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Heavy metals in Greenland seabirds

Christian Overgaard Nielsen and Rune Dietz

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Nielsen, Christian Overgaard and Dietz, Rune. 1989. Heavy metals in Greenland seabirds. – Meddr Grønland, Bioscience 29, 26 pp. Copenhagen 1989-10-3.

From six Greenland districts we report the concentration of Zn, Cd, Hg and Se in muscle (pectoral), liver and kidney for 320 seabirds of the following species: *Cepphus grylle, Uria lomvia, Clangula hyemalis, Mergus serrator, Larus glaucoides, L. hyperboreus, Rissa tridactyla, Pagophila eburnea, Fulmarus glacialis, Phalacrocorax carbo* and *Stercorarius pomarinus.*

Concentrations vary widely within species. Yearlings are low in Cd and Hg. Concentrations tend to increase with age. No significant differences between sexes were found.

On a wet weight basis, the Zn concentration in liver and kidney is c. three times that of muscle. Gulls and the fulmar possess significantly more Zn in muscle than do other seabirds. The Cd concentration in liver and kidney is c. 20 and 80 times higher than in muscle, whereas the Hg concentration in liver and kidney is three to five times higher than that of muscle. The Se concentration in liver and kidney is c. five times the muscle concentration. Muscle, liver and kidney concentrations tend to correlate positively for Cd, Hg and Se. For Zn only liver and kidney concentrations correlate mutually.

On a molar basis, the three organs of all species have a large excess of Se over Hg. The intra-organ association of elements is strongest for Zn and Cd in liver and kidney, and for Hg and Se generally.

All four elements show consistently higher concentrations in birds from NW and NE Greenland than in those from S Greenland. For *C. grylle* from Avanersuaq, NW Greenland, the Cd concentration is twice that of birds from S Greenland, the difference being highly significant. Hg concentrations are not significantly different.

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Key words: Seabirds, Arctic, Greenland, heavy metals, Zn, Cd, Hg, Se.

Introduction

For centuries the Greenland population has depended on marine products for its staple food, fish being relatively more important in the south and marine mammals in the north. Everywhere birds contribute a welcome variation of the diet. Quantitatively, their importance is presumably greater in the north. It is well substantiated (Airey 1983) that in fish-eating populations the body burden of mercury increases as more fish is eaten. For the Greenland population, Hansen et al. (1983) point to the consumption of seal as an even more important determinant of the level of mercury in human blood and hair. High mercury levels are more frequently encountered in people from the northern districts. To a larger extent they prefer traditional food to imported food. However, when comparing individuals with traditional food habits, evidence is at hand that mercury reaches higher levels in northern than in southern consumers with similar intakes. One explanation might be the increased consumption in the north of particular species such as beluga (*Delphinapterus leucas*) and narwhal (*Monodon monoceros*) with high mercury levels. However, evidence is accumulating that widely distributed species, e.g. ringed seal (*Phoca hispida*) carry higher metal burdens towards the north. This seems particularly true for cadmium. Unfortunately, the cadmium burden of the Greenland population is hardly known. Several human blood and hair analyses for cadmium are available (e.g. Hansen & Pedersen 1986), but this type of analysis largely reflects momentary values and correlates poorly with the genuine cadmium burden in kidney and liver (Shaikh & Smith 1984).

The research project "Heavy metals in the Greenland marine environment" was launched in 1985 with the aim of providing a reliable mapping of heavy metal concentrations within the major compartments of the marine ecosystem. The data were to be stratified into two dimensions: the trophic levels of the ecosystem and the geographical regions of Greenland. The former in order to trace the path of heavy metals within the ecosystem, and the latter to disclose possible geographical gradients of metal level. The repercussion of both aspects on the human consumption of marine products will receive due consideration in later papers.

The Commission for Scientific Research in Greenland financed the collecting of marine mammals, seabirds, fish and invertebrates in the Thule district in 1984. The field work was organized by the Greenland Environment Research Institute (GERI) and the analytical work carried out by the Institute of Hygiene, Aarhus University (IH). In 1985 the Ministry for Greenland provided funds for equipping the chemical laboratory of the project in the premises of GERI. From 1985 the project was financed for a three-year period by the Commission for Scientific Research in Greenland, the Danish Natural Science Research Council and the two participating institutes, GERI and the Geological Survey of Greenland.

It has been planned to publish the general results of the project in a number of papers, each dealing with a particular section of the ecosystem. Some special problems are referred to separate publications, and a final paper based upon these general results deals with various aspects of the human consumption of Greenland marine products.

This first paper presents the general data concerning seabirds. Although in many ways seabirds are a side line in the marine ecosystem, their choice of food shows an overlap with that of other consumers. It is, therefore, of some interest to compare the level of metals in seabirds with that of other consumers exploiting the same food resource.

Materials and methods

Collection of material

The collection of birds took place between the spring of 1984 and the autumn of 1986. All birds were bought from local hunters during the hunt. Thus, they provide a representative sample bagged for local consumption. The birds were caught with nets or fishing hooks, or they were shot with rifles. Birds killed with shotguns or otherwise much damaged were rejected to avoid contaminaton. Most of the birds were collected in spring (March–June), but those from the Uummanaq district in August–September. The material is presented in Table 1. The birds collected in Avanersuaq (Thule) district in 1984 are included in the sample totals of Table 1, but the selection of 120 birds for analysis (App. 4) took place prior to the project and independently of the selection reported in Table 1.

Table 1. Number of birds available (upper figures) and size of sample selected for analysis (lower figures), according to species and districts. The abbreviated species names are those used in the appendices.

	Districts						
Species:	THU	UPV	UUM	KAN	NAN	ITT	TOT
Black Guillemot	43	48	28	46	21	14	200
Cepphus grylle							
CE GRY	4	5	9	11	9	8	46
Brünnich's Guillemot	50	50		2		13	115
Uria lomvia							
UR LOM	3	8		2		6	19
Little Auk	144		1			30	175
Alle alle							
AL ALL	4		1			10	15
Eider	1		1	20	11		33
Somateria mollissima							
SO MOL	1		1	8	11		21
King Eider			7	25	2		34
Somateria spectabilis							
SO SPE			6	13	3		21
Long-tailed Duck				10			10
Clangula hyemalis							
CL HYE				5			5
Red-breasted Merganser					1		1
Mergus serrator							
ME SER					1		1

Iceland Gull			1		12		13
Larus glaucoides							
LA GLA			1		10		11
Glaucous Gull	23	6	11		8	2	50
Larus hyperboreus							
LA HYP	4	4	4		5	2	19
Kittiwake	51	50	34		1		136
Rissa tridactyla							
RI TRI	4	4	7		1		16
Ivory Gull	25	9	1				35
Pagophila eburnea							
PA EBU	4	4	1				9
Fulmar	17	28	25			1	71
Fulmarus glacialis							
FU GLA	4	5	7			1	17
Cormorant				1			1
Phalocrocorax carbo							
PH CAR				1			1
Pomarine Skua			1				1
Stercorarius pomarinus							
ST POM			1				1
Total	354	191	110	104	56	60	875
	28	30	38	40	39	27	202

The sequence of abbreviated district names indicates:
Avanersuaq (Thule), Upernavik, Uummanaq, Kangatsiaq, Nanortalik and Ittoqqortormiit (Scoresbysund).

Selection of sample for analysis

Prior to the selection of samples for analysis, experts at the Zoological Museum, University of Copenhagen, undertook the determination of sex and age of all birds based on plumage and gonad characteristics. In order to obtain a reasonably representative sample for analysis, four individuals were selected from each species, age group and district. Failing that, the highest possible number was accepted. Sex was disregarded as a biological parameter in the selection procedure. Thus, a total of 202 individuals representing 14 species were selected for analysis (Tab. 1). The geographical location of districts is shown in Fig. 1.

Handling of material

In the field all birds were placed in polyethylene bags and put into a deep-freeze as soon as possible. During shipment from Greenland to storage in Copenhagen the material was kept at −20°C. Dissection took place in the laboratory. Body and liver weights were recorded routinely. Muscle (pectoralis), liver and kidney samples were removed and stored separately at −20°C in metal-free polyethylene bags pending analysis. Furthermore, the stomachs were kept for future analysis of food selection, and the (right) tibial bone for possible future lead analysis. Skins and skeletons were deposited for collection use at the Zoological Museum, Copenhagen, or at the Natural History Museum, Århus.

Chemical analysis

After removal from the deep-freeze the tissue samples were slightly thawed, and the surface tissue layer was cut away to minimize potential contamination and changes due to frozen storage. Scalpels of stainless steel, polyethylene gloves and cutting boards were used. Approximately 0.5 g of tissue was transferred to the tared teflon liner of a Berghof stainless steel bomb. After the addition of 3 ml of 65% HNO_3 (Merck Suprapur ®) the bombs were closed and incubated for four hours at 120°C. After cooling, the digests were transferred to 50 ml screw-cap polyethylene bottles and the

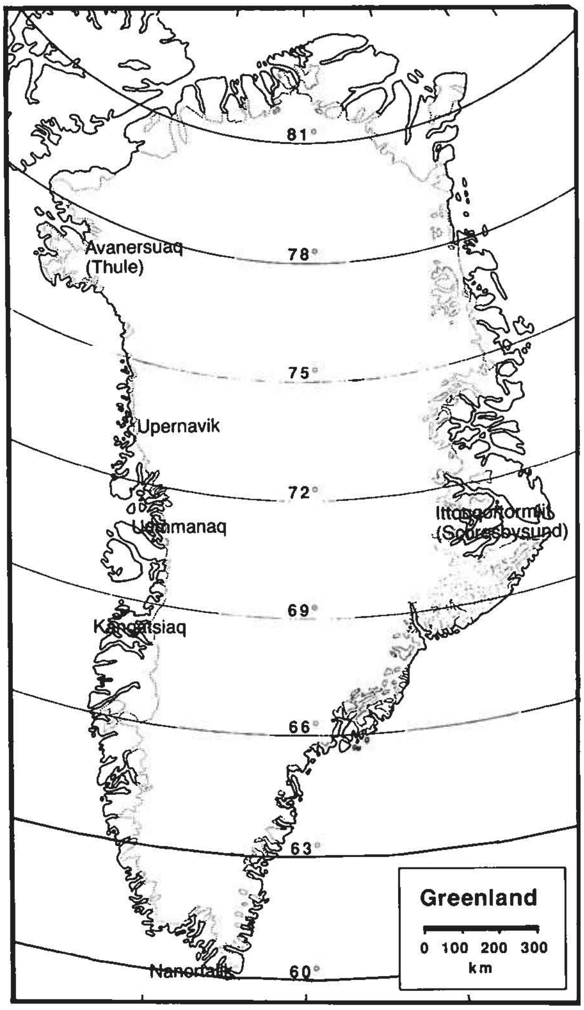

Fig. 1. Map of Greenland showing location of districts.

volume adjusted to c. 26 ml (25 g) using metal-free, deionized water (Millipore ®). For all further dilutions c. 8% HNO_3 was used.

