Mercury in the Faroe Islands – a review of available data

Kyksilvur í Føroyum – ein gjøgnumgongd av tøkum dátum

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Summary

Rættiliga stórt kyksilvurmagn er funnið í nøkrum føroyskum sýnum tikin av kræklingi, mógv, mold og bleikju, um borið verður saman við sýni tikin í grannalondunum. Hinvegin vísa evropisku mosakanningarnar, sum Føroyar hava luttikið í síðan 1996, at kyksilvurmagnið í mosaslagnum *Hylocomium splendens* sum heild í Føroyum er minni enn í Svøríki, Noregi og Danmørk. Ein ábending, sum eisini samsvarar væl við myndilsúrslitini, ið vísa, at kyksilvurupptøkan úr luft og avfalli í Føroyum yvirhøvur er tveir valdar lægri enn í Danmørk (Christensen, 2003). Kyksilvurið kemur til Føroya langvegis frá, og nøgdirnar eru lítlar ella á leið sum tær í eitt nú skandinaviskum londum. Tað stendur tó eftir at lýsa, hví so er og hví nøgdirnar eru so stórar í ávísum sýnum.

Summary

Elevated mercury concentrations in some matrices have been found in Faroese samples as compared to samples from neighbour countries/waters. These matrices are blue mussels, peat and soil, and even Arctic char. These results indicate that there are elevated concentrations of mercury in the Faroes. On the other hand, the European moss survey in which the Faroe Islands have participated since 1996, indicate that the mercury concentrations in *Hylocomium s.* is overall lower in the Faroes than in Sweden, Norway and Denmark. An indication, which also fits well with the model results that deposition of mercury in air/precipitation in the Faroes is generally lower by a factor of two than in Denmark (Christensen, 2003). Thus, the question apparently is limited to one of describing how the amount of mercury that is transported to the Faroe by long-range transport, in amounts that are low or comparable to the one to for examples Scandinavian countries, do become so concentrated in some compartments.

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Introduction

Mercury, Hg, is a metal and thus is a natural component of our environment. We are familiar with mercury from our every-day life through our dental "silver" fillings, which are in fact amalgams, where the term amalgam means a mixture of mercury and other metals. This property to blend with other metals at ambient temperature is a special feature of mercury and is the basis for the use of mercury in gold extraction in some areas, an application that leads to at least locally significant pollution. Due to suitable electrochemical and electronic characteristics mercury has also been used in electric equipment and in chlor-alkali production, applications which are now highly restricted in the developed parts of the world. The toxicity of mercury is highly dependent on the physiochemical form it occurs in, *i.e.* the actual species. Pure, metallic mercury for example is more poisonous than mercury bound in amalgams, and methylated mercury is more poisonous that mercury in inorganic species. The species are however not static and transition between most chemical forms occur depending on the environment. In the present review, only inorganic, divalent mercury and occasionally methylated mercury or gaseous elemental mercury species are discussed.

There are many different mercury sources in the environment but the most important ones are burning of fossil fuels and waste (Pacyna and Keeler, 1995), where stationary combustion[1] in 1995 of mainly coal accounted for ¾ of the global emission (Pacyna and Pacyna, 2000). In addition to this, a large quantity comes from the earth itself as evaporation from the crust and vegetation and from volcanic activities. Inventories indicate that approximately 60% of the mercury entering the atmosphere every year is anthropogenic (AMAP, 1998), where anthropogenic or man-made in this case of a naturally occurring substance simply means that the metal is released to the biosphere through mans activities. Inventories based on 1990 and 1995 emission data indicate that there were no major changes in global emission in this period (Pacyna and Pacyna, 2000). There have however, been a decrease estimated to 45% in emissions in Europe and North America during this time, but globally this decrease is offset by an almost doubling in the contribution from the Asian sources where the emission which stems from stationary combustion of fossil fuel have increased markedly (Pacyna and Pacyna, 2000; Pacyna *et al.*, 2001). In the eighties, Nriagu and Pacyna (1988) estimated the amount of mercury being emitted to the atmosphere from anthropogenic activities to be equal to that being directly discharged to the sea and approximately half the amount that is deposited on land (Pacyna and Keeler, 1995), implying thus that the other half of the mercury deposited were stemming from natural processes.

For areas with limited local emission, it is mainly the emissions to air of elemental gaseous mercury which is the most interesting part of the overall mercury release, because mercury has a long residence time in the atmosphere and can be transported over long distances until it is eventually de-

posited either by dry or by wet deposition. Recent research suggests that there is a polar-sunrise driven mechanism for deposition of atmospheric mercury, and this, in combination with the biomagnifying properties of mercury, makes the Artic areas susceptible to global mercury emissions (Schroeder *et al*, 1998; Lindberg *et al.*, 2002).

The purpose of the present review is to produce a mercury data compilation and through that process also to achieve an overview of the mercury concentrations and levels found in the Faroese environment. The overview will serve as a pointer to sources of data on mercury, and pinpoint the areas of the environment where further study on the mercury inflow, concentration and transport is needed. Finally, it will provide a route to a realization of where or in what matrices there is a potentially elevated mercury concentration.

Literature sources

The present review is based mainly on the environmental data report "Føroya Umhvørvi í tølum" which is a series of data reports, published every second year since 1997 by the Faroese institutions which keep, use and/or produce environmental data; the Food and Environmental Agency, the Fisheries Laboratory, the Faculty of natural sciences of the University of the Faroe Islands and the Museum of Natural History. Other sources of data are project reports published by the Food and Environmental Agency since 1996, some of which are only available as technical reports as photocopies whereas others are published in printed versions with ISBN no. A plentiful source on new information both on metals like mercury but also covering environmental pollutants in general, is the report "AMAP Greenland and the Faroe Islands 1997-2001 Vol. 3 The environment of the Faroe Islands (Hoydal and Dam, 2003). Other sources of data have been scientific report including those produced by students who have undertaken to elucidate mercury in various parts of the environment. For further references on Faroese scientific papers in general, readers are referred to the archive at the Museum of Natural History and to "Fróðskaparrit", a Faroese scientific journal issued yearly by "Føroya Fróðskaparfelag" (Societas Scientiarum Færoensis).

Atmosphere and precipitation

As per today, there have been two studies involving actual measurements of mercury in air in the Faroe Islands (Daugaard, 2003; Skov *et al.*, 2003). Apart from these, a study modelling the deposition of mercury on the Faroes based on the 1995 global mercury inventory was completed in 2002 (Christensen, 2003).

Measurements of mercury in air

The longest and most comprehensive measurement-series on air in the Faroe Islands is the one that was done at the EMEP station Akraberg at the southernmost part of the Faroe Islands in the period 1979 to1991 by the National Environmental Research Institute, NERI, (Kemp, 1984; 1993; 1994). These measurements were done on

compounds in gaseous state or in aerosols, and embraced a series of metals and acid rain components, but not mercury. The results are however, very likely of value in interpreting subsequent analyses on the air medium in the Faroes and are thus mentioned here.

From May 2000 to March 2001 NERI has in cooperation with the Faroese Food- and Environmental Agency investigated mercury Hg^0 in the air on the Faroe Islands using a Tekran Model 2537A Mercury Vapour Analyser (Skov *et al.*, 2003). The purpose of this investigation was to determine the concentration of mercury in the air on the Faroes. Also, part of this study was to examine possible anthropogenic, local mercury sources and to find the origin of the airborne mercury.

The study revealed that the measured quantities of mercury in air were very variable. During some time intervals the measured values were as high as 2,8 ng/m^3 and at others it was as low as 0,5 ng/m^3, which is lower than the global background value for mercury at 1,7 ng/m^3. The mean value for the entire period was 1,33 ng/m^3.

Possible mercury sources on the Faroes were presumed to be: The incineration plants, the hospital, the shipyard and dentists. After questioning the staff in these places it was concluded that the mercury source of most significance was the incineration plants. The last couple of years the mercury emissions from the incineration plants have been generally lower than the max. allowed value in those years of 100 µg/m^3. Furthermore it was concluded that smoke from the incineration plants in Tórshavn and Leirvík would probably not reach the location of the air sampling and measurements.

Also, if the incineration plants were to blame for the high values measured, one would expect a large variation in the measured mercury concentration and high values to be measured from time to time throughout the year, but this was not the case. Instead, the work was concentrated on wind direction during measurements of high and low values. However, due to the high air humidity, and the sensitivity of the equipment towards this, there was a degree of uncertainty in the measured values.

It was concluded that the sources of the high air mercury levels were not to be found on the Faroes but rather that the mercury was transported to the Faroe Islands via long-range atmospheric transport.

In the summer months of 2002 from June through September, passive mercury vapour samplers were placed at 5 study stations around the Eysturoy and Streymoy islands as part of a Ms.Sc. study on the extent of uptake of mercury in grass under the influence of factors as dry and wet deposition (Daugaard, 2003). The passive samplers consisted of gold-nets in glass-tubes inverted so as not to be wetted by rain. The application of the passive samplers was part of pioneer work on these and the efficiency of the samplers was not fully known at the beginning of the study. It turned out however, that the measured overall mean concentration of air mercury in the study period was close to 1,24 ng/m^3 (Daugaard, 2004) and thus within the range found using the Tekran analyser (Skov *et al.*, 2003).

Also, and very interestingly, a significant increase in the deposition of gaseous mercury in the samplers with increasing station elevation above sea level was observed, an observation which would also be predicted from the cold condensation mechanism which have been suggested as important pathways for the transport of POPs and mercury to the Arctic (Mackay *et al.*, 1995; Wania and Mackay, 1995).

Recently, Christensen (2003) simulated the air transport of mercury, sulphur and lead to the Faroe Islands. The simulations were based on the Danish Hemispheric Eulerian Model system developed at NERI (Christensen 1997; 1999). There were 13 mercury species in the DEHM, of which 3 in gas phase (Hg^0, HgO and $HgCl_2$), 9 species in the aqueous phase, and one species of particulate mercury. As input data to the model were used the 1995 global inventory on mercury (Pacyna and Pacyna, 2002) which includes Hg^0, reactive gaseous mercury (RGM) and particulate mercury and a background concentration of 1,5 ng/m^3 of Hg^0 were used as initial concentration and boundary conditions. The model is capable of incorporating the polar-sunrise driven mercury depletion into the composite transport and deposition prediction. The model which was run for the period October 1998 to December 2000, predicted that the polar sunrise event will result in a modest 8% increase in the mercury deposition on the Faroe Islands where the increase in the total area north of the polar circle amounts to more that 100 %. The model also predicted that mercury emitted as particles will be a minor part (2%) of the mercury deposited in the Faroes whereas the atmospheric reservoir of elemental mercury, Hg^0, is the main contribution (more than 93%) to the total deposition, a reservoir which is global and which combines both natural and anthropogenic mercury. It was also calculated that the total deposition would amount to approx. half the deposition of mercury in Denmark.

The model have been compared with measurements many places in Europe and generally there have been very good agreement between the calculated results and the measured ones. For the Faroes however, there was a poor agreement between the calculated values and the observed concentration of gaseous mercury Hg^0 (Christensen, 2003; Skov *et al.*, 2003), and the model results for lead and SO_x were not compared to measured ones. The reason for the lack of agreement between the model values of mercury deposition to those actually measured were later accounted to malfunctioning of the mercury analyser in the high humidity environment of the Faroe Islands (Skov, personal comm.).

Precipitation

As mentioned in the last section, an EMEP station run by NERI was operative at Akraberg in the period 1979 to 1991. At this station acid rain components and parameters were analysed in deposition, and for the last four years also the major cations sodium, potassium, magnesium and calcium was included in the analyses scheme (Kemp 1984; 1993; 1994). This scheme did not encompass mercury, neither do the analyses performed by the Heilsufrøðiliga

Starvsstovan in precipitation collected three times yearly since 1996 (Dam 1998) at Norðuri á Fossum. The locality Norðuri á Fossum is used as the Faroese reference station to the UN/ECE Long-range transboundary air pollution programme on Integrated Monitoring. At this site, regular analyses of major ions in precipitation are made and results are reported to the UN/ECE Integrated monitoring data centre at the Finnish Environmental Institute.

However, mercury in precipitation was measured for the first time at the Faroe Islands in 2002 as part of a Master of Science program (Daugaard, 2003).

Deposition was collected at Elduvík, Eiði, Saksun, Vestmanna and Kirkjubøur for 6 periods each of 3 weeks duration covering the period June to October 2002. The sum mercury deposition during the 6 week period varied from 5,3 ng to 10,9 ng Hg. A distinct negative correlation was found between the amount of deposition and the concentration of mercury in deposition, indicating that the washout of mercury from the atmosphere were most intense during the first mm of the rain-shower. (Daugaard, 2003).

The terrestrial and freshwater environment

Peat and Soil

Peat core samples were collected in May 2000 from the two peat-bogs á Mýrunum in Vestmanna and the Klovin bog in Vatnsoyrar (Roos *et al.*, 2001). The samples from á Mýranar were analysed for mercury and dated in order to study the changes in mercury fluxes with time. The results (Shotyk *et al.*, 2003; 2004) indicated that the major part of mercury in the peat has been transported through the atmosphere. Several layers of ash in the peat cores were noticed and these seemed to originate from Icelandic volcanoes. Although it was presumed that some volcanoes have had a certain influence on the mercury supply to these samples, some very high values in the peat for the time-period around 1950 could not be explained by natural sources alone.

Besides mercury, high values of bromide and chloride were found which showed the impact of sea spray on the peat. Despite the cutting of peat it appeared that the time periods were well preserved (Goodsite *et al.* 2002).

Shotyk *et al.* (2004) declared that the measured mercury values were higher than those found in other Nordic countries and that the results indicated that the natural background flux of mercury to the Faroes was always elevated, compared to continental bogs. Superimposed on these elevated natural fluxes, however, they found a much greater Hg flux in samples from the last two centuries. The large total mercury peak (498 ng Hg/g dw) at á Mýranar were found in depths between 5 cm and 6 cm, and was higher than what could reasonably be explained by geo-chemical mechanisms or natural input.

Data are available on a number of metals and minerals in soil and basalt (Rasmussen and Noe-Nygaard, 1969; Joensen and Vestergaard 1995; Mikkelsen *et al.*, 2002) but few data are available on mercury, (Table 1).

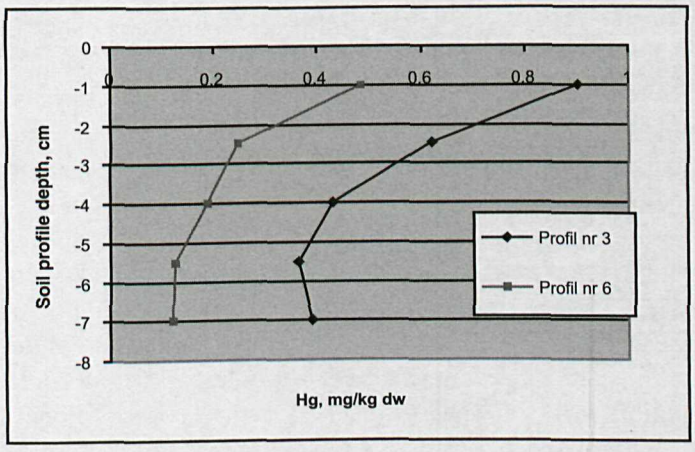

Fig. 1. Mercury in soil profiles from Norðuri á Fossum, 2002. (Heilsufrøðiliga Starvsstovan, unpubl.

