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Twenty years of trace metal analyses of marine mammals:

Evaluation and Summation of data from Alaska and other Arctic regions

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Abstract

Trace metals are ubiquitous in the environment, originating from natural and anthropogenic sources. Existing data on trace metals in the marine food chain was compiled in an effort to help address the magnitude of exposures to wildlife and to humans consuming subsistence species. This paper presents a summary of studies on trace metals in tissues of Alaskan and other Arctic and subarctic marine mammals from the 1970s to the present along with summary statistics on tissue trace metal concentrations. With few exceptions, the compiled data show comparable tissue trace metal concentrations within species. The data provide a range of reference trace metal levels against which future monitoring results may be compared, and may be used to estimate human exposure to trace metals through the consumption of marine mammals. The compiled literature suggests that despite considerable efforts to monitor marine mammal species, significant gaps in data remain. Few published reports are available for any given species, sample sizes are small, and age estimates and sex information is rarely reported. Because age is a significant predictor of trace metal concentrations in organ tissues in these species, age data are needed to help compare study populations over time and by geographic region. Tissue concentrations of methylmercury, particularly for muscle tissue, is lacking and insufficient information is available regarding the ratio of methylmercury to total mercury in marine mammal organ tissues. These data are essential to developing an assessment of potential changing patterns in trace metal concentrations and in evaluating the safety of subsistence food consumption.

Introduction

Many trace metals occur naturally, ubiquitously distributed in the earth's crusts and oceans. Trace metals also have anthropogenic origins, including local pollution from industrial activity and from global contamination from the atmospheric distribution of pollution. Trace metals bioaccumulate in the aquatic food chain. Tissue sampling and environmental monitoring of subsistence species in Alaska and in other Arctic regions have taken place over the last twenty years with the primary objectives of establishing contaminant baselines, determining partition distributions of various compounds between the environment and the species of concern, and determining partition distributions of the chemicals among tissues in a given species. These environmental sampling efforts have resulted in the collection of tissues and environmental media, and the analysis of samples for a suite of organic compounds, radionuclides, and trace metals. These analyses, however, have not been collated into a single document with the objective of providing an overview of the status of concentrations in marine species and in assessing the public health implications of consumption of these tissues. This paper presents a compilation of available information on trace metals in marine mammals of Alaska, and with other Arctic regions. Marine mammals were chosen as the focus of this report because they represent species in the highest trophic level of the food chain and, therefore, provide an indication of the highest range of potential trace metal exposure to those consuming these subsistence species. In addition to presenting a compilation of the available information, this paper identifies gaps in sampling and knowledge of tissue concentrations and makes recommendations for future work.

Methods

Data presented in the summary tables were obtained from the published literature. The available information on trace metals was entered into an Excel spreadsheet (v. 5.0, Microsoft Corp., Bellevue, WA). The criteria for including a specific data set in this review were that sample results were reported in wet weight, that mean data or raw data were available, and that the number of samples analyzed was provided. Sample conversion from dry weight to wet weight was not possible because of a lack of information on tissue moisture content. Reported mean tissue concentrations along with the reported standard deviations were entered for arsenic (As), mercury (Hg), methylmercury (MeHg), selenium (Se) and cadmium (Cd). Tissue concentration data were available for liver, kidney, muscle and blubber. Summary mean values for each tissue and each metal were derived by weighting mean tissue trace metal concentrations from each report where data was available according to the number of tissue samples which were analyzed. Standard deviations were first squared to obtain the variance; a weighted summary variance was calculated which was then converted back to a standard deviation (Appendix A). The summary statistic of the weighted mean of means provides a measure of central tendency in data when sample size discrepancies exist. Because of the small number of samples for any given species, analyte, and tissue, particularly for Alaska, and because reports lacked age data, no attempt was made to compare trace metal levels in species sampled in Alaska with levels in species sampled in other Arctic areas.

Tissue trace metal levels below the reported level of detection were assumed to be one-half the level of detection for each metal species. When insufficient information was available to calculate a standard deviation, we assumed that the standard deviation was 100% of the reported mean tissue concentration. This is a conservative assumption that is consistent with studies discussed in this paper, and with summary analyses on tissue trace metal levels in marine mammals conducted in Canada (Chan, 1996). For reports of a sample size of one, no standard deviation was derived.

