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HEAVY METALS IN RINGED SEALS
FROM THE CANADIAN ARCTIC

Prepared for:
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Abstract

Liver, kidney and muscle from ringed seals from the Strathcona Sound area and the Admiralty Inlet area were analysed for heavy metals, arsenic and selenium. Metal concentrations in tissues of animals from the latter area served as a reference base for the assessment of metal levels in animals from the Strathcona Sound area. The reference data were subjected to multiple linear regression, which showed various associations among metals, and between age of animals and metals. Age was strongly, positively associated with mercury and cadmium concentrations in kidney, while copper was strongly, negatively associated with age in all three types of tissue.

Nearly one half of all the animals from the Strathcona Sound area had significantly elevated levels of at least one of the toxic metals (Hg,Pb,Cd) in either liver or kidney relative to the reference group. A one-year old animal from the Strathcona Sound area had an abnormally high concentration (for its age) of both, cadmium and lead in the kidney. This animal was taken at one of the sampling sites closest to the Nanisivik mine site.

Introduction

The work described here, was jointly undertaken by the Departments of Fisheries and Oceans (DFO) and Indian Affairs and Northern Development (DIAND). The latter Department supplied the samples. The terms and conditions of this study were defined in a letter of understanding (April, 1984), jointly endorsed by the Regional Directors of the respective Departments (Appendix I).

Tissue samples (liver, kidney, muscle) from ringed seals (Phoca hispida) were collected during April and May, 1983 (DIAND) from two areas in the Canadian Arctic: the Admiralty Inlet area in general (15 animals), designated as the AB-series, and the Strathcona Sound area specifically, including the vicinity of the Nanisivik mine (13 animals), designated as the NA-series. The samples were received at the Freshwater Institute (Winnipeg) in a frozen state in June, 1984, where they were stored at -60°C, until analysed.

This report lists concentrations of Cu, Cd, Zn, Pb, As, Se, and Hg, in liver, kidney and muscle from 28 ringed seals. The data are discussed in terms of the significance of the various associations among elements and the age of animals, and the relevance to possible pollution effects of any abnormally high concentrations of heavy metals in samples from series NA.

Chemical Methodology

Frozen tissue samples (approx. 50 gm) were thawed (1.5 min. in a microwave oven on defrost setting) just sufficiently to be cut. An analytical sample was cut out from the interior of the bulk sample. This was cut into smaller pieces, placed in an acid-washed petri-dish and dried at 80°C for 16 hours. After moisture determination the dried samples were ground to a fine mesh using a small "Braun" coffee grinder. The ground samples were stored in acid-washed plastic bottles.

Approximately 0.5 gm of dried and ground liver and kidney tissue (1.0 gm muscle tissue) was heated initially with 5 ml nitric acid and subsequently with an additional 2 ml perchloric acid in volume-graduated quartz test tubes until perchloric acid fumes appeared. After cooling, the volume was brought to 25 ml with distilled, deionized water. The solutions were analysed for Cu, Cd, and Zn by flame atomic absorption. Blanks and NBS bovine liver standards were carried through the entire procedure and analysed along with samples.

For lead, tissues (0.2-0.3 gm dried wt.) were digested in the same way as for other metals, but preanalysis concentration of lead was required. Lead was complexed with sodium diethyldithio carbamate, and extracted with 3 ml n-butyl acetate from alkaline, citrate-buffered (pH 8.6) digests, and analysed by flameless atomic absorption. Low blank readings were insured by purification of reagents and careful cleaning of glassware.

For selenium and arsenic, digestion of tissues (0.2 gm, dry wt.) was also with nitric and perchloric acids. After cooling, 7.5 ml of concentrated hydrochloric acid was added, and the volumes brought to 25 ml with distilled, deionized water. Analysis was by semi-automatic flameless atomic absorption, of the hydrides of these elements, generated by reduction with sodium borohydride solution (1%).

Mercury was determined by cold-vapour atomic absorption after digestion of tissues (0.1-0.2 gm, dry wt.) with sulfuric and nitric acids (4:1) at 60°C for 2 hours, followed by the addition of 15 ml of $KMnO_4$ solution (6%) and standing overnight at room temperature. The digests were clarified by the addition of a few drops of 30% hydrogen peroxide prior to analysis.

Statistical Treatment

Multiple linear regressions were performed by the stepwise backward procedure using, to begin with, all the metal concentration variables and age. Each metal concentration variable was used sequentially as the dependent variable. Sexes were not differentiated due to the relatively small number of data points in each set (15 and 13). A critical probability level of 0.95 was chosen for retention of any variable in the model. The regression analyses were carried out with both untransformed and log-transformed sets of data. A log(x+1) transformation (natural log) rather than the simpler log(x) transformation was used, since the latter gave problems with some of the low concentration values. Concentration variables in regression analyses were in terms of dry weight (µg/G), and years for age. The same number and type of variables were finally retained in the model with transformed as with untransformed data in nearly all cases, except that a marginally improved probability for the retained variables was obtained with transformed data. Only results with transformed data are reported. The assumption was made that the data were log normally distributed. There may be some loss of confidence if the distribution was not strictly as assumed.

In those cases where only one independent variable remained, the confidence interval for a single future point at coordinate x on the regression line was calculated at the significance level of α = 0.05 in the usual way:

$\hat{y} \pm (t_{1-\frac{\alpha}{2}, n-2})(a)$. Where $a = s_{y/x}\sqrt{1+1/n + (x_o-x)^2/(n-1)s_x^2}$. The symbols in the preceding formula have the usual meaning. For the calculation of a confidence interval for a point on a regression surface, a more complicated version of the above formula was used (Snedecor and Cochran, 1980, p. 351).

Results and Discussion

Samples designated AB (reference samples) were taken from animals caught in the general area of Admiralty Inlet. Sampling locations are shown in Figure 1. This series of samples represents a reasonably uniform age distribution between ages 0.5 and 18 years. The capture locations for this series of animals were deemed sufficiently far removed from any mining activities, for these animals to be used as references for the Strathcona Sound samples (NA). Metal concentrations in the various tissues are expressed in terms of two weight bases: on a dry weight basis (Tables 1, 2, 3, for series AB; Tables 4, 5, 6 for series NA) and on a wet tissue weight basis (Tables 1a, 2a, 3a for series AB; Tables 4a, 5a, 6a for series NA). Some samples from the NA-series, consisting largely of young animals ($\leq$2 years), appeared to have a high concentration of one or more of the toxic metals Cd, Pb, and Hg (marked with an asterisk in Tables 4,5,6 and Tables 4a,5a,6a). Direct comparison of the concentration means of the two series of samples was inappropriate because of the interdependence among metals and age of animals, as was previously found to be the case for another marine mammal (Wagemann et al. 1983).

The zero-order correlation matrices (Tables 7, 8, 9), show a number of associations among variables. Multilinear regression showed that association was not restricted to pairs of variables (Table 10), although for liver and muscle this was largely the case. Where only one independent variable remained in the model, scatter plots were constructed. Some of the relationships appear to have some general validity as they have been reported previously for marine mammals. Cadmium and mercury in the kidney were each positively associated with age of animals, (Figure 2). A similar relationship (i.e. between length of animals and Hg or Cd in kidney) was previously reported for narwal (Wagemann et al. 1983). Mercury in the liver was positively associated with selenium (Figure 3) which has also been reported previously for different marine mammals including seals (Koeman et al. 1975; Wagemann et al. 1983). The antagonistic relationship between selenium and mercury has been reviewed by Beijer and Jernelov, 1978. Copper was negatively correlated with age in all three tissues (Figures 4, 5), implying a loss of this essential metal from tissues with increasing age of animals. In kidney, copper was also associated with zinc. The association of cadmium with zinc in kidney and muscle (Figure 6), and with copper in liver (Figure 7), may be a reflection of the presence of metallothionein in tissues. Both zinc and cadmium, and sometimes copper, are found in association with each other in this metalloprotein (Olafson and Thompson, 1974).

The accumulation of mercury and cadmium in the kidney of marine mammals with increasing age appears to be a general phenomenon. The question is whether some of the apparently high concentrations of Hg, Cd, and Pb, in tissues of young animals from the Strathcona Sound area (NA), are excessively high for their age in relation to the reference samples (AB). To asses this, a 95% confidence interval for a future point on the regression line was calculated at the age (or concentration) in question, and the suspiciously high concentration value of the toxic metal (Cd, Pb, Hg) from the NA-series was compared with the high limit of this confidence interval. Where only one independent variable remained in the regression model, it was possible to show this graphically. A concentration value from the NA-series was considered abnormally high, when the point in question fell above this confidence interval. When more than two independent variables remained in the model, the calculated confidence interval could, of course, not be shown graphically. By this criterion, the following animals had abnormally high levels of one or more of the toxic metals in their tissues: NA-11, 6.04 µg/G Hg in kidney (Figure 2); NA-1, 0.21 µg/G Pb in liver (Figure 8); NA-7, 0.21 µg/G Pb in liver (Figure 8); NA-12, 178 µg/G Cd in kidney (not shown graphically, see Tables 5, 5a); NA-13, 1.58 µg/G Pb in kidney (Figure 9); NA-13, 222 ug/G Cd in kidney (not shown graphically, see Tables 5, 5a). The relatively high mercury value in the liver of NA-4 (Figure 3), is problematic in that it only exceeded the confidence interval with untransformed data used in regression analysis, but not with transformed data. This mercury concentration, although relatively high (173 µg/G), was therefore considered to be only a borderline case. Anomalies such as this one did not arise with any other values.

