Mercury in liver, eggs and feather of black guillemot *Cepphus grylle faeroeensis* in the Faroe Islands

Kyksilvur í livur, eggum og fjøður frá *Cepphus grylle faeroeensis* í Føroyum

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Úrtak

Í tíðarskeiðnum 1995-1997 varð eitt størri tal av teisti tikin til kanningar nær sunnari parti av Streymoy og við Hestoy. Kanningarskráin fevndi um hvat føði teisti tekur og innihaldi av umhvørviseitri av ymiskum slagi. Í seinri árum eru eisini egg undan teisti tikin til endamáli kanningar av umhvørviseitrandi evnum. Hesi egg hava verið heintaðið á Skúvoy og í Koltri, og eru tey kannaðið fyri millum annað kyksilvur og stabilar isotopar av køvievni og kolevni. Hendan greinin er ein samanstilling av kyksilvur úrslitunum fyri ymiskan vevnað og aldursbólkar av teisti sum eru íkomin eftir eini røð av kanningum í ymiskum høpi. Sæð samlað varð funnið eitt miðalinnihald av kyksilvuri í fjøður og livrum uppá ávíkavíst 4,72 mg/kg og 1,11 mg/kg í teimum 33 fuglunum sum vórðu kannaðir einkultvís, sum gevur eitt lutfall ímillum hesar uppá 4,2. Stórar individuallar variatiónir vórðu ávístar, serliga millum hannarnar, og tí var ikki gjørligt at ávísa nakran eftirfarandi mun á kyksilvur-innihaldinum millum vaksnar og ungar hannar. Miðalinnihaldið av kyksilvuri í eggum sum vóru heintaði á hesum báðum plássum minkaði úr 0,46 mg/kg í 1999 til 0,32 mg/kg í 2001.

Abstracts

During 1995-1997 a large number of black guillemots from an area near the southern part of Streymoy and Hestoy were sacrificed in connection with a large study of the birds' diet and of pollutants load in the Faroe Islands. In recent years also black guillemot eggs have been sampled for the purpose of environmental monitoring. The eggs have been gathered on Skúvoy and Koltur and have been analysed for pollutants such as mercury as well as for stable isotopes of nitrogen and carbon. The present article is a synthesis of the mercury data gathered in these projects studying mercury in various black guillemot tissues and age classes. The overall mean feather and liver mercury concentrations in 33 individually analysed birds was 4,72 mg/kg and 1,11 mg/kg respectively, thus with a ratio between them of 4,2. There were large individual variations especially among the males, but significant differences in liver mercury concentration between adult and juveniles could not be discerned. The mercury concentration in eggs sampled at both locations decreased from an average of 0,46 mg/kg in 1999 to 0,32 mg/kg in 2001.

Introduction

During recent years a suite of species inhabitating the Faroese coastal environmental has been investigated for use in regular monitoring of pollutants. The pollutants in focus have been heavy metals such as mercury, lead and cadmium, and manmade pollutants such as PCB and pesticides or metabolites of these, often as a bulk referred to as persistent organic pollutants, POPs.

The species investigated have been recruited at several trophic levels, from alga (*Laminaria hyperborea*) to invertebrates like limpets (*Patella vulgata*) through fish such as dab (*Limanda limand*), but most of all seabirds like black guillemots (*Cepphus grylle*) and fulmars (*Fulmarus glacialis*) have been subject to study (Dam, 1998a; 2000, Larsen and Dam, 2003; Dam *et al.*, 2001; Hoydal *et al.* 2003; Olsen *et al.*, 2003.).