In 2002 two soil profiles were collected at Norðuri á Fossum. The soil profiles were cut in segments of 1,5 cm starting at 1 cm below the surface, and analysed for mercury as well as a selection of other metals (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, V and Zn) as well as the dry matter content (Heilsufrøðiliga Starvsstovan). The results of the mercury analyses are given in (Fig. 1) as a function of the upper level of profile segment depth. There are significant differences in the mercury concentrations among the two profiles even though they were taken only approx. 50 m apart in an area that is not influenced by local pollution sources. The profile no. 3 was taken from the eastern side of the river Dalá, in an area where regular wet deposition collection has been ongoing since 1996. The profile no. 6 was taken from the western side of Dalá, in a moist and bog-like area. The soil from the two sites have not been characterised apart from the metal analyses indicated in the parenthesis above. When comparing medians of metal concentrations in the two profiles, it appears that there are three metals which are markedly different in the profile no. 3 compared to no. 6, they are mercury, vanadium and arsenium, where the two fist mentioned are elevated and the last mentioned is lowered. The median mercury concentration in the profile no. 3 is more than twice as high as the one in the profile from the more moist area. In the surface layer (-1 to 2,5 cm) , the concentration of mercury in the profiles no. 3 and 6 are 0,90 and 0,48 mg/kg dw respectively. The transition from organic soil to mineral soil occurred at a depth of approx. 6 cm in the profile no. 3. Diagenetic processes may relocate metal-ions in a sediment or moist soil environment. The process is driven by redox-reactions and it is known that man-

Sampling	depth segment, cm	Hg
Norðuri á Fossum, no. 3, peat	1-9	0,54
Norðuri á Fossum, no. 6, peat	1-9	0,23
Reference site[a]	0-20	0,15

[a] Heilsufrøðiliga Starvsstovan, 1991

***Table 1** Mercury (mg/kg dw) in peat cores taken Norðuri á Fossum in 2002 and at a reference site in 1991.*

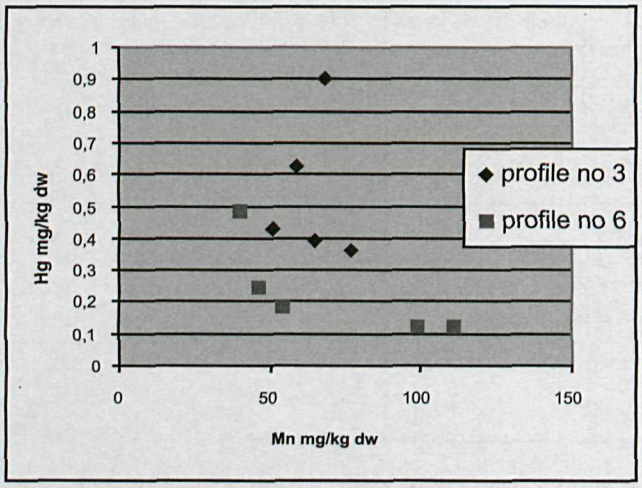

Fig. 2. Mercury versus manganese concentrations in the soil profile segments collected Norðuri á Fossum, are plotted against each other. (Heilsufrøðiliga Starvsstovan, unpubl.)

ganese and mercury mobilise under similar conditions, thus a correlation between these elements hints that a possible relocation has taken place. In Fig. 2, the mercury concentration in the profile segments were plotted against manganese, and the striking lack of correlation suggest that the mercury concentration in the various segments mirror the original deposition of mercury on top of a changing matrix of growing and subsequently decomposing humus layer.

Mercury in vegetation

The Faroe Islands joined the European Moss sampling Survey in 1995 and in 2000 (Rühling *et al.*, 1996; 1998; Buse *et al.*, 2003). In this program, moss of the species *Hylocomium splendens* is analysed for metals that may be emitted by local sources or transported over longer distances by air masses. The special feature of *Hylocomium s.* of easily discernable segmented growth is utilised by selecting for analyses only the two to three outermost segments that corresponds to the growth during the last two to three years. Comparisons between results of the 1995 and the 2000 study (Table 2) indicate a decrease in lead and cadmium from 1995 to 2000, whereas mercury was analysed in the 2000 survey only so comparisons in time cannot be made.

In connection with the implementation of the first phase of the Arctic Monitoring and Assessment Programme, AMAP, in the Faroes, moss of the species *Racomitrium* and lichen of the species *Cladonia sp.* were analysed (Larsen and Dam, 1999). It appears (Table 2) that the mercury concentrations are higher in the *Racomitrium* and *Cladonia* species than in *Hylocomium s.* even when sampled in the same area. However, the sampling of the latter was done three years later than the two first so comparisons must be made with regard to this.

It is well known that moss as an indicator of metal ions in air and deposition is of limited use in areas where the air is full of locally produced metal ions from soil erosion (Steinnes, 1995). In order to overcome the dusting problem, the study includes analy-

	Cd	Cr	Cu	Fe	Ni	Pb	V	Zn	Hg
Hylocomium s. 1996 [1,2]	0,12	0,73	5,43	539	1,53	7,58	4,45	15,17	
Average all locations, range	0,09-0,15	0,49-1,17	4,44-6,92	312-1064	1,19-1,91	5,37-10,3	3,21-6,84	12,0-21,6	
Hylocomium s. 1996[1]	0,13	0,51	5,67	382	1,45	7,38	3,43	16,9	
Hylocomium s. 2000 [1]	0,06	0,86	6,88	812	1,78	3,78	3,98	15,06	0,05
Average all locations, range	0,04-0,09	0,50-1,83	4,48-9,87	270-1755	1,02-2,97	2,18-5,94	1,81-8,03	10,7-20,3	0,02-0,07
Hylocomium s. 2000[1]	0,05	0,54	7,21	878	1,95	3,67	2,50	13,7	0,05
Racomitrium lanuginosum	0,07	2,47	3,65	731	2,10	13,2	4,33	10,6	0,16
Cladonia mitis	0,08	2,42	16,5	251	2,22	2,35	0,84	20,4	0,14

1 The growth during the last 2-3 years were analysed.

2 Rühling *et al.* 1996

***Table 2** Heavy metals in moss and lichen, in mg/kg dw, sampled Norðuri á Fossum ,Vestmanna in 1997 and in moss (Hylocomium splendens) sampled at Norðuri á Fossum plus 7 other locations in Eysturoy and in the Streymoy in 1996 og 2000. (Dam, 1998; Larsen and Dam, 1999).*

ses of so-called conservative elements, like iron, so the degree of dusting may be inferred from the magnitude of the conservative element in the moss. Not surprisingly, the concentration of iron is high in the *Hylocomium s.* samples. Dividing the concentration of mercury by the one of iron in the various moss samples do not give a constant value, which could otherwise be expected if the local geology was the source of the mercury. Neither the lead/iron nor the mercury/ironratio in moss is constant, but interestingly, they correlate (squared Pearson's regression coeff. =0,83) with a maximum value in the sampling site renown for its high precipitation volume (Saksunardalur/Hvalvík). These findings indicate that the source of both mercury and lead is not local geology and that deposition of airborne metals from more remote sources may be a significant contribution to the measured moss metal concentration. Comparing the results of the moss samples to the 1995 European survey indicate that the mercury concentration in *Hylocomium s.* from the Faroe Islands are comparable to what was found in Russia at the Kola peninsula and in the Leningrad and Pskov regions as well as in Finland. Also, it may be said that it was generally in the lower end of what was found in Sweden, Norway, Denmark and the Baltic States (Rühling *et al.*, 1996; 1998).

In 2002 the uptake of mercury in vegetation was studied in uniclone grass (*Lolium multiflorum*) specially grown for the purpose in controlled circumstances and stationed at five stations on Eysturoy and Streymoy during June to October (Daugaard, 2003). The uptake of mercury in grass was found to be positively correlated ($P<0,001$) to the uptake of mercury in the passive samplers, but in contrast to what was expected, not to the total wet deposited mercury. Also, a correlation to the elevation of the station above sea level was found ($P<0,01$). The study concluded that there are no indications of an elevated exposure

of air-borne mercury in the Faroes above the level found in the Scandinavian countries.

Freshwater lakes

Since the late nineties trout (*Salmo trutta*) and Artic char (*Salvelinus alpinus*) from selected waters have been analysed for mercury (Table 3). Some of these waters are dams constructed for hydroelectric purposes, as Eiðisvatn, which was dammed in recent years and the oldest dam, á Mýranar, which was dammed in 1960/1961 (Jacobsen, 2003) closely followed by Heygardalsvatn in the same waterway during 1961/1962 (Hermansen, 1999). The lakes Leynavatn, Leitisvatn and Fjallavatn are natural lakes, and the former is the only one in which Arctic char is naturally occurring. To the á Mýranar dam, Arctic char has been set out, and from this it has found its way down to the Heygardalsvatn after the emptying of the Heygardalsvatn dam in 1992 due to a furunculosis outbreak (Niðristovu, 1998).

The smaller (and younger) trout were found to contain smaller amounts of mer-

Species	Location	Year	Number of samples	Average age (year) / weight (g)	Hg, mg/kg ww	Source
Trout	Fjallavatni	1997	19	4+ / 109	0,23	Larsen and Dam, 1999
	Fjallavatni	1997	9	5+ / 203	0,36	
	Leitisvatni	1997	16	4+ / 123	0,30	
	Leitisvatni	1997	7	5+ / 201	0,35	
	Eiðisvatni	2000	3	2+	0,08	Hentze, 2000
	Eiðisvatni	2000	3	5+	0,11	
median					0,26	
Arctic char	Heygardalsvatni	1998	15	8,0 / 3221	0,07	Dam, 1999
	Leynavatni	1998	15	7,8 / 131	0,18	
	Mýrarnar	2000	5	7,2 / 558	0,14	Olsen *et al.*, 2001
	Mýrarnar	2000	10	8,4 / 616	0,17	
	Mýrarnar	2000	10	8,4 / 686	0,18	
	Mýrarnar *	2001	(n=8)	- / 384	0,16	Olsen *et al.*, 2001
	Mýrarnar *	2001	(n=8)	- / 543	0,21	
	Mýrarnar *	2001	(n=8)	- / 494	0,26	
	Mýrarnar *	2001	(n=8)	- / 554	0,23	
	Mýrarnar *	2001	(n=8)	- / 549	0,25	
median					0,18	

* Analysed in pooled samples each combining 8 individuals.

Table 3 *Mercury concentrations in trout and Arctic char. (Adapted from Mikkelsen et al., 2002)*

cury than the larger (and older) ones. This is in line with the well-known potential for bioaccumulation of mercury. One may also note that the concentrations of mercury in trout from the two freshwaters Leitisvatn (=Sørvágsvatn) and Fjallavatn are very similar, and these waters are also close in geographical terms situated on the island Vágar.

Overall, the mercury concentrations in trout were higher than in the Arctic char. It is also seen that the mercury concentration in Arctic char from Leynavatni is higher than in the Heygardalsvatni, even though the ones from Leynavatni were smaller in both weight and length. Of importance to note in this case is that the average age of the two groups of char is about the same, where Arctic char from Leynavatni had an average age of 7,8 years while the average age for char from Heygardalsvatni was 8,0 years. There was however, a dramatic difference in size-at-age between these two populations stemming from on the one side the fact that the fish in Heygardalsvatn feed on manmade feed because there was smolt rearing in this basin, and on the other, that the Leynavatn char population is what is usually termed a dwarf morph (Gydemo, 1983).

The mercury concentration in Arctic char from á Mýrunum in 2000 is at a similar level as in Arctic char from Leynavatni, whereas the 2001 data á Mýrunum seem somewhat elevated. This may be interannual variability stemming from what may be termed natural variations in food availability, or it may result from differences in water body regulations. At present there are not many waters with Arctic char in the Faroe Islands, so it is not possibly to completely avoid waters with watersheds disturbed to some extent by human activities. It is believe however, that á Mýrunum is the best choice for Arctic char sampling, because the damming here was done relatively early in the hydro electrical development history of the Faroes, and hence the erosion at the shoreline is as low as it can be under the circumstances. In addition to mercury analyses, the Arctic char from á Mýrunum was also analysed for selenium. Average selenium concentration for the 2000 samples was 1,4 mg/kg, while the selenium concentration in 2001 was between 1,76 - 2,26 mg/kg (Olsen *et al.*, 2003).

Compared to lakes in Arctic Canada, where the majority of lakes have Artic char mercury levels less than 0,2 mg/kg (Lockhart *et al.*, 2001), the mercury concentration in the á Mýranar lake is high. It is also high compared to the results of a study of brown trout and Arctic char from high mountain lakes in Europe and the Svalbard Archipelago, where the mean mercury concentrations varied between 0,021 and 0,179 mg/kg (Rognerud *et al.*, 2002). In Lake Thingvallavatn, Iceland, the mercury concentration in Arctic char is approx. a tenth of the level in the Faroese lakes (Jonsson, 1995). However, in certain lakes in west and southwestern Greenland the average mercury concentration in Arctic char is two to three-fold higher than in the Faroes (Riget *et al.*, 2000). Overall thus, it may be stated that the mercury concentration in Arctic char in the Faroes is elevated above the common level in many places.

The mercury concentration in brown trout is similar to the common level in Arctic Canada (Lockhart *et al.*, 2001). It is still elevated above the level in Finland (AMAP 1998) where brown trout in Finnish Lappland was less than 0,1 mg/kg.

Several studies have been undertaken to elucidate the factors influencing the uptake of mercury from a watershed/lake. It appears that apart from the magnitude of the actual atmospheric mercury deposition, a wet and boggy upland with high organic matter content is a driving force for elevated fish mercury concentration in a lake (Fjeld, 1993), and than the mobilization is increased by disturbances not only from flooding in connection with electricity production, but also from other erosion-creating activity like agriculture and the use of heavy terrain-going machinery (Gustin, 2002; St.Louis *et al.*, 2004).

This indication that what would be termed moderate watershed erosion in other circumstances could render the water less suitable in monitoring the long range transported (also called "background level") pollutants is bad news for monitoring in the Faroe Islands where there is no fish-containing water where the watershed is not being used for some sort of erosion-creating activity like sheep grazing and growing of crops. The natural erosion however, i.e. that driven by wind, temperature and wet deposition, is significant and may overshadow the anthropogenic initiated erosion.

Sediments from freshwater lakes

During the summer-period of 2000, sediments were collected from different Faroese fresh water lakes as part of the NorLake project (Landkildehus *et al.*, 2002). Some cores were made available for retrospective mercury analyses where the sediments are cut in sections representing a certain time period as defined by radiological analyses, and where the mercury concentration is measured in each slice (Table 4). Sediment cores were taken from Sørvágsvatni and Leynavatni and each core was sliced in 5 cm thick segments. Knowledge about mercury concentration and the age of the various sediment slices allows the drawing a profile of the mercury pollution from the time of the sedimentation of the oldest slices in the core to the present time. The uppermost slices of the sediment from Leynavatni could not be dated because of extensive bioturbation in these sections, so the estimated sedimentation rate applies only to the two slices at the bottom of the core. Fig. 3 shows the mercury concentration in the sediment profile sampled in Sørvágsvatn. To eliminate variability stemming from the tendency of mercury to bind to the organic fraction, the mercury concentration in the figure has been corrected for the organic content of the actual segment by dividing with the loss on ignition (in g/kg dw).