Four of the six animals with excessively high metal levels (NA-7, NA-11, NA-12, NA-13), were quite young ($\leq$ 1 year). The locations where these animals were taken (Figure 1), were not (with the exception of NA-13) in close proximity to the mine. The pattern of water currents in Strathcona Sound (as in other fjords with tidal influences) is undoubtedly complex. The detailed distribution of pollutants, eminating from a coastal area of the fjord, is unpredictable from the limited body of water current data at present available for this fjord. Additionally, subadult seals may move considerable distances in search of food, and in response to changing ice conditions (Smith, 1976). A closer proximity of a capture site to the mine site would therefore not necessarily show a correspondingly higher metal concentration in tissues of seals. Nevertheless, animal NA-13 (1 year old), which was taken at one of the capture sites closest to the mine site (Figure 1), had the highest concentration (in this group of animals, i.e. NA-series) of cadmium in kidney and liver, and also the highest concentration of lead in kidney (1.58 µg/G) of all the animals collected. This is a surprisingly high concentration of lead in a soft tissue. Over the long term, lead is accumulated in bony tissue. High levels of lead in a soft tissue may indicate a more recent high level of lead intake by the animal.

The chemical methodology employed in these analyses was validated by participation in an international interlaboratory comparitive study (Wagemann, 1985), undertaken just before this project. Standard reference samples (NBS, bovine liver) were analysed along with the seal samples as additional checks. The analytical results obtained for the reference samples were within the certificate norms. Contamination of the tissue samples with lead is very improbable. The concentration of cadmium was also high in the same sample (NA-13). It is unlikely that the same sample could be contaminated with both elements simultaneously to such a high degree. Additionally, mercury levels were high in some other samples. Contamination with three different metals of only some samples and not others is improbable and it is more likely that the animals in question had indeed high metal concentrations in their tissues. This would not be the first time that some seals from the Canadian arctic were found to have high mercury concetrations in tissues (Smith and Armstrong, 1975). Similarly, some whales from the Canadian arctic have been reported to have high cadmium concentrations in kidney (Wagemann, 1980). Marine mammals from other parts of the world, notably from coastal waters near highly industrialized or densely populated areas, have also been reported to have high metal concentrations in their tissues (Wagemann and Muir, 1984).

There is some question whether the AB-series of samples was an appropriately pristine set with respect to cadmium to be used as a reference basis. Two animals in this series, AB-7 and AB-10, had a relatively high concentration of cadmium in the kidney, 379 and 608 µg/G (dry wt.) respectively, Table 2 (or 109 and 128 µg/G respectively on a wet weight basis, Table 2a). The high values had the effect of increasing the size of the confidence interval, making the test of what is and is not an excessivly high cadmium concentration in the NA-series, a more conservative test than would otherwise be the case. Concentrations of cadmium as high as these have not been reported previously for seals from anywhere in the world (Wagemann and Muir, 1984), although whales from the Canadian Arctic and elsewhere have shown similarly high or higher concentrations in kidney (Wagemann and Lutz, 1980; Wagemann and Muir, 1984). The critical level of cadmium concentration in the kidney (cortex) of pinnipeds at which signs of disturbance of renal function may appear is unknown. For the human kidney the critical level appears to be in the range of 100 to 300 µg/G, wet weight (Marc Report No. 20, 1980). If such values are applicable to pinnipeds, the high cadmium concentrations in the kidney of animals AB-7 and AB-10, may be near the critical level.

The establishment of a reliable reference base of data representing normal metal concentrations in marine mammalian tissues that in turn reflect normal environmental conditions, will require a broader data base than is presented here, and should consist of samples sufficiently large to permit the exclusion of high outliers and the inclusion of all the essential variables for a statistical analysis. A reference base sufficiently broadly based in time and geographic extent is indispensible for a proper assessment of normalcy or abnormalcy of toxic metal burdens in biota. The present work can only be considered as a small step in what should be done in the next four to five years.

Acknowledgements

The competent work of Mr. A. Lutz and Mrs. K. Dickson who performed the chemical analyses, and of Ms. B.E. Webb who determined the ages of the animals, is gratefully acknowledged. The assistance rendered by Mrs. G. Boila and Ms. L. Rotoff in compiling, tabulating and graphing data has been most helpful. The support and personal interest in this project of Dr. G.B. Ayles, Director of Freshwater and Arctic Research, Western Region, was much appreciated.

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APPENDIX I

Letter of Agreement

see next 3 pages

A G R E E M E N T

between

Department of Fisheries and Oceans

and

Department of Indian Affairs and Northern Development

on

Ringed Seal Study

An agreement between Department of Indian Affairs and Northern Development and the Department of Fisheries and Oceans Western Region, to conduct chemical analysis on tissues of Ring Seals from Strathcona Sound/Admiralty Inlet, N.W.T. during the fiscal year 1984-85.

This agreement made in duplicate on this 2nd day of April, 1984.

Between: The Department of Indian Affairs and Northern Development herein after represented by Regional Director, Renewable Resources, N.W.T. Region (herein after referred to as DIAND).

And: Department of Fisheries and Oceans represented by Director, Freshwater and Arctic Research, Western Region (herein after referred to as DFO).

The parties have agreed as follows:

1) The Department of Fisheries and Oceans will conduct analyses to determine the concentration of lead, zinc and cadmium in selected tissues from twenty-eight (28) specimens of Ring Seal.

2) Tissue samples of twenty-eight (28) specimens of Ring Seal collected in the vicinity of Strathcona Sound and Admiralty Inlet, N.W.T. will be provided to DFO and DIAND, N.W.T. Region within two (2) weeks of the effective date of this Agreement;

3) Chemical analyses of the tissues provided by DIAND will be conducted under the direction of Dr. R. Wagemann, Chemical Research and Analytical Services, Freshwater Institute;

4) Chemical analyses of the tissue will be completed on or before March 31st, 1985;

5) A report presenting and discussing results of analyses will be prepared by Dr. R. Wagemann and presented to DIAND by DFO on or before July 31st, 1985;

6) A jawbone to be used for the purposed of ageing will be included with each tissue sample provided by DIAND. It is understood that age determination will be completed in sufficient time to be included in the report prepared by Dr. R. Wagemann;

7) DIAND will provide appropriate field notes describing length; girth; thickness of blubber; sex; location of collection; method of collection and date of collection for each specimen;

8) Upon release of the report by DFO, information contained therein may be used by either party for other publications;

9) The use or release of data prior to release of the final report will only be by mutual consent;

10) The report may be released to the general public upon review and consent of both parties;

11) Methodologies to be used for the determination of tissue metal concentrations will be representative of currently recognized techniques and will incorporate standard quality control procedures;

12) Pay for the analytical and scientific services provided by DFO will be made available by DIAND through incumbrance transfer from DIAND, N.W.T. Region. It is understood that funds provided by DIAND will be used solely for the recovery costs associated with the above noted project;

13) DIAND, N.W.T. Region shall make aforesaid transfers of funds in fiscal year 1984 within two (2) weeks of the effective date of this Agreement; and

14) The total amount of funds provided shall not exceed $10,000.00.

In witness thereof, the parties hereto have set their hand this 2nd day of April, 1984.

Signed, Sealed and Delivered by:

Regional Director, Renewable Resources Directorate, Northern Affairs Program - N.W.T. Region, Department of Indian Affairs and Northern Development

Director, Freshwater and Arctic Research Western Region, Department of Fisheries and Oceans

APPENDIX II

Field Data of AB-series and NA-series

see next 2 pages

Arctic Bay / Admiralty Inlet

Sample Number	Sex	Age (yrs)	Length (cm)	Girth (cm)	Blubber (cm)	Date	Location*
AB-1	F	10	152	132	4.5	02/04/83	1
AB-1-a	F	< 1/2	71	45	< 1	02/04/83	1
AB-2	F	9	139	125	6.5	02/04/83	2
AB-2-a	F	< 1/2	65	40	< 1	02/04/83	2
AB-3	F	7	131	121	5	08/04/83	3
AB-4	F	7	136	129	5.5	08/04/83	4
AB-5	F	12	138	123	5	08/04/83	5
AB-6	F	7	146	121	4.5	14/04/83	6
AB-7	F	8	124.5	114.5	6	16/04/83	7
AB-8	M	5	120.5	100.5	4	19/04/83	8
AB-9	M	15	137.5	115.5	5	03/05/83	9
AB-10	M	10	135.4	107	5.5	03/05/83	10
AB-11	M	18	146	125	3.5	04/05/83	11
AB-12	M	6	113	86.5	3.5	04/05/83	12
AB-13	M	8	128	110.5	6	04/05/83	13

* See accompanying map

Strathcona Sound

Sample Number	Sex	Age (yrs)	Length (cm)	Girth (cm)	Blubber (cm)	Date	Location*
NA-1	M	8	142	117	5.5	27/05/83	1
NA-2	F	2	108	79	2.5	28/05/83	2
NA-3	F	22	145	111.5	4.5	28/05/83	3
NA-4	---	4	143	131.5	5.5	28/05/83	4
NA-5	F	1	99.5	85.5	3.5	09/06/83	5
NA-6	M	1	89	57	1.5	11/06/83	6
NA-7	F	< 1/2	101.5	92	5.0	13/06/83	7
NA-8	M	< 1/2	94.5	88	6.0	14/06/83	8
NA-9	M	< 1/2	99	98	6.5	14/06/83	9
NA-10	M	< 1/2	96.5	96.5	5	15/06/83	10
NA-11	F	< 1/2	86.5	78.5	4	15/06/83	11
NA-12	F	1	99.5	66.5	2.25	24/07/83	12
NA-13	M	1	112.5	86	3	24/07/83	13

* See accompanying map

APPENDIX III

Age Estimates (Report by B.E. Webb)

see next 5 pages

Contract Report:

Ringed Seal Age Estimates

by

B.E. Webb

Contract No. OSF84-00038

Frozen mandibles from 28 ringed seals were boiled in water for approximately 2 hours to loosen teeth for extraction. Canine teeth were embedded in clear casting resin (J.T. Keenan Co., Winnipeg) (n=26) or stored in a 1:1:1 volumetric mixture of glycerin, alcohol and distilled water (n=6).

Specimens no. AB-1a and AB-2a were identified as neonate seals as the permanent teeth had not erupted from the gums (Harrison and King, 1965) and were assigned to the zero (0) age class category.

