included in table 5.9 which shows the DDT and PCB contents in fulmars caught on Svalbard and in Arctic Canada. The results for the Faroese fulmars vary within a factor 10 from the lowest mean concentrations in *pullus* to the highest in the adult fulmars. There is great uncertainty in comparing PCB data entered as a non-defined sum of PCB and the ones based on the quantification and addition of single congeners. However, as more information has been accumulated over the years and if we dare to assume that the congener profile[12] is the same in birds as in people, PCB quantified by Aroclor 1260 can be converted to CB 153 by multiplying with a factor 1/7.5. If it is further assumed that the congener profile of whale can be compared with that of birds, a Sum PCB, that is the sum of the individually determined congeners, can be converted to CB 153 by multiplying with a factor 1/7. These conversion factors were used to convert some of the results of table 5.9, and considering the assumptions on which the conversions are based, one should not be too conclusive when making the comparisons unless there are marked differences. Generally, PCB in Faroese fulmars is comparable with results from Svalbard and the Kara Sea (Russia), but the DDT content and its metabolite are lower than in the 1980-results from Svalbard. In addition, the by-product of technical lindane, the α-HCH, is found in lower concentrations in the Faroe Islands than on Prince Leopold Island, Canada, (Muir *et al.*, 1996), but in the same concentrations as in the Kara Sea. Comparisions of the results of the organochlorine analyses made on fulmar eggs collected in the Faroes in 1989 (Cederberg, 1989) to those on fulmar eggs from high Arctic Canada in 1993 (AMAP, 1998) are rather interesting; the concentration of dieldrin in the two countries is eqvivalent, at 0,012 mg/kg, the α-HCH in the Canadian sample was 0,0029 mg/kg but was not detected (at approx. 0,002 mg/kg) in the Faroese sample, in other words supporting the above observation. p,p´-DDE was analysed in the samples and found in concentrations of 0,428 mg/kg in the Canadian eggs and 0,372 mg/kg in the Faroese. Also HCB was found in very similar concentrations in the egg samples from the two locations, 0,063 mg/kg in Canada and 0,052 mg/kg in the Faroe Islands.

5.9 Conclusion

In a general perspective it is pertinent to draw attention to the fact that the fulmar has had great success in colonising the Faroe Islands, it has developed from a scarce bird to the most abundant bird species in a little over 100 years, with presently 600 000 breading couples (Bloch *et al.*, 1996) in spite of times with heavy catching.

At the same time there is every indication that fulmars are among the most burdened bird species when it comes to environmental toxins, particularly in the Faroese marine ecosystem. In the entire material on PCB results from sea birds included in the AMAP report (AMAP, 1998) there were however only few fulmars and the birds with the highest content were 5 common gulls (*Larus hyperboreus*) which were caught on Svalbard in 1991 with a Sum PCB of 320 mg/kg lipid. The PCB content of Faroese gulls is not known, except in 15 lesser black-backed gull eggs (*Larus fuscus*) caught in 1998 which had a CB 153 content of approx. 1,250 mg/kg lipid and Sum DDT at 1,300 mg/kg lipid

[12] Congener profile here means the relative distribution of the single congeners. The reflections in section 6.3.2 on the relative contribution from each congener is thus an evaluation of an extract of the congener profile.

(Food and Environmental Agency, not published). These values correspond to the concentrations found in the unfledged fulmars from Vestmanna in 1997. In conclusion the content of organochlorines in Faroese fulmars is substantial if not extreme and there is no reason to doubt the results from the fulmar samples analysed for pesticides and PCB in 1989. However, within the limited matrix of data which are readily comparable, among these are the results for the eggs, there are no values lower than in the Faroese material of the same species.
Unfortunately, the data cannot support an evaluation of any tendencies on whether the various substances are present in higher or lower concentrations today than 10 years ago, in order to do that we need to know the standard variation among the birds but also some more descriptive data on the material with which the comparisions are to be made. There is however one conclusion to be drawn from the present material, the organochlorine concentration is markedly lower in *pullus* than in adults. The difference however evaporates if body burdens rather than concentration is considered; where the difference between the two age groups in concentrations terms may be defined as a factor 10, the same factor would propably apply to the difference in fat deposits, but then inversely. Studies to confirm this are in progress.

5.10 References

AMAP, 1998. *AMAP Assessment report: Arctic pollution issues*. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xii+859 pp.

Bloch, D., Jensen, J.-K. and Olsen, B., 1996. *Listi yvir fuglar sum eru sæddir í Føroyum*. Føroya Náttúrugripasavn, Føroya Fuglafrøðifelag og Føroya Skúlabókagrunnur.

Cederberg, T., 1989. Pers. comm.

Dam, M.,1998. Hvad spiser tejst, edderfugl og topskarv på Færøerne, og hvad er indholdet af miljøgifte i disse fugle? Heilsufrøðiliga Starvsstovan, 1998:2.

Jensen, J.-K., 1998. Pers. comm.

Joensen, H. Debes, 1997. *Årsberetning 1997*. Landslæknin. ISSN 0903-7772.

Joensen, H. Debes, 1998. Pers. comm.

Muehleback S. and Bickel M.H. 1981. Pharmacokinetics in rats of 2,4,5,2´,4´,5´-hexachlorobiphenyl an unmetabolisabel lipophilic model compound. Xenobiotica 11, 249-259.

Nielsen, C.O. and Dietz, R. 1989. *Heavy metals in Greenland seabirds*. Meddelselser om Grønland, Biosience 29.

Norheim, G. 1987. Levels and interactions of heavy metals in seabirds from Svalbard and the Antarctic. Environ. Pollut. 47, 7-13.

Norheim, G. and Kjos-Hansen, B., 1984. Persistent chlorinated hydrocarbons and mercury in birds caught off the west coast of Spitsbergen. Environ. Pollut. 33A, 143-152.

Olsen, B., 1998. Pers. comm.

Osborn, D., Harris, M.P. and Nicholson, J.K., 1979. Comparative tissue distribution of mercury, cadmium and zinc in three species of pelagic seabirds. Comp. Biochem. Physiol. C:61-67.

Savinova, T.N. and Gabrielsen, G.W., 1994. *Trace metals in marine birds from the Barents sea in 1991*. In: Chemicals in the Arctic-Boreal environment. ECOVISION World monograph series (W. Munawar, Ed.) S.P.B. Academic Publ., Nederland

Thompson, D.R., Furness, R.W and Walsh, P.M., 1992. Historical changes in mercury concentrations in the marine ecosystem of the north and north-east Atlantic ocean as indicated by seabird feathers. Jour. Applied Ecology 29, 79-84.

Wenzel, C. and Gabrielsen, G.W., 1995. *Trace element accumulation in three seabird species from Hornøya Norway*. Arch. Environ. Contam. Toxicol. 29, 198-206.

World Health Organization 1989. *DDT and its derivatives- Environmental Aspects*. Environmental Health Criteria 83. 98 pp.

World Health Organisation, 1993. *Polychlorinated biphenyls and terphenyls* (Second Edition). Environmental Health Criteria 140. 682 pp. (and references therein; Melnikov et al. 1995, Mizutani et al.1977).

6 Cod (*Gadus morhua*)

6.1 Sampling

45 cod, which were caught on Mýlingsgrunnur on position 62°23`N and 7°30`W in October 1997, were analysed.

6.2 Pre-treatment

The cod were weighed and measured on the day they were caught. The mean length was 59 cm. The weight of the livers was registered and pooled samples were made of livers and fillets. Two pooled samples with 24 and 20 cod in each sample were made; T1-T25 (-T4) and T26-T45. T4 was not used because both liver and fillet contained many parasites (nematoda).

Pooled samples were made of the cod's right fillet. The homogenised samples were stored in bags at <-18°C.

The tip of the left liver lobe of the fish was used in the pooled samples. The homogenised samples were stored in heat-treated jars at <-18°C.

6.3 Results

6.3.1 Heavy metals

According to normal practice the heavy metals in fish are not all measured in liver matrix as with birds and mammals. Instead the fillet is used for mercury analysis whereas the metals Cd, Pd and Cu are measured in the liver (table 6.1).

Table 6.1. Heavy metals in cod (mg/kg wet weight)

Parameters	Matrix	T1-T25 (-T4)	T26-T45
Number in pooled samples [pcs]	fillet and liver	24	20
Dry weight [g/100g]	fillet	18,8	18,7
Hg	fillet	0,027	0,028
Dry weight [g/100g]	liver	66,8	62,9
Cd	liver	0,17	0,19
Cu	liver	5,54	4,43
Pb	liver	<0,15	<0,15

6.3.2 Persistent organic pollutants

The PCB and total toxaphene concentrations in cod liver are given in table 6.2. The pesticide content is shown in table 6.3.

Table 6.2 PCB and total toxaphene contents of cod liver (µg/kg wet weight)

Parameters	T1-T25 (-T4)	T26-T45
Lipid content [weight %]	56,9	53,5
CB 28	<0,2	<0,3
CB 31	<0,1	<0,3
CB 47	<0,2	<0,2
CB 49	<0,2	<0,2
CB 52	1,3	<0,2
CB 56	<0,4	<0,5
CB 66+95	<0,2	<0,2
CB 85	<0,2	<0,3
CB 87	<0,2	<0,3
CB 97	<0,2	<0,3
CB 101	8,1	7,5
CB 105	2,7	2,7
CB 110	<0,3	<0,4
CB 118	9,4	<0,7
CB 128	<0,2	<0,2
CB 137	<0,1	<0,2
CB 138+163	14	14
CB 141	<0,2	<0,3
CB 149	<0,5	<0,6
CB 151	<0,2	<0,2
CB 153	25	26
CB 156	<0,2	7,2
CB 170	<0,2	<0,3
CB 180	6,6	7,2
CB 187	<0,2	<0,3
CB 194	<0,2	<0,2
CB 202	<0,2	<0,2
CB 206	<0,2	<0,2
Total toxaphene	760	620

Table 6.3 Pesticides in cod liver (µg/kg wet weight)

Parameters	T1-T25 (-T4)	T26-T45
HCBD	<0,1	<0,1
QCB	<0,1	<0,1
HCB	9,8	8,9
α-HCH	3,8	4
γ-HCH	<0,5	<0,7
β-HCH	<0,2	<0,3
β-heptachloro-epoxide	2,5	2,5
p,p'-DDE	40	37
Dieldrin	16	14
Endrin	<0,1	<0,2
p,p'-DDD	18	17
p,p'-DDT	11	10
Heptachlor	<0,1	<0,1
Cis-chlordene	<0,2	<0,2
Trans-chlordene	<0,2	<0,3
Oxychlordane	<0,2	<0,2
Cis-chlordane	<0,2	10
Trans-chlordane	<0,2	<0,2
Trans-nonachlor	21	19
Cis-nonachlor	<0,2	<0,2

6.3.3 Polycyclic aromatic hydrocarbons

The following table contains the PAH content of cod liver.

Table 6.4 PAH in cod liver (µg/kg wet weight)

Parameters	T1-T25 (-T4)	T26-T45
Acenaphthene	<1	<1
Fluorene	3	2
Phenanthrene	4	3
Anthracene	<0,2	<0,2
Fluoranthene	<0,5	<0,5
Pyrene	0,3	<0,2
Benz(a)anthracene	<0,1	<0,1
Chrysene	<0,2	0,4
Benzo(e)pyrene	<0,8	<0,8
Benzo(b)fluoranthene	<0,9	<0,9
Benzo(k)flouranthene	<0,2	<0,2
Benzo(a)pyrene	<0,1	<0,1
Dibenz(ah)anthracene	<1	<1
Benzo(ghi)perylene	<0,5	<0,5
Indeno(123cd)pyrene	<1	<1

7 Grey seal (*Halichoerus grypus*)

7.1 Sampling

45 grey seals were analysed. The seals were shot at various places in the Faroes during the summer months of 1993 to 1995. For further information on the seals, reference is made to the report "Summer diet of grey seals *Halichoerus grypus* in the Faroe Islands"[13].

7.2 Pre-treatment

Muscle, liver and blubber samples were taken from every seal. The samples were wrapped in aluminium foil and plastic bags and stored in the freezer at <-18°C.

The age of some of the seals was determined by means of the lower canine teeth. A growth curve of age vs. body length was constructed based on these seals[14]. The age of the remaining seals was estimated from this growth curve from their body length.

Table 7.1. The seals were divided into the following groups

Males (n = 4)	Age > 8 years
Females (n = 20)	Pregnant seals
Juvenile seals (n = 21, 15 females and 6 males)	Younger than 4 years, but older than 2 years

The males become sexually mature at the age of 4-5 years, but generally they do not become sexually active until they reach the age of 8 years because of body size dominance and local conditions at the breeding grounds. As a consequence only males older than 8 years of age are included in the group of males. All pregnant seals were placed in the adult female group.

Pool samples of liver, blubber and muscles were prepared from both males, females and juvenile seals. The part of the tissue samples which had been in contact with the wrapping was cut away before the analysis material was taken. Muscle and liver samples were homogenised and stored in heat-treated jars. The blubber was pre-treated at RIVO-DLO (chapter 4.5), where it was cut into small pieces and melted. The oil was weighed and mixed with pentane after which the mixture was purified with alumina and silica chromatography.

[13] Mikkelsen, Bjarni. Summer diet of grey seals *Halichoerus grypus* in the Faroe Islands. University of Tromsø. 1998

[14] Hewer H.R. 1963. The determination of age, sexual maturity, longevity and a life-table in the grey seal (*Halichoerus grypus)*. Prpc. Zool. Soc., London. pp. 593-632

7.3.1 Heavy metals

The mercury concentration in seal muscles and the heavy metal content of the livers are shown in table 7.2.

Table 7.2 Heavy metals in seal muscle and liver (mg/kg wet weight)

Parameters	Matrix	Males	Females	Juveniles
Number in pooled sample [pcs]		4	20	21
Dry weight [g/100g]	Muscle	28,3	29,8	28,4
Hg	Muscle	1,88	0,80	0,38
Dry weight [g/100g]	Liver	27,5	29,3	29,2
Hg	Liver	151	155	11,6
Pb	Liver	<0,15	<0,15	<0,15
Cd	Liver	1,85	14,6	0,94
Cu	Liver	32,1	53,7	40,1

7.3.2 Persistent organic pollutants

The PCB and total toxaphene content of seal blubber are given in table 7.4. The pesticide concentrations are shown in table 7.3.

Table 7.3 Pesticides in grey seal blubber (µg/kg wet weight)

Parameters	Males	Females	Juveniles
HCBD	<0,1	<0,1	<0,1
QCB	<0,3	<0,3	<0,3
HCB	21	21	28
α-HCH	8,9	7,6	15
γ-HCH	2,8	8,5	4,3
β-HCH	7,7	7	9,7
β-heptachloro-epoxide	43	13	49
p,p'-DDE	3200	490	1400
Dieldrin	52	34	61
Endrin	7,3	<0,7	<0,7
p,p'-DDD	120	24	41
p,p'-DDT	450	79	200
Heptachlor	<0,4	<0,5	<0,5
Cis-chlordene	<0,8	<1	<1
Trans-chlordene	<0,9	<1	<1
Oxychlordane	410	80	270
Cis-chlordane	29	84	9,7
Trans-chlordane	<0,8	<0,9	<1
Trans-nonachlor	570	110	230
Cis-nonachlor	64	13	23

Table 7.4 PCB and total toxaphene in seal blubber (µg/kg wet weight)

Parameters	Males	Females	Juveniles
Lipids [weight %]	100	100	100
CB 28	16	<1,0	13
CB 31	17	<0,7	<0,7
CB 47	32	3,7	16
CB 49	55	5,9	19
CB 52	59	16	43
CB 56	<2,0	<2,0	<0,2
CB 66+95	12	<1,0	<1,0
CB 85	51	12	36
CB 87	11	<1,0	7,4
CB 97	21	<1,0	5
CB 101	370	63	160
CB 105	22	6	8,3
CB 110	10	<2,0	<2,0
CB 118	55	17	25
CB 128	130	17	40
CB 137	67	10	21
CB 138+163	2000	240	600
CB 141	13	<1,0	<1,0
CB 149	150	20	53
CB 151	74	9,1	21
CB 153	4900	540	1200
CB 156	48	9,2	18
CB 170	800	80	130
CB 180	2300	240	330
CB 187	840	74	140
CB 194	310	30	27
CB 202	73	4,7	7,4
CB 206	110	12	27
Total toxaphene	610	220	430

7.3.3 Polycyclic aromatic hydrocarbons

The PAH content of seal blubber is shown in the following table.

Table 7.5 PAH in seal blubber (µg/kg wet weight)

Parameters	Males	Females	Juvenile seals
Acenaphthene	<1	<1	<1
Fluorene	<1	<1	2
Phenanthrene	<2	<2	4
Anthracene	<0,2	<0,2	0,4
Fluoranthene	<0,5	0,7	1
Pyrene	<0,2	0,3	0,2
Benz(a)anthracene	<0,1	<0,1	<0,1
Chrysene	<0,2	<0,2	0,5
Benzo(e)pyrene	<0,8	<0,8	<0,8
Benzo(b)fluoranthene	<0,9	<0,9	<0,9
Benzo(k)flouranthene	<0,2	<0,2	<0,2
Benzo(a)pyrene	<0,1	0,2	0,3
Dibenz(ah)anthracene	<1	<1	<1
Benzo(ghi)perylene	<0,5	<0,5	<0,5
Indeno(123cd)pyrene	<1	<1	<1

8 Pilot whales (*Globicephala melas*)

8.1 Sampling

Every year particularly in the period from July to September pilot whales are hunted in the traditional drive kills in the Faroe Islands. Both meat and blubber are favoured as parts of the Faroese diet.

In September 1997 samples were taken from 49 pilot whales from the whale bay in the village of Vági on Suðuroy. Following the hunt the whales are taken up on a suitable quay area while the authorities calculate the shares to be distributed. To slow down the degradation process the whales are opened and the intestines pulled out. Blubber and muscle samples were taken at the sides of these abdominal cuts. The samples were stored in PE bags (Minigrip®).

The identification number given to each of the pilot whales was registered. With this identification number the length and sex of the individuals could later be obtained from the local authorities.

8.2 Pre-treatment

The pilot whales were divided into the following three groups according to sex and body length (table 8.1):

Table 8.1. The pilot whales were divided into the following groups

Adult males	All males > 494 cm
Adult females	All females > 375 cm
Juvenile whales	Both males < 494 cm and females < 375 cm

According to Desportes *et al.*[15] early sexually mature whales are 494 cm long, which corresponds to an age of approximately 14 years, but generally whales become sexually mature when they reach the age of 17 years. According to Martin & Rothery[16] the female whales are sexually mature when they are 375 cm long, corresponding to approximately 8 years.

Pooled samples were made of muscle and blubber from each of the above three groups. The outer part of the muscle and blubber was removed to ensure that the tissue for the pooled sample had not been in contact with the

[15] G. Desportes, M. Sabourea & A. Lacroix, 1993. "Reproductive maturity and seasonality of male long-finned pilot whales, off the Faroe Islands" Rep. Int. Whal. Commn (Special issue no. 14) p. 233

[16] A. R. Martin & P. Rothery, 1993, "Reproductive parameters of female long-finned pilot whales (*Globicephala melas)* around the Faroe Islands", Rep. Int. Whal. Commn (Special issue no. 14) p. 263

wrapping. The muscle was homogenised and stored in heat-treated jars. The blubber was sent to RIVO in jars and pre-treated as in chapter 9.2.

8.3 Results

8.3.1 Heavy metals

The cadmium and mercury concentrations in pilot whale muscle are given in table 8.2.

Table 8.2 Heavy metals in pilot whale muscle (mg/kg wet weight)

Parameters	Males	Females	Juveniles
Number in pooled sample [pcs]	8	24	17
Dry weight [g/100g]	29,5	29,3	27,5
Cd	0,11	0,15	0,05
Hg	2,66	2,46	1,55

8.3.2 Persistent organic pollutants

The PCB and total toxaphene content of pilot whale blubber are given in table 8.4. Other pesticides are shown in table 8.3.

Table 8.3 Pesticides and chlordanes in pilot whale blubber (µg/kg wet weight)

Parameters	Males	Females	Juveniles
HCBD	<0,2	<0,1	<0,1
QCB	18	15	37
HCB	460	260	1000
α-HCH	18	17	29
γ-HCH	20	11	24
β-HCH	29	19	41
β-heptachloro-epoxide	130	64	250
p,p'-DDE	13000	4500	13000
Dieldrin	690	450	1400
Endrin	150	100	230
p,p'-DDD	1900	810	2100
p,p'-DDT	2400	1200	2700
Heptachlor	27	15	42
Cis-chlordene	<1	<0,9	<1
Trans-chlordene	<1	<0,9	<1
Oxychlordane	570	230	740
Cis-chlordane	320	230	480
Trans-chlordane	46	36	68
Trans-nonachlor	2700	1200	3600
Cis-nonachlor	660	280	910

Table 8.4 PCB and total toxaphene in pilot whale blubber (µg/kg wet weight)

Parameters	Males	Females	Juveniles
Total lipid [g/kg]	1000	1000	1000
CB 28	100	46	110
CB 31	34	14	44
CB 47	120	43	160
CB 49	200	93	280
CB 52	580	230	820
CB 56	<3,0	<2,0	<2,0
CB 66+95	630	220	940
CB 85	260	97	310
CB 87	240	110	380
CB 97	75	43	87
CB 101	1700	680	2300
CB 105	400	160	520
CB 110	86	64	120
CB 118	1100	480	1600
CB 128	330	130	370
CB 137	110	43	120
CB 138+163	2400	890	2600
CB 141	100	66	130
CB 149	2100	810	2700
CB 151	550	230	650
CB 153	2900	1200	3300
CB 156	120	50	120
CB 170	410	200	380
CB 180	1300	630	1100
CB 187	1100	500	960
CB 194	110	87	75
CB 202	77	44	54
CB 206	33	42	<1,0
Total toxaphene	12000	7300	22000

8.3.3 Polycyclic aromatic hydrocarbons

The PAH content of pilot whale blubber is shown in the following table.

Table 8.5 PAH in pilot whale blubber (µg/kg wet weight)

Parameters	Males	Females	Juveniles
Acenaphthene	<1	<1	<1
Fluorene	2	3	2
Phenanthrene	4	4	4
Anthracene	0,2	0,4	0,3
Fluoranthene	1,2	0,7	0,9
Pyrene	0,5	0,7	0,4
Benz(a)anthracene	<0,1	<0,1	<0,1
Chrysene	0,2	<0,2	<0,2
Benzo(e)pyrene	<0,8	<0,8	<0,8
Benzo(b)fluoranthene	<0,9	<0,9	<0,9
Benzo(k)flouranthene	<0,2	<0,2	<0,2
Benzo(a)pyrene	0,1	0,1	<0,1
Dibenz(ah)anthracene	<1	<1	<1
Benzo(ghi)perylene	<0,5	<0,5	<0,5
Indeno(123cd)pyrene	<1	<1	<1

Terrestrial and freshwater environments

Moss *Racomitrium lanuginosum*

Lichen *Cladonia mitis*

Sheep *Ovis aries*

Brown trout *Salmo trutta*

Arctic char *Salvelinus alpinus*

9 Moss (*Racomitrium sp.*) and lichen (*Cladonia mitis*)

Lichen: *Cladonia mitis* (with strains of *Chladonia arbuscula*).
Moss: *Racomitrium sp*.

9.1 Sampling

Sampling date: 24 August, 1997.
Moss and lichen samples were taken at the station Norðuri á Fossum, a few kilometres north of the village Vestmanna on Streymoy (appendix A7). This site is a reference station in the Faroese monitoring system, and was established in 1996 according to the guidelines for the international programme for Integrated monitoring on air pollution effects[17]. Sampling took place over an area of approximately 200 x 50 m. The moss is abundant in this area and the required amount, at least one litre, was easily collected. The lichen on the other hand is only found in small patches in between grass and moss, and sampling this species was more time consuming.

9.2 Pre-treatment

The samples were stored cool, 5° C, for maximum 3 days until sorting and drying. It was in particular necessary to sort the lichen sample, as it could not be picked without intertwined grass and moss. The samples were spread on laboratory bench paper sheets and dried at 40° C until dry, that is for about two days. After drying the samples were cut to powder in a glass blender with stainless steel knives, and stored in PE bags at ambient temperature until analysis. The dry weight of moss was 27 – 30%. The dry weight of lichen varied in the range 20 – 40%. All analyses were made on dried samples.

9.3 Results

9.3.1 Heavy metals

Table 9.1.. Heavy metals in moss and lichen (mg/ kg dry weight)

	Al	As	Cd	Cr	Cu	Fe	Ni	Pb	Se	V	Zn	Hg
Racomitrium sp. Norðuri á Fossum	767	0,25	0,07	2,47	3,65	731	2,10	13,2	1,01	4,33	10,6	0,164
Cladonia mitis. Norðuri á Fossum	212	0,10	0,08	2,42	16,5	251	2,22	2,35	<0,50	0,84	20,4	0,136

[17] UN ECE Convention on long-range transboundary air pollution. International Co-operative Programme on Integrated monitoring on Air Pollution Effects. Manual for integrated monitoring, programme phase 1993 – 1996. Environmental Report 5, Environment data Centre, National Board of Waters and the Environment, Helsinki 1993.

9.3.2 Persistent organic pollutants

Unfortunately the analyses were not successful, presumably due to the drying procedure which can result in loss of volatile environmental toxins.

10 Sheep (*Ovis aries*)

Sheep form part of the traditional Faroese diet. There are approximately 70,000 sheep on the 18 Faroese islands. The sheep pasture in outlying fields, and it is quite common that they have no contact with developed areas before they are slaughtered. Sometimes at the end of the winter they are given imported fodder for a couple of months until there is enough grass for them to feed on.

10.1 Sampling

Samples were taken from two sheep flocks, one from the village of Vestmanna and the other from Koltur. Koltur is a small island with only one household. Samples were taken from 8 female sheep and 17 lambs from each place. The farmers took samples of tallow, liver and muscle in connection with the slaughtering in October 1997. The tallow samples were taken from the kidney area. The liver samples were taken from the lower part of the sheep's smaller liver lobe and the muscle samples were taken from the lower part of the tenderloin. Samples of tallow, liver and muscle were taken from the female sheep while only tallow and liver samples were taken from the lambs. The samples were stored, frozen in PE bags until analysis.

10.2 Pre-treatment

10.2.1 Vestmanna samples

The livers of the female sheep and of eight of the lambs from Vestmanna were analysed on an individual basis with regard to heavy metal concentrations. The rest of the lamb livers were combined in a pooled sample. Only one pooled sample was made of the female sheep muscles, otherwise there would not have been sufficient material for the radioactivity analysis. Also tallow was blended into pooled samples.

10.2.2 Koltur samples

The liver and tallow samples from the Koltur sheep were blended to pooled samples with four specimens represented in each sample. The lambs were divided into two pools, with eight and nine lambs in each sample. The muscles were combined in one pooled sample.

10.3 Results

10.3.1 Heavy metals

Separate analysis was made on all the sheep livers from Vestmanna, the results are given in table 10.1. Mercury analyses were made on four sheep only, as the concentrations tended to be below or near the detection limit. Table 10.1 shows that the liver concentrations of heavy metals varies between the individuals.

Table 10.1. Heavy metals in sheep from Vestmanna (mg/kg wet weight)

Parameters	Female no 1	Female no 2	Female no 3	Female no 4	Female no 5	Female no 6	Female no 7	Female no 8	Mean	Std. dev.
Matrix	Liver	Liver	Liver	Liver	Liver	Liver	Liver	Liver	Liver	
Number [pcs]	1	1	1	1	1	1	1	1	8	
Cd	0,30	0,22	0,09	0,30	0,16	0,15	0,1	0,06	0,17	0,093
Cu	53,6	83,2	22,9	9,92	27,50	21,7	4,39-17,11*	11,2	29,82	26,00
Hg	<0,02	<0,02	<0,02	<0,02	-	-	-	-	<0,02	
Pb	0,08	0,11	0,08	0,28	-	-	-	-	0,14	0,096

* Four subsamples of this liver were analysed with results in the range given, see text on inhomogeneous copper distribution.

The inhomogeneous copper distribution

For sheep no 7 the copper concentration is given as an interval because it was difficult to match the determination in duplicate. Approximately 2 grams of the liver were cut off for each sample. A total of four liver samples were taken from female sheep no 7. The four samples showed concentrations of 4.39, 7.92, 4.57 and 17.11 mg Cu/kg wet weight, respectively. This must be due to an inhomogeneous copper distribution in the liver. Individual determinations were also made on eight of the lambs from Vestmanna. The copper content varied as for the sheep.

Table 10.2. Heavy metals in lamb from Vestmanna (mg/kg wet weight)

Parameters	Lamb no 1	Lamb no 2	Lamb no 3	Lamb no 4	Lamb no 5	Lamb no 6	Lamb no 7	Lamb no 8	Lamb nos 9-17	Mean	Std. dev.
Matrix	Liver	Liver	Liver	Liver	Liver	Liver	Liver	Liver	Liver	Liver	
Number [pcs]	1	1	1	1	1	1	1	1	9	17	
Cd	0,03	0,05	0,04	0,07	0,11	0,03	0,03	0,05	0,05	0,05	0,026
Cu	17,10	49,80	4,62	24,00	32,20	39,0	17,3	28,7	38,3	27,89	13,77
Hg	<0,02	<0,02	0,021	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02	
Pb	0,092	0,090	0,079	0,087	0,10	0,12	0,087	0,10	0,093	0,09	0,012

The nine lamb livers which were not analysed separately were combined in one pooled sample. The pooled sample results are shown in the above table (the dry weight percentage of the pooled sample was 31.6).

The heavy metal contents of the livers from Koltur and of the sheep muscles from Vestmanna and Koltur are given in tables 10.3 and 10.4.

Table 10.3. Heavy metals in sheep and lamb from Koltur (mg/kg wet weight)

Parameters	Sheep nos 1-4	Sheep nos 5-8	Mean	Lamb nos 1-8	Lamb nos 9-17	Mean
Matrix	Liver	Liver	Liver	Liver	Liver	Liver
Number in pooled sample [pcs]	4	4	8	8	9	17
Dry weight [g/100g]	29,9	30,4	30,15	29,2	30,5	29,85
Cd	0,089	0,049	0,069	0,019	0,013	0,016
Cu	6,18	30,40	18,29	9,80	20,4	15,1
Hg	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02
Pb	0,063	0,085	0,074	0,067	0,059	0,063

Table 10.4. Heavy metals in sheep from Vestmanna and Koltur (mg/kg wet weight)

Place	Vestmanna	Koltur
Parameters	Sheep nos 1-8	Sheep nos 1-8
Matrix	Muscle	Muscle
Number in pooled sample [pcs]	8	8
Dry weight [g/100g]	26,4	29,5
Cd	<0,002	<0,002
Cu	1,3	1,35
Hg	<0,020	<0,020
Pb	<0,020	0,022

10.3.2 Persistent organic pollutants

The PCB and pesticide concentrations in liver and tallow samples from sheep and lamb are given in the following tables.

Table 10.5 PCB and pesticides in liver and tallow from lamb (µg/kg of lipids)

Place	Vestmanna				Koltur							
Species	Lamb nos 1-8		Lamb nos 9-17		Lamb nos 1-8		Lamb nos 9-17					
Number [pcs]	8		9		8		9		Mean	Std. dev. [%]	Mean	Std. dev. [%]
Matrix	Liver	Tallow	Liver	Tallow	Liver	Tallow	Liver	Tallow	Liver		Tallow	
% Lipids	8,8	87	7,1	88	6,2	87	7,9	94	7,50	15	89,0	4
Aroclor 1260, mg/kg	0,06	0,07	0,05	0,01	0,02	0,02	0,03	0,01	0,04	46	0,03	104
CB 28	nd	nd	1,5	nd	nd	nd	nd	nd				
CB 52	nd	nd	1,5	nd	nd	nd	nd	nd				
CB 99	nd	nd	nd	nd	nd	nd	nd	nd				
CB 101	0,94	0,49	1,6	nd	1,9	nd	1,4	nd				
CB 105	int.	0,35	1,5	nd	int.	nd	nd	nd				
CB 118	nd	0,38	nd	nd	nd	0,39	nd	nd				
CB 128	nd	nd	nd	nd	nd	nd	nd	nd				
CB 138	2,1	2,5	1,7	0,75	1,5	0,9	1,8	0,57	1,8	14	1,18	75
CB 153	9,2	11	7,5	1,5	2,7	2,3	4,4	1,5	6,0	49	4,1	114
CB 156	nd	0,92	nd	nd	nd	0,34	nd	nd				
CB 170	nd	1,7	nd	nd	nd	nd	nd	nd				
CB 180	1,6	3,8	1,8	0,59	nd	0,86	nd	0,54			1,4	109
CB 183	nd	0,38	nd	nd	nd	nd	nd	nd				
CB 187	nd	1,1	1	0,4	1,6	0,38	nd	nd				
β-HCH	3,4	nd	nd	nd	3,3	nd	2,3	nd				
α-chlordane	nd	nd	1,2	nd	nd	nd	nd	nd				
γ-chlordane	nd	nd	1,9	nd	nd	nd	nd	nd				
cis-nonachlor	nd	nd	nd	nd	nd	nd	nd	nd				
p,p'-DDE	2,6	7,3	3,2	1,5	2,2	3,6	1,8	2,4	2,5	24	3,7	69
p,p'-DDT	nd	1,2	nd	0,75	nd	0,48	nd	0,93				
Parlar 26 (T2)		nd				nd						
Parlar 32		nd				nd						
Parlar 50 (T12)		nd				nd						
Parlar 62 (T20)		nd				nd						
Parlar 69		nd				nd						
Hexachloro-benzene	12	5,1	11	3,9	8,8	4,2	5,1	4,1	9,2	33	4,3	12
Mirex	nd	nd	nd	nd	nd	nd	nd	nd				
Oxychlordane	nd	2	nd	0,93	nd	0,53	nd	0,59				
Transnonachlor	nd	nd	1,5	0,35	nd	0,33	nd	nd				
Limits of detection												
β-HCH and *p,p'*-DDT	1,7	0,7	2,0	0,6	2,4	0,6	1,8	0,5				
Other compounds	0,8	0,3	1,0	0,3	1,2	0,3	0,9	0,3				
Parlars 26, 32, 50		0,1				0,1						
Parlar 62		0,4				0,4						
Parlar 69		0,2				0,2						

nd: not detected
int.: interference

Table 10.6 PCB and pesticides in liver and tallow from sheep (µg/kg of lipids)

Place	Vestmanna				Koltur							
Species	Female sheep nos 1-4		Female sheep nos 5-8		Female sheep nos 1-4		Female sheep nos 5-8					
Number [pcs]	4		4		4		4		Liver		Tallow	
Matrix	Liver	Tallow	Liver	Tallow	Liver	Tallow	Liver	Tallow	Mean	Std. dev. [%]	Mean	Std. dev. [%]
% Lipids	14	93	3,8	79	5,8	92	4,9	89	7,13	65	88,3	7
Aroclor 1260, mg/kg	0,02	0,02	0,04	0,01	0,04	0,01	0,04	0,01	0,04	29	0,01	40
CB 28	nd	nd	4	nd	nd	0,31	nd	nd				
CB 52	2,8	nd	nd	nd	nd	nd	nd	nd				
CB 99	nd	nd	nd	nd	nd	nd	nd	nd				
CB 101	nd	nd	nd	nd	nd	nd	nd	nd				
CB 105	0,92	nd	nd	nd	nd	nd	nd	nd				
CB 118	nd	nd	nd	0,61	nd	nd	nd	0,31				
CB 128	nd	nd	nd	nd	nd	nd	nd	nd				
CB 138	0,69	0,76	2,9	1,1	2	0,42	2,2	0,72	1,9	47	0,75	37
CB 153	3,3	2,3	5,5	1,5	5,3	1,1	5,3	1,6	4,9	21	1,6	31
CB 156	0,72	0,59	nd	nd	1,6	0,52	nd	nd				
CB 170	nd	0,31	nd	nd	nd	nd	nd	nd				
CB 180	0,87	0,92	nd	0,48	1,4	0,43	nd	0,62			0,6	36
CB 183	nd	nd	nd	nd	nd	nd	nd	nd				
CB 187	nd	0,34	nd	0,52	nd	nd	nd	0,46				
β-HCH	1,8	nd	4	nd	nd	nd	nd	nd				
α-chlordane	nd	nd	nd	nd	nd	nd	nd	nd				
γ-chlordane	nd	nd	nd	nd	nd	nd	nd	nd				
cis-nonachlor	nd	nd	nd	nd	nd	nd	nd	nd				
p,p'-DDE	1,8	1,8	9,4	1,3	6,3	1,4	7,8	2	6,3	51,7	1,6	20
p,p'-DDT	nd	nd	5,2	nd	4,3	0,64	4,5	0,99				
Parlar 26 (T2)		nd				nd						
Parlar 32		nd				nd						
Parlar 50 (T12)		nd				nd						
Parlar 62 (T20)		nd				nd						
Parlar 69		nd				nd						
Hexachloro-benzene	8,3	4,4	12	6,3	9,2	3	16	3,6	11,4	30,4	4,3	33
Mirex	nd	nd	nd	nd	nd	nd	nd	nd				
Oxychlordane	nd	0,51	nd	0,71	nd	nd	nd	0,39				
Transnonachlor	0,79	nd	nd	nd	nd	nd	nd	nd				
Limits of detection												
β-HCH and *p,p'*-DDT	1	0,6	3,8	0,7	2,5	0,6	3	0,7				
Other compounds	0,5	0,3	1,9	0,4	1,3	0,3	1,5	0,3				
Parlars 26, 32, 50		0,1				0,1						
Parlar 62		0,4				0,4						
Parlar 69		0,2				0,2						

nd: not detected

11 Brown trout (*Salmo trutta*)

11.1 Sampling

Brown trout, *Salmo trutta*, (Faroese: *síl*) were caught by sport fishermen by angling. The fish were taken in two inland waters, Fjallavatn and Leitisvatn (same as Sørvágsvatn) on Vágoy in August and September 1997 (appendix B1). These trout are confined to fresh water and are thus of the stationary type.

11.2 Pre-treatment

The fish were frozen after collection, and kept frozen at < –18 ^{0}C until sample preparation. Prior to sample preparation, the fish were thawed in ambient temperature. The whole length, full weight and various other parameters were recorded. The right side fillet of the fish were used for mercury and radioactivity analyses. The fish were analysed as pooled samples. For the smaller sized individuals, that is those of full length of 25 cm or less, the weight of fillet included from each individual was approx. 20 grams. For the larger fish, from 26 cm full length and upwards, the weight of fillet from each individual included in the pooled samples was approx. 40 g. The smallest individual was 19,5 cm and the largest 31 cm full length (tip of the snout to tip of the tail fin), corresponding to a full weight of 69 g and 241 g, respectively. The whole liver of each fish was dissected, weighed and combined into pooled samples, as with the fillets. However, the fillets were analysed in sub-divided pools, to get an idea of the variation between fish of similar size at a low cost. The tissues in the pooled samples were homogenised in blenders as described in the method section (chapter 4).

11.3 Results

11.3.1 Heavy metals

Fillets of brown trout were analysed for mercury, results are given in tables 11.1 and 11.2.

Table 11.1 Mercury in landlocked brown trout muscle (mg/kg wet weight). From Fjallavatn in Vágoy. Small means less than or equal to 25 cm whole length of fish.