Results

The following species were represented in the published literature from Alaska: bearded seal (*Erignathus barbatus*), bowhead whale (*Balaena mysticetus*), beluga whale (*Delphinapterus leucas*), northern fur seal (*Callorhinus ursinus*), harbor seal (*Phoca vitulina*), walrus (*Odobenus rosmarus*) and ringed seal (*Phoca hispida*). Few published reports from Alaska were identified: a total of four separate published articles included bowhead whale, 2 reports included beluga whale, 2 included bearded seal, harbor seal, pacific walrus, ringed seal, or polar bear, and only one report included northern fur seals. From other Arctic areas, there were 4 published reports that included beluga whale, one report included walrus, 3 reports included ringed seal, and one report included polar bear. The literature from other Arctic areas often included multiple sample groups by tissue and analyte. Sample sizes of these reports for any given analyte for each tissue ranged from one to 69 for Alaskan reports and from one to 445 for reports from other Arctic areas. Ringed seals were the most frequently

studied species in other Arctic areas, with 445 mercury liver tissue tests, representing a total of 11 different sample groups reported in 3 publications from Canada and Greenland. In contrast, only 13 liver mercury tissue tests were available from two Alaska reports on ringed seal.

Most reports lacked information on the distribution of the observed concentrations in the samples analyzed. For example, trace metal levels are potentially highly skewed, but few reports included information on median values. In addition, the standard deviation was missing and had to be derived for 35% of 23 separate reports of arsenic levels, 30% of 33 reports of selenium levels, 20% of 35 reports of cadmium levels, 17% of 70 reports of total mercury levels, and 21% of 13 reports of methylmercury levels (Tables 1-6).

Reported trace metal concentrations, along with the summary weighted means and standard deviations, are presented separately for Alaska and other Arctic regions (Tables 1-6). Summary data on arsenic, selenium and cadmium are presented for bowhead whale in table 1, for beluga whale, bearded seal, harbor seal and walrus in table 2, and for ringed seal and polar bear in table 3. Mercury and methylmercury (MeHg) are depicted for beluga whale and ringed seal in table 4, for bearded seal, northern fur seal, harbor seal and polar bear in table 5; and for bowhead whale and walrus in table 6. Summary information for concentrations of arsenic, mercury, MeHg, selenium and cadmium from all available studies, combining Alaska with other Arctic areas, is presented in Table 7.

Two overall consistencies across all species and geographic regions emerged: a low level of methylmercury relative to total mercury in liver and kidney tissues and low arsenic levels. Among the 13 reports that included measurements on total and methylmercury, methylmercury levels represented a small percentage of total mercury organ levels. For example, in beluga whale, mean liver methylmercury levels were 2.8% (0.79 μg/g) of the mean total mercury concentrations (28 μg/g) based on six methylmercury and 11 total mercury measurements; in ringed seal, mean liver methylmercury levels were 2.8% (0.33 μg/g) of the mean total mercury concentrations (11.6 μg/g) based on 94 methyl mercury measurements and 458 total mercury measurements; and in walrus, mean liver methylmercury levels were 6% (0.10 μg/g) of the total mercury levels (1.6 μg/g) based on 56 methyl mercury and 115 total mercury measurements.

Arsenic liver and kidney levels were very low: means of studies were below 0.8 μg/g with only the exception of ringed seal liver (mean of 14 samples was 1 μg/g) and kidney (mean of 2 samples was 3.1 μg/g). In contrast to arsenic, a greater variation in mercury, cadmium, and selenium were observed within and between species. In most cases, however, there was considerable consistency, within species and by tissue type. For example, mean liver cadmium levels in bowhead whale ranged from 1.5 to 12.9 μg/g, with a weighted mean of 9.42 μg/g; and liver selenium levels ranged from .08 to 1.3 μg/g, with a weighted mean of 1.06 μg/g (Table 1). For ringed seals, mean liver concentrations of mercury in Canada and Greenland reports vary from a low of 0.32 μg/g to a high of 25.5 μg/g, with an overall weighted mean of 12 μg/g based on a total of 445 tissue samples (Table 4), while the mean level of mercury in the Alaska ringed seals (1.8 μg/g) was in the low range of levels observed in other Arctic areas based on only two studies and 13 tissue samples (Figure 1).

While the majority of tissue level concentrations were homogeneous, a few

exceptions should be noted. A greater variation in mercury and selenium liver concentrations were noted for beluga whale and bearded and ringed seal, and for cadmium in kidney of ringed seal than levels observed in other species (Figures 1 and 2). For example, bearded seal mean liver mercury levels in other Arctic areas ranged from 1.9 µg/g to 143 µg/g, with a weighted mean of 37.5 µg/g based on 62 tissue samples and two studies from Canada, compared to a weighted mean of 2.8 µg/g based on 7 tissue samples and two Alaska studies. Also, ringed seal kidney mean cadmium level was 37 µg/g, based on 30 tissue samples in other Arctic areas compared to a mean of 5 µg/g in Alaska based on two tissue samples) (Table 3). In contrast, mean mercury liver levels among 11 Alaska beluga whales was 28 µg/g compared to a mean of 5.3 µg/g among 55 beluga whales from Canada and Greenland (Table 4 and Figure 1).