Longitudinal sections of canine teeth (n=25) were cut using a thin sectioning saw (University of Guelph). Two canines were available for 4 seals. In these cases the left canine was cross sectioned at the gingival line. Fragments of the NA-2 canine that shattered during extraction were also cross sectioned. All sections were cut between 0.17 mm and 0.22 mm thick and were subsequently stored in the alcohol-glycerin solution.

Dentinal annuli were counted in longitudinal sections or available cross sections optimizing use of tooth sections with the highest clarity (McLaren, 1958; Smith, 1973). Cementum annuli in NA-3 were recorded since dentinal material was poorly annulated.

Age determinations were made according to the method of Stewart and Lavigne (1979). Readings of annuli using transmitted light were done until 3 readings were in agreement or until a maximum of 5 readings had been made. Ninety five percent confidence limits were calculated; outliers deleted, and the final age estimate determined as the median age of remaining readings.

Final age estimates are expressed as age in years in the following table, using birthdate of April 1 (Finley et al, 1983; McLaren, 1958) to assign the appropriate age class.

It is recommended that both left and right mandibles be collected in future studies. One canine may not be a suitable specimen for aging purposes (AB-2, extremely worn cusp; cavity developing); may fracture in the extraction (NA-2) or sectioning process, beyond the point of being useful.

Dentinal annuli were clearly defined in cross section and less readily identified in longitudinal section. Due to the greater ease of preparing the tooth sections and clearer definition of dentinal annuli, it is recommended that cross sections be used for aging ringed seals.

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Final age estimate (year class) for AB-series and NA-series Ringed Seals.

Seal ID no.	Reading no. 1	2	3	4	5	Final Age Estimate	Section/Layer
AB-1	9	~~13~~	10	10	9	10	LS/D
AB-1a						0	Newborn
AB-2	~~8~~	10	9	9	10	9	LS/D
AB-2a						0	Newborn
AB-3	7	6	~~8~~	7	6	7	LS/D
AB-4	8	7	8	7	7	7	LS/D
AB-5	~~15~~	12	10	12	11	12	LS/D
AB-6	7	6	6	~~10~~	7	7	LS/D
AB-7	10	8	8	10	8	8	LS/D
AB-8	4	5	~~2~~	4	5	5	LS/D
AB-9	15	15	~~8~~	13	10	15	LS/D
AB-10	10	10	9	8	10	10	LS/D
AB-11	~~20~~	18	18	~~15~~	17	18	XS/D
AB-12	6	6	6			6	XS/D
AB-13	9	9	8	8	8	8	LS/D
NA-1	8	10	7	~~13~~	11	8	LS/D
NA-2	2	2	2			2	XS/D
NA-3	20	~~19~~	22	22	23	22	LS/C
NA-4	4	4	4			4	LS/D
NA-5	1	1	0	1		1	LS/D
NA-6	1	1	1			1	LS/D
NA-7	0	0	0			0	LS/D
NA-8	0	0	0			0	LS/D
NA-9	0	0	0			0	LS/D
NA-10	0	0	0			0	LS/D
NA-11	0	0	0			0	LS/D
NA-12	1	1	1			1	LS/D
NA-13	1	1	1			1	XS/D

LS - longitudinal section
XS - cross section
D - dentine
C - cementum
~~x~~ - 95% confidence interval outlier

Table 1. Metals in liver of ringed seals from Arctic Bay

Animal No.	Age (yrs)	Cd	Cu	Zn	Pb	As	Se	Hg	% Moist.
		-----------	-----------	-----------	μg/G, dry wt.	-----------	-----------	-----------	
AB-1	10	23.70	159.00	148.00	0.06	1.22	46.32	70.90	65.12
AB-1-a	<.5	1.00	370.00	576.00	0.02	2.13	3.02	4.19	76.18
AB-2	9	43.50	29.80	147.00	0.11	1.91	23.18	36.70	68.47
AB-2-a	<.5	1.00	151.00	197.00	0.02	1.38	3.97	2.29	74.37
AB-3	7	27.50	25.80	144.00	0.04	0.81	28.52	42.00	66.92
AB-4	7	30.70	15.40	132.00	0.03	2.63	22.75	29.20	69.58
AB-5	12	47.40	49.90	139.00	0.09	1.80	38.19	35.40	68.27
AB-6	7	41.10	19.30	163.00	0.11	0.59	39.53	50.10	69.02
AB-7	8	52.00	12.40	156.00	0.04	0.53	29.93	56.60	67.76
AB-8	5	66.60	37.70	190.00	0.05	1.57	6.49	8.62	69.04
AB-9	15	16.60	13.80	126.00	0.06	2.21	13.89	6.08	67.76
AB-10	10	62.00	14.40	199.00	0.04	2.04	7.55	9.68	70.63
AB-11	18	6.36	14.10	136.00	0.04	1.47	23.03	44.50	66.15
AB-12	6	46.70	31.20	122.00	0.04	2.49	14.55	18.20	66.34
AB-13	8	31.10	21.20	151.00	0.04	2.54	7.01	12.00	71.19

Table 1a. Metals in liver of ringed seals from Arctic Bay

Animal No.	Age (yrs)	Cd	Cu	Zn	Pb	As	Se	Hg
		-----------µg/G, wet wt.-----------						
AB-1 5	10	8.27	55.46	51.62	0.02	0.43	16.16	24.73
AB-1-a	<.5	0.24	88.13	0.00	0.00	0.51	0.72	1.00
AB-2	9	13.72	9.40	46.35	0.03	0.60	7.31	11.57
AB-2-a	<.5	0.26	38.70	50.49	0.01	0.35	1.02	0.59
AB-3	7	9.10	8.53	47.64	0.01	0.27	9.43	13.89
AB-4	7	9.34	4.68	40.15	0.01	0.80	6.92	8.88
AB-5	12	15.04	15.83	44.10	0.03	0.57	12.12	11.23
AB-6	7	12.73	5.98	50.50	0.03	0.18	12.25	15.52
AB-7	8	16.76	4.00	50.29	0.01	0.17	9.65	18.25
AB-8	5	20.62	11.67	58.82	0.02	0.49	2.01	2.67
AB-9	15	5.35	4.45	40.62	0.02	0.71	4.48	1.96
AB-10	10	18.21	4.23	58.45	0.01	0.60	2.22	2.84
AB-11	18	2.15	4.77	46.04	0.01	0.50	7.80	15.06
AB-12	6	15.49	10.35	40.46	0.02	0.83	4.82	6.04
AB-13	8	8.96	6.11	43.50	0.02	0.73	2.02	3.46

Table 2. Metals in kidney of ringed seals from Arctic Bay

Animal No.	Age (yrs)	Cd	Cu	Zn	Pb	As	Se	Hg	% Moist.
		-----	-----	-----	μg/G, dry wt.	-----	-----	-----	
AB-1	10	158.00	20.80	162.00	0.07	1.03	10.76	8.94	75.77
AB-1-a	<.5	2.00	64.90	207.00	0.16	0.28	9.89	2.04	78.46
AB-2	9	385.00	24.50	242.00	0.12	1.80	11.46	8.09	75.95
AB-2-a	<.5	2.00	24.00	104.00	0.11	0.22	7.27	1.51	79.52
AB-3	7	178.00	31.10	168.00	0.06	1.73	9.23	5.82	74.77
AB-4	7	120.00	26.20	138.00	0.03	2.54	10.96	6.94	77.33
AB-5	12	281.00	25.00	203.00	0.05	2.60	8.88	7.86	76.92
AB-6	7	109.00	24.90	159.00	0.20	2.12	9.84	4.30	74.98
AB-7	8	379.00	23.20	281.00	0.05	1.63	7.45	3.54	71.20
AB-8	5	303.00	39.70	239.00	0.06	2.45	8.84	3.08	75.74
AB-9	15	70.20	12.70	129.00	0.06	0.06	10.64	4.52	77.10
AB-10	10	608.00	27.80	441.00	0.05	1.43	8.67	4.99	78.86
AB-11	18	59.80	15.50	158.00	0.03	0.47	8.59	12.40	77.38
AB-12	6	298.00	25.80	232.00	0.08	0.79	9.44	5.14	73.99
AB-13	8	172.00	22.60	180.00	0.19	0.56	8.31	4.27	78.02

Table 3. Metals in muscle of ringed seals from Arctic Bay

Animal No.	Age (yrs)	Cd	Cu	Zn	Pb	As	Se	Hg	% Moist.
		----------------------µg/G, dry wt.------------------							
AB-1	10	0.36	7.10	78.70	0.01	0.05	1.78	0.90	69.90
AB-1-a	<.5	0.05	10.15	135.00	0.04	0.73	1.35	1.19	75.20
AB-2	9	0.48	5.62	85.60	0.04	0.05	1.72	1.16	69.52
AB-2-a	<.5	0.07	7.40	113.00	0.05	0.29	1.25	1.26	73.23
AB-3	7	0.49	7.65	59.20	0.02	0.08	1.35	0.88	67.97
AB-4	7	0.57	6.39	68.00	0.01	0.52	1.67	1.56	71.37
AB-5	12	0.30	6.03	71.40	0.01	0.11	1.66	0.95	71.68
AB-6	7	0.45	7.40	53.60	0.09	0.20	1.34	0.88	68.91
AB-7	8	0.71	5.82	60.70	0.01	0.12	1.59	0.61	70.35
AB-8	5	0.54	7.09	54.60	0.04	0.05	1.50	0.68	70.21
AB-9	15	0.32	5.20	52.00	0.03	0.15	1.77	0.96	69.74
AB-10	10	0.78	5.37	75.60	0.01	0.05	1.34	0.63	68.33
AB-11	7	0.14	5.40	84.20	0.02	0.05	1.33	2.48	68.15
AB-12	6	0.52	10.20	66.50	0.03	0.05	1.29	1.06	67.59
AB-13	8	0.36	7.02	69.60	0.02	0.31	1.36	0.80	70.22