The task of finding suitable species for use in regular environmental monitoring that will reflect the present status of pollutants in a given compartment, often called indicator species, was initiated by the Food and Environmental Agency in 1995. The bird species focussed on in that study was the black guillemot, *Cepphus grylle faroensis* (Asbirk, 1979), which occurs in a distinct family in the Faroe Islands, and is thought to be stationary there. The assumption of the black guillemots being stationary in the Faroe Islands is quite important as this property of an indicator species allows the assumption that the pollutant signature found is reflecting the local pollution status, being it long-range transported pollutants or pollutants released locally. The long-range transported pollutants are among others PCB and DDT and mercury (see also http://www.unece.org/env/lrtap/lrtap_h1.htm). This does not exclude the possibility of pollutants being transported by sea or by animals, but transport by air masses has been found to be an important route of transfer of POPs and mercury from industrialised parts of the hemisphere to more remote parts. The question of routes and transport mechanisms of pollutants has been treated in detail in the multi-lateral scientific effort Arctic Monitoring and Assessment Programme, see for instance AMAP 1998 and Nilsson and Huntington (2002).

Apart from the stationarity, the black guillemot is well suited as an indicator species because it in several places is found to have a relatively stable diet consisting of sandeel, it is thus not mainly an opportunistic scavenge feeder like some other seabirds. Another element that makes the black guillemot better suited as an indicator species than the other alciids is that in contrast to these, it lays two eggs, thus allowing for sampling of one egg from the clutch without emptying the nest. The reason for sampling eggs is that these make good matrices for monitoring of a variety of pollutants.

Monitoring of metals in bird feathers is much preferred to for instance monitoring liver tissue due to the nonintrusive nature of the sampling method. The application of feathers in monitoring the occurrence of bioavailable mercury has been the subject in several studies, among which the studies describing the sturdiness of feathers as a monitoring matrix and their representativity of blood mercury levels are of particular interest (Appelquist *et al.*, 1984; Goede *et al.*, 1989; Lewis and Furness, 1991; Monteiro and Furness 1995; Bearhop *et al.* 2000). In essence it has been found that mercury is excreted into feathers during moult, so that the moulting becomes an important part of the detoxification of the body pool of mercury (see for instance Lewis and Furness, 1991), and thus feathers will reflect the contamination at the site of foraging during moult (Goede *et al.*, 1989).

Therefore, as a stationary species is chosen as indicator species, it can be assumed that the feather mercury concentration will reflect the mercury load of that particular area as long as the trophic level of the species remains the same. Studies have revealed that indications of the trophic level of a seabird (or other species) may be achieved via the analyses of fractionation of stable isotopes of nitrogen in particular, but also of carbon and sulphur (Hobson and Welch, 1992; Hobson *et al.*, 1994). Especially the fractionation of nitrogen isotope ^{15}N relative to that of ^{14}N (denoted $\delta\ ^{15}N$) is supposed to provide information on the trophic level, whereas the fractionation of carbon isotopes ($^{13}C/\ ^{12}C$, denoted $\delta\ ^{13}C$) is supposed to give insight into the proximity to the terrestrial environment. Typically, a change in 3-4 ‰ of $\delta\ ^{15}N$ is thought to accompany a one tier shift in trophic status (Peterson and Fry, 1987).

Due to the storage of birds in museums it has been possible to elucidate historical trends in mercury contamination through the analyses of feathers (Thompson and Furness, 1989; Appelquist *et al.*, 1984) as well as spatial trends like the study including guillemots from the Baltic and the North East Atlantic (Somer and Appelquist, 1974; Appelquist *et al.*, 1985; Furness *et al.*, 1995).

Methods

Black guillemots (142 individuals in all) were shot using mainly steel-hail near Sveipur and Hestoy from November 1995 to February 1997, with sampling taking place approximately every second month. The birds were registered and the external measures taken on one and the same day. The birds were stored frozen until further treatment. During dissection, the sexual status was recorded, for the female this status was inferred from the appearance of the ovary and oviduct, and for the males the sexual status was determined from the external appearances among them the plumage and possible brood patches in combination with an assessment of the gonads. The birds where thus sorted into age and sex classes of adult (*ie.* breeding) females and males and juveniles (pre-breeding). Body feathers from the back and under one wing were taken from 15 individuals and analysed separately for mercury. These individuals were taken at Hestoy in August 1996 and near Sveipur at Streymoy in June 1996. A selection of samples from each bird were taken into storage at $\div 20^{0}$C in the Environmental Specimen Bank at the Food and Environmental Agency, awaiting further opportunities for analyses and studies (see also www.hfs.fo/enviromental_specimen.htm).