Comparing the mercury concentration in the segments of two cores that corresponds to sediments deposited approx. 100 years ago, shows that the concentration in lake Sørvágsvatn sediments was approx. twice as high as in the Leynavatn sediments. Correcting, however, both mercury concentrations for the organic material content, ex-

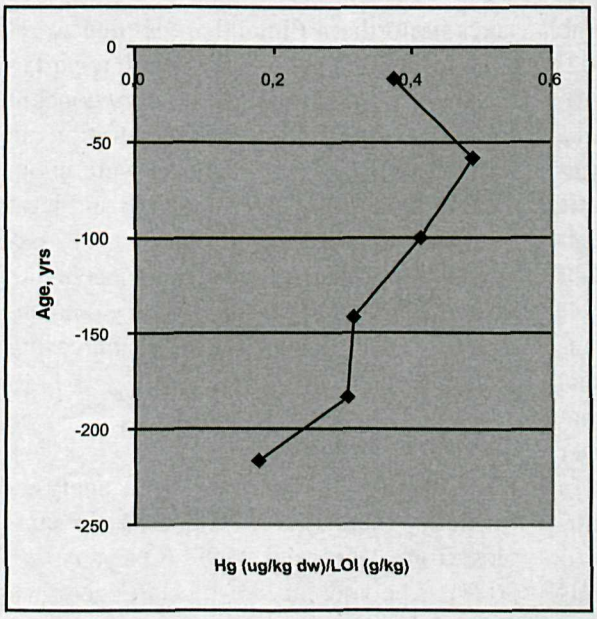

Fig. 3 Mercury corrected for the organic content in dated segments of sediment core from Sørvágsvatni (Olsen et al.2003).

pressed as loss on ignition, LOI, gives more equal concentrations, of approx. 0,4 and 0,33 µg Hg/g org. material in Sørvágsvatn and Leynavatn respectively.

The results (Fig. 3 and Table 4) indicate that the mercury concentration has doubled during the last 200 years up to a maximum occurring approx. 60 years ago, after which time it appears to decline again. Because of the distance between the points (i.e. the thickness of the slices) the profile is rather uncertain, and the analyses should be repeated with higher resolution in time.

Information on water chemistry in Sør-

	Sørvágsvatn			Leynavatn		
Sedimentation rate	0,12			0,2*		
Segment depth	Age	Hg	LOI	Age	Hg	LOI
cm	years	ug/kg dw	g/kg dw	years	ug/kg dw	g/kg dw
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

* This value applies only to two slices at the bottom of the sediment core.

***Table 4** Age, mercury concentration and loss on ignition (LOI) in segments of sediment cores from Sørvágsvatn and Leynavatni (Olsen et al., 2003).*

vágsvatn and Leynavatn is available trough the NorLake project (Landkildehus, 2002) and inspection of the pH values for the two waters show that these are exactly the same (pH= 6,7) and thus a differences in pH-values which has been suggested as possible explanation for different mercury concentrations in sediments due to the impact of pH on metal-complexation processes (AMAP, 1998) is obviously not a contributing element. It is reasonable to assume that the aforementioned binding to organic material is the dominating vector. The water chemistry indicates that the difference in organic material in the sediments is mirrored in the water column, where significantly higher concentrations of nutrients are found in Sørvágsvatn than in Leynavatn (Jensen, 2002). In Sørvágsvatn, the concentration of nitrate is 10 times higher than in Leynavatn, total nitrogen is twice as high, and total phosphorus is also higher, at 3 g P/l and 5gP/l respectively.

Results from analyses of sediments from lakes in northern Finland are similar to results from lakes in the Faroes with regard to the shape of the profile of mercury concentration *vs.* time. Mercury concentrations in sediments from lake Nitsijärvi were about 100 µg/kg approx. 200 years ago and have increased to about 200 µg/kg in 1988. Except from transient reductions occurring about 1850 and 1950 the mercury concentrations have been gradually increasing (Mannio *et al.*, 1997).

Terrestrial mammals

Hare, *Lepus timidus*, have been analysed for heavy metals (Hg, Cd and Se) in samples from 1997 and 1999 (Olsen *et al.*, 2003). The mercury results are given in Table 5.

Compared to hares in northern parts of Norway (Kålås *et al.*, 1995) where the mercury concentration in liver from young hares and adult hares were 0,0065 mg/kg and 0,016 mg/kg respectively, the mercury concentration in the Faroese hares are high-

	N	Lenght, cm	Weight, kg	dw, g/100g	Hg
♀ Hare '97	1		3,3	28,60	0,07
♀ Hare '99	3	71 (14,6)	3,0 (0,30)	24,27 (0,63)	0,06 (0,05)
♀ Hare '99*	6			23,89	0,05
♂Hare '97	1		3,2	25,70	0,07
♂Hare '99	3	78 (3,5)	2,9 (0,30)	24,87 (0,18)	0,04 (0,02)
♂Hare '99*	5				0,03
Juvenile '97	1		2,4	25,90	0,10
Juvenile '99	3	74 (2,1)	2,3 (0,05)	24,16 (1,77)	0,05 (0,04)
Juvenile '99*	6			23,68	0,06
Juvenile '99*	6			23,53	0,07

* Pooled sample

Table 5 *Mercury in hare livers, mg/kg ww. Mean values are given as well as standard deviations in parentheses. (Olsen et al., 2003).*

er and similar to Arctic hare in Qeqertarssuaq, Greenland, where the mercury concentration in 5 adults was 0,03 mg/kg (Riget *et al.*, 2003). Also selenium concentrations were higher in the Faroese hares at 0,52 to 0,71 mg/kg ww (Olsen *et al.*, 2003), however with a smaller difference to the same Norwegian samples where the concentration was 0,20 mg/kg Se in young and 0,48 mg/kg Se in adult hares, but more than five times the concentration in the Greenland hares.

Sheep

In the Faroe Islands, sheep, *Ovis aries*, have been analysed for heavy metals and persistent organic pollutants as part of the international AMAP program (Olsen *et al.*, 2003) and for heavy metals and dioxin for a longer period, in industry-related monitoring programs. Results from the industry-related monitoring programs have been made available to the public in the "*Føroya Umhvørvi í tølum*" report series (Dam *et al.*, 1997; Gregersen *et al.*, 2000; Mikkelsen *et al.*, 2002).

Sheep and lamb liver and lamb meat sampled from Vestmanna and Koltur in 1997 were analysed for Pb, Cd, Hg and Cu (Larsen and Dam, 1999). In 1995/96 and 1999 samples of sheep and lamb liver from 4 stations each year, were analysed for Pb, Cd and Hg (Mikkelsen *et al.*, 2002). In 1997 and 1999 combined, mercury could not be detected at 0,02 mg/kg in lamb meat (n=8) and lamb liver (n=8 from six locations and n=17 from two) (Larsen and Dam, 1999). For samples of sheep liver these same years mercury could likewise not be detected at 0,02 mg/kg at six stations each represented by 8 liver samples. In the 1995/96 samples, the analyses were done using an other detection limit, at 0,01 mg/kg, for liver samples of sheep and lamb from two stations. Among these, mercury was detected at 0,012 mg/kg in sheep and at 0,01 mg/kg for lamb from one single location, the other samples that year were analysed using the 0,02 mg/kg detection limit, and mercury could not be detected.

The Marine Environment

Analysis of the sea- and seabed

In the fjords

To date, the broadest investigation of the metal concentrations in a Faroese fjord ecosystem was the investigation of the Skálafjord described in "Skálafjarðarkanningin" (Heilsufrøðiliga starvsstovan 1992). Sediments were collected from 5 locations in the fjord and the top-most 20 cm analysed for lead, cadmium, nickel, copper, zinc, mercury and iron. The results from the analysis of the uppermost 5 cm of the sediments are shown in Table 6 as means for the fjord, and as individual location results in Table 7.

In 1997, sediments were collected from Skálafjord, Kollafjord, Kaldbaksfjord, and the sound Sundalagnum – both north and south of the bridge, and Funningsfjord, see Fig. 5. The sediments were analysed for a series of metals. Some of the results are shown in Table 6 with an average value representing all the fjords. The results from the individual analysis of mercury are given in Table 7, with concentrations in the range 0,02 to 0,14 mg/kg dw.

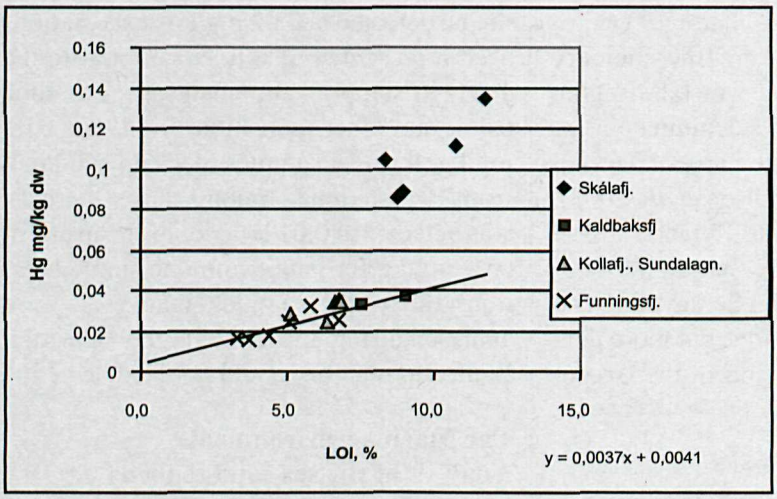

Fig. 4 Mercury concentrations in sediments are shown as a function of organic matter (% loss on ignition at 550 °C) in the 1997 fjord sediment samples. A regression curve based on the Funningsfjord data is shown. (Adapted from Mikkelsen et al., 2002).

In recent years, quite a number of sediment samples have been analysed as part of the environmental monitoring done as part fulfilment of the permit conditions by license holders on aquaculture pens. Apart from analyses of nutrients like nitrogen and phosphate this monitoring includes analyses for the metals Zn, Cu, Cr, Ni, Hg, Cd and Pb (Mikkelsen *et al.*, 2002). Results from the reference stations of these analyses are given in Table 7 along with those from the same stations in 1992 and 1997.

The highest concentrations of mercury were found in Skálafjord, with concentra-

Locations and year	Pb	Hg	Cd	Cu	Zn	Dry weight, %	Organic carbon % #	Source	Depth
Skálafjørður, 1992 (min. – max.)	15,0-38,6	0,11 0,08-0,17	0,14-0,25	61,2-131,3	44,4-90,9	32,9-0,0	6,4-12,6	Heilsufrøðiliga starvsstovan, 1992	0-5 cm
Tangafjørður, 1994	16,5	< 0,04	0,221	21,2	78,2			Granmo, 1996	0-2 cm
Fjords 1997* (min. – max.)	19,9 9,4-27,7	0,04	0,15	92,4 65,4-116	61,7 30-91		6,7 3,3-11,8	Heilsufrøðiliga starvsstovan	0-2 cm

# Organic carbon in % dw or Loss on ignition in % dw.
nd = Depth of analysed sediment core not defined.
* Fjords in 1997 are: Skálafj., Tangafj., Funningsfj., Kaldbaksfj. and Sundalagið N.

***Table 6** Heavy metals in sediments from Faroese fjords. Values are in mg/kg dw. Underlined values are geometric means. (Adapted from Mikkelsen et al., 2002)*

Location	1992 LOI, %	1992 Hg, mg/kg	1997 LOI, %	1997 Hg, mg/kg	2000 LOI, %	2000 Hg, mg/kg
St 1 og 2 1992	7,3	0,085				
SK 05 (1) (st 4)	9,8	0,11	9,0	0,089		0,033
SK 05 (2)**			8,4	0,104	8,3	0,043
SK 05 (3)			8,8	0,086		
SK 07 (st 3II)	12,6	0,11	10,7	0,111	12,6	0,058
SK 09 (st 3I)	10,9	0,17	11,8	0,135	13,1	0,035
KA 05			9,1	0,037	9,4	0,031
KA 05			9,1			
KA 09			7,6	0,033	10,0	0,020
KA 09				0,034		
KO 07			6,6	0,034	6,8	0,028
SU 05			5,1	0,028	9,4	0,015
SU 15			6,8	0,035	9,3	0,018
SU 37			6,9	0,034		
SU 41			6,4	0,024		
FU 13			3,7	0,016		
FU 17 (1)			4,4	0,018		
FU 17 (2)			3,3	0,017		
FU 21 (1)			5,9	0,032		
FU 21 (2)			6,8	0,025		
FU 21 (3)			5,1	0,024		
FU 21 (3)				0,024		

** In 2000 analyses; the -2cm to -7 cm segment.

Table 7 *Mercury, mg/kg dw, and Loss on ignition (LOI at 550^{0}C) in %, in sediments from some Faroese fjords in 1992, 1997 and 2000. Values are in mg/kg dry weight when not otherwise is stated. The sampling locations are shown in* ***Fig. 5****. In some cases up to 3 replicates were collected from one location in 1997 and analysed independently. These are numbered 1 to 3 (in parenteses). The mercury analysis on sample FU21 (3) 1997 was done in duplicate. The analyses were done on the 0-2 cm segment of the sediment core. Adapted from Gregersen et al., 2000 and Mikkelsen et al. 2002.*

tion reaching 0,17 mg/kg at one station in 1992. Plotting the concentration of mercury as a function of the LOI (Fig. 4) reveals that the elevated concentrations in the Skálafjord sediments are not in line with the concentrations in the other fjords even when elevated organic material content is taken into consideration. This is an indication that the mercury concentration in the Skálafjørðinum in 1992 and 1997 was elevated above the natural background.

Comparing the results of the two (three) years indicate that overall the mercury concentration is either stable or decreasing. In Skálafjord, the median of mercury concentration in the upper sediment layer in the three years 1992, 1997 and 2000 were 0,11 mg/kg, 0,10 mg/kg and 0,04 mg/kg respectively, with the largest decreases occurring at station SK09 (Fig. 5) in going from 0,17 mg/kg in 1992 (the station was then called St.3 I) to 0,14 mg/kg in 1997 and ending at 0,04 mg/kg in 2000.

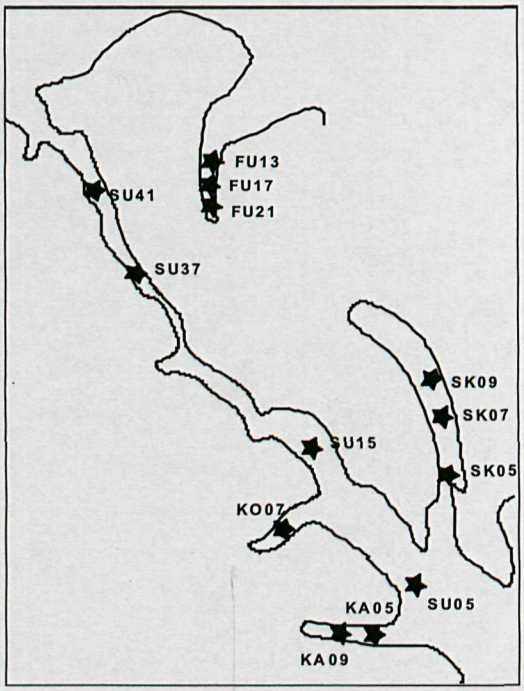

Fig. 5 Sampling areas in the Faroese fjords are shown (Gregersen et al., 2000).

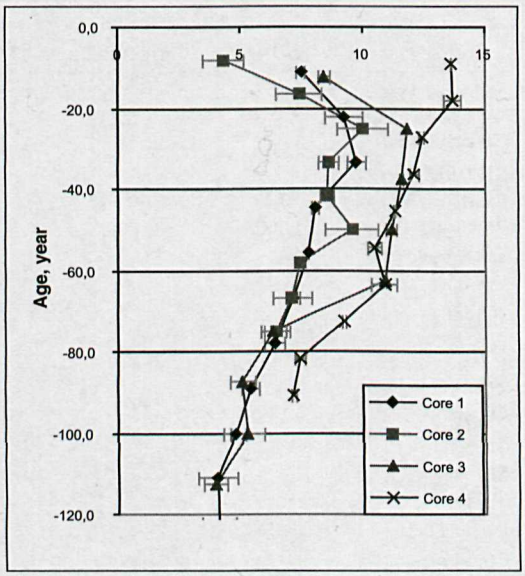

Fig. 6 Age (in years) and mercury concentration (µg/kg dw) profile for seabed-sediments from Sandoyarbanka (Olsen et al., 2003)

On the banks

In Table 8 results of heavy metal analyses on marine sediments are given. The sediment samples have been taken from the banks Skeivabanka, Sandoyarbanka and Føroyabanka, where the latter is located west of the Faroe Plateau. Analyses of these sediments show a mercury concentration of between 4 and 10 µg/kg. The sediments from Skeivabanka were also analysed for PAH, PCB and some pesticides (Magnusson *et al.*, 1996; Stange *et al.*, 1996).