All the zinc analyses were carried out by flame AAS (Perkin-Elmer 3030). For cadmium all samples were screened using the same technique, but for the final analysis of samples with < 2.5 μg cadmium/g the graphite furnace technique (Perkin-Elmer 3030 with Zeeman background correction) was used. This latter technique was also used for the selenium analyses. The mercury analyses were performed by hydride generation including the amalgam technique. Detection limits applying to the analytical procedures were, on a wet weight basis, for Cd: 0.014 μg/g, for Hg: 0.005 μg/g and for Se: 0.203 μg/g. None of the Zn analyses were anywhere near the detection limit.

The analytical quality was regularly checked by repeating the analyses and by the frequent use of various reference standards, especially Tort-1 (lobster hepatopancreas) supplied by the National Research Council Canada (Marine Analytical Chemistry Standards Program) and the dried tuna internal standard of Statens Levnedsmiddelinstitut. The laboratory participates in the international intercalibration exercises conducted by the International Council for the Exploration of the Sea (ICES) and by the Dept. of Fisheries & Oceans, Winnipeg, Canada.

The analytical work concerning Cd and Hg in birds from the Thule district (App. 4) was carried out by the Institute of Hygiene, Aarhus University, using the AAS graphite furnace technique.

All the results are reported as μg/g w.w. (= mg/kg = ppm wet weight). For recalculation to dry weight basis the data of Appendix 2 is appropriate.

Analysis of data

All the primary data of the project is stored in a database under consecutive individual identity numbers. The data were retrieved directly or fed into the SAS (SAS Institute Inc.) processing facilities. The latter procedure was used for the calculation of all the values presented in Appendices 1–5 and for the calculation of the final values of most of the statistics. Before subjecting the raw data to statistical analysis it was briefly inspected for type of distribution, feasible transformations, etc.

Although some sets of data permitted the use of parametric tests (at least after logarithmic transformation) non-parametric tests have been widely used for the sake of uniformity of the treatments. All the correlations were based on Spearman rank correlation coefficients. The comparisons among species, concentrations of elements in different tissues and geographical regions were based on Mann-Whitney two-sample rank testing or, when there were more samples, on the Kruskal-Wallis test followed by multiple comparisons using the Tukey test. In case the SAS output was in a less suitable form for our purpose, the statistical analysis was made by a hand-held computer and the critical values of test statistics tabulated in Zar (1984). For the calculations the very few values below detection limit were replaced by half the value of the detection limit.

Results and discussion

Biological parameters

Body weights (Wgt), liver weights (Lwgt) and Lwgt/Wgt ratios for all birds dissected are shown in Appendix 1, and dry weight percentages of muscle, liver and kidney tissues in Appendix 2.

The wide variation of body and liver weights among individuals is largely due to the pooling of age classes and sexes. However, considerable fluctuations of body and liver weights do take place during the year. Our material does not permit a detailed analysis of this phenomenon, but it may be exemplified by *C. grylle:* among the subadult and adult birds ($n = 115$) no age or sex class or any geographically defined group of birds differ significantly from any other group as regards the slope (b) of the regression line

$$Lwgt = a + b\ Wgt.$$

However, using plumage characters as expressions of biological seasonality the intercept (a) is significantly lower ($p = 0.001$) for birds in full summer plumage than for those in the transistion between winter and summer plumage. This loss of weight, amounting to c. 6% of the body weight and 26% of the liver weight during the summer may reasonably be assumed to reflect the drain on resources associated with moulting, migration, egg production, brooding and the raising of young.

Element levels in Greenland seabirds

All the analytical results are summarized in Appendices 3 and 4 where only two age groups have been distinguished: (1) yearlings, i.e. youngs in their first year of life and (2) subadults + adults comprising all older birds. The age dependence of element concentrations is treated separately in a later section. A few general features concerning subadult and adult birds should be commented on (neglecting species with $n = 1$).

Zinc

In muscle the mean Zn concentration ranges from 11.3 (*S. spectabilis*) to 22.7 µg/g (*L. hyperboreus*). In liver the level is about three times higher, range: 31.4 (*C. grylle*) to 52.0 µg/g (*F. glacialis*) and similar to that of kidney: 26.2 (*C. hyemalis*) to 54.2 µg/g (*L. hyperboreus*). Liver and kidney concentrations are only significantly different ($p < 0.01$) in *C. grylle* (55.4 and 39.6 µg/g, respectively). The high level of zinc in the (pectoral) muscle of gulls and the fulmar is notable.

Cadmium

The muscle concentration of Cd ranges from 0.08 in *L. glaucoides* to 1.4 µg/g in *F. glacialis*, but, unlike zinc, no biologically meaningful grouping is obvious. In liver the concentration of Cd is 10–20 times higher than muscle values, ranging from 1.6 (*L. glaucoides*) to 11.1 µg/g (*L. hyperboreus*). Kidney Cd is usually three to five times higher than liver values, and significantly different from those for $n > 15$.

Mercury

In muscle the mean concentration of Hg ranges from 0.1 (*C. hyemalis*) to 0.7 µg/g (*L. hyperboreus*) with only few signifcant differences between species. Liver levels of Hg are usually three to five times higher than muscle values, ranging from 0.5 (*A. alle*) to 2.6 µg/g (*L. hyperboreus*). Kidney levels of Hg tend to be lower than liver levels, ranging from 0.3 (*S. mollissima*) to 2.1 µg/g (*L. hyperboreus*), but the difference is rarely significant.

Selenium

The mean level of Se in muscle ranges from 0.5 (*L. glaucoides*) to 3.0 µg/g (*R. tridactyla*). In liver the Se level is three to six times higher, ranging from 2.2 (*L. glaucoides*) to 9.9 µg/g (*R. tridactyla*). Kidney levels tend to be higher than those of liver, ranging from 5.0 (*L. glaucoides*) to 15.6 µg/g (*F. glacialis*), but, with four exceptions, the difference is not significant.

The twelve boxes in Table 2 summarize for each metal and organ, all species that differ significantly at least at the 5% level. The element concentration of two species, A and B, is significantly different if, and only if, A is in the left column and B *further down* in the right column. There are no significant differences *within* any column. Thus, for Zn in muscle: LA HYP differs significantly from all species listed in the right column (and only from those). PA EBU, LA GLA, FU GLA, and RI TRI differ each significantly from SO MOL, CE GRY and SO SPE, and only from those. Two boxes, Zn in kidney and Cd in liver show a discontinuity, marked by a horizontal line: PA EBU has been moved from a higher position in the left column to the bottom, because it only differs significantly from one other species, and not the one with the lowest concentration.

For each element and organ, concentrations decline down the two columns, at the left from high to intermediate and at the right from intermediate to low. Only *F. glacialis* is in category high to intermediate concentration for all elements and organs. *L. hyperboreus* has relatively high Zn and Hg concentrations in all organs and also high concentration of Cd in liver. *U. lomvia* is relatively high in Cd in all three organs, whereas *A. alle* and *C. grylle* are low in Cd, but *A. alle* high in muscle Se.

Table 2. Differences among species in element levels of muscle, liver and kidney. For explanation, see text.

Organ Element	Muscle		Liver		Kidney	
Zn	LA HYP		FU GLA		FU GLA	
		AL ALL	SO SPE			CE GRY
		UR LOM		LA GLA		SO SPE
		CL HYE	SO MOL		AL ALL	
	PA EBU		UR LOM		LA HYP	
	LA GLA		LA HYP			CL HYE
	FU GLA			CE GRY	RI TRI	
	RI TRI					SO MOL
		SO MOL			....	
		CE GRY			PA EBU	
		SO SPE				CL HYE
Cd	FU GLA		FU GLA		FU GLA	
		LA HYP	UR LOM		UR LOM	
		CE GRY		SO MOL		SO MOL
		SO MOL	RI TRI			LA GLA
	UR LOM			CE GRY		
		LA GLA	SO SPE			
			LA HYP			
				LA GLA		
			....			
			PA EBU			
				CE GRY		
Hg	LA HYP		FU GLA		LA HYP	
	FU GLA			SO MOL		CE GRY
		SO SPE		RI TRI		RI TRI
			LA HYP			AL ALL
				CE GRY	FU GLA	
				SO SPE		SO SPE
				AL ALL		SO MOL
Se	FU GLA		FU GLA		FU GLA	
		SO MOL		LA HYP		SO SPE
		UR LOM	RI TRI			LA HYP
		LA HYP	SO MOL			SO MOL
		SO SPE	SO SPE			UR LOM
	AL ALL		AL ALL			LA GLA
	RI TRI			CE GRY	AL ALL	
		CE GRY		UR LOM		CE GRY
		LA GLA		LA GLA		

Comparison of element levels in organs

The level of significance of a difference is determined by three contributing factors: the absolute difference between the mean values compared, the intrinsic variability within the categories compared, and the sample size.

Using muscle levels as a common reference value for all four elements (concentration = 1.0) the relative concentration of the four elements in liver and kidney are (overall mean values for all species with n > 1):

	Zn	Cd	Hg	Se
liver	2.8	18.1	4.7	4.2
kidney	2.9	86.2	2.6	6.2
kidney/liver	1.1	4.8	0.6	1.7

The intrinsic variability (expressed as the coefficient of variation within species) varies considerably among metals. It is low for Zn, c. 25%, high for Cd, c. 70%, and intermediate, c. 50%, for Hg and Se.

The sample size for each species is used as the ordering principle of Table 3, where the left half shows the significance levels of differences between element concentrations in muscle, liver and kidney in all species with n = 5 ≥ 5. It is obvious that highly significant

Table 3. The level of significance of differences (Friedman, Tukey) between concentrations (left half of table) and of significance of correlations between concentrations (right half). Comparisons of muscle (M) and liver (L), muscle and kidney (K), and liver and kidney levels for each metal and species with $n \geq 5$. The levels of significance indicated are: -: non significant at $p = 0.05$; *: $0.05 > p > 0.01$; **: $0.01 > p > 0.001$; ***: $p < 0.001$.