Black guillemot eggs were sampled on Koltur and on Skúvoy in three consecutive years in 1999, 2000 and 2001. One egg was taken from each nest and the sampling would ideally be done early in the egg-laying period, which begins in early June. The eggs were stored in refrigerator until further sample preparation. The target number of eggs from each location was 10, but on Skúvoy in 1999 and 2000, the sample size was 8 and 9 eggs respectively.

Chemical analyses of metals were done using AAS (FIMS 400 amalgam system, Perkin Elmer AA600 or cold vapour AAS) or ICP-MS at commercial laboratories which could provide accredited analyses or at a laboratory with similar quality control.

Results

Liver

Fig. 1 shows the mercury concentration in liver from black guillemots taken in two periods during 1996 and 1997. The results are given for adult males and females and for juveniles of both sexes. The light bars represent pooled sample results whereas the dark bars represent individually analysed birds. Because the variability in the January/February 1997 data is not known, it is not possible to determine whether the apparent differences between the two periods for the adult male group is real or merely a sampling artefact. Pooled sample analyses of mercury in adult male livers were made for August 1997 (Fig. 2) also, the results indicate that this may be the time of year with maximum mercury concentration in the adult male liver whereas there appears to be a low concentration in November, Fig. 2. Generalisation from these data in terms of influence of parameters like age and sex on the mercury concentration should be done with care as the individual variability in the data is not quantified for every group, and generalisation in terms of temporal trends is also restricted by lack of continuous data. Nonetheless, the individual analyses of a subset of 33 specimens indicate that there are large individual variations in going

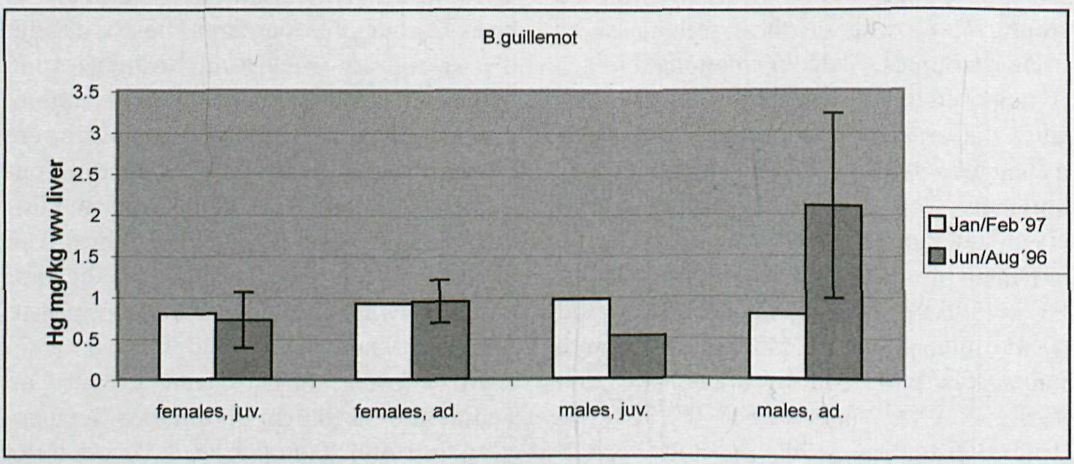

Fig. 1. Mercury in black guillemot livers. The samples taken in January and February 1997 were analysed in pools, whereas data from June/August 1996 refers to individual analyses, except the one for juvenile males, that was analysed as one pool and where the sampling was actually done in April/June 1996. The number of individuals represented by each bar is in the order of appearance from left to right: 8;5;14;4;5;6;18;4. Adapted from Dam, 1998b, Dam, 2000 and Olsen et al., 2003.