As part of the AMAP project four replicate sediments cores collected on Sandoyarbanka were dated by radiological analyses and analysed for mercury concentration in segments of 1 cm (Olsen *et al.*, 2003). The mercury concentration in the uppermost segment is given in Table 8. In Fig. 6 the mercury concentrations in all segments of the four cores are given as a function of the age determined for the segments. Fig. 6 shows that there are some variation in mercury concentrations in the four cores especially in the top-most sediment layers. Despite this variation it is clear that the mercury concentration in the sediments have increased from about 5 µg/kg 100-120 years ago, to about the double 30-40 years ago, after which it seems to decline again during the last 20-25 years.

Comparing the results of the Sandoyarbanka sediments to those in the fjords may be done by comparing results in Table

Sample location- and year	Pb	Hg µg/kg dw	Cd	Cu	Zn	Dry weight, %	Organic carbon, weight %#	Source	Depth
Skeivibanki, 61.41.50 N-07.47.2 W, 350 m depth, 1991	4,78		0,122	26,4	37,2	63,3	0,61	Magnusson *et al.* 1996	0-2 cm
Skeivibanki, 61.39 N-07.50 W, 347 m depth, 1994	7,3	< 60	0,15	59,3	86,8	63	0,58 TOC	Stange *et al.* 1996	0-1 cm
Sandoyarbanki 61.51 N, 05.44 W, 330 m depth, 2000		8						Olsen *et al.* 2003	0-1 cm
Føroyabanki, outer areas, 197-254 m depth, 1992	6,73	10	0,19	10,85	22,50			Gaard and Poulsen 1992	nd
Føroyabanki, towards the middle, 104-127 m depth, 1992	2,44	4	0,22	5,60	2,38			Gaard and Poulsen 1992	nd

#: Organic carbon in weight percent of dw. Possible loss on ignition as weight percent of dw.
: Depth of analysed sediment core (nd = not analysed).

Table 8. *Heavy metals in sediments from some banks. Values are in mg/kg dw when otherwise not stated. (Adapted from Mikkelsen et al., 2002)*

6 and Table 8. It is noticed that the concentration of mercury in the Skálafjord is approx. 10 times as high as on the Sandoyarbanka. A better basis for comparison arises if the mercury concentrations are expressed on an organic carbon or organic matter content basis. The organic matter content is often analysed as loss on ignition (LOI), but this parameter is not known for the Sandoyarbanka samples. Such data are available though for samples from other banks, and a LOI of 0,6 % may be used as an approximate value. Using the assumed LOI it may be estimated using the equation for the regression line from the fjord sediments (Fig. 4) that a corresponding mercury concentration at LOI = 0,6% would be 0,006 mg/kg. The measured Sandoyarbanka mean mercury concentration was 0,008 mg/kg in the top segments of the cores, which is fairly close to the value calculated from the assumed LOI, also when taken into consideration that the mercury concentrations in question were close to the detection limit of the analyses laboratory and thus that the analysis error may be relatively large.

On the shelf edge

As part of the preparations for the oil exploration in Faroese water, 20 sediment samples were collected in 1999 along the southeastern part of Faroese shelf on the slope towards the Faro-Shetland Channel, and at one station on the western part of the slope at similar latitudes. The samples were taken at between 275 and 517 meters depth, and were analysed for mercury as well as

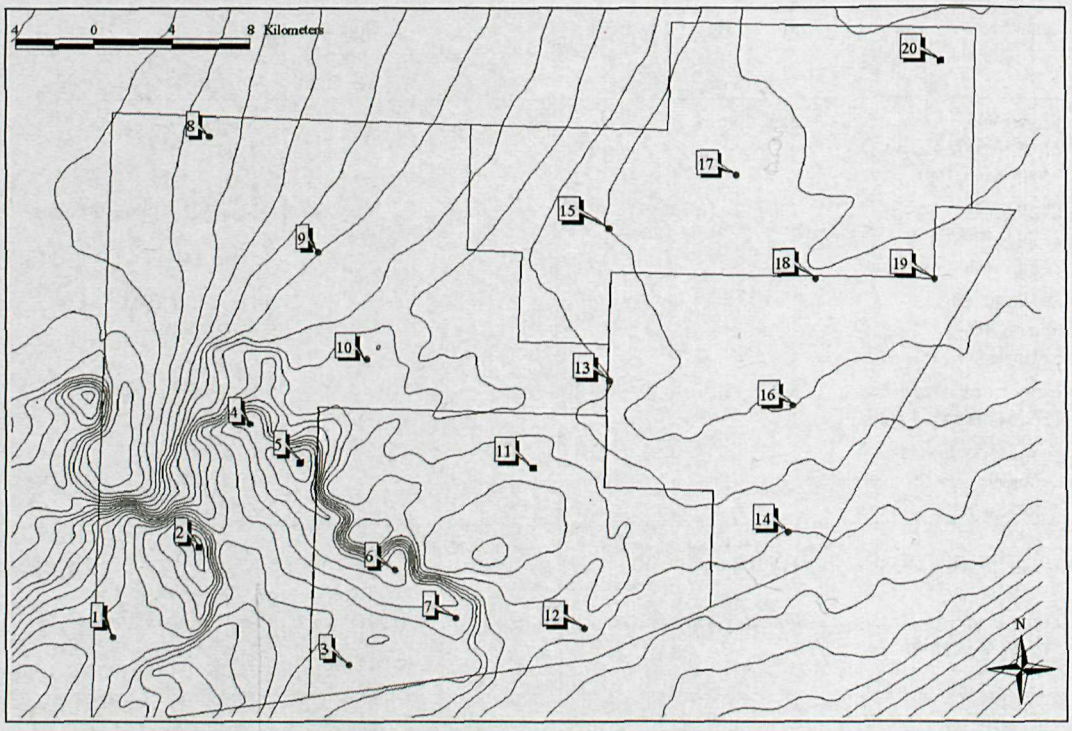

Fig. 7 Bathymetric map of the south-east part of the Faroese territory where the first exploratory drillings are located. The planned sediment sampling sites for the 2001 regional baseline are marked with numbered squares. The squares 10, 11 and 12 are on the ridge in the Faroe-Shetland Channel. (Adapted from Mannvik et al., 2002).

for Li, Cr, Fe, Ni, Cu, As, Sr, Ag, Cd, Ba and Pb (Grøsvik *et al.*, 2000). Sediment grain-size and loss on ignition was also analysed The content of particles <63 μm varied between 0,3% and 20% with an average of 5,0 ±0,9% (excluding the results from one station). The loss on ignition varied between 2,4-4,2%. Summary results from this study are given in Table 9 along with those from the regional baseline in the 1st Licence Area in 2001 (Mannvik *et al.*, 2002). Results are given for the so called conservative elements Al and Li as well, as these may be used to normalize the data of the other metals to a natural background, equivalent to what is done in the case of moss studies but then using Fe.

In 2001 a regional, environmental baseline in the Faroe-Shetland Channel was done, based on sediment samples from 16 different stations with a sampling plan involving three replicates inn all stations. The scope of the baseline was prepared in cooperation with Faroese scientists according to governmental guidelines and Norwegian standards for environmental monitoring around oil and gas-producing fields (SFT 1999) and included both biological analy-

	d.w. (%)	Al	Cd	Cu	Hg µg/kg dw	Pb	Li
F platau shelf/slope, 300-500 m depth, mean of 20 stations	73		0,09	15,9	2	6,84	6,43
std.dev	4,1		0,021	5,3	0	1,85	1,21
Min.	67,4		0,067	7,6	<1	3,43	4,64
Max.	78,1		0,148	28,7	3	10,1	8,13
F-S Channel 800-1200 m depth, mean of 16 stations		34100	0,031	7,9	8	5,7	13,2
std.dev		548	0,007	1,5	3	0,8	1,3
Min.			0,024	5,3	3	4,6	
Max.			0,042	9,6	15	6,4	

Table 9 *Concentrations of metals (in mg/kg d.w.) in sediments from the south-east slope of the Faroe shelf in 1999 and in the Faroe-Shetland Channel in 2001 (Grøsvik et al., 2000; Mannvik et al., 2002).*

ses and chemical analyses of the topmost centimetres of the sediments (Mannvik *et al.*, 2002).

It is of interest to note that in the Faroe-Shetland Channel, the sedimentation rate was analysed in four samples (station 1,2,11 and 20 in Fig. 7) and the very low sedimentation rates found indicated that this area is non-depositional, meaning that particulates present in the deeper waters don't settle at the seabed but are transported along in a southward bound current.

The littoral

The earliest analyses of heavy metals (Pb, Cd, Cu, Ni, Zn, Hg and Fe) in kelp *Laminaria sp.* and barnacle *Balanus sp.* were done on material sampled in Skálafjord at the coast just off the stations St.1, St.2, St.3 (SK09, Fig. 5) and St.4 (SK05) (Heilsufrøðiliga Starvsstovan, 1992). The stations 1 and 2 are in the bottom of the fjord and station 4 at the sill near the outer end. In the 1992 study, mercury was not detected (at 0,03 mg/kg dw) in *Laminaria sp.* nor in *Balanus sp.* In 1996-97 samples of kelp *Laminaria hyperborea*, and limpets *Patella vulgata*, sampled in Kirkjubøur, were analysed for heavy metals (Cd, Cu, Hg and Pb) and persistent organic pollutants and PAH, as part of a project dedicated to Integrated Monitoring in the coastal zone (Dam, 2000). In the project, seasonal variations in food-choice, lipid content, pollutant levels etc. as well as food-web interactions on pollutant levels were studied. The analyses were done on the *lamina* of kelp and on soft parts of limpets, but mercury could not be detected at 0,02 mg/kg dw and 0,02 mg/kg ww in kelp and limpets respectively. Limpets in the size range of approx. 4,5 to 5,5 cm diameter shell base were also sampled at Velbastaður, Gamlarætt, Torshavn, Kaldbak, Veðranes and Trøllavík. In the two first mentioned sites, mercury could not be detected (at 0,02 mg/kg), whereas at the two last mentioned locations mercury was 0,02 mg/kg and in Torshavn and Kaldbak 0,03 mg/kg (Dam, 2000). In the same period, heavy metal analyses were

Species, location and time.	Number of animals	Size (cm) (min–max)	Hg
Blue mussel, Svínáir 96[a]	210	3,9 (3,1-4,4)	0,02
Blue mussel, Svínáir, 01/02[d]	150	4,3-5,4	0,01
Blue mussel, Kaldbak nov 97[b]	57	2,3 (1,9-2,7)	0,03
Blue mussel, Kaldbak, 01/02[d]	130	4,0-6,3	0,02
Blue mussel, Hvannasund 01/02[d]	59	4,3-6,4	0,03
Blue mussel, Trongisvágur, 01/02[d]	151	4,2-5,2	0,05
Horse mussel, Kirkjubøur, 01/02[d]	68	7,1-9,6	0,02
Limpets, Kirkjubøur, 96[c]	361	4-4,8	nd at 0,02
Limpets, Velbastaður, Aug´96[c]	43	4,5-5	nd at 0,02
Limpets, Velbastaður, 01/02[d]	159	4,0-5,0	0,02
Limpets, Svínáir, 01/02[d]	139	4,2-5,0	0,02
Limpets, Hvannasund, 01/02[d]	178	4,4-4,9	0,03
Limpets, Trongisvágur, 01/02[d]	141	4,0-4,9	0,02
Dog whelk, Gamlarætt 97[c]	38	na	0,02
Dog whelk, Svínáir, 01/02[d]	65	2,9-3,8	0,04
Dog whelk, Hvannasund, 01/02[d]	266	2,5-2,9	0,07
Periwinkles, Svínáir, 01/02[d]	100	(1,2-1,8)	0,01
Periwinkles, Hvannasund, 01/02[d]	300	(1,2-1,8)	0,02
Queen scallop (Pecten opercularis) Húsagrynna 97[b]	106	6,3 (5,5-7,5)	< 0,02
Starfish (Asteria rubens), Svínáir 96[a]	66	13,3 (5,4-21,0)	0,04
Sea-urchin (Echinus esculentus), Svínáir dec 96[c]	28	7,6 (6,4-8,9)	< 0,02

na. = not analysed.

Table 10 *Average concentrations of mercury in various littoral and/or bentic fauna from the Faroes. Values are in mg/kg wet weight.*
(a. Dam, 1998c, b Larsen and Dam, 1999,c. Dam, 2000, d. Hoydal, 2004)

done on various species of molluscs and other benthos from the littoral; blue mussels (*Mytilus edulis*), grey top shells (*Gibbula sp.*), banded chinc shells (*Lacuna vincta)*, dog whelks (*Nucella lapillus*), starfish (*Asteria rubens*), sea urchins (*Echinus esculentus*) and queen scallops (*Pecten opercularis*) and the results of these are given in Table 10.

In 2001-2003, a study on heavy metals (Ba, Cd, Cr, Cu, Hg, Pb and Zn) often related to oil pollution and PAH (SFT, 1999) was undertaken. The study (Hoydal, 2004) involved analyses of blue mussels, horse mussels (*Modiolus modiolus*), limpets, periwinkles (*Littorina obtusata*) and dog whelks from the littoral sampled during four seasons at 6 selected study locations, and the mercury results as means for the entire study period, are given in Table 10. Overall, a weak and not consistent tendency of elevated mercury concentrations in blue mussels during winters or early spring was found (Dam, 2000; Hoydal, 2004). The mercury level in blue mussels in the Faroe Islands, which have been found to be are in

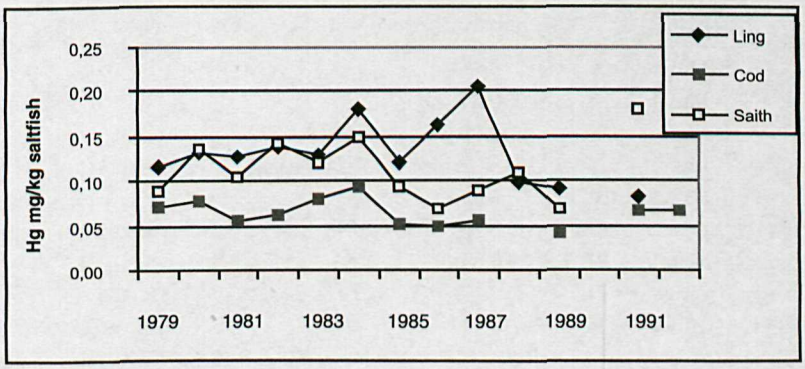

Fig. 8 Mercury in fish caught in Faroe shelf waters intended for the export market is shown, in mg/kg salt fish. (HS Journals 1979-1989).

the range 0,01-0,05 mg/kg (Table 10) is comparable to what is found in Denmark (Markager *et al.*, 1998) and in the Hardangerfjord and Langesund area in Norway, that is at the higher end of the range of concentrations found in the Norwegian JAMP (Green *et al.*, 2000).