Table 3a. Metals in muscle of ringed seals from Arctic Bay

Animal No.	Age (yrs)	Cd	Cu	Zn	Pb	As	Se	Hg
		-----------------------	µg/G, wet wt.	-----------------------				
AB-1	10	0.11	2.14	23.69	.003	0.02	0.54	0.27
AB-1-a	<.5	0.01	2.52	33.48	.01	0.18	0.33	0.30
AB-2	9	0.15	1.71	26.09	.012	0.02	0.52	0.35
AB-2-a	<.5	0.02	1.98	30.25	.013	0.08	0.33	0.34
AB-3	7	0.16	2.45	18.96	.006	0.03	0.43	0.28
AB-4	7	0.16	1.83	19.47	.003	0.15	0.48	0.45
AB-5	12	0.08	1.71	20.22	.003	0.03	0.47	0.27
AB-6	7	0.14	2.30	16.66	.028	0.06	0.42	0.27
AB-7	8	0.21	1.73	18.00	.003	0.04	0.47	0.18
AB-8	5	0.16	2.11	16.27	.012	0.01	0.45	0.20
AB-9	15	0.10	1.57	15.74	.009	0.05	0.54	0.29
AB-10	10	0.25	1.70	23.94	.003	0.02	0.42	0.20
AB-11	7	0.04	1.72	26.82	.006	0.02	0.42	0.79
AB-12	6	0.17	3.31	21.55	.01	0.02	0.42	0.34
AB-13	8	0.11	2.09	20.73	.006	0.09	0.41	0.24

Table 4. Metals in liver in ringed seals from Strathcona Sound

Animal No.	Age (yrs)	Cd	Cu	Zn	Pb	As	Se	Hg	% Moist.
		µg/G, dry wt.							
NA-1	8	18.40	15.50	138.00	0.21*	3.04	6.37	3.32	67.11
NA-2	2	6.72	64.30	144.00	0.05	2.61	11.73	6.74	68.90
NA-3	22	30.10	44.80	159.00	0.10	0.10	65.89	99.60	71.11
NA-4	15	13.50	84.00	158.00	0.18	0.15	61.00	173.00*	69.12
NA-5	1	15.70	21.10	156.00	0.15	0.30	4.06	2.65	70.14
NA-6	1	3.81	82.20	282.00	0.07	0.49	6.66	6.89	70.43
NA-7	<.5	1.00	13.00	131.00	0.21*	0.05	2.77	2.11	71.75
NA-8	<.5	1.00	12.40	181.00	0.06	0.41	2.70	0.98	73.55
NA-9	<.5	1.00	34.90	287.00	0.12	0.21	3.75	0.89	67.82
NA-10	<.5	1.00	12.90	167.00	0.06	0.44	2.40	1.06	70.98
NA-11	<.5	1.00	26.30	168.00	0.05	0.93	2.92	3.60	68.15
NA-12	1	22.40	20.10	121.00	0.05	0.07	5.96	2.40	70.35
NA-13	1	39.40	28.80	136.00	0.06	0.41	4.60	2.91	70.58

* Abnormally high values

Table 4a. Metals in liver of ringed seals from Strathcona Sound

Animal No	Age	Cd	Cu	Zn	Pb	As	Se	Hg
		----------------μg/G, wet wt.-------------------------						
NA-1	8	6.05	5.10	45.39	0.07*	1.00	2.10	1.09
NA-2	2	2.09	20.00	44.78	0.02	0.81	3.65	2.10
NA-3	22	8.73	12.99	46.11	0.03	0.03	19.11	28.88
NA-4	15	4.17	25.94	48.79	0.06	0.05	18.84	53.42*
NA-5	1	4.69	6.30	46.58	0.04	0.09	1.21	0.79
NA-6	1	1.13	24.31	83.39	0.02	0.14	1.97	2.04
NA-7	<.5	0.28	3.67	37.01	0.06*	0.01	0.78	0.60
NA-8	<.5	0.26	3.28	47.87	0.02	0.11	0.71	0.26
NA-9	<.5	0.32	11.23	92.36	0.04	0.07	1.21	0.29
NA-10	<.5	0.29	3.74	48.46	0.02	0.13	0.70	0.31
NA-11	<.5	0.32	8.38	53.51	0.02	0.30	0.93	1.15
NA-12	1	6.64	5.96	35.88	0.01	0.02	1.77	0.71
NA-13	1	11.59	8.47	40.01	0.02	0.12	1.35	0.86

* Abnormally high values

Table 5. Metals in kidney of ringed seals from Strathcona Sound

Animal No.	Age (yrs)	Cd	Cu	Zn	Pb	As	Se	Hg	% Moist.
		µg/G, dry wt.							
NA-1	8	175.00	18.20	205.00	0.15	1.49	8.80	6.09	75.80
NA-2	2	36.80	33.30	120.00	0.03	0.05	11.95	2.08	75.74
NA-3	22	153.00	32.40	230.00	0.07	0.10	8.89	6.57	75.40
NA-4	15	119.00	33.20	210.00	0.02	0.22	8.84	11.30	73.10
NA-5	1	89.70	58.40	191.00	0.02	0.07	8.22	2.08	74.30
NA-6	1	12.00	77.50	197.00	0.02	0.68	8.62	3.55	76.64
NA-7	<.5	2.00	22.30	189.00	0.12	0.05	4.92	2.86	74.36
NA-8	<.5	2.00	15.70	196.00	0.02	0.15	5.97	2.25	78.66
NA-9	<.5	2.00	40.60	356.00	0.06	0.07	6.39	3.44	74.04
NA-10	<.5	2.00	15.20	214.00	0.02	0.05	5.77	3.05	74.03
NA-11	<.5	3.67	43.70	276.00	0.02	0.81	7.45	6.04*	77.38
NA-12	1	178.00*	67.50	233.00	0.06	0.47	7.21	2.39	73.21
NA-13	1	222.00*	44.70	194.00	1.58*	0.47	6.44	3.10	77.77

* Abnormally high values

Table 5a. Metal in kidney of ringed seals from Strathcona Sound

Animal No.	Age (yrs)	Cd	Cu	Zn	Pb	As	Se	Hg
		µg/G, wet wt.						
NA-1	8	42.35	4.40	49.61	0.04	0.36	2.13	1.47
NA-2	2	8.93	8.08	29.11	0.01	0.01	2.90	0.50
NA-3	22	37.64	7.97	56.58	0.02	0.02	2.19	1.62
NA-4	15	32.01	8.93	56.49	0.01	0.06	2.38	3.04
NA-5	1	23.05	15.01	49.09	0.01	0.02	2.11	0.53
NA-6	1	2.80	18.10	46.02	0.00	0.16	2.01	0.83
NA-7	<.5	0.51	5.72	48.46	0.03	0.01	1.26	0.73
NA-8	<.5	0.43	3.35	41.83	0.00	0.03	1.27	0.48
NA-9	<.5	0.52	10.54	92.42	0.02	0.02	1.66	0.89
NA-10	<.5	0.52	3.95	55.58	0.01	0.01	1.50	0.79
NA-11	<.5	0.83	9.88	62.43	0.00	0.18	1.69	1.37*
NA-12	1	47.69*	18.08	62.42	0.02	0.13	1.93	0.64
NA-13	1	49.35*	9.94	43.13	0.35*	0.10	1.43	0.69

* Abnormally high values

Table 6. Metals in muscle of ringed seals from Strathcona Sound

Animal No.	Age (yrs)	Cd	Cu	Zn	Pb	As	Se	Hg	% Moist.
		--------------	--------------	μg/G, dry wt.	--------------	--------------	--------------	--------------	
NA-1	8	0.23	4.75	57.60	0.15	0.30	1.25	1.23	68.71
NA-2	2	0.14	8.69	73.30	0.07	0.05	1.94	0.46	68.90
NA-3	22	0.63	6.83	75.20	0.09	0.18	1.90	0.68	71.11
NA-4	15	0.14	5.86	71.40	0.04	0.05	1.73	1.19	69.12
NA-5	1	0.15	8.93	71.60	0.07	0.12	1.59	0.35	70.14
NA-6	1	<0.05	10.14	134.00	0.04	0.28	1.92	0.60	70.43
NA-7	<.5	0.11	11.38	98.20	0.06	<0.05	1.33	0.16	71.75
NA-8	<.5	<0.05	11.12	88.90	0.02	0.26	1.80	0.14	73.55
NA-9	<.5	<0.05	10.86	92.40	0.02	<0.05	1.84	0.17	67.82
NA-10	<.5	<0.05	4.68	91.40	0.02	<0.05	1.63	0.18	70.98
NA-11	<.5	<0.05	11.66	94.40	0.01	<0.05	1.43	0.30	68.15
NA-12	1	0.40	9.75	63.40	0.04	0.13	1.48	0.39	70.35
NA-13	1	0.41	6.67	65.80	0.05	0.09	1.46	0.46	70.58

Table 6a. Metals in muscle of ringed seals from Strathcona Sound

Animal No.	Age (yrs)	Cd	Cu	Zn	Pb	As	Se	Hg
		µg/G, wet wt.						
NA-1	8	0.07	1.49	18.02	0.05	0.09	0.39	0.38
NA-2	2	0.04	2.70	22.80	0.02	0.02	0.60	0.14
NA-3	22	0.18	1.97	21.70	0.03	0.05	0.55	0.20
NA-4	15	0.04	1.81	22.05	0.01	0.02	0.53	0.37
NA-5	1	0.04	2.67	21.38	0.02	0.04	0.47	0.10
NA-6	1	0.00	3.00	39.62	0.01	0.08	0.57	0.18
NA-7	<.5	0.03	3.21	27.74	0.02	0.00	0.38	0.05
NA-8	<.5	0.00	2.94	23.51	0.01	0.07	0.48	0.04
NA-9	<.5	0.00	3.49	29.73	0.01	0.00	0.59	0.05
NA-10	<.5	0.00	1.36	26.52	0.01	0.00	0.47	0.05
NA-11	<.5	0.00	3.71	30.07	0.00	0.00	0.46	0.10
NA-12	1	0.12	2.89	18.80	0.01	0.04	0.44	0.12
NA-13	1	0.12	1.96	19.36	0.01	0.03	0.43	0.14