	Species	Significance of differences between concentrations				Significance of correlations between concentrations		
		M v. L	M v. K	L v. K	n	M v. L	M v. K	L v. K
Zn	CE GRY	***	***	**	46	-	-	***
	SO MOL	***	***	-	21	-	-	***
	SO SPE	***	**	*	21	-	-	**
	UR LOM	***	***	-	19	-	-	*
	LA HYP	**	***	-	18	-	-	*
	FU GLA	***	***	-	17	-	-	*
	RI TRI	*	***	-	15	*	-	-
	AL ALL	*	***	*	12	-	-	-
	LA GLA	.-	***	-	11	-	-	-
	PA EBU	-	**	-	8	-	-	-
	CL HYE	*	-	-	5	-	-	-
Cd	CE GRY	***	***	***	46	***	***	***
	SO MOL	**	***	**	21	***	***	***
	SO SPE	**	***	**	21	***	***	***
	UR LOM	**	***	**	19	-	**	**
	LA HYP	*	***	*	18	***	***	***
	FU GLA	**	***	**	17	-	-	***
	RI TRI	*	***	-	15	*	***	-
	ALALL	*	***	*	12	-	-	-
	LA GLA	-	***	-	11	-	*	**
	PA EBU	-	*	-	8	-	-	-
	CL HYE	-	**	-	5	-	-	-
Hg	CE GRY	***	***	**	46	***	***	***
	SO MOL	***	**	*	21	***	***	***
	SO SPE	***	**	*	21	***	*	**
	UR LOM	***	**	**	19	***	*	**
	LA HYP	***	**	-	18	***	***	***
	FU GLA	***	**	**	17	**	***	**
	RI TRI	**	***	-	15	***	***	**
	AL ALL	***	*	*	12	***	***	***
	LA GLA	**	*	-	11	***	**	***
	PA EBU	*	-	-	8	-	-	***
	CL HYE	**	-	-	5	-	-	-
Se	CE GRY	***	***	***	46	**	***	***
	SO MOL	***	***	-	21	*	**	***
	SO SPE	***	***	-	21	-	-	-
	UR LOM	**	***	**	19	***	***	**
	LA HYP	*	***	*	18	***	***	***
	FU GLA	**	***	**	17	**	*	*
	RI TRI	*	***	-	15	***	**	***
	AL ALL	*	***	*	12	***	**	***
	LA GLA	-	***	-	11	-	-	**
	PA EBU	*	-	-	8	-	-	-
	CL HYE	-	**	-	5	-	-	***

differences dominate in all comparisons involving muscle, even for Zn with concentration differences of only 2.8 to 2.9 times. The high level of significance is favoured by the low variability of Zn concentrations. For Cd the intrinsic variability is high, but so are the concentration differences, especially when comparing muscle and kidney, hence the consistenly high level of significance. For Hg and Se with a similar intrinsic variability, a somewhat lower level of significance is attained for Hg when comparing muscle and kidney levels. This is to be expected, since this comparison involves the smallest absolute difference between the mean values.

The comparison of liver and kidney values is less satisfactory. The kidney/liver ratio of concentrations is hardly different from 1 for Zn and Hg. Genuine differences cannot be demonstrated unless much larger samples are available, presumably of the order of 50 birds, whereas genuine differences of Cd concentrations between kidney (higher) and liver concentrations seem well documented for samples of $n > 15$.

The *relative* concentrations of Zn, Cd, Hg and Se in pectoral muscle, liver and kidney of Greenland seabirds (summarized in tabular form on p. 8) lead to the same ranking of elements and organs as found, e.g. for *Larus argentatus* (Nicholson 1981, Hutton 1981) and *Catharacta skua* (Furness & Hutton 1979, Hutton 1981) from Scottish localities.

Inter-organ correlation of element concentrations

Muscle, liver, and kidney concentrations are positively correlated for each of the elements Cd, Hg and Se. The significance usually exceeds the 1‰ level somewhere between $n = 10$ and 20 becoming more erratic at lower values of n. A few cases of non-significance at the 5% level occur, and the consistent lack of significant correlation between Se concentrations in all three organs of *S. spectabilis* (but not in *S. mollissima*, with the same n) is striking. For Zn the situation is quite different. The two pairwise comparisons involving muscle show an almost complete absence of correlation between Zn concentrations. This is almost certainly due to the fact that Zn is an essential element, whereas Cd is an extraneous contaminant. Liver and kidney concentrations are closely correlated at $n \geq 20$ (Tab. 3, right half).

Intra-organ association of elements

The more consistent association of elements (Tab. 4) seems to involve Zn and Cd in liver and kidney of most species, and Hg and Se in all three organs of four species. In general, an association between elements is likely to reflect some similarity in the handling of these elements by the biological systems. Chemically, Zn and Cd are very similar and often associated in nature. On a molar basis, Zn is by far the most abundant of the four elements considered here, 0.15–0.3 µmol per g being typical of muscle and twice this concentration in liver and kidney. Judging from the relative lack of association between Zn and Cd in muscle, this tissue would seem to possess means of distinguishing the two metals, whereas this ability seems much less pronounced in liver and kidney. When considering the molar ratio of Zn:Cd, violent fluctuations occur in muscle (22–390), whereas the ratio is more stable in liver (8–33) and almost constant in kidney (2–6).

This association between Hg and Se is quite clear in four species, but entirely absent in others with reasonably high values of n. This complicates the distinction

Table 4. The significance of association between elements. Pairwise correlation of element concentrations in muscle, liver and kidney of all species with $n > 5$. Symbols as in Table 3.

	Zn - Cd			Zn - Hg			Zn - Se		
	M	L	K	M	L	K	M	L	K
CE GRY	-	***	***	*	-	*	*	-	-
SO MOL	-	**	*	-	-	-	-	***	-
SO SPE	-	***	***	-	-	-	-	*	-
UR LOM	-	**	-	-	-	-	-	-	-
FU GLA	*	***	***	-	-	-	-	-	-
RI TRI	-	**	**	*	-	-	-	-	-
LA HYP	-	**	***	*	**	*	**	*	-
AL ALL	-	-	*	-	-	-	-	-	-
LA GLA	-	-	**	-	-	-	-	-	-
PA EBU	**	*	*	-	*	-	-	-	-

	Cd - Hg			Cd - Se			Hg - Se		
	M	L	K	M	L	K	M	L	K
CE GRY	**	***	***	**	**	*	**	***	***
SO MOL	-	*	-	-	*	**	-	-	-
SO SPE	*	-	-	-	*	-	-	-	-
UR LOM	*	*	-	-	-	-	-	-	-
FU GLA	-	-	-	-	-	-	***	-	-
RI TRI	-	-	*	***	*	-	**	***	**
LA HYP	*	**	-	*	*	-	***	***	*
AL ALL	-	-	-	-	-	-	**	**	*
LA GLA	*	-	-	-	-	-	-	-	-
PA EBU	-	-	-	-	-	-	-	-	-

between genuine species differences and random effects. The data of Appendix 3 indicate molar ratios of Se to Hg far in excess of the 1:1 ratio of marine mammals (Koeman et al. 1975). In all organs of Greenland seabirds this ratio is exceeded by a factor of often 10–30 in muscle and liver and 20–50 in kidney. Liver concentrations of Se and Hg are reported by Koeman et al. (1975) for three individuals of *Uria aalge* and one *Alca torda* (all found dead as oiled birds along the Dutch coast). From his data Se:Hg ratios of 2.9 to 6.5 can be calculated, i.e. low compared to Greenland seabirds. Se concentrations are similar in Dutch and Greenland birds, but Hg levels tend to be higher in the Dutch birds, 1.8 to 2.4 µg/g. An excess of Se over Hg on a molar basis was also found by Hutton (1981) in liver and kidney of Scottish seabirds. In *Larus argentatus* and *Catharacta skua* Se exceeds Hg by a factor of c. 5 in liver and c. 10 in kidney (calculated on a dry weight basis).

The association between Zn – Hg is generally weak (six significant correlations among 30 possible, only one reaching the 1% level of significance). This also applies to Zn – Se (five significant correlations, two at the 1% level). For Cd – Hg 11 correlations are significant, in *C. grylle* (n = 46) at the 1‰ level in liver and kidney, and at the 1% level in muscle. For Cd – Se ten correlations are significant (Tab. 4).

Age dependence of element concentrations

Birds are not very suitable for a discussion of this aspect of ecotoxicology. Absolute ages are difficult to obtain and rarely available for a reasonably extended span of years. Ages are mostly quoted as minimum ages, e.g. 2+ meaning in the second or later year of life. However, in some cases it has been possible to regroup birds of different ages into two non-overlapping, albeit wider, groups, a younger and an older one, such as yearlings (age 1) and all older birds (App. 3). Furthermore, claiming that each group should contain at least two individuals and that all members of the two groups are from the same district (in order to avoid possible geographical differences), the groups of Table 5 were obtained.

Concerning mercury, no significant differences could be detected between the groups comprising younger and older birds. Even a tendency towards higher concentration in older birds is doubtful except for the comparison of yearlings and older individuals of *C. grylle*. The older birds have a c. three times higher concentration of mercury.

Concerning cadmium, most older birds carry higher concentrations. This is particularly pronounced in *S. mollissima* and *S. spectabilis* in which four differences are significant at the 5% level and three at the 1% level among nine comparisons. Even in *C. grylle*, with a relatively poor age differentiation, one difference is significant at the 5% level, and the tendency towards higher values in subadult and adult birds than in yearlings is very pronounced.

The relatively weak documentation of the dependence of element concentration on age in our material is primarily due to the few and poorly defined age classes. Furness and Hutton (1979) analysed 13 *Catharacta skua* of known ages (ringed birds) between 3 and 12 years (Foula, Scotland). They found significant correlations between element concentration and bird age, for Cd in kidney at $p = 0.05$ and for Se in kidney at $p = 0.01$. Concerning Hg and Se in liver, significance was reached only at the 10% level. On the other hand, Nicholson (1981) did not find any significant correlations between metal (Zn, Cd and Hg) concentration and age in 11 *Larus argentatus* (Isle of May, Scotland) of known ages between 4 and 11 years.