OSPAR (QSR 2000) has reported a background/reference range of 0,005 to 0,01 mg/kg mercury in blue mussels. Overall, the mercury concentration in blue mussel samples from the Faroes are above this background level, and if ranked by the same criteria as used in Norway (Molvær *et al.*, 1997) the locations Hvannasund and Trongisvágur where the mercury concentration expressed on a dry weight basis equals 0,2 and 0,3 mg/kg dw respectively, will be in the category "moderately polluted".

Marine fish

Monitoring of mercury in fish for export was common during the eighties, and data on mercury in various fish species with information on fish length and often origin, in the period from 1979 to 1992, are in store at the Heilsufrøðiliga Starvsstovan. Fish species included in this monitoring were mainly cod (*Gadus morhua*), saithe (*Pollachius virens*), ling (*Molva molva*), blue ling (*Molva byrkelange*) and torsk (*Bros-*

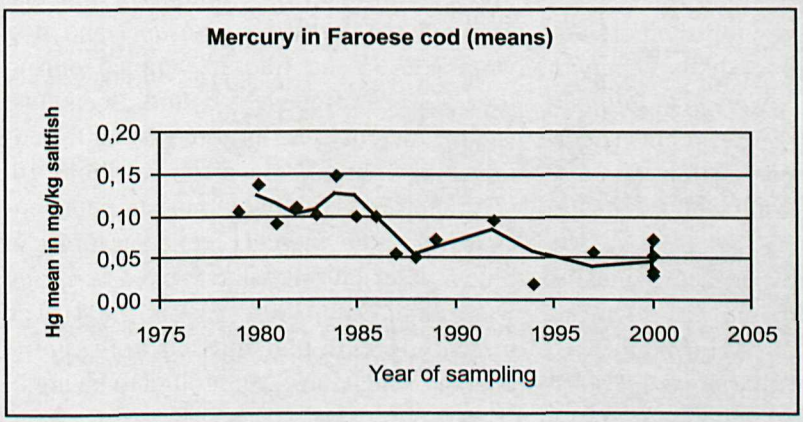

Fig. 9 Mercury in cod for the export market is shown, in mg/kg saltfish (HS Journals 1979-1989; Gregersen, 2001; Heilsufrøðiliga starvsstovan). Data from 1993 and onwards have been adjusted to be comparable to saltfish-data by multiplying the measured mercury concentration by two. Only results for cod fillets of length 40-60 cm were included.

Species	Matrix	N	Hg	Cd	Cu	Pb	Se
Orange roughy[c], 1993	Muscle	6	0,78				
Orange roughy[c], 1993	Muscle	6	0,55				
Redfish [f], 1994	Muscle	25	0,18				
Redfish [f], 1994	Liver	25		4,26		0,025	1,74
Dab[a] March-Dec. ´96, 4yrs	Muscle	101	0,03				
Dab[a] March-Dec ´96, 4 yrs	Liver	101		0,93	7,28	< 0,15	
Long rough dab[a] March´96, 5,6 yrs	Muscle	21	0,05				
Long rough dab[a] March´96, 5,6 yrs	Liver	21		0,41	8,87	< 0,15	
Long rough dab[a] Sep.´96, 10,2 yrs	Muscle	34	0,12				
Long rough dab[a] Sep.´96, 10,2 yrs	Liver	34		0,4	8,12	< 0,15	
Tuna[c] Nov.´97	Muscle	1	0,24				
Tuna[c] Nov.´97	Liver	1	0,13				
Greenland halibut[e] May´1999	Muscle	25#	0,096 [1] (0,039)	0,004	0,3	<0,03	2,9
Greenland halibut[e] May´1999	Liver	23	0,033 [2]	0,79 (0,59)	12,1 (13,5)	<0,03	<1
Sculpin[d] 1999	Liver	39	0,25	0,26			1,27
Sculpin[d] 2000	Liver	23	1,12	0,76			1,46
Sculpin [d] 2001	Liver	25	0,13	0,56			1,63
Cod[f] Nov.´94, 3 yrs£, 53cm	Muscle	25	0,01				
Cod[f] Nov.´94, 3 yrs£, 53cm	Liver	25		0,07		0,004	1,03
Cod[b] Oct. ´97 3,5 yrs, 59 cm	Muscle	44	0,028				
Cod[b] Oct.´97, 3,5 yrs, 59 cm	Liver	44		0,18	4,99	< 0,15	
Cod[c] Oct.´2000, 2 yrs£, 49cm	Muscle	10	0,017 (0,0036)				
Cod[c] Oct.´2000, 2 yrs£, 48 cm	Muscle	15 #	0,015				
Cod[c] Oct´2000, 4 yrs£, 65 cm	Muscle	10	0,026 (0,0089)				
Cod[c] Oct´2000, 4 yrs£, 64 cm	Muscle	14 #	0,036				
Cod[g] Oct´2000, 4 yrs£, 64 cm	Muscle	24 #		<0,0002		0,0107	
Cod[c] Nov´2001, 2 yrs£, 45 cm	Muscle	25	(0,006)0,022				
Cod[c] Nov´2001, 2 yrs£, 45 cm	Muscle	25 #		<0,002	0,138	<0,02	
Cod[c] Nov´2001, 2 yrs£, 47 cm	Liver	19 #	0,005		8,24	<0,15	
Haddoc[c] Nov´2001, 2 yrs£, 38 cm	Muscle	25	<0,012				
Haddoc[c] Nov´2001, 2 yrs£, 38 cm	Muscle	25		<0,002	0,154	<0,02	
Haddoc[c] Nov´2001, 2 yrs£, 38 cm	Liver	20 #	0,005		4,29	<0,15	
Halibut[c] May 2002, 1,6 kg (gutted weight), 52 cm	Muscle	10	0,023 (0,006)		0,68 (0,22)		

£ According to the statistics of the Fishery laboratory of the Faroe Island (Steingrund, pers commn.).

[1] N=25 (individual samples).

[2] N=25 (pooled sample).

One or more pooled samples

Table 11 *Concentrations of mercury and selenium (in mg/kg) in marine fish from the Faroe Islands in the period 1993 – 2001. Sources: a. Dam 1998; b. Larsen and Dam 1999; c. Heilsufrøðiliga starvsstovan; d. Olsen et al., 2003; e. Grøsvik et al., 2000 ; f. Stange et al., 1996 and g. Gregersen, 2001*

mius brosme). This monitoring of mercury in fish for export was discontinued in the early nineties and in the mid nineties environmental monitoring on a wider selection of species was begun. In Table 11 a broad presentation of the mercury concentrations measured in Faroese marine fish species since 1993 is given. The highest concentration of mercury in fish is found in orange roughly and tuna muscle and in sculpin liver. Comparing the results of long rough dab in Table 10 with those for the same species taken at Norðurhavinum at 66° 01´N and 11° 54´W (Stange *et al.*, 1996), where mercury in muscle was found to be 0,02 mg/kg, and cadmium in liver was 0,27 mg/kg, it is apparent that the metal concentrations in the fish from the Faroese shelf area are somewhat higher.

A selection of the mercury data from the monitoring of fish for export has been included in Fig. 8 and in Fig. 9. In the Fig. 8 the results for a selection of these results are given. The selection was done so as to include only mercury results for a given interval of fillet lengths, so that for cod and saithe the results for fillets in the interval 40 cm to 80 cm were included, and for ling results for fillets between 60 cm and 120 cm are included. The analyses were done on salted or fresh fillets, and when fresh fillets were analysed, the reported value has been multiplied by two thus to be comparable to salt fish measurements where the salting is assumed to have led to a mass reduction of 50%. The actual mass reduction due to water loss during salting and subsequent drying is variable, depending on the actual quality produced (Hoydal, 1954). The water content in the various qualities varied from an average 32% to 48%, whereas that of the fresh fish will be close to 80% (Gregersen, 2001). Thus assuming a 50% weight reduction may be an underestimation of the actual weight loss due to evaporation, but on the other hand does allow for the weight of salt, which in a salted cod may account for 16-18% (Hoydal, 1854).

The full length of the cod represented in the 40-80 cm fillet range can be approx. 60 cm to 120 cm, when assuming the fillet length is approx 2/3 of the fork length. This is a quite wide range compared to the fish included in the monitoring since 1994. In the eighties, cod of all sized were analysed, whereas when the purpose of the monitoring during the nineties changed to become a more general watch-keeping on the ambient pollution, a smaller fish size have been used for analyses. This selection of monitoring size have been done with reference to the monitoring guidelines of the JAMP, and generally speaking this cod for monitoring use is younger (2-3 years of age) and smaller than the fish taken for consumption (JAMP Guidelines 1999). Thus, the results of the earlier monitoring should be compared to cod of the larger size in Table 11, and then with the salt fish presentation of data in Fig. 8 in mind; meaning that values in the figure must be divided by two to be comparable to those in the table.

The overall level of mercury in cod in Fig. 8, especially in the first part of the graph, is high compared to those in Table 11 and apart from the obvious skewness incorporated when comparing salt fish-ww data to fresh fish-ww data, part of the ex-

planation could be differences in size. Also apparent is a tendency of decrease in the mercury concentration when cod data in the period 1979 to 1992 are regarded. This could stem from variability in the average size the various years, but could also stem from actual decreases of environmental mercury. In order to exclude some of this uncertainty a new selection of the 1979-1992 data were made by including only results representing fillets from 40 cm to 60 cm, and preparing a new graph, Fig. 9. Inspecting the time-trend in the new figure reveals that the tendency seen in Fig. 8 is now even more pronounced. Thus it is assumed that there were overall higher concentration of mercury in cod from the Faroese shelf area during the eighties than in the late nineties and the present levels.

Overall, the level of mercury in cod from the Faroese shelf area the last 5-10 years may be described with the range 0,01- 0,04 mg/kg muscle (Table 11). This is low compared to for instance mercury in cod in the Lofoten area in Norway, where in the same period the concentrations measured as part of JAMP have been in the range 0,04 mg/kg to 0,13 mg/kg muscle (Green *et al.*, 2000). Compared however, to cod (*Gadus m.)* from the Nuuk area, Greenland, where the muscle mercury in 35-43 cm fish was 0,014 mg/kg, the level in Faroese cod is of equal magnitude.

Sculpin, *Myoxocephalus scorpius*, has been analysed as part of the AMAP program in 1999, 2000 and 2001 (Olsen *et al.*, 2003). The sculpin fishery for this monitoring has taken place in Kaldbaksfjørd, at various sites, selected so as to avoid sewage discharge sites. The fish has been analysed either in pools combining fish of similar length or as individuals. The results so far have been highly variable in particular with respect to mercury, Fig. 10, but also cadmi-

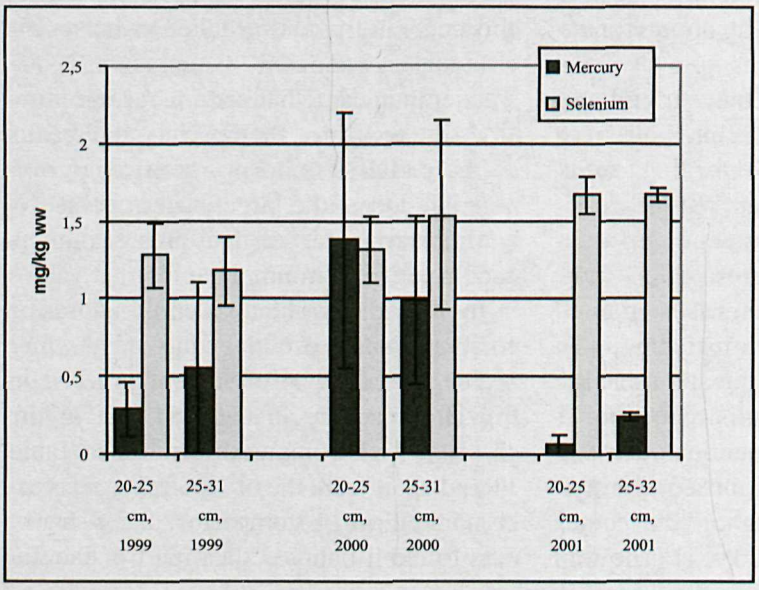

Fig. 10. *Mercury and selenium in sculpin liver from Kaldbaksfjord are shown in mg/kg ww along with error bars depicting the standard deviation (Olsen et al., 2003).*

um concentrations have varied markedly, between 0,5 and 1,2 mg/kg in the 25-31 cm group in 1999 and 2001 respectively. In the Fig. 10, the mercury concentrations for two size groups, the 20-25 cm and 25-31 cm fork length groups, in the three succeeding years are given. For cadmium it is apparent that there is a relation between fish size and cadmium concentration, in that the cadmium concentration in the smaller size group is always lower than or equal to the one in the larger group. Although increasing cadmium and mercury concentration in groups of increasing age/length has been shown to be the rule rather than the exception within the single study years (Olsen *et al.*, 2003) the individual and between year variation is so large as to incur a closer investigations of its source in 2004. It is hard not to interpret this variability as stemming from local sources, however, the fact that this variation in mercury is mirrored also in PCB and DDT concentrations (as found by inspection of raw data) makes such an interpretation a bit dubious.

Comparing the metal concentrations of sculpin from Kaldbakfjord with those from similar monitoring in Greenland (Riget *et al.*, 2003) where the highest mercury concentrations in shorthorn sculpin (*Myoxocephalus quadricornis*) in the 1999-2000 was found in Ittoqqortoormiit in fish of length approx. 25 cm, and which amounted to 0,061 mg/kg liver, it is apparent that the level in the Faroese sculpin of similar length is more than ten times higher. For cadmium however, the concentrations in the Greenland sculpin and the Faroese ones are more comparable, but also for cadmium there are large individual and annual variations in the Faroese material. The selenium concentrations in the Faroese sculpin (Fig. 10) are similar to those in Greenland, although somewhat higher.

Analyses of dab (*Limanda limanda*) from the coastal area off Kirkjubøur show relatively low values of mercury, in the range 0,02-0,03 mg/kg muscle (Dam, 2000), compared to for instance dab in Norway where mercury concentrations in the range 0,04 mg/kg-0,09 mg/kg muscle were found in 1998 (Green *et al.*, 2000) and to levels in Denmark, where mercury in flounder (*Platichtus flesus*) and plaice (*Pleuronectes platessoides*) were found to be in the range 0,12-0,25 mg/kg and 0,05-0,07 mg/kg respectively (Markager *et al.*, 1998). Flounder were analysed in the Norwegian JAMP as well, and the concentration range in this species was somewhat broader than in dab, spanning from 0,04 mg/kg to 0,26 mg/kg muscle in 1998 *i.e.* the upper end of this range is aligned with the Danish results (Markager *et al.*, 1998; Green *et al.*, 2000). Thus it appears that mercury concentrations in the fish in shallow coastal areas of the Faros Islands are low compared to Norway and Denmark, but elevated at least for sculpin at one site, compared to the Greenland coastal environment.

In 1977-1984 mercury was analysed in halibut larger that 60 kg full weight which were caught in Faroese waters (Priebe, 1984). In all, muscle samples from 377 individuals were analysed, and the results were that in 28,4% of the fish a mercury concentration in the range 2,0-3,5 mg/kg was found. In approx. 30% of the fish, the

mercury concentration were in the range 1,5-2,0 mg/kg, in 16%, a mercury concentration in the range 1,0-1,5 mg/kg was found, and in 25,6 % the mercury concentration was below 1 mg/kg, and thus within the present day "edible" range as defined for instance by the directives of the European Union.

Squid

Analyses of squid (*Loligo forbesi,* n =14) of mantle length between 21 and 42 cm (mean =28,2 cm) in 1987 gave an overall mercury mean concentration of 0,02 mg/kg (Bloch *et al.*, 1987).