Fillet	Mean length (age)[18] / weight [cm (years) / g]	Dry weight, g/100g	Hg	Mean Hg
Fjallavatn				
Small, F1 - F8 n = 8	23,2 (4+)/ 107,5	23,6	0,19	Small: 0,23
Small, F9 - F18... n = 11	23,4 (4+)/ 111,5	23,7	0,26	
Large, F 13, F 19 n = 5	28,5 (5+)/ 196,2	24,4	0,38	Large: 0,36
Large, F23 - F26, n = 4	28,9 (5+)/210,5	24,3	0,34	

Table 11.2. Mercury in landlocked brown trout muscle (mg/kg wet weight). From Leitisvatn in Vágoy. Small means less than or equal to 25 cm whole length of fish. Reference for determining approximate age is given in table 11.1

Fillet	Mean length (age) / weight [cm (years) / g]	DRY WEIGHT, G/100G	Hg	Mean Hg
Leitisvatn				
Small, L4, L5.. n = 5	23,3 (4+)/ 120,9	25,2	0,30	Small: 0,30
Small, L9, L10 ... n = 11	23,4 (4+)/ 125,1	25,0	0,29	
Large, L1 - L3, n = 3	27,4 (5+)/ 204	24,7	0,31	Large: 0,35
Large, L11 - L14, n = 4	27,3 (5+)/ 199	24,6	0,38	

[18] Jón Kristjánsson, 1979. "Frágreiðing um rannsóknir av sílunum í Fjallavatni og Leitisvatni 1978". Reykjavík

11.3.2 Persistent organic pollutants

Table 11.3 Pesticides in landlocked brown trout, (µg/ kg wet weight liver). Lipid content of samples and mean size of fish in groups are given in table 11.4

Parameters	Mixed size Leitisvatn n = 8 L1-L8	Mixed size Leitisvatn n = 15 L9-L23	Small Fjallavatn n = 19 F1-F8, F9-F18 (-F13); F20, F22	Large Fjallavatn n = 8 F13,F19; F21; F23-F28
HCBD	<0,1	<0,1	<0,1	<0,1
QCB	<0,3	<0,1	<0,1	<0,1
HCB	0,5	0,6	0,4	0,4
α-HCH	<0,2	<0,1	0,2	<0,1
γ-HCH	<0,2	<0,1	<0,1	<0,7
β-HCH	<1	<0,5	<0,6	<0,3
β-heptachloro-epoxide	<0,5	<0,2	<0,3	<0,1
p,p'-DDE	4,8	3,4	2,4	2,9
Dieldrin	<0,7	<0,3	<0,4	<0,2
Endrin	<0,6	<0,3	<0,3	<0,2
p,p'-DDD	<0,6	<0,3	<0,4	<0,2
p,p'-DDT	<2	<0,8	<0,9	<0,5
Heptachlor	<0,4	<0,2	<0,2	<0,2
Cis-chlordene	<0,8	<0,4	<0,4	<0,2
Trans-chlordene	<0,8	<0,4	<0,5	<0,3
Oxychlordane	<0,8	<0,4	<0,4	<0,2
Cis-chlordane	<0,8	<0,4	<0,5	<0,2
Trans-chlordane	<0,8	<0,4	<0,4	<0,2
Trans-nonachlor	2,3	1,6	0,7	0,9
Cis-nonachlor	<0,7	<0,4	<0,4	<0,2

Table 11.4 PCB in landlocked brown trout (µg/ kg wet weight liver)

Parameters	Mixed size Leitisvatn n = 8 L1-L8	Mixed size Leitisvatn n = 15 L9-L23	Small Fjallavatn n = 19 F1-F8, F9-F18 (-F13); F20, F22	Large Fjallavatn n = 8 F13,F19; F21; F23-F28
mean whole length / weight of fish in subgroup, [cm / g]	24,8 / 152,0	24,4 / 144,8	23,4 / 109,8	28,7 / 199,8
Total lipids [weight %]	3,4	4,0	3,8	2,8
CB 28	<0,8	<0,4	<0,5	<0,3
CB 31	1	<0,3	<0,3	<0,2
CB 47	<0,8	<0,4	<0,4	<0,2
CB 49	<0,8	<0,4	<0,4	<0,2
CB 52	<0,7	<0,4	<0,4	<0,2
CB 56	<2,0	<0,8	<0,9	<0,5
CB 66+95	<0,8	<0,4	<0,5	<0,3
CB 85	<1,0	<0,5	<0,6	<0,3
CB 87	<0,8	<0,4	<0,5	<0,2
CB 97	<0,9	<0,4	<0,5	<0,3
CB 101	<2,0	<0,9	<1,0	<0,5
CB 105	<0,8	<0,4	<0,4	<0,2
CB 110	<1,0	<0,6	<0,7	<0,4
CB 118	<2,0	<1,0	<1,0	<0,7
CB 128	<0,8	<0,4	<0,5	<0,3
CB 137	<0,6	<0,3	<0,3	<0,2
CB 138+163	1,1	0,9	0,5	1,5
CB 141	<0,9	<0,4	<0,5	<0,3
CB 149	<2,0	<1,0	<1,0	<0,6
CB 151	<0,8	<0,4	<0,5	<0,3
CB 153	2,6	2	1,6	2,9
CB 156	<0,9	<0,4	<0,4	<0,3
CB 170	<0,9	<0,5	<0,5	0,4
CB 180	1,2	0,8	0,9	1,5
CB 187	<1,0	<0,5	<0,5	<0,3
CB 194	<0,6	<0,3	<0,4	<0,2
CB 202	<0,6	<0,3	<0,3	<0,2
CB 206	<0,7	<0,4	<0,4	<0,2
Total toxaphene	23	9,5	6,7	11

12 Arctic char (*Salvelinus alpinus*)

12.1 Introduction

In the Faroe Islands Arctic char were originally found in lake Leynavatn only, and have not been reported in neither the two small lakes which flow out into Leynavatn nor in the rivers which flow to and from Leynavatn.

In 1956 Arctic char from Leynavatn were released in the reservoir Frammi á Vatni and later in 1961 also in the dammed lake Á Mýrunum. Later the Arctic char have spread from these places to the lower reservoirs, Lomundaroyri and Heygardalsvatn. These reservoirs are situated above Vestmanna (Reinert, 1998).

The Arctic char of Leynavatn have been described in Gydemo (1983). The population is said to have decreased in recent years (Joensen, 1998; Fjallstein, 1998), the suggested reason is increased salmon density and salmon ladders (Fjallstein, 1998).

12.2 Anadromous versus stationary

Many salmonoids are anadromous, which means that they live in the ocean except when they are young and that they only return to fresh water to spawn. Based on the description of eleven Arctic char caught in Leynavatn at the end of October 1963 (Reinert, 1964) it is possible to determine the beginning of the spawning season. At this time, in late October, half of the females were spawning while the other half were spent. The male fish which were caught at the same time for the 1963-study were all except one characterised as spawning.

There are without doubt also anadromous fish in Leynavatn, and this is why it is necessary to determine whether the fish taken from this lake are anadromous or not. In addition to Arctic char there was originally a large population of small, stationary brown trout (*Salmo trutta*) in Leynavatn and the above small lakes and rivers. In earlier days large waterfalls prevented anadromous salmon to ascend the lake from the sea. In 1967 annual releases of salmon fry in the river systems which run to Leynavatn were initiated at the same time as the population of small trout was reduced by electro-fishing (Reinert, 1999). Following the completion of the salmon ladders in the river below Leynavatn in 1972, brown trout and salmon have ascended Leynavatn and the above small lakes, Mjáuvøtn.

Some fish can be identified as anadromous or stationary based on their colour. This is for example possible with brown trout because trout which come in from the sea have a more silvery look than those who have spent some time in fresh water. Normally the meat of stationary brown trout from lake Leynavatn is quite white compared to the meat of anadromous brown trout which is more or less pink coloured like salmon. In addition to this colour-based evaluation, which both demands that the fish are caught before they get the nuptial coloration and also requires a trained eye, the distinction between anadromous and stationary fish can be based on the following:

1. Fish with no access to the sea are inevitably stationary

2. Fish caught outside the spawning season, that is in the period when anadromous fish are found in the sea, are stationary.

On rare occations the locals have observed thin specimens of Arctic char in the area where the river from Leynavatn leads into the sea. In this study, however, it is taken for reliable that the Arctic char of Leynavatn are stationary, and this is based on the findings of the above mentioned experiments with electro-fishing, which took place in the river both above and below Leynavatn (Reinert, 1998) and where no char were taken.

12.3 Material and methods

Fishing permit for Heygardalsvatn and Leynavatn were granted by the Faroese Government and the local landowners, and for Leynavatn also from the angling association Føroya Sílaveiðifelag.

Some of the Arctic char from Heygardalsvatn were in the pre-spawning phase in May/June, probably due to good food access. The Arctic char from Leynavatn were not spawning in June.

12.4 Disinfecting fishing tackle etc

It was recommended by the Chief Veterinary Officer to disinfect the fishing tackle thoroughly prior to the fishery, the solutions recommended were 1% Viakon S solution, 0,2% sodium hypochlorite or Iobac-P. However, the mentioned chemicals were not available at the pharmacy and therefore Actomar K30 was used in stead. The concentration used was the same as the one used for disinfecting trout eggs according to the instructions on the bottle.

Trout nets, kindly provided by the electricity company SEV, by Bjarki Johannesen, with a mesh width of 40, 60 and 80 mm were used for the fishing. The nets were set approx. 50 cm above the bottom of the lake. A rubber boat (3 person, children toy type) was used for setting the nets. Boots, fishing tackle and boat were disinfected in the wet room at the Food and Environmental Agency prior to the fishing.

12.5 Leynavatn

The nets were placed at the north-west end of lake Leynavatn. The nets were set at night at a right angle to the shoreline. The nets were hauled the following day.

Catch:
1. haul: 6 Arctic char with a by-catch of 12 trout
2. haul: only trout, 6 pieces.
3. haul: 10 Arctic char, with a by-catch of 21 Salmon sp. (8 pieces, approx. 25 – 40 cm full length and 13, approx. 12-15 cm).
4. haul: only trout, approx. 20 pieces.

Due to the considerable by-catches it was decided to stop the fishing even though the optimal number of 25 Arctic char had not been reached. The total catch was 16 Arctic char and approx. 60 trout.

Summary:

- The best fishing spot with nets is just outside the steepest area (where it is most inconvenient to stand) off the shore.
- Discoloured nets following disinfection do not result in considerably poorer fishing.
- The by-catch of trout was substantial.

12.6 Heygardalsvatn

At the beginning of June 1998 Arctic char were caught in Heygardalsvatn above Vestmanna. A feeding machine in the fish farm on the dam was started and then a seine was set out to encircle the fish which then were caught by a landing net. 25 large Arctic char of incredible good condition were easily caught this way.

Heygardalsvatn is a dammed riverbed which is used as a reservoir for the production of hydroelectric power. The river was dammed in 1961/62 and at normal operation there is an annual water level variation of 2 to 3 m (Hermansen, 1999). Following a disease outbreak (furunculosis) in the fish farm on the dam, Heygardalsvatn was emptied in 1992. Since then the fish farm has only been in operation occasionally and had not been in operation the month preceding the catching of Arctic char for this study. The Arctic char in the lake have most likely come from the lake upstream, Á Mýrarnar in the period following 1992 (Niðristovu, 1998). The results of the age determination from otolith readings also correspond to such a process.

12.7 Sample preparations

The fish were stored at –25^{0}C from a few hours after the fishery until sample preparation. Prior to dissection for sample preparations the partially thawed fish were weighed and the length of the fish (fork length) was registered. The otoliths were taken (except for fish Bl-17) for age determination. For the analyses of organochlorinated environmental toxins the whole liver was taken from the fish caught in Leynavatn, while the fish from Heygardalsvatn were so much bigger that only part of the liver was put aside for analysis. The part of the liver taken from these Heygardalsvatn specimens was the distal part of the right side liver lobe. In addition, a part of the muscle of the right hand side of the fish, behind the pectoral fin, was taken for mercury analysis. Pooled samples were made. The aim was to make homogeneous pooled samples, by making separate female and male samples and by separating the fish according to size so that fish of similar size and sex were combined for the same samples. Care was also taken to match the pooled samples of the various tissues so that the same individuals which were combined into one muscle tissue pooled sample were also combined into a liver tissue pooled sample.

12.8 Analysis

Prior to analysis the samples were homogenised in stainless steel blenders (liver samples) or plastic vessel ones (muscle samples). The mercury and dry weight analyses of the muscle samples were made at the Food and Environmental Agency. Mercury was analysed by means of hydrid-AAS[19]. The organochlorines and the lipid percentage of the liver were analysed at the Norwegian Institute for Water Research by GC-ECD[20]. The specific organochlorines analysed were: a selection of single PCB (polychlorinated biphenyl) congeners; CBs 28, 52, 101, 105, 118, 138, 153, 156, 180 and 209. In addition *p,p´*-DDT, *p,p´*-DDE and *p,p´*-DDD, as well as γ- HCH (lindane), α- HCH (hexachlorohexane), HCB (hexachlorobenzene), QCB (pentachlorobenzene) and OCS (octachlorostyrene). PCB 7 is the calculated sum of the measured concentrations of the following congeners: CBs 28, 52, 101, 118, 138, 153 and 180.

12.9 Tissue bank

The unused liver from the Arctic char caught in Heygardalsvatn were taken for tissue banking. The gonads and a piece of muscle in continuation of the sampling material behind the pectoral fin were also taken from each fish, wrapped individually and placed in the "bank". Material taken for environmental sample banking was wrapped in special foil to avoid freeze-drying during long term storage and was put back in the freezer (-20° C). The foil, aluminium laminate, is used for the same purpose at the Swedish Museum of Natural History (Odsjø, 1998).

12.10 Age determination

The individual age of the fish was read from the growth zones of the otoliths at the National Environmental Research Institute in Denmark by Jørgen Andersen, Department of Arctic Environment, and in Sweden by Johan Hammar, Stockholm. The Faroese climate has only moderate annual temperature variations, with the average temperature of the coldest and warmest month being approx. 4° C and 9° C, respectively. Consequently the growth zones are not as distinct and the transitions between the zones more sliding than in areas with more marked seasonal variations. However, the otoliths from Leynavatn had distinct seasonal variations and could therefore be compared to those from Arctic char in for example the southern parts of Sweden (Hammar, 1999). The determining of the age of the fish from Heygardalsvatn was more complicated, but otoliths from fish B1-9 were more distinct (Jørgensen, 1998; Hammar 1999) and these may be regarded as typical for a fish which has lived in a reservoir its entire life (6-7 years) (Hammar, 1999).

12.11 Results

A survey of the Arctic char caught in Heygardalsvatn and Leynavatn is shown in table 12.1. Pooled samples of female and male fish from Heygardalsvatn

[19] AAS: atomic absorption spectroscopy
[20] GC-ECD: gas chromatography with electron capture detector

and Leynavatn were analysed for mercury in muscle tissue and organochlorines in liver samples.
In total, the mean concentration of PCB 7 corresponds to 30 µg/kg liver, cf table 12.2. The congeners CB 153 and CB 138 constitute a total of 65% (64% and 66% in the pooled sample with female and male fish, respectively) in the fish from Leynavatn and 54% in the fish from Heygardalsvatn (exactly the same percentage in the three pooled samples).

However, the **Fulton's Condition Index** of the fish from Heygardalsvatn is quite dissimilar to that what is seen in our neighbouring countries or in New Foundland/Labrador, even though there are individual cases for example in Greenland (Aarkrog *et al.*, 1997, the longest fish from Thule; 57 cm) of Arctic char which naturally have reached a body length corresponding to that of the fish from Heygardalsvatn. There are on the other hand several cases of Arctic char reaching the same size as that from Heygardalsvatn if the surroundings in one way or the other are particularly favourable regarding growth. Fish which live in lakes with fish farms (Greer, 1991) or in lakes heated by geothermal activity (Mývatn, Iceland) or by waste heat (Visjön, Sweden) can reach the same extreme size and weight (Hammar, 1999).

Table 12.1. Arctic char from the two different lakes

Location	Catching-date			Length cm	Weight g	Condi-tion Index*	Age 1** year	Age 2** year	Liver g	Gonads g
Heygardals-vatn	June 98	n = 24	Mean	50,4	3178	2,46	7,8	7,4	60	54
		17 males	Min	38,5	1090	1,91	6	5	18	7
		7 females	Max	57,5	4880	2,82	12	11	114	208
Leynavatn	May/June 98	n = 15	Mean	23,3	151	1,12	7,8	8,3	1,3	1,6
		4 males	Min	19,0	76	0,99	6	5	0,6	0,6
		11 females	Max	33,3	420	1,19	11	18	2,1	2,6

* Fulton's Condition Index
** Age 1 and Age 2 are two independent determinations of the otoliths

12.12 Evaluation

The median length of Arctic char from Leynavatn of both sexes was 23 cm. Compared to experiments in 1963, figure 12.1, and in 1981, this suggests that the fish are not smaller today than they were 35 and 17 years ago, respectively (Reinert 1964; Gydemo, 1983). Observations of the 89 Arctic char in 1981 suggest that the majority of the Arctic char from Leynavatn were 6 to 7+ years old and had a length of approx. 21 and 22 cm, respectively. Full size for Arctic char from Leynavatn was estimated to be 23 and 24 cm, and this length is reached at the age of 8+ and 9+ years old (Gydemo, 1983). In the study from 1963 only three fish were age determined from otolith readings, and the results correspond to the results of the age-length ratio in the 1981-study, but if a trend is to be identified based on the slender material from 1998, it has to be that Arctic char have become bigger rather than smaller during these years.

Age-wise there is accordance between the Arctic char from the two lakes, both have an average age of approx. 7 to 8 years.

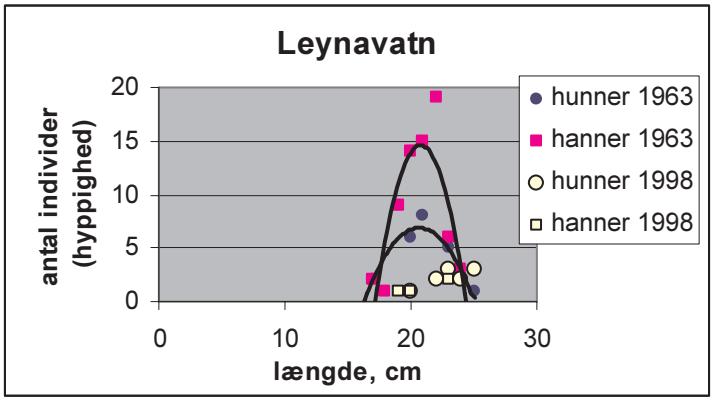

Figure 12.1 Comparison between Arctic char from 1963 and 1998 in Leynavatn. The X-axis shows the length in cm and the Y-axis shows numbers of individual.
Hunner = females, hanner = males.

12.13 POPs

12.13.1 Heygardalsvatn versus Leynavatn

If the two groups of Arctic char from the Faroe Islands are compared, there is no conspicuous difference between the concentration of the chlorinated persistent compounds on a wet weight basis. If, on the other hand, the results are converted to a lipid-dependent concentration, the PCB 7 concentration is approx. 3 times higher in the fish from Leynavatn than in the fish from Heygardalsvatn, but as it is shown (table 12.2) this is a natural consequence of the lipid content of the wild fish liver only being one third of that of the Heygardalsvatn fish.
The fish from Leynavatn tend to have a larger share of the higher chlorinated[21], most persistent congeners (CB 138, 153 and 180) than fish from Heygardalsvatn (table 12.3 and figure 12.2). Another difference between the two populations is that the ratio of DDE/Sum DDT (table 12.4) is markedly higher in the Leynavatn samples. The ratio DDE/Sum DDT (table 12.4) gives the distribution of the metabolite, *p,p'*-DDE, in relation to Sum DDT, where Sum DDT is the total concentrations of the original pesticide *p,p'*-DDT and *p,p'*-DDE, as well as the other metabolite *p,p'*-DDD. This ratio has been used as an indicator on the "age" of the DDT pool in the environment, in other words as a indicator on how long ago the original insecticide *p,p´*-DDT was released into the biosphere. Pilot whale studies (Dam, in prep.) have shown that the share of the original *p,p'*-DDT in pilot whale is lower than 10 years ago, and that the concentration of the sum DDT and its metabolites have been reduced. These observations are interpreted as being a natural consequence of the restrictions which in recent decades have applied for the use of DDT in our part of the world. Sum DDT in the Arctic char from Heygardalsvatn has a larger element of *p,p'*-DDT, which suggests

[21]CB 101 and 118 are pentachloro- substituted, CB 138 and 153 are hexachloro- and CB 180 is heptachloro-substituted. Halflives of the hexa- and hepta- substituted congeners in air are approx. 8 months, halflives of the penta-substituted are approx. 2 months (AMAP, 1998).

that the fish fodder comes from an area with younger pollution or is taken from a lower level in the food chain, where the capacity for metabolic degradation of POPs is lower and where the period from the environmental toxin is released into nature until it is dissolved in the lipid tissue of the fish, is shorter. Table 12.4 also contains the analysis results for the other pesticides.

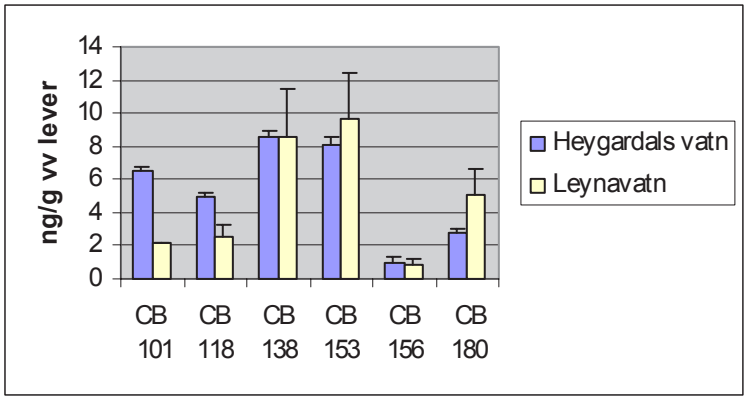

Figure 12.2. Comparison of some CBs between Arctic char in Heygardalsvatn and Leynavatn (the unit is ng/g wet weight in liver).

Table 12.2. PCB and Hg concentration in Arctic char

Location	Pooled samples		length cm	weight g	age 1 year	age 2 year	lipid %	PCB 7 µg/kg liver	PCB 7 µg/kg lipid	dry matter, g/100g	Hg, mg/kg ww muscle	Hg, mg/kg dw muscle
Heygar-dalsvatn	6 mixed: Bl-01, Bl-02, Bl-03, Bl-04, Bl-05, Bl-06	Mean	51,8	3662	8,5	7,8	34%	31,3	93,2			
		Std.dev.	*3,1*	*856*	*2,3*	*2,1*						
Heygar-dalsvatn	6 males: Bl-09, Bl-10, Bl-11, Bl-12, Bl-15, Bl-17	Mean	51,3	3292	6,8	6,6	38%	31,9	85,1	38,74	0,058	0,150
		Std.dev.	*3,1*	*669*	*1,0*	*1,3*						
Heygar-dalsvatn	5 females: Bl-14, Bl-16, Bl-18, Bl-19, Bl-21	Mean	52,0	3273	8,6	8,4	31%	29,1	95,4	42,78	0,080	0,187
		Std.dev.	*6,1*	*1023*	*1,1*	*1,5*						
Heygar-dalsvatn	4 males: Bl-20, Bl-22, Bl-23, Bl-24	Mean	50,3	3100	9,5	8,3				40,02	0,059	0,147
		Std.dev.	*2,9*	*181*	*3,5*	*2,6*						
Leynavatn	5 females: Bl-25, Bl-26, Bl-28, Bl-30, Bl-31	Mean	23,3	147	8,6	8,6				22,31	0,20	0,90
		Std.dev.	*2,0*	*34*	*2,7*	*3,4*						
Leynavatn	4 males: Bl-27, Bl-29, Bl-36, Bl-37	Mean	21,3	106	7,3	6,5	9%	34,8	391	19,42	0,19	0,98
		Std.dev.	*1,9*	*31*	*0,5*	*1,3*						
Leynavatn	6 females: Bl-32, Bl-34, Bl-35, Bl-38, Bl-39, Bl-40	Mean	23,0	139	8,4	7,5	13%	23,6	182	21,32	0,16	0,75
		Std.dev.	*1,3*	*27*	*1,8*	*2,1*						

dw: dry weight
ww: wet weight
age 1 and age 2: determinated by two different institutions

Table 12.3. PCB in liver from Arctic char (µg/kg wet weight in liver)

PCB		lipid %	CB 28	CB 52	CB 101	CB 118	CB 105	CB 138	CB 153	CB 156	CB 180	CB 209
Heygardalsvatn	6 males	38%	<0,5	<0,5	6,5	5,2		8,6	8,6	1,3	3	<0,5
Heygardalsvatn	5 females	31%	<0,5	<0,5	6,2	4,8		8	7,6	0,8	2,5	<0,5
Heygardalsvatn	6 mixed	34%	<0,5	<0,5	6,7	4,9		8,9	8	0,9	2,8	<0,5
Leynavatn	4 males	9%	<0,5	<0,5	2,2	3,2	3,6	11	12	1,2	6,4	<0,5
Leynavatn	6 females	13%	<0,5	<0,5	2,2	2,1	4,1	7	8,1	0,7	4,2	<0,5

Table 12.4. Pesticides in liver from Arctic char (µg/kg wet weight in liver)

Pesticides		lipid %	QCB	HCB	α-HCH	γ-HCH	OCS	p,p-DDE	p,p-DDD	p,p-DDT	Sum DDT	DDE/ Sum DDT
Heygardalsvatn	6 males	38%	1,5	9,0	3,8	4	<0,5	21	11	10	42	0,50
Heygardalsvatn	5 females	31%	0,8	7,2	3	3,300	<0,5	20	11	7,7	39	0,52
Heygardalsvatn	6 mixed	34%	0,7	7,4	3,3	3,7	<0,5	21	11	9,9	42	0,50
Leynavatn	4 males	9%	0,6	2	0,6	0,5	<0,5	19	0,7	3,9	24	0,81
Leynavatn	6 females	13%	0,5	3	0,8	0,6	<0,5	13	0,6	2,5	16	0,81

12.13.2 Comparison with Arctic char in other countries

In the present study of Faroese Arctic char the liver tissue has been analysed for POPs, whereas such analyses in other countries has been done on the muscle tissue (table 12.5). However, the concentration of POPs on a lipid basis is expected to be pretty similar in these two tissue types, consequently comparison should be possible with the values entered as "µg/kg lipid" in the table. There are other factors which are likely to be more decisive and which are related to the "mode of life" of the fish, such as the fish's position in the food web which can vary in the same lake, both as a more permanent adjustment and on a temporary basis, but also the use of the consumed energy; whether it is used for somatic growth or reproduction affects the concentration of the organic environmental toxins (Hammar *et al.*, 1993; Hammar, 1998). Consequently it is important to evaluate not only age but also parameters such as length and weight when comparisons are made. The Arctic char caught in Heygardalsvatn are not comparable with Arctic char for which the environmental toxins are known, from similar studies in our neighbouring countries. Therefore it has been decided to include only Arctic char from Leynavatn in the following comparisons.

If the results from Arctic char in Leynavatn are compared with Arctic char of similar size and age in our neighbouring countries (*e.g.* Stora Blåsjön), it can be seen (table 12.5) that the PCB content is approx. 1/5 as high as in the dwarf population from Stora Blåsjön and that the *p,p'*-DDE concentration is approx. 1/3 as high. On the other hand, the PCB content in the Faroese small Arctic char population is lower than the highest concentrations identified in a

dwarf population of Arctic char from Linnévannet in Svalbard (Skotvold *et al.*, 1997) but at the same time at least 10 times as high as the PCB concentrations in Arctic char from other localities on Svalbard (Skotvold *et al.*, 1997). Based on an outline of the results (table 12.5), it can generally be said that the content of these environmental toxins in the Faroese Arctic char is in the same range as in fish from the northern parts of Sweden (Stora Blåsjön), Norway and Canada as well as from Svalbard and Greenland. There are however exceptions, and these are for example seen in the dwarf populations from Linnévann and Kongressvann on Svalbard.

Table 12.5. Some environmental pollutants in Arctic char from different location

Location	n	length cm	weight g	age year	Matrix	Lipid %	**α-HCH µg/kg lipids	CB 153 µg/kg lipids	PCB 7, µg/kg liver	PCB 7, µg/kg lipids	p,p´-DDE, µg/kg lipids	Sum DDTs µg/kg lipids	Hg, mg/kg muscle	*Ref.*
Heygadals-vatn	17	51,7	3417	7,6	Liver/ muscle	34%	9,9	23,8	30,9	91	60,8	353,8	0,044	*this work*
Leynavatn	10	22,3	126	7,1	Liver/ muscle	11%	6,3	85,0	28,1	265	135,6	1479,8	0,172	*this work*
Stora Blåsjøn, Sweden	16	21,1	75	7,4	Muscle	ca 1%				1300	370			*Hammar et al., 1993*
Stora Blåsjøn, Sweden	14	29,0	239	4,9	Muscle	ca 1,4%				300	90			*Hammar et al., 1993*
Vattern, SE			741		Muscle	5%				3612				*Jansson et al., 1993*
Greenland, Qaqortoq, lake B	22	34,7		10,6	Muscle								0,531	*Aarkrog et al., 1997*
Greenland, Qaqortoq, lake B		41,0	622	12,6	Muscle	2%	10,6	375,0			437,5	468,8		*Aarkrog et al., 1997*
Greenland, Thule	26	41,2	494	13,6	Muscle	3%	10,3	86,2					0,135	*Aarkrog et al., 1997*
Greenland, all	200	35,9		11,7	Muscle								0,465	*Aarkrog et al., 1997*
Greenland, all	100	36,0	457		Muscle	3%	12,6	214,8		621	200	233,3		*Aarkrog et al., 1997*
Svalbard	39				Muscle	0,9 - 6,2%								*Skotvold et al., 1997*
Svalbard			500		Muscle					7				*Skotvold et al., 1997*
Svalbard			200		Muscle					27				*Skotvold et al., 1997*
Svalbard, Linnévann & Kongress vannet			15	9	Muscle	0,45-0,98 %				1800-2700				*Skotvold et al., 1997*
N-Norway, Cuolb-majavri	20	26,1	197	7,7	Muscle								0,043	*Skotvold et al., 1997*
Bear island, Ellasjøen	20	27,7		9,4	Muscle								0,119	*Skotvold et al., 1997*
N. Ellesmere Island, Lake Hazen, Can.$	45*				Muscle	4,6%	58,7			430		258,7	0,18	*Muir and Lockhart, 1993*
Cornwallis Is. Can.$	19*				Muscle	4,2%				3452			0,216	*Lockhart, 1994*
NWT, Amituk lake, Can.$	12	28			Muscle	4,4%	46,6			824		731,8	0,5	*Lockhart, 1995*

*: or POP results from Lake Hazen n = 6, from Cornwallis Is. n = 5
**: results from Canada are given as Sum HCH
$: PCB 7 was estimated to be Sum PCB * 0,5

12.14 Mercury

Studies for example from Greenland and Canada (Aarkrog *et al.*, 1997; Muir *et al.*, 1996) have shown that Arctic char which live in fresh water all their lives have a higher mercury content (approx. factor 10) than anadromous Arctic char. There is also a general tendency for the mercury content to increase with age, however among the phenotypes (fish of same species but with different "adult size") the small dwarf stocks have the highest mercury concentrations (see for example Skotvold *et al.*, 1997). This latter phenomenon where comparisons between dwarf fish and fish of "normal" size give a length versus concentration curve which is reverse to what otherwise is the case when comparing fish from the same population, is explained as being the result of the dilution effect of new tissue on the body's pool of persistent environmental toxins (Hammar *et al.*, 1993).

The mercury concentrations of the Faroese Arctic char are generally in the lower end of those found in fish from especially Greenland.

The mercury content of Arctic char from Leynavatn is approx. 4 times higher than in fish from N-Norway of similar size and age, but comparable to the content identified in Arctic Canada and on Bjørnøya.

12.15 References

AMAP, 1998. *AMAP Assessment Report: Arctic Pollution Issues*. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xii + 859 pp.

Fjallstein, I. 1998. Fiskaaling við Áir. Pers. comm.

Greer, R., 1991. *Arctic char in lochs of the Grampian Highlands of Scotland*. In: (Eds) Hammar, J. Proceedings of the sixth ISACF workshop on Arctic char, 1990. Institute of freshwater research, Drottningholm, Sverige.

Gydemo, R., 1983. *The Arctic char in Lake Leynavatn, Faroe Islands*. ISACF information Series 2, Institute of Freshwater Research, Drottningholm, Sverige.

Hammar, J. 1998. *Sex, bodybuilding and more sex: fast ontogenetic shifts in allopatric Arctic char* (*Salvelinus alpinus* (L)). In: Evolutionary ecology of Arctic char (*Salvelinus alpinus* (L.))- Intra and interspecific interactions in circumpolar populations. Dissertation for the degree of Doctor Philos. Uppsala Univ. Sweden.

Hammar, J., Larsson, P. and Klavins, M. 1993. *Accumulation of persistent pollutants in normal and dwarfed Arctic char* (*Salvelinus alpinus* sp. Comples). Can. J. Fisheries and Aquatic Sci. 50: 2574-2580.

Hermansen, B. 1999. SEV. Pers. comm.

Jansson, B., Andersson, R., Asplund, L., Litzen, K., Nylund, K., Sellstrom, U., Uvemo, U-B., Wahlberg, C. Widequist, U., Odsjø, T., Olsenø, M and Olssen, M. 1993. *Chlorinated and brominated persistent organic compounds in biological samples from the environment*. Env. Toxicol. Chem., 12, 1163-1174.

Joensen, H. 1998. Føroya Sílaveiðifelag. Pers. comm.

Lockhart, W.L., 1994; unpublished data presented in the Muir et al. 1996.

Lockhart, W.L. 1995. Implications of chemical contaminants for aquatic animals in the Canadian Arctic; some review comments. Sci. Total Environ. 160/161, 631-641.

Muir, D.C. and Lockhard, W.L. 1993. *Contaminant trends in freshwater biota*. In: J.L.Murray and R.G. Shearer (Eds): Synopsis of research conducted under the 1992/93 Northern Contaminants Programme, Env. Studies no. 70, Indian and Northern Affairs Canada Ottawa, 285 pp.

Muir, D., Braune, B., DeMarch, B., Norstrom, R., Wagemann, R., Gamberg, M., Poole, K., Addison, R., Bright, D., Dodd, M., Duschenko, W., Eamer, J., Evans, M., Elkin, B., Grundy, S., Hargrave, B., Hebert, C. Johnstone, R., Kidd, K., Koenig, B., Lockhart, L., Payne, J., Peddle, J.and Reimer, K 1996. Chapter 3. Ecosystem uptake and effects. In: Jensen, J., Adare, K. and Shearer, R. (Eds), *Canadian Arctic Contaminants Assessment Report*, Indian and Northern Affairs Canada, Ottawa 1997. 428 pp.

Niðristovu, H. í. 1998. Opsynsmand ved opdrætsanlægget i Heygardalsvatn. Pers. comm.

Odsjö, T., 1998. Pers. comm.

Reinert A., 1998. Fiskaaling við Áir. Pers. comm.

Skotvold, T. 1998. Pers. comm.

Skotvold, T., Wartena E.M.M. and Rognerud, S. 1997. Heavy metals and persistent organic pollutants in sediments and fish from lakes in Northern and Arctic regions of Norway. SFT Rapport 688/97, Statens Forurensningstilsyn, Oslo.

Aarkrog, A., Aastrup, P., Asmund, G., Bjerregaard, P., Boertmann D., Carlsen, L., Christensen, J., Cleemann M., Dietz, R., Fromberg, A., Storr-Hansen, E., Zeuthen-Heidam, N., Johansen, P., Larsen, H., Paulsen, G.B., Petersen, H., Pilegaard, K., Poulsen, M.E., Pritzl, G., Riget, F., Skov, H., Spliid, H., Weihe, P. and Wåhlin, P. 1997. *AMAP Greenland, 1994-1996*. Miljøprojekt nr. 356, Miljøstyrelsen. 788 pp.

13 Radioactivity

Intentionally, all the species that were analysed for heavy metals and persistent organic pollutants were also to be analysed for Cs-137 radioactivity. Unfortunately, there proved to be insufficient quantities of blue mussel soft parts. Also the queen scallop material was insufficient but re-sampling was arranged and a new pooled sample made (queen scallop 3).

In general, pooled samples of homogenised muscle were analysed for Cs-137 activity. Moss and lichen were analysed as dry, crushed samples.

Table 13.1. Cs-137 content [Bq/kg]

Species	Cs-137 [Bq/kg]	Std. * [%]	Pre-treatment described in chapter
Marine environment			
Queen scallop 3	<0,1		6
Fulmar (Nólsoy)	<0,1		7
Fulmar (Vestmanna)	<0,1		7
Cod (T1-T25 (-T4))	<0,1		8
Cod (T26-T45)	<0,1		8
Grey seal (males)	<0,1		9
Grey seal (females)	0,14	46,3	9
Grey seal (juveniles)	<0,1		9
Pilot whales (males)	0,11	56,1	10
Pilot whales (females)	<0,1		10
Pilot whales (juveniles)	<0,1		10
Terrestrial and freshwater environments			
Moss	59		11
Lichen	21		11
Sheep (Vestmanna)	17,2	3,5	12
Sheep (Koltur)	1,9	13,6	12
Brown trout, small and large specimens (Leitisvatn)	2,31	4,4	13
Brown trout, small specimens (Fjallavatn)	1,07	7,5	13
Brown trout, small and large specimens (Fjallavatn)	2,44	4,4	13

*Std. is the counting standard deviation

6 AMAP Faroe Islands 1999 - 2001 Heavy Metals

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Faroe Islands

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Content

Summary and conclusions

This report is based on results from metal analyses done as part of the Arctic monitoring and Assessment Program (AMAP) on the Faroe Islands in the period 1999-2001. Selected marine, terrestrial and freshwater species as well as sediments have been analysed. The metals which have been analaysed are: Hg, Cd and Se.

The following species from the marine environment were analysed:
Short-horn sculpin *Myoxocephalus scorpius*
Black guillemot *Cepphus grylle*
Pilot whale *Globicephala melas*

The following species from the terrestrial and freshwater environment were analysed:
Mountain hare *Lepus timidus*
Sheep *Ovis aries*
Arctic char *Salvelinus alpinus*

In addition, marine and freshwater sediments have been analysed for Hg.

The highest mercury concentrations were found in pilot whale muscle, with 3 mg/kg in a group of adult males. Next highest mercury concentrations were found in black guillemot livers, and in sculpin livers of the 2000 samples. The mercury concentrations in the three years of sculpin samples spanned a wide range from 0,1 mg/kg to almost 1,5 mg/kg varying among the age-groups but more markedly between the years. Then comes black guillemots eggs with mercury concentrations around 0,5 mg/kg, and Arctic char with a mercury level around 0,2 mg/kg. Hare livers had mercury concentrations at 0,1 mg/kg or below, while in sheep no mercury could be detected at a detection limit of 0,02 mg/kg.
The highest cadmium concentrations, just below 1,4 mg/kg were found in the black guillemot livers and next highest concentrations were found in the sculpins livers in the largest fish-size groups. As with mercury there were large variations between years, but even more marked was the variation between fish-size groups.
The highest selenium concentrations were found in the two fish species, with concentrations in the range 1 – 1,5 mg/kg. Selenium in pilot whales muscle were normally 0,5 mg/kg as was also the level found in hare livers.
Freshwater sediment cores were taken from two lakes, where the core from one of these turned out to be highly influenced by bioturbation and thus unfit for trend analyses. The intact core, from Sørvágsvatn, indicate a doubling in mercury concentration during the last 200 years, but this needs to be confirmed and for this repeated sampling is required.
The marine sediment samples taken at the Faroese shelf just east of the islands at the Sandoyarbanka, were taken as four parallel cores, each of which was analysed with respect to sedimentation rate and mercury concentration. The dating showed that the sediments in the cores were deposited during the last 120 years, and that there were increasing mercury concentrations from the earliest sediments of approx. 1880 until approx 1980, with an indication of decreasing concentrations during the last 20 years. The results are

preliminary in the context of detecting real time-trends in that additional analyses are required in order to tell whether these mercury concentrations were the result of changing physiochemical environment or changing input.

1 Introduction

When selecting the species to be analysed, they are evaluated according to two different purposes:

1) the main purpose is the concern for human health related to intake of traditional foods of the Arctic (and sub-Arctic) populations. To meet this criteria, pilot whales and sheep/lamb are included, and probably also hares.
2) the second purpose, which is also the reason for undertaking this monitoring programme in AMAP context, is to monitor such species and matrices that allow comparisons between countries of the distribution of environmental pollutants into the Arctic and sub-Arctic areas. In order to meet the demands of this criterion, we incorporate species that live stationary in or off the Faroe Islands like sculpins and black guillemot liver and eggs.

The metal analysis for AMAP phase II include mercury, cadmium and selenium, and in the tables below there is an overview over the metal analysis for 1999 2000 and 2001.

Table 1.1 shows the species analysed in 1999. All the samples were collected in 1999 except for the black guillemot liver and the hare samples which were collected in 1996 and 1997 respectively.

Table 1.1. Overview over analysed species in 1999

Species	Matrix	Cadmium	Mercury	Selenium
Short-horn sculpin	Liver	+	+	+
Black guillemot	Egg		+	
	Liver	+	+	
Pilot whale	Muscle	+	+	+
Mountain hare	Liver	+	+	
Sheep	Liver	+	+	

Table 1.2 shows the species analysed in 2000. All the samples were collected in 2000 exept for the mountain hare and pilot whale samples which were collected in 1999.

Table 1.2 Overview over analysed species in 2000

Species	Matrix	Cadmium	Mercury	Selenium
Short-horn sculpin	Liver	+	+	+
Black guillemot	Egg		+	
Pilot whale	Muscle	+	+	+
Mountain hare	Liver	+	+	+
Artic char	Muscle		+	+

Table 1.3 shows species analysed in 2001. The samples were collected in 2001 except for the black guillemot livers and feathers which were collected in 1995 and 1996 and the pilot whales, which were collected in 2000.

Table 1.3. Species analysed in 2001

Species	Matrix	Cadmium	Mercury	Selenium
Short-horn sculpin	Liver	+	+	+
Black guillemot	Liver	+	+	+
	Egg		+	
	Feather		+	
Arctic char	Muscle		+	+
Pilot whale	Muscle	+	+	+

As a special task in 2000 marine sediments were dated and analysed for mercury to determine the trend of mercury pollution from the past about 100 years until present. In 2001 a special task was to do the same analyses on freshwatersediments.

Table 1.4. Special tasks for 2000 and 2001

Matrix	Dating	Mercury
Marine sediments	+	+
Freshwater sediments	+	+

1.1 Analytical methods

For all the species, except for the short-horn sculpins, the mercury and cadmium analysis were performed at the Food and Environmental Agency in the Faroe Islands and the selenium analysis were performed at NERI (National Environmental Research Institute, Denmark). The short-horn sculpins were analysed for mercury, cadmium and selenium at CTQ (Centre de Toxicologie du Quebec, Canada).