Discussion

The lack of age data in the available reports prevents meaningful comparisons overtime and between geographic areas, because organ concentrations of trace metals are known to increase with age. Thus, the difference observed in liver mercury levels between Alaska beluga whale and those reported from other Arctic areas, may, at least in part, be an artifact of age. Another limitation in making meaningful comparisons overtime or by geographic region, is the small sample sizes and small number of studies. Thus, while comparisons between Alaska and other Arctic regions by species and tissue type showed some statistically significant differences in tissue metal concentrations, it is not possible to assume that these results are representative of the greater population of each species.

Despite the wide geographic areas represented in the studies and the reported differences in sampling and analytical techniques of studies conducted from the early 1970s to the present, the available data, for the most part, reveal consistency among trace metal values reported in tissues within Alaska and the Arctic. In general, values vary by less than an order of magnitude, usually by less than 100% of the derived mean. For the most part, the consistency in tissue trace metal burdens suggest ubiquitous levels of trace metals in the Arctic through anthropogenic emissions and natural sources. However, these data must be interpreted with caution. Given the large migratory ranges of many of the species tested, evaluating the impact of local sources of pollution may not be possible with these data.

In the process of developing the summary tables, we identified several limitations in the published literature. Chief among these limitations is lack of information on trace metals in many marine mammal species. In particular, there is little or no data on methylmercury levels in tissues in most species, and little data on trace metal levels in muscle tissue is more frequently consumed than organ tissue. Even when analytical data on trace metal levels are available for an Alaskan species, often only

one study exists, and often the sample size less than 10. Another limitation identified is incomplete information on the distribution of the values. Medians, a preferred measure of central tendency, are rarely reported. Because means are heavily influenced by extreme values, summary mean data may overestimate average tissue concentrations in these species. Other limitations which we found in the review of published literature involved inconsistencies in data reporting (e.g., wet weight versus dry weight, units of measure, number of samples, limits of detection, location of sampling, etc.) and incomplete information on sampling and analytical methodologies employed in the studies. Additional research efforts should be directed to carrying out a systematic sample plan so that tissue trace metal concentrations are characterized and correlated with age, sex, and sample location.

Although there remain significant limitations in attempting to generalize the available information on tissue trace metal levels to the broader population of animals in a species, there is some value in the compilation of data because of the overall consistency among studies that report trace metal concentrations. Summary data may serve as a useful baseline upon which to evaluate future marine mammal monitoring efforts.

Implications for Public Health and Risk Assessment

In the few studies which examined both total and methylmercury, methylmercury comprised a very low percentage of total mercury, suggesting that significant demethylation occurs. Because of the low methylmercury to total mercury ratio in liver and kidney, caution is warranted in applying standard risk assessment methods using total mercury in these organs as is typically done when evaluating the safety of fish (where total mercury levels reflect methylmercury concentrations). Inorganic mercury is of low bioavailability and is significantly different toxicologically from methylmercury. Likewise, usual risk assessment assumptions for dietary cadmium exposure may be inappropriate because cadmium in liver and kidney of marine mammal species is largely bound to metallothionein, is not as bioavailable (at least to the liver), and may be considerably less toxic than cadmium in its unbound state (Goyer, 1991; Groten, 1990).

In addition, selenium, found in high concentrations in marine mammals (Tables 1 and 2) has been shown to be protective against mercury and cadmium toxicity (Ohi et al., 1975; Whanger, 1992). These critical issues in developing food consumption guidelines are being considered in an ongoing effort to better quantify food safety and risks and are beyond the scope and purpose of this initial compilation and summation of available data.