Sex dependence of element concentrations

An analysis of the concentrations of four elements in three tissues of nine species (with $n \geq 10$) showed no significant differences between sexes except for Zn in muscle of *C. grylle*, Zn in kidney of *S. spectabilis*, Hg in liver of *S. mollissima* and Se in kidney of *S. spectabilis*. In all four cases, only the 5% level of significance was reached. Among the 108 possible comparisons, higher concentrations occurred 57 times in males and 51 times in females. No sex differences were consistent within species, metals or organs. Thus, the four significant differences actually found were considered random events. The statistical noise introduced by neglecting sex as a biological parameter is considered small and not likely to materially affect the results of our analysis.

Geographical variation in element concentrations

Variation within Greenland

For this analysis we have defined three main regions:
(1) Northwest: Avanersuaq (Thule) + Upernavik
(2) Northeast: Ittoqqortormiit (Scoresbysund)
(3) South: Nanortalik + Kangatsiaq.

Uummanaq was excluded from this analysis for two reasons: (1) birds from this district were collected in August, whereas all others are from the spring and early summer, (2) by excluding this district, the risk of overlap between regions was avoided by a gap of 535 km

Table 5. Muscle, liver and kidney concentrations (µg/g) of Cd og Hg in non-overlapping age groups from the same district. Column 4 records the age groups and the number of individuals in each group (n). In some cases in which a few kidney samples were missing, the actual value of n is recorded in the column "kidney". All significant differences are indicated by one or two asterisks (p = 0.05, 0.01, resp.).

Element	Species	District	Ages and n	Muscle	Liver	Kidney
Cd	SO MOL	KAN	2(4)	0.02	1.35	5.20
			3,3+4(4)	0.20*	5.17*	20.10(3)
		NAN	2(4)	0.03	2.37	6.80
			3,4,4+,5+(7)	0.24**	3.47	16.84*
	LA GLA	NAN	2,3(3)	0.06	1.53	12.27
			4,4+,5(7)	0.09	1.47	12.51(6)
	SO SPE	KAN	2(4)	0.02	1.67	3.95
			3,3+(9)	0.33**	5.28*	20.87**
	UR LOM	ITT	2(2)	0.20	9.92	
			3+(4)	0.42	8.50	
	CE GR	KAN	2(4)	0.04	1.81	10.69
			3+(4)	0.31*	3.11	31.28
		ITT	2(4)	0.30	3.57	22.84(3)
			3+(4)	0.10	3.53	19.74
		NAN	2(4)	0.07	1.53	15.94
			3+(4)	0.08	1.96	15.79
		UUM	1(4)	0.02	0.44	2.74
			2,2+(5)	0.29	3.20	21.58
Hg	SO MOL	KAN	2(4)	0.11	0.48	0.25
			3,3+,4(4)	0.12	1.19	0.24(3)
		NAN	2(4)	0.16	1.00	0.30
			3,4,4+,5+(7)	0.20	0.92	0.25(5)
	LA GLA	NAN	2,3(3)	0.22	0.97	0.84
			4,4+,5+(7)	0.14	0.66	0.58(6)
	SO SPE	KAN	2(4)	0.14	0.52	0.36
			3,3+(9)	0.11	0.49	0.24(8)
	UR LOM	ITT	2(2)	0.20	0.99	
			3+(4)	0.27	0.95	
	CE GRY	ITT	2(4)	0.10	0.51	0.34(3)
			3+(4)	0.16	0.53	0.38
		UUM	1(4)	0.04	0.13	0.10
			2,2+(5)	0.11	0.56	0.33

thus created between the northwestern and southern regions. Only species with at least five adults from at least two of the three regions were used for the analysis. Thus, three species could serve the analysis: *C. grylle, U. lomvia* and *L. hyperboreus.*

Birds from NW and NE had higher concentrations than those from S (in 27 of 36 possible comparisons: Zn: 9/9, Cd: 9/9, Hg: 5/9 and Se: 4/9), whereas the differences between birds from the two northern regions were more erratic (Tab. 6). However, it also appears that only few differences are statistically significant, but in all cases, significance is associated with higher concentrations in the northern regions. The paucity of significant differences may be explained by the relatively low number of birds available for the analysis. This is supported by a comparison of our analytical results for S Greenland *C. grylle* (n = 20) with the analyses of *C. grylle* from Avanersuaq (n = 26). This latter material, extracted from data on which Appendix 4 is based, was analyzed for Cd and Hg by the IH. To facilitate comparison, samples from four individuals were analyzed by both laboratories. The use of different samples and different techniques of digestion and analysis may explain the significant differences found between two sets of data (Cd in liver and Hg in muscle). Whereas this is almost certainly the case for the Hg data, the lowest concentration of Hg in muscle, the discrepancy between the Cd analyses are harder to explain (Tab. 7).

When disregarding the data on Cd in liver and Hg in muscle, Table 8 shows the concentration differences recorded between *C. grylle* from S and NW Greenland. Cadmium concentrations in birds from Avenersuaq are

Table 6. Element concentrations (μg/g w.w.) in *L. hyperboreus* from S (n = 5) and NW Greenland (n = 8), in *C. grylle* from S (n = 20), NW (n = 9) and NE Greenland (n = 8), and in *U. lomvia* from NW (n = 12) and NE Greenland (n = 6).

Element	Species	Organ	Geometric mean S	 NW	 NE	Significance of difference S-NW	 S-NE	 NW-NE
	LA HYP	M	20.28	23.35		-		
		L	39.06	42.36		-		
		K	52.97	54.28		-		
Zn	CE GRY	M	10.33	12.31	36.96	**	***	-
		L	29.65	30.14	36.50	-	**	**
		K	36.82	39.89	43.83	-	-	-
	UR LOM	M		12.14	13.75			-
		L		36.67	45.91			*
		K		42.69	47.23			-
	LA HYP	M	0.20	0.35		-		
		L	5.13	12.57		-		
		K	39.91	60.55		-		
Cd	CE GRY	M	0.10	0.30	0.17	**	-	-
		L	2.00	4.07	3.48	-	-	-
		K	14.34	26.96	19.79	*	-	-
	UR LOM	M		0.26	0.32			-
		L		6.66	8.75			-
		K		30.89	32.12			-
	LA HYP	M	0.39	0.66		-		
		L	0.68	2.67		*		
		K	1.37	2.06		-		
Hg	CE GRY	M	0.20	0.23	0.12	-	-	*
		L	0.63	0.64	0.50	-	-	-
		K	0.50	0.44	0.35	-	-	-
	UR LOM	M		0.19	0.24			-
		L		0.72	0.95			**
		K						
	LA HYP	M	0.54	1.07		-		
		L	2.85	3.67		-		
		K	6.75	5.57		-		
Se	CE GRY	M	0.77	0.83	0.60	-	-	-
		L	2.38	3.41	1.52	-	-	-
		K	5.68	5.07	4.52	-	-	-
	UR LOM	M		0.65	0.98			*
		L		1.84	2.44			*
		K		3.69	9.01			**

about twice those of birds from S Greenland. The difference is of the same order as reported in Table 6, but due to larger sample sizes, it is now highly significant. Concerning Hg the mean concentration in birds from the NW tends to be higher, but no differences are significant. Also in this case, the reported NW-S differences are similar to those of Table 6.

The last body of data available for the analysis of differences in concentration levels within Greenland is provided by a sample representing five species collected in the Uummanaq district to serve monitoring purposes in connection with mining activities at Maarmorilik (App. 5). Unfortunately, these data hardly add anything new to the analysis. The concentration of Zn and Cd in yearling birds are not significantly different from those reported in Appendix 3. This also applies to subadults and adults, although Cd levels tend to be higher in *L. glaucoides* and *L. hyperboreus* from Uummanaq.

Variation within the Arctic

Analytical data on element levels are available for seabirds from Svalbard. They are summarized in Appendix

Table 7. Comparison of analytical results by GERI and IH. Each laboratory analyzed different samples of three organs of the same four individuals of *C. grylle* from Avanersuaq. Different techniques were used by the two laboratories.

Element	Organ	Mean concentration GERI	Mean concentration IH	Mean diff.	S diff.	Level of significance
Cd	muscle	0.25	0.28	−0.03	0.10	-
	liver	3.58	4.98	−1.40	0.37	**
	kidney	21.70	24.05	−3.70	2.52	-
Hg	muscle	0.22	0.40	−0.18	0.04	**
	liver	0.75	0.61	0.13	0.26	-
	kidney	0.47	0.56	−0.03	0.15	-

6. Seven of our species from Greenland were analyzed by Carlberg & Bøler (1985), but based on only two individuals except for *Uria lomvia* (n = 4). For all four metals they report lower concentrations than in Greenland birds. Norheim (1987) presented data from a larger number of individuals (n = 9–11). He reports concentrations quite similar to those found in our material from Greenland.

Comparison of arctic and temperate regions

Appendix 7 presents the more relevant analytical results for birds of the temperate region. The analyses available for Canadian birds (Noble & Elliot 1986, Braune 1987) are similar to those for Greenland birds. For *F. glacialis* from St. Kilda, Scotland, Bull et al. (1977) report Cd levels of liver and kidney c. 10% lower than, but not significantly different from Greenland fulmars. Karlog et al. (1983) analyzed 43 *S. mollissima* from Denmark. The Cd concentrations in liver were almost identical to those of the present study, whereas the kidney values were almost 40% lower, but not significantly different from those of Greenland eiders. However, the concentrations recorded may not be representative of average population levels, since most of the birds were found dead (8) or killed in a weakened state (36), and five were nestlings, which were said to have much lower concentrations than adults. In Sweden, Frank (1976) claims that birds found dead had 1.7 and 3.1 times higher Cd concentrations in liver and kidney. Should this apply for Danish eiders as well, the levels quoted could well overestimate the concentrations of a population in a normal state of health by 14 and 42% for liver and kidney, respectively.

Mercury in muscle of birds from the Baltic was analyzed by Jensen et al. (1972). Significantly higher values were found in *C. grylle* and *U. lomvia*, i.e. 9.4 and 4.0 times the Greenland levels, respectively. Also in Danish eiders, Karlog et al. (1983) found high levels, and in three birds from Scotland, Dale et al. (1973) report values more than 20 times the level in Greenland eiders. On the other hand, their analyses of *L. hyperboreus*, *R. tridactyla* and *F. glacialis* did not differ significantly from those of Greenland birds.