At The Food and Environmental Agency cadmium was analysed with atom absorption spectrophotometry using either graphite (Perkin Elmer 1100B) or flame (Perkin Elmer 2380) depending on the content of the examined material. Mercury was analysed on a Perkin Elmer 2380 + MHS 10 (Mercury Hydrid System) until november 2000. Since november 2000 the mercury has been analysed with the FIMS 400 (Mercury analysis system) + amalgam system, PERKIN ELMER (AA600).

The determination of the dry-weight percentage was based on the loss of mass after 10 to 20 hours at 105°C.

Quality assurance: Double determinations were performed. A certified reference material and a blank sample were analysed in connection with each series. The certified reference material and the blank were destroyed in the same manner as the samples. A 4-point standard curve was always made. The laboratory participates in regular intercalibration, for example Quasimemes (quality assurance of information for marine environmental monitoring in Europe).

The laboratory was accredited to the performed analyses: mercury, cadmium and dry-weight.

At NERI the selenium was analysed with "Perkin Elmer FIMS" instrument coupled to the flame instrument Perkin Elmer 3030 spectrophotometer with a heated quarts tube (900°C) mounted in the light path (see Asmund & Cleemann, 2000).

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

2 *Myoxocephalus scorpius* – Short-horn Sculpin

In AMAP the four-horn sculpin, *Myoxocephalus quadricornis,* is selected to be an AMAP species, because it occurs throughout the Arctic region, and because it is very stationary. However, in Iceland and the Faroe Islands *Myoxocephalus quadricornis* does not occur and therefore the short-horn sculpin (*Myoxocephalus scorpius*) is used instead. Greenland has analysed on short-horn sculpins as well.

Short-horn sculpin (*Myoxocephalus scorpius*) is the dominant sculpin species in the Faroes, but a different species, the long-spined sculpin (*Taurulus bubalis*), can sometimes be mistaken with a young short-horn sculpin. In the Faroe Islands the short-horn sculpin does not reach a large size: maximum female size is 32 cm, while the male size is less. In Iceland they do become up to 40 cm (Joensen, J. S. and Vedel Tåning, Å. 1969) and in Greenland the largest reach 60 cm (Pethon, P. 1985).
The stationary nature of the sculpin makes it suitable as an indication on local pollution. They are bentic and not good swimmers, and the diet consists most likely of different species that pass by the very well camouflaged still laying sculpin.

2.1 Sampling

In 1999 we caught sculpins for analysis for the first time, so basically the project in 1999 must be regarded as a pilot project from the start. In 2000 there were made some changes on the sampling procedure from the experience gained in 1999.

In 1999 an area from Tórshavn to Kaldbaksbotn and to Kaldbak was decided to represent one station with a number of exactly marked substations.
Due to local pollution, this area is not ideal when the long-range transport of environmental pollutants is estimated. The area of fishing was very practical, mainly due to the close proximity from Tórshavn which made several field visits possible during the collection period. In 2000 the sampling area was restricted only to include the substations Kaldbak and Sund. In 2001 the samples were collected in Kaldbak, Sund and Tangafjørður

Sculpins were collected with a fishing rod from land and from boat in 1999. Fish trap and hand collecting by scuba diving were used as alternative methods. In 2000 all the sculpins were collected with fishing rod, and in 2001 almost all were collected with fisk trap. The few which were not, were collected with fishing rod.

The sampling periode was during July and August in 1999 and a total number of 55 sculpins were collected, of which 39 were analysed. The remaining 16 (collected in Kaldbaksbotn), which had been kept in a fibre glass tub for several weeks, were not suitable for analysis. However, these sculpins were examined for age, and the length and weight were also measured.

In 2000 the sampling periode was changed to be from April to June and a total number of 23 sculpins were collected and analysed. Due to the liver size, mainly larger sculpins were collected in 2000 by which large pooled samples were avoided.
In 2001 the sampling started late June, and ended late August.

In 1999 the sculpins were heavily infected with nematodes (sandmaðkur). The nematodes were found in the muscles, abdominal cavity and sometimes in the liver. This was thougth to be due to the period chosen for sampling, and this was the reason for moving the catching period to be conducted earlier in the year in 2000. However, in 2000 the sculpins were also heavily infected with nematodes.

2.2 Sample treatment

All the sculpins were rinsed in milli-Q water and stored in PE plastic bags (Minigrip®) in a freezer (-20°C) until further preparation. When the sample preparation took place, we tried to be very careful not to handle the samples too much. We used talcum-free gloves and all the instruments, *e.g.* scalpel, scissors and tweezers, were thoroughly rinsed with milli-Q water. All organs (liver, muscles, gonads) were stored in heat treated glass (400°C for at least four hours) with similarly heat treated aluminium foil between glass and lid and finally stored individually in the freezer (-20°C) until shipment to CTQ[1] for analysis. The samples were transported in polycarbonate boxes to the laboratory, and all the further handling of the samples (homogenization etc.) were conducted by the laboratory in Canada. At CTQ, the liver was analysed for the metals: mercury, cadmium and selenium. In addition the samples from 1999 were analysed for dry matter content. The other samples (muscles, gonads and stomachs with contents) are stored in the Faroese Environmental Specimen Bank. Because of deficient liver tissue samples some individual analysis and some pooled sample analysis have been made.

The gender was registered for each individual, but because of the small size of the gonads, it was very difficult to determine the sex, so the sculpins sex shall be taken with reservation. For age determination, otoliths were extracted from all the sculpins, except for sculpin number Ms-0002, but only the otoliths from 1999 were analysed at the Faroese Fisheries Laboratory.

The sample compositions are shown below in Table 2.1, Table 2.2. and Table 2.3. The composition of the samples was based on the length of the sculpins, and therefore sub-stations were not considered in this context.

As mentioned before, the similarity between the short-horn sculpin (*Myoxocephalus scorpius*) and the long-spined sculpin (*Taurulus bubalis)* is great, and unfortunately in 1999 there appear to be two individuals of the long-spined sculpin in the pool presumed to be all short-horn sculpin. These two have ID numbers Ms-0008 and Ms-0028. This mix up was discovered when the otoliths were studied. The two misplaced individuals belong to the pooled samples number 1-1999 and 2-1999.

[1] Centre de toxicologie du Quebec, Canada

Table 2.1. Composition of sculpin liver samples from 1999

Sample no.	Number of sculpins in sample	ID of sculpins in sample	Age*	Size group cm	Total liver tissue, g
1-1999	5	Ms-0028, Ms-0007, Ms-0009, Ms-0011, Ms-0001	3,4	10-15	2,1
2-1999	5	Ms-0027, Ms-0029, Ms-0008, Ms-0016, Ms-0018	2,8	10-15	2,5
3-1999	7	Ms-0035, Ms-0036, Ms-0034, Ms-0006, Ms-0010, Ms-0017, Ms-0014	3,9	15-20	10,1
4-1999	7	Ms-0002, Ms-0003, Ms-0015, Ms-0019, Ms-0012, Ms-0013, Ms-0022	3,6	15-20	9,9
5-1999	4	Ms-0030, Ms-0037, Ms-0033, Ms-0020	5,5	20-25	16,7
6-1999	1	Ms-0005	6	20-25	7,6
7-1999	1	Ms-0021	6	20-25	6,7
8-1999	1	Ms-0023	6	20-25	6,1
9-1999	2	Ms-0032, Ms-0025	7	25-31	10,6
10-1999	1	Ms-0031	7	25-31	11,1
11-1999	1	Ms-0038	5	25-31	10,1
12-1999	1	Ms-0039	6	25-31	14,9
13-1999	1	Ms-0004	5	25-31	8,0
14-1999	1	Ms-0024	5	25-31	8,6
15-1999	1	Ms-0026	7	25-31	18,6

*The age in the pooled samples (sample no. 1-5 and 9) is the mean age of sculpins

Table 2.2. Composition of sculpin liver samples from 2000

Sample no.	Number of sculpins in sample	ID of sculpins in sample	Length cm	Size group cm	Total liver tissue, g
Ms-1-2000	2	Ms-0058, Ms-0059	21,5*	20-25	7,987
Ms-2-2000	2	Ms-0075, Ms-0076	22,25*	20-25	6,45
Ms-0057	1	Ms-0057	21,5	20-25	6,902
Ms-5-2000	3	Ms-0056, Ms-0070, Ms-0073	21*	20-25	6,159
Ms-6-2000	3	Ms-0069, Ms-0071, Ms-0072	24,3*	20-25	6,166
Ms-3-2000	2	Ms-0060, Ms-0066	25,75*	25-30	7,942
Ms-4-2000	2	Ms-0063, Ms-0067	26*	25-30	7,029
Ms-0068	1	Ms-0068	26	25-30	21,458
Ms-0061	1	Ms-0061	28,5	25-30	8,466
Ms-0065	1	Ms-0065	29	25-30	14,066
Ms-0064	1	Ms-0064	29	25-30	15,967
Ms-0062	1	Ms-0062	29,5	25-30	6,895
Ms-0077	1	Ms-0077	31	25-30	11,414
Ms-0078	1	Ms-0078	30,5	25-30	8,215
Ms-0074	1	Ms-0074	30,5	25-30	7,802

*The length in the pooled samples is the mean length of sculpins

Table 2.3. Composition of sculpin liver samples from 2001.

Sample no.	Number of sculpins in sample	ID of sculpins in sample	Length cm	Size group cm	Total liver tissue in pool, g
Ms-01-09-01	7	Ms-0075; Ms-0076; Ms-0078; Ms-0079; Ms-0083; Ms-0096; Ms-0097	17,8	15-20 cm	10,2
Ms-02-09-01	5	Ms-0077; Ms-0080; Ms-0081; Ms-0082; Ms-0085	23,0	20-25 cm	23,5
Ms-03-09-01	5	Ms-0085; Ms-0090; Ms-0093; Ms-0094; Ms-0095	23,6	20-25 cm	22,9
Ms-04-09-01	5	Ms-0086; Ms-0087; Ms-0088; Ms-0089; Ms-0091	27,6	25-30 cm	24,8
Ms-05-09-01	3	Ms-0092; Ms-0098; Ms-0099	28,8	25-32 cm	24,1

2.3 Results

2.3.1 Age determination

The age of the sculpins collected in 1999 was determined at the Faroese Fisheries Laboratory and in the figure below age is depicted against length, showing the correlation between length and age. The age ranges between two and seven years.

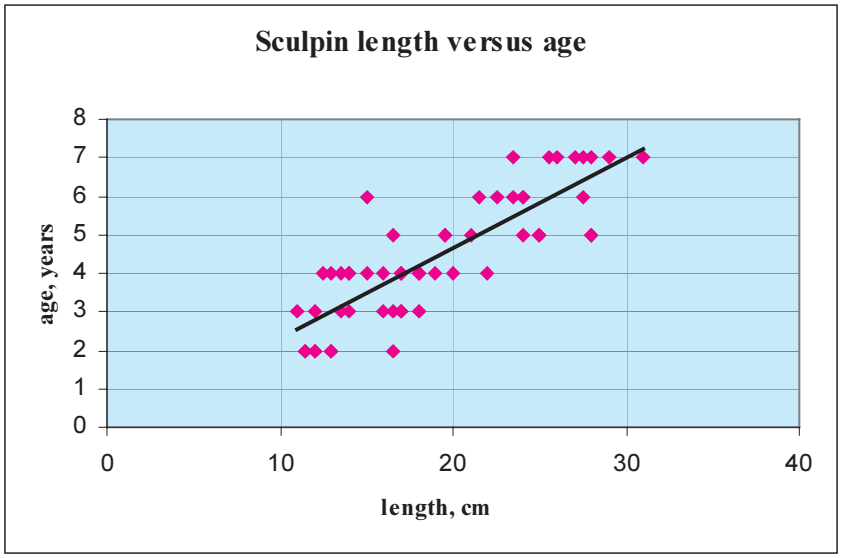

Figure 2.1. Sculpin length versus age

The length of the sculpins collected in 2000 ranged from 19,5 - 30,5 cm and according to Figure 2.1 the age of the sculpins is somewhere between 4-7 years. The mean length was 25,3 cm which corresponds to an age of 6 years.

2.3.2 Heavy metals

The liver was analysed for some heavy metals and the results of the analysis is listed below in Table 2.4, Table 2.5 and Table 2.6. The metal results were presented in dry weight from the laboratory and in the tables the results have been converted into wet weight because of comparison of our results with other results, which are presented in wet weight.

Table 2.4. Metal content in sculpin liver 1999

Length, cm		Cd µg/g dw	Hg µg/g dw	Se µg/g dw	Dry matter %	Cd mg/kg ww	Hg mg/kg ww	Se mg/kg ww
10-15	Min.	0,65	0,14	3,95	27,6	0,18	0,04	1,09
	Max.	0,73	0,16	4,39	27,6	0,20	0,04	1,21
	Mean	**0,69**	**0,15**	**4,17**	**27,6**	**0,19**	**0,04**	**1,15**
	Std. dev.	*0,06*	*0,01*	*0,31*	*0,0*	*0,02*	*0,0*	*0,09*
15-20	Min.	0,51	0,28	4,86	27,6	0,14	0,08	1,34
	Max.	0,58	0,68	5,81	27,6	0,16	0,19	1,60
	Mean	**0,55**	**0,48**	**5,34**	**27,6**	**0,15**	**0,13**	**1,47**
	Std. dev.	*0,05*	*0,28*	*0,67*	*0,0*	*0,01*	*0,08*	*0,19*
20-25	Min.	0,35	0,55	4,12	26,0	0,09	0,14	1,07
	Max.	1,89	2,09	5,59	27,6	0,52	0,54	1,54
	Mean	**0,74**	**1,11**	**4,83**	**26,4**	**0,20**	**0,29**	**1,28**
	Std. dev.	*0,77*	*0,68*	*0,65*	*0,81*	*0,21*	*0,18*	*0,20*
25-31	Min.	0,24	0,25	3,27	26,0	0,07	0,07	0,92
	Max.	4,62	5,64	5,66	28,2	1,20	1,59	1,47
	Mean	**1,89**	**2,02**	**4,29**	**27,6**	**0,50**	**0,55**	**1,18**
	Std. dev.	*1,73*	*1,99*	*0,95*	*1,1*	*0,44*	*0,55*	*0,22*

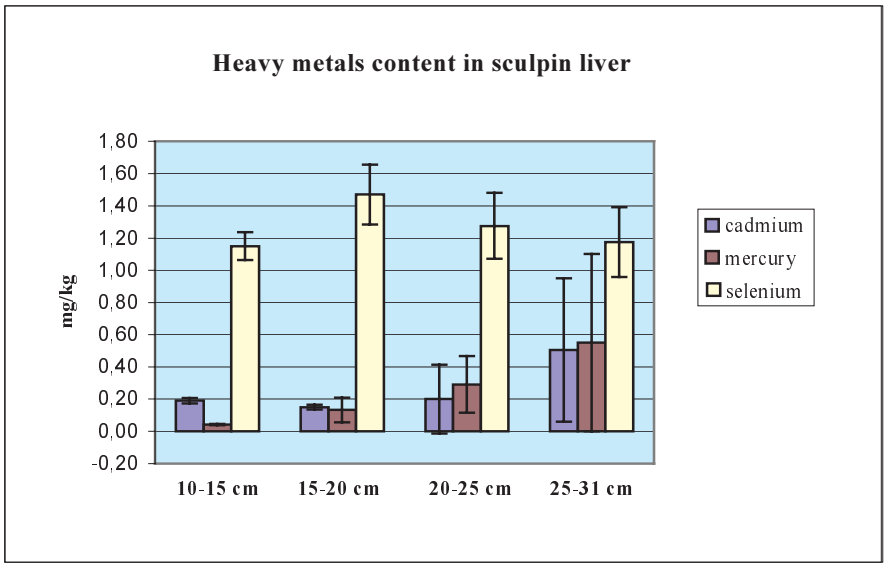

Figure 2.2. Cd, Hg and Se content in sculpin liver from 1999

In the figure and table above the results of the heavy metal analysis in 1999 are shown, as the mean concentration of the four different size groups. There are substantial individual variations between the results leading to large standard deviations. The mean concentration of mercury and cadmium appears to be increasing with the length of the sculpins (Figure 2.2.). It is stressed that there are both individual and pooled samples in this study.

In 2000 only sculpins from the two largest size groups were analysed and the heavy metal results are shown in Table 2.5. The water content was not analysed at the laboratory; instead we used the dry matter content from the 1999 samples to convert the results in to wet weight. For all the samples we used a dry matter content of 27,0 %.

Table 2.5. Metal content in sculpin liver 2000 (Bold indicates pooled samples)

Length, cm	Sample ID	Cd ug/g dw	Hg ug/g dw	Se ug/g dw	Cd mg/kg ww	Hg mg/kg ww	Se mg/kg ww
21	Ms-5-2000	2,980	2,540	5,120	0,805	0,686	1,382
21,5	Ms-0057	0,600	4,220	5,070	0,162	1,139	1,369
21,5	Ms-1-2000	0,700	2,340	3,480	0,189	0,632	0,940
22,25	Ms-2-2000	0,940	9,340	5,420	0,254	2,522	1,463
24,33	Ms-6-2000	1,890	7,110	5,320	0,510	1,920	1,436
20-25	Min.	0,600	2,340	3,480	0,162	0,632	0,940
	Max.	2,980	9,340	5,420	0,805	2,522	1,463
	Mean	**1,422**	**5,110**	**4,882**	**0,384**	**1,380**	**1,318**
	Std.dev.	*1,009*	*3,040*	*0,797*	*0,273*	*0,821*	*0,215*
25,75	Ms-3-2000	0,280	3,220	2,270	0,076	0,869	0,613
26	Ms-0068	2,670	3,040	4,320	0,721	0,821	1,166
26	Ms-4-2000	0,340	5,330	3,530	0,092	1,439	0,953
28,5	Ms-0061	0,190	4,950	3,750	0,051	1,337	1,013
29	Ms-0064	3,570	7,510	4,990	0,964	2,028	1,347
29	Ms-0065	11,660	5,040	7,990	3,148	1,361	2,157
29,5	Ms-0062	2,300	1,810	7,780	0,621	0,489	2,101
30,5	Ms-0074	3,780	0,930	8,760	1,021	0,251	2,365
30,5	Ms-0078	6,410	2,350	7,720	1,731	0,635	2,084
31	Ms-0077	3,830	2,410	5,810	1,034	0,651	1,569
25-30	Min.	0,190	0,930	2,270	0,051	0,251	0,613
	Max.	11,660	7,510	8,760	3,148	2,028	2,365
	Mean	**3,503**	**3,659**	**5,692**	**0,946**	**0,988**	**1,537**
	Std.dev.	*3,475*	*1,998*	*2,254*	*0,938*	*0,539*	*0,608*

Figure 2.3 shows the mean concentrations of metals for the two large size groups in 1999, 2000 and 2001. It appears to be some difference between the the results from 1999 and 2000 where the content of especially cadmium and mercury seems to be higher in 2000 than in 1999. In 2001 the mercury results are much lower than in both 1999 and 2000, whereas cadmium remains high in the larger size group.

Table 2.6. Metal content in sculpin liver 2001

Length, cm	Sample ID	Cd µg/g dw	Hg µg/g dw	Se µg/g dw	Dry matter %	Cd mg/kg ww	Hg mg/kg ww	Se mg/kg ww
15-20 cm	Ms- 01-09-01	0,65	0,45	9,56	15,5	0,10	0,07	1,48
20-25 cm	Ms- 02-09-01	0,95	0,05	8,27	21,2	0,20	0,01	1,75
20-25 cm	Ms- 03-09-01	0,90	0,50	7,14	22,1	0,20	0,11	1,58
25-30 cm	Ms- 04-09-01	5,02	1,00	7,43	22	1,10	0,22	1,63
25-32 cm	Ms- 05-09-01	5,58	1,22	7,97	21,3	1,19	0,26	1,70

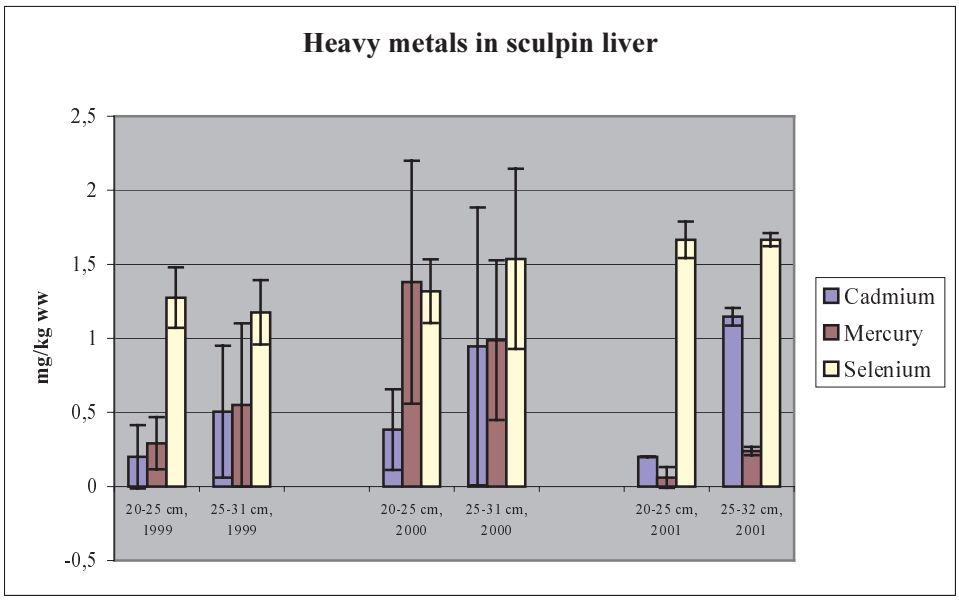

FIGURE 2.3. HEAVY METAL CONTENT IN LIVER FROM 20-30 CM SCULPIN

It has been found that selenium may interact with mercury and other metals, and in the figure below mercury is depicted against selenium. The concentration of selenium appears to be high and quite stable in all the size groups all three years.

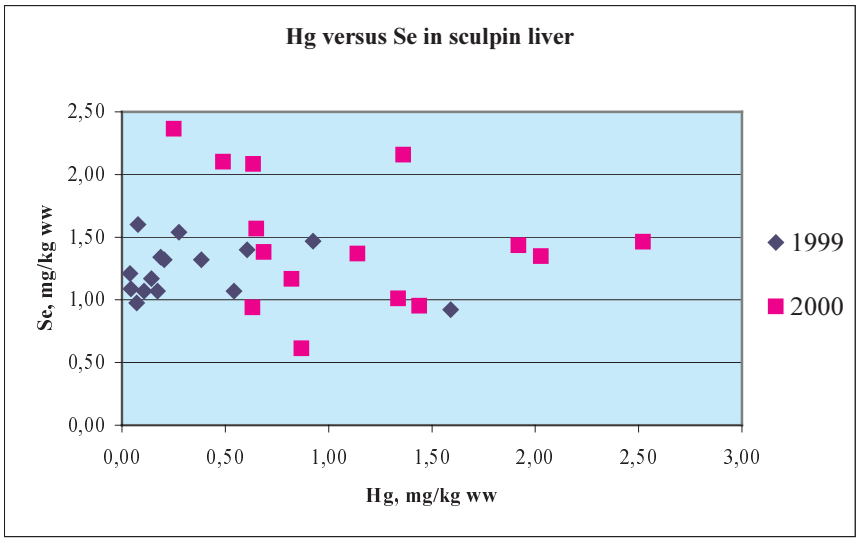

FIGURE 2.4. MERCURY VERSUS SELENIUM IN LIVER OF SCULPIN (MG/KG WET WEIGHT)

In Figure 2.5 the concentration of mercury and cadmium is depicted against the age of the sculpins from 1999.

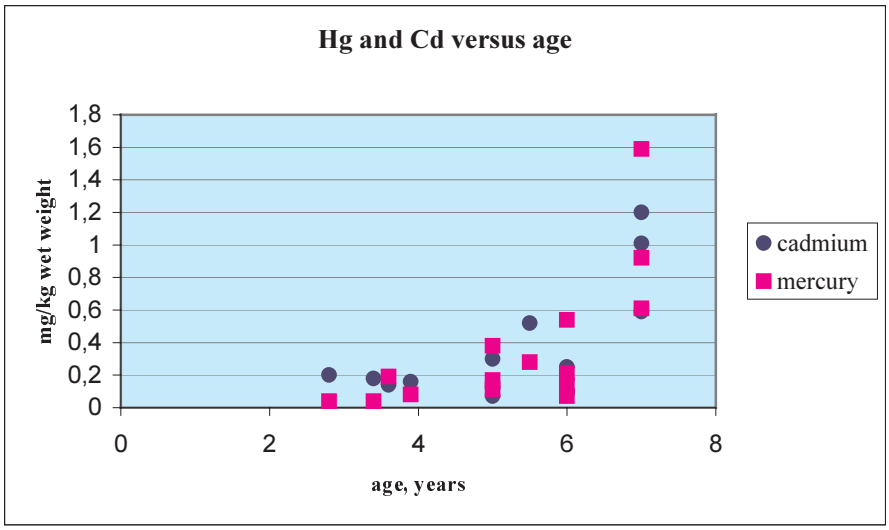

FIGURE 2.5. AGE VERSUS HG AND CD IN THE LIVER OF SCULPIN FROM 1999

In Table 2.7 similar results from Greenland are listed for comparison to the Faroese results. It appears to be overall higher mercury concentration in the the Faroese sculpins. Part of the explanation may be that the choice of location was not optimal for avoiding local pollution. However, there are also a wide range of concentrations found in the samples from Greenland, as indicated by the magnitude of the standard deviations.

TABLE 2.7. METAL RESULTS IN SHORT-HORN SCULPIN LIVER FROM GREENLAND (DIETZ ET AL. 1997). THE SAMPLES ARE COMPOSED OF BOTH MALE AND FEMALES FISH.

Location	Matrix	Length, cm	Year of sampling	Number of individuals	Cd µg/g ww	Hg µg/g ww	Se µg/g ww
Avanersuaq	Liver	26,7	1987	24	1,73 (1,66)	0,024 (1,86)	0,75 (1,26)
Upernavik	Liver	28,2	1985	10	2,34 (1,48)		
Uummannaq	Liver	25,4	1988	20	0,350 (2,63)		
	Liver	30,5	1989	20	0,331 (2,14)		
	Liver	29,1	1990	14	0,523 (2,54)		
	Liver	28,2	1991	14	0,654 (2,04)		
	Liver	25,6	1992	15	0,341 (4,85)		
	Liver	22,2-27,6	1993	9-23	0,548 (2,21)		
Maniitsoq	Liver	26,8	1987	18	1,13 (2,34)	0,019 (1,98)	
Nuuk	Liver	35,0	1986	2	0,193 (2,46)	0,007 (4,17)	1,10 (1,48)
	Liver	12,0	1987	3	0,956 (1,30)	0,006 (2,28)	
Nanortalik	Liver	24,2-26,5	1985	1-30	1,44 (2,08)	0,037 (3,43)	0,64
Kong Oscars Fjord	Liver	16,8	1985	14	0,478 (3,12)	0,029 (1,53)	
Ittoqqortoormiit	Liver	9,2-10,3	1985	1-3	1,07	0,021 (1,23)	1,53 (1,39)
Ammassalik	Liver	26,9-27,1	1985	2-25	0,623 (2,44)	0,087 (1,23)	0,72 (1,88)

all these results are from AMAP Assessment Report: Arctic Pollution Issues (1998)
Figures in brackets are relative standard deviations

3 *Cepphus grylle* – Black Guillemot

In the Faroe Islands the black guillemot have been a protected species for many years. The population is estimated to 3500 breading pairs (Bloch et al.,1996). The black guillemot in the Faroe Islands belongs to subspecies *Cepphus grylle faroensis*. In Iceland, the subspecies is *Cepphus grylle islandicus* and in Norway and Britain it is *Cepphus grylle atlantis*. The Icelandic and the Faroese birds are known to be smaller than the others. There are also other differences between the subspecies (Sørensen, S. and Bloch, D. 1990).

The black guillemot lives in the coastal zone and gets food from the sea. The local diet consists of a mixture of crustacean, gastropods and pisces with great seasonal variation (Dam, M. 1998). The egg-laying period is around the 10th of June. The black guillemot normally lay two eggs in the nest, which is found along the rocky coastline, well hidden between the stones. Most of the time the bird stays in the Faroe Islands, although there is some speculation that some of the birds migrate in the winter period (Sørensen, S. and Bloch, D. 1990 and Ryggi, M. 1951).

3.1 Black Guillemot eggs

3.1.1 Collection of the samples

The eggs were taken by local people from two different locations – Koltur and Skúvoy in 1999 2000 and 2001. Only one egg was taken from each nest and stored in a refrigerator until further treatment. The eggs were taken over a wide period of time, which indicates that the egg-laying period is wide. Because the black guillemot has been protected for a long time, no previous pattern for egg collection was known. Consequently, numerous attempts were made to locate the nests and to follow the birds' egg-laying behaviour.

3.1.2 Sample treatment and analysis

The eggs were carefully rinsed in milli-Q water before breaking the eggshell. A hole (1-1½ cm) was made on the top of the egg and the content was carefully poured into glasses. The yolk and white were mixed with a fork (also washed in mill-Q water). In some of the eggs, the embryo were beginning to grow. The contents were stored in heat treated glass (400°C for at least four hours) and stored in a freezer (-20°C) prior to analysis. The eggs were analysed for mercury at the Food and Environmental Agency in Faroe Islands.
The eggshells thickness was measured in all the eggs with a micrometer-caliper (*mikrometur-skrúva*), in four different places as near to the equator as possible.

3.1.3 Results

The eggs were taken from two different locations three following years and the mercury results are listed below in separate tables.

Table 3.1. Mercury content in black guillemot eggs from Koltur in 1999

ID	Location	Date of sampling	Matrix	Weight, yolk and white, g	Hg mg/kg ww
Cg-0143	Koltur	16-06-99	egg	40,149	0,41
Cg-0144	Koltur	05-06-99	egg	40,945	0,41
Cg-0145	Koltur	09-06-99	egg	45,382	0,58
Cg-0146	Koltur	06-06-99	egg	39,997	0,65
Cg-0147	Koltur	09-06-99	egg	41,409	0,97
Cg-0148	Koltur	09-06-99	egg	42,439	0,47
Cg-0149	Koltur	11-06-99	egg	41,291	0,35
Cg-0150	Koltur	09-06-99	egg	43,201	0,38
Cg-0151	Koltur	11-06-99	egg	33,685	0,42
Cg-0152	Koltur	14-06-99	egg	37,393	0,46
			Min	33,685	0,35
			Max	45,382	0,97
			Mean	40,589	0,510
			Std. dev.	*3,213*	*0,186*

Table 3.2. Mercury content in black guillemot eggs from Skúvoy in 1999

ID	Location	Date of sampling	Matrix	Weight, yolk and white, g	Hg mg/kg ww
Cg-0153	Skúvoy	June 1999	egg	39,777	0,48
Cg-0154	Skúvoy	June 1999	egg	37,147	0,39
Cg-0155	Skúvoy	June 1999	egg	32,680	0,47
Cg-0156	Skúvoy	June 1999	egg	39,586	0,43
Cg-0157	Skúvoy	June 1999	egg	42,178	0,6
Cg-0158	Skúvoy	June 1999	egg	42,614	0,73
Cg-0159	Skúvoy	June 1999	egg	39,484	0,44
Cg-0160	Skúvoy	June 1999	egg	45,759	0,57
			Min	32,680	0,39
			Max	45,759	0,73
			Mean	39,903	0,514
			Std. dev.	*3,907*	*0,122*

Table 3.3. Mercury content in black guillemot eggs from Koltur in 2000

ID	Location	Date of sampling	Matrix	Weight, yolk and white, g	Hg mg/kg ww
Cg-0161	Koltur	June 2000	egg	37,527	0,35
Cg-0162	Koltur	June 2000	egg	47,609	0,33
Cg-0163	Koltur	June 2000	egg	41,125	0,4
Cg-0164	Koltur	June 2000	egg	43,336	0,24
Cg-0165	Koltur	June 2000	egg	43,847	0,33
Cg-0166	Koltur	June 2000	egg	40,271	0,42
Cg-0167	Koltur	June 2000	egg	46,07	0,55
Cg-0168	Koltur	June 2000	egg	41,995	0,16
Cg-0169	Koltur	June 2000	egg	43,273	0,49
Cg-0170	Koltur	June 2000	egg	37,626	0,34
			Min	37,527	0,160
			Max	47,609	0,550
			Mean	**42,268**	**0,361**
			Std. dev.	*3,283*	*0,113*

Table 3.4. Mercury content in black guillemot eggs from Skúvoy in 2000

ID	Location	Date of sampling	Matrix	Weight, yolk and white, g	Hg mg/kg ww
Cg-0171	Skúvoy	June 2000	egg	44,266	0,38
Cg-0172	Skúvoy	June 2000	egg	40,771	0,34
Cg-0173	Skúvoy	June 2000	egg	45,021	0,18
Cg-0174	Skúvoy	June 2000	egg	38,877	0,42
Cg-0175	Skúvoy	June 2000	egg	40,645	0,29
Cg-0176	Skúvoy	June 2000	egg	44,893	0,29
Cg-0177	Skúvoy	June 2000	egg	39,113	0,39
Cg-0178	Skúvoy	June 2000	egg	44,055	0,14
Cg-0179	Skúvoy	June 2000	egg	36,555	0,34
			Min	36,555	0,14
			Max	45,021	0,42
			Mean	41,241	0,299
			Std. dev.	*3,121*	*0,097*

Table 3.5. Mercury content in black guillemot eggs from Koltur in 2001

ID	Location	Date of sampling	Matrix	Weight, yolk and white, g	Hg mg/kg ww
Cg-0180	Koltur	June 2001	egg	44,4	0,449
Cg-0181	Koltur	June 2001	egg	39	0,378
Cg-0182	Koltur	June 2001	egg	33,4	0,182
Cg-0183	Koltur	June 2001	egg	44,6	0,414
Cg-0184	Koltur	June 2001	egg	42,3	0,324
Cg-0185	Koltur	June 2001	egg	42,3	0,378
Cg-0186	Koltur	June 2001	egg	44,3	0,331
Cg-0187	Koltur	June 2001	egg	30,7	0,19
Cg-0188	Koltur	June 2001	egg	46	0,259
Cg-0189	Koltur	June 2001	egg	45,6	0,338
			Min	30,70	0,182
			Max	46,00	0,449
			Mean	41,26	0,324
			Std. dev.	*5,29*	*0,090*

Table 3.6. Mercury content in black guillemot eggs from Skúvoy in 2001

ID	Location	Date of sampling	Matrix	Weight, yolk and white, g	Hg mg/kg ww
Cg-0190	Skúvoy	June 2001	egg	36	0,292
Cg-0191	Skúvoy	June 2001	egg	40,4	0,223
Cg-0192	Skúvoy	June 2001	egg	42,2	0,437
Cg-0193	Skúvoy	June 2001	egg	38,9	0,335
Cg-0194	Skúvoy	June 2001	egg	38,2	0,283
Cg-0195	Skúvoy	June 2001	egg	41,4	0,335
Cg-0196	Skúvoy	June 2001	egg	45	0,428
Cg-0197	Skúvoy	June 2001	egg	34,3	0,311
Cg-0198	Skúvoy	June 2001	egg	33,3	0,428
Cg-0199	Skúvoy	June 2001	egg	41,6	0,19
			Min	33,30	0,190
			Max	45,00	0,437
			Mean	39,13	0,326
			Std. dev.	*3,72*	*0,085*

As the tables and Figure 3.1 show there is very little difference in mercury concentration between the locations each year, but there is a difference between the years. The mercury content was significantly higher in 1999 than in 2000 in both Koltur (P=0,04) and Skúvoy (P=0,001) while there was no significant change from 2000 to 2001.

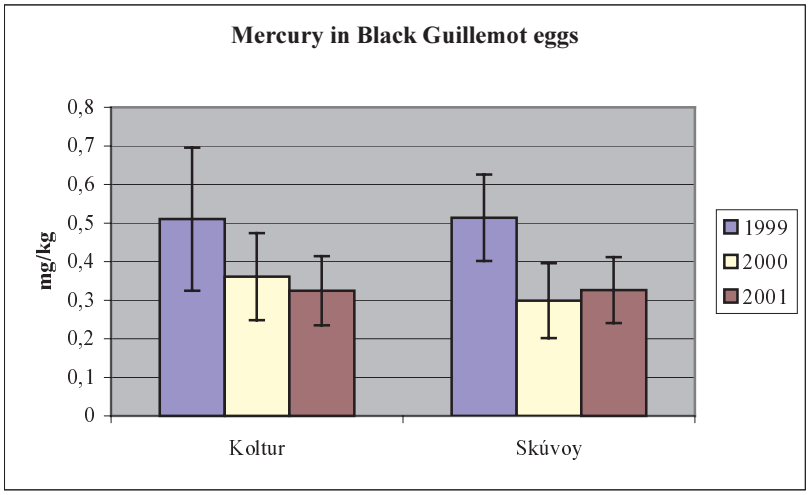

Figure 3.2. Mercury content in eggs

3.2 Black Guillemot liver

3.2.1 Sampling and sample treatment

The liver samples are taken from birds shot in 1995 and 1996 at Sveipur and Hestoy. The birds were shot with 3,70 mm and 4,70 mm 32g loaded

Winchester steel-hail, and the livers were stored in PE plastic bags (Minigrip®) in a freezer.
Liver samples were analysed at the Food and Environmental Agency in the Faroe Islands, for mercury and cadmium. For some of the birds also feathers, from the back and under the wing, were analysed for mercury

All the biological data on the birds are taken from the Faroese Environmental Specimen Bank. For further details see the study of Dam, M. 1998[2].

3.2.2 Heavy metals

In the table below the results of the heavy metal analyses are listed. The sexual status was recorded and the birds were separated into juvenile and adult, male and female. Furthermore, the age was assessed from the *Bursus fabriosus* and the birds' age was assigned to be for the males either juveniles (2K = younger than or equal to two calendar years), or adults (3K+ = older than three calendar years), and the females were regarded as juveniles when the oviduct appeared slim and rather straight (Dam, M. 1998).

Table 3.7. Heavy metal concentration in black guillemot liver (mg/kg wet weight)

Sexstatus	Number of birds	Year of sampling		Dry weight g/100g	Hg	Cd
Juveniles	11	1995	Min	29,24	0,21	0,41
			Max	34,02	0,48	1,10
			Mean	**31,63**	**0,33**	**0,64**
			Std. dev.	*1,33*	*0,09*	*0,21*
Juveniles	13	1996	Min	29,80	0,25	0,26
			Max	40,18	1,28	2,27
			Mean	**33,74**	**0,54**	**0,98**
			Std. dev.	*2,70*	*0,26*	*0,76*
Females	4	1996	Min	32,1	0,63	1,15
			Max	34,9	1,25	1,51
			Mean	**33,7**	**0,95**	**1,36**
			Std. dev.	1,17	*0,26*	*0,17*
Males	5	1996*	Min	32,38	0,29	0,94
			Max	42,30	3,77	1,93
			Mean	**35,78**	**1,73**	**1,27**
			Std. dev.	*3,79*	*1,26*	*0,42*

*One of the birds from 1995

[2] Dam, Maria 1998. Hvad spiser teist, edderfugl og topskarv på Færøerne, og hvad er indholdet af miljøgifte i disse fugle? Food and Environmental Agency, Faroe Islands. ISBN 99918-940-1-2

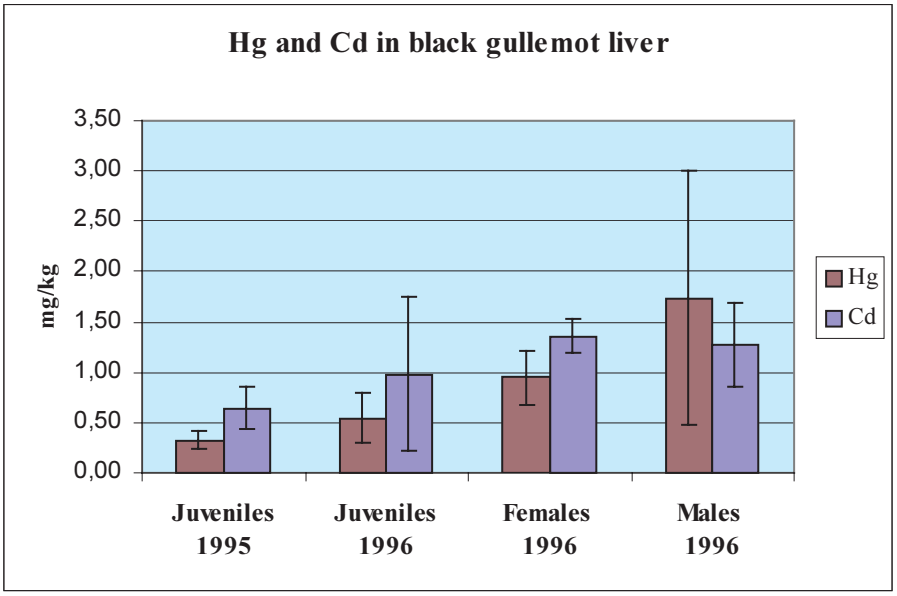

FIGURE 3.3. MERCURY AND CADMIUM IN THE LIVER OF BLACK GUILLEMOT (MG/KG WET WEIGHT)

The results for mercury and cadmium are shown in Figure 3.3 and Table 3.7. The Faroese black guillemot appear to have higher levels of mercury and cadmium than those from other locations (Table 3.8). However, as the age is an important parameter especially for the mercury body burden, it is necessary to consider that the age-groups must be similar for comparisions to be valid.