Squid (*Todarodes sagittatus*) and *Gonatus sp.* samples from 1999 and 2000 were analysed for mercury and cadmium as well as persistent organic pollutant in a study of pollutants in fulmars and their possible prey (Dam *et al.*, 2001). The mantle mercury concentration in the *Todarodes s.* samples (n= 21) from the Faroe shelf area were in the range 0,01 to 0,12 mg/kg, with dry weight in the range 20-23%, in individuals of mantle length between 19 and 40 cm (mean 25 cm). In two smaller *Todarodes s.* individuals (mantle length 10 and 15 cm) samples in 2000 also from the shelf area, the mantle mercury concentration was 0,034 and 0,030 mg/kg respectively. In a batch of *Gonatus sp.* (n=50) samples taken in 2000 at 68 N, 00 E, the whole animal mercury concentration was not detected at 0,1 mg/kg dw.

Todarodes s. (n= 10) from Falkland waters in 1999 and mantle length in the range 18-25 cm were analysed as well, and the mantle mercury concentration was found to be 0,01 mg/kg (unpubl. results) and thus highly comparable to the Faroese waters samples. The most peculiar results of the studies were the cadmium concentrations, which appeared to be very variable in the range 0,02 to 0,74 mg/kg. A larger selection of cephalopods (*Todarodes s.*, *Loligo f.* and *Eledone cirrhosa*) from Faroese waters were analysed for cadmium in a study where the aim was to elucidate the vectors for the high marine mammal cadmium concentrations often encountered (Bustamante *et al.*, 1998). In this study, the cadmium concentrations found were 0,46 mg/kg in *Loligo f.*, 3,46 mg/kg in *Todarodes s.* and 9,06 mg/kg in *Eledone c.* and thus increasing still the range of cephalopod cadmium concentrations.

Seabirds

Feathers

Birds' feathers may be used in retrospective mercury analyses and such samples are often available in museum collections and can thus provide valuable data of comparisons to the present day mercury load in the same bird species (Somer 1981; Appelquist *et al.*, 1985)

The mercury data which describe the oldest samples of seabirds from the Faroe Islands are those of feathers from Common guillemot (*Uria aalge*) and Black guillemot (*Cepphus grylle*) as Appelquist *et al.*, 1985 analysed museum specimens in search of a time tend in mercury in *Guillemot sp.* in the Baltic as well as in the North-east Atlantic area. The authors were able to describe an increasing trend in mercury levels in the Baltic as well as in the Faroes, where the

Species	Hg	Reference
Black guillemot, 15 ind., Jun.-Aug.1996, dorsal contours	3,4 ± 0,9*	Olsen et al., 2003
Black guillemot, 5 ind., shaft, fifth primary, left wing 1974	2,8± 0,5	Appelquist et al., 1985
Black guillemot, 9 ind., 1909- 1949	1,8	Somer and Appelquist, 1974
Common guillemot, 12 ind., shaft, fifth primary, left wing 1973	1,21±0,07	Appelquist et al., 1985

*Exluded in this mean is one individual with mercury concentration above 20 mg/kg, while the concentration in all the others was below 5 mg/kg. The mean value including this outlier was 4,7 mg/kg.

***Table 12** Mercury in seabirds' feathers, in mg/kg.*

mercury concentration in guillemots at ca 1900 were approx. 0,6 mg/kg and in 1973 approx. 1,1 mg/kg. In Table 12 summary results of mercury in feather analyses are presented, including those on black guillemot feathers samples from the summer of 1996 (adapted from Olsen *et al.*, 2003). The analyses of the1996 samples were done on dorsal (from the back between the wings) and ventral (from the body under the wing) body contour feathers and with some down in-between. Turning from analyses of intestinal organs to feathers (or hair) may warrant access to samples even from protected birds because the sampling in itself may be done without inflicting harm to the bird, it is however essential to be able to correlate the feather mercury concentration to some concentration in the bird and therefore the livers were analysed in the same birds (Olsen *et al.*, 2003). The aim of the study was thus to compare mercury in feather sampled under the wings as is regarded as the place where some loss of cover is presumed to inflict the least harm to a living bird, to mercury in feather sampled at the back, and to relate these to the liver concentrations. Testing showed, that there was no significant difference between the median mercury concentrations in the dorsal feathers to the ventral ones[2], but also that the feather mercury concentration may not be used to extrapolate to a liver mercury concentration.

Comparisons with earlier analyses (Somer and Appelquist, 1974; Appelquist *et al.*, 1985) are complicated by he fact that the earlier analyses are done on primaries *i.e.* the principal quills of a bird's wing, and even though the variability of mercury concentration among primaries are known for black guillemot (Appelquist *et al.*, 1984) it still remains to describe the concentration in primaries to that in body feathers. In analyses on Bonaparte´s gull a marked difference was found between mercury concentrations both within one individual feather, but also among the various feather types (Braune and Gaskin, 1987). In the Bonaparte´s gulls, the mercury concentration in body feathers were higher than in primaries, but in a similar study then on herring gulls (*Larus argentatus)* the opposite was found (Lewis *et al.*, 1993). Thus, a

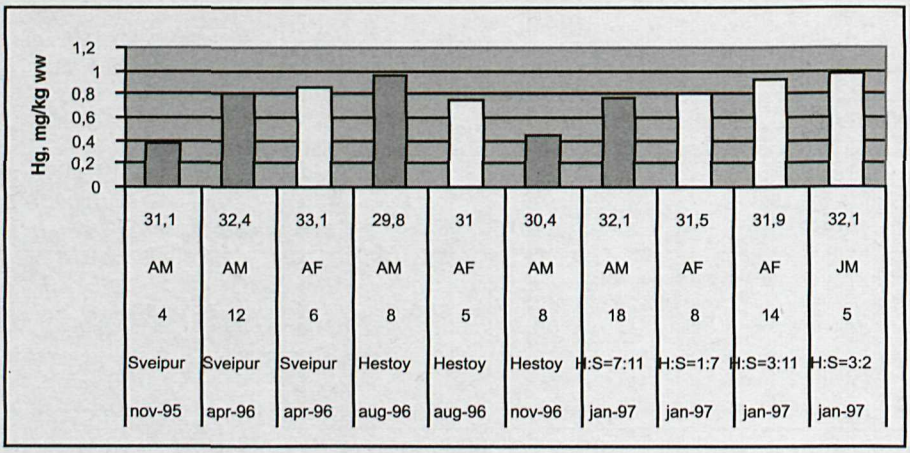

Fig. 11 *Mercury in Black guillemot s are given for groups of adult males (AM), adult female (AF) and juvenile males (JM) in mg/kg ww liver. Under the bars, the dry weight, %, is shown, along with group description incl. number of samples in the pools and sampling areaand period.(Adapted from Dam, 1998b).*

comparison between feather mercury concentrations in the Black guillemot plumage should await a species-specific description on interfeather variation preferentially in the population in question.

Liver and muscle tissue

The first study integrating biological parameters and environmental pollutants concentrations in various trophic levels in the coastal zone in the Faroe Islands were done on material sampled in the period 1995-1997 and the study included black guillemot as a representative of a stationary seabird species (Dam, 2000). In this study, the diet of black guillemots were analysed through stomach contents and the result was not as expected, where the major difference to the expectations was that black guillemots obviously had a much greater variety in its food choice than anticipated. Also, it was found that there were marked summer and winter diets, with fish dominating in the early summer and crustacea in winter (Dam, 2000). At the same time, a similar investigation was undertaken on eider (*Somateria mollissima*) and to a smaller extent on shag (*Phalacrocorax aritsotelis*) (Dam, 1998b; 1998c). Overall, a large number of birds was analysed for heavy metals and persistent organic pollutants, both to elucidate seasonal trends and differences among sexes and age groups. The majority of the analyses were done on pools of birds of similar age/sex, and thus individual variability can not be described, the results still give a fair amount of data, and may as such serve as valuable reference for future studies.

The results of the food choice studies (Dam, 1998b) showed that the eider feeds on a variety of gastropods and bivalves whereas the shag is a dedicated fish eater. Mercury concentrations (Table 13) are

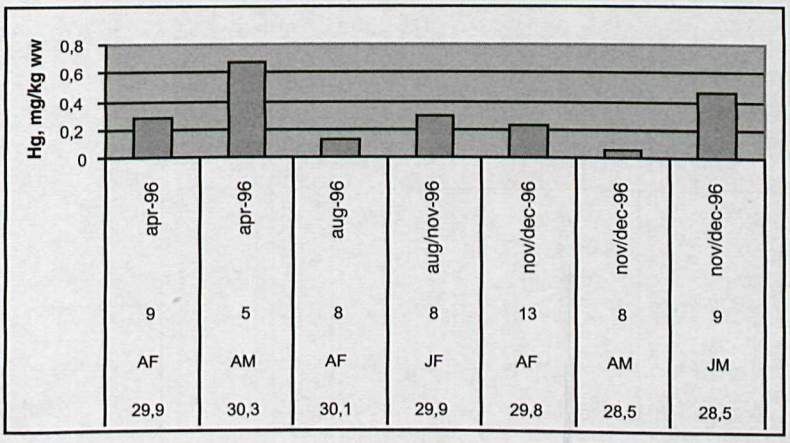

Fig. 12 Mercury in eider in groups of adult females (AF), adult males (AM), juvenile females (JF) and juvenile males (JM) are given in mg/kg ww liver. Under the bars are the sampling period, the number of individuals in each pool (between 5 and 13) and the liver dry weight (%) shown. (Adapted from Dam, 1998c)

quite similar in eider and shag and do not suggest large differences in food choices, but then only 7 out of the 40 shags analysed were adults, and when compared to a sample of mainly adult eiders, this may skew the picture substantially. However, the results of cadmium and copper in these seabirds (not shown) do strongly point to a different food source in eider than in shag, where the copper liver concentration in eider and shag were 90 mg/kg and 9 mg/kg, and the cadmium liver concentrations were 3,3 and 0,4 mg/kg respectively. Analyses of molluscs were part of these same investigations and particular high concentrations of these metals were found in molluscs from the littoral (Dam, 1998c). In the eiders, the highest mercury and copper concentrations were found in adult males. Especially the copper concentrations in these adults were high, with 394 mg/kg liver in one adult male. Earlier studies from Svalbard revealed a liver copper concentration of 1050 mg/kg in one eider and closer inspection

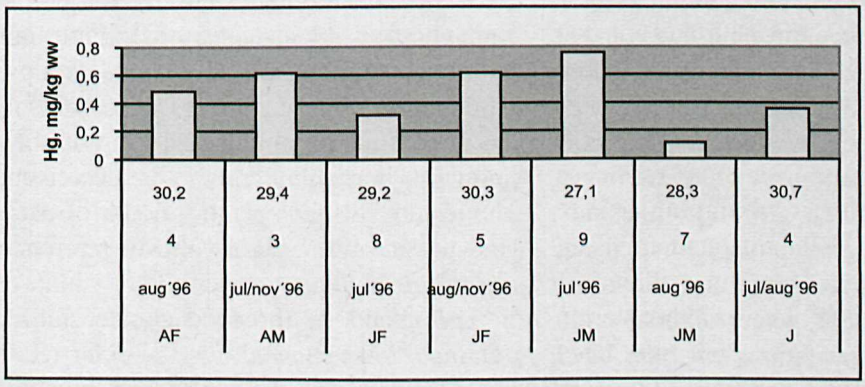

Fig. 13 Mercury in shag in groups of adult females (AF), adult males (AM), juvenile females (JF) and juvenile males (JM) or just undeterm. juveniles (J) are given in mg/kg ww liver. Under the bars are the sampling period, the number of individuals in each pool (between 3 and 9) and the liver dry weight (%) shown.(Adapted from Dam, 1998b).

	Sampling	Sampling area	n	matrix	Hg, mg/kg ww
Black guillemot *[a]	Nov'95-Feb'97	Hestoy/Sveipur	88	liver	0,74
Black guillemot[c]	Jun'96-Aug'96	Hestoy/Sveipur	33	liver	0,7
Eider *[a]	Apr'-96-Feb'97	Tangafjørð	52	liver	0,26
Shag *[a]	Nov'95-Nov'96	Sandoy	40	liver	0,41
Fulmar pullus[b]	Aug'97	Vestmanna	15	liver	0,11
Fulmar pullus [b]	Aug'97	Nólsoy	25	liver	0,19
Fulmar, juvenile[d]	Sep'99	Viðareiði	10	muscle	0,52**

* Geometric means are given.
** mg/kg dw.

Table 13. *Mercury in seabirds from the Faroe Islands (a.Dam, 1998b; b.Larsen and Dam, 1999; c.Olsen et al., 2001, d. Dam et al., 2001).*

did not indicate that this was accompanied by any negative impacts (Norheim, 1987; Norheim and Borch-Iohnsen, 1990).

Liver mercury in black guillemot from Greenland in 1984-1986 (Nielsen and Dietz, 1989) and 1999 (Riget *et al.*, 2003) was found to be in the range 0,5-0,64 mg/kg ww and 0,61 (0,19 mg/kg respectively, *i.e.* in the lower end of the range found in the Faroese birds. Whereas in eider liver from Greenland the mercury concentration was in the range 0,48-1,19 mg/kg which is partly overlapping the range found in the Faroese and partly exceeding this range (Nielsen and Dietz, 1989).

Included in the Table 13 are also results of not yet fledged fulmars. Young fulmars are part of the Faroese local diet, and are taken in large numbers each autumn. At the time of catch, these young birds have not started food seeking on their own, but have been fed by parents in the nest until they were caught sitting on the sea surface. The fulmars in the table were taken in Nólsoy and Vestmanna in 1997, and were analysed for heavy metals as well as organochlorine pollutants (Larsen and Dam, 1999). In 1998 and 1999, more samples of fulmars were taken for extensive analyses of persistent organic pollutants in various tissues, and in a batch of 10 juveniles from September 1999 muscle mercury (Table 13) and cadmium was analysed (Dam *et al.*, 2001).

Eggs

Analyses of seabirds' eggs were done in a few studies in the seventies and eighties on mainly great skua (*Stercorarius skua*) by Bloch *et al.* (1987). In the late nineties a systematic sampling and analysing of pollutants in black guillemots eggs were implemented as part of the AMAP work (Hoydal and Dam, 2003). Yearly sampling of ten eggs has been done in two colonies, in Koltur and in Skúvoy since 1999 and continues.

Analyses of the black guillemot eggs indicate that in recent years, there may be a decreasing trend in mercury concentration

Species	Hg, mean (range)	Reference
Black guillemot, 10 eggs, Koltur, 1999	0,51 (0,35-0,97)	Olsen et al., 2003
Black guillemot, 8 eggs, Skúvoy, 1999	0,51 (0,39-0,73)	
Black guillemot, 10 eggs, Koltur, 2000	0,36 (0,16-0,55)	
Black guillemot, 9 eggs, Skúvoy, 2000	0,30 (0,14-0,42)	
Black guillemot, 10 eggs, Koltur, 2001	0,32 (0,18-0,45)	
Black guillemot, 10 eggs, Skúvoy, 2001	0,33 (0,19-0,44)	
Northern Fulmar, 3 eggs, 1972	0,21 (0,17-0,26)[1]	Bloch *et al.*, 1987
Puffin, 1 egg, 1972	0.45	Bloch *et al.*, 1987
Great skua, 3 eggs, 1972	1,35 (0,95- 1,59)[1]	Bloch *et al.*, 1987
Great skua, 8 eggs, Saksun, 1977	1,0 (0,68 - 1,4)	Bloch *et al.*, 1987
Great skua, 5 eggs, Skúvoy, 1977	1,2 (0,92 - 1,7)	Bloch *et al.*, 1987
Great skua, 6 eggs, Svínoy, 1977	0,9 (0,63 - 1,2)	Bloch *et al.*, 1987
Larus fuscus, 1 egg, 1972	0,44	Bloch *et al.*, 1987
Common guillemot, 5 eggs, 1972	0,20	Dyck and Kraul, 1984

[1]: The concentration of methylated mercury is available in the ref.
Numbers in parentheses are minimum and maximum values.