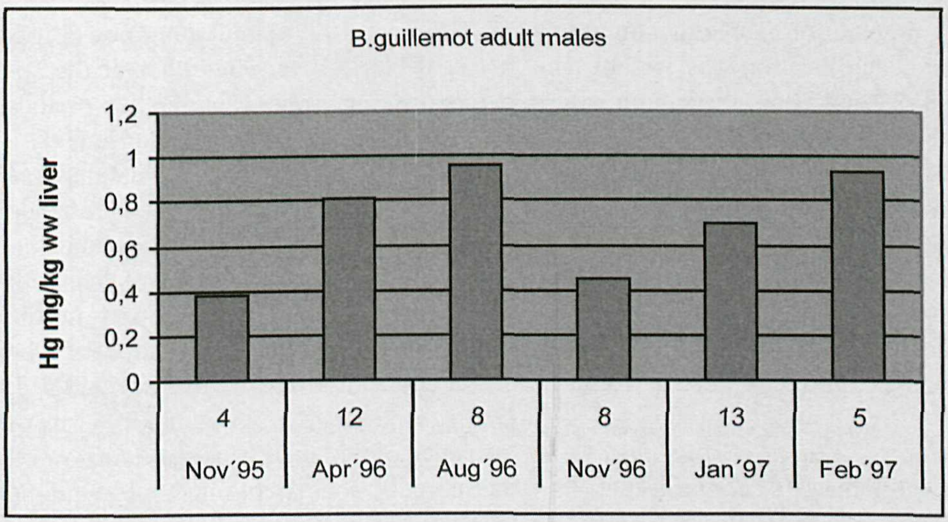

Fig. 3. Mercury in black guillemot adult male livers. The samples were analysed in pools consisting of from 4 to 12 individuals. The data of January 1997 is the mean of two pools of 7 and 6 individuals. Modified from Dam, 1998b.

from the lowest liver mercury at 0,21 mg/kg ww liver to 3,77 mg/kg (Olsen *et al.*, 2003). Testing with Mann–Whitney U-test shows significantly higher liver Hg content in adult females than in juvenile females (P=0,05) while the difference between adult and juvenile males and between males and females was not found to be significant. When all adults were seen as one group and compared to all juveniles, however, the difference was significant.

The variability is also reflected in the pool results, where the lowest pooled liver sample mercury concentration was 0,38 mg/kg and the highest was 0,97 mg/kg (Dam, 1998b; Dam, 2000), with the highest pooled liver sample mercury concentration found in a group of juvenile males and the lowest in a group of adult males.

Feather

For the purpose of determining whether the concentration of mercury is the same in body feathers plucked from the plumage at two different sites and to determine whether such samples are comparable, feather samples were taken from 15 birds. These 15 birds were taken at two different locations (though separated by a few kilometres only) and at two different times. The majority of the birds making up the first sample (n=8) were taken near Sveipur in June 1996 and the second sample (n=7) near Hestoy in August the same year. The samples were taken of contour feathers from two sites; from the back between the wings and from under one wing, where the latter is thought to be the best site, as it is supposed to lead to a minimum of insulation loss when feathers are removed from

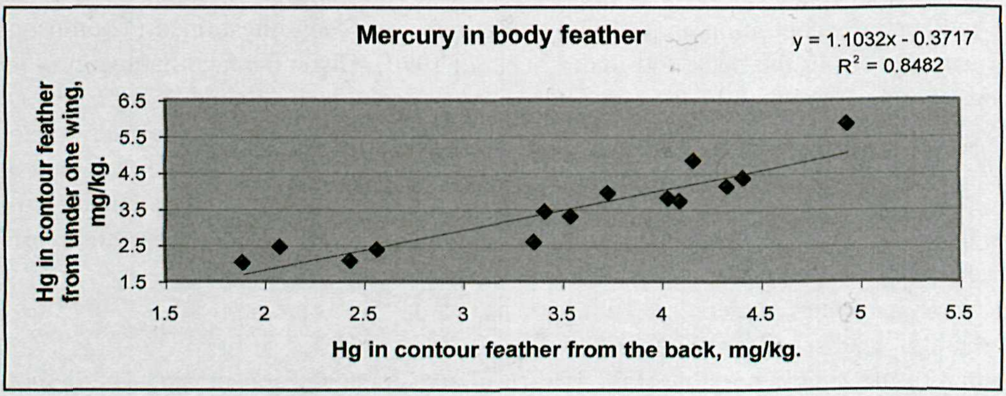

Figure 5. Mercury in body feather from black guillemots is given. The body feathers were taken from under one wing and from the back between the wings of the birds. One bird with a very high mercury concentration (Cg-0058) has been excluded from the figure. Modified from Olsen et al., 2003.