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Table 8. Cd and Hg concentrations (µg/g w.w.) in *C. grylle* from S Greenland (Nanortalik + Kangatsiaq) (n = 20) and from Avanersuaq (Thule) (n = 26). Avanersuaq data based on analyses by IH.

Element	Organ	Mean concentration S Greenland	Mean concentration Avanersuaq	Significance of difference
Cd	muscle	0.10	0.25	***
	kidney	14.34	35.45	***
Hg	liver	0.63	0.66	-
	kidney	0.50	0.55	-

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Appendices

Appendix 1. Body weights, (Wgt) liver weights (Lwgt) and the ratio Lwgt/Wgr (%) for all birds dissected.

Species	n	mean g	s.d.	median g	range g	Lwgt/Wgt %
Body weight						
CE GRY	147	421.4	45.6	420.0	304–542	
UR LOM	78	981.6	83.7	988.0	787–1179	
AL ALL	56	159.0	11.4	158.5	132–187	
SO MOL	32	1859.4	250.8	1814.5	1455–2389	
SO SPE	34	1620.1	216.0	1627.0	1030–1957	
CL HYE	10	820.4	75.7	798.0	713–948	
ME SER	1	1288.0	.	1288.0	1288–1288	
LA GLA	13	782.3	103.4	770.0	624–989	
LA HYP	38	1498.4	246.4	1496.5	922–1927	
RI TRI	113	412.7	44.2	419.0	310–503	
PA EBU	25	583.4	93.4	598.0	435–750	
FU GLA	64	690.0	91.2	690.5	488–940	
PH CAR	1	4062.0	.	4062.0	4062–4062	
ST POM	1	498.0	.	498.0	498–498	
Liver weight						
CE GRY	147	22.3	5.6	21.6	9.4–40.2	5.29
UR LOM	79	45.7	10.3	44.6	24.4–69.1	4.66
AL ALL	51	7.3	1.4	6.9	5.6–12.7	4.59
SO SPE	34	69.0	14.9	70.1	25.8–96.7	4.29
SO MOL	32	79.8	18.4	79.9	36.1–124.0	4.26
CL HYE	10	37.3	5.0	37.5	30.6–46.5	4.55
ME SER	1	50.8	.	50.8	50.8–50.8	3.94
LA GLA	13	25.8	3.2	26.1	19.5–30.4	3.30
LA HYP	38	42.6	12.2	40.4	24.6–73.1	2.84
RI TRI	113	14.8	3.0	14.9	8.9–22.4	3.59
PA EBU	25	15.8	3.0	16.1	6.4–19.4	2.71
FU GLA	64	19.3	5.3	17.9	9.8–34.2	2.80
PH CAR	1	133.8	.	133.8	133.8–133.8	3.29
ST POM	1	20.7	.	20.7	20.7–20.7	4.16

Appendix 2. Dry weight percentage of muscle, liver and kidney.

Species	n	mean	s.d	median	range
Muscle					
AL ALL	12	28.5	2.3	28.0	24.5–33.3
CE GRY	46	27.3	1.5	27.3	23.1–30.3
CL HYE	5	27.5	1.5	27.2	25.5–29.6
FU GLA	17	29.3	1.8	29.2	26.7–32.7
LA GLA	11	28.2	1.6	28.0	26.0–31.4
LA HYP	18	27.2	2.8	26.9	22.4–31.9
ME SER	1	27.5	.	27.5	27.5–27.5
PA EBU	8	32.2	4.6	30.9	27.4–42.5
PH CAR	1	33.2	.	33.2	33.2–33.2
RI TRI	15	31.6	2.1	31.3	28.9–35.8
SO MOL	21	26.3	2.5	26.8	20.1–31.6
SO SPE	21	25.2	1.4	25.1	23.0–28.4
ST POM	1	29.7	.	29.7	29.7–29.7
UR LOM	19	27.5	2.2	27.4	21.8–30.5

Liver					
AL ALL	13	31.1	1.8	31.1	28.2–34.8
CE GRY	45	30.4	2.2	30.2	22.6–35.2
CL HYE	4	29.7	2.8	28.5	27.9–33.9
FU GLA	16	30.1	2.0	30.0	26.4–35.0
LA GLA	11	31.0	1.7	31.6	28.3–32.9
LA HYP	18	29.6	3.4	29.2	23.4–39.9
ME SER	1	26.5	.	26.5	26.5–26.5
PA EBU	9	29.9	2.4	30.7	26.1–33.0
PH CAR	1	28.6	.	28.6	28.6–28.6
RI TRI	16	31.0	1.4	31.2	28.1–33.3
SO MOL	19	27.5	1.5	27.7	25.1–31.1
SO SPE	21	28.5	2.2	28.6	23.8–33.3
ST POM	1	31.5	.	31.5	31.5–31.5
UR LOM	19	29.3	2.1	29.0	26.2–32.9
Kidney					
AL ALL	7	24.9	1.8	24.4	22.4–27.9
CE GRY	37	25.2	2.3	25.2	17.9–29.2
CL HYE	5	25.8	2.1	25.9	22.4–27.9
FU GLA	15	25.3	4.8	24.4	15.4–36.0
LA GLA	7	24.9	2.3	25.6	21.8–28.7
LA HYP	18	25.6	3.0	26.2	17.8–30.0
ME SER	1	25.8	.	25.8	25.8–25.8
PA EBU	3	27.3	2.0	27.9	25.0–28.9
PH CAR	1	21.6	.	21.6	21.6–21.6
RI TRI	2	26.6	1.7	26.6	25.4–27.8
SO MOL	19	23.8	1.7	23.7	21.5–27.4
SO SPE	20	24.2	1.7	24.0	21.3–26.9
UR LOM	11	24.1	2.3	23.9	21.0–28.1

Appendix 3. Element concentrations (µg/g w.w.) in tissues of Greenland seabirds: numbers analysed (n), arithmetic mean (X(A)), standard deviation (s.d.), geometric mean (X(G)), relative standard deviation of the geometric mean (s.d.(rel.)), i.e. the antilogarithm of the standard deviation of ln concentration, median and the range of concentrations.

Element/Species		n	X(A)	s.d.	X(G)	s.d.rel	median	range
Muscle levels in yearling birds								
ZN	CE GRY	4	14.20	1.602	14.14	1.117	13.89	12.66– 16.37
	LA GLA	1	17.30	.	17.30	.	17.30	17.30
	LA HYP	4	18.44	4.328	18.03	1.287	19.05	12.76– 22.91
	RI TRI	1	15.20	.	15.20	.	15.20	15.20
CD	CE GRY	4	0.02	0.035	<0.015	3.204	<0.015	<0.015– 0.08
	LA GLA	1	<0.015	.	<0.015	.	<0.015	<0.015
	LA HYP	4	<0.015	0.000	<0.015	1.000	<0.015	<0.015
	RI TRI	1	<0.015	.	<0.015	.	<0.015	<0.015
HG	CE GRY	4	0.04	0.026	0.03	1.841	0.03	0.02– 0.08
	LA GLA	1	0.01	.	0.01	.	0.01	0.01
	LA HYP	4	0.04	0.017	0.04	1.482	0.04	0.03– 0.07
	RI TRI	1	0.02	.	0.02	.	0.02	0.02
SE	CE GRY	4	<0.200	0.114	<0.200	1.839	<0.200	<0.200– 0.33
	LA GLA	1	<0.200	.	<0.200	.	<0.200	<0.200
	LA HYP	4	<0.200	0.060	<0.200	1.483	<0.200	<0.200– 0.22
	RI TRI	1	<0.200	.	<0.200	.	<0.200	<0.200
Liver levels in yearling birds								
ZN	CE GRY	4	24.82	3.498	24.63	1.157	25.17	20.23– 28.71
	LA GLA	1	22.91	.	22.91	.	22.91	22.91
	LA HYP	4	35.06	17.558	31.76	1.686	32.73	16.87– 57.92
	RI TRI	1	29.85	.	29.85	.	29.85	29.85

CD	CE GRY	4	0.44	0.694	0.18	4.034	0.10	0.08– 1.48
	LA GAL	1	0.05	.	0.05	.	0.05	0.05
	LA HYP	4	0.13	0.028	0.12	1.276	0.14	0.09– 0.15
	RI TRI	1	0.40	.	0.40	.	0.40	0.40
HG	CE GRY	4	0.13	0.041	0.13	1.368	0.13	0.09– 0.18
	LA GLA	1	0.02	.	0.02	.	0.02	0.02
	LA HYP	4	0.25	0.055	0.24	1.256	0.25	0.19– 0.31
	RI TRI	1	0.08	.	0.08	.	0.08	0.08
SE	CE GRY	4	1.09	0.417	1.03	1.512	1.09	0.60– 1.59
	LA GLA	1	1.05	.	1.05	.	1.05	1.05
	LA HYP	4	1.24	0.054	1.24	1.044	1.24	1.18– 1.29
	RI TRI	1	1.13	.	1.13	.	1.13	1.13
Kidney levels in yearling birds								
ZN	CE GRY	4	25.16	5.612	24.66	1.268	25.73	17.78– 31.42
	LA GLA	1	25.83	.	25.83	.	25.83	25.83
	LA HYP	4	28.83	5.577	28.44	1.212	27.90	24.17– 35.37
	RI TRI	1	33.46	.	33.46	.	33.46	33.46
CD	CE GRY	4	2.74	5.004	0.57	7.095	0.27	0.16– 10.24
	LA GLA	1	0.11	.	0.11	.	0.11	0.11
	LA HYP	3	0.35	0.030	0.35	1.090	0.34	0.32– 0.38
	RI TRI	1	1.34	.	1.34	.	1.34	1.34
HG	CE GRY	4	0.10	0.088	0.07	2.309	0.06	0.03– 0.22
	LA GLA	1	0.02	.	0.02	.	0.02	0.02
	LA HYP	4	0.20	0.052	0.20	1.292	0.20	0.15– 0.27
	RI TRI	1	0.05	.	0.05	.	0.05	0.05
SE	CE GRY	4	1.98	0.484	1.94	1.268	1.90	1.50– 2.64
	LA GLA	1	1.57	.	1.57	.	1.57	1.57
	LA HYP	4	2.07	0.439	2.04	1.238	2.05	1.61– 2.57
	RI TRI	1	2.55	.	2.55	.	2.55	2.55