Table 7. Zero-order correlation matrix for liver of ringed seals from Admiralty Inlet (AB-series), 0.95<P≤0.98 (underlined), 0.98<P≤0.99 (doubly underlined) and 0.99<P (triply underlined)

	Cu	Zn	Pb	As	Se	Hg	Age
Cd	-0.6295	-0.5759	0.4885	-0.0810	0.5073	0.5258	0.6518
Cu		0.6702	-0.2104	0.0675	-0.3702	-0.3606	-0.7290
Zn			-0.3412	0.0564	-0.6422	-0.5181	-0.7403
Pb				-0.2367	0.5950	0.4899	0.4571
As					-0.4654	-0.4825	-0.0220
Se						0.9292	0.6777
Hg							0.6312

Table 8. Zero-order correlation matrix for kidney of ringed seals from Admiralty Inlet (AB-series), 0.95<P≤0.98 (underlined), 0.98<P≤0.99 (doubly underlined) and 0.99<P (triply underlined)

	Cu	Zn	Pb	As	Se	Hg	Age
Cd	-0.2645	0.5905	-0.4299	0.6423	0.1490	0.5503	0.7602
Cu		0.3340	0.2884	0.2297	-0.0154	-0.4945	-0.6865
Zn			-0.2221	0.3701	-0.1064	0.0565	0.1912
Pb				-0.2992	-0.2063	-0.5438	-0.4565
As					0.1547	0.3077	0.2823
Se						0.4410	0.2549
Hg							0.8183

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Table 9. Zero-order correlation matrix for muscle of ringed seals from Admiralty Inlet (AB-series), 0.95<P≤0.98 (underlined), 0.98<P≤0.99 (doubly underlined) and 0.99≤P (triply underlined)

	Cu	Zn	Pb	As	Se	Hg	Age
Cd	-0.2760	-0.6644	-0.2593	-0.4359	0.2286	-0.5701	0.4614
Cu		0.3065	0.3256	0.4035	-0.4870	-0.0546	-0.6729
Zn			-0.0010	0.4896	-0.2764	0.4149	-0.6394
Pb				0.1535	-0.3563	0.0041	-0.3963
As					-0.1420	0.2131	-0.6343
Se						-0.1200	0.4593
Hg							0.0243

Table 10. Association between variables (metals, As, Se, Age) and the dependent variable at $0.95<P\leq0.98$, $0.98<P\leq0.99$ (*), and $0.99<P$ (**) in various tissues of ringed seal. The direction of the regression slope is indicated by the algebraic sign.

Dependent Variables	Independent Variables: Kidney	Liver	Muscle
Cd	+Zn**, +As*, +Age**	-Cu*	-Zn**
Pb	-Hg	+Se*	
Hg	+Age**	+Se**	-Cd
As	+Cd**, +Cu**		-Age*
Cu	-Age**, +Zn	-Age**	-Age**
Zn	+Cd**, +Cu**	+Cu, -Se	-Age*, +Cd
Se		+Hg**	

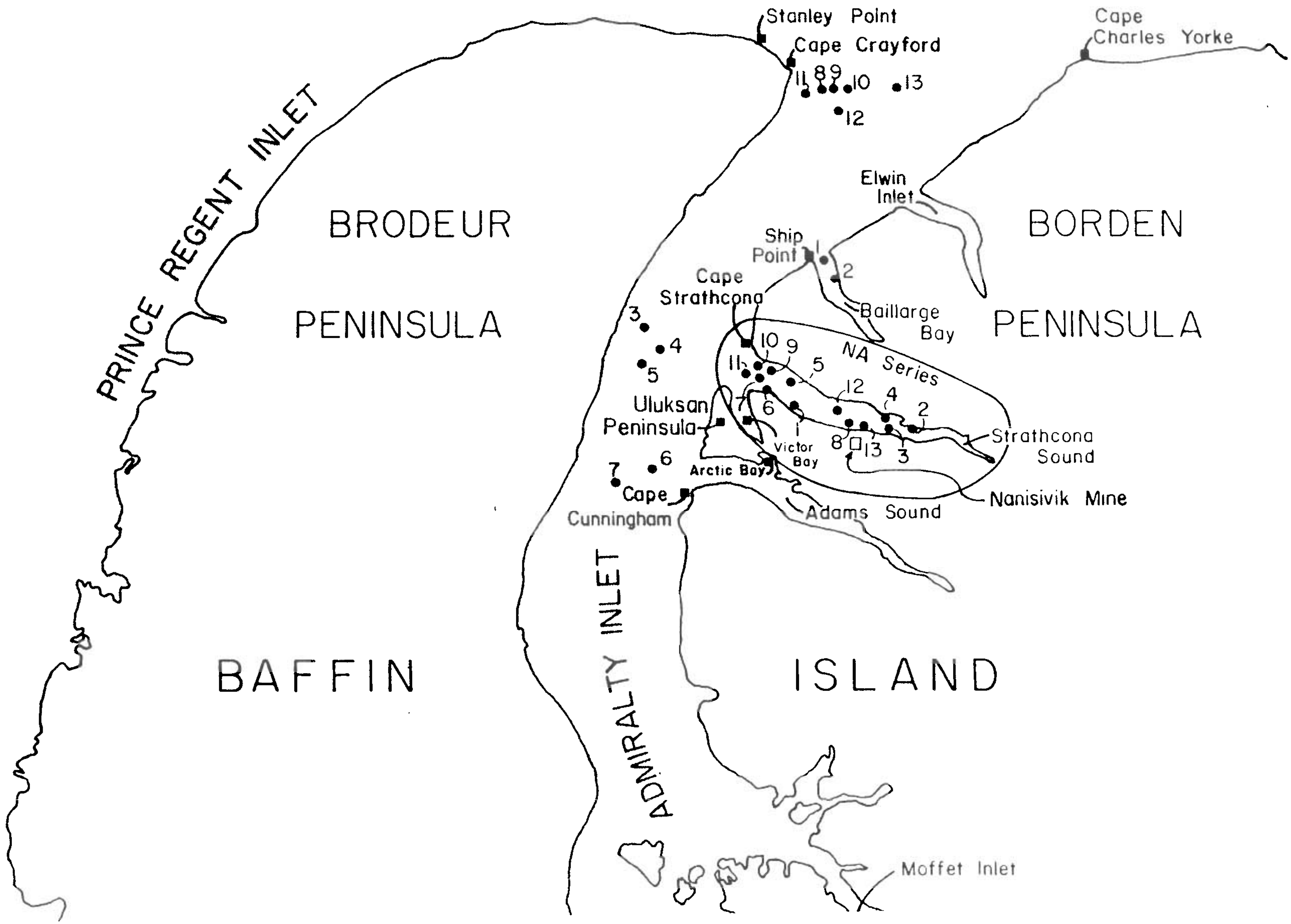

Figure 1: Locations of sampling sites of ringed seals, and the Nanisivik mine site. Numbered locations not included in the NA-series (circled) belong to the AB-series.

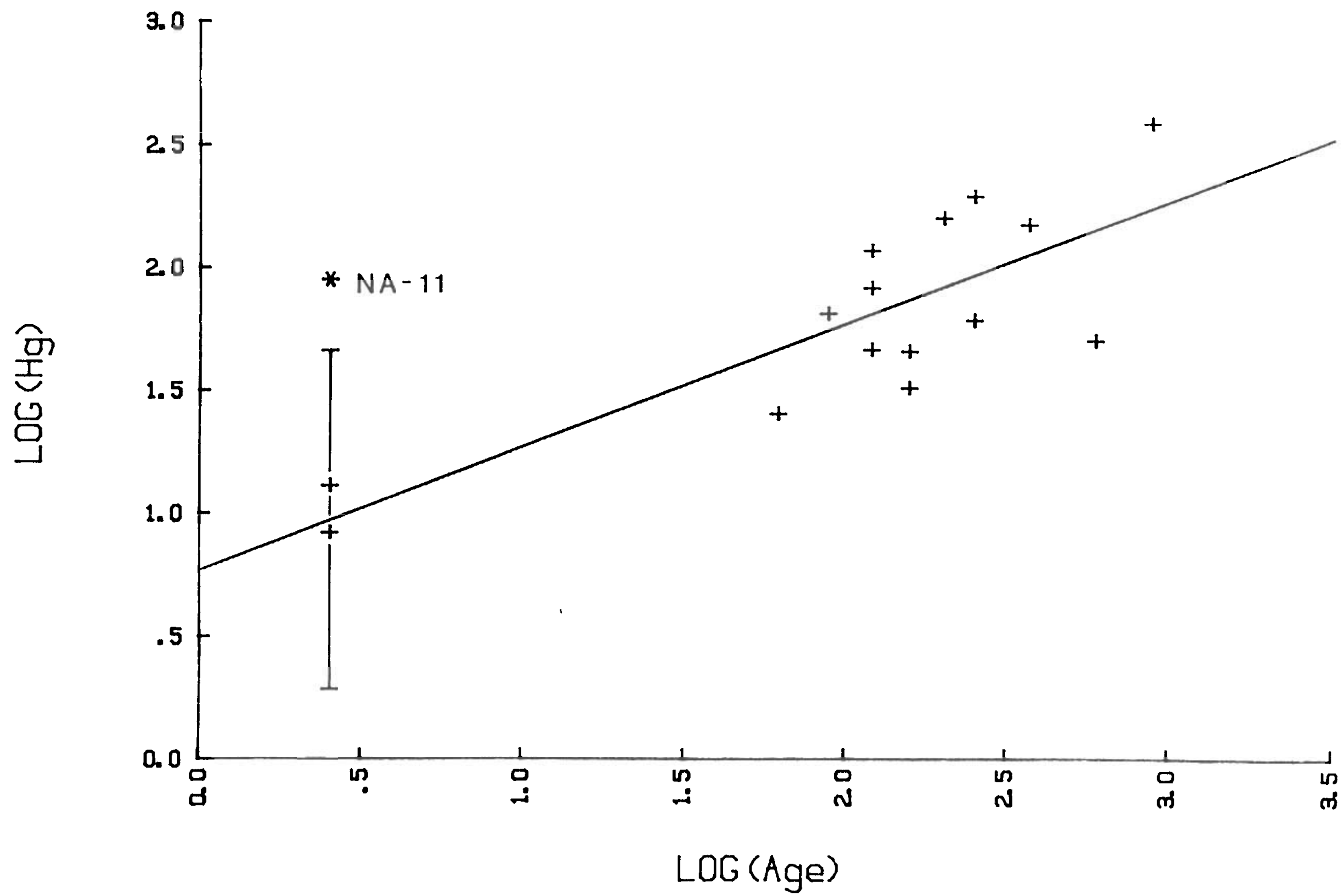

Figure 2: Mercury concentration in kidney tissue vs age of ringed seals, in terms of log transformed variables (μg/G, dry wt; years) for the AB-series (+), with one data point (*) from the NA-series, not part of the regression set. Error bar represents a 95% confidence interval for a single, future point on the regression line.