In 2001 the livers were analysed for selenium and Figure 3.4 shows the concentration of selenium versus the concentration of mercury and cadmium.

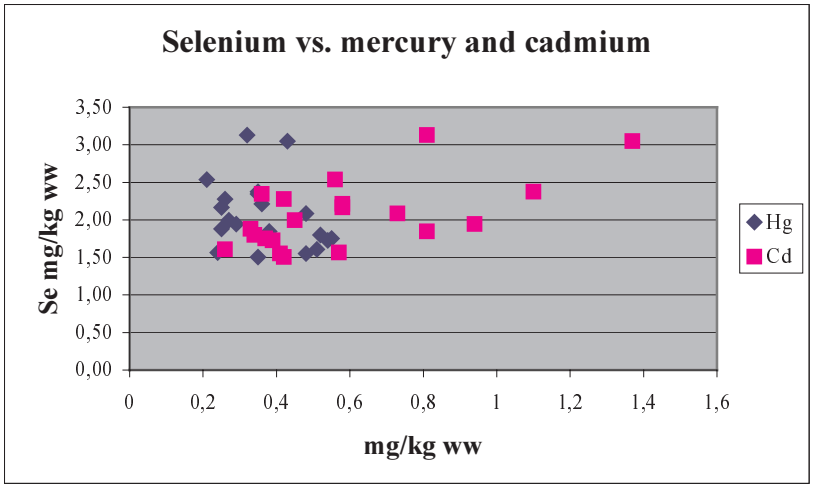

FIGURE 3.4. SELENIUM VERSUS MERCURY AND CADMIUM IN BLACK GUILLEMOT LIVER

Table 3.8. Content of heavy metals in black guillemot from different locations (µg/g wet weight).

Location	Year of sampling	Age	n	Matrix	Cd	Hg	Se	*Ref.**
Lancaster Sound Canada **	1977	Young		Liver	0,812 (1,24)	0,212 (1,50)		*RRCS Ltd. 1997*
	1977	Adult	5	Liver	14,5 (1,37)	0,752 (1,35)		
Prince Leopold Island, Canada	1993	1+ yrs	5	Liver	7,38	1,15		*Braune*
Green Island, Canada	1993	1+ yrs	10	Liver	4,62	1,13	2,72	*Braune*
Avanersuaq, Greenland	1984	1+ yrs	4	Liver	3,32 (1,61)	0,738 (1,17)	2,73 (1,41)	*Dietz et al. 1997*
Upernavik, Greenland	1985	1+ yrs	5	Liver	4,80 (1,39)	0,566 (1,61)	4,07 (1,51)	*Dietz et al. 1997*
Uummannaq, Greenland	1982	0 yr	1	Liver	0,410			*Dietz et al. 1997*
	1985	0 yr	17	Liver	0,099 (2,15)			
	1985	1 yr	4	Liver	0,183 (4,03)	0,125 (1,37)	1,03 (1,51)	
	1985	1+ yrs	5	Liver	1,55 (5,18)	0,337 (3,07)	1,44 (1,35	
	1985	1+ yrs	3	Liver	4,88 (1,39)			
	1987	1+ yrs	20	Liver	3,93 (1,44)			
	1991	1+ yrs		Liver	4,15 (1,61)			
Kangaatsiaq, Greenland	1986	1+ yrs	11	Liver	2,37 (2,08)	0,771 (1,91)	2,89 (1,62)	*Dietz et al. 1997*
Nanortalik, Greenland	1986	1+ yrs	9	Liver	1,63 (1,31)	0,497 (1,44)	1,87 (1,53)	*Dietz et al. 1997*
Ittoqqortoormiit, Greenland	1986	1+ yrs	8	Liver	3,479 (1,24)	0,505 (1,26)	2,16 (1,21)	*Dietz et al. 1997*
Svalbard, Norway	1984		2	Liver	0,283	0,084	2,04	*Carlberg and Bøler 1985*

* all these results are from AMAP Assessment Report: Arctic Pollution Issues (1998)
** results are present in µg/g dry weight
Numbers in brackets are relative standard deviation

3.3 Black guillemot feathers

From 15 of the black guillemots from 1996 feathers were also taken and analysed for mercury at the Food and Environmental Agency in the Faroe Islands. From each bird, one sample was taken from the back between the wings and one from under the wing. The feathers were stored in PE plastic bags (Minigrip®) until analyses. The results are shown below.

Table 3.9. Mercury in black guillemot feathers

Species	ID	Location	Date	Feather (Back) Hg, mg/kg	Feather (Under the wing) Hg, mg/kg	Mean content in feathers Hg, mg/kg	Content in liver Hg, mg/kg d.w.
Cephus grylle	Cg-0050	Hestoy	12-08-1996	2,43	2,07	2,25	4,32
Cephus grylle	Cg-0057	Hestoy	12-08-1996	3,54	3,3	3,42	4,24
Cephus grylle	Cg-0058	Hestoy	12-08-1996	20,7	23,1	21,90	8,91
Cephus grylle	Cg-0065	Hestoy	12-08-1996	4,93	5,86	5,40	1,81
Cephus grylle	Cg-0067	Hestoy	12-08-1996	3,73	3,93	3,83	1,18
Cephus grylle	Cg-0068	Hestoy	12-08-1996	4,16	4,83	4,50	2,17
Cephus grylle	Cg-0069	Hestoy	12-08-1996	4,41	4,35	4,38	1,34
Cephus grylle	Cg-0086	Hestoy	09-11-1996	1,89	2,02	1,96	1,63
			Min	1,89	2,02	1,955	1,18
			Max	20,7	23,1	21,9	8,91
			Mean	**5,72**	**6,18**	**5,95**	**3,20**
			Std. dev.	*6,13*	*6,96*	*6,54*	*2,62*
			Median	***3,95***	***4,14***	***4,11***	*1,99*
Cephus grylle	Cg-0044	Sveipur	07-06-1996	4,03	3,79	3,91	3,89
Cephus grylle	Cg-0045	Sveipur	07-06-1996	4,33	4,11	4,22	4,71
Cephus grylle	Cg-0046	Sveipur	07-06-1996	4,09	3,72	3,91	3,04
Cephus grylle	Cg-0047	Sveipur	07-06-1996	3,36	2,58	2,97	2,13
Cephus grylle	Cg-0048	Sveipur	07-06-1996	3,41	3,43	3,42	3,61
Cephus grylle	Cg-0049	Sveipur	07-06-1996	2,57	2,37	2,47	2,57
Cephus grylle	Cg-0091	Sveipur	28-12-1996	2,08	2,45	2,27	1,33
			Min	2,08	2,37	2,27	1,33
			Max	4,33	4,11	4,22	4,71
			Mean	**3,41**	**3,21**	**3,31**	**3,04**
			Std. dev.	*0,83*	*0,72*	*0,76*	*1,14*
			Median	***3,41***	***3,43***	***3,42***	***3,04***

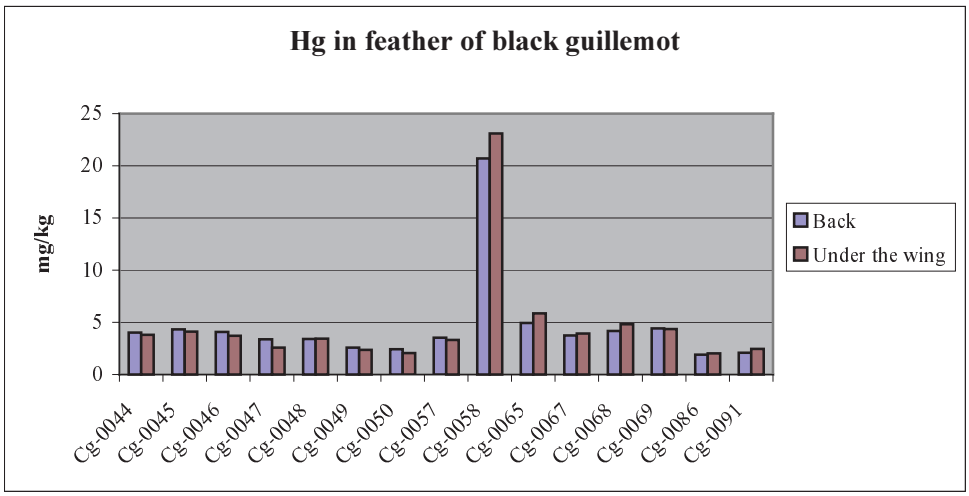

Figure 3.5. Mercury in feather from the back and under the wing of black guillemot

The purpose of analysing mercury in, feathers both from the back and from under the wing of the same individuals (Figure 3.5) was to see, if there is a difference in the content depending on were the feathers were taken. Testing showed, that there is no significant difference between the median contents in

the feathers from the two places on the bird (T=61, P>0,05, Wilcoxon's test for matched pairs).

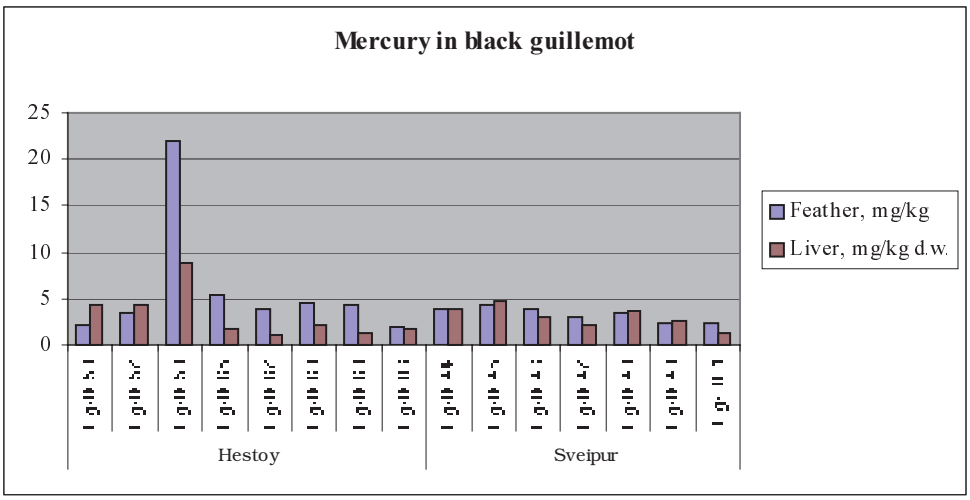

FIGURE 3.6. MERCURY IN BLACK GUILLEMOT FEATHER AND LIVER

Table 3.9 and Figure 3.6 show, that the concentration of mercury in black guillemot feathers from Sveipur and Hestoy is between app. 2 and 5 mg/kg with only a few exeptions. One of the exeptions is Cg-0058, which has a concentration over 20 mg/kg. This influences the mean mercury concentration of black guillemots from Hestoy, which is 5,95 while the mean mercury concentration of black guillemots from Sveipur is 3,31 mg/kg. The mean concentration from Hestoy is 3,68 mg/kg, when excluding the outlier Cg-0058.

When comparing the result of mercury in liver with the mean results in feathers from the same individual, the picture is different for Hestoy and Sveipur. In Sveipur the results from the two tissues are quite comparable, while the results from Hestoy show higher Hg concentration in feather than in liver (Figure 3.6). Another parameter, which differs between the two groups is the time when they have been shot. Almost all the birds from Sveipur were shot in June, while almost all the birds from Hestoy were shot in August. The diet of the black guillemot varies during the year by consisting mostly of fish during early summer (Apr.- Aug.) and mostly of crustaceans and molluscs during the winther (Nov-Dec.) (Dam, 1998). The content of fish in the diet has been found to be highest in April and declining during the summer.

4 *Globicephala melas* – Long-finned Pilot Whale

The reason for analysing the long-finned pilot whale in AMAP context is that pilot whales are part of the traditional Faroese diet – both the blubber and meat is consumed. The pilot whale is a toothed whale and feeds on squid (*Todarodes sagittatus* and *Gonatus sp.*) and fish, usually greater silver smelt and blue whiting (Bloch, D. and Fuglø, E. 1999).

4.1 Sample collection

Pilot whale samples are collected in connection with hunting, and the sampling takes place after the killing but before the meat distribution. At this time the whales are opened and the intestines pulled out. The entire operation (from the killing to the meat distribution) is well organised. Before we collect our samples the whales are measured (length and the whale size in *skinn*[3]) and the sex is determined. The number written in the whales head is used as our sample mark; then we are able to obtain all the other information (size and gender) from The Museum of Natural History at a later stage.

4.1.1 Sampling

The samples are from four different whale schools from 1999 and 2000 and the results are treated separately. The samples from 1999 were collected on the 14th of March 1999 in Tórshavn and the 8th of September 1999 in Vestmanna. The samples from 2000 were collected on the 31th of August 2000 in Hvannasund and on the 9th of september 2000 in Tórshavn.

One piece of muscle and one piece of blubber were taken at the sides of the abdominal cuts. From the school from 09.09.00 one piece of kidney was taken as well. The samples were stored in PE bags (Minigrip®). The sample were stored in a freezer (-20°C).

The muscle samples were analysed for Hg, Cd and Se, except for the school from 31.08.00 which only was analysed for Hg and Se. The kidney samples were analysed for Cd. The samples from 31.08.00 were analysed as pooled samples. Three pools were made: Females, males and juveniles.

4.1.2 Defining groups

According to Desportes, G. *et al.* (1993) early sexually mature male whales are 494 cm long, which corresponds to an age of approximately 14 years, but generally whales become sexually mature when they reach the age of 17 years. According to Martin A.R. and Rothery P. (1993) the female whales are sexually mature when they are 375 cm long, corresponding to an age of approximately 8 years.

[3] *Skinn* is a special Faroese unit for measuring the whale size based on an assessment of the mass fit for human consumption.

The pilot whales were divided into the following four groups according to sex and body length:

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

The pilot whale school from 14.03.99 consisted of 131 whales and the sex and age distribution were as follows:

Table 4.1 The entire pilot whale school from 14.03.99

Age and sex group	Number		Length	*Skinn*
Juvenile females	8	Min	220	1,5
		Max	340	5
		Mean	**283**	**3,3**
Adult females	76	Min	380	7
		Max	480	12
		Mean	**441**	**9,8**
Juvenile males	22	Min	260	2,5
		Max	490	12
		Mean	**394**	**7,3**
Adult males	25	Min	500	13
		Max	600	20
		Mean	**541**	**16,6**

In the table below some biological parameters are given for the whales, from which samples where taken. The juvenile whales (12 males and 2 females) were combined in one group for chemical analyses.

Table 4.2. The sampled part of the pilot whale school from 14.03.99

Age and sex group	Date of sampling	Numbers of whales		Length, cm	*Skinn*
Juveniles	14-03-1999	14	Min	225	1,5
			Max	490	12
			Mean	**393**	**7,3**
Adult females	14-03-1999	25	Min	415	7
			Max	465	12
			Mean	**443**	**9,7**
Adult males	14-03-1999	11	Min	505	13
			Max	588	20
			Mean	**549**	**16,7**

The whale school from 08.09.99 consisted of 34 whales and the size distribution was as follows:

Table 4.3. The entire pilot whale school from 08.09.99

Age and sex group	Number		Length	*Skinn*
Juvenile females	5	Min	267	2
		Max	364	6
		Mean	**336**	**4,8**
Adult females	15	Min	396	5
		Max	470	11
		Mean	**436**	**8,6**
Juvenile males	4	Min	305	4
		Max	449	10
		Mean	**377**	**6,8**
Adult males	8	Min	504	9
		Max	590	20
		Mean	**551**	**16,8**

Samples were taken from 22 individuals (Table 4.4). The juvenile group consisted of four females and three males.

Table 4.4. The sampled part of the pilot whale school from 08.09.99

Age and sex group	Date of sampling	Numbers of whales		Length, cm	*Skinn*
Juveniles	08.09.1999	7	Min	267	2
			Max	449	10
			Mean	**363**	**6**
Adult females	08.09.1999	8	Min	396	7
			Max	470	11
			Mean	**438**	**9**
Adult males	08.09.1999	7	Min	504	9
			Max	590	20
			Mean	**547**	**16**

The pilot whale school from 31.08.00 consisted of 246 whales and the sex and age distribution were as follows:

Table 4.5. The entire pilot whale school from 31.08.00

Age and sex group	Number		Length, cm	*Skinn*
Juvenile males	28	Min	250	2
		Max	490	12
		Mean	**402**	**7,1**
Adult males	28	Min	510	12
		Max	650	26
		Mean	**570**	**19,2**
Juvenile females	12	Min	250	1
		Max	370	5
		Mean	**319**	**3,7**
Adult females	178	Min	380	5
		Max	520	12
		Mean	**459**	**8,8**

In the table below some biological parameters are given for the whales, from which samples where taken. The juvenile whales (6 males and 1 female) were combined in one group for chemical analyses.

Table 4.6. The sampled part of the pilot whale school from 31.08.00

Age and sex group	Date of sampling	Numbers of whales		Length, cm	*Skinn*
Juveniles	31.08.2000	7	Min	250	2
			Max	475	11
			Mean	**384**	**6,4**
Adult females	31.08.2000	35	Min	380	6
			Max	505	12
			Mean	**461**	**9,9**
Adult males	31.08.2000	8	Min	510	12
			Max	650	26
			Mean	**562**	**19,1**

The whale school from 09.09.00 consisted of 21 whales of which 3 were pregnant and samples were taken of all the whales and the foetuses as well. The juvenile group consisted of two females and two males. The size distribution was as follows:

Table 4.7. The pilot whale school from 08.09.99

Age and sex group	Date of sampling	Numbers of whales		Length, cm	*Skinn*
Juveniles	09.09.2000	4	Min	311	4
			Max	415	7
			Mean	**362**	**5,3**
Adult females	09.09.2000	11	Min	435	9
			Max	484	40
			Mean	**452**	**12**
Adult males	09.09.2000	6	Min	540	14
			Max	563	17
			Mean	**553**	**15,8**

			ID	Length, cm	Sex
Foetus	09.09.2000	3	090900-004F	175	male
			090900-007F	130	female
			090900-013F	50	male

According to Martin & Rothery (1993) the mean length of a new born pilot whale calf is 177 cm and the weight is 74 kg, but foetuses with a length between 163 cm and 191 cm were found.

4.2 Heavy metal results

Mercury and cadmium in muscle were analysed at the Food and Environmental Agency in the Faroe Islands while the selenium analysis were made at NERI[4] , Department of Arctic Environment for the samples from 1999 and at CTQ[5] for the samples from 2000. The results are shown below as mean concentrations.

Table 4.8. Heavy metal concentration in pilot whale muscle (mg/kg wet weight) from 14.03.99

Age and sex group	Numbers of whales in the sample pool		Dry matter %	Cd	Hg	Se
Juveniles	14	Min	26,55	0,001*	0,20	0,43
		Max	36,77	0,319	3,66	1,29
		Mean	**31,86**	**0,113**	**1,31**	**0,61**
		Std. dev	*3,13*	*0,082*	*0,79*	*0,23*
Adult females	25	Min	27,58	0,036	0,76	0,43
		Max	37,65	0,441	6,31	2,52
		Mean	**31,90**	**0,257**	**1,63**	**0,63**
		Std. dev	*2,66*	*0,108*	*1,03*	*0,45*
Adult males	11	Min	26,96	0,104	1,11	0,39
		Max	33,75	0,348	3,22	1,00
		Mean	**30,66**	**0,180**	**1,85**	**0,55**
		Std. dev	*2,27*	*0,078*	*0,70*	*0,16*

* the detection limit for cadmium was 0,002 mg/kg, and in statistical analysis values below detection limit was replaced by half the value of the detection limit.

[4] National Environmental Research Institute of Denmark
[5] Centre de toxicologie du Quebec, Canada

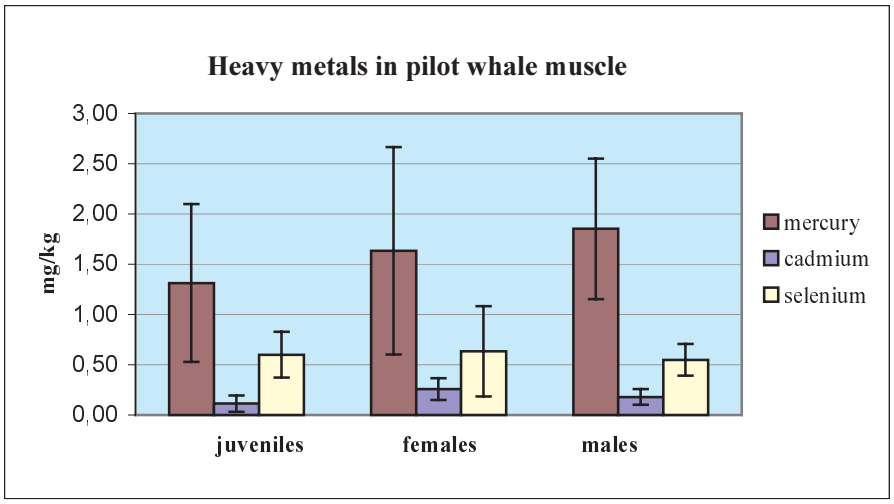

Figure 4.1. Heavy metals in pilot whale muscle (mg/kg wet weight) from 14.03.99

Table 4.9. Heavy metal concentration in pilot whale muscle (mg/kg wet weight) from 08.09.99

Age and sex group	Numbers of whales in the sample pool		Dry matter %	Cd	Hg	Se
Juveniles	7	Min	25,89	0,046	0,840	0,448
		Max	32,93	0,200	1,930	0,562
		Mean	28,29	0,107	1,463	0,525
		Std. dev	*2,69*	*0,063*	*0,420*	*0,039*
Adult females	8	Min	27,92	0,240	1,560	0,488
		Max	30,82	0,730	4,520	1,768
		Mean	29,27	0,418	2,488	0,842
		Std. dev	*1,10*	0,214	0,914	0,538
Adult males	7	Min	28,25	0,120	1,630	0,551
		Max	30,64	0,270	2,930	0,723
		Mean	29,56	0,180	2,056	0,613
		Std. dev	*0,76*	0,058	0,437	0,060

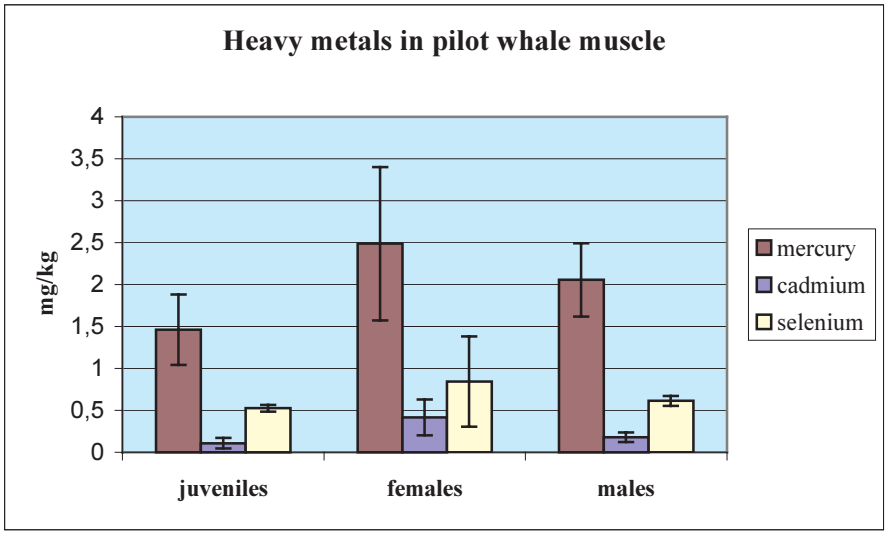

Figure 4.2. Heavy metals in pilot whale muscle (mg/kg wet weight) from 08.09.99

Table 4.10. Heavy metal concentration in pilot whale muscle (mg/kg wet weight) from 31.08.00

Age and sex group	Numbers of whales in the pooled sample	Dry matter %	Hg	Se
Juveniles	7	29,1	1,62	0,67
Adult females	35	29,3	2,86	0,70
Adult males	8	30,1	3,07	0,81

* the detection limit for cadmium was 0,002 mg/kg, and in statistical analysis values below detection limit was replaced by half the value of the detection limit.

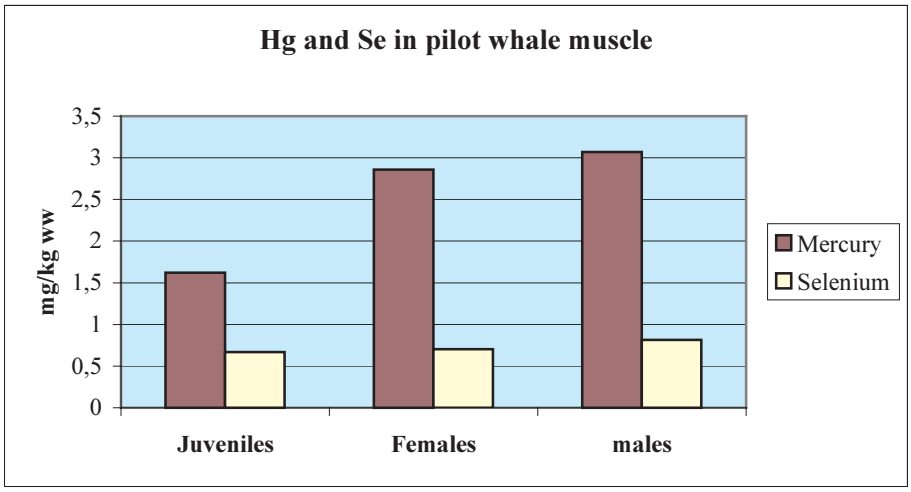

Figure 4.3. Heavy metals in pilot whale muscle (mg/kg wet weight) from 31.08.00

Table 4.11. Heavy metal concentration in pilot whale muscle (mg/kg wet weight) from 09.09.00

Age and sex group	Numbers of whales in the sample pool		Dry matter %	Hg	Cd	Se
Juveniles	4	Min	29	0,690	0,064	0,363
		Max	30	1,380	0,109	0,501
		Mean	**29,75**	**1,128**	**0,087**	**0,450**
		Std. dev	*0,50*	*0,328*	*0,020*	*0,061*
Adult females	11	Min	29	0,560	0,157	0,432
		Max	33	2,610	0,743	0,785
		Mean	**29,91**	**1,857**	**0,391**	**0,547**
		Std. dev	*1,22*	*0,542*	*0,197*	*0,098*
Adult males	6	Min	28	1,780	0,165	0,426
		Max	31	2,160	0,495	0,543
		Mean	**28,67**	**2,002**	**0,281**	**0,485**
		Std. dev	*1,21*	*0,171*	*0,117*	*0,043*

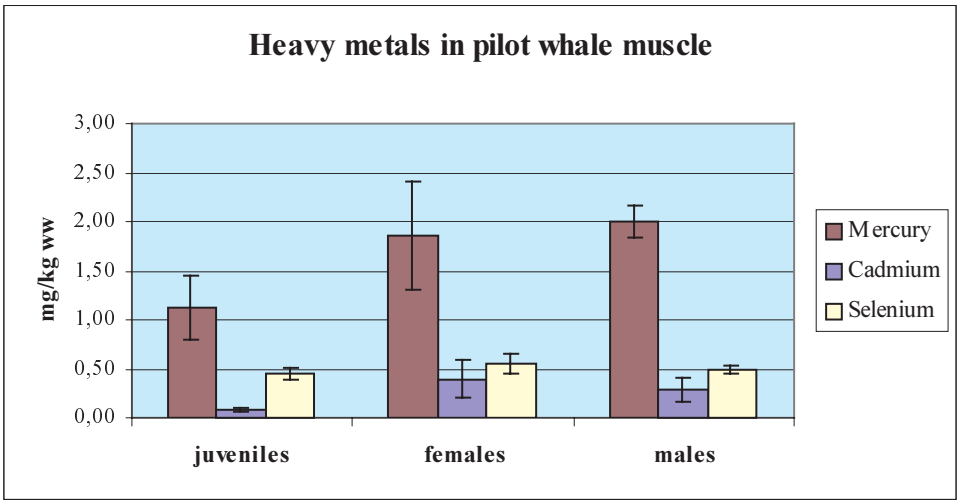

Figure 4.4. Heavy metals in pilot whale muscle (mg/kg wet weight) from 09.09.00

Table 4.12. Heavy metals in muscle from pregnant females and their foetuses from 09.09.00 (mg/kg wet weight)

	ID	Dry matter %	Hg	Cd	Se
Adult female	090900-004	29	1,53	0,157	0,432
Foetus	090900-004F	27	0,30	0,013	0,238
Adult female	090900-007	30	1,82	0,209	0,510
Foetus	090900-007F	27	0,53	<0,002	0,230
Adult female	090900-013	31	2,03	0,591	0,567
Foetus	090900-013F	15	0,30	0,012	0,147

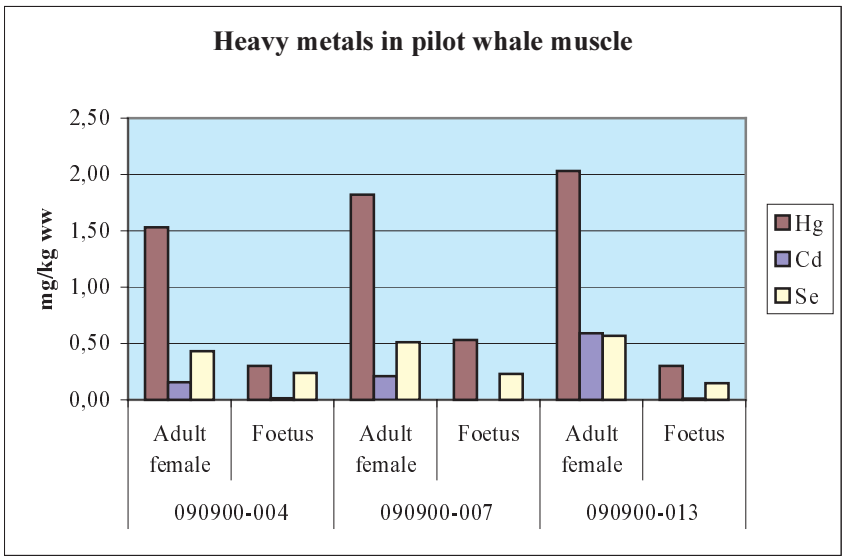

FIGURE 4.5. HEAVY METALS IN PREGNANT FEMALES AND THEIR FOETUSES FROM 09.09.00 (MG/KG WW).

The figures and tables above show the mean concentrations of Hg, Cd and Se in muscle for the four whale schools. When comparing the results for the two different whale schools the pattern is quite similar. For the mercury results, the content is highest for the males and lowest for the juveniles exept for the school from 08.09.99 where the mercury content is highest for adult females. The cadmium content is highest for the adult females for all whale schools.

In Figure 4.6 the Se content is depicted against Hg. It appears that the Se concentrations are quite stable when the Hg concentration is lower than approximately 3 mg/kg, but when it exceeds that limit the Se concentration seems to be increasing with increasing Hg concentration. The three individuals with the lowest selenium content (<0,3 mg/kg ww) from 09.09.00 are the three foetuses analysed.

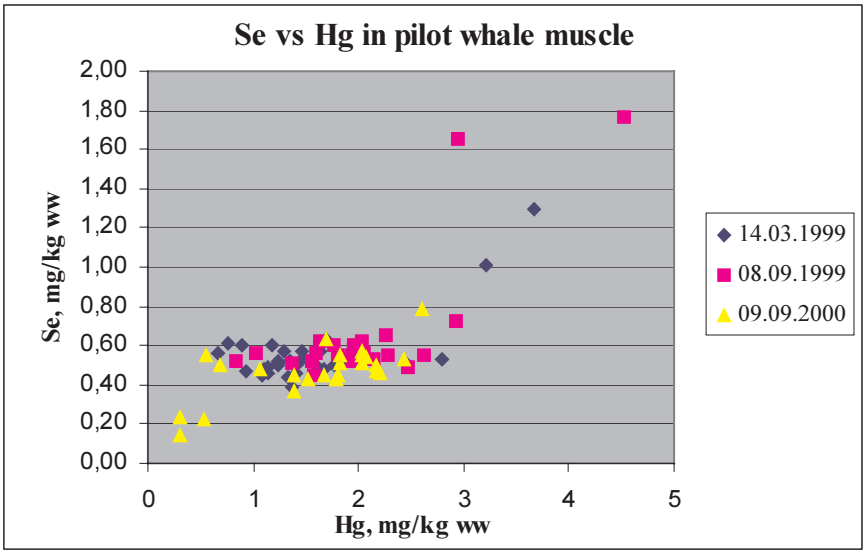

FIGURE 4.6. MERCURY VERSUS SELENIUM IN PILOT WHALE MUSCLE.

4.2.1 Kidney

Kidney samples were taken from the school from 08.09.99 and the school from 09.09.00 and analysed for cadmium at the Food and Environmental Agency in the Faroe Islands. The results are shown below.

Table 4.13. Cadmium in pilot whale kidney from 08.09.99

Age and sex group	Numbers of whales in the sample pool		Dry matter %	Cd mg/kg ww
Juveniles	3	Min	20,7	22,6
		Max	23,2	188,4
		Mean	**21,9**	**103,2**
		Std. dev	*1,25*	*83,01*
Adult females	5	Min	20,8	135,1
		Max	23	215,1
		Mean	**22,1**	**160,0**
		Std. dev	*0,99*	*32,73*
Adult males	8	Min	19,7	74,7
		Max	21,9	144,7
		Mean	**20,8**	**110,4**
		Std. dev	*0,77*	*26,41*

Of the samples from 09.09.00 only one kidney sample (090900-001) was analysed for dry matter content and the result was 23,9 g/100g.

Table 4.14. Cd in pilot whale kidney from 09.09.00

Age and sex group	Numbers of whales in the sample pool		Cd mg/kg ww
Juveniles	2	Min	52,1
		Max	68,7
		Mean	**60,40**
		Std. dev	*11,74*
Adult females	10	Min	83
		Max	239
		Mean	**155,36**
		Std. dev	*47,61*
Adult males	6	Min	100
		Max	215
		Mean	**146,17**
		Std. dev	*47,00*
Foetus	3	Min	0,6
		Max	3,1
		Mean	**1,7**
		Std. dev	*1,3*

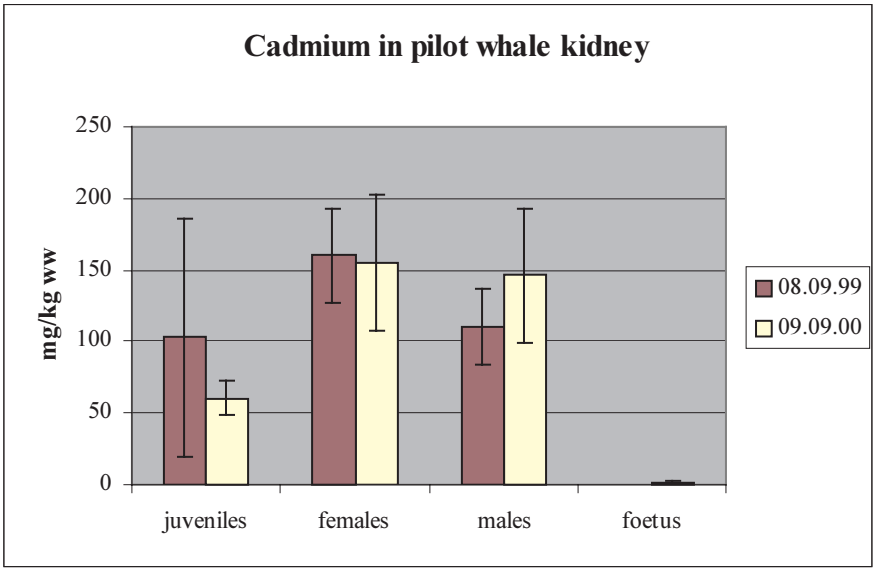

FIGURE 4.7. CADMIUM IN KIDNEY FROM THE WHALE SCHOOLS FROM 08.09.99 AND 09.09.00

During the years 1986-87 samples of 93 individuals of pilot whales belonging to three schools were analysed for cadmium.The average concentration in these three schools were 86, 93 and 55 mg Cd /kg kidney (where n= 43, 23 and 31 respectively) (Caurant et al., 1994), with three pregnant females having concentrations as high as 500 -960 mg/kg (Caurant and Amiard-Triquet, 1995). Such high individual levels where not found when kidney were analysed in samples from one pilot whale school in 1999 (n= 16, maximum Cd conc. 215 mg/kg) and one in 2000 (n= 21, maximum Cd conc. 240 mg/kg), Tables 4.13 and 4.14. However, the overall average cadmium concentrations in these schools where high, 125 mg/kg and 122 mg/kg respectively, also compared to earlier results like in 1978 where the average of Cd in pilot whales were 73 mg/kg (n =10) and 6 mg/kg (n=6) (Juelshamn et al., 1987) and the earlier mentioned results from 1986/87. In order to establish whether the results in 1999 and 2000 are reflecting an increased overall cadmium concentation in the pilot whales, an assessment must be done based on the relative amount of young individuals in the the 1986-87 samples compared to the 1999/2000 samples, as it is well known that young individuals tend to have lower cadmium concentrations in the kidneys (Caurant et al., 1994). Such analysis however, will demand tracing the data of the individual pilot whales analysed in the 1986-87 study.

5 *Lepus timidus* – Mountain Hare

The wild living terrestrial mammals on the Faroe Islands are mice, rats and hare. These species have been brought to the islands with humans. The hare was imported to the Faroes in 1855 from Norway and has been here since. The hare diet consists for of *e.g.* grass, herbs and horsetail (Bloch, D. and Fuglø, E. 1999)

In the Faroe Islands the hunting season for hares starts on 2nd of November and ends on 31st of December. The hares used in this project were shot in 1997 and 1999. The hares from 1997 were hunted north of Vestmanna in an area called Heimi í Haga, in a subarea called Postulakirkja. In this area the reference station Norðuri á Fossum[6] is situated. In 1999 the hares were hunted at three different locations: Heimi í Haga in Vestmanna, Heimihagi in Norðadalur and in Signabø hagi.

5.1 Collection of samples and sample treatment

In November 1997 the hares were shot with 3,70 mm and 4,70 mm 32g loaded Winchester steel-hail but in 1999 other types of hail were used. The tissue samples were stored in heat treated glass jars (400°C for at least four hours) with similarly heat treated aluminium foil between jar and lid and stored at -20°C until shipment to the laboratory. The samples 1997 were analysed for mercury and cadmium at the Food and Environmental Agency in the Faroe Islands and in addition the samples from 1999 were analysed for selenium at NERI, Department of Arctic Environment.

5.2 Results

Only three hares were shot in 1997 and the analyses were made on individual basis. Results of mercury and cadmium analyses on liver tissues are shown in Table 5.1.

Table 5.1. Heavy metals in hare in 1997 (mg/kg wet weight)

ID	Gender	Matrix	Dry matter g/100g	Cd	Hg
Lt-0001	Male	Liver	25,7	0,22	0,070
Lt-0002	Juvenile female	Liver	25,9	0,15	0,10
Lt-0003	Female	Liver	28,6	0,52	0,074

[6] "Norðuri á Fossum" – Færøernes referansestation i det internasjonale nettverk for Integrert Monitorering av Langtransportert Luftforurensning UN/ECE, Miljø og Levnedsmiddelstyrelsen Færøyene 1998

In 1999 analyses were made on both individuals and on pooled samples and they were analysed for mercury, cadmium and selenium. The results are shown in Table 5.2.