To be continued

Element/Species		n	X(A)	s.d.	X(G)	s.d.rel	median	range
Muscle levels in subadult and adult birds								
ZN	CE GRY	42	11.53	1.605	11.43	1.149	11.23	8.86– 14.66
	UR LOM	20	12.82	2.734	12-54	1.245	13.30	8.80– 17.67
	AL ALL	13	15.49	7.613	14.31	1.458	12.11	10.84– 34.60
	SO MOL	21	11.91	2.357	11.69	1.221	11.98	8.34– 17.02
	SO SPE	21	11.34	1.568	11.24	1.150	11.25	8.17– 15.19
	CL HYE	5	11.75	2.038	11.59	1.208	11.96	8.50– 13.53
	LA GLA	10	18.14	4.664	17.67	1.260	16.47	13.48– 27.85
	LA HYP	15	22.66	4.087	22.31	1.200	22.48	16.29– 28.68
	RI TRI	15	15.92	2.866	15.71	1.177	15.28	12.61– 23.79
	PA EBU	9	17.67	1.680	17.59	1.104	17.93	14.41– 19.95
	FU GLA	17	18.23	6.561	17.46	1.326	17.89	10.57– 41.54
	PH CAR	1	20.82	.	20.82	.	20.82	20.82
	ME SER	1	10.68	.	10.68	.	10.68	10.68
	ST POM	1	20.33	.	20.33	.	20.33	20.33
CD	CE GRY	42	021.	0.188	0.13	2.880	0.14	<0.015– 0.74
	UR LOM	19	0.37	0.203	0.29	2.197	0.42	0.04– 0.83
	AL ALL	13	0.37	0.170	0.30	2.439	0.35	0.02– 0.71
	SO MOL	21	0.18	0.269	0.08	4.147	0.08	<0.015– 1.12
	SO SPE	21	0.36	0.387	0.15	4.897	0.17	<0.015– 1.16
	CL HYE	5	0.22	0.191	0.16	2.638	0.16	0.04– 0.53
	LA GLA	10	0.08	0.043	0.07	1.683	0.07	0.03– 0.17
	LA HYP	15	0.37	0.350	0.26	2.325	0.25	0.05– 1.25
	RI TRI	15	0.48	0.378	0.29	3.385	0.42	0.04– 1.09
	PA EBU	9	0.42	0.325	0.27	3.356	0.38	0.02– 0.94
	FU GLA	17	1.39	1.601	0.82	2.769	0.52	0.17– 5.75
	PH CAR	1	0.17	.	0.17	.	0.17	0.17
	ME SER	1	0.06	.	0.06	.	0.06	0.06
	ST POM	1	0.03	.	0.03	.	0.03	0.03
HG	CE GRY	42	0.20	0.133	0.17	1.946	0.18	0.03– 0.61
	UR LOM	20	0.20	0.067	0.19	1.427	0.21	0.09– 0.31
	AL ALL	12	0.14	0.080	0.12	1.903	0.13	0.03– 0.29
	SO MOL	20	0.15	0.080	0.13	1.706	0.14	0.04– 0.35
	SO SPE	21	0.13	0.073	0.12	1.544	0.12	0.06– 0.40
	CL HYE	5	0.11	0.027	0.11	1.287	0.12	0.08– 0.14
	LA GLA	10	0.17	0.084	0.15	1.678	0.15	0.06– 0.34
	LA HYP	15	0.68	0.377	0.56	1.995	0.66	0.16– 1.24
	RI TRI	15	0.17	0.116	0.12	2.706	0.19	0.03– 0.33
	PA EBU	9	0.19	0.124	0.16	1.703	0.14	0.10– 0.43
	FU GLA	17	0.27	0.113	0.24	1.669	0.29	0.08– 0.47
	PH CAR	1	2.16	.	2.16	.	2.16	2.16
	ME SER	1	0.21	.	0.21	.	0.21	0.21
	ST POM	1	0.15	.	0.15	.	0.15	0.15
SE	CE GRY	42	0.78	0.450	0.65	1.891	0.69	<0.200– 2.00
	UR LOM	20	0.87	0.376	0.79	1.563	0.81	0.30– 1.63
	AL ALL	12	2.51	1.556	1.87	2.806	2.20	<0.200– 5.84
	SO MOL	21	1.06	0.802	0.75	2.603	0.73	<0.200– 3.09
	SO SPE	21	0.84	0.590	0.57	2.860	0.91	<0.200– 1.99
	CL HYE	5	0.89	0.550	0.65	2.979	0.83	<0.200– 1.43
	LA GLA	10	0.54	0.134	0.53	1.255	0.51	0.41– 0.81
	LA HYP	15	1.43	1.144	0.97	2.702	0.67	<0.200– 3.92
	RI TRI	15	2.95	1.791	2.31	2.206	3.02	0.60– 5.63
	PA EBU	9	1.46	0.562	1.18	2.555	1.69	<0.200– 1.99
	FU GLA	17	2.45	0.873	2.29	1.470	2.28	0.96– 3.98
	PH CAR	1	0.75	.	0.75	.	0.75	0.75
	ME SER	1	<0.200	.	<0.200	.	<0.200	<0.200
	ST POM	1	<0.200	.	<0.200	.	<0.200	<0.200

To be continued

Element/Species		n	X(A)	s.d.	X(G)	s.d.rel	median	range
Liver levels in subadult and adult birds								
ZN	CE GRY	42	31.36	4.645	31.02	1.161	31.28	22.56– 43.61
	UR LOM	20	39.76	7.963	38.99	1.227	40.05	24.70– 55.04
	AL ALL	13	38.01	4.222	37.78	1.123	39.03	30.95– 43.02
	SO MOL	21	43.92	16.112	41.48	1.401	38.63	25.43– 81.50
	SO SPE	21	47.59	14.450	45.48	1.368	44.74	24.15– 71.38
	CL HYE	5	33.64	7.175	33.06	1.228	30.42	26.27– 44.49
	LA GLA	10	31.86	3.712	31.66	1.126	32.43	25.79– 36.60
	LA HYP	14	42.73	13.827	40.68	1.388	41.06	21.34– 67.88
	RI TRI	15	36.79	8.006	35.96	1.251	38.67	26.71– 47.78
	PA EBU	9	37.08	4.741	36.81	1.138	36.50	29.11– 45.48
	FU GLA	17	51.95	19.781	49.01	1.404	46.94	31.54– 97.63
	PH CAR	1	26.44	.	26.44	.	26.44	26.44
	ME SER	1	31.40	.	31.40	.	31.40	31.40
	ST POM	1	28.73	.	28.73	.	28.73	28.73
CD	CE GRY	42	3.12	1.790	2.51	2.160	2.91	0.17– 7.51
	UR LOM	20	7.33	2.867	6.83	1.474	6.86	3.44– 14.73
	AL ALL	13	5.42	2.666	4.64	1.950	5.34	0.74– 11.39
	SO MOL	21	3.26	1.938	2.71	1.916	2.83	0.83– 8.23
	SO SPE	21	5.81	4.134	4.50	2.127	4.08	1.40– 14.28
	CL HYE	5	5.24	4.039	4.28	1.981	3.05	2.41– 11.93
	LA GLA	10	1.63	0.545	1.52	1.554	1.67	0.52– 2.33
	LA HYP	15	11.13	11.165	7.45	2.572	7.28	1.49– 44.23
	RI TRI	15	7.97	4.126	7.01	1.708	7.59	2.47– 17.36
	PA EBU	9	7.38	3.036	6.78	1.573	7.57	3.13– 12.84
	FU GLA	17	10.47	6.161	9.03	1.735	8.16	3.80– 22.51
	PH CAR	1	1.11	.	1.11	.	1.11	1.11
	ME SER	1	1.41	.	1.41	.	1.41	1.41
	ST POM	1	0.93	.	0.93	.	0.93	0.93
HG	CE GRY	42	0.67	0.421	0.56	1.813	0.58	0.12– 2.14
	UR LOM	20	0.77	0.243	0.72	1.450	0.77	0.27– 1.22
	AL ALL	13	0.50	0.285	0.42	1.932	0.43	0.11– 1.08
	SO MOL	21	0.85	0.555	0.70	1.899	0.62	0.25– 1.91
	SO SPE	21	0.59	0.397	0.49	1.869	0.53	0.13– 1.63
	CL HYE	5	0.64	0.192	0.62	1.304	0.60	0.48– 0.98
	LA GLA	10	0.75	0.386	0.68	1.571	0.56	0.41– 1.60
	LA HYP	15	2.58	1.402	2.18	1.911	2.70	0.60– 5.55
	RI TRI	15	0.65	0.443	0.46	2.610	0.81	0.12– 1.32
	PA EBU	9	0.84	0.568	0.71	1.793	0.56	0.40– 1.81
	FU GLA	17	2.22	1.337	1.84	2.008	2.05	0.26– 6.11
	PH CAR	1	10.63	.	10.63	.	10.63	10.63
	ME SER	1	1.38	.	1.38	.	1.38	1.38
	ST POM	1	1.41	.	1.41	.	1.41	1.41
SE	CE GRY	42	2.65	1.380	2.37	1.606	2.37	0.74– 7.93
	UR LOM	20	2.22	0.768	2.12	1.366	2.01	1.35– 4.43
	AL ALL	13	6.14	2.727	5.37	1.854	6.35	1.03– 10.72
	SO MOL	21	7.54	5.118	6.01	2.102	6.22	0.75– 21.40
	SO SPE	21	7.71	6.053	6.02	2.089	7.16	1.58– 29.07
	CL HYE	5	3.16	1.969	2.73	1.827	3.03	1.32– 6.37
	LA GLA	10	2.16	0.907	2.02	1.444	1.98	1.30– 4.12
	LA HYP	15	4.86	3.752	4.00	1.815	3.48	2.01– 15.41
	RI TRI	15	9.91	6.357	7.74	2.204	9.03	1.91– 21.38
	PA EBU	9	5.70	2.443	5.13	1.703	5.65	1.62– 9.09
	FU GLA	17	8.64	2.306	8.34	1.321	8.63	4.80– 12.79
	PH CAR	1	2.54	.	2.54	.	2.54	2.54
	ME SER	1	1.24	.	1.24	.	1.24	1.24
	ST POM	1	3.14	.	3.14	.	3.14	3.14