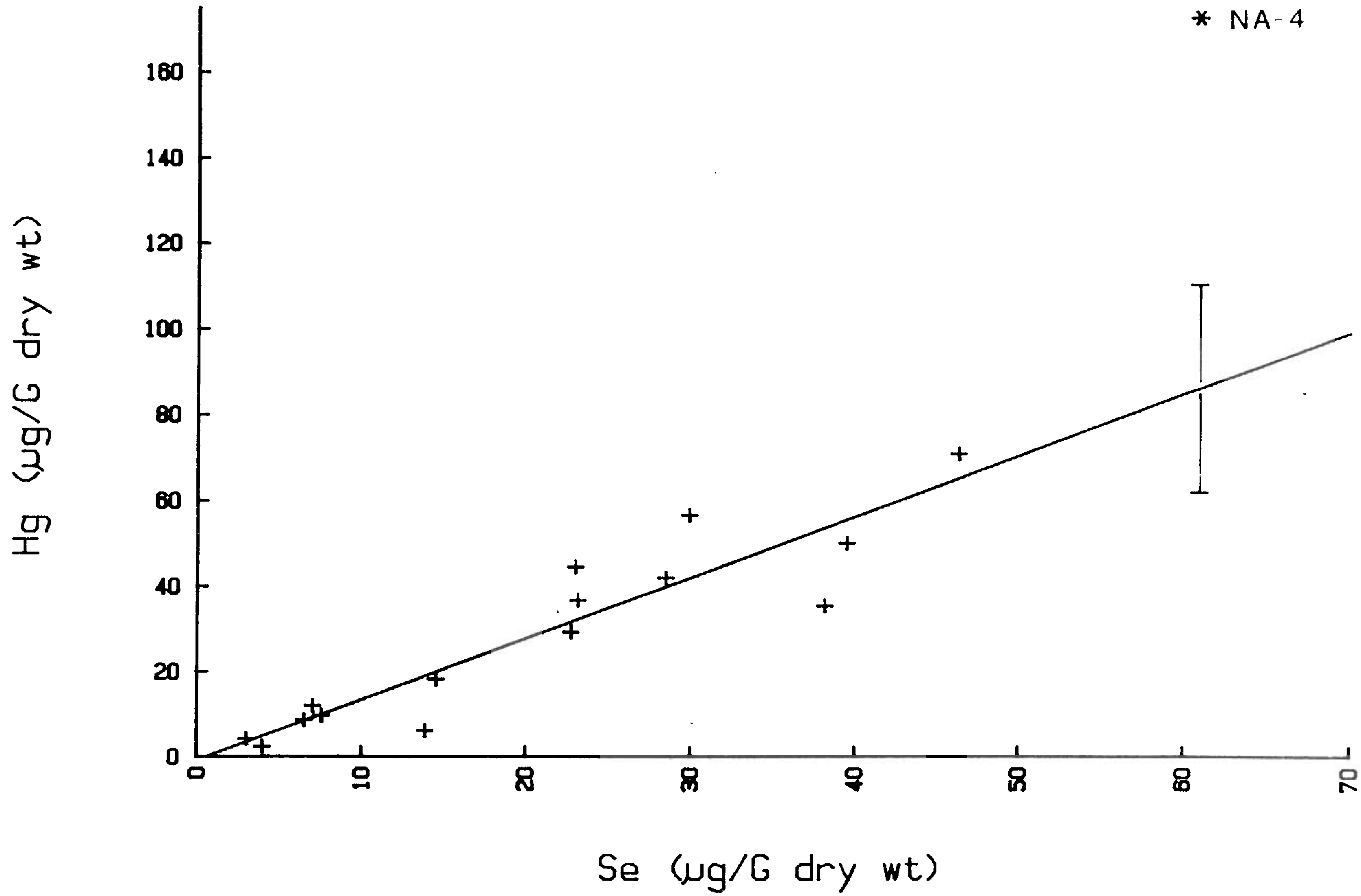

Figure 3: Mercury concentration vs selenium concentration in liver tissue of ringed seals (µg/G, dry wt.) for the AB-series (+), with one data point (*) from the NA-series, not part of the regression set. Error bar represents 95% confidence interval for a single, future point on the regression line.

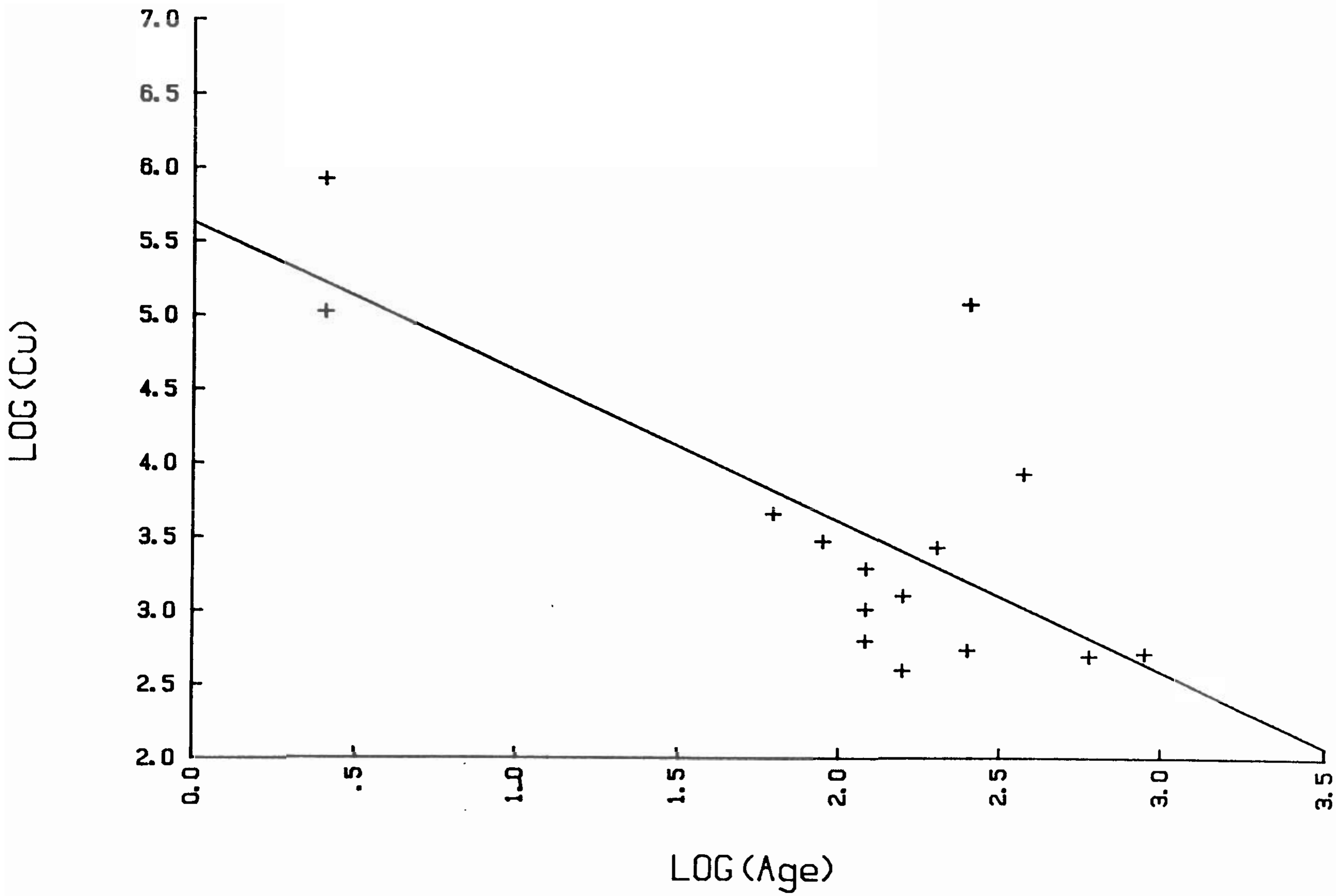

Figure 4: Copper concentration in liver tissue *vs* age of ringed seals, in terms of log transformed variables (μg/G, dry wt.; years) for the AB-series (+).