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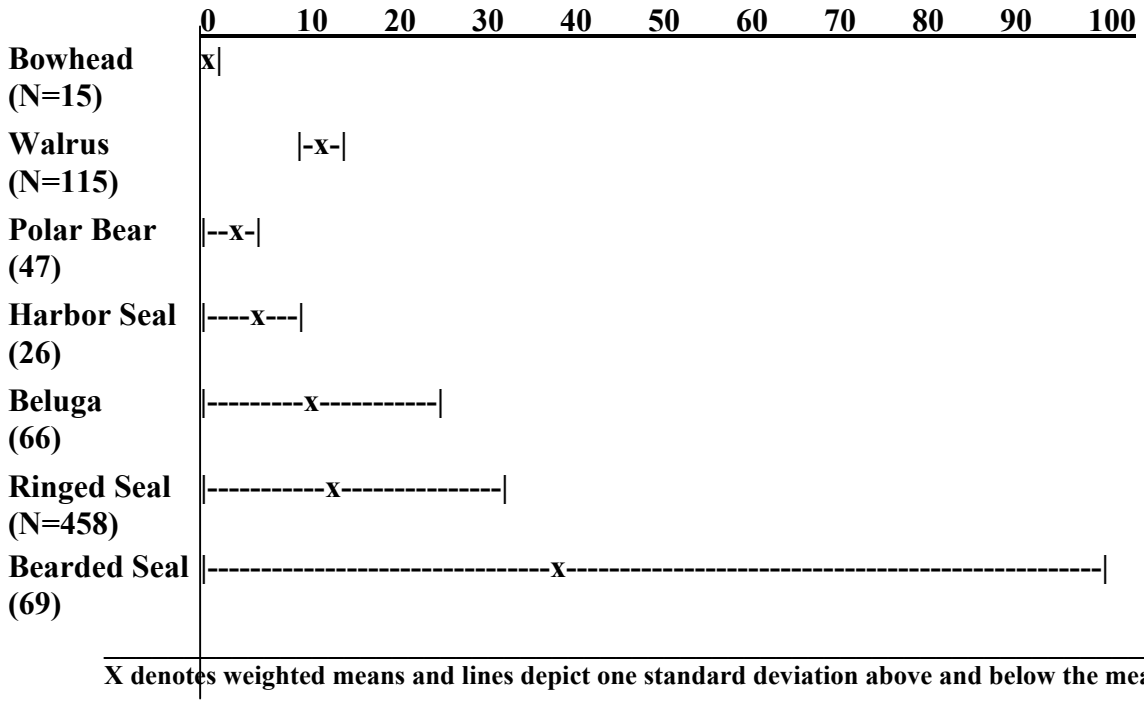
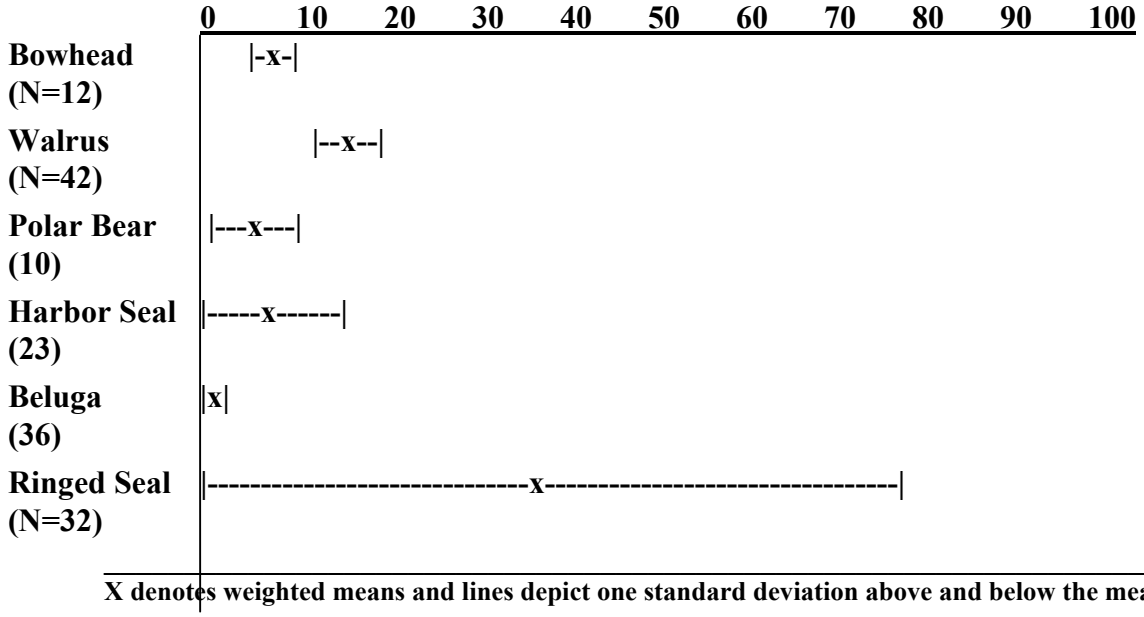
Figure 1. Total Mercury Concentrations (µg/g) in Liver tissues of Arctic Marine Mammals



X denotes weighted means and lines depict one standard deviation above and below the mean.

Figure 2. Cadmium Concentrations (µg/g) in kidney tissues of Arctic Marine Mammals



X denotes weighted means and lines depict one standard deviation above and below the mean.

Table 1: Arsenic, selenium and cadmium in bowhead whale.