Table 5.2. Heavy metals in 1999 hare samples (mg/kg wet weight)

ID	Sample ID	Gender	Matrix	Dry matter %	Hg	Cd	Se
Lt-0015	Lt-0015	male	Liver	25	0,05	0,089	0,683
Lt-0022	Lt-0022	male	Liver	24,75	0,02	0,133	0,582
Lt-0029	Lt-0029	male	Liver		0,05	0,078	0,637
Lt-0010, Lt-0015, Lt-0017, Lt-0022, Lt-0029	Pooled sample 1-1999	male	Liver		0,03	0,280	0,562
Males			Min	24,75	0,02	0,08	0,56
			Max	25,00	0,05	0,28	0,68
			Mean	**24,88**	**0,04**	**0,15**	**0,62**
			Std.dev.	*0,18*	*0,02*	*0,09*	*0,05*
Lt-0005	Lt-0005	female	Liver	24,86	0,11	0,045	0,573
Lt-0013	Lt-0013	female	Liver	24,34	0,01	0,047	0,443
Lt-0027	Lt-0027	female	Liver	23,6	0,05	0,127	0,53
Lt-0005, Lt-0013, Lt-0019, Lt-0020, Lt-0021,Lt-0027	Pooled sample 2-1999	female	Liver	23,89	0,05	0,128	0,607
Females			Min	23,60	0,01	0,05	0,44
			Max	24,86	0,11	0,13	0,61
			Mean	**24,17**	**0,06**	**0,09**	**0,54**
			Std.dev.	*0,55*	*0,04*	*0,05*	*0,07*
Lt-0009	Lt-0009	juvenile	Liver	22,16	0,02	0,139	0,539
Lt-0018	Lt-0018	juvenile	Liver	24,84	0,10	0,399	0,856
Lt-0028	Lt-0028	juvenile	Liver	25,49	0,04	0,180	0,735
Lt-0004, Lt-0011, Lt-0014, Lt-0016, Lt-0023, Lt-0026	Pooled sample 3-1999	juvenile	Liver	23,68	0,06	0,092	0,619
Lt-0006, Lt-0007, Lt-0008, Lt-0012, Lt-0024, Lt-0025	Pooled sample 4-1999	juvenile	Liver	23,53	0,07	0,142	0,535
Juveniles			Min	22,16	0,02	0,09	0,54
			Max	25,49	0,10	0,40	0,86
			Mean	**23,94**	**0,06**	**0,19**	**0,66**
			Std.dev.	*1,29*	*0,03*	*0,12*	*0,14*

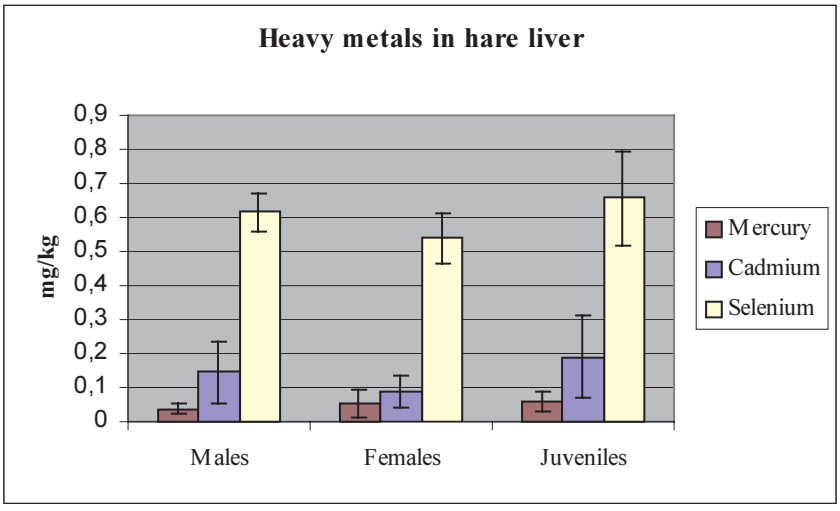

Figure 5.1. Heavy metals in hare liver in 1999 (mg/kg wet weight)

When comparing the heavy metal results from 1997 and 1999 the levels seem quite similar. The results from 1997 are within the range of the levels from

1999 except from the mercury content of the adult male and the cadmium content of the adult female. These levels are higher than the maximum levels in 1999, however, as seen from the Table 5.3 there may be quite wide range in the concentration of these metals. The relatively high levels of heavy metals in the Faroese juveniles were not expected and do not follow the normal pattern of increasing bodyburden with age as is normally seen especially for mercury. However, given the limitied sample size this could be a result of the already mentioned large individual variations.

In Table 5.3 concentrations of mercury, cadmium and selenium in various hare samples from other countries are given along with the results of the present study in comparable units.

Table 5.3. Some results of heavy metals in hare from other countries(µg/g dry weight)

Species	Matrix	Age	Year of sampling	Number of individual	Cd µg/g dw	Hg µg/g dw	Se µg/g dw	*Ref.**
Lepus americanus (Canada)**	Kidney		1993-1995	29♀+♂	6-166	<0,01-1,74	<1,7-7,5	*Gamberg 1996*
	Liver		1993-1995	28♀+♂	0,05-8,9	<0,05-0,54	1,5-3,5	
	Muscle		1994,1995	7♀+♂	<0,01-0,04	<0,05-0,16	<0,05-3,5	
Lepus timidus (N. Finland) **	Muscle		1980-1982	7	0,010 +/- 0,007			*Venäläinen et al. 1996*
	Muscle		1992-1993	8	0,005 +/- 0,004			
	Liver		1980-1982	36	0,390 +/- 0,300			
	Liver		1992-1993	8	0,185 +/- 0,107			
	Kidney		1980-1982	35	4,55 +/- 4,04			
	Kidney		1992-1993	7	3,73 +/- 3,16			
Lepus europaeus (N.Finland) **	Muscle		1980-1982	2	0,003			*Venäläinen et al. 1996*
	Muscle		1992-1993	3	0,001			
	Liver		1980-1982	15	0,171 +/- 0,153			
	Liver		1992-1993	3	0,057 +/- 0,029			
	Kidney		1980-1982	13	1,46 +/- 1,07			
	Kidney		1992-1993	3	0,627 +/- 0,439			
Lepus sp. Sør-Varanger, Jarfjord	Kidney	juvenile	1991-1993	14	3,9	0,17		*Kålås et al. 1995*
	Kidney	adult	1991-1993	4	33	0,359		
	Liver	juvenile	1991-1993	14	0,53	0,025	0,79	
	Liver	adult	1991-1993	4	1,7	0,055	1,69	
Lepus sp. Sør-Varanger, N-Varanger	Kidney	adult	1991-1993	3	99	0,176		*Kålås et al. 1995*
	Liver	adult	1991-1993	3	5	0,024	0,8	
Lepus sp. Sør-Varanger, Neiden	Kidney	juvenile	1991-1993	3	1,9	0,212		*Kålås et al. 1995*
	Kidney	adult	1991-1993	2	47	0,734		
	Liver	juvenile	1991-1993	3	0,34	0,025	1,15	
	Liver	adult	1991-1993	2	1,3	1,06	1,85	
Lepus sp. Finnmark (reference area)	Kidney	juvenile	1991-1993	3	1,9	0,065		*Kålås et al. 1995*
	Kidney	adult	1991-1993	2	16	0,145		
	Liver	juvenile	1991-1993	3	0,43	0,01	0,48	
	Liver	adult	1991-1993	2	0,61	0,024	0,58	
Lepus timidus Faroe Island	Liver	adult	1997	1 ♂	0,856	0,272		*This work*
	Liver	juvenile	1997	1 ♀	0,579	0,386		
	Liver	adult	1997	1 ♀	1,818	0,259		
	Liver	adult	1999	5 ♂	0,582	0,150	2,47	
	Liver	adult	1999	6 ♀	0,362	0,226	2,23	
	Liver	juvenile	1999	15	0,786	0,240	2,73	

* all these results are from AMAP Assessment Report: Arctic Pollution Issues (1998)

** results are presented in µg/g wet weight

6 *Ovis aries* – Sheep

Sheep and lamb form a considerable part of the traditional Faroese diet. Almost everything on the sheep is consumed *e.g.* meat and entrails. There are approximately 70,000 sheep on the 18 Faroese islands. The sheep pasture in outlying fields, and it is quite common that they have no contact with developed areas before they are slaughtered. Sometimes at the end of the winter they are given imported fodder for a couple of months until there is enough grass for them to feed on.

The sheep which were analysed in this context, had been grazing north of Vestmanna in an area called Heimi í Haga and in this area the reference station Norðuri á Fossum[7] is situated.

6.1 Samples collection and pre-treatment

In connection with slaughtering of sheep in October 1999, arrangements were made with farmers to take the samples and they were given instructions on the procedure. The samples consisted of approximately 50 g liver from the lowest part of the liver lobe and were put individually in PE (Minigrip®) bags and then frozen. Samples were taken from 17 juvenile females and six adult female sheep.

Liver from sheep and lambs were analysed for mercury and cadmium as pooled samples at the Food and Environmental Agency in the Faroe Islands. There were made one sample for the lambs and one for the sheep. The pooled samples consisted of equal amounts of liver tissue from each individual, one comprising all the juveniles and one the adult females.

6.2 Heavy metal results

In the table below the results from the heavy metal analyses are shown. As expected the content of heavy metals are low, for mercury the concentrations were below the detection limit. The concentrations of cadmium were, as expected, higher in the adult females than in the juveniles.

In our first AMAP study from 1997 (Larsen, R.B. and Dam, M. 1997), sheep and lamb were analysed for mercury and cadmium, and these results are comparable to the results presented here. In 1997 mercury was not detectable in any of the analysed samples and the mean level for cadmium was 0,17 mg/kg wet weight in adult females and 0,05 mg/kg wet weight in juvenile females.

[7] "Norðuri á Fossum" – Færøernes referansestation i det internasjonale nettverk for Integrert Monitorering av Langtransportert Luftforurensning UN/ECE, Miljø og Levnedsmiddelstyrelsen Færøyene 1998

Table 6.1. Concentration of mercury and cadmium in sheep and lamb liver (mg/kg wet weight)

	Number of individual in pooled sample	Dry matter g/100g	Cd	Hg
Juvenile females	17	30,5	0,064	<0,020
Adult females	6	29,6	0,19	<0,020

7 *Salvelinus alpinus* - Arctic char

In the Faroe Islands Arctic char were originally found only in lake Leynavatn (Gydemo, 1983). In 1956 Arctic char from Leynavatn were released in the reservoir Frammi á Vatni and later in 1961 also in the dammed lake Á Mýrunum. Later the Arctic char have spread from these places to the lower reservoirs, Lomundaroyri and Heygardalsvatn. These reservoirs are situated above Vestmanna (Reinert, 1998). The Arctic char in this study are from the dammed lake Á Mýrunum.

Arctic char can be either anadromous or stationary. Anadromuous means that they live in the ocean except when they are young and that they only return to fresh water to spawn. Arctic char from Á Mýrunum have no access to the sea, hence they are necessarily stationary.

Since 1992 the dammed lake Á Mýrunum has been preserved for fishing because of outbreak of the disease furunculosis in the lower reservoir Heygardalsvatn, and special permission must be achieved before fishing in the lake.

7.1 Sampling and sample treatment

Permission for fishing in the lake Á Mýrunum was granted by the Chief Veterinary Officer and the Arctic char was caught by angling by men from the angling association "Føroya Sílaveiðufelag" on 28th of June in 2000 and 27th of June and 5th of July in 2001. The fish were wrapped individually in plastic bags and kept in a cool-box until further treatment. In 2001 the fish were frozen before further treatment. Before and after fishing the fishing tackle was disinfected, in 2000 with the commercial disinfectant Actomar and in 2001 with VirkonS.

In 2000 a total of 35 Artic char were caught, of which 25 were analysed. In 2001 40 Arctic char were caught and analysed. The char was examined for sympthoms of a selection of fish diseases but no signs of diseases or ectoparasites were found.

In 2000 individual samples of muscle were taken from the right fillet and stored in polycarbonate boxes in the freezer (-20°C) until chemical analysis. The muscle samples were analysed for mercury at the Food and Environmental Agency in the Faroe Islands, and for selenium and dry matter content at NERI[8], Department of Arctic Environment. Otoliths were extracted from all the individuals from 2000, except for one (Bl-01), for age determination and analysed by Jørgen Andersen, formerly employed at NERI, Department of Arctic Environment.

In 2001 the Arctic char were analysed as pooled samples. Each pool consisted of equal amount of right fillet muscle from 8 individuals. The division of the fish into pools was made according to size. The samples were stored in heat

[8] National Environmental Research Institute of Denmark

treated glass jars (400°C for at least four hours) with similarly heat treated aluminium foil between jar and lid, and analysed for mercury, selenium and dry matter content at CTQ in Canada.
The liver samples were taken from all the individuals both years for storage in the Faroese Environmental Specimen Bank and kept in the freezer (-20°C) in heat treated glass jars (400°C for at least four hours) with similarly heat treated aluminium foil between jar and lid.

7.2 Results

7.2.1 Age determination

The age was determined for the Arctic char from 2000. The age ranged between six and ten years with a mean age of approximately 8 years. The figure below shows the correlation between lenght and age.

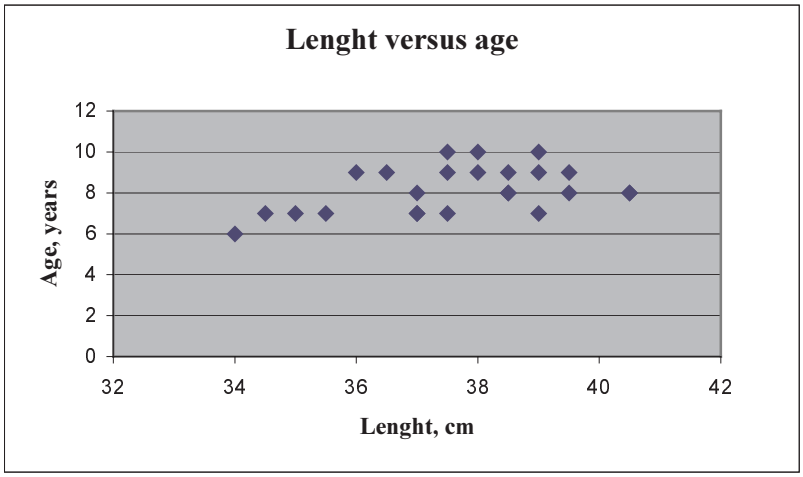

Figure 7.1. Correlation between age and lenght for Arctic char

In 2001 the length ranged between 28 cm and 40 cm with a mean length of 36,2 cm.

7.2.2 Heavy metals

The results of the heavy metal analyses from 2000 are shown in Table 7.1, and the mean Hg and Se values for the three size groups are shown in Figure 7.2. The molar ratio for Hg/Se for the largest size group is 0,0009/0,0184 mmol/kg. Figure 7.3 shows the correlation between mercury and selenium.

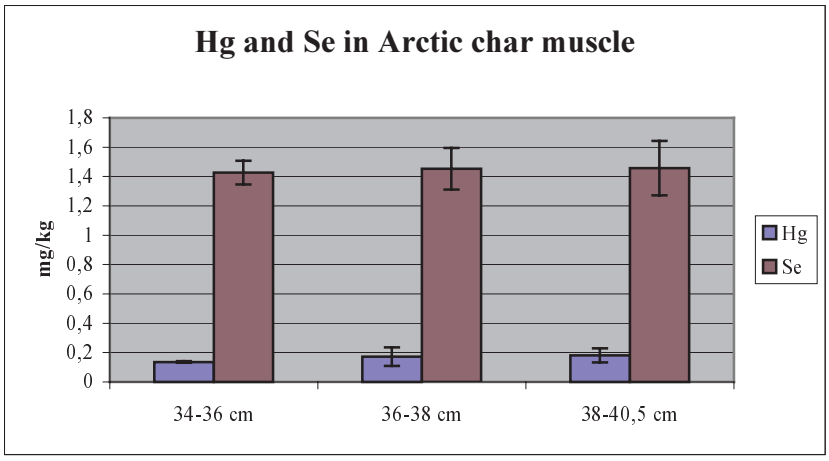

Figure 7.2. Mean Hg and Se in Arctic char muscle for the different size groups

Table 7.1. Content of mercury and selenium in Arctic char muscle

Size group	ID	Gender	Age	Length, cm	Condition index	Dry matter %	Hg, mg/kg ww	Se, mg/kg ww
34-36 cm	Bl-17	female	6	34,0	1,305	28,48	0,14	1,532
	Bl-20	male	7	34,5	1,571	27,72	0,13	1,460
	Bl-07	female	7	35,0	1,190	26,19	0,14	1,341
	Bl-06	male	7	35,5	1,194	24,12	0,13	1,351
	Bl-08	female	9	36,0	1,267	29,19	0,14	1,449
36-38 cm	Bl-12	female	9	36,5	1,337	26,04	0,15	1,274
	Bl-03	male	7	37,0	1,250	26,63	0,12	1,622
	Bl-19	male	8	37,0	1,230	24,85	0,13	1,685
	Bl-22	male	7	37,0	1,337	31,79	0,14	1,482
	Bl-21	female	7	37,5	1,185	27,88	0,13	1,556
	Bl-24	female	10	37,5	1,240	26,52	0,2	1,346
	Bl-25	male	9	37,5	0,848	19,01	0,33	1,262
	Bl-05	female	10	38,0	1,066	28,03	0,21	1,430
	Bl-01	male		38,0	1,144	23,76	0,14	1,492
	Bl-14	male	9	38,0	1,179	24,24	0,18	1,385
38-40,5 cm	Bl-10	male	8	38,5	1,405	24,63	0,1	1,557
	Bl-11	male	8	38,5	1,116	22,41	0,21	1,474
	Bl-13	male	9	38,5	1,179	21,23	0,19	1,037
	Bl-18	female	10	39,0	1,086	25	0,24	1,638
	Bl-04	male	9	39,0	1,150	23,2	0,11	1,602
	Bl-09	male	7	39,0	1,239	23,49	0,15	1,542
	Bl-15	male	8	39,5	1,121	22,75	0,18	1,487
	Bl-23	male	9	39,5	0,993	21,97	0,23	1,421
	Bl-02	male	8	40,5	1,060	24,46	0,21	1,244
	Bl-16	male	8	40,5	1,030	23,42	0,19	1,571
		Min	6	34,0	0,85	19,01	0,1	1,037
		Max	10	40,5	1,57	31,79	0,33	1,685
		Mean	**8,17**	**37,7**	**1,19**	**25,08**	**0,17**	**1,45**
		Std.dev	*1,13*	1,72	*0,14*	*2,82*	*0,051*	*0,147*

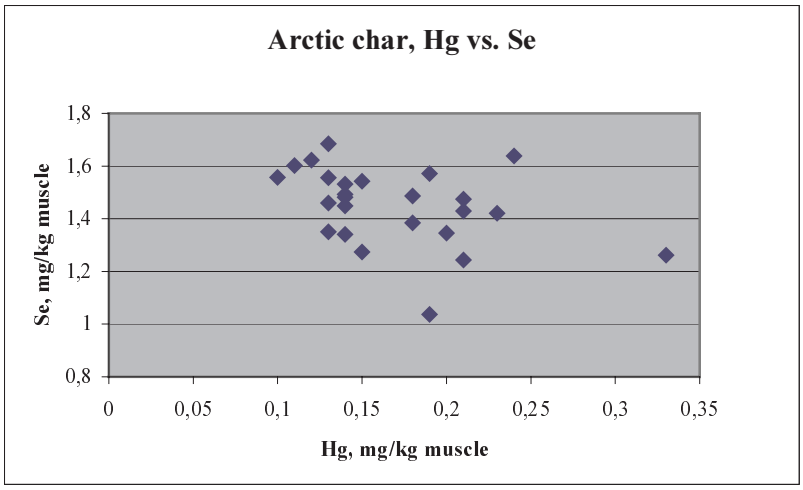

Figure 7.3. Content of mercury versus selenium in Artic char muscle

Figure 7.4 and Figure 7.5 show the concentration of mercury versus length and condition index respectively. Mercury content was not significantly correlated to length (5 % level of significance), but significantly correlated to condition index with P(2 tail)=0,00001.

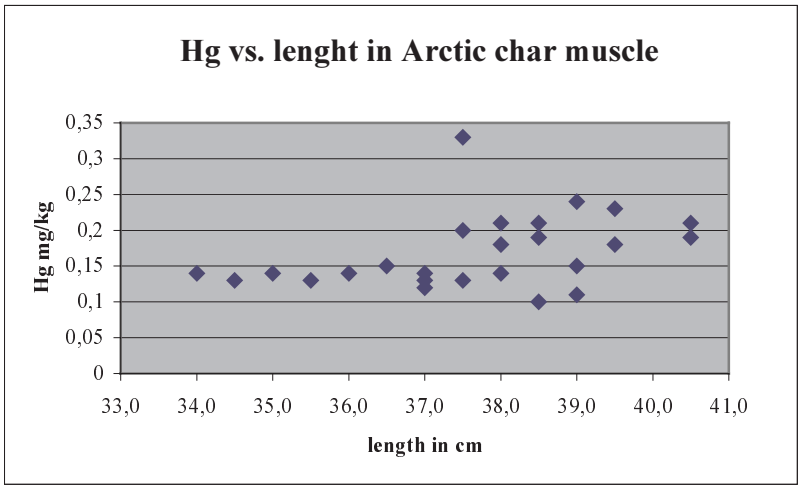

Figure 7.4. Mercury versus length in Arctic char muscle

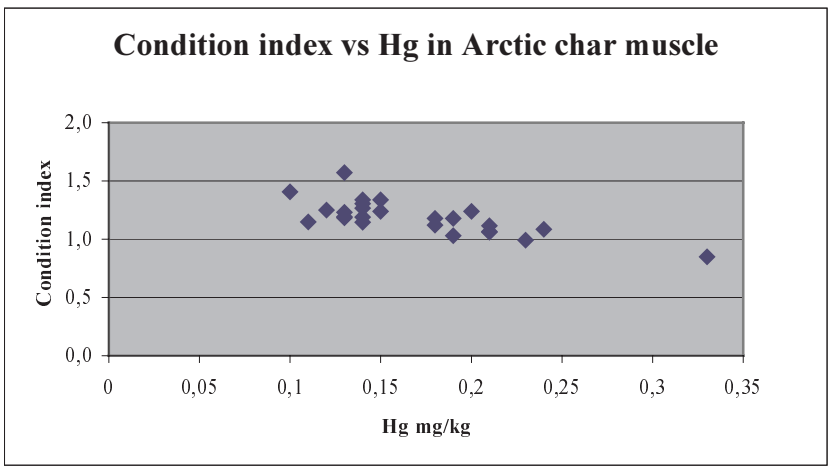

Figure 7.5. Condition index versus mercury in Arctic char muscle

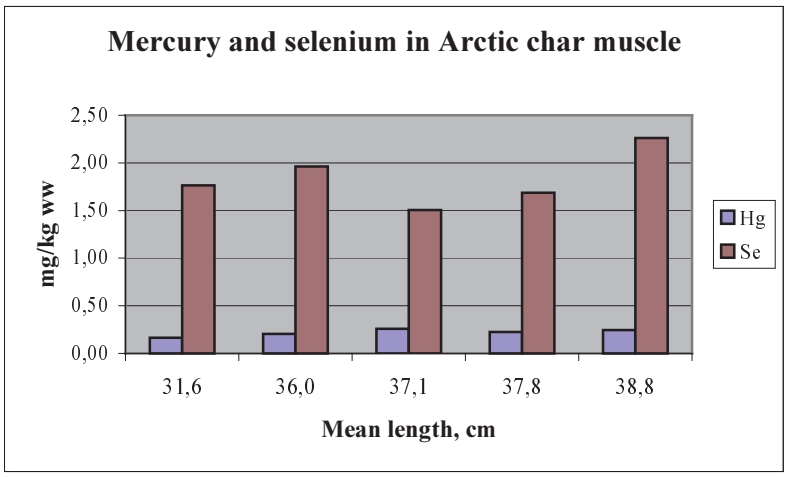

Figure 7.6. Mercury and selenium in pooled samples of Arctic char muscle from 2001

In 2001 the Arctic char were analysed as pooled samples and Table 7.2 shows the results of the heavy metal analysis.

Table 7.2. Heavy metals in Arctic char muscle from 2001

ID	Sample ID	Mean lenght of sample, cm	Dry matter %	Hg mg/kg ww	Se mg/kg ww
Sa-0059, Sa-0060, Sa-0061, Sa-0062, Sa-0063, Sa-0064, Sa-0065, Sa-0066	Sa-1-2001	31,6	25,23	0,164	1,766
Sa-0067, Sa-0068, Sa-0069, Sa-0070, Sa-0071, Sa-0072, Sa-0073, Sa-0074	Sa-2-2001	36,0	22,80	0,205	1,961
Sa-0075, Sa-0076, Sa-0077, Sa-0078, Sa-0079, Sa-0080, Sa-0081, Sa-0082	Sa-3-2001	37,1	17,32	0,260	1,507
Sa-0083, Sa-0084, Sa-0085, Sa-0086, Sa-0087, Sa-0088, Sa-0089, Sa-0090	Sa-4-2001	37,8	19,60	0,225	1,686
Sa-0091, Sa-0092, Sa-0093, Sa-0094, Sa-0095, Sa-0096, Sa-0097, Sa-0098	Sa-5-2001	38,8	18,24	0,246	2,262

In Table 7.3 heavy metal results from Arctic char in other countries are listed and our results are high compared to other countries. Only the results from Greenland and some Canadian lakes are higher.

Table 7.3. Heavy metals in Arctic char from other countries (•g/g wet weight)

Location	Matrix	Year	n	Hg**	Se**	*Ref.**
Ellis River, Canada	Muscle	1971	2	0,03		Hendzel 1990
	Muscle	1977	3	0,42	0,39	
	Muscle	1984	5	0,03		
	Muscle	1987	6	0,05		
	Muscle	1989	4	0,04		
	Muscle	1990	5	0,03+/-0,012		
Ekaluk River, Canada	Muscle	1990	5	0,026+/-0,011		
Surrey Lake, Canada	Muscle	1984	5	0,04		
Tree River, Canada	Muscle	1977	8	0,02		
	Muscle	1980	2	0,03	0,314	
Saputing Lake, Canada	Muscle	1979	5	0,052	0,256	
Koukdjuak River, Canada	Muscle	1970	1	0,13		
Nettilling Lake, Canada	Muscle	1990	5	0,084+/-0,027		
Tessikakjuak Lake, Canada	Muscle	1977	5	0,01	0,29	
Thirty Mile Lake, Canada	Muscle	1988	5	0,03		
	Muscle	1989	5	0,05		
	Muscle	1990	5	0,024+/-0,015		
Keyhole Lake, Canada	Muscle	1970	2	0,04+/-0,01		
Wilson River, Canada	Muscle	1988	5	0,03		
Kaminuriak Lake, Canada	Muscle	1975	1	0,02		
Esker Lake, Canada	Muscle	1978	17 (males)	0,33		Bruce 1979
	Muscle	1978	9 (females)	0,33		
Tasialuk Lake, Canada	Muscle	1978	8 (males)	0,07		
	Muscle	1978	16 (females)	0,10		
Char Lake Cornwallis Island, Canada	Muscle		7	0,26		Muir and Lockhart 1984
Lake Cornwallis Island, Canada	Muscle		3	0,26		
Resolute Lake Cornwallis Island, Canada	Muscle		7	0,2		
Small Lake Cornwallis Island, Canada	Muscle		2	0,05		
Victory Lake Cornwallis Island, Canada	Muscle		1	0,42		
Hazen Lake, N. Ellesmere Island, Canada			45	0,181+/-0,093	0,902+/-0,403	Muir and Lockhart 1994
Amituk Lake, Cornwallis Island, Canada			27	0,567+/-0,597	0,846+/-0,189	Lockhart 1994
Ammassalik, Greenland	Muscle	1994	25	0,165+/-0,113		Riget *et al.* 1997a
Isortoq, Greenland	Muscle	1994	25	0,994+/-0,763		
Itinnera, Greenland	Muscle	1994	25	0,594+/-0,334		
Olrik Fjord, Greenland	Muscle	1994	11	0,276+/-0,141		
Lake Thinkvallavatn Vatnskot, Iceland	Muscle	1994	1	0,026+/-0,0026		Jonsson 1995
Lake Thinkvallavatn Thorsteinsvik, Iceland	Muscle	1994	1	0,018+/-0,0055		
Lake Coulbmajavri (Finmark), Norway	Muscle	1995	20	0,03-0,06		Skotvold *et al.* 1996
Ellasjøen (Bear Island), Norway	Muscle	1995	20	0,067-0,223		
Lake Peltojarvi, Fin.Lapland	Muscle	1987		0,20+/-0,13		Iivonen *et al.* 1992
Lake Aalisjarvi, Fin.Lapland	Muscle	1987		0,10+/-0,04		

* all these results are from AMAP Assessment Report: Arctic Pollution Issues (1998),
**+/- std.dev.

8 Sediments

Mercury is released to the atmosphere in connection with combustion of fossil fuels and in particular combustion of coal. The atmospheric mercury can be transported over large areas and later dry-deposited or precipitated with rain or snow and thus re-enter soil and sediments. By analysing the age and the mercury content of the deposits, the trend of mercury pollution during the years can be depicted.

8.1 Marine sediments

A special task for 2000 was to look for time trend in mercury in marine sediment cores.

8.1.1 Sampling and sample treatment

The sampling was carried out by the research vessel "Magnus Heinason" on the 26th of July 2000. Four sediment cores were taken at position 61° 51' N, 05° 44' V at sea depth approx. 330 m with a HAPS bottom-corer westerly on the "Sandoyarbanki" which is a bank area east of the Faroe Islands.

The sediment cores were frozen and cut into 1 cm segments before delivery to the laboratory for analysis. The mercury analyses were carried out at the Food and Environmental Agency on the Faroe Islands, where the samples also were freeze dried and sieved in a 500 •m mesh sieve before they were sent to dating. The dating procedure was carried out at Risø National Laboratory, Department of Nuclear Safety Research based on analyses of ^{210}Pb.

8.1.2 Results

The dating and mercury results are shown in the table below. By comparing the mercury results with the age of the sediment layers, a profile of how the mercury content has changed during the years can be shown. The figure below shows the profiles for the four sediment cores from "Sandoyarbanki".

As seen on the figure, the different cores show a great variation in the mercury content, especially the results for the last 20 years. The difference between the cores is on a scale of 10 ppb, while the variation within one sample is approximately 4 ppb where the deviation is largest.

Some bioturbation was noted in the upper 1- 2 cm of core 1 – 3 and more subtle in core 4, though this was taken into consideration for the sedimentation rate analyses.

Table 8.1. Age and mercury content of marine sediments

	Core 1			Core 2			Core 3			Core 4		
Sedimentation rate	0,9 mm/y			1,2 mm/y			0,8 mm/y			1,1 mm/y		
Depth in cm	Age, years	Hg, ug/kg	*Std. dev.*	Age, years	Hg, ug/kg	*Std. dev.*	Age, years	Hg, ug/kg	*Std. dev.*	Age, years	Hg, ug/kg	*Std. dev.*
0-1	-11,1	7,48	*0,17*	-8,3	4,31	*0,84*	-12,5	8,43	*0,22*	-9,1	13,6	*0,02*
1-2	-22,2	9,23	*0,75*	-16,7	7,4	*0,93*	-25,0	11,8	*0,02*	-18,2	13,7	*0,33*
2-3	-33,3	9,75	*0,36*	-25,0	10	*1,04*	-37,5	11,6	*0,10*	-27,3	12,4	*0,10*
3-4	-44,4	8,07	*0,16*	-33,3	8,62	*0,43*	-50,0	11,2	*0,21*	-36,4	12,1	*0,17*
4-5	-55,6	7,76	*0,00*	-41,7	8,54	*0,29*	-62,5	10,9	*0,05*	-45,5	11,3	*0,02*
5-6	-66,7	7,15	*0,28*	-50,0	9,55	*1,11*	-75,0	6,34	*0,50*	-54,5	10,5	*0,26*
6-7	-77,8	6,37	*0,41*	-58,3	7,41	*0,08*	-87,5	5,08	*0,52*	-63,6	10,9	*0,52*
7-8	-88,9	5,4	*0,36*	-66,7	7,11	*0,78*	-100,0	5,27	*0,71*	-72,7	9,22	*0,06*
8-9	-100,0	4,78	*0,45*	-75,0	6,47	*0,53*	-112,5	3,94	*0,50*	-81,8	7,45	*0,21*
9-10	-111,1	4,05	*0,78*							-90,9	7,16	*0,10*
10-11	-122,2	4,12										

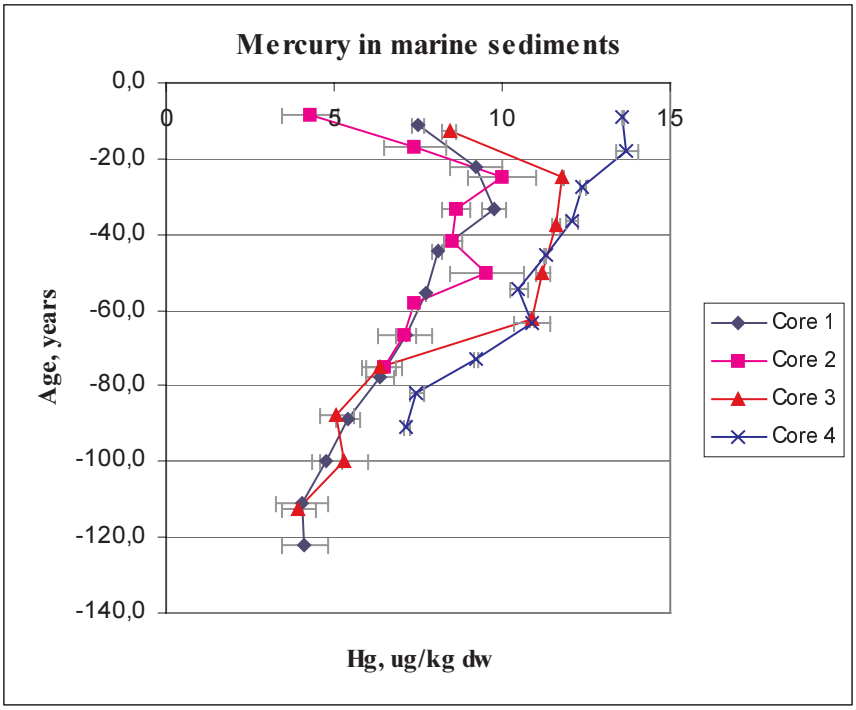

Figure 8.1. Age and mercury profile af marine sediments

8.2 Freshwater sediments

A special task in 2001 was to look for time trend in mercury in freshwater sediment cores.

8.2.1 Sampling and sample treatment

The sampling was carried out on the 1th and 2nd of August 2000 in Leynavatn and Sørvágsvatn respectively. One sediment core was taken at each lake with a

HAPS (kajak) bottom-corer at the deepest part of the lake at the positions 62° 07.72 N, 07° 01.05 V in Leynavatn and 62° 03.06 N, 07° 13.69 V in Sørvágsvatn.

The sediment cores were frozen and cut into segments on 2 and 5 cm before delivery to the laboratory for analysis. The mercury analyses were carried out at the Food and Environmental Agency on the Faroe Islands. The dating procedure, based on analyses of ^{210}Pb, was carried out at Risø National Laboratory, Department of Nuclear Safety Research, where the samples also were freeze dried and sieved.

8.2.2 Results

The dating and mercury results are shown in the table below. By comparing the mercury results with the age of the sediment layers, a profile of how the mercury content has changed during the years can be shown. Unfortunately the 4 top layers of the core from Leynavatn could not be dated because there of some reason had been a some mixing in the upper sediment layers. So only the two lowest layers of the core from Leynavatn had not been effected by the mixing and could therefore be dated. The figure below shows the profile for the sediment core from Sørvágsvatn.

TABLE 8.2. AGE AND MERCURY CONTENT IN FRESHWATER SEDIMENTS

	Sørvágsvatn			Leynavatn		
Sedimentation rate	0,12 cm/y			0,2 cm/y		
Depth in cm	Age years	Hg µg/kg d.w.	LOI g/kg d.w.	Age years	Hg µg/kg d.w.	LOI g/kg d.w.
0-2	-16,7	91,3	245		33,9	129
2-7	-58,3	104	214		38	105
7-12	-100,0	95,3	232		40,2	102
12-17	-141,7	85,7	273		45,3	116
17-22	-183,3	90,3	296	-110,0	46,8	142
22-26	-216,7	56,9	322	-120,0	37,1	99,8

LOI: Loss on ignition

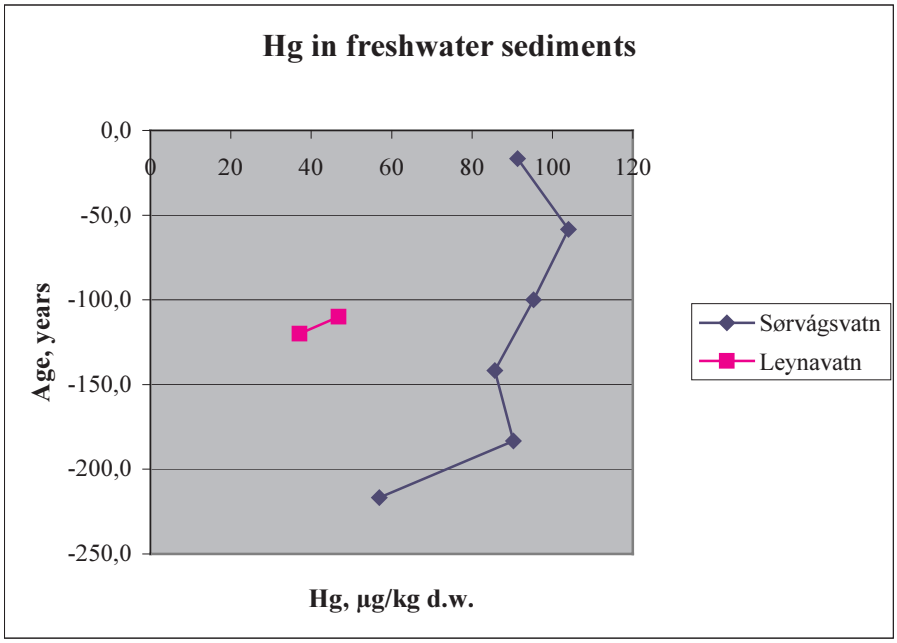

FIGURE 8.2. AGE AND MERCURY PROFILE OF FRESHWATER SEDIMENTS.

Overall, the mercury concentrations appear to be approx. twice as high in sediments from Sørvágsvatns as in those from Leynavatn. Compared to similar analyses in other places, we may note that the Leynavatn results are alike the ones in Grenland (Riget et al., 2000) and in the lower end of the results found in Arctic Norway Lakes and in Spitsbergen lake sediments (Skotvold et al., 1996). The mercury concentration Sørvágsvatn sediment are also within the range found in Arctic Norway and Spitsbergen. As a standalone set of data the present results on mercury in freshwater sediments do not allow any conclusions as to whether the increased mercury concentrations in the last 200 yrs which are observed in the Sørvágsvatn are caused by natural variations, manmade variations introduced by land use or manmade variations caused by long-range transport.

9 Conclusion

In this report the results of AMAP fase II heavy metal analysis from the Faroe Islands, as coordinated by the Food and Environmental Agency, are presented. Table 9.1 and the figures below give overviews of all the species analysed in 1999, 2000 and 2001. The content of heavy metals in the different species varies much and this reflects the difference between the analysed species, *e.g.* their position in the food web and their longevity. Most heavy metal analyseses in our AMAP program has been done on liver tissue, in compliancy with the guidelines. However, in certain instances like with the pilot whale, we have special interests in analysing other or additional tissues to what has been agreed on an international basis, and this stems primarily from our interest to monitor the contaminants concentration in species which are known to be important sources for human heavy metal exposure.

In 1998 fulmar (*Fulmarus glacialis*) liver was analysed (Larsen, R.B. and Dam. M. 1999) and these results showed also very high concentration of cadmium (8,55 mg/kg wet weight) and for mercury the mean concentration for adult and immature birds was 2,66 mg/kg wet weight. When comparing black guillemot with other Faroese seabirds, the mean level of mercury in shag (*Phalacrocorax aristotelis*) liver was approximately 0,5 mg/kg wet weight, and for cadmium the concentration in shag liver was approximately 0,5 mg/kg wet weight with the highest concentration in adult female. For common eider (*Somateria molissima*) the mercury concentration did not exceed 0,7 mg/kg wet weight and for cadmium the concentration range was 2,5 to 5 mg/kg wet weight (Dam. M. 1998).

Direct comparison between the species is difficult because of the different tissues analysed, however some broad lines may be drawn. Not surprisingly, the concentration in the sheep are lowest with no detectable mercury. After the sheep comes the hares and the heavy metal contents are also low for the hares livers. The sheep and hares are herbivorous, and herbivores are known to have low concentrations of environmental pollutants because of a short food web.

Mercury and cadmium concentration in sculpin liver range between 0,04 and 0,55 mg Hg/kg and 0,15 to 0,44 mg Cd/ kg for 1999, between 0,99 and 1,38 mg Hg /kg and 0,38 to 0,95 mg Cd/kg for 2000 and between 0,07 and 0,26 mg Hg/kg and 0,1 to 1,19 mg Cd/kg in 2001. Recent research has not been made on sculpins in the Faroes and the diet of sculpins is not known in detail. In The Zoology of the Faroes the diet is described as consisting of crustaceans etc. (Joensen, J. S. and Vedel Tåning, Å., 1969). From all the sculpins we have analysed, the stomachs with content are stored, and these may be used for a future study of the sculpins diet.

When comparing the mercury results from pilot whales with mercury results from 1997 (Larsen, R.B. and Dam, M. 1999) we see that the results for the school from 08.09.99 are comparable with the results from 1997, while the results from 14.03.99 are lower. The results from 1997 however, pertain to pooled samples while the results from this study apply to individual samples.

In the table below the selenium results are also included, and for the sculpins the results are very high, about twice as high as the selenium concentration in pilot whales and hares. However, the comparision shall be done with care, because the results apply not only to different species but to different tissues as well; for the sculpins and the hares the liver content is measured and for pilot whales the muscle content is measured.