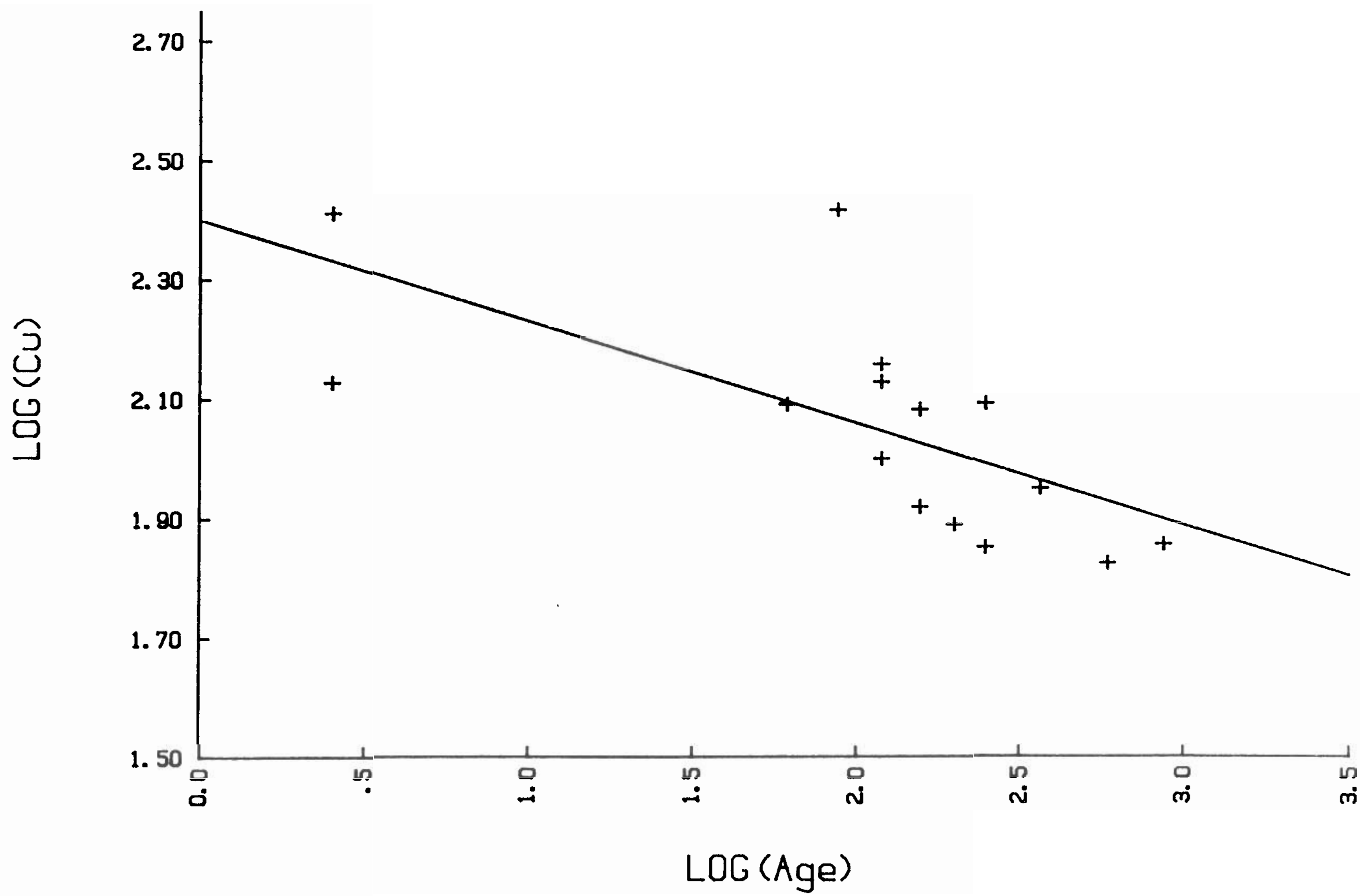

Figure 5: Copper concentration in muscle tissue *vs* age of ringed seals, in terms of log transformed variables (μg/G, dry wt.; years) for the AB-series (+).

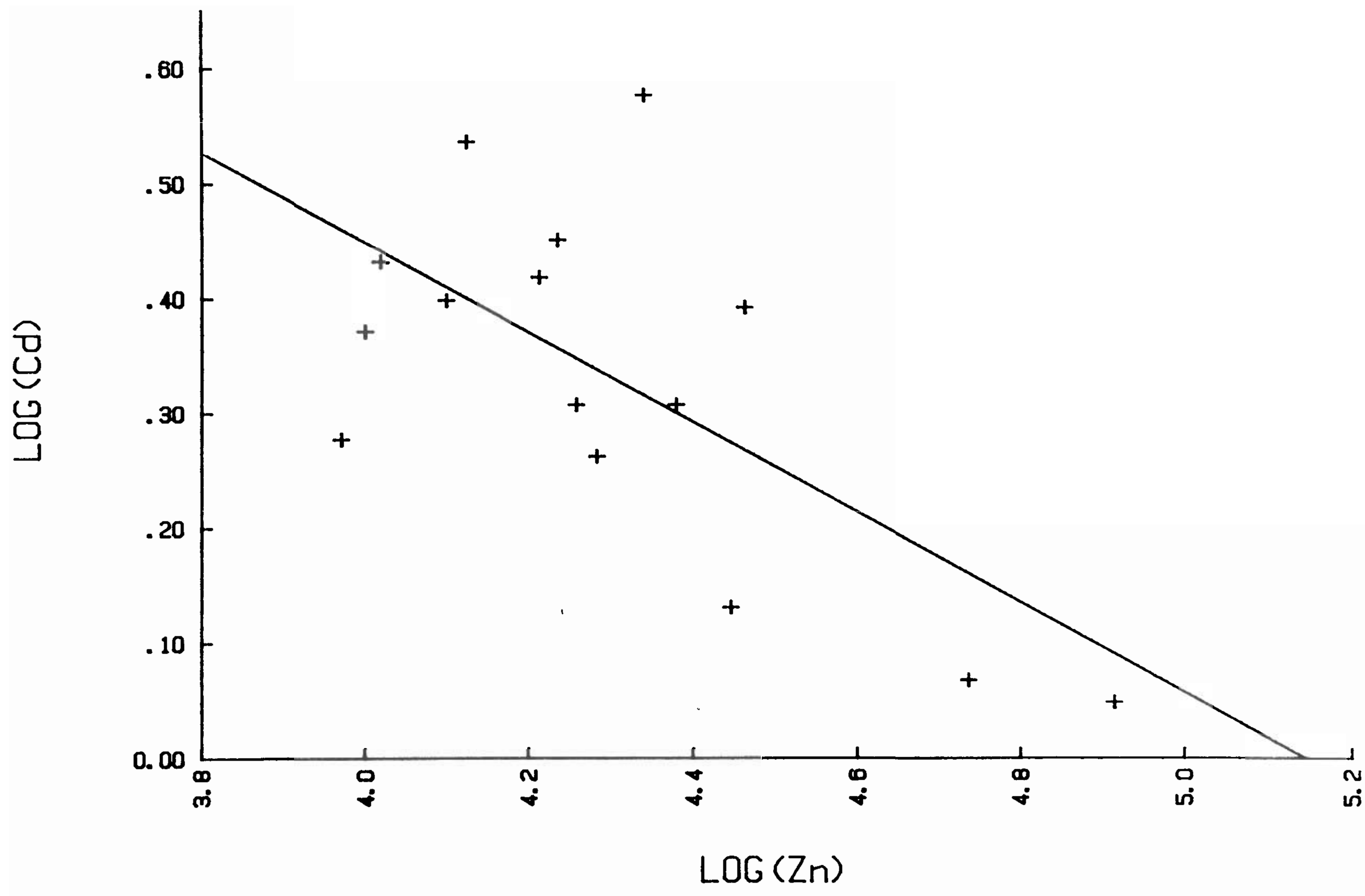

Figure 6 Cadmium concentration vs zinc concentration in muscle tissue of ringed seals. in terms of log transformed variables (µg/G, dry wt.) for the AB-series (+).