(Olsen *et al.*, 2003). However, paralleling this decrease in mercury was also a decrease in PCB, and this is interpreted as an indication that the reason for the decrease may not be that the ambient level of these pollutants has decreased, but rather that the birds have a decreasing intake of "typical" mercury and PCB carriers. Therefore as part of a BSc study black guillemot eggs samples from the Environmental Specimen Bank were analysed for stable isotopes of nitrogen and carbon to study whether the observed decrease in PCB was accompanied by a decrease in trophic position and thus could stem from interannual variations in diet (Ólafsdóttir, 2002). The results indicated that there had *not* been any shift to lower trophic level feeding accompanying the decreasing pollutant concentrations. It is nonetheless "suspicious" that both mercury and PCB decrease to such extents and other explanations are sought which may sustain such change. Hence it is speculated whether the black guillemots these years may have changed the diet from a more lipid rich fish species towards a leaner and thus less polluted kind.

The mercury concentration in great skua eggs are twice as high or more than the concentration in black guillemot eggs (Table 14), a finding which is most likely related to a higher intake of mercury with prey in the predators great skuas than in the lower tier feeding black guillemot. It is also noted that the mercury concentration in black guillemot eggs are higher than in the guillemot sp. eggs sampled in 1972 (Dyck and Kraul, 1984). This may not be an indication of a trend though, as the study of black and common guillemot feathers in early seventies (Appelquist *et al.*, 1985) showed a 100% higher feather mercury concentration in the former species. Analyses of mercury in black guillemots eggs in Greenland

(Riget *et al.*, 2003) revealed 0,34 mg/kg and 0,26 mg/kg in two colonies sampled in 1999 (Ittoqqortoormiit, n=10) and 2000 (Qeqertarsuaq, n=7) respectively. The mean mercury concentration in black guillemot eggs from three colonies in Arctic Canada in 1993 and 1998, were shown to be somewhat higher than the Greenland eggs at 0,39 mg/kg to 0,60 mg/kg (Braune *et al.*, 2002). Thus it appears that the mercury concentration in the Faroese black guillemot eggs (Table 14) are within the range defined by the Greenland birds in the low end and those from Arctic Canada in the higher.

Marine mammals

Long-finned pilot whale

The long-finned pilot whale, *Globicephala melas,* was taken in the local Faroese drive hunt in a number of approx. 1000 individuals per year during the last decade, but the annual catch is highly variable, from 500 to 2500 individuals (Bloch, 2004). The annual harvest which in the years 2000 and 2001 were 588 and 918 respectively, provided a pro persona annual meat amount of 5 kg and with this, 4,5 kg of blubber (Mikkelsen *et al.*, 2002). The long-finned pilot whale have provided valued addition of meat and blubber to the Faroese diet for centuries (Bloch, 2004), a tradition which has become threatened in recent times by the high concentrations of mercury and persistent organic pollutants and their adverse effects on child development (Grandjean *et al.*, 1992; 1995a; 1995b; 1997).

The first dietary advice issued by the Health Authorities on the Faroe Islands on pilot whale consumption, was given in 1977, and then the message was to warn against eating whale liver due to high mercury concentrations (Fig. 14) which had been found in concentration up to 270 mg/kg liver (HS Annual Report 1976/78). But also whale meat was then known to contain mercury at concentrations of concern (Fig. 15) and the general advice was to abstain from whale liver, and only eat whale meat once a week (HS Annual Report 1976/78).

Ten years later the advice was tightened so as to suggest that whale dinners were limited to once or twice a month (HS, 1989).

And finally, in 1998, the dietary advice was far more restrictive, now pertaining to blubber as well as meat and entrails and this time the language in the advice was to advice female in reproductive age and girls to abstain from eating blubber where high

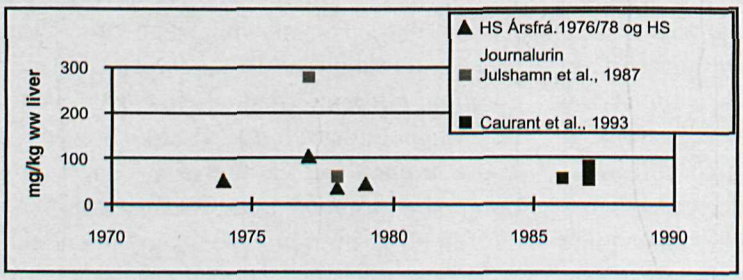

Fig. 14 *Mercury in long-finned pilot whale livers. The mean mercury for the sample pool is shown, in mg/kg ww liver. (HS Ársfrág. 1976/78= HS Annual Report1976/78; HS Journalurin =HS journal 1979-87 and 1987-89).*

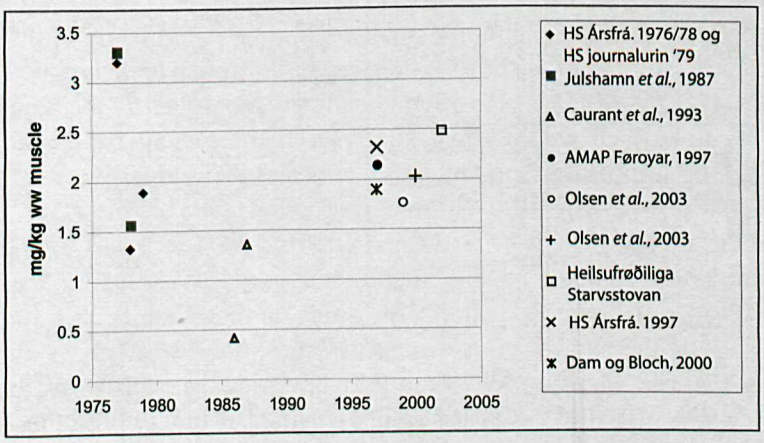

Fig. 15 Mercury in long-finned pilot whale muscle is shown, in mg/kg ww. The mean mercury for the sample pool has been calculated from the average distribution of muscle from males, females and young. (HS Ársfrág. 1976/78= HS Annual Report 1976/78; HS Journalurin =HS journal 1979-87 and 1987-89).

concentrations of lipid soluble persistent organic pollutants had been found. (HS, 1998)

Recent research suggest that the food advice have been effective in reducing almost by a factor 10 the mercury concentration in

					Hg, mg/kg ww muscle		
Location	Date	No of whales in pod	No analysed	Norm. pod mean Hg *	Adult males	Adult females	Juveniles
Vágur[a]	16-08-1997	108	49[P]	2,14	2,66	2,46	1,55
Sandavágur[b]	26-08-1997	165	57[P]	2,3	3,25	2,73	1,28
Bøur[b]	28-08-1997	36	35[P]	1,72	2,3	2,03	1,06
Hvannasund[b]	01-09-1997	60	50[P]	0,89	1,27	0,97	0,59
Tórshavn[b]	05-09-1997	39	36[P]	2,59	3,17	2,74	2,22
Bøur[b]	06-09-1997	35	35[P]	1,49	1,76	1,88	0,94
Bøur[b]	20-09-1997	158	50[P]	2,23	3,10	2,58	1,34
Tórshavn[b]	24-09-1997	157	54[P]	1,65	1,93	1,97	1,19
Tórshavn[b]	13-11-1997	81	50	2,61	2,92	3,30	1,74
Leynar[b]	02-12-1997	74	50	1,44	1,94	1,65	0,95
Tórshavn[c]	14-03-1999	131	50	1,54	1,85	1,63	1,31
Vestmanna[c]	08-09-1999	34	22	1,99	2,06	2,49	1,46
Hvannasund[c]	31-08-2000	246	50[P]	2,44	3,07	2,86	1,62
Tórshavn[c]	09-09-2000	21	21	1,61	2,00	1,86	1,13
Tórshavn[2]	03-09-2002	42	42	2,48	3,18	3,18	1,27

* The normalised pod mean mercury concentration is based on the average distribution of adults and juveniles, males and females (Bloch *et al.*, 1993b).

[P] These samples were analysed in three pooled samples consisting of adult males, adult females and juveniles of both sexes.

***Table 15** Mercury in pilot whales analysed since 1997 (a. Larsen and Dam, 1999, b. Dam and Bloch, 2000 c. Olsen et al., 2003; d: Heilsufrøðiliga starvsstovan, 2002).*

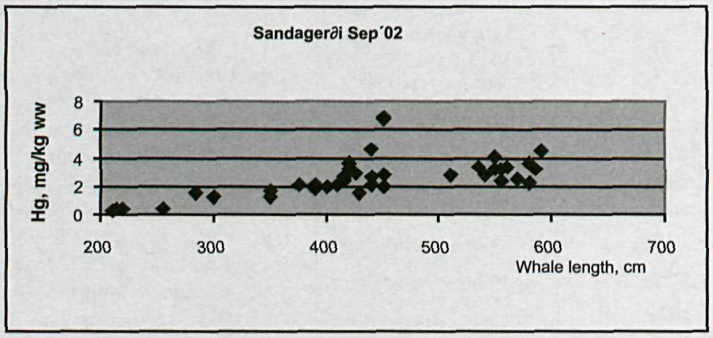

Fig. 16 Mercury in pilot whale muscle in one particular grind taken in Sandagerði in 2002 (Heilsufrøðiliga Starsvsstovan)

females (Weihe *et al.*, 2003) because, as is indicated in the tables below, there are not many indications that there have been reductions in the mercury levels in the whales.

In 1986-1988 an extensive sampling of data on and tissue from long-finned pilot whales took place in the Faroe Islands, in connection with the traditional whale hunt (Bloch *et al.*, 1993). Major results from the study were published in a special issue of the Report of the International Whaling Commission (Donovan *et al.*, 1993). Part of the study was to elucidate the pollutant load in pilot whales, both the persistent organic pollutants and the heavy metals like mercury.

Whale muscle has been the main tissue for analyses of mercury performed by the Food and Environmental Agency since the mid 1990s as muscle was the presumed major mercury vector in the whale to people transfer, since advice against eating whale livers has been in effect since 1977.

In the earlier studies however, more efforts were put on analysing the mercury concentration in tissues of blubber (Juelshamn, *et al.*, 1987; Simmonds *et al.*, 1994), kidney and liver in addition to muscle (HS Annual Report 1976/78; HS Journal 1979-89; Juelshamn *et al.*, 1987; Caurant *et al.*, 1993; Caurant *et al.*, 1994) as well as in milk and mammary gland (Caurant *et al.*, 1993). In the studies of Juelshamn *et al.*, 1987 and Caurant *et al.*, (1993;1994), also other metals like As, Cd, Cu, Zn and selenium were analysed. In addition, total as well as methylated mercury is given for 1977 and 1978 pilot whale samples of muscle, liver, blubber and kidney in the study of Juelshamn *et al.*, 1987. Likewise, organomercury as well as total mercury were analysed in liver samples from 1987 by Schintu *et al.* (1992). The mercury and methyl-mercury along with selenium concentrations were analysed in pilot whale muscle, kidney and liver in a study by Caurant *et al.*, 1996, with special emphasis on lactating females. In Hvalvík 1998, samples of pilot whale hearts were taken from 10 individuals, in fact 15 individuals were investigated for sampling but in 5 of these the heart had already been taken. The heart mean mercury concentration was 2,04 mg/kg (± 0,53) with the lower values in the young males at 1,23 ±0,0 mg/kg (n=2) and higher in adult females at 2,2±0,4 mg/kg (n=6) and in adult males 2,4±0,2 mg/kg

Whale ID	Size	SEX	Hg, mg/kg ww		
no.	(skinn)		Muscle	Kidney	Liver
14	8	female	4,7	11,2	230
		(3)	*(2)*	*(19)*	
20	12	male	7,0	5,8	107
		(5)	*(1)*	*(9)*	
25	13	male	3,5	5,4	63
		(2)	*(1)*	*(5)*	
median (n=37)	**5**		**1,45**	**5,4**	**12,1**

Table 16 *Mercury in muscle, kidney and liver tissue from the grind in Sandagerði 28 Aug 1979. The numbers in parentheses are the ratio of the mercury concentration in the specified individual and tissue to that of the median for the sample. (HS journal 1977-79).*

(n=2) (Heilsufrøðiliga Starvsstovan, unpubl.)

In 1997, sampling was done in 10 out of 15 whale hunting events. In this sampling 466 whales were included, but the analyses were mainly done on pooled samples (Dam and Bloch, 2000). In Table 15, the results of the mercury analyses on pilot whale muscle (=meat) from 1997 and onward is shown. In the table, results are presented for the pods as well as for the adult males and females and the young. The sorting of the individuals into pools have been done according to the studies of age/length at sexual maturity (Bloch *et al.*, 1993b, Desportes *et al.*, 1993; Martin and Rothery, 1993) and was done because the concentrations of pollutants do vary with age and sex, and a large number of individuals thus could be analysed in pools at reduced costs The overall mean of the pod muscle mercury concentration was 1,94 mg/kg in the period 1997 to 2002, where the majority of the samples were taken in 1997 (Dam and Bloch, 2000). Samples from in all 100 individuals, from the Tórshavn, Nov'97 and Leynar Dec'97 pods were analysed individually, for mercury as well as for persistent organic pollutants (Dam, 2001).

A comparison of mercury in muscle, kidney and liver is given in Table 16 where it is seen that the most marked increase in mercury with size is taking place in the liver tissue. To a certain but for females limited extent, body length is correlated to age (Bloch *et al.*, 1993b) and several analyses have shown that mercury is positively correlated to length (as in Fig. 16). Explicitly, mercury and age have indeed been shown to be positively correlated in studies by Caurant *et al.* (1994). In the Table 16, it is seen that a ratio of 19 is found for the mercury liver concentration in an 8 *skinn* (see below) female to the median mercury liver concentration of the entire sample, whereas the kidney mercury concentration in this same individual is only two times the sample median. The relatively low median liver mercury of 12 mg/kg also indicate that there are many individuals whose liver mercury concentration is low and comparable to the muscle mercury concentration, which is overall lower than in kidney and especially compared to what may be found in the liv-

er (see also Caurant *et al.*, 1994). The highest recorded mean liver mercury concentrations was detected in the Hvalba 1977 *grind*[3], at 280 ± 100 mg/kg ww (n=8) (Juelshamn *et al.*, 1987). The inter and intracellular distribution of mercury in long-finned pilot whales muscle, liver and kidney tissue was described by autometallographic tracing (Stoltenberg *et al.*, 2003).

A large, but variable part of the total mercury in pilot whale is present as methylated mercury. According to the study by Juelshamn *et al.*, (1987) involving pilot whales from Hvalba in 1977 and Hvannasundi in March 1978, an average of 48% and 64% of the total mercury in the meat was methylated mercury in the two samples respectively. The range however, was quite wide, with the lowest values in the Hvannasund samples at 24% and the highest at 86%. These 86% equalled 1,72 mg/kg of methylated mercury and this concentration was found in the largest individual of 16 *skinn*.

The *skinn* value is a traditional measure of the size of the whale in edible amounts of meat and blubber, where one *skinn* is approx. equal to 34 kg of meat and 38 kg of blubber (Bloch and Zachariassen, 1989).