Reference	Date Collected	Sampling Location	Tissue	Mean As (µg/g), ww	SD As	As N	Mean Se (µg/g), ww	SD Se	Se N	Mean Cd (µg/g), ww	SD Cd	Cd N
Bowhead Whale												
Byrne et al., 1985	1979-80	Alaska	B	1.00E-03	*1.00E-03*	7	5.00E-04	*5.00E-04*	7	2.80E-02	3.70E-02	7
Bratton et al., 1990	1986	Alaska	B	1.00E-03	*1.00E-03*	6	5.00E-03	*5.00E-03*	6	3.00E-02	4.00E-02	6
Bratton et al., 1990	1988	Alaska	B							6.00E-02	3.00E-02	4
Derived Mean, Derived SD, N (Alaska)				**1.00E-03**	**1.00E-03**	**13**	**2.58E-03**	**3.39E-03**	**13**	**3.62E-02**	**3.67E-02**	**17**
Byrne et al., 1985	1979-80	Alaska	K	6.30E-02	*6.30E-02*	2	2.75E-02	*2.75E-02*	2	1.42E+00	*1.42E+00*	2
Bratton et al., 1990	1986	Alaska	K	9.00E-02	1.00E-01	6	1.59E+00	3.30E-01	6	6.56E+00	1.76E+00	6
Bratton et al., 1990	1988	Alaska	K	2.10E-01	1.60E-01	4	1.76E+00	2.00E-01	4	1.53E+01	2.84E+00	4
Derived Mean, Derived SD, N (Alaska)				**1.26E-01**	**1.20E-01**	**12**	**1.39E+00**	**2.72E-01**	**12**	**8.63E+00**	**2.15E+00**	**12**
Byrne et al., 1985	1979-80	Alaska	L	5.50E-02	*5.50E-02*	2	8.00E-02	*8.00E-02*	2	1.50E+00		1
Bratton et al., 1990	1986	Alaska	L	2.10E-01	1.10E-01	6	1.33E+00	3.00E-01	6	7.21E+00	1.69E+00	6
Bratton et al., 1990	1988	Alaska	L	4.40E-01	1.80E-01	4	1.25E+00	1.90E-01	4	1.21E+01	1.79E+00	4
Becker, 1995	1992-93	Alaska	L	2.35E-01	1.66E-01	3	9.14E-01	3.96E-01	3	1.29E+01	1.09E+01	3
Derived Mean, Derived SD, N (Alaska)				**2.56E-01**	**1.40E-01**	**15**	**1.06E+01**	**2.83E-01**	**15**	**9.42E+00**	**5.11E+00**	**14**
Byrne et al., 1985	1979-80	Alaska	M	9.10E-02	*9.10E-02*	2	1.30E-01	*1.30E-01*	2	1.50E-02	*1.50E-02*	2
Bratton et al., 1990	1986	Alaska	M	6.00E-02	7.00E-02	6	4.20E-01	1.60E-01	6	7.00E-02	6.00E-02	6
Bratton et al., 1990	1988	Alaska	M	1.00E-01		1	4.70E-01		1	8.00E-02		1
Derived Mean, Derived SD, N (Alaska)				**7.13E-02**	**7.39E-02**	**9**	**3.61E-01**	**1.55E-01**	**9**	**5.89E-02**	**5.51E-02**	**9**

Table headings (for Tables 1-6) include the citation reference (Reference), the date the sample was collected (Date Collected), the sampling location (Sampling Location), the tissue analyzed (Tissue), the mean reported analyte concentration (Mean), the reported standard deviation (SD), and the number of samples analyzed (N). Derived mean, SD and the total number of samples across studies are shown separately for samples taken in Alaska and from other locations, and are depicted in bold. Where standard deviation information was not available in the original citation, a standard deviation of 100% of the reported mean was assumed (see Methods); these data are depicted in italics.

Other abbreviations used in the tables include: ww, wet weight; B, blubber; K, kidney; L, Liver; M, muscle; As, arsenic, Hg, mercury; MeHg, methylemrcury; Se, selenium; Cd, cadmium.

Table 2: Arsenic, selenium and cadmium in beluga whale, bearded seal, harbor seal and walrus.