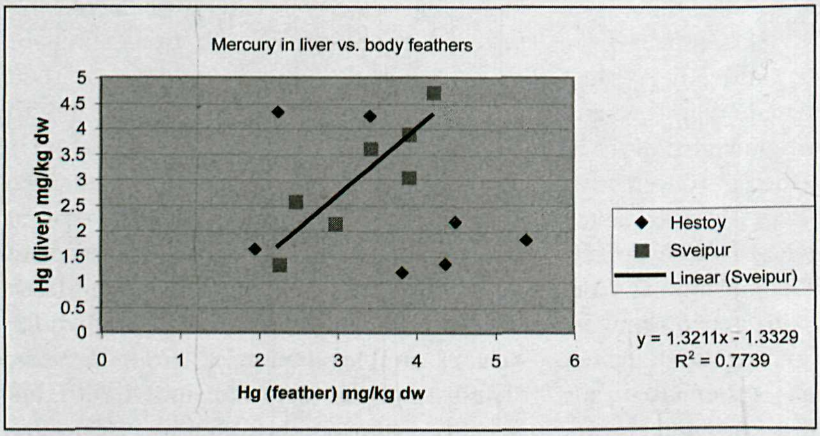

Fig. 7. Mercury concentration in black guillemot liver (in mg/kg dw) is seen vs. that of feathers (in mg/kg). The feather mercury concentration used is the mean of the measured concentration in the body feathers under the wing and body feathers from the back between the wings. A bird with very high mercury concentration (Cg-0058) has been excluded from the figure. The birds marked as Sveipur were taken at this site in June 1996 (4 adult females and 3 juvenile males), the ones marked as Hestoy were taken there in August 1996 (2 adult males and 5 juveniles both sexes). Modified from Olsen et al., 2003.

live birds. The results are given in Fig. 3 as a plot of mercury concentration in feathers under one wing and the concentration of mercury in feathers from the back. In the figure the outlier (Cg0058) has been excluded so as not to distort the regression coefficient, but a plot including this outlier (not shown) has a similar equation for the regression line, but then with y = 1,14x-0,49.

The mercury concentration in the two feather samples (from the back and under one wing) was not significantly different (at P=0,05) in the two locations Hestoy and Sveipur (Mann-Whitney U-test) and thus the two samples may be seen as a unity.

Also liver samples from the birds whose feather mercury concentration was determined were analysed for mercury. Thus a comparison of feather mercury concentration to that of the liver is possible (Fig. 4). In the plot, the data series from the two sites Sveipur and Hestoy are shown separately regardless of the fact that there, as already mentioned, were no significant differences in the feather mercury concentrations at these two locations. The samples from Sveipur consist of liver and feather from 4 adult females and 3 juvenile males, whereas the Hestoy sample is composed of tissue from 3 adult males (hereof one outlier Cg0058) and five juveniles of both sexes. The four Hestoy samples whose feather mercury concentration is elevated in comparison to the inserted regression line for the Sveipur material (Fig. 4) are juveniles. The outlier Cg0058, an adult male, in the Hestoy batch had a feather mercury concentration of 21,9 mg/kg and a liver mercury concentration of 3,77 mg/kg (Olsen *et al.*, 2003).

The overall mean feather and liver mercury concentrations were 4,72 mg/kg and 1,11 mg/kg respectively, thus with a ratio between them of 4,2. A standard value for this ratio of feather to liver mercury concentration of 2,3 (fresh weight) has been suggested (Appelquist *et al.*, 1985; Thompson *et al.*, 1990). However, the validity of this ratio has been questioned (Thompson *et al.*, 1990). Given the fact that mercury is excreted from the liver (Stickel *et al.*, 1977) but once deposited in the feather is no longer bioactive, it is plausible that such a ratio may only be valid if all parameters influencing the mercury concentration are constant.