Table 9.1 Mean content of Hg, Cd and Se in all the analysed species (mg/kg wet weight)

Species	Matrix	Year or date	Size, age or sex	Mercury	Cadmium	Selenium
Short-horn sculpin	Liver	1999	10-15 cm	0,04	0,19	1,15
			15-20 cm	0,13	0,15	1,47
			20-25 cm	0,29	0,20	1,28
			25-31 cm	0,55	0,44	1,18
		2000	20-25 cm	1,38	0,384	1,318
			25-31 cm	0,988	0,946	1,537
		2001	15-20 cm	0,070	0,101	1,482
			20-25 cm	0,061	0,200	1,666
			25-32 cm	0,240	1,146	1,666
Arctic char	Muscle	2000	All	0,169		1,45
		2001	All	0,22		1,84
Black guillemot	Egg	1999		0,51		
		2000		0,33		
		2001		0,33		
	Feather	1996	All	4,72		
	Liver	1995	Juveniles	0,33	0,64	
		1996	Juveniles	0,54	0,98	
			Females	0,95	1,36	
			Males	1,73	1,27	
Pilot whale	Muscle	14.03.99	Juveniles	1,31	0,113	0,61
			Females	1,63	0,257	0,63
			Males	1,85	0,180	0,55
		08.09.99	Juveniles	1,46	0,11	0,52
			Females	2,49	0,418	0,842
			Males	2,06	0,18	0,61
		31.08.00	Juveniles	1,62		0,67
			Females	2,86		0,70
			Males	3,07		0,81
		09.09.00	Juveniles	1,13	0,087	0,45
			Females	1,86	0,391	0,547
			Males	2,00	0,281	0,485
			Foetus	0,377	0,013	0,205
Mountain hare	Liver	1997	All	0,08	0,296	
		1999	Juveniles	0,06	0,19	0,66
			Females	0,06	0,09	0,54
			Males	0,04	0,15	0,62
Sheep	Liver	1999	Juvenile females	<0,020	0,064	
			Adult females	<0,020	0,19	

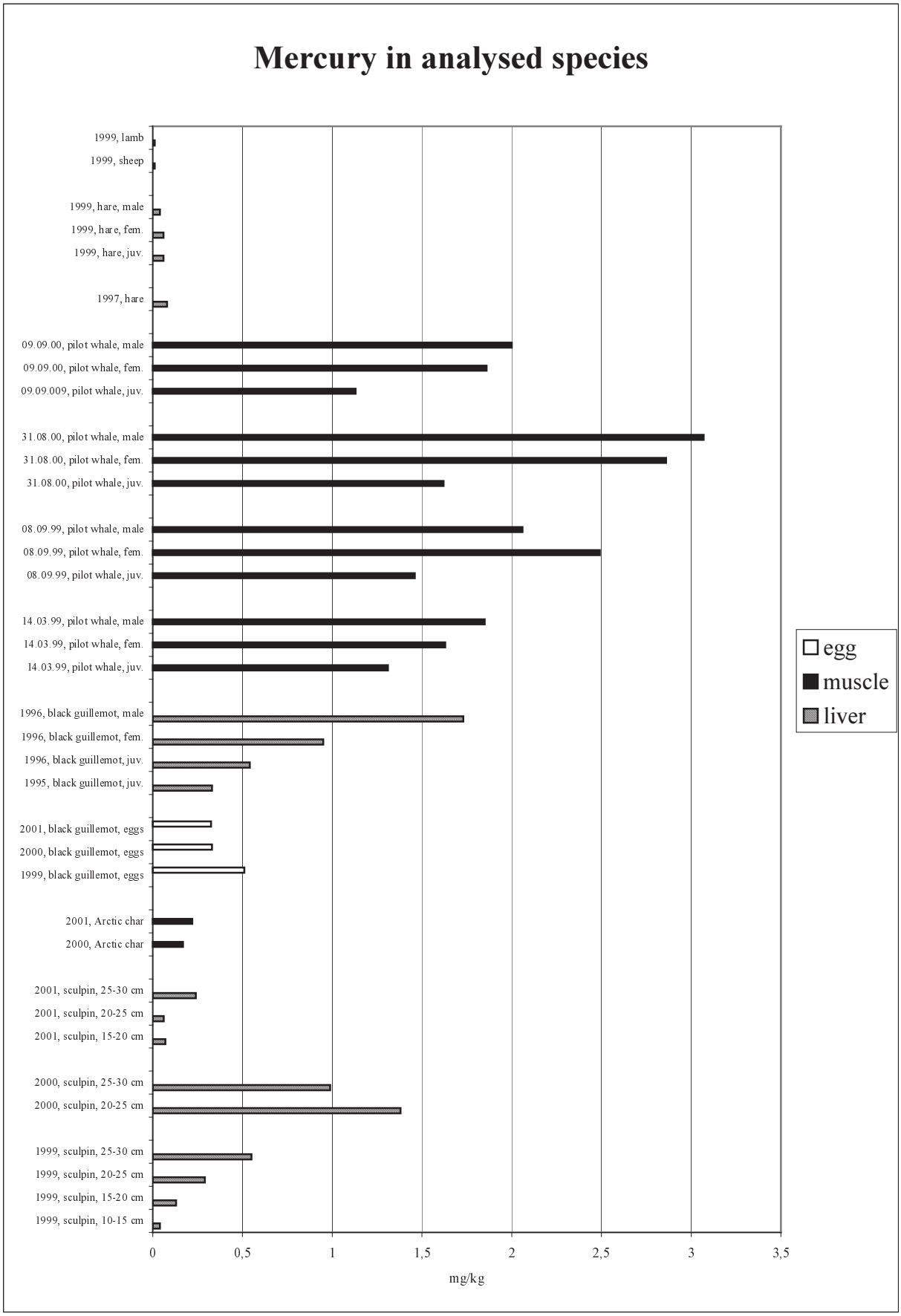

FIGURE 9.1. CONTENT OF MERCURY IN THE ANALYSED SPECIES (MG/KG WET WEIGHT)

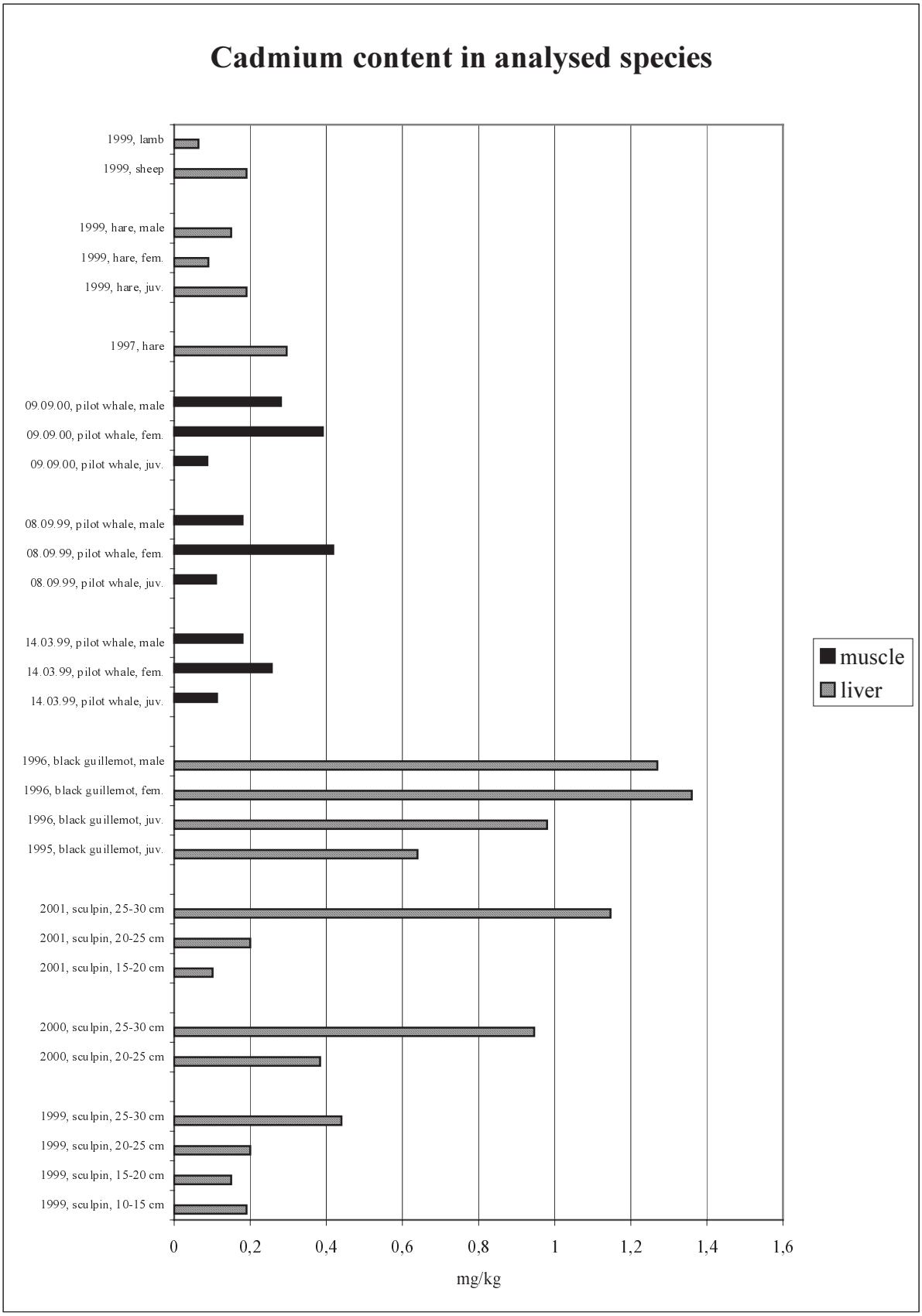

Figure 9.2. Content of cadmium in the analysed species (mg/kg wet weight)

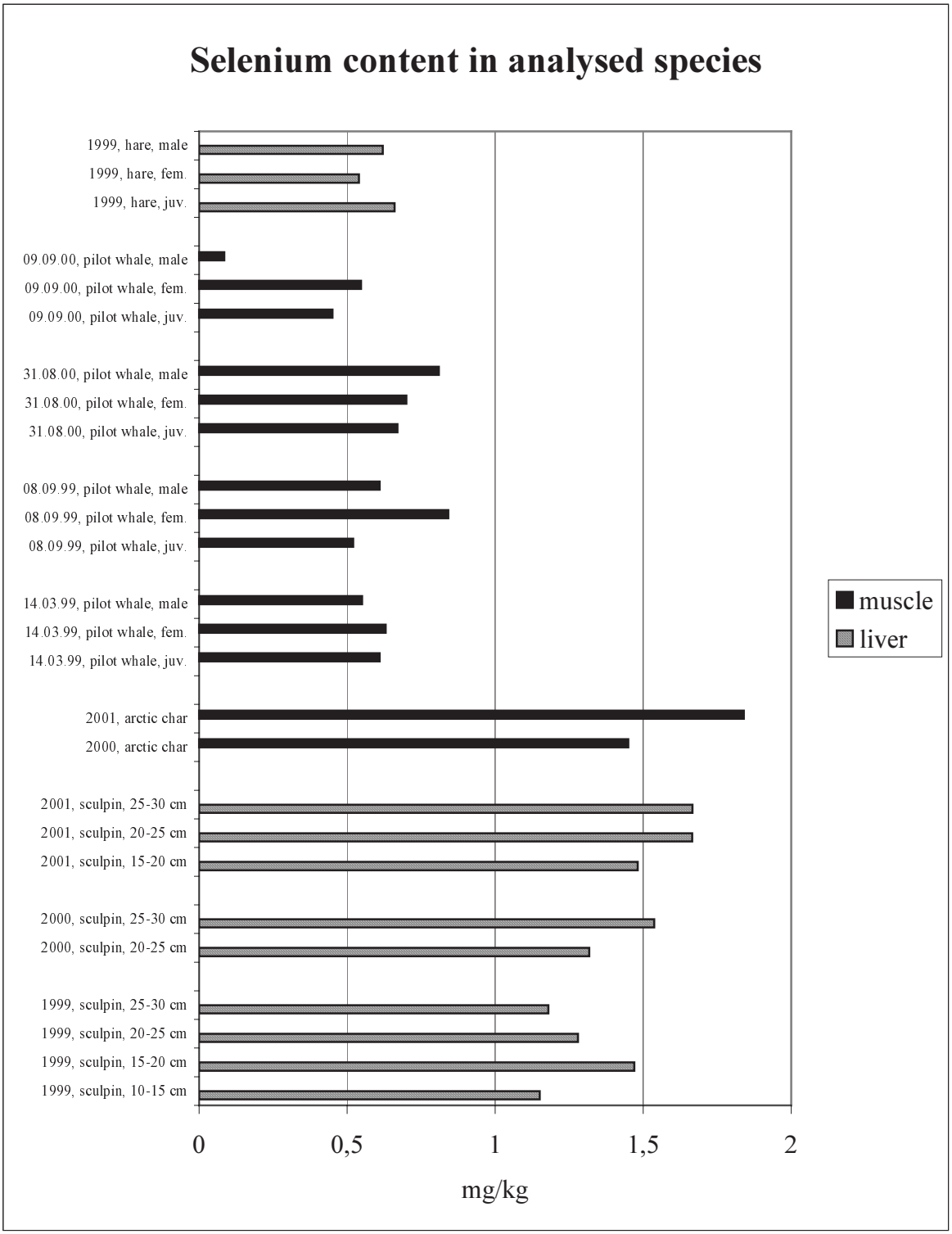

Figure 9.3. Content of selenium in the analysed species (mg/kg wet weight)

10 References

AMAP Assessment Report: Arctic Pollution Issues (1998)
Arctic Monitoring and Assessment Programme
Oslo, 1998
ISBN 82-7655-061-4

Asmund, G. & Cleemann, M. (2000)
Analytical methods, quality assurance and quality control used in the Greenland AMAP programme.
The Science of the Total Environment 2000 (Vol. 245, Issue. 1-3) pp 203-221

Bloch, D. and Fuglø, E. (1999)
Villini súgdjór í Útnorðuri
Føroya Skúlabókagrunnur
ISBN: 99918-0-189-8

Bloch, D., Jensen, J-K. and Olsen, B. (1996)
Listi yvir fuglar sum eru sæddir í Føroyum.
Føroya Náttúrugripsasavn, Føroya Fuglafrøðifelag, Føroya Skúlabókagrunnur.

Caurant, F. and Amiard-Triquet, C. (1995).
Cadmium contamination in pilot whales Globicephala melas: Source and potential hazard to the species.
Marine Pollution Bulletin, 30, 207-210.

Caurant, F., Amiard, J.C., Amiard-Triquet, C. and Sauriau, P.G.(1994).
Ecological and biological factors controlling the concentrations of trace elements (As, Cd, Cu, Hg, Se, Zn) in delphinids Globicephala melas in the North Atlantis Ocean.
Marine Ecology Progress Series, 103: 207-219.

Dam, Maria (1998)
Hvad spiser teist, edderfugl og topskarv på Færøerne, og hvad er indholdet af miljøgifte i disse fugle?
Food and Environmental Agency, Faroe Islands, 1998:2
ISBN 99918-940-1-2

Desportes, G., Sabourea M. and Lacroix A. (1993)
Reproductive maturity and sesonality of male long-finned pilot whales, off the Faroe Islands.
Rep. Int. Whal. Commn. (Special Issue 14), pp. 233-262
ISSN 0255-2760, ISBN 0 906975 27 1

Gydemo, R. (1982)
The Arctic Char in Lake Leynavatn, Faroe Islands, Proceedings of the Second Workshop on Arctic Char 1982, ISACF information series No.2

Joensen, J. S. and Vedel Tåning, Å. (1969)
Marine and Freshwater Fishes in *The Zoology of the Faroes*,
ed. by Sparck, R. and Tuxen, S. L. 1928-1971

Juelshamn, K., Andersen, A., Ringdal, O. and Mørkøre, J. (1987).
Trace element intake in the Faroe Islands I. Element levels in edible parts of pilot whales (Globicephala meleanus).
The Science of the Total Environment 65: 53-62.

Kålås, John Atle and Lierhagen, Syverin (1992)
Terrestrisk naturovervåking. Metallbelastninger i lever fra hare, orrfugl and lirype i Norge.
NINA Oppdragsmelding 137: 1-72
ISSN 0802-4103, ISBN 82-426-0248-4

Larsen, Rikke Berg and Dam, Maria (1999)
AMAP, phase 1, the Faroe Island
Food and Environmental Agency, Faroe Islands, 1999:1
ISBN 99918-940-2-0

Martin, A.R. and Rothery, P. (1993)
Reproductive Paramenters of Female Long-Finned Pilot Whales (*Globicephala melas*) Around the Faroe Islands.
Rep. Int. Whal. Commn. (Special Issue 14), pp. 263-304
ISSN 0255-2760, ISBN 0 906975 27 1

Pethon, P. (1985)
Aschehougs store Fiskebok
Aschehoug ISBN 83-03-11014-2

Reinert A., (1998)
Fiskaaling við Áir. Pers. medd.

Riget, F. Asmund, G and Aastrup, P. (2000).
Mercury in Arctic char (Salvelinus alpinus) populations from Greenland.
The Science of the Total Environment, 245: 161-172.

Ryggi, Mikkjal á (1951)
Fuglabókin, Dýralæra II
Føroya Skúlabókagrunnur, Tórshavn 1978, 2nd edition

Skotvold, T., Wartena, E.M.M. and Rognerud, S. (1996).
Heavy metals and persistent organic pollutants in sediments and fish from lakes on northern and arctic regions of Norway.
Akvaplan-niva. Tromsø. 77 pp.

Sørensen, Søren. and Bloch, Dorete. (1990)
Fuglar í Norðurhøvum
Føroya Skúlabókagrunnur, Tórshavn 1990

7 AMAP Faroe Islands 1999 - 2001 POPs

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Content

Summary and conclusions

This report is based on results from POP analyses in connention with the Arctic monitoring and Assessment Program (AMAP) on the Faroe Islands in the period 1999-2001. Different marine, terrestrial and freshwater species have been analysed. The compounds which have been analaysed for are: PCB and organochlorinated pesticides (14 single congeners, chlordanes, ß-HCH), DDT (o,p-isomers and metabolites) and toxaphene (incl. total toxaphene and 5 single parlars).

The following species were analysed from the marine environment:
Short-horn sculpin *Myoxocephalus scorpius*
Black guillemot *Cepphus grylle*
Pilot whale *Globicephala melas*

The following species were analysed from the terrestrial and freshwater environment:
Mountain hare *Lepus timidus*
Arctic char *Salvelinus alpinus*

In addition cows milk has been analysed for dioxin.

1 Introduction

The POP analysis for AMAP phase II include PCB and organochlorinated pesticides (14 single congeners, chlordanes, ß-HCH), DDT (o,p-isomers and metabolites) and toxaphene (incl. total toxaphene and 5 single parlars). Total toxaphene is quantified from the response for 21 components of the technical toxaphene standard. The selected peak set includes: Parlar's number 26, 31, 32, 38, 39, 40+41, 42, 44, 50, 51, 58, 59, 62, 63, 69 and 6 peaks unidentified. This method can only be accurate if the technical toxaphene standard remains intact in the samples.

Table 1.1 shows the species analysed in 1999 and 2000. All the samples were collected the respective years except for the hare samples, which were collected in 1997 and 1999 and the pilot whale samples, which were collected in 1999 and 2000.

Table 1.1. Overview over analysed species

Species	Matrix	1999	2000	2001
Short-horn sculpin	Liver	+	+	+
Black guillemot	Egg	+	+	+
Pilot whale	Blubber	+	+	+
Mountain hare	Liver	+	+	
Arctic char	Muscle		+	+

As a special task in 1999 cows milk was analysed for dioxin

Matrix	Analyses
Cows milk	Dioxin

1.1 Sampling and sample treatment

Besides the POP analyses, the collected samples have also been analysed for heavy metals. The heavy metal results have been reported separately and the description of sample collection and sample treatment in the heavy metal report also represents the POP samples. Hence, a further description of sample collection and sample treatment is found in Chapter 6, Olsen et al.

1.2 Analysis

All the POP analyses, except for the dioxin analyses, were made at CTQ (Centre de toxicologie du Quebec, Canada). All the analysed compounds, except cis-nonachlor and p,p'-DDT, were determined by GC/ECD. Cis-nonachlor and p,p'-DDT were determined by GC/MS. For a more detailed description of the analyses see Pedersen et al. (2000).

The dioxin analyses were performed at the University of Umeå in Sweden. A high resolution gas chromatograph and a high resolution mass spectrometer (HRGC/HRMS) were used for the analyses.

2 Short-horn Sculpin

The POP analysis were made on liver tissue and the division of the samples were made the same way as for the heavy metal analysis (Chapter 6, Olsen et al.), with the exception that sample number 1-1999 and 2-1999 not were analysed because of lack of tissue material. There were all together 13 analyses in 1999 and 15 analyses in 2000 of which some were made on pooled samples and some on individual samples, and 5 analyses in 2001 which were made on pooled samples. The composition of the sculpin samples are shown in Chapter 6, Olsen et al., table 2.1 and 2.2. The analyses were carried out at CTQ. The tissue was stored in polycarbonate jars until analysis.

2.1 PCB

In the tables below the content of PCB is shown as Aroclor 1260, PCB 7 and level of CB 153 from 1999 and 2000. PCB 7 is the sum of seven PCB congeners, which are CB 28, CB 52, CB 101, CB 118, CB 138, CB 153 and CB 180.

Table 2.1. PCB in sculpin liver (µg/kg of lipids)

Year	Length	n		% Lipids	Aroclor 1260 mg/kg of lipids	CB 153	PCB 7
1999	15-20 cm	2	Min	6,8	2,1	220,0	602,0
			Max	9,3	7,7	936,7	2082
			Mean	**8,1**	**4,9**	**578,4**	**1342**
			Std.dev.	*1,77*	*3,98*	*506,8*	*1047*
	20-25 cm	4	Min	7,1	4,1	489,6	1078
			Max	15,9	9,8	1185	2762
			Mean	**10,0**	**6,4**	**739,4**	**1818**
			Std.dev.	*3,99*	*2,46*	*305,9*	*705,4*
	25-30 cm	7	Min	2,6	2,0	246,0	556,1
			Max	9,9	27,5	3355	7472
			Mean	**6,4**	**6,5**	**800,1**	**1791**
			Std.dev.	*2,86*	*9,28*	*1133*	*2517*
2000	20-25 cm	5	Min	1,8	4,2	482,6	1175
			Max	9,1	28,3	3324	7479
			Mean	**4,7**	**15,0**	**1756**	**3986**
			Std.dev.	*2,93*	*10,24*	*1196*	*2677*
	25-30 cm	10	Min	1,6	3,0	376,4	773,9
			Max	14,9	30,9	3629	8374
			Mean	**7,0**	**11,3**	**1379**	**3024**
			Std.dev.	*4,54*	*7,87*	*940,3*	*2143*
2001	15-20 cm	7*	MS-01-09-01	3,0	2,5	614,1	299
	20-25 cm	5*	MS-02-09-01	7,1	2,1	549,3	262
	20-25 cm	5*	MS-03-09-01	8,6	2,6	699,7	312
	25-30 cm	5*	MS-04-09-01	7,2	3,4	961,7	407
	25-32 cm	3*	MS-05-09-01	6,8	13	3648	1567

n: number of samples analysed. Some of the samples are analysed as individuals, some as pooled samples.
* number of individuals in pooled sample.

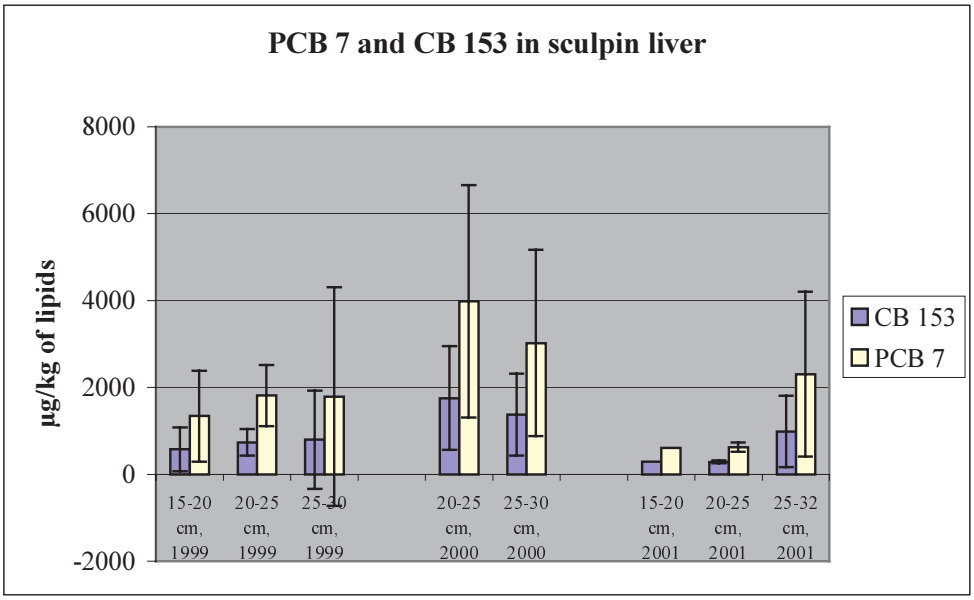

FIGURE 2.1. PCB IN SCULPIN LIVER FOR DIFFERENT SIZE GROUPS

2.2 PESTICIDES

Table 2.2 and Table 2.4 show the content of different pesticides in sculpin liver. Toxaphene parlar no. 32 and 69, o,p'-DDD and ß-HCH were not detected in any of the sculpins analysed.

TABLE 2.2. TOXAPHENE AND DDT IN SCULPIN LIVER (µG/KG OF LIPIDS)

Year	Length	n		Toxaphene			o,p'-DDE	p,p'-DDE	p,p'-DDD	o,p'-DDT	p,p'-DDT
				Parlar no. 26 (T2)	Parlar no. 50 (T12)	Parlar no. 62 (T20)					
1999	15-20 cm	2	Min	14,0	24,0	3,2	0,8	161,7	3,2	0,8	3,2
			Max	64,0	85,0	23,0	5,3	1225	4,5	7,0	12,0
			Mean	**39,0**	**54,5**	**13,1**	**3,1**	**693,4**	**3,9**	**3,9**	**7,6**
			Std.dev.	*35,36*	*43,13*	*14,0*	*3,18*	*751,90*	*0,92*	*4,38*	*6,22*
	20-25 cm	4	Min	24,0	38,0	nd	0,9	459,3	nd	1,5	11,0
			Max	51,0	74,0	nd	2,8	1793	nd	3,6	39,0
			Mean	**35,5**	**54,75**	**nd**	**1,49**	**864,9**	**nd**	**2,76**	**26,25**
			Std.dev.	*12,82*	*15,04*	nd	*0,92*	*626,6*	nd	*1,01*	*12,09*
	25-30 cm	7	Min	5,7	14,0	3,20	0,8	267,3	3,3	2,4	3,3
			Max	100	170	37,5	7,2	6440	25,0	8,5	60,0
			Mean	**37,03**	**62,29**	**12,7**	**2,5**	**1297**	**9,8**	**4,5**	**21,4**
			Std.dev.	*33,21*	*59,20*	*12,19*	*2,24*	*2273*	*7,36*	*2,17*	*18,96*
2000	20-25 cm	5	Min	39,0	53,0	8,9	1,3	467	nd	1,3	34,0
			Max	230	320	63,0	10,0	4392	nd	21,0	170
			Mean	**87,6**	**129,2**	**27,78**	**4,0**	**2338**	**nd**	**6,4**	**80,4**
			Std.dev.	*80,19*	*108,27*	*20,53*	*3,53*	*1707*	nd	*8,27*	*52,36*
	25-30 cm	10	Min	42,0	73,0	13,0	0,7	773	nd	0,6	47,0
			Max	140	250	59,0	4,6	3788	nd	17,0	150
			Mean	**77,1**	**129,2**	**32,2**	**2,4**	**1904**	**nd**	**5,5**	**94,5**
			Std.dev.	*35,54*	*53,99*	*16,39*	*1,33*	*988*	nd	*5,12*	*41,01*

n: number of samples analysed. Some of the samples are individuals, some are pooled samples.
nd: not detected

Table 2.3. Toxaphene and DDT in sculpin liver from 2001 (µg/kg of lipids)

Year	Length	n		Toxaphene			o,p'-DDE	p,p'-DDE	p,p'-DDD	o,p'-DDT	p,p'-DDT
				Parlar no. 26 (T2)	Parlar no. 50 (T12)	Parlar no. 62 (T20)					
2001	15-20 cm	7	MS-01-09-01	9,4	8,4	ND	5,4	184	ND	ND	ND
	20-25 cm	5	MS-02-09-01	9,8	13	ND	3,9	233	ND	ND	ND
	20-25 cm	5	MS-03-09-01	18	24	ND	2,5	268	8,8	ND	ND
	25-30 cm	5	MS-04-09-01	11	18	ND	2,3	314	4,7	ND	ND
	25-32 cm	3	MS-05-09-01	31	50	ND	5,2	1853	13	ND	11

n: number of individuals in pooled sample. nd: not detected

Table 2.4. Organochlorinated pesticides in sculpin liver (µg/kg of lipids)

Year	Length	n		alpha-chlordane	gamma-chlordane	cis-nonachlor	hexachlorobenzene	mirex	oxychlordane	trans nonachlor
1999	15-20 cm	2	Min	3,8	3,2	18,0	14,8	4,5	13,9	30,8
			Max	11,4	16,0	95,8	24,3	31,5	36,8	191,7
			Mean	**7,6**	**9,6**	**56,9**	**19,6**	**18,0**	**25,3**	**111,3**
			Std.dev.	*5,41*	*9,05*	*54,98*	*6,68*	*19,08*	*16,20*	*113,79*
	20-25 cm	4	Min	1,5	0,9	40,4	21,9	12,3	18,7	47,9
			Max	9,5	15,0	160,7	33,0	35,8	51,4	317,3
			Mean	**6,0**	**4,5**	**77,2**	**26,4**	**21,9**	**34,0**	**145,6**
			Std.dev.	*3,45*	*6,99*	*56,01*	*4,69*	*10,48*	*16,12*	*120,98*
	25-30 cm	7	Min	1,2	0,8	27,0	15,7	7,1	10,4	26,1
			Max	24,0	7,9	420,0	49,0	95,4	95,7	733,1
			Mean	**6,4**	**3,5**	**97,6**	**29,0**	**23,1**	**34,3**	**151,4**
			Std.dev.	*8,03*	*2,43*	*143,25*	*12,93*	*32,06*	*29,67*	*257,97*
2000	20-25 cm	5	Min	1,9	0,8	82,0	21,5	18,4	25,6	114,5
			Max	20,1	40,6	310,0	76,8	124,6	147,3	610,7
			Mean	**11,0**	**17,4**	**171,4**	**40,8**	**55,8**	**60,6**	**255,5**
			Std.dev.	*8,62*	*19,63*	*100,45*	*21,50*	*42,95*	*49,79*	*201,29*
	25-30 cm	10	Min	3,7	0,6	67,0	28,1	10,1	25,3	103,3
			Max	86,4	54,3	360,0	78,9	102,3	105,5	388,4
			Mean	**17,2**	**9,6**	**163,3**	**38,5**	**40,9**	**51,6**	**232,8**
			Std.dev.	*24,69*	*16,87*	*87,40*	*15,58*	*31,57*	*24,30*	*106,05*
2001	15-20 cm	7*	MS-01-09-01	ND	ND	21,4	14,1	ND	16,7	23,7
	20-25 cm	5*	MS-02-09-01	ND	ND	23,5	13,1	4,2	22,0	30,5
	20-25 cm	5*	MS-03-09-01	4,6	ND	26,6	19,1	7,3	19,7	41,5
	25-30 cm	5*	MS-04-09-01	ND	ND	24,5	14,9	8,4	17,7	38,3
	25-32 cm	3*	MS-05-09-01	5,1	ND	126,6	21,2	32	48,4	241,4

n: number of samples analysed. Some of the samples are individuals, some are pooled samples.
* number of individuals in pooled sample.

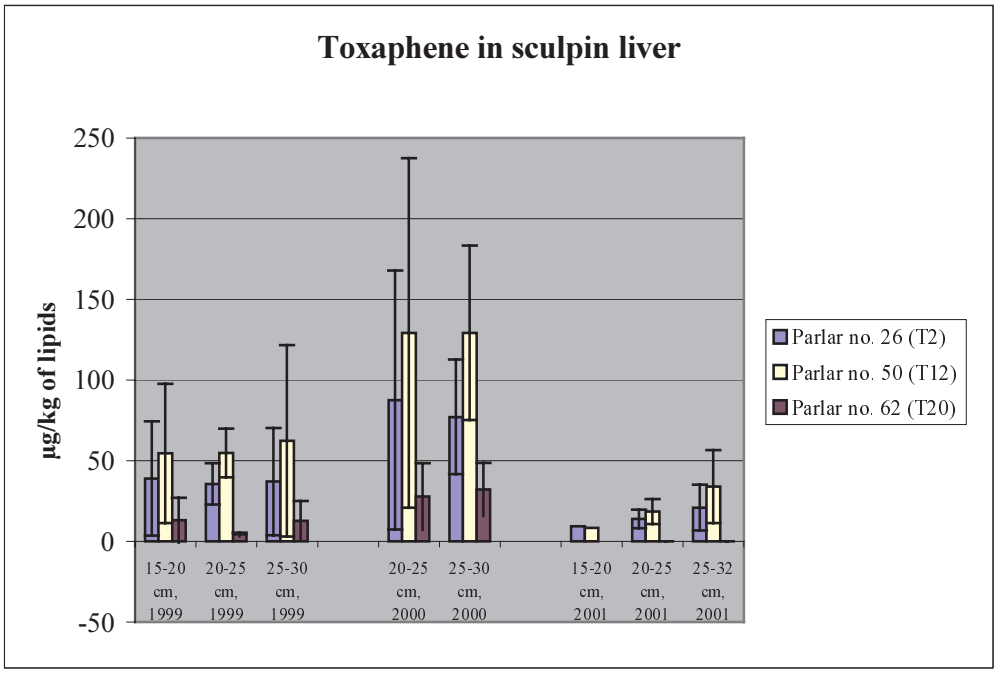

FIGURE 2.2. TOXAPHENE CONTENT IN SCULPIN LIVER FOR DIFFERENT SIZE GROUPS

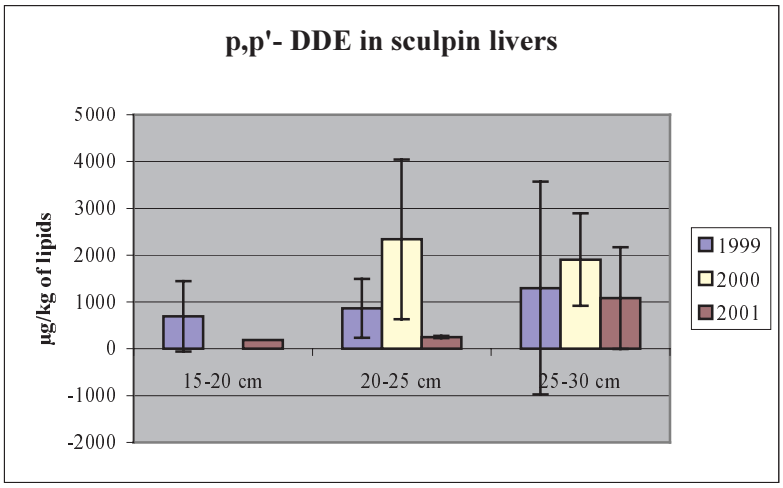

FIGURE 2.3. P,P'-DDT IN SCULPIN LIVER FOR DIFFERENT SIZE GROUPS

The POP results are grouped according to length. The POP content seems to be increasing with increasing length although POP content and length are not significantly correlated. There was not found significant correlation with age either. All the POP results show great variation, but the results seem to be quite similar among the size groups the respective years. The results from 2000 seem to be higher than the 1999 results, which seem to be higher than the 2001 results. There was also found higher levels of heavy metals for the sculpins from 2000 (Chapter 6, Olsen et al.). One parameter that is different for the years is the fishing stations, but according to the information available regarding sewage outlets etc., the substations used in 2000 are not nearer to local pollution than the substations used in 1999. The stations used in 2001 are though different from the other two years by, that almost all the sculpins from 2001 were catched by fish trap instead of with fishing rod.

3 Black guillemot eggs

Black guillemot eggs were sampled at two different locations – Koltur and Skúvoy - in 1999, 2000 and 2001. Each year 8-10 eggs were taken at each location and the eggs were analysed individually at CTQ. The content of the egg was stored in polycarbonate jars until analysis.

3.1 PCB

In the table below the PCB content is shown as Aroclor 1260, PCB 7 and CB153.

Table 3.1. PCB in black guillemot eggs (µg/kg of lipids)

Year	Location	n		Aroclor 1260 mg/kg of lipids	PCB 7	CB 153
1999	Koltur	10	Min	5,8	1633	815,9
			Max	14,7	3868	2074
			Mean	**8,2**	**2207**	**1146**
			Std.dev.	*3,22*	*779,4*	*435,7*
	Skúvoy	8	Min	4,8	1315	674,3
			Max	8,4	2299	1195
			Mean	**6,7**	**1843**	**956,2**
			Std.dev.	*1,42*	*403,5*	*205,6*
2000	Koltur	10	Min	2,9	858	411,1
			Max	10,2	2861	1548,
			Mean	**5,0**	**1424**	**760,8**
			Std.dev.	*2,38*	668,1	*384,3*
	Skúvoy	9	Min	3,3	888	461,2
			Max	9,3	2491	1278
			Mean	**5,3**	**1480**	**740,8**
			Std.dev.	*1,79*	*460,1*	*254,3*
2001	Koltur	10	Min	2,4	742	321,5
			Max	4,7	1332	613,9
			Mean	**3,4**	**984,7**	**449,0**
			Std.dev.	*0,8*	*220,2*	*100,3*
	Skúvoy	10	Min	2,4	671,6	288,2
			Max	5,0	1444	618,5
			Mean	**4,0**	**1131**	**497,6**
			Std.dev.	*0,9*	*256,3*	*111,2*

The content of CB153 is approximately half of the level of PCB 7 for all the groups. The results are on the same level for the different locations, but the levels are decreasing each year. The decrease in CB 153 from 1999-2000 is found to be significant in Koltur (P= 0,05) but not in Skúvoy (P=0,08) while the decrease from 2000-2001 was significant for both Koltur (P= 0,02) and Skúvoy (P=0,01). For the mercury results the levels were decreasing from 1999 to 2000 but appeared to be unchanged from 2000 to 2001 (Chapter 6, Olsen et al.). A fall in Hg and PCB levels could be indicating a change in throphic level and this needs to be investigated further.

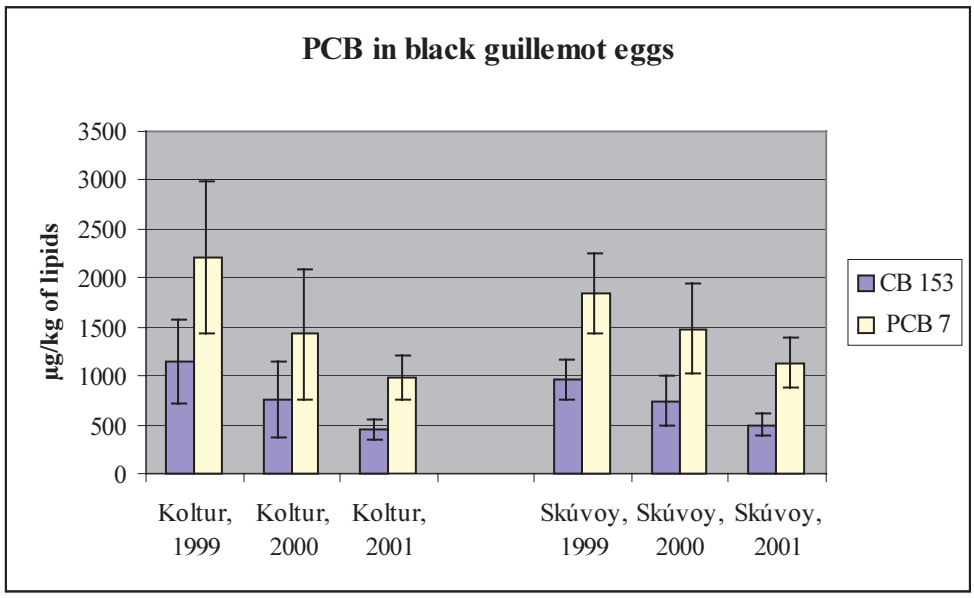

FIGURE 3.1. PCB IN BLACK GUILLEMOT EGGS

3.2 PESTICIDES

Table 3.2 and Table 3.3 show the content of organochlorinated pesticides and derivated compounds in black guillemot eggs. Toxaphene parlar no. 32 and 69, o,p'-DDE, o,p'-DDD, p,p'-DDD, o,p'-DDT, p,p'-DDT, alpha-chlordane and gamma-chlordane were either not detected or found in levels just above detection limit.