Reference	Date Collected	Sampling Location	Tissue	Mean As (µg/g), ww	SD As	As N	Mean Se (µg/g), ww	SD Se	Se N	Mean Cd (µg/g), ww	SD Cd	Cd N
Beluga Whale												
Becker, 1995	1989-90	Alaska	L	1.75E-01	1.42E-01	15	1.95E+01	1.80E+01	15	1.99E+00	9.29E-01	15
Hansen et al., 1990	1980	Greenland	L				6.10E-01	*6.10E-01*	40	7.50E-03	*7.50E-03*	40
Derived Mean, Derived SD, N (Alaska)				**1.75E-01**	**1.42E-01**	**15**	**1.95E+01**	**1.80E+01**	**15**	**1.99E+00**	**9.29E-01**	**15**
Derived Mean, Derived SD, N (Other)							**6.10E-01**	**6.10E-01**	**40**	**7.50E-03**	**7.50E-03**	**40**
Hansen et al., 1990	1980	Greenland	K				3.40E-01	*3.40E-01*	37	7.50E-03	*7.50E-03*	36
Derived Mean, Derived SD, N (Other)							**3.40E-01**	**3.40E-01**	**37**	**7.50E-03**	**7.50E-03**	**36**
Hansen et al., 1990	1980	Greenland	M				1.00E-01	*1.00E-01*	41	7.50E-03	*7.50E-03*	41
Derived Mean, Derived SD, N (Other)							**1.00E-01**	**1.00E-01**	**41**	**7.50E-03**	**7.50E-03**	**41**
Bearded Seal												
Becker, **1995**	1989-93	Alaska	L	3.86E-01	2.02E-01	3	3.07E+00	2.04E+00	3	1.03E+00	9.90E-01	3
Smith and Armstrong, 1975	1973	Canada	L				3.44E+01	3.32E+01	6			
Smith and **Armstrong**, 1975	1974	Canada	L				2.08E+01	1.35E+01	10			
Derived Mean, Derived SD, N (Alaska)				**3.86E-01**	**2.02E-01**	**3**	**3.07E+00**	**2.04E+00**	**3**	**1.03E+00**	**9.90E-01**	**3**
Derived Mean, Derived SD, N (Other)							**2.59E+01**	**2.26E+01**	**16**			
Harbor Seal												
Miles et al., 1992	1976-78	Alaska	K							6.60E+00	6.60E+00	23
Derived Mean, Derived SD, N (Alaska)										**6.60E+00**	**6.60E+00**	**23**
Miles et al., 1992	1976-78	Alaska	L	8.00E-02	*8.00E-02*	23	1.60E+00	1.60E+00	23			
Derived Mean, Derived SD, N (Alaska)				**8.00E-02**	**8.00E-02**	**23**	**1.60E+00**	**1.60E+00**	**23**			
Pacific Walrus												
Taylor et al., 1989	1981-84	Alaska	K	1.30E-01	2.00E-02	3	9.53E+00	6.32E+00	3	4.65E+01	2.02E+01	42
Derived Mean, Derived SD, N (Alaska)				**1.30E-01**	**2.00E-02**	**3**	**9.53E+00**	**6.32E+00**	**3**	**4.65E+01**	**2.02E+01**	**42**
Taylor et al., **1989**	1981-84	Alaska	L	1.00E-02	4.00E-02	57	2.32E+00	1.96E+00	65	9.47E+00	8.26E+00	65
Derived Mean, Derived SD, N (Alaska)				**1.00E-02**	**4.00E-02**	**57**	**2.32E+00**	**1.96E+00**	**65**	**9.47E+00**	**8.26E+00**	**65**

Table 3: Arsenic, selenium and cadmium in ringed seal and polar bear.