To be continued

Element/Species		n	X(A)	s.d.	X(G)	s.d.rel	median	range
Kidney levels in adult birds								
ZN	CE GRY	39	39.60	7.862	38.83	1.226	40.50	25.75– 58.75
	UR LOM	19	44.20	7.693	43.58	1.189	42.60	32.30– 61.46
	AL ALL	11	46.72	5.189	46.45	1.122	47.00	38.82– 52.62
	SO MOL	20	33.55	7.100	32.82	1.245	32.03	18.49– 46.38
	SO SPE	20	35.55	6.899	34.92	1.215	34.73	23.28– 50.89
	CL HYE	5	26.17	8.425	25.26	1.331	23.11	20.05– 40.57
	LA GLA	9	44.31	10.432	43.23	1.265	41.19	30.53– 59.15
	LA HYP	15	54.18	12.017	52.91	1.256	57.04	34.19– 75.75
	RI TRI	11	50.22	14.246	48.54	1.311	47.97	30.97– 83.17
	PA EBU	5	51.37	13.742	49.85	1.321	52.93	33.62– 69.97
	FU GLA	17	52.15	6.864	51.74	1.137	50.41	43.57– 65.82
	PH CAR	1	18.22	.	18.22	.	18.22	18.22
	ME SER	1	23.31	.	23.31	.	23.31	23.31
	ST POM	1	28.54	.	28.54	.	28.54	28.54
CD	CE GRY	39	21.22	13.712	16.21	2.423	18.54	0.54– 58.38
	UR LOM	19	31.80	12.566	29.37	1.524	30.24	13.34– 54.26
	AL ALL	11	32.21	11.755	28.39	1.933	32.07	4.25– 50.80
	SO MOL	20	14.90	12.879	11.23	2.137	11.81	3.41– 58.10
	SO SPE	20	19.28	15.386	13.96	2.391	16.18	2.98– 62.49
	CL HYE	5	11.75	3.660	11.18	1.451	12.47	6.02– 15.55
	LA GLA	9	12.77	4.686	11.97	1.475	13.37	6.72– 19.73
	LA HYP	15	53.18	37.069	43.02	2.008	49.86	12.87–163.28
	RI TRI	10	42.86	30.042	31.69	2.538	38.08	4.30–102.65
	PA EBU	5	27.96	18.370	19.42	3.300	28.40	2.51– 51.79
	FU GLA	17	34.77	17.719	31.27	1.586	27.82	15.31– 77.97
	PH CAR	1	6.38	.	6.38	.	6.38	6.38
	ME SER	1	9.32	.	9.32	.	9.32	9.32
	ST POM	1	4.21	.	4.21	.	4.21	4.21
HG	CE GRY	39	0.49	0.301	0.41	1.860	0.42	0.08– 1.48
	UR LOM	19	0.44	0.165	0.38	2.016	0.46	0.03– 0.76
	AL ALL	11	0.32	0.170	0.28	1.867	0.32	0.08– 0.64
	SO MOL	20	0.28	0.123	0.26	1.503	0.27	0.12– 0.63
	SO SPE	20	0.31	0.115	0.29	1.471	0.27	0.11– 0.58
	CL HYE	5	0.31	0.058	0.31	1.211	0.33	0.23– 0.39
	LA GLA	9	0.67	0.301	0.61	1.571	0.55	0.33– 1.23
	LA HYP	15	2.09	1.218	1.80	1.785	2.05	0.61– 5.44
	RI TRI	10	0.38	0.259	0.32	1.904	0.23	0.15– 0.84
	PA EBU	5	0.44	0.099	0.43	1.265	0.48	0.32– 0.55
	FU GLA	17	0.70	0.259	0.63	1.689	0.69	0.12– 1.03
	PH CAR	1	28.09	.	28.09	.	28.09	28.09
	ME SER	1	0.65	.	0.65	.	0.65	0.65
	ST POM	1	0.64	.	0.64	.	0.64	0.64
SE	CE GRY	39	5.20	2.085	4.81	1.497	5.04	1.96– 11.91
	UR LOM	18	6.06	3.476	5.26	1.709	4.34	2.86– 12.94
	AL ALL	11	11.53	5.112	9.81	2.089	11.87	1.26– 20.06
	SO MOL	20	5.91	2.959	5.32	1.582	4.76	2.78– 12.42
	SO SPE	20	6.87	2.657	6.44	1.444	6.30	3.26– 14.08
	CL HYE	5	5.81	3.575	5.07	1.765	3.82	2.89– 11.48
	LA GLA	9	4.97	2.287	4.60	1.491	4.11	2.94– 9.29
	LA HYP	15	9.49	10.153	7.33	1.886	6.43	3.27– 44.35
	RI TRI	10	11.69	6.920	9.77	1.925	10.64	3.55– 24.18
	PA EBU	5	5.85	3.782	4.64	2.322	4.67	1.24– 10.75
	FU GLA	17	15.57	3.773	15.11	1.298	15.61	8.79– 21.26
	PH CAR	1	9.26	.	9.26	.	9.26	9.26
	ME SER	1	2.75	.	2.75	.	2.75	2.75
	ST POM	1	4.54	.	4.54	.	4.54	4.54

Appendix 4. Element concentrations (µg/g w.w.) in tissues of birds collected in the Avanersuaq (Thule) district in spring 1984. Results extracted from the GERI data base. Analyses by Institute of Hygiene, Aarhus University.

Element/Species	n	X(A)	s.d.	X(G)	s.d.rel	median	range
Muscle levels in subadult and adult birds							
CD CE GRY	25	0.30	0.153	0.27	1.668	0.30	0.10– 0.70
UR LOM	15	0.84	0.568	0.72	1.766	0.60	0.24– 2.60
AL ALL	25	1.40	0.846	1.18	1.820	1.30	0.38– 3.40
LA HYP	11	0.48	0.401	0.36	2.314	0.40	0.10– 1.42
RI TRI	14	1.19	0.588	1.04	1.771	1.15	0.33– 2.50
PA EBU	15	0.36	0.157	0.32	1.678	0.40	0.10– 0.70
FU GLA	14	1.65	1.223	1.29	2.081	1.40	0.37– 4.80
HG CE GRY	26	0.37	0.164	0.33	1.562	0.34	0.14– 0.82
UR LOM	15	0.30	0.133	0.27	1.550	0.28	0.15– 0.58
AL ALL	25	0.11	0.023	0.11	1.251	0.11	0.06– 0.15
LA HYP	11	0.94	0.458	0.87	1.480	0.89	0.55– 2.18
RI TRI	14	0.39	0.165	0.36	1.501	0.38	0.20– 0.82
PA EBU	15	0.32	0.147	0.28	1.732	0.33	0.07– 0.65
FU GLA	14	0.47	0.207	0.42	1.676	0.42	0.13– 0.84
Liver levels in subadult and adult birds							
CD CE GRY	26	6.26	2.612	5.72	1.567	5.70	1.72– 12.70
UR LOM	15	7.39	2.829	6.84	1.530	7.64	2.80– 12.40
AL ALL	25	4.84	1.083	4.72	1.260	5.00	3.00– 7.30
LA HYP	11	14.36	11.950	10.97	2.133	9.30	3.90– 44.23
RI TRI	14	11.30	12.693	8.60	1.913	7.50	4.30– 54.20
PA EBU	15	12.63	9.282	10.59	1.781	8.80	4.50– 41.70
FU GLA	14	16.26	9.638	13.84	1.813	15.60	5.20– 38.20
HG CE GRY	26	0.69	0.242	0.65	1.350	0.60	0.43– 1.52
UR LOM	15	0.79	0.205	0.76	1.314	0.71	0.41– 1.15
AL ALL	25	0.31	0.101	0.30	1.413	0.30	0.13– 0.54
LA HYP	11	2.68	1.064	2.52	1.427	2.48	1.57– 5.23
RI TRI	14	1.08	0.270	1.05	1.282	1.02	0.70– 1.61
PA EBU	15	0.90	0.262	0.86	1.329	0.85	0.50– 1.42
FU GLA	14	1.86	0.715	1.74	1.461	1.67	0.80– 3.20
Kidney levels in subadult and adult birds							
CD CE GRY	26	44.73	32.017	34.82	2.197	32.54	2.70–134.60
UR LOM	15	36.97	23.846	30.85	1.856	27.80	11.50– 91.30
AL ALL	25	19.13	5.752	18.33	1.351	18.60	11.00– 33.50
LA HYP	11	67.68	56.594	48.17	2.526	53.40	8.80–183.30
RI TRI	14	75.86	64.745	41.04	7.409	58.35	0.05–275.20
PA EBU	15	58.47	31.265	52.37	1.592	48.90	29.30–125.00
FU GLA	14	67.46	45.375	56.01	1.876	55.55	22.49–185.20
HG CE GRY	26	0.55	0.165	0.53	1.346	0.52	0.32– 0.91
UR LOM	15	0.53	0.184	0.50	1.449	0.53	0.24– 0.86
AL ALL	25	0.26	0.176	0.22	1.817	0.23	0.09– 0.86
LA HYP	11	1.50	0.754	1.32	1.771	1.61	0.52– 2.96
RI TRI	14	0.61	0.107	0.60	1.181	0.58	0.47– 0.85
PA EBU	15	0.57	0.112	0.56	1.228	0.58	0.39– 0.78
FU GLA	14	0.88	0.350	0.82	1.417	0.77	0.50– 1.84