Eggs

Mercury concentration in black guillemot eggs is given in Tab 1 along with data on the fractionation of stable isotopes of nitrogen and carbon in these (Olsen *et al.*, 2003; Ólafsdóttir, 2002). Judging from this data there appears to be a trend of decreasing mercury concentration at both locations of egg sampling, going from a mean 0,46 mg/kg mercury at the two sites in 1999 to 0,33 mg/kg in 2001. This decrease is equivalent to a relative decrease of almost 30% from 1999 to 2001, and represents quite a substantial change. At the same time there is a gradual increase in $\delta 15N$, going from an approx. average of 10 ‰ at the two locations in 1999 to approx. 12 ‰ in 2001, that is an increase of 18% since 1999. This increase corresponds to roughly a ½ trophical level elevation and could have been expected to be accompanied by an increase in mercury concentration, but this expected increase is not found. On the contrary a decrease is seen. In addition to the observed decrease in egg mercury concentration, there is a parallel decrease also in PCB (Hoydal *et al.*, 2003). This is seen as an indication that the reason for the decrease may be that the birds have a decreasing intake of "typical" mercury and PCB carriers, as would be the case if the bird had changed their diets the years the pollutants measurements were ongoing towards a lower trophic level. But as the stable isotopes analyses do indicate a change in the downward direction, it is speculated whether the black guillemots these years may have changed the diet from a migrating species towards a local species occupying a higher trophic level, as would be the case in going from for example sandeel to cod. The likelihood of the reduction in egg mercury concentration being a reflection of changing environmental pollution of mercury is limited. It is plausible that part of this decrease could be a consequence of reduced pollution, however it is not possible to substantiate this because the location of the source of the mercury, which is available for these black guillemots colonies, is not known. A similar study of stable nitrogen isotopes and mercury in fulmars from Shetland and Outer Hebrides gave a similar trend where spatial comparisons of mercury and δ 15N gave inverse relative changes and thus concluded that the trophic level was not the principal factor in determining mercury concentration (Thompson *et al.*, 1998).

Discussion

Spatial comparisons

As the growth of feathers offloads the bioavailable body pool of mercury, the production of eggs provides a route for detoxication in the female (Backstrom, 1969; Lewis *et al.*, 1993). It is questionable whether this excretion is detectable above excretion following the non-sexually related processes, and studies of mercury in adult specimens of known age of gulls, great skuas and an albatross species have revealed that the mercury concentration in adults is not dependent on age nor sex (Furness *et al.*, 1990; Thompson *et al.*, 1991; 1993). The present study did find a difference between the adult female liver mercury concentration and that in the juvenile females, but not between the females and males. Thus the detoxification due to growth of eggs is not of a magnitude sufficient to be detected above the variability stemming from other elements of biological processes and "lifestyle". The analyses of the present material also showed that there were age-related differences in liver mercury concentrations, but that the individual variability among the males was so great that this difference could not be detected when only the males were studied.

Data for comparision is available from Greenland, where the black guillemot egg mercury concentration was found to be 0,34 mg/kg and 0,26 mg/kg ww in 1999 and 2000 respectively, in two different colonies (Riget *et al.*, 2003). Combining the data from the two sites in the present study gives mean egg mercury values of 0,51 and 0,33 mg/kg (calculated from data in Tab 1), for 1999 and 2000 respectively. Black guillemot eggs from three colonies in Arctic Canada in 1993 and 1998 have been shown to contain mercury in the range 0,39 mg/kg to 0,60 mg/kg (Braune *et al.*, 2002), and are thus in the same range as the ones from the Faroe Islands.