Reference	Date Collected	Sampling Location	Tissue	Mean As (µg/g), ww	SD As	As N	Mean Se (µg/g), ww	SD Se	Se N	Mean Cd (µg/g), ww	SD Cd	Cd N
Ringed Seal												
Becker, 1995	1989-93	Alaska	K	3.12E+00	*3.12E+00*	2	3.15E+00	*3.15E+00*	2	5.13E+00	*5.13E+00*	2
Fallis, unpubl. in Muir et al., 1992	1977	Canada	K							2.79E+01		1
Johansen et al., 1980 in Muir et al., 1992	1979	Greenland	K							3.74E+01	3.37E+01	29
Derived Mean, Derived SD, N (Alaska)				**3.12E+00**	**3.12E+00**	**2**	**3.15E+00**	**3.15E+00**	**2**	**5.13E+00**	**5.13E+00**	**2**
Derived Mean, Derived SD, N (Other)										**3.71E+01**	**3.37E+01**	**30**
Becker, 1995	1989-93	Alaska	L	1.03E+00	7.22E-01	14	2.96E+00	1.46E+00	14	2.33E+00	2.32E+00	14
Smith and Armstrong, 1975	1975	Canada	L				1.64E+01	7.83E+00	12			
Smith and Armstrong, 1975	1976	Canada	L				9.44E+00	6.66E+00	10			
Smith and Armstrong, 1975	1976	Canada	L				4.13E+00	2.67E+00	8			
Smith and Armstrong, 1975	1972-73	Canada	L				1.52E+01	7.75E+00	42			
Smith and Armstrong, 1975	1977	Canada	L				1.50E+01	6.42E+00	112			
Fallis, unpubl. in Muir et al., 1992	1975	Canada	L							4.20E+00	3.30E+00	5
Fallis, unpubl. in Muir et al., 1992	1977	Canada	L							5.50E+00	8.00E-02	5
Johansen et al., 1980 in Muir et al., 1992	1979	Greenland	L							7.32E+00	3.00E+00	29
Derived Mean, Derived SD, N (Alaska)				**1.03E+00**	**7.22E-01**	**14**	**2.96E+00**	**1.46E+00**	**14**	**2.33E+00**	**2.32E+00**	**14**
Derived Mean, Derived SD, N (Other)							**1.09E+01**	**6.75E+00**	**184**	**6.69E+00**	**2.87E+00**	**39**
Fallis, unpubl. in Muir et al., 1992	1975	Canada	M							3.00E-02	2.00E-02	6
Fallis, unpubl. in Muir et al., 1992	1977	Canada	M							5.00E-02	1.00E-02	7
Johansen et al., 1980 in Muir et al., 1992	1979	Greenland	M							7.00E-02	1.00E-01	29
Derived Mean, Derived SD, N (Other)										**6.10E-02**	**8.51E-02**	**42**
Polar Bear												
Norheim et al., 1992	1978-89	Norway	L	6.00E-02	3.00E-02	16	2.40E+00	9.00E-01	16	6.00E-01	3.00E-01	16
Norheim et al., 1992	1978-89	Norway	L	4.00E-02	4.00E-02	6	2.00E+00	5.00E-01	6	3.00E-01	2.00E-01	6
Derived Mean, Derived SD, N (Other)				**5.45E-02**	**3.30E-02**	**22**	**2.29E+00**	**8.19E-01**	**22**	**5.18E-01**	**2.78E-01**	**22**
Norheim et al., 1992	1978-89	Norway	K	4.00E-02	2.00E-02	7	4.60E+00	3.30E+00	7	8.10E+00	7.20E+00	7
Norheim et al., 1992	1978-89	Norway	K	3.00E-02	1.00E-02	3	2.50E+00	8.00E-01	3	3.80E+00	2.80E+00	3
Derived Mean, Derived SD, N (Other)				**3.70E-02**	**1.80E-02**	**10**	**3.97E+00**	**2.89E+00**	**10**	**6.81E+00**	**6.39E+00**	**10**

Table 4: Mercury and methylmercury (MeHg) in beluga whale and ringed seal.