TABLE 3.2. TOXAPHENE AND DDT IN BLACK GUILLEMOT EGGS (µG/KG OF LIPIDS)

Year	Location	n		% Lipids	Parlar no. 26 (T2)	Parlar no. 50 (T12)	Parlar no. 62 (T20)	p,p'-DDE
1999	Koltur	10	Min	7,1	17,0	61,0	22,0	399
			Max	10,0	45,0	160,0	39,0	1146
			Mean	**8,9**	**27,0**	**100,3**	**29,3**	**599**
			Std.dev.	*0,96*	*9,60*	*38,35*	*6,99*	*210,39*
	Skúvoy	8	Min	4,1	20,0	63,0	28,0	245
			Max	12,1	48,0	190,0	81,0	687
			Mean	**9,2**	**30,8**	**109,8**	**39,0**	**407**
			Std.dev.	*2,68*	*8,15*	*36,73*	*17,40*	*148,18*
2000	Koltur	10	Min	4,7	18	52	19	217,5
			Max	11	40	120	42	703,5
			Mean	**8,43**	**26,1**	**75,8**	**30,6**	**337,8**
			Std.dev.	*1,78*	*7,53*	*21,62*	*7,66*	*161,26*
	Skúvoy	9	Min	4,9	29,0	92,0	46,0	280,0
			Max	15,4	59,0	200,0	93,0	820,4
			Mean	**9,0**	**40,7**	**122,4**	**63,3**	**429,9**
			Std.dev.	*3,16*	*9,37*	*33,60*	*14,41*	*162,65*
2001	Koltur	10	Min	8,2	21,0	54,0	16,0	218,5
			Max	13,0	76,0	190,0	58,0	634,9
			Mean	**10,1**	**39,9**	**107,1**	**37,1**	**406,3**
			Std.dev.	*1,4*	*15,7*	*39,2*	*12,7*	*133,8*
	Skúvoy	10	Min	8,3	39,0	130,0	17,0	424,3
			Max	12,0	110,0	290,0	110,0	900,2
			Mean	**9,9**	**73,2**	**208,0**	**76,3**	**630,7**
			Std.dev.	*1,2*	*21,7*	*53,1*	*33,0*	*158,6*

n: number of eggs

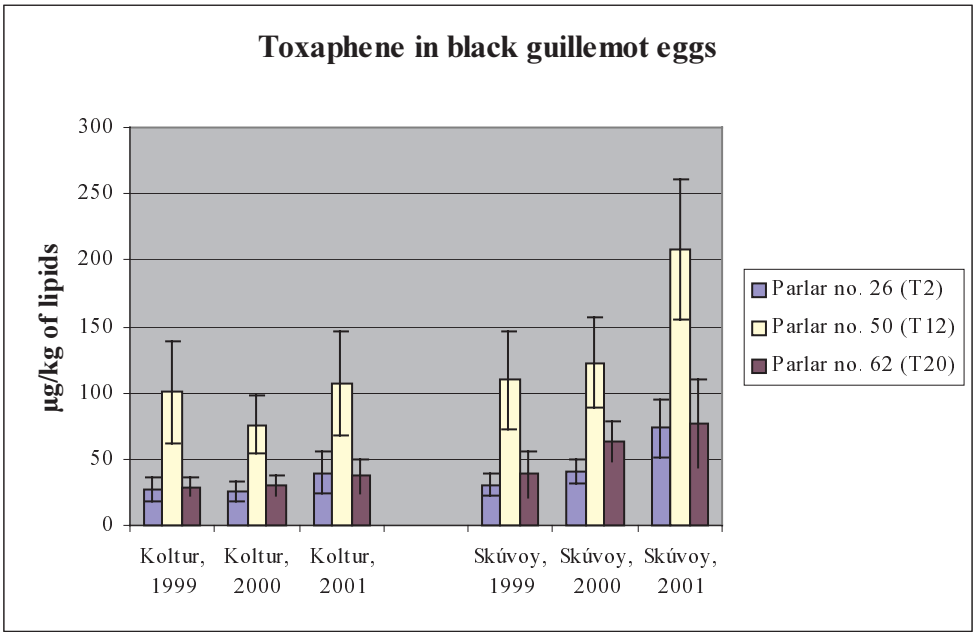

FIGURE 3.2. TOXAPHENE IN BLACK GUILLEMOT EGGS

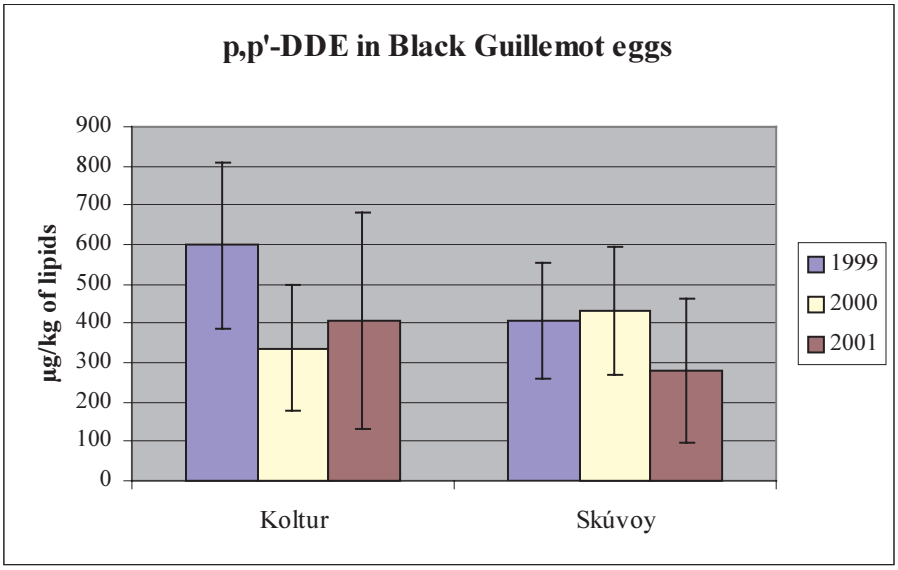

FIGURE 3.3. P,P'-DDE IN BLACK GUILLEMOT EGGS

Table 3.3. Organochlorinated pesticides in black guillemot eggs (µg/kg of lipids)

Year	Location	n		ß-HCH	cis-nona chlor	hexa-chloro-benzene	mirex	oxy chlor dane	trans nona chlor
1999	Koltur	10	Min	16,7	38,0	110,8	43,6	33,4	11,4
			Max	41,1	126,0	434,7	74,0	80,3	37,6
			Mean	**25,4**	**64,0**	**168,3**	**56,1**	**54,2**	**25,4**
			Std.dev.	*7,21*	*28,52*	*96,12*	*10,22*	*20,60*	*10,02*
	Skúvoy	8	Min	12,6	33,0	78,3	41,0	20,5	8,8
			Max	32,1	86,0	263,3	75,9	64,4	38,0
			Mean	**23,0**	**53,6**	**195,5**	**58,2**	**41,3**	**18,1**
			Std.dev.	*6,09*	*15,15*	*66,01*	*14,37*	*12,11*	*9,15*
2000	Koltur	10	Min	21,66	28	103	23,9	22,6	12,1
			Max	149,7	64	399,7	73,6	54,3	24,3
			Mean	**45,9**	**41,5**	**173,1**	**39,4**	**37,9**	**18,6**
			Std.dev.	*38,34*	*12,20*	*86,26*	*18,44*	*10,99*	*3,99*
	Skúvoy	9	Min	10,6	38,0	83,8	25,4	32,9	17,4
			Max	28,4	80,0	256,5	63,4	70,7	39,2
			Mean	**21,5**	**51,3**	**139,1**	**38,8**	**43,5**	**26,7**
			Std.dev.	*6,89*	*13,93*	*54,30*	*12,58*	*11,35*	*6,34*
2001	Koltur	10	Min	12,8	21,5	74,0	21,1	25,0	15,8
			Max	32,6	78,1	170,9	40,8	53,9	43,4
			Mean	**20,9**	**47,6**	**116,4**	**28,8**	**39,5**	**24,6**
			Std.dev.	*6,2*	*17,1*	*26,2*	*6,4*	*9,2*	*8,4*
	Skúvoy	10	Min	9,4	53,1	82,7	18,0	37,4	20,5
			Max	30,2	99,2	181,5	43,9	72,5	51,5
			Mean	**15,3**	**71,2**	**133,6**	**31,3**	**53,8**	**31,8**
			Std.dev.	*6,2*	*15,3*	*29,9*	*7,9*	*14,4*	*10,9*

n: number of eggs

4 Pilot whale

The POP analysis were made on blubber from four different whale schools and the results are treated separately. The analyses were made on 45 individuals from the school from 14.03.99, 23 individuals from 08.09.99, 50 individuals from the school from 31.08.00, which were analysed as three pooled samples (males, females and juveniles) and on 21 individuals from 09.09.00 of which three were pregnant and samples were taken of the foetuses as well (altogether 24 samples).
Analysis on PCB and organochlorinated pesticides, DDT and toxaphene congeners were made at CTQ. The blubber was stored in polycarbonate jars until analyses.

4.1 PCB

In the table below the PCB results are shown as Aroclor 1260, PCB 7, and CB 153. CB 153 is the congener which is absolutely dominant. PCB 7 is the sum of seven PCB congeners, which are CB 28, CB 52, CB 101, CB 118, CB 138, CB 153 and CB 180.

Table 4.1. PCB results in pilot whale blubber from 14.09.99

Age and sex group	Number of whales		Length cm	*Skinn*[1]	Lipids %	Aroclor 1260 mg/kg of lipids	PCB 7 µg/kg of lipids	CB 153 µg/kg of lipids
Juveniles	14	Min	225	1,5	74	8,3	2930	863
		Max	490	12	93	30,7	9530	3393
		Mean	**393**	**7**	**84**	**18,0**	**5908**	**2061**
		Std. dev	*75,9*	*3,2*	*5,3*	*6,3*	*1748*	*726,4*
Adult females	20	Min	415	7	67	0,3	984	322
		Max	465	12	92	41,0	12014	4641
		Mean	**443**	**9,7**	**82**	**13,9**	**4574**	**1612**
		Std. dev	*14,0*	*1,9*	*6,6*	*9,3*	*2620*	*1046*
Adult males	11	Min	505	13	72	17,2	5612	2276
		Max	588	20	95	52,7	16660	5657
		Mean	**549**	**16**	**82**	**32,9**	**10308**	**3636**
		Std. dev	*27,9*	*2,5*	*7,3*	*13,2*	*4063*	*1336*

[1] *Skinn* is a special Faroese unit for measuring the whale size based on an assessment of the mass fit for human consumption.

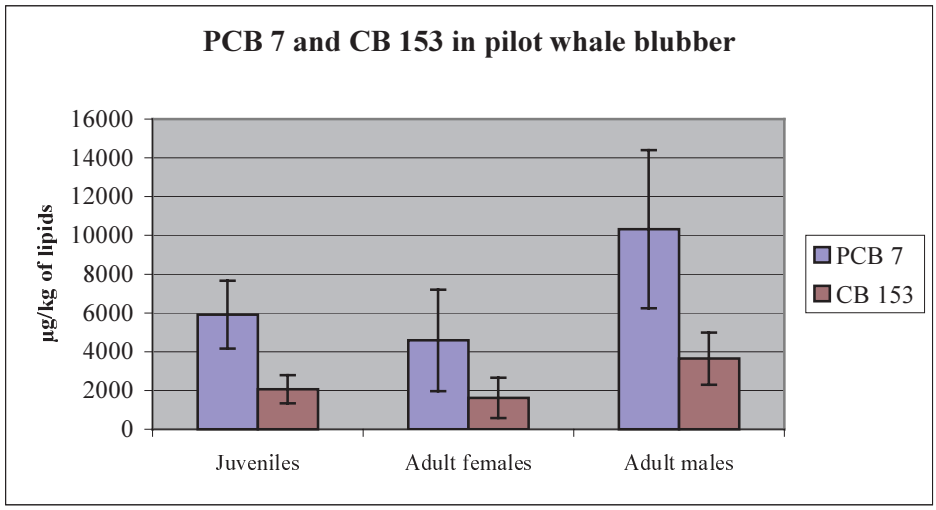

FIGURE 4.1. PCB IN PILOT WHALE BLUBBER FROM 14.03.99

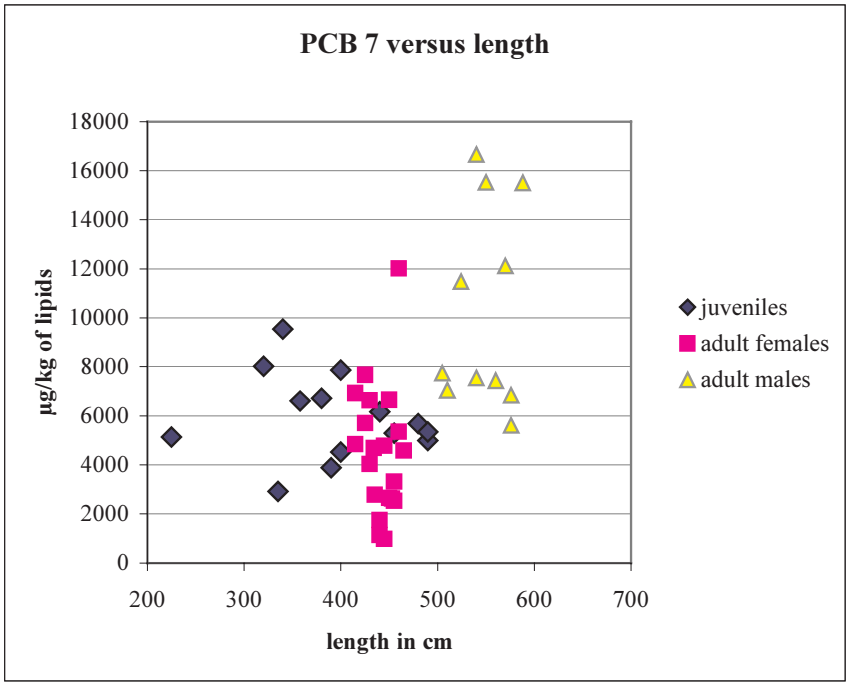

FIGURE 4.2. PCB 7 VERSUS LENGTH OF PILOT WHALES FROM 14.03.99

Table 4.2. PCB results in pilot whale blubber from 08.09.99

Age and sex group	Number of whales		Length	*Skinn*	Lipids %	Aroclor 1260 mg/kg of lipids	PCB 7 µg/kg of lipids	CB 153 µg/kg of lipids
Juveniles	7	Min	267	2	85,53	21,09	6931	2275
		Max	449	10	91,1	43,98	15117	4717
		Mean	**363,4**	**6,0**	**88,9**	**34,7**	**11728**	**3650**
		Std. dev	*61,86*	*2,52*	*2,14*	*8,52*	*2897*	*878,3*
Adult females	8	Min	396	7	86,8	3,98	1357	438
		Max	470	11	91,18	52,70	16249	5899
		Mean	**438,25**	**9,1**	**89,3**	**16,8**	**5529**	**1835**
		Std. dev	*24,96*	*1,25*	*1,63*	*15,92*	*4872*	*1778*
Adult males	7	Min	504	9	86,57	18,99	6388	2001
		Max	590	20	92,43	45,79	15240	4680
		Mean	**546,6**	**16,4**	**89,7**	**30,1**	**9955**	**3129**
		Std. dev	*32,83*	*4,08*	*2,09*	*9,53*	*3033*	*965,4*

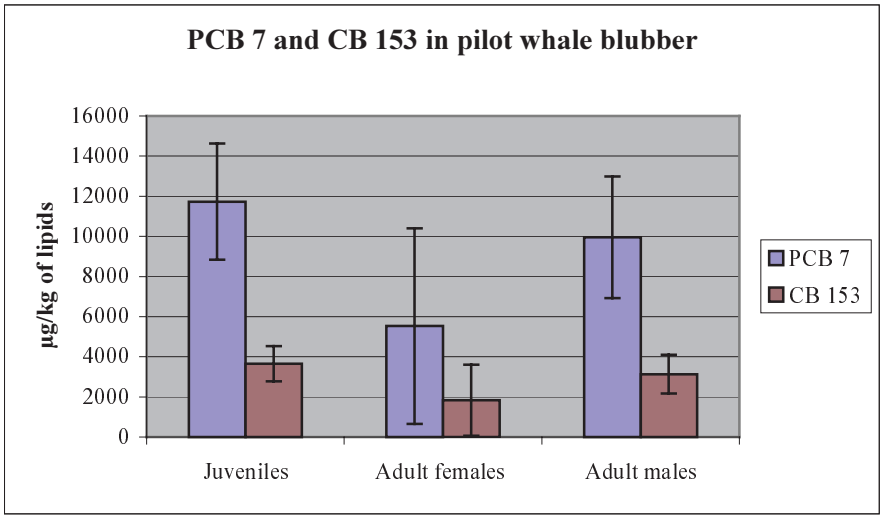

Figure 4.3. PCB in pilot whale blubber from 08.09.99

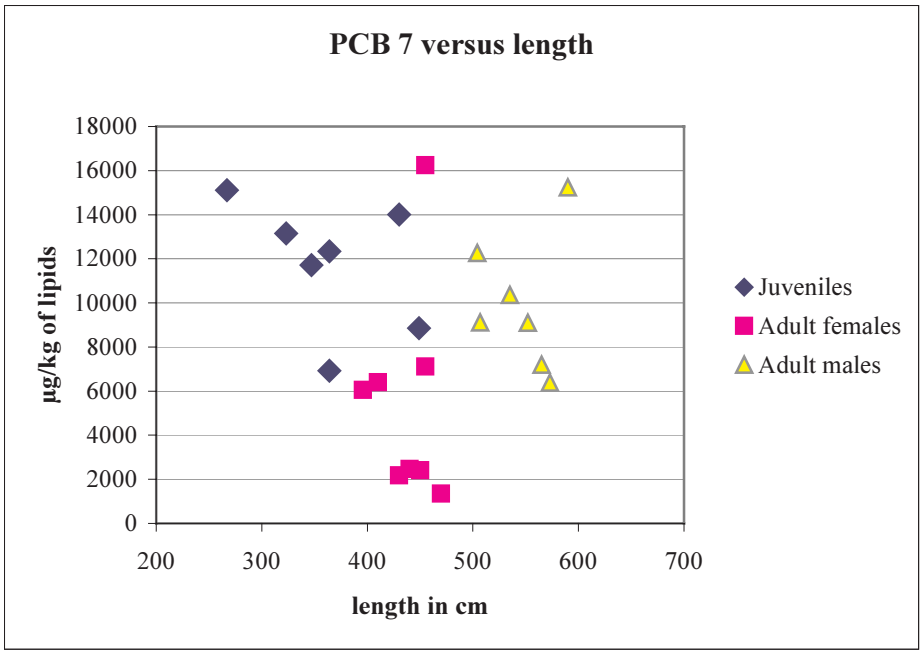

FIGURE 4.4. PCB 7 VERSUS LENGTH OF PILOT WHALES FROM 08.09.99

TABLE 4.3. PCB RESULTS IN PILOT WHALE BLUBBER FROM 31.08.00

Age and sex group	Number of whales in pooled sample		Length cm	*Skinn*[2]	Lipids %	Aroclor 1260 mg/kg of lipids	PCB 7 µg/kg of lipids	CB 153 µg/kg of lipids
Juveniles	7	Pooled sample 2	384	6,4	88	38	11817	3797
Adult females	35	Pooled sample 1	461	9,9	86	18	5756	1863
Adult males	8	Pooled sample 3	562	19,1	81	34	10834	3514

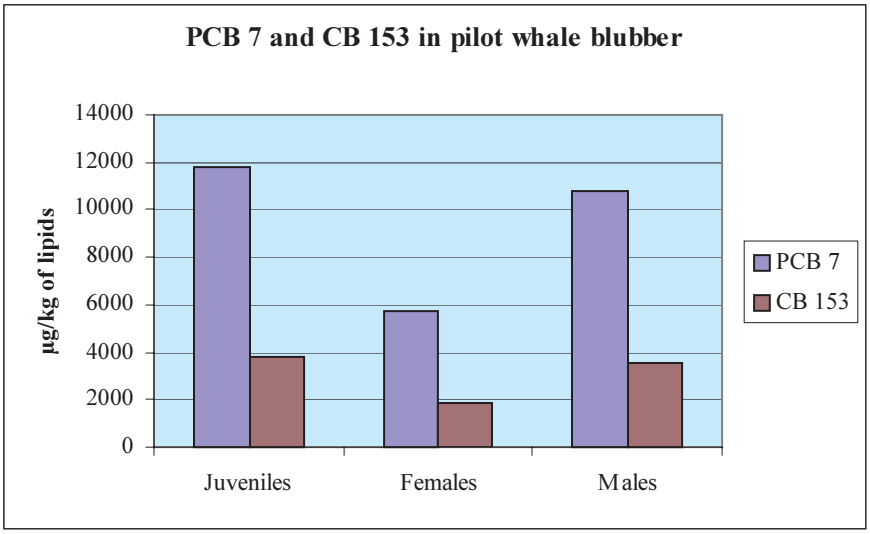

FIGURE 4.5. PCB IN PILOT WHALE BLUBBER FROM 31.08.00

[2] *Skinn* is a special Faroese unit for measuring the whale size based on an assessment of the mass fit for human consumption.

Table 4.4. PCB results in pilot whale blubber from 09.09.00

Age and sex group	Number of whales		Length, cm	*Skinn*	Lipids %	Aroclor 1260 mg/kg of lipids	PCB 7 µg/kg of lipids	CB 153 µg/kg of lipids
Juveniles	4	Min	311	4	80,7	37,2	11274	3772
		Max	415	7	82,8	56,9	17418	5791
		Mean	**362**	**5,3**	**81,8**	**43,7**	**13652**	**4425**
		Std. dev.	*42,7*	*1,26*	*0,86*	*8,94*	*2636*	*924*
Adult females	11	Min	435	9	73,8	4,7	1584	506
		Max	484	40	84,2	36,2	11582	3703
		Mean	**452**	**12**	**81,1**	**11,6**	**3822**	**1194**
		Std. dev.	*13,7*	*9,31*	*3,04*	*9,33*	*2971*	*942*
Adult males	6	Min	540	14	72,8	25,2	7853	2551
		Max	563	17	86,4	55,8	17578	5587
		Mean	**553**	**15,8**	**80,7**	**41,5**	**12947**	**4173**
		Std. dev.	*8,14*	*1,33*	*5,00*	*12,76*	*3979*	*1286*
Foetus	3	Min	50,0	-	1,3	6,7	2150	715
		Max	175,0	-	71,4	14,3	4916	1411
		Mean	**118,3**	-	**46,6**	**10,7**	**3646**	**1084**
		Std. dev.	*63,31*	-	*39,26*	*3,81*	*1397*	*350*

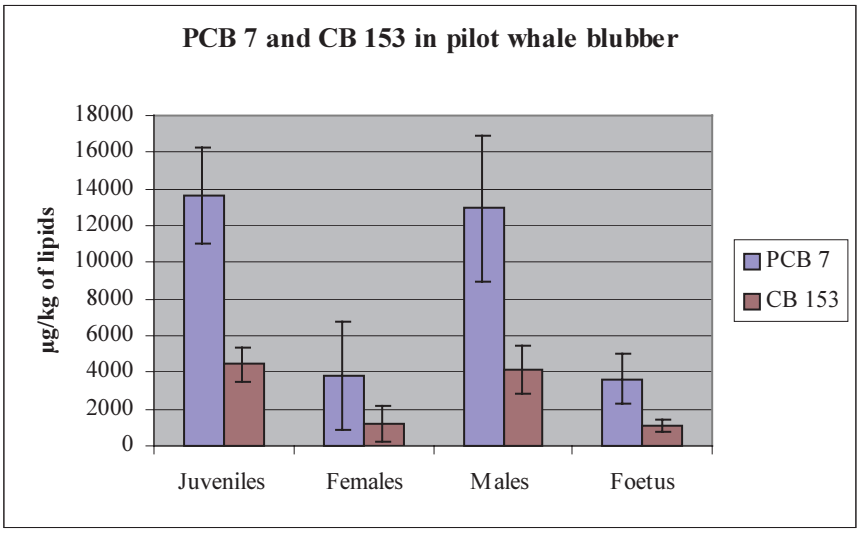

Figure 4.6. PCB in pilot whale blubber from 09.09.00

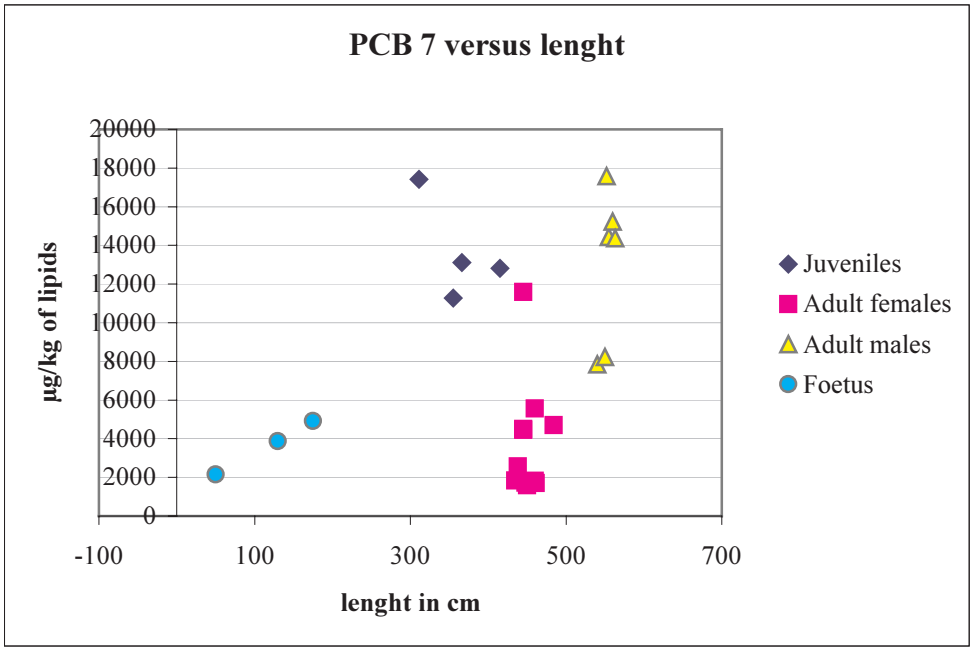

Figure 4..7. PCB 7 versus length of pilot whales from 09.09.00

Table 4.5. PCB in pregnant females of pilot whale and their foetuses from 09.09.00

	Lipids %	Aroclor 1260 mg/kg of lipids	153 µg/kg of lipids	PCB 7 µg/kg of lipids
090900-004	80,7	17	1748	5567
090900-004F	71,4	14,3	1411	4916
090900-007	82,9	13	1351	4503
090900-007F	67,0	11,2	1128	3872
090900-013	78,5	5,2	556	1707
090900-013F	1,3	6,7	715	2150

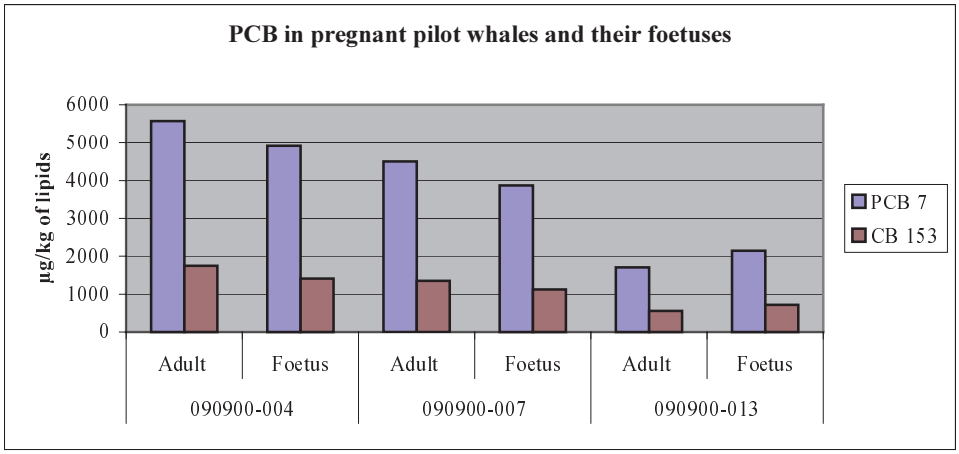

Figure 4.8. PCB in pregnant females of pilot whale and their foetuses from 09.09.00

CB153 is the PCB congener that forms most of the content of PCB 7. In Figure 4.1, Figure 4.3, Figure 4.5 and Figure 4.6 PCB 7 is shown together with CB 153 for the three age and sex groups for the four whale schools. The enhancement in the males above that in females are similar for all four whale schools. POPs are lipid soluble and therefore female mammals have possibility to remove these toxic compounds via the milk, and that is reflected in the juveniles which have higher concentrations of PCB than the adult females. The school from 14.03.99 shows, as would be expected, that the males have the highest content of PCB, but in the three other schools the juveniles have the highest content of PCB, even higher than the males. This was also seen in two whale schools from the Faroe Islands in 1997 (Dam and Bloch, 2000).

Figure 4.8 shows that the PCB content in foetuses is almost as high as in the pregnant females. In 090900-013 the foetus has even higher concentration of PCB than the mother based on the lipid weight. This can be due to that this foetus is very small and has a very low lipid content (1,3 %) even though it was the blubber that was analysed.

In Figure 4.2, Figure 4.4. and Figure 4.7 PCB 7 is depicted against the length of the whales for the three groups.

4.2 Pesticides

4.2.1 Toxaphene

Table 4.6. Toxaphene in pilot whale from 14.03.99 (µg/kg of lipids)

Age and sex group		% Lipids	Parlar no. 26 (T2)	Parlar no. 32	Parlar no. 50 (T12)	Parlar no. 62 (T20)	Parlar no. 69	Total toxaphene
Juveniles	Min	73,8	530,0	ND	930	230	ND	25000
	Max	93,4	2200	ND	3700	780	ND	108000
	Mean	**84,41**	**1069**	**ND**	**1616**	**395**	**ND**	**46786**
	Std.dev.	*5,31*	*429,6*	ND	*728,3*	*161,2*	ND	*21225*
Adult females	Min	66,6	130	ND	250	120	ND	7000
	Max	91,9	1600	ND	2600	790	ND	73000
	Mean	**82,0**	**724**	**ND**	**1152**	**333**	**ND**	**32425**
	Std.dev.	*6,66*	*355,0*	ND	*527,8*	*140,6*	ND	*14865*
Adult males	Min	71,5	800	ND	1200	300	ND	33000
	Max	94,8	2300	ND	3200	830	ND	90000
	Mean	**82**	**1337**	**ND**	**1873**	**473**	**ND**	**54364**
	Std.dev.	*7,27*	*539,4*	ND	*681,3*	*160,3*	ND	*20334*

ND: Not detected

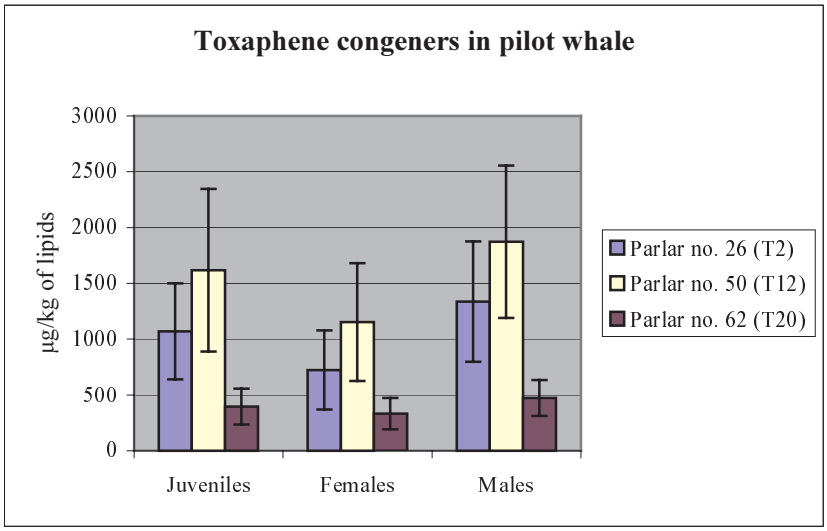

FIGURE 4.9. TOXAPHENE CONGENERS IN PILOT WHALE FROM 14.03.99

TABLE 4.7. TOXAPHENE IN PILOT WHALE FROM 08.09.99 (µG/KG OF LIPIDS)

Age and sex group		% Lipids	Parlar no. 26 (T2)	Parlar no. 32	Parlar no. 50 (T12)	Parlar no. 62 (T20)	Parlar no. 69	Total toxaphene
Juveniles	Min	85,53	840,0	ND	1300	280	ND	35000
	Max	91,1	2000	ND	3900	1200	ND	107000
	Mean	**88,94**	**1577**	**ND**	**2686**	**613**	**ND**	**72429**
	Std.dev.	*2,14*	*438,5*	ND	*961,6*	*355,3*	ND	*25909*
Adult females	Min	86,8	140	ND	280	130	ND	8100
	Max	91,18	1800	ND	2200	390	ND	68000
	Mean	**89,3**	**671**	**ND**	**1044**	**251**	**ND**	**29138**
	Std.dev.	*1,63*	*574,8*	ND	*717,0*	*82,4*	ND	*20552*
Adult males	Min	86,57	880	ND	1200	170	ND	35000
	Max	92,43	1600	ND	2600	600	ND	69000
	Mean	**89,7**	**1187**	**ND**	**1800**	**394**	**ND**	**50143**
	Std.dev.	*2,09*	*301,1*	ND	*538,5*	*166,2*	ND	*13196*

ND: Not detected

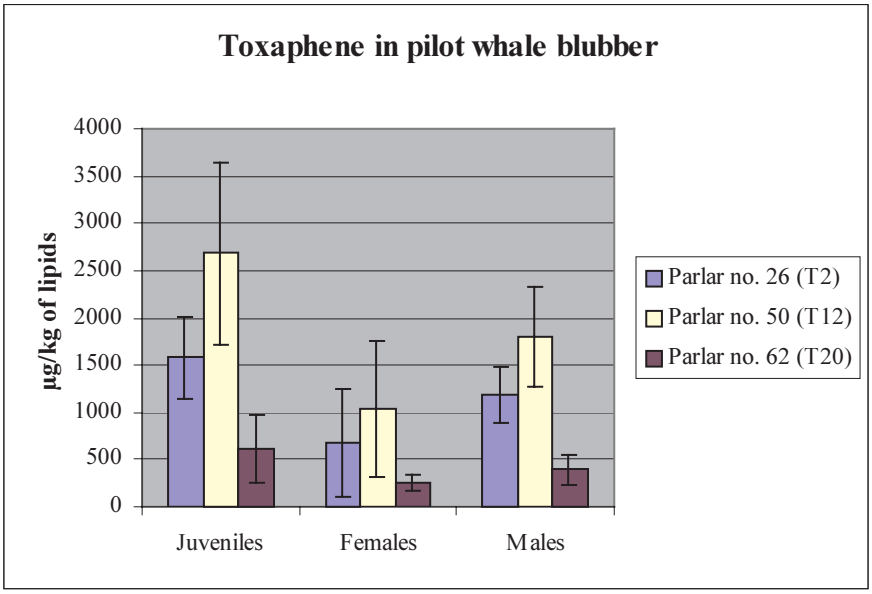

FIGURE 4.10. TOXAPHENE CONGENERS IN PILOT WHALE FROM 08.09.99

TABLE 4.8. TOXAPHENE IN PILOT WHALE BLUBBER FROM 31.08.00

Age and sex group		% Lipids	Parlar no. 26 (T2)	Parlar no. 32	Parlar no. 50 (T12)	Parlar no. 62 (T20)	Parlar no. 69	Total toxaphene
Juveniles	Pooled sample 2	88,0	1500	ND	2400	540	ND	59000
Females	Pooled sample 1	85,5	690	ND	1100	300	ND	27000
Males	Pooled sample 3	80,5	1100	ND	1700	390	ND	42000

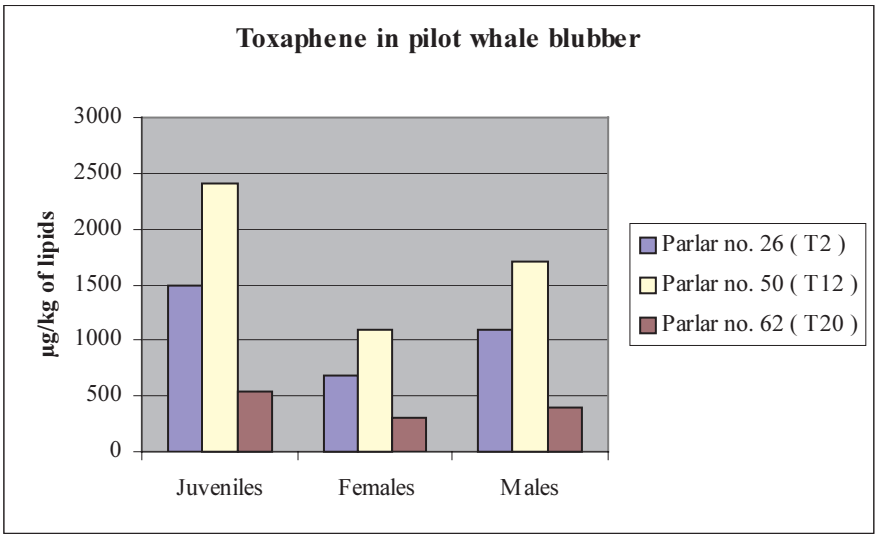

FIGURE 4.11. TOXAPHENE CONGENERS IN PILOT WHALE FROM 31.08.00

Table 4.9. Toxaphene in pilot whale blubber from 09.09.00

Age and sex group		% Lipids	Parlar no. 26 (T2)	Parlar no. 32	Parlar no. 50 (T12)	Parlar no. 62 (T20)	Parlar no. 69	Total toxaphene
Juveniles	Min	80,7	1600	ND	2500	510	ND	81000
	Max	82,8	2300	ND	4000	1100	ND	130000
	Mean	**81,8**	**1975**	**ND**	**3225**	**715**	**ND**	**98000**
	Std.dev.	*0,86*	*287,2*	ND	*618,5*	*264,9*	ND	*21985*
Adult females	Min	73,8	150	ND	310	140	ND	9400
	Max	84,2	1400	ND	2300	540	ND	71000
	Mean	**81,1**	**503**	**ND**	**915**	**271**	**ND**	**28218**
	Std.dev.	*3,04*	*390,8*	ND	*633,3*	*127,6*	ND	*19221*
Adult males	Min	72,8	1000	ND	1700	370	ND	55000
	Max	86,4	2000	ND	2800	560	ND	92000
	Mean	**80,7**	**1617**	**ND**	**2300**	**452**	**ND**	**70500**
	Std.dev.	*5,00*	*430,9*	ND	*532,9*	*85,4*	ND	*14488*
Foetus	Min	1,3	270	ND	560	160	ND	16000
	Max	71,4	840	ND	1400	350	ND	48000
	Mean	**46,6**	**583**	**ND**	**1053**	**273**	**ND**	**33667**
	Std.dev.	*39,26*	*289*	ND	*439*	*100*	ND	*16258*

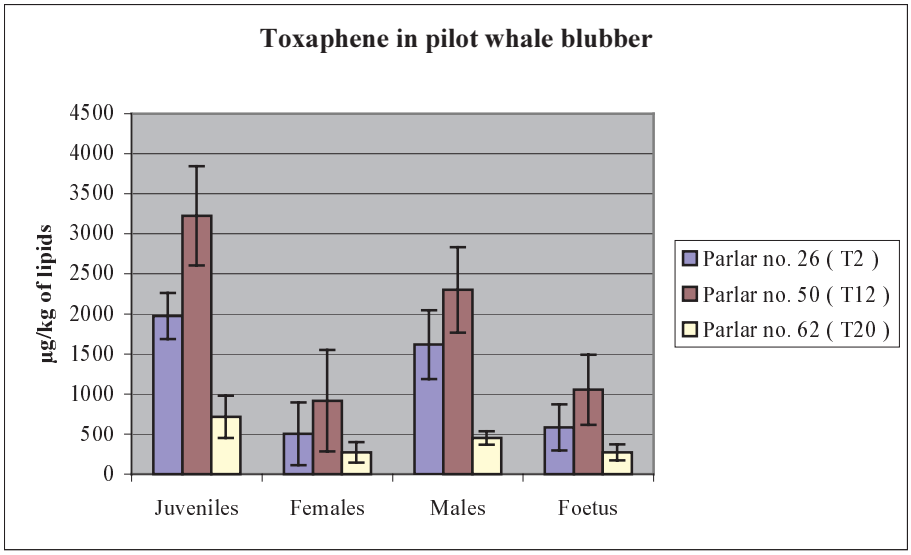

Figure 4.12. Toxaphene congeners in pilot whale from 09.09.00

Tabel 4.1. Toxaphene in pregnant females and their foetuses from 09.09.00

	% Lipids	Parlar no. 26 (T2)	Parlar no. 32	Parlar no. 50 (T12	Parlar no. 62 (T20)	Parlar no. 69	Total toxaphene
090900-004	80,7	820	ND	1300	320	ND	45000
090900-004F	71,4	840	ND	1400	350	ND	48000
090900-007	82,9	730	ND	1400	360	ND	42000
090900-007F	67,0	640	ND	1200	310	ND	37000
090900-013	78,5	180	ND	360	150	ND	9400
090900-013F	1,3	270	ND	560	160	ND	16000