The *skinn* value is also used when depicting the mean pod mercury concentration as in Fig. 15, because this gives the possibility to calculate a pod mercury average which is then unrelated to possible abnormal distribution of females and males and young and adults in the pod. By introducing a correction factor based on the *skinn* values mass weighed mercury pod means may be calculated. The calculation is done by multiplying the group mercury means with the average percent of the total pod mass the particular group normally represents. For the adults males this percentage was found to be 23% in the large 1986-88 study, and similarly, the mass made up of adult females was on average 42%, and the one comprised of juveniles is 32 % (Bloch *et al.*, 1993b). The overall mean adult male and female muscle mercury concentration (mean of figures presented in Table 15) in recent years was 2,4 and 2,3 respectively, with the mean concentration in the young at 1,3 mg/kg. Seen in a larger time perspective (Fig. 15) these concentrations do not appear to be markedly lower than in earlier analyses. However, a pod mean of 3 mg/kg as in the Hvalba 1977 study has not been recorded since, and the reason may be found in the sampling, because the Hvalba sample size was only 10 individuals of unknown size, so if these were solely adults, then a mean of 3 mg/kg would be consistent with later samples for instance those of Tórshavn Sep. 1997 and Nov. 1997 as well as Tórshavn Sep'2002.

White-sided dolphin

In the Faroes, white-sided dolphin, *Lagenorhynchus acutus,* schools are occasionally taken for food in the same manner as the pilot whales. The average annual number of white-sided dolphins taken during drive hunts in the last decade is 370 individuals (Bloch, 2004) with some years no catch at all, as in 1999, and with peak years in between, with a maximum in 2002 where 774 white-sided dolphins were taken.

Few analyses of environmental pollutants including mercury have been done on

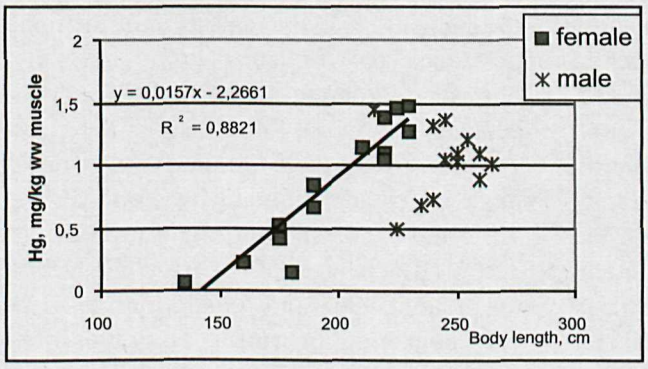

Fig. 17 Mercury in white sided dolphin muscle from Klaksvík 1997. The regression line based on the female results is shown (Adapted from Dam, 2001).

this species. However, during the Klaksvík, 21st August 1997 hunt, involving 150 white-sided dolphins, samples were taken for analyses. From a total of 28 individuals samples of muscle and blubber were taken and analysed for mercury and persistent organic pollutants respectively (Dam, 2001). The overall mean muscle mercury (Fig. 17) concentration was 0,94 mg/kg and thus lower than in an average pilot whale pod. The representativity of this sample, which consisted of 12 adult males, 8 adult females and 8 juveniles, of which only one male, is uncertain though. From the same school, kidney tissues were taken for cadmium and mercury analyses. The kidney mercury concentration were in the range 0,1 to 2,5 mg/kg, with the lowest concentrations in individuals younger than 1 year and the highest in a 10 year old male. The kidney cadmium concentration, which occurred in calcium-cadmium-phosphate in a Ca:Cd ratio of 10, was not detectable in the juveniles (at 0,1 mg/kg) and was 31,1 mg/kg in the same 10 yrs old male (Gallien *et al.*, 2001). In a study involving a few white-sided dolphins from the Irish coast, concentrations of mercury in muscle (n=3) were 2,7 mg/kg dw and in kidney (n=1) the concentration was 7,8 mg/kg dw (Das *et al.*, 2003). Assuming a dry weight of 30%, these findings would compare to approx. 0,8 mg/kg and 2,3 mg/kg in muscle and kidney respectively, which is in the range found in the studies on the Klaksvík 1997 samples. In a single white-sided dolphin adult male found stranded on the Belgian coast in 1999, kidney cadmium and mercury concentrations at 2 mg/kg and 12 mg/kg were found, thus also within this same range (Das *et al.*, 2002).

Grey seal

Grey seal, *Halichoerus grypus,* is abundant in the Faroe Islands, but there are few data available on pollutants concentrations in this species.

In connection with a Ms.Sc. study in 1993-1995 on the Faroese grey seal diet (Mikkelsen, 1998) samples were also taken to be deposited in the Environmental Specimen Bank (http://www.hfs.fo/enviromental_specimen.htm) for future analyses of pollutant concentrations as well as for other purposes. A subset of samples from 45 individuals were analysed for mercury,

	Ad. ♂♂	Ad. ♀♀	Juveniles	
Study 1				
N	4	20	21	
Age, mean	17	14,6	2,4	
Hg, muscle	1,88	0,8	0,38	
Hg, liver	151	155	11,6	
Study 2				
N	3	11	7♂♂	10♀♀
Age, yrs, mean	19	15	3♂♂	2♀♀
Age, yrs, range	13 – 22	8 – 27	1 – 5	1 – 5
Length,cm,range	204 – 227	164 – 190	129 – 171	121 – 156
Hg, muscle	2,31	0,84	0,37	0,37
" , stddev.	2,22	0,4	0,26	0,27
" , range	0,42–4,76	0,23–1,51	0,15–0,90	0,16–0,92

Table 17. *Mean Mercury concentation, in mg/kg ww, in grey seal from around the Faroe Islands 1993-1995. (Study 1: Larsen and Dam, 1999; Study 2: Dam, 2001).*

cadmium, lead and copper as well as persistent organic pollutants and polycyclic aromatic hydrocarbons in pooled samples consisting of muscle and liver from 4 adult males, 20 adult females and 21 juveniles (from 2-4 yrs) (Larsen and Dam, 1999). The mercury results are given in Table 17 along with those from a more detailed study, in which individual analyses of persistent organic pollutants and mercury (Fig. 18) were done on muscle and blubber from 31 grey seals (Dam, 2001).

Liver and muscle metal concentration in grey seal from the Baltic and Sable Island (Arctic Canada) are available for comparison (Nyman *et al.*, 2002). In the Baltic, the average liver mercury concentration in females (n=11) was 109 mg/kg with a range of 15-348 mg/kg, In the males, the similar mean was 41 mg/kg with a range 15-99 mg/kg mercury in liver. In the sable Island, the corresponding mercury concentrations were 101 mg/kg (range 45-252) and 116 mg/kg (range 27-278) in females (n=10) and males (n=10) respectively. Direct comparison to the Faroese grey seals are complicated by the fact that the mercury concentrations in the other study were calculated for seals of not available age, and likely includes both adult and juvenile individuals. However, the mercury concentration in the groups of adult grey seals in the Faroes are approx. 150 mg/kg whereas the concentration in the pool of juveniles were 11,6 mg/kg, thus it appears likely that the mercury concentration in Baltic, Sable Island and Faroe Islands grey seal are quite similar. Interestingly, the liver cadmium concentration in the Faroese grey seal (not shown), which was 14,6 mg/kg in the adult females (n=20) and 1,85 mg/kg (n=4) in the adult males was found to be significantly higher in females also in the Baltic Sea and Sable Island samples. The overall liver cadmium concentrations in the Baltic and Sable Islands female grey seal samples

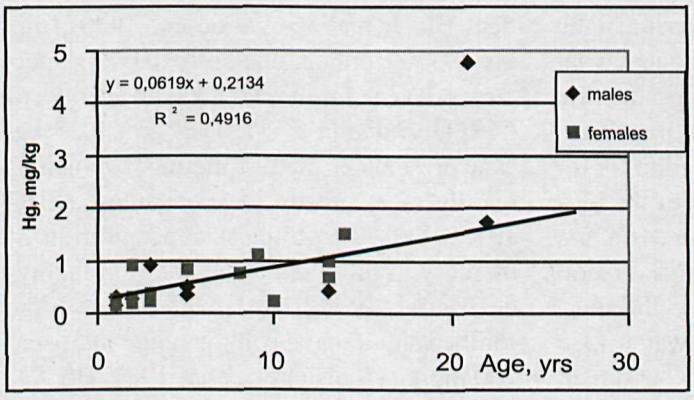

Fig. 18 Mercury in grey seal muscle, in mg/kg, in samples taken around the Faroe Islands 1993-1995. The regression line based on the female results is shown (Adapted from Dam et. al., 2001).

were however much lower than in the Faroese ones, with concentration of 0,5 mg/kg (range 0,3-1,1) and 2,5 mg/kg (range 0,9-4,1) respectively.

Discussion

In the present paper the available information on mercury concentration in the Faroese environment is reviewed, and mercury concentration from matrices in the atmospheric compartment, the terrestrial freshwater compartment and the marine environment has been described. When available, data on similar matrices in neighbour countries or in countries from which comparable data has been recently published, are discussed for comparison. The overall purpose of the review is to gather mercury data so as to be able to discern where elevated concentrations occur and if possible also to elucidate the question of sources.

The studies undertaken on atmospheric transport of mercury to the Faroes and the results of the European moss metal survey do not indicate elevated mercury input to the terrestrial environment above what is seen in for instance the Scandinavian countries. This may be supported also by observations that mercury in sheep was low, and not detected at 0,02 mg/kg. A bit puzzling then, is the finding of somewhat elevated mercury concentrations in hare livers, as these two grazers would have the same food source.

Also, the analyses of mercury in soil (incl. peat) and freshwater fish like Artic char in particular, do indicate high concentrations of mercury in the soil and in the freshwater system. It should be recalled in this context though, that concentration is not just a question of the amount of soluble material that is put into a system, it is just as much a question of what volume this system has available for diluting the material. This must be kept in mind when evaluating the concentration of mercury in the Leynavatn Arctic char samples, but it may also be of relevance to the mercury in soil and sediment concentration, such that low yearly increments in "dilution mass" will result in relatively high concentrations even when the deposit or intake was not elevated. Also, it may be speculated whether the moderate temperatures and high humidity

of the Faroes climate may have a role in the mercury cycling, so as to produce what may be ideal conditions for the production of methylated mercury which in turn is effectively absorbed and maintained in for instance fish. Also of importance for the bioavailability of mercury deposited on the ground, is the natural and manmade erosion that has been shown to increase the mercury mobilisation into runoff water to a larger extent than was earlier assumed (Gustin *et al.*, 2002). The implication of this is not only that the actual influence of such processes needs to be clarified, but also that it becomes imperative to keep a record on and preferentially also a check on the land use in the watersheds and in the coastal areas where sampling for environmental purposes are done.

Assuming that the import of mercury with long-range transported air pollution is low, it may be of interest to check the magnitude of other potentially important vectors. It has been shown that fish and in particular whale meat is a likely major source of mercury in the Faroese diet (Grandjean *et al.*, 1995a), and it is therefore pertinent to get an overall estimate of the magnitude of the mercury flow through the pilot whale pathway. The total import of mercury with long-finned pilot whale catches may be estimated by assuming that the overall 2 mg/kg mercury in muscle that was found in 10 schools in 1997 (Dam and Bloch, 2000) is representative, and multiply with the average amount of whale meat harvested in the years of 2000 to 2003 of 5233 *skinn* pr. year (Bloch, 2004). When one *skinn* is equivalent to 38 kg muscle and 34 kg blubber (Bloch and Zachariassen, 1989), this gives a net import of approx. 0,4 kg mercury per year. Of these 0,4 kg, an average of 64% (Juelshamn *et al.*, 1987), or 0,25 kg, was present as methyl-mercury, which is readily taken up by the consumers (EHC 101, 1990). The highest concentration of mercury in pilot whales is found in the liver (Caurant *et al.*, 1993) where an average for the school may be in the range of 50 and 100 mg/kg (Juelshamn *et al.*, 1987, HS Annual Report 1976/78 and HS Journal 1979-89; Caurant *et al.*, 1993). Assuming an average liver mass of 5 kg for the mean of 660 individuals taken each year during 2000-2003, it can be calculated that the liver will contribute a mercury amount in the range 0,16 g to 0,33 kg/year which is comparable to the one in the muscle mass but this amount is then deposited at sea, as livers are not eaten.

Compared to the input via the atmospheric pathway, which even if it is not elevated above the common Scandinavian level, still amounts to a calculated net wet deposition of mercury of approx. 6,6 $\mu g/m^2$/year (Daugaard, 2003) on the total land area of approx. 1 400 km^2 (140 $*10^7$ m^2) amounts to 9 kg per year. The dry deposition was estimated to 10 μg Hg/m^2/year (Christensen, 2003) that gives a total of 14 kg/year. The study of Shotyk *et al.*, (2004) gives a 1998 rate of total mercury deposition of 15,9 $\mu g/m^2$/year from measurements of mercury in dated peat-segments, which then fits well with the sum of the measured and modelled amounts in wet and dry deposition respectively, and which amounts to in all 23 kg mercury per year.

The long-range transported mercury thus outweighs many times the import that occurs via pilot-whale catches, even though the mercury in meat may lead to locally elevated concentrations of more concern than the air-borne one.

In the marine environment, the mercury concentrations in marine mammals, and in particular in long-finned pilot whales are elevated compared to the level off Newfoundland (Muir *et al.*, 1988) where the mean muscle mercury concentration in two groups of stranded pilot whales were 0,9 mg/kg (n=15) and 0,8 mg/kg (n=29) with a range of individual age in the last pod of 1-17 yrs.

The pilot whale and white-sided dolphins utilize large sea areas and it is thus not correct to use these species to describe the Faroese environment. For this, stationary species must be used, and widely used such indicator species for the coastal area is the blue mussel.

Overall, the mercury concentrations in blue mussel sampled from sites around the Faroese coast are higher than the OSPAR background/reference level (QSR, 2000). Whether the sources for these are local ones, like sewage outlets, fish farms of land based industry, is not known. The bad news is however, that a certain anthropogenic impact is likely inherent in every blue mussel sample from the Faroe Islands because the mussel do only live in the sheltered fjord areas which receive inflow of nutrients from anthropogenic activity.

Mercury in fjord sediments have been analysed in 1997 and 2000, and in one fjord, Skálafjord, also in 1992. It appears that mercury concentrations in Skálafjord have been elevated above what may be defined as the natural level, but that the mercury concentration in this fjord is decreasing. Comparisons between mercury concentrations in sediments from the banks to those taken in the fjords (Skálafjord excluded) when expressed on a organic content basis, indicate that the relative levels of mercury are similar in the fjords and on the banks.

Conclusion

The available mercury data for the Faroese environment do indicate that there are elevated mercury concentration in certain matrices, among them soil, marine mammals and in certain instances also marine and freshwater fish. There are however, no indication that the transport of mercury to the Faroe Islands is elevated above what could be expected from comparisons to the other Nordic countries except of course from the import carried by pilot whales which result in an elevated mercury level in the Faroese population as is also seen in other communities utilizing marine mammals as a food source (AMAP 1998; 2002; Weihe *et al.*, 2003). Still, the elevated mercury levels in certain matrices in the Faroese environment warrant a closer study of the mechanism behind the apparent concentration of deposited mercury. At present, studies are ongoing on some of these matrices, with particular emphasis to examine the geographical extent of the elevated levels and possibly trace sources, but these are not the needed in-depth analyses with a potential to explain mechanisms.

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Notes

1 Meaning souces from transportation i.e. cars, vessels, etc. is excluded.

2 There was one outlier in the August (Hestoy) samples with > 20 mg/kg Hg in feathers and almost 10 mg/kg dw Hg in liver.

3 Where "grind" is the term used to describe the total number of pilot whales taken in one particular drive.