The May liver mercury concentration in black guillemots in Iceland (Gunnarsson *et al.*, in press), was 0,9 mg/kg, and thus sim-

	1999		2000		2001	
	Koltur	*Skúvoy*	*Koltur*	*Skúvoy*	*Koltur*	*Skúvoy*
n	10	8	10	9	10	10
Mean Hg, mg/kg ww	0,510	0,514	0,361	0,299	0,324	0,326
Stddev.	*0,186*	*0,122*	*0,113*	*0,097*	*0,09*	*0,085*
Median Hg, mg/kg ww	**0,44**	**0,48**	**0,34**	**0,34**	**0,33**	**0,32**
min, mg/kg ww	0,35	0,39	0,16	0,14	0,182	0,19
max, mg/kg ww	0,97	0,73	0,55	0,42	0,449	0,437
d ^{15}N, ‰	9,89	10,54	10,60	11,23	11,40	12,65
d ^{13}C, ‰	-21,22	-21,80	-20,10	-20,37	-19,36	-18,03

Table 1 Mercury (Olsen et al., 2003) and stable isotopes of Nitrogen and Carbon (Ólafsdóttir, 2002) in black guillemot eggs from Koltur and Skúvoy in 1999-2001.

ilar to the level of mercury in the Faroese birds. The mercury concentration in black guillemot males appears to be elevated compared to the Icelandic counterparts (Fig. 1) with approx. 100% higher mercury concentration than in the Icelandic birds. It is worth noting however, that this high mean includes an outlier, without whom, the mean would be 1,2 mg/kg, and seen in relation to the August 1996 value in Fig. 2 this appears to be the common mercury level, which is very similar to the Icelandic one. Mean liver mercury concentration in three specimens from Franz Josef Land Archipelago was reported to be 0,88 mg/kg (Savinov *et al.*, 2000). Generally speaking, there is little data available for comparison, the data available indicates however that the level of mercury in the Faroese black guillemots is at the same level as in Iceland, eastern high Arctic Canada and Greenland.

Temporal comparisons

Seasonal variations

In a similar study of black guillemots in Iceland, mercury concentration in pooled liver samples of birds taken in March, May and December in 1996 indicated a maximum mercury concentration in May at 0,9 mg/kg, descending in March to 0,7 mg/kg with the lowest concentration in December at 0,3 mg/kg ww (Gunnarsson *et al.*, in press). These findings correspond to findings in the present Faroese material, where the November pooled samples appeared to be consistently low compared to the other months (see Fig. 2).

Historical comparisons

The mercury concentration of museum specimens of black guillemots from the Faroe Islands has been studied (Somer, 1974; Appelquist, 1985). In these studies the mercury analyses were done on primaries and the results indicated increasing mercury concentration in going from 1,8 mg/kg in the first half of the twentieth century, to approx. 2,77 mg/kg in 1974. One of these studies showed that the mercury concentration in black guillemot primaries was lowest in the first primary on the right wing and that the fifth and tenth primaries on both wings were higher and rather similar in mercury concentration (Appelquist *et al.*, 1984), and that similar results were seen for guillemots in the North Baltic. Findings of consistent high mercury concentration in the first primaries moulted were reported for a number of seabird species with different migratory habits (Furness *et al.*, 1986), and in the same study, as well as in one by Lewis *et al.* (1993), it was found that the mercury concentration in body feathers was consistently lower, of varying degree, and with less variability than that of the primaries. In the present study mercury was analysed in body feathers, and even though it was found that the mercury concentration in body feathers at two different sites was equal, it is reasonable to assume that the difference observed in several other seabird species between mercury in primaries and body feathers, may also be found in black guillemots. Given that in black guillemots in the Faroes primaries are the first feathers to moult after the fish-season (Asbirk, 1977; Dam, 1998b), it is plausible that also the primaries in this bird will be higher than in the body feathers sampled in the summer months which had grown during late winter, at a time when the diet mainly has been dominated by crustacean and molluscs (Dam, 2000). It could be tempting to perform a direct extrapolation of the results of other seabirds to black guillemots, but it is hardly worthwhile because the details in moulting and foraging area as well as diet choice, all factors which are known to influence the body mercury pool, would have to be taken into consideration for such extrapolation. Thus it is recommended that comparative analyses of mercury are undertaken on primaries and body feathers from black guillemots in the Faroe Islands for the purpose of continuing the time-trend established by Appelquist *et al.* (1985). But prior to this, however, one should determine whether there are differences in the primary mercury concentration among the sexes as was found to be the case for herring gulls (Lewis *et al.*, 1993), in which case it will only be possible to track historical changes if details of specimen sex are known.

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