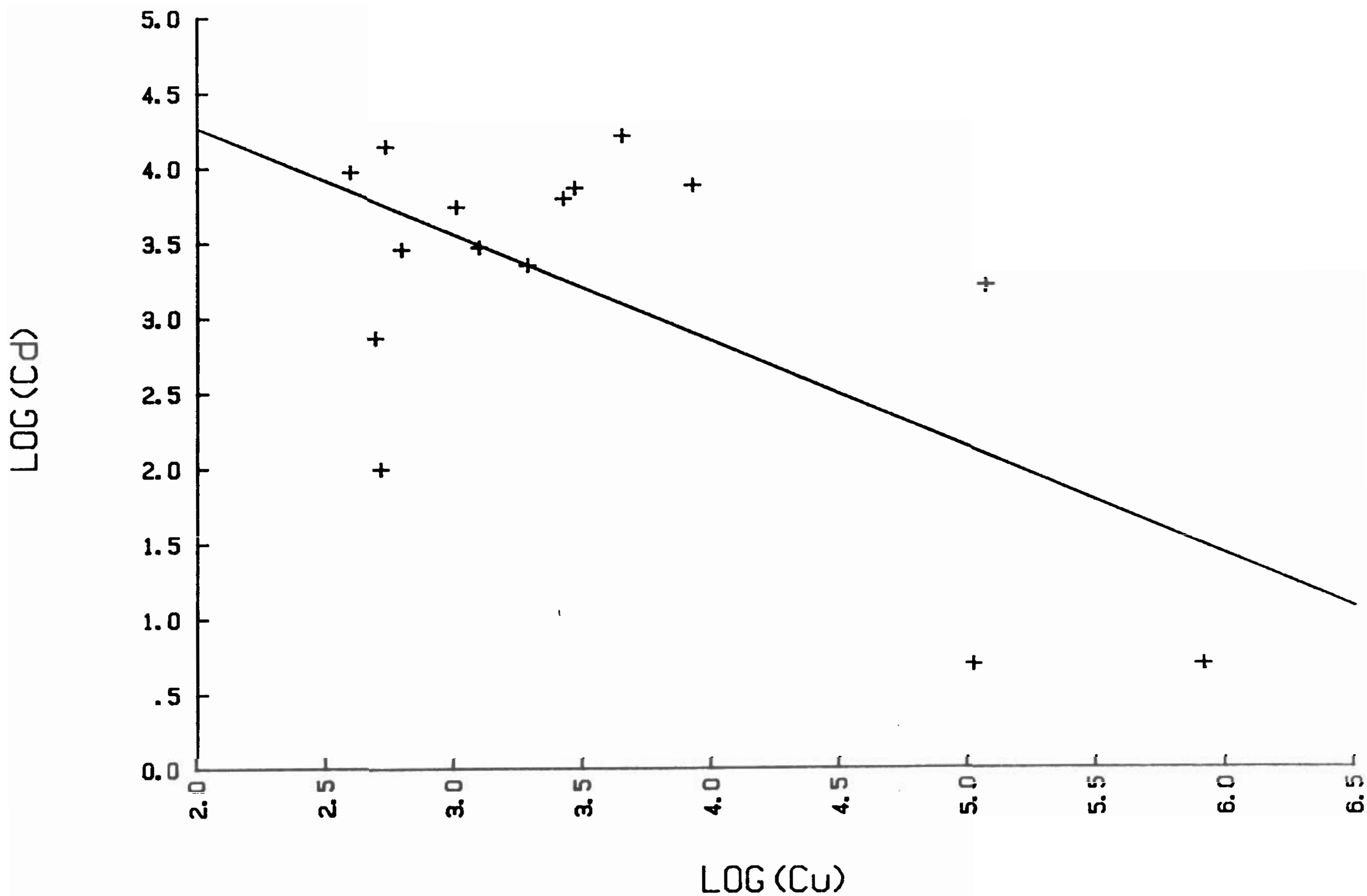

Figure 7: Cadmium concentration vs copper concentration in liver tissue of ringed seals, in terms of log transformed variables (μg/G, dry wt.) for the AB-series (+).

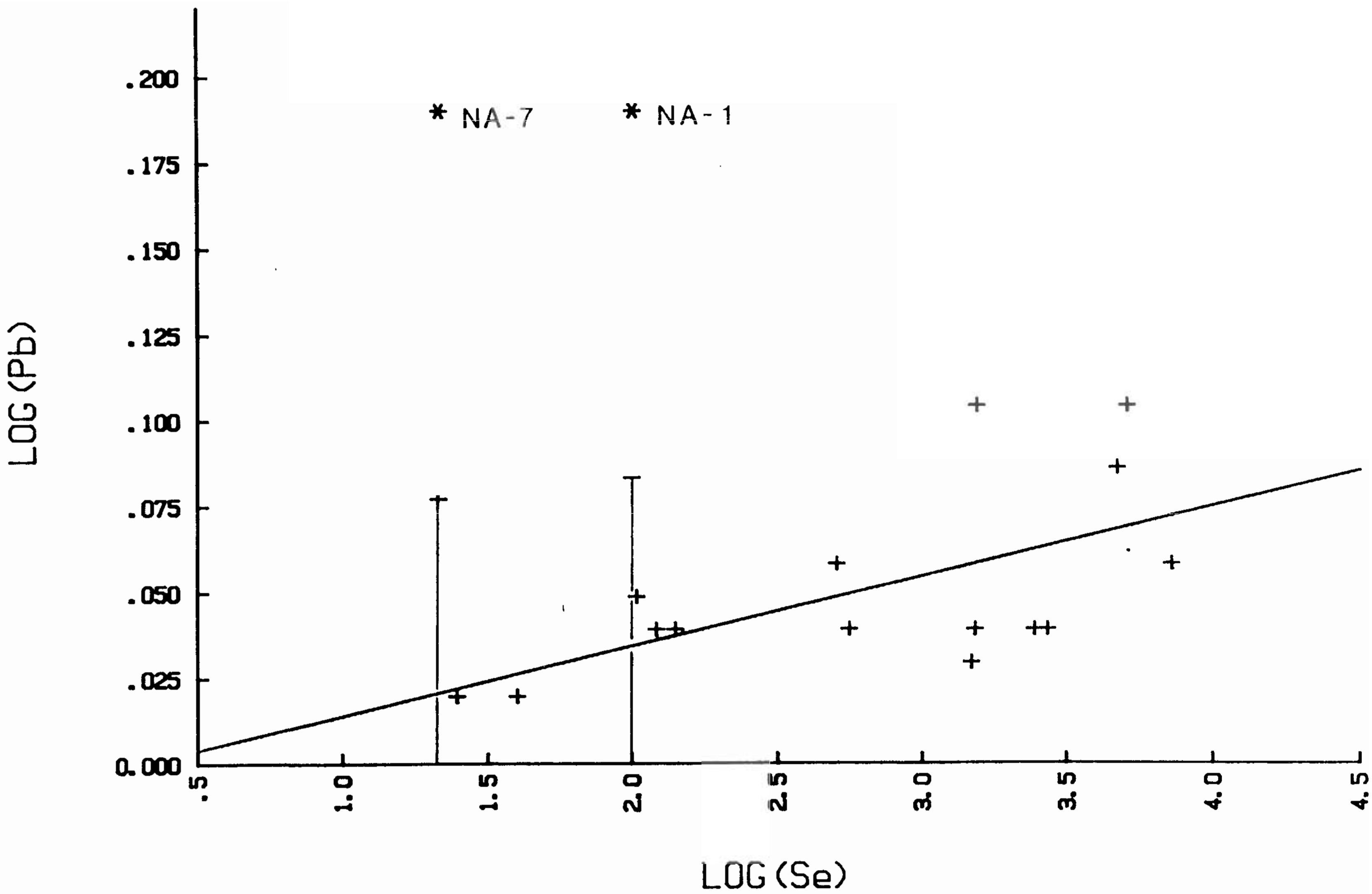

Figure 8: Lead concentration *vs* selenium concentration in liver tissue of ringed seals, in terms of log transformed variables (µg/G, dry wt.) for the AB-series (+), with two data points (*) from the NA-series, not part of the regression set. Error bars represent 95% confidence interval for a single, future point on the regression line.

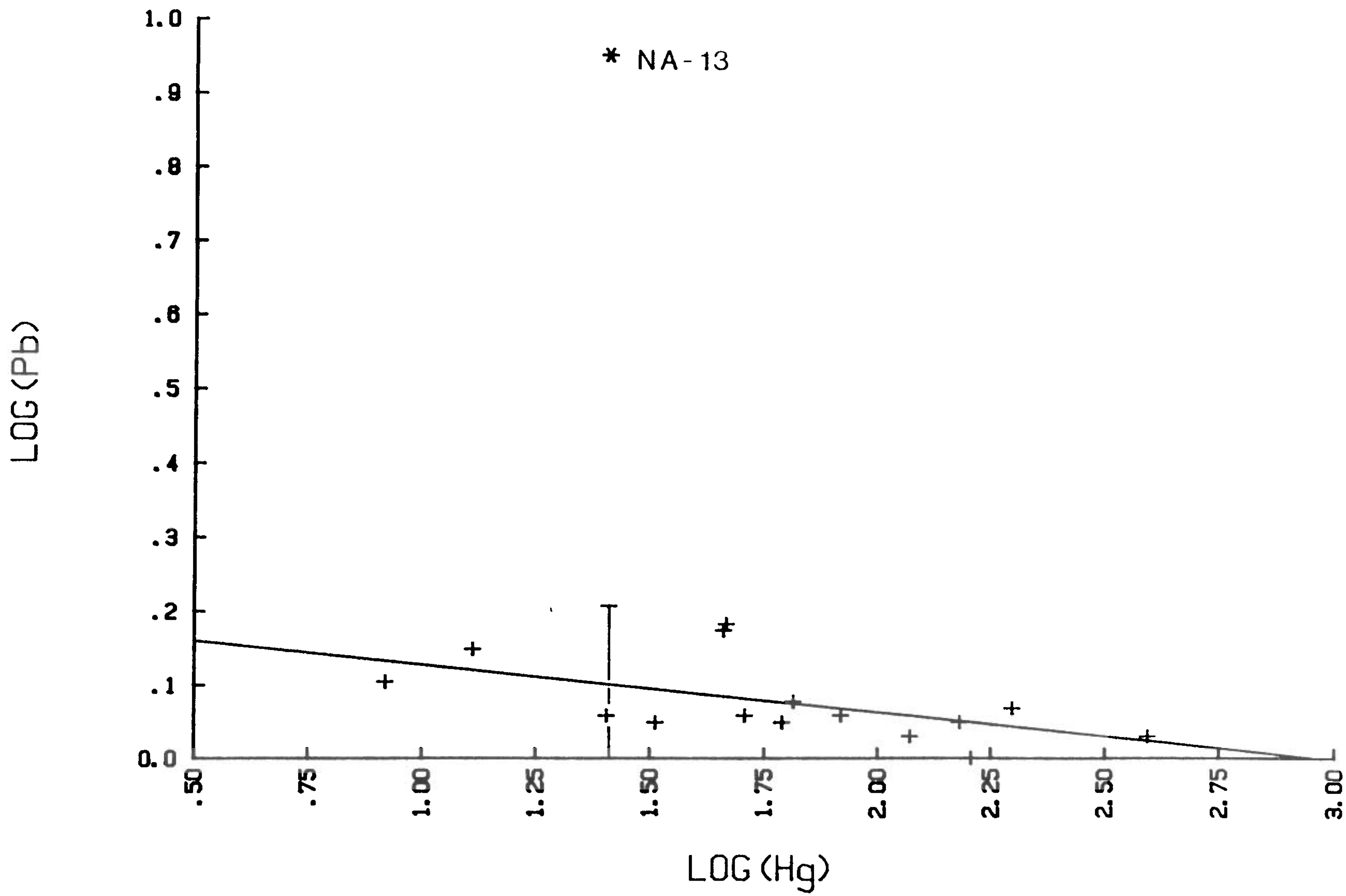

Figure 9: Lead concentration vs mercury concentration in kidney tissue of ringed seals, in terms of log transformed variables (μg/G, dry wt.) for the AB-series (+), with one data point (*) for the NA-series, not part of the regression set. Error bar represents 95% confidence interval for a single, future point on the regression line.