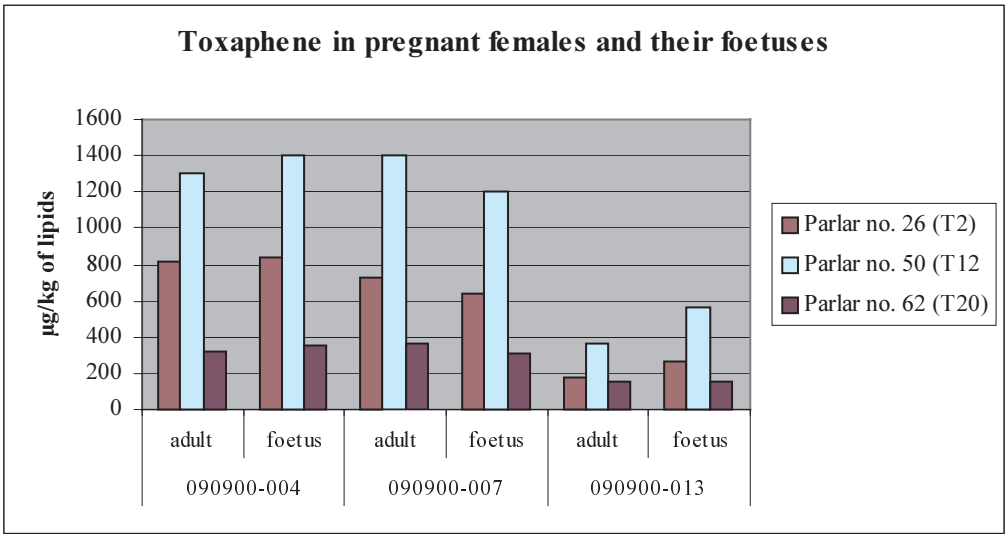

Figure 4.13. Toxaphene in pregnant females and their foetuses from 09.09.00

4.2.2 DDT

Table 4.10. DDT in pilot whale from 14.03.99 (µg/kg of lipids)

Age and sex group		% Lipids	o,p'-DDE	p,p'-DDE	o,p'-DDD	p,p'-DDD	o,p'-DDT	p,p'-DDT
Juveniles	Min	73,8	94,0	2215	120	590	520	660
	Max	93,4	310	8712	460	2200	1600	1800
	Mean	**84,41**	**195,29**	**5632**	**255,7**	**1229**	**1131**	**1246**
	Std.dev.	*5,31*	*67,10*	*2219*	*90,19*	*464,7*	*350,7*	*365,4*
Adult females	Min	66,6	17,0	470	25,0	140	120	210
	Max	91,9	360	10701	480	2000	1900	1900
	Mean	**82,0**	**140**	**3948**	**170**	**853**	**823**	**954**
	Std.dev.	*6,66*	*81,5*	*2709*	*100,2*	*446,2*	*466,5*	*468,7*
Adult males	Min	71,5	150	5023	200	1100	1100	990
	Max	94,8	400	19891	520	2900	3000	3500
	Mean	**82**	**248**	**11512**	**314**	**1745**	**1800**	**1954**
	Std.dev.	*7,27*	*79,73*	*5653*	*99,9*	*681,7*	*660,3*	*892,5*

Table 4.11. DDT in pilot whales from 08.09.99 (µg/kg of lipids)

Age and sex group		% Lipids	o,p'-DDE	p,p'-DDE	o,p'-DDD	p,p'-DDD	o,p'-DDT	p,p'-DDT
Juveniles	Min	85,53	200	4844	190	890	1100	1300
	Max	91,10	450	12274	520	2400	2400	3000
	Mean	**88,94**	**359**	**8992**	**413**	**1799**	**1943**	**2429**
	Std.dev.	*2,14*	*94,2*	*2681*	*122*	*529*	*465*	*624*
Adult females	Min	86,80	30	617	38	190	150	290
	Max	91,18	620	14952	650	2200	4200	3000
	Mean	**89,26**	**180**	**4061**	**193**	**801**	**1084**	**1160**
	Std.dev.	*1,63*	*194*	*4728*	*200*	*673*	*1331*	*890*
Adult males	Min	86,6	190	4658	230	1100	1200	1500
	Max	92,4	390	17959	410	2400	2700	3400
	Mean	**89,7**	**286**	**9477**	**311**	**1471**	**1800**	**1986**
	Std.dev.	*2,09*	*75,5*	*4578*	*63,1*	*450*	*520*	*652*

Table 4.12. DDT in pilot whales from 31.08.00 (µg/kg of lipids)

Age and sex group		% Lipids	o,p'-DDE	p,p'-DDE	o,p'-DDD	p,p'-DDD	o,p'-DDT	p,p'-DDT
Juveniles	Pooled sample 2	88	168	16625	223	1920	1287	2354
Adult females	Pooled sample 1	86	73	6905	82	859	533	1164
Adult males	Pooled sample 3	81	174	15247	194	1483	1279	1767

Table 4.13. DDT in pilot whale blubber from 09.09.00

Age and sex group		% Lipids	o,p'-DDE	p,p'-DDE	o,p'-DDD	p,p'-DDD	o,p'-DDT	p,p'-DDT
Juveniles	Min	80,7	266	13336	335,2	1708	1857	2422
	Max	82,8	417	20798	549,0	2586	2963	3580
	Mean	**81,8**	**344**	**15932**	**443,0**	**2066**	**2250**	**2812**
	Std.dev.	*0,86*	*62,17*	*3413*	*89,2*	*370,9*	*510,5*	*533,4*
Adult females	Min	73,8	26,2	978,5	30,9	149,2	181	298
	Max	84,2	290	13585	356	1480	2017	1916
	Mean	**81,1**	**94,1**	**3746**	**117**	**543**	**589**	**799**
	Std.dev.	*3,04*	*80,0*	*3744*	*98,3*	*414*	*548*	*523*
Adult males	Min	72,8	193,0	9908	241	1163	1265	1477
	Max	86,4	474,8	26853	559	2209	2994	3178
	Mean	**80,7**	**322**	**17881**	**391**	**1720**	**2201**	**2242**
	Std.dev.	*5,0*	*109*	*6602*	*124*	*452*	*707*	*635*
Foetus	Min	1,3	57,2	1998	78,2	375	233	334
	Max	71,4	180	6427	219	1007	938	1109
	Mean	**46,6**	**120**	**4251**	**149**	**718**	**599**	**787**
	Std.dev.	*39,3*	*61,6*	*2215*	*70,6*	*320*	*353*	*404*

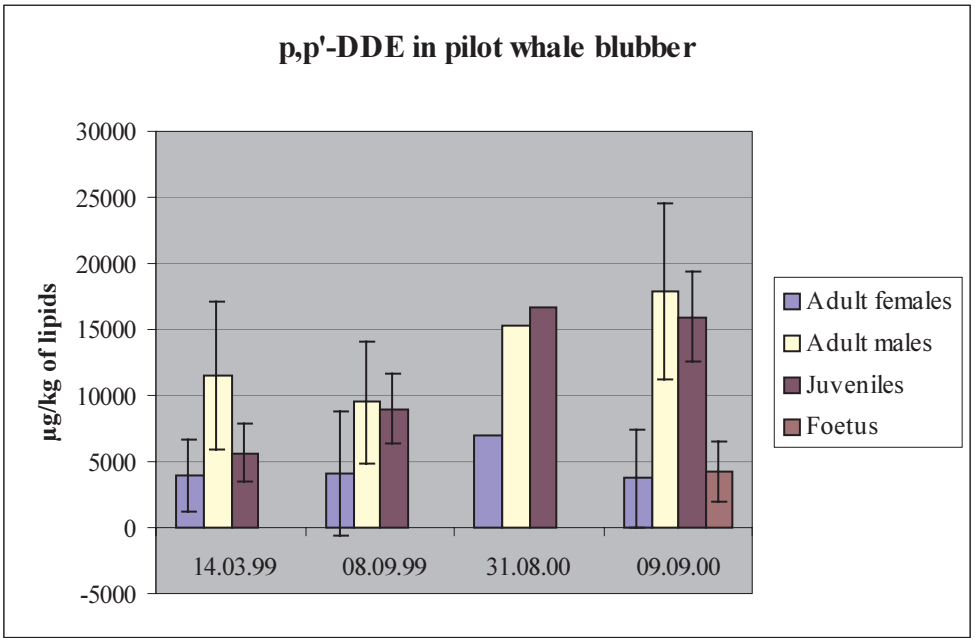

Figure 4.14. p,p'-DDE in four different pilot whale schools

Table 4.14. DDT in pregnant females and their foetuses from 09.09.00

	% Lipids	o,p'-DDE	p,p'-DDE	o,p'-DDD	p,p'-DDD	o,p'-DDT	p,p'-DDT
090900-004	80,7	152	6335	187	857	978	1256
090900-004F	71,4	180	6427	219	1007	938	1109
090900-007	82,9	120	4448	146	793	698	1140
090900-007F	67,0	124	4328	150	773	625	918
090900-013	78,5	33	1183	43	211	190	339
090900-013F	1,3	57	1998	78	375	233	334

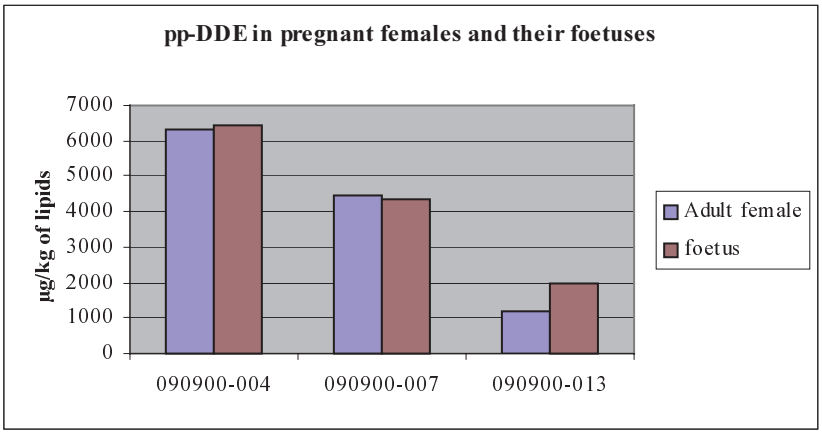

Figure 4.15. pp'-DDE in blubber from pregnant females and their foetuses from 09.09.00

4.2.3 Other organochlorinated pesticides

Table 4.15. Organochlorinated pesticides in pilot whale from 14.03.99 (µg/kg of lipids)

Age and sex group		% Lipids	ß-HCH	alpha-chlordane	gamma-chlordane	cis-nonachlor	hexachlorobenzene	mirex	oxychlordane	trans nonachlor
Juveniles	Min	73,8	21,9	187	38,4	290	201	77	133	869
	Max	93,4	84,7	1843	308,0	800	2145	188	1943	6004
	Mean	84,4	44,9	424	88,4	556	495	129	449	2179
	Std.dev.	*5,31*	*17,3*	*423*	*73,8*	*153*	*502*	*40,9*	*458*	*1396*
Adult females	Min	66,6	11,9	51	10,4	70	59,6	57,0	22,8	158
	Max	91,9	111,3	735	149,3	1000	1005	304	716	3910
	Mean	82,0	35,1	291	50,8	418	343	138	275	1515
	Std.dev.	*6,66*	*21,6*	*197*	*29,9*	*217*	*243*	*57,8*	*218*	*1075*
Adult males	Min	71,5	23,7	210	38,7	510	236	92,9	221	1209
	Max	94,8	86,7	628	118,1	1400	781	394	609	3981
	Mean	81,9	54,1	383	70,7	806	369	210	366	2580
	Std.dev.	*7,27*	*20,4*	*161*	*27,2*	*315*	*166*	*112*	*144*	*1077*

Table 4.16. Organochlorinated pesticides in pilot whale from 08.09.99 (µg/kg of lipids)

Age and sex group		% Lipids	ß-HCH	alpha-chlordane	gamma-chlordane	cis-nonachlor	hexachlorobenzene	mirex	oxychlordane	trans nonachlor
Juveniles	Min	85,5	19,7	222	61,5	490	311	127	247	1644
	Max	91,1	117,2	876	229,1	1320	1400	350	625	4192
	Mean	88,9	65,4	507	150,2	954	740	184	479	3064
	Std.dev.	*2,14*	*32,8*	*258*	*58,2*	*297*	*396*	*78,9*	*134*	*873*
Adult females	Min	86,8	9,2	82	26,5	110	94,6	59,2	32,3	266
	Max	91,2	60,6	311	105,1	970	570	205	301	1917
	Mean	89,3	27,8	166	55,3	406	251	104	149	1079
	Std.dev.	*1,63*	*18,1*	*74*	*31,9*	*292*	*146*	*46,4*	*97*	*694*
Adult males	Min	86,6	27,1	187	68,5	480	353	87,8	251	1512
	Max	92,4	74,3	396	153,1	1020	540	319	543	3769
	Mean	89,7	48,6	310	115,7	709	431	156	347	2443
	Std.dev.	*2,09*	*14,6*	*80*	*34,0*	*196*	*80*	*75*	*109*	*927*

Table 4.17. Organochlorinated pesticides in pilot whale from 31.08.00 (µg/kg of lipids)

Age and sex group		% Lipids	ß-HCH	alpha-chlordane	gamma-chlordane	cis-nonachlor	hexachlorobenzene	mirex	oxychlordane	trans nonachlor
Juveniles	Pooled sample 2	88	37	260	8,8	843	477	147	542	2642
Adult females	Pooled sample 1	86	15	143	6,8	405	226	136	250	1250
Adult males	Pooled sample 3	81	31	217	8,5	652	386	162	423	2200

Table 4.18. Organochlorinated pesticides in pilot whale from 09.09.00 (µg/kg of lipids)

Age and sex group		% Lipids	ß-HCH	alpha-chlor dane	gamma-chlor dane	cis-nona chlor	hexa-chloro-benzene	mirex	oxy chlor dane	trans nona chlor
Juveniles	Min	80,7	35,5	361	11,8	878,	400	122	453	3003
	Max	82,8	42,9	851	67,0	1448	947	200	683	4452
	Mean	**81,8**	**38,9**	**578**	**29,3**	**1163**	**674**	**155**	**603**	**3668**
	Std.dev.	*0,86*	*3,10*	*203*	*25,41*	*233*	*232*	*36,5*	*107*	*599*
Adult females	Min	73,8	6,71	76,2	10,6	110	82,2	56,8	43,2	320,3
	Max	84,2	27,4	462	22,5	962	527	206	515	3123
	Mean	**81,1**	**14,6**	**183**	**14,7**	**331**	**251**	**104**	**169**	**1005**
	Std.dev.	*3,04*	*7,09*	*117*	*3,69*	*257,2*	*149,8*	*38,5*	*143,3*	*841*
Adult males	Min	72,8	23,1	303	15,5	633	294	98,0	320	2052
	Max	86,4	37,1	433	19,6	1142	586	213	618	4075
	Mean	**80,7**	**28,2**	**367**	**17,5**	**913**	**449**	**169**	**503**	**3234**
	Std.dev.	*5,00*	*4,99*	*51,6*	*1,62*	*212*	*117,4*	*52,82*	*140,4*	*881*
Foetus	Min	1,3	16,9	115	10,8	179	192	22,7	80,3	506
	Max	71,4	25,4	295	19,0	550	410	68,3	298	1600
	Mean	**46,6**	**21,7**	**207**	**13,8**	**381**	**324**	**41,5**	**208**	**1104**
	Std.dev.	*39,26*	*4,37*	*90*	*4,52*	*188*	*116*	*23,8*	*114*	*554*

Table 4.19. Organochlorinated pesticides in blubber from pregnant females of pilot whale and their foetuses from 09.09.00 (µg/kg of lipids)

	% Lipids	ß-BHC	alpha-chlor dane	gamma-chlor dane	cis-nona chlor	hexa-chloro-benzene	Mirex	Oxy chlor dane	Trans nona chlor
090900-004	80,7	16	247	18	498	230	75	247	1572
090900-004F	71,4	25	295	19	550	369	23	298	1600
090900-007	82,9	19	207	13	406	312	108	239	1256
090900-007F	67,0	23	210	11	414	410	33	247	1207
090900-013	78,5	6,9	90	11	134	122	89	58	377
090900-013F	1,3	17	115	12	179	192	68	80	506

The pesticide results show the same tendency as the PCB results. For the school from 14.03.99 the adult males have the highest content followed by the juveniles which have higher content than the females. For the other three schools the concentration in the juveniles is just as high or higher than the concentration in males while the concentration in the females is lowest. However, in the DDT analyses, only the school from 31.08.00 show that the juveniles have higher content than the males. They also show, that the the schools from 2000 seem to have higher DDT content than the schools from 1999. The toxaphene results seem to be higher in the school from 09.09.00 than in the other schools.

5 Hare

In 1999 only three hares were analysed. The hares were hunted in 1997 and liver, muscle and intestinal fat were analysed for PCB and organochlorinated pesticides including DDT and toxaphene.

In 2000 liver samples were analysed from 26 hares, which were hunted in 1999. Both individual and pooled samples were made, all together 13 samples, which were analysed for PCB and organochlorinated pesticides. The composition of the samples is seen in Chapter 6, Olsen et al., table 5.2.

The analyses were performed at CTQ.

5.1 POP results from 1997

Table 5.1 shows the results of the PCBs and organochlorinated pesticide analyses in different tissue of three individuals of hare from 1997. The PCB congeners: CB 28, CB 52, CB 105, CB 128, CB 156, CB 170 and CB 183, beta-HCH, alfa-chlordane, gamma-chlordane, trans-nonachlor, o,p'-DDE, o,p'-DDD, p,p'-DDD, o,p'-DDT and toxaphene parlars no. 26(T2), 32, 50(T12), 62(T20) and 69 were not detected in any of the tissues analysed.

Table 5.1 PCB and organochlorinated pesticides in hare from 1997

ID	Lt-0001 male			Lt-0002 juvenile female		Lt-0003 female		
Matrix	liver	intestinal fat	muscle	liver	muscle	liver	intestinal fat	muscle
%lipids	3	80	na	2,9	na	2,1	81	na
Units	µg/kg of lipids		µg/kg of tissue	µg/kg of lipids	µg/kg of tissue	µg/kg of lipids		µg/kg of tissue
Aroclor 1260	24	19	nd	21	nd	50	11	nd
CB 99	nd	0,52	nd	nd	nd	nd	0,4	nd
CB 101	nd	0,49	nd	nd	nd	nd	nd	nd
CB 118	nd	0,83	nd	nd	nd	nd	0,5	nd
CB 138	nd	1,3	nd	nd	nd	4,1	0,79	nd
CB 153	2,8	2,5	nd	2,5	nd	5,5	1,4	nd
CB 180	nd	1	nd	nd	nd	nd	0,52	nd
CB 187	nd	0,31	nd	nd	nd	nd	nd	nd
cis-nonachlor	nd	nd	nd	nd	nd	3,7	nd	nd
hexachloro-benzene	11	8	nd	13	nd	23	8,4	nd
Mirex	4,6	nd	nd	nd	nd	nd	nd	nd
oxy chlordane	51	0,88	nd	50	nd	25	0,67	nd
p,p'-DDE	3,3	2,9		nd		18	2,2	
p,p'-DDT	nd	1,2		nd		10	0,94	

na: not available, the lipids content is to low to be evaluated
nd: not detected

5.2 POP results from 1999

Table 5.2 gives the results of PCB and pesticide analyses in hare liver samples from 1999. The PCB congeners: CB 28, CB 52, CB 99, CB 105, CB 118, CB 128, CB 138, CB 170, CB 180, CB 183 and CB 187, beta-HCH, alfa-chlordane, gamma-chlordane, cis-nonachlor, trans-nonachlor, o,p'-DDE, o,p'-DDD, p,p'-DDD, o,p'-DDT and toxaphene parlars no. 26(T2), 32, 50(T12), 62(T20) and 69 were not detected in any one of the individuals.

Table 5.2. POPs in hare liver from 1999 (µg/kg of lipids)

Age and sex group	n		Lipids %	Aroclor 1260 mg/kg of lipids	CB 153	pp'-DDE	hexa-chloro-benzene	mirex	oxy chlor dane
Juveniles	4	Min	1,33	0,03	2,10	5,33	14,75	2,05	18,55
		Max	3,60	2,10	6,51	9,21	122,87	5,91	62,26
		Mean	**2,12**	**0,45**	**4,60**	**6,57**	**46,05**	**3,74**	**39,86**
		Std. dev.	*0,87*	*0,92*	*1,74*	*1,52*	*43,80*	*1,65*	*16,56*
Adult females	4	Min	1,53	0,04	1,30	3,29	11,85	nd	7,32
		Max	2,78	2,10	5,59	11,95	60,99	nd	38,73
		Mean	**1,94**	**0,87**	**3,39**	**7,93**	**27,65**	**nd**	**23,00**
		Std. dev	*0,57*	*1,01*	*2,03*	*3,83*	*22,76*	nd	*13,70*
Adult males	5	Min	1,30	0,04	2,00	2,00	18,11	1,70	12,48
		Max	2,28	2,00	6,54	8,36	33,13	4,32	34,22
		Mean	**1,77**	**0,53**	**4,52**	**5,84**	**24,26**	**2,77**	**27,59**
		Std. dev	*0,41*	*0,98*	*1,88*	*2,71*	*6,35*	*1,13*	*10,30*

n: number of samples analysed. Some of the samples are individuals, some are pooled samples.

CB 153 was the only PCB congene detected except CB 101 and CB 156 which each was detected in one individual, and the values were around the detection limit. Of the DDT derivatives p,p'-DDE was the only one detected except p,p´-DDT which was detected in two individuals, and the values were also quite low. Toxaphene was not detected, and for the other pesticides only hexachlorobenzene, mirex and oxychlordane were detected and for mirex only some of the individual results were above the detection limit while others were not detected.

When looking at the different groups the juveniles have the higher values than the adults for several compounds. This may be reflecting the fact that juveniles receive the lipid soluble pollutants with the milk from the mother, and at the same time offloads some of her body burden. The adults, which are herbivores receive only a small amount of lipid soluble pollutants with their food.

6 Arctic char

Arctic char were sampled in 2000 and 2001 and analysed for PCB and organochlorinated pesticides, DDT and toxaphene congeners. In 2000 muscle tissue from 25 Arctic char was analysed individually and the samples were stored in polycarbonate jars until analysis.
In 2001 the Arctic char were analysed as pooled samples. 40 individuals were grouped according to size and divided into 5 pooled samples. The samples were stored in heat treated glass jars (400°C for at least four hours) with similarly heat treated aluminium foil between glass and lid. The analyses were performed at CTQ.

6.1 PCB

Table 6.1 and Table 6.2 show the PCB concentration in Arctic char muscle from 2000 and 2001 respectively, as Aroclor 1260, PCB 7 and CB 153.

Table 6.1. PCB in Arctic char muscle from 2000

Length	n		Lipids %	Aroclor 1260 mg/kg of lipids	PCB 7 µg/kg of lipids	CB 153 µg/kg of lipids
34-36 cm	5	Min	1,5	0,10	35,3	11,2
		Max	5,8	0,19	67,9	21,4
		Mean	**4,2**	**0,15**	**56,3**	**17,1**
		Std. dev	*1,69*	*0,04*	*13,39*	*4,09*
36-38 cm	10	Min	1	0,16	59,5	17,6
		Max	7,2	1,06	343,6	130,6
		Mean	**3,0**	**0,37**	**131,6**	**42,8**
		Std. dev	*1,96*	*0,27*	*84,3*	*33,41*
38-40,5 cm	10	Min	1,1	0,36	123,8	40,68
		Max	5,7	0,83	261,7	95,27
		Mean	**2,9**	**0,56**	**184,7**	**62,82**
		Std. dev	*1,59*	*0,15*	*47,05*	*18,17*

n: number of individuals analysed

Table 6.2. PCB in Arctic char muscle from 2001

ID	n	mean length, cm	% Lipids	Aroclor 1260 mg/kg of lipids	CB 153 µg/kg of lipids
SA-1-2001	8	31,6	2,5	0,19	23,2
SA-2-2001	8	36,0	2,0	0,30	33,6
SA-3-2001	8	37,1	2,1	0,46	52,9
SA-4-2001	8	37,8	1,4	0,56	65,1
SA-5-2001	8	38,8	0,9	0,74	87,6

n: number of individuals in pool

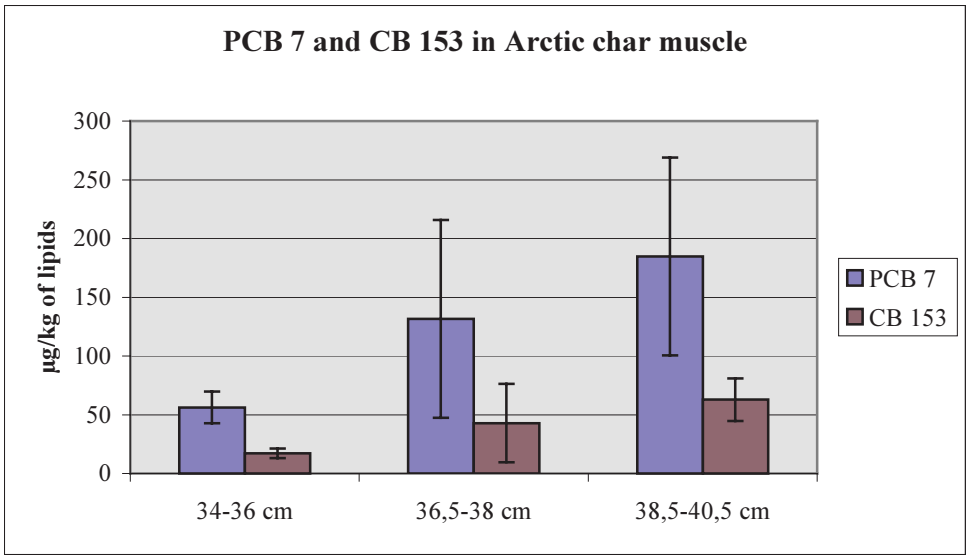

FIGURE 6.1. PCB IN ARCTIC CHAR FROM 2000 FOR DIFFERENT SIZE GROUPS

The PCB content is significantly correlated to length with P(2 tail)= 0,00001 for both PCB 7 and CB 153. Correlation with age is only significant for PCB 7 (with 5% level of significance), with P(2 tail)= 0,04 and 0,06 for PCB 7 and CB153, respectively.

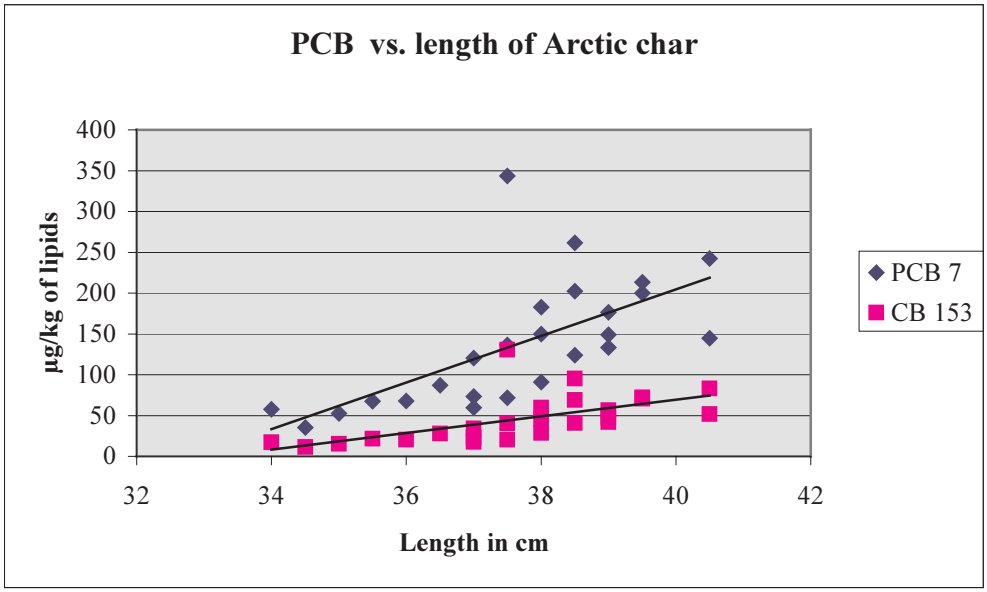

FIGURE 6.2. CORRELATION BETWEEN PCB AND LENGTHT IN ARCTIC CHAR MUSCLE FROM 2000

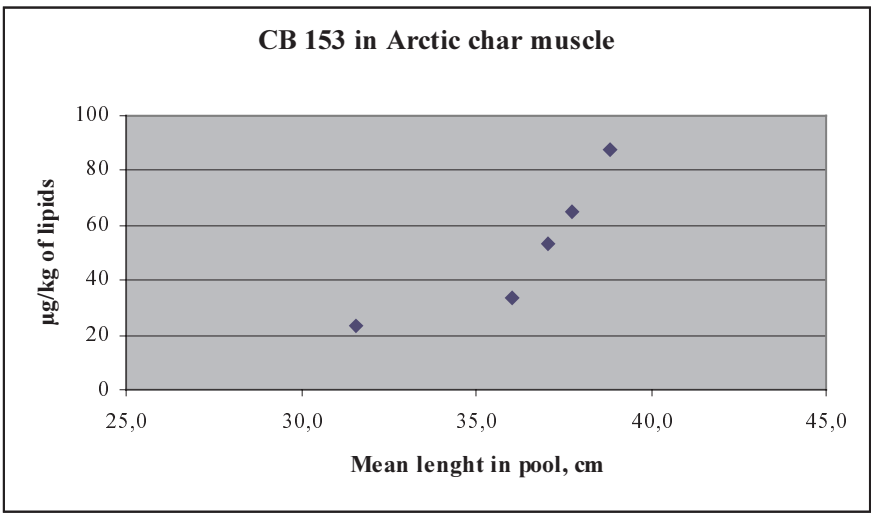

FIGURE 6.3. CB 153 VERSUS LENGTH FOR ARCTIC CHAR FROM 2001

6.2 PESTICIDES

Table 6.3 shows the concentration of pesticides in Arctic char muscle from 2000. Toxaphene parlars no. 32, 62(T20) and 69, o,p'-DDE, o,p'-DDD, p,p'-DDD, o,p'-DDT, p,p'-DDT, ß-HCH, gamma-chlordane and mirex were not detected in any of the individuals analysed in 2000.

TABLE 6.3. PESTICIDES IN ARCTIC CHAR MUSCLE FROM 2000 (µG/KG OF LIPIDS)

Length	n		pp'-DDE	Toxaphene		alpha-chlor dane	cis-nona chlor	hexa-chloro-benzene	oxy chlor dane	trans nona chlor
				Parlar no. 26 (T2)	Parlar no. 50 (T12)					
34-36 cm	5	Min	15,4	3,5	7,8	2,2	1,7	35,1	1,2	2,2
		Max	31,2	5,1	13,0	8,8	4,8	45,1	4,0	8,5
		Mean	**24,2**	**4,4**	**10,5**	**5,8**	**3,6**	**41,7**	**2,8**	**5,5**
		Std. dev.	*6,11*	*0,71*	*2,16*	*2,39*	*1,33*	*4,09*	*1,18*	*2,42*
36 -38 cm	10	Min	29,6	4,0	7,5	5,2	4,5	38,3	1,9	7,5
		Max	76,0	8,5	23,0	16,7	9,0	52,6	7,5	19,2
		Mean	**50,9**	**6,1**	**15,7**	**8,9**	**5,8**	**45,7**	**4,1**	**12,5**
		Std. dev.	*17,23*	*1,38*	*4,45*	*3,49*	*1,52*	*4,03*	*1,60*	*4,43*
38-40,5 cm	10	Min	37,5	4,3	6,4	4,3	6,4	6,1	2,4	6,4
		Max	127,1	11,0	28,0	24,5	12,8	53,6	6,4	25,5
		Mean	**81,6**	**7,6**	**18,9**	**11,6**	**10,1**	**41,2**	**5,1**	**17,7**
		Std. dev.	*22,39*	*2,26*	*6,86*	*6,32*	*2,14*	*12,95*	*1,25*	*5,57*

n: number of individuals analysed

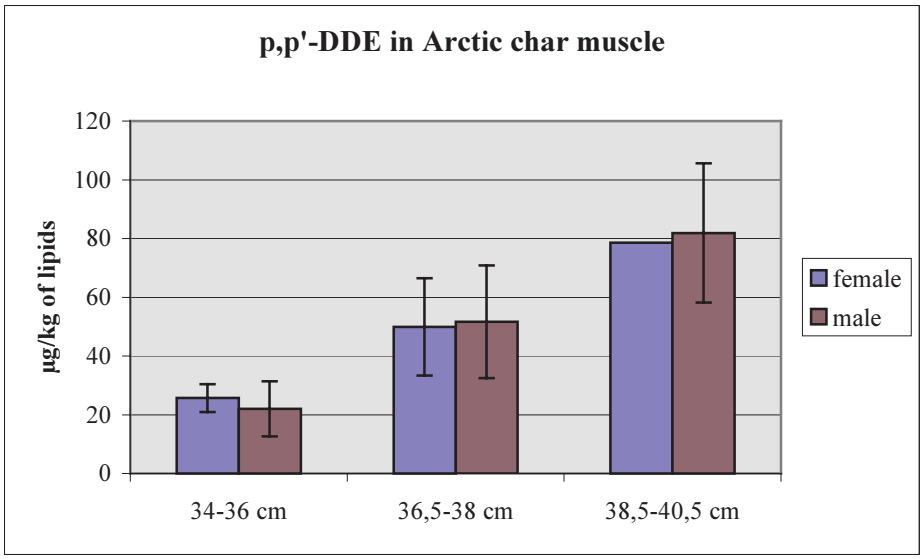

FIGURE 6.4. P,P'-DDE IN ARCTIC CHAR FROM 2000 FOR DIFFERENT SIZE GROUPS

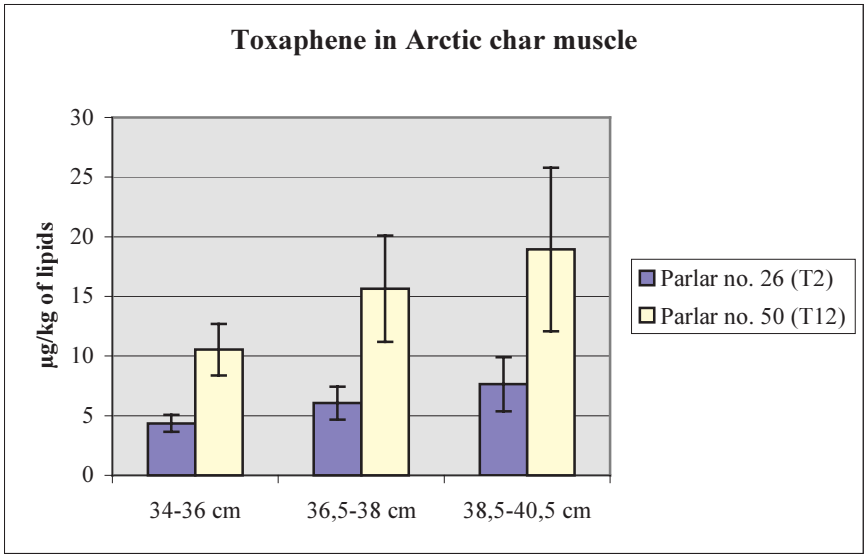

FIGURE 6.5. TOXAPHENE IN ARCTIC CHAR FROM 2000 FOR DIFFERENT SIZE GROUPS

As for the PCB results, the concentration of pesticides, except alphachlordane and hexachlorobenzen, are correlated to length (P(2tail)=<0,0005).

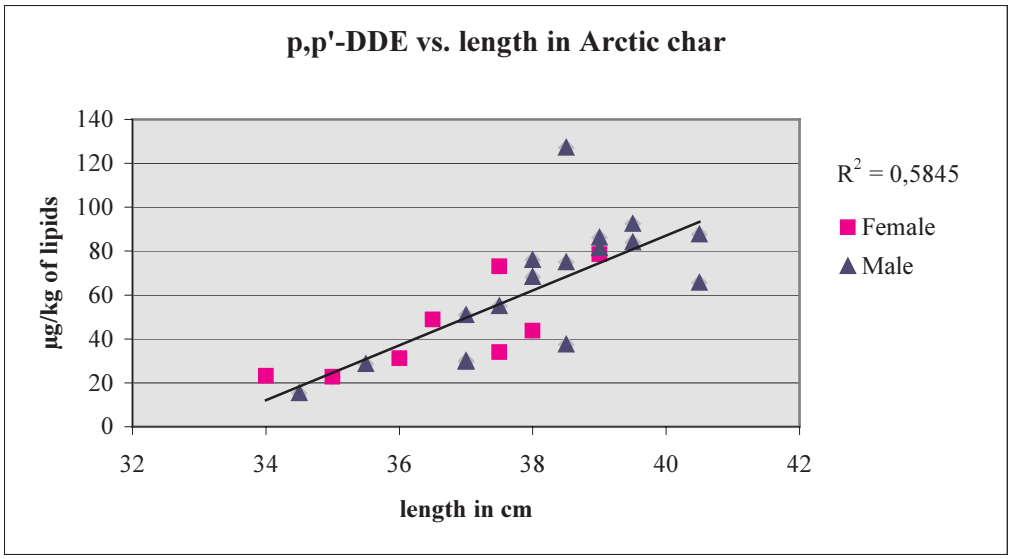

FIGURE 6.6. CORRELATION BETWEEN P,P'-DDE AND LENGTH OF ARCTIC CHAR FROM 2000

Table 6.4 show the concentration of pesticides in the pooled samples of Arctic char from 2001. Toxaphene parlars no. 32, 62(T20) and 69, o,p'-DDD, p,p'-DDD, o,p'-DDT, ß-HCH, gamma-chlordane, cis-nonachlor, mirex and oxy-chlordane were not detected in the samples analysed in 2001.

TABLE 6.4. PESTICIDES IN POOLED SAMPLES OF ARCTIC CHAR MUSCLE FROM 2001 (µG/KG OF LIPIDS)

ID	o,p'-DDE	p,p'-DDE	p,p'-DDT	Toxaphene		alpha-chlordane	Hexa-chloro-benzene	Trans nonachlor
				Parlar no. 26 (T2)	Parlar no. 50 (T12)			
SA-1-2001	ND	31	ND	ND	13	6,9	55	6,5
SA-2-2001	ND	45	ND	8,6	16	11	63	15
SA-3-2001	9,6	109	ND	ND	13	10	43	14
SA-4-2001	13	131	ND	ND	14	ND	56	15
SA-5-2001	19	162	38	ND	ND	ND	53	17

ND: Not detected

7 Cows milk

As a special task in 1999 cows milk was analysed for dioxin. In countries, where marine mammals are not a part of the human diet, milk and milk products are the most important source of dioxin exposure. The Faroe Islands are approximately self-sufficient on milk. Generally app. 40% of the cows fodder is imported from Denmark and Iceland while 60% is locally produced but the percentages vary among farmers

One sample was taken from each of three milk-producing farms. These three were among the five biggest milk producers in the Faroe Islands. The samples were taken directly form the milk-tank at the farm. In addition two parallel samples were taken of the final product at the dairy. The milk samples were frozen and sent to the University of Umeå for analyses.

7.1 Results

Table 7.1. Dioxin in cows milk

	Farms			Dairy	
ID	Cowsmilk 1 pg/g lipid	Cowsmilk 2 pg/g lipid	Cowsmilk 3 pg/g lipid	Cowsmilk 4 pg/g lipid	Cowsmilk 5 pg/g lipid
2378-TCDF	ND 0,026	ND 0,028	ND 0,039	ND 0,071	ND 0,042
2378-TCDD	ND 0,050	ND 0,052	ND 0,060	ND 0,10	ND 0,079
12378-PeCDF	ND 0,030	ND 0,036	0,037	ND 0,064	ND 0,060
23478-PeCDF	0,29	0,36	0,46	0,46	0,42
12378-PeCDD	0,16	0,24	0,22	0,23	0,22
123478-HxCDF	0,19	0,17	0,22	0,24	0,25
123678-HxCDF	0,14	0,14	0,15	0,17	0,22
234678-HxCDF	0,18	0,16	0,17	0,24	0,22
123789-HxCDF	ND 0,089	ND 0,086	ND 0,090	ND 0,16	ND 0,15
123478-HxCDD	0,14	0,12	0,12	0,12	0,2
123678-HxCDD	0,19	0,19	0,21	0,28	0,31
123789-HxCDD	0,12	0,12	0,14	0,17	0,21
1234678-HpCDF	0,15	0,13	0,13	ND 0,14	0,19
1234789-HpCDF	ND 0,086	ND 0,091	ND 0,090	ND 0,16	ND 0,16
1234678-HpCDF	0,53	0,33	0,35	0,55	0,63
OCDF	0,25	0,26	0,32	0,44	0,36
OCDD	0,66	0,29	0,32	0,55	0,62
I-TEQ PCDD/PCDF*	0,36	0,43	0,49	0,54	0,52
PCB #77	0,52	0,4	0,44	0,64	0,65
PCB #126	2,4	1,8	4,2	3,9	3,7
PCB #169	0,38	0,35	0,84	0,78	0,81

*Toxic equivalents

8 References

Dam, M. & Bloch, D. (2000). Screening of Mercury and Persistent Organochlorine Pollutants in Long-Finned Pilot Whale (Globicephala melas) in the Faroe Islands. Marine Pollution Bulletin Vol. 40, No. 12, pp 1090-1099

Pedersen, B., Glausius, M. and Hansson, B. (2000). Report from audit visit at Centre de Toxicologie du Quebec, Quebec, Canada, Concerning POP-analyses in the AMAP- programme - Report prepared for Dancea-AMAP December 2000. Ministry- of Environment and Energy, National Environmental Research Institute