To be continued

Element/Species		n	X(A)	s.d.	X(G)	s.d.rel	median	range
Muscle levels in yearling birds								
ZN	CE GRY	1	13.70	.	13.70	.	13.70	13.70–13.70
	SO MOL	6	17.87	1.233	17.83	1.071	17.66	16.45–19.34
	SO SPE	8	17.75	2.033	17.63	1.135	18.02	13.12–19.51
	LA GLA	19	18.25	4.029	17.86	1.236	16.69	13.72–26.97
	LA HYP	1	18.04	.	18.04	.	18.04	18.04–18.04
CD	CE GRY	1	0.52	.	0.52	.	0.52	0.52–0.52
	SO MOL	6	0.08	0.089	0.03	5.805	0.05	0.00–0.23
	SO SPE	8	0.23	0.237	0.14	3.072	0.12	0.02–0.72
	LA GLA	19	0.01	0.004	0.00	1.888	0.00	0.00–0.02
	LA HYP	1	0.00	.	0.00	.	0.00	0.00–0.00
Liver levels in yearling birds								
ZN	CE GRY	1	21.29	.	21.29	.	21.29	21.29–21.29
	SO MOL	6	31.68	5.549	31.27	1.193	31.68	25.80–38.86
	SO SPE	8	32.99	13.880	31.18	1.395	29.20	23.06–65.91
	LA GLA	19	32.18	13.888	30.19	1.409	29.19	20.09–80.64
	LA HYP	1	31.50	.	31.50	.	31.50	31.50–31.50
CD	CE GRY	1	0.41	.	0.41	.	0.41	0.41–0.41
	SO MOL	6	0.43	0.291	0.32	2.684	0.50	0.07–0.81
	SO SPE	8	0.68	0.892	0.45	2.313	0.40	0.17–2.86
	LA GLA	19	0.20	0.133	0.15	2.209	0.20	0.03–0.50
	LA HYP	1	0.33	.	0.33	.	0.33	0.33–0.33
Kidney levels in yearling birds								
ZN	CE GRY	1	24.22	.	24.22	.	24.22	24.22–24.22
	SO MOL	6	20.92	1.962	20.85	1.099	21.08	18.04–23.79
	SO SPE	8	21.34	3.598	21.11	1.164	19.63	18.96–29.41
	LA GLA	19	35.18	18.772	32.39	1.456	30.73	20.77–104.98
	LA HYP	1	92.31	.	92.31	.	92.31	92.31–92.31
CD	CE GRY	1	1.62	.	1.62	.	1.62	1.62–1.62
	SO MOL	6	1.28	0.960	0.90	2.806	1.42	0.22–2.83
	SO SPE	8	1.38	1.796	0.92	2.323	0.77	0.32–5.78
	LA GLA	19	0.55	0.402	0.45	1.861	0.39	0.14–1.79
	LA HYP	1	1.29	.	1.29	.	1.29	1.29–1.29

Appendix 5. Element concentrations (µg/g w.w.) in tissues of birds collected in the Uummanaq district. Results extracted from the GERI data base. Analyses carried out by the Center of Industrial Research, Oslo.

Element/Species		n	X(A)	s.d.	X(G)	s.d.rel	median	range
Muscle levels in subadult and adult birds								
ZN	SO MOL	40	12.02	1.822	11.88	1.165	12.23	8.24–17.14
	SO SPE	24	11.91	1.884	11.76	1.178	11.76	7.88–15.62
	LA GLA	8	20.78	3.454	20.51	1.190	21.10	15.47–25.04
	LA HYP	5	23.11	5.343	22.69	1.228	20.80	19.63–32.55
CD	SO MOL	40	0.25	0.193	0.17	2.740	0.18	0.01– 0.85
	SO SPE	24	0.66	0.427	0.51	2.281	0.61	0.10– 1.55
	LA GLA	8	0.26	01.60	0.18	3.433	0.25	0.01– 0.52
	LA HYP	5	0.10	0.197	0.02	5.906	0.01	0.01– 0.45
Liver levels in subadult and adult birds								
ZN	SO MOL	40	44.70	9.713	43.69	1.243	44.12	27.82–70.22
	SO SPE	24	44.35	6.355	43.90	1.160	45.33	32.49–58.92
	LA GLA	7	28.97	8.911	27.32	1.503	32.80	11.57–38.13
	LA HYP	5	30.45	5.454	30.01	1.215	31.33	21.70–36.58
CD	SO MOL	40	3.45	1.422	3.14	1.584	3.13	0.76– 6.77
	SO SPE	24	5.15	2.828	4.49	1.736	4.69	1.24–14.72
	LA GLA	7	10.54	9.822	5.38	4.655	7.79	0.33–26.39
	LA HYP	5	2.12	4.062	0.43	6.782	0.16	0.09– 9.36
Kidney levels in subadult and adult birds								
ZN	SO MOL	40	31.46	4.514	31.13	1.160	32.22	21.14–41.69
	SO SPE	24	35.40	6.646	34.76	1.221	35.31	18.86–54.44
	LA GLA	8	50.04	16.928	47.36	1.444	50.23	23.45–80.78
	LA HYP	5	37.02	23.188	33.04	1.627	26.42	25.20–78.40
CD	SO MOL	40	15.78	7.022	13.86	1.819	16.25	1.64–41.69
	SO SPE	24	24.30	12.802	21.58	1.661	20.95	5.06–68.38
	LA GLA	8	48.11	30.402	28.26	5.145	47.30	0.60–85.27
	LA HYP	5	16.37	35.635	1.15	11.153	0.46	0.22–80.12

Appendix 6. Element cencentrations (µg/g w.w.) in tissues of birds from Svalbard. From literature.

	Species	Ref.	Muscle	Liver	Kidney	n
ZN	CE GRY	1?	–	26 (25–27)	29 (28–29)	2
	UR LOM	1?	–	37 (33–45)	40 (33–43)	4
		2M	–	35 (31–38)	39 (27–50)	9
	AL ALL	1?	–	34 (32–35)	33 (32–34)	2
		2M	–	37 (31–43)	40 (32–46)	9
	SO MOL	1?	–	43 (32–53)	28 (21–35)	2
		2M	–	50 (40–61)	33 (26–44)	9
	LA HYP	1?	–	37 (32–41)	46 (42–49)	2
		2M	–	32 (26–47)	46 (37–57)	11
	RI TRI	1?	–	36 (34–38)	56 (48–63)	2
	FU GLA	1?	–	55 (44–65)	40 (36–43)	2
		2M	–	73 (50–95)	50 (32–96)	10
CD	CE GRY	1?	–	0.5 (0.1–0.8)	1.8 (0.2–3.4)	2
	UR LOM	1?	–	3.0 (2.2–4.1)	14.4 (5.7–27)	4
		2M	–	3.9 (1.8–10.7)	16 (6.8–38)	9
	AL ALL	1?	–	0.7 (0.7–0.7)	7.5 (7.3–7.6)	2
		2M	–	4.3 (2.4–5.8)	21 (5.9–34)	9
	SO MOL	1?	–	1.1 (0.1–2.0)	3.6 (0.2–6.9)	2
		2M	–	4.3 (2.3–9.4)	14 (8.5–26)	9
	LA HYP	1?	–	2.1 (2.0–2.2)	13.9 (8.7–19)	2
		2M	–	3.6 (0.4–9.4)	23 (4.1–58)	11
	RI TRI	1?	–	5.5 (5.1–5.8)	32 (27–36)	2
	FU GLA	1?	–	0.3 (0.2–0.4)	0.8 (0.8–0.8)	2
		2M	–	17 (6.1–32)	55 (22–114)	10
HF	CE GRY	1?	–	0.09 (0.07–0.10)	–	2
	UR LOM	1?	–	0.20 (0.7–0.45)	–	4
		2M	–	0.6 (0.3–0.9)	–	9
	AL ALL	1?	–	0.04 (0.03–0.04)	–	2
		2M	–	0.6 (0.4–0.7)	–	9
	SO MOL	1?	–	0.07 (0.04–0.09)	–	2
		2M	–	1.0 (0.5–1.7)	–	9
	LA HYP	1?	–	0.21 (0.-21–0.21)	–	2
		2M	–	1.6 (0.8–2.3)		11
	RI TRI	1?	–	0.07 (0.05–0.08)	–	2
	FU GLA	1?	–	0.08 (0.06–0.09)	–	2
		2M	–	2.1 (0.6–4.2)	–	10
SE	CE GRY	1?	–	2.1 (1.8–2.3)	–	2
	UR LOM	1?	–	2.0 (1.2–3.4)	–	4
		2M	–	1.9 (1.1–2.6)	–	9
	AL ALL	1?	–	1.5	–	1
		2M	–	2.5 (1.5–4.5)	–	9
	SO MOL	1?	–	2.3 (2.1–2.5)	–	2
		2M	–	8.9 (3.4–25)	–	9
	LA HYP	1?	–	2.2 (1.9–2.5)	–	2
		2M	–	2.2 (1.3–3.8)	–	11
	RI TRI	1?	–	4.1 (2.9–5.3)	–	2
	FU GLA	1?	–	2.2 (1.8–2.5)	–	2
		2M	–	3.0 (1.4–6.4)	–	10

REFERENCES:
1 Carlberg & Bøler 1985
2 Norheim 1987

SIGNATURE:
M Mixed age groups
? information on age missing

Appendix 7. Element concentrations (µg/g w.w., unless otherwise stated) in tissues of seabirds from the temperate zone. From literature.

	Species	Ref.	Locality	Muscle	Liver	Kidney	n
CD	CE GRY	7DW	CANADA	0.19 (0.05–0.31)	–	–	6
	SO MOL	3DW	DENMARK	–	13 (1–44)	38 (3–134)	43
		4	SWEDEN	–	1.8 (0.5–3.9)	3.5 (1.0–6.4)	22
		4FD	SWEDEN	–	3.0 (0.4–9.2)	11.0 (0.7–38)	41
	FU GLA	5DW	ENGLAND	–	29.8±23.88	126.0±102.20	4
HG	CE GRY	7?	CANADA	0.290	–	–	1
		8	CANADA	0.113	0.513	0.491	4
		6J	BALTIC	0.15 (0.14–0.16)		–	2
		6	BALTIC	1.5 (1.3–1.8)	–	–	2
	UR LOM	6J	BALTIC	0.10 (0.08–0.12)		–	10
		6	BALTIC	0.64 (0.44–0.90)		–	10
	AL ALL	3	SCOTLAND	–	5.5	–	1
	SO MOL	7	CANADA	0.05	–	–	1
		8	CANADA	0.153	0.987	0.358	11
		3DW	SCOTLAND	–	37.5±11.9	–	3
		1	NORWAY	0.2	0.6	–	6
		2DW	DENMARK	–	–	1.0 (0.5–3)	26
	LA HYP	3DW	SCOTLAND	–	5.2	–	1
	RI TRI	8	CANADA	0.037	0.372	0.242	20
		3DWJ	SCOTLAND	–	3.13±1.83	–	3
	FU GLA	3DW	SCOTLAND	–	3.7±0.14	–	2
	PH CAR	6J	BALTIC	0.48 (0.30–0.71)		–	4
		6	BALTIC	3.3 (2.9–3.7)	–	–	3

DW: mg/kg dry weight
J: juvenile birds
FD: birds found dead
?: information on age missing
M: mixed age groups

References:
1 Lande (1977)
2 Karlog et al. (1983)
3 Dale et al. (1973)
4 Frank (1976)
5 Bull et al. (1977)
6 Jensen et al. (1972)
7 Noble & Elliot (1986)
8 Braune (1986)

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