Reference	Date Collected	Sampling Location	Tissue	Mean Hg (µg/g),ww	SD Hg	Hg N	Mean MeHg (µg/g), ww	SD MeHg	MeHg N
Beluga Whale									
Imperial Oil Limited in Muir et al., 1992	1977	Canada	B	8.00E-02	9.00E-02	11			
Derived Mean, Derived SD, N (Other)				**8.00E-02**	**9.00E-02**	**11**			
Hansen et al., 1990	1980	Greenland	K	2.50E-03	*2.50E-03*	37			
Derived Mean, Derived SD, N (Other)				**2.50E-03**	**2.50E-03**	**37**			
Becker, 1995	1989-90	Alaska	L	2.80E+01	2.75E+01	11	7.88E-01	6.88E-01	6
Behlke and Schantz, 1996	1989-95	Alaska	L				9.74E-01	6.23E-01	16
Hansen et al., 1990	1980	Greenland	L	7.00E-02	*7.00E-02*	40			
Lutz and Armstrong in Muir et al., 1992	1971	Canada	L	6.26E+00	3.71E+00	7			
Imperial Oil Limited in Muir et al., 1992	1977	Canada	L	3.06E+01	2.05E+01	8			
Derived Mean, Derived SD, N (Alaska)				**2.80E+01**	**2.75E+01**	**11**	**9.23E-01**	**6.40E-01**	**22**
Derived Mean, Derived SD, N (Other)				**5.30E+00**	**7.63E+00**	**55**			
Hansen et al., 1990	1980	Greenland	M	5.10E-01	5.10E-01	41			
Bligh and Armstrong in Muir et al., 1992	1971	Canada	M	9.70E-01	*9.70E-01*	1			
Lutz and Armstrong in Muir et al., 1992	1972	Canada	M	7.10E-01	1.40E-01	7			
Lutz and Armstrong in Muir et al., 1992	1971	Canada	M	5.30E-01	*5.30E-01*	43			
Imperial Oil Limited in Muir et al., 1992	1977	Canada	M	2.12E+00	1.15E+00	11			
Derived Mean, Derived SD, N (Other)				**7.08E-01**	**5.08E-01**	**103**			
Ringed Seal									
Smith and Armstrong, 1975	1975	Canada	L	1.93E+01	1.84E+01	88			
Smith and Armstrong, 1975	1976	Canada	L	1.61E+01	1.38E+01	27	8.90E-01	4.50E-01	10
Smith and Armstrong, 1975	1976	Canada	L	3.20E-01	8.00E-02	36			
Smith and Armstrong, 1975	1976	Canada	L	3.76E+00	3.42E+00	33	5.00E-01	2.40E-01	8
Smith and Armstrong, 1975	1972	Canada	L	1.00E+00	1.16E+00	13			
Smith and Armstrong, 1975	1972-73	Canada	L	2.75E+01	3.01E+01	83	9.60E-01	4.50E-01	42
Smith and Armstrong, 1975	1977	Canada	L	2.55E+01	1.50E+01	112	8.50E-01	3.90E-01	13
Fallis, unpubl. in Muir et al., 1992	1975	Canada	L	3.27E+00	7.50E-01	5			
Johansen et al., 1980 in Muir et al., 1992	1973	Greenland	L	2.40E+00	1.49E+00	10	3.00E-01	*3.00E-01*	10
Johansen et al., 1980 in Muir et al., 1992	1974	Greenland	L	3.40E-01	3.80E-01	7	8.50E-02	*8.50E-02*	7
Johansen et al., 1980 in Muir et al., 1992	1976	Greenland	L	2.10E+00	4.10E+00	31			
Becker, 1995	1989-93	Alaska	L	1.97E+00	2.03E+00	9	4.10E-01	2.34E-01	4
Demiralp et al., 1995	1993	Alaska	L	1.33E+00	1.93E+00	4			
Derived Mean, Derived SD, N (Alaska)				**1.77E+00**	**2.00E+00**	**13**	**4.10E-01**	**2.34E-01**	**4**
Derived Mean, Derived SD, N (Other)				**1.19E+01**	**1.52E+01**	**445**	**3.06E-01**	**3.97E-01**	**90**
Fallis, unpubl. in Muir et al., 1992	1975	Canada	K	2.32E+00	*2.32E+00*	1			
Derived Mean, Derived SD, N (Other)				**2.32E+00**	**2.32E+00**	**1**			
Smith and Armstrong, 1975	1975	Canada	M	4.40E-01	1.60E-01	89			
Smith and Armstrong, 1975	1976	Canada	M	9.10E-01	3.80E-01	27			
Smith and Armstrong, 1975	1976	Canada	M	8.00E-02	7.00E-02	37			
Smith and Armstrong, 1975	1976	Canada	M	3.10E-01	1.70E-01	33			
Smith and Armstrong, 1975	1972	Canada	M	2.30E-01	1.10E-01	13			
Smith and Armstrong, 1975	1972-73	Canada	M	7.20E-01	3.30E-01	83			
Fallis, unpubl. in Muir et al., 1992	1977	Canada	M	3.30E-01	6.00E-02	7			
Johansen et al., 1980 in Muir et al., 1992	1973	Greenland	M	2.30E-01	1.60E-01	10	1.50E-01	*1.50E-01*	10
Johansen et al., 1980 in Muir et al., 1992	1974	Greenland	M	9.00E-02	4.00E-02	7	3.60E-02	*3.60E-02*	7
Johansen et al., 1980 in Muir et al., 1992	1976	Greenland	M	1.80E-01	1.80E-01	31			
Derived Mean, Derived SD, N (Other)				**1.75E+01**	**2.31E-01**	**337**	**1.03E-01**	**1.18E-01**	**17**

Table 5: Mercury and methylmercury (MeHg) in bearded seal, northern fur seal, harbor seal and polar bear.

Reference	Date Collected	Sampling Location	Tissue	Mean Hg (µg/g),ww	SD Hg	Hg N	Mean MeHg (µg/g), ww	SD MeHg	MeHg N
Bearded Seal									
Becker, 1995	1989-93	Alaska	L	4.17E+00	4.56E+00	3			
Galster, 1971		Alaska	L	1.91E+00	1.20E+00	4			
Smith and Armstrong, 1975	1973	Canada	L	1.43E+02	1.70E+02	6	3.00E-01	2.60E-01	6
Smith and Armstrong, 1975	1974	Canada	L	2.62E+01	2.61E+01	56	1.20E-01	4.00E-02	10
Derived Mean, Derived SD, N (Alaska)				**2.88E+00**	**3.03E+00**	**7**			
Derived Mean, Derived SD, N (Other)				**3.75E+01**	**5.51E+01**	**62**	**1.88E-01**	**1.62E-01**	**16**
Galster, 1971		Alaska	M	2.00E-01	1.50E-01	7			
Smith and Armstrong, 1975	1973	Canada	M	5.30E-01	3.50E-01	3			
Smith and Armstrong, 1975	1974	Canada	M	9.00E-02	4.00E-02	55			
Derived Mean, Derived SD, N (Alaska)				**2.00E-01**	**1.50E-01**	**7**			
Derived Mean, Derived SD, N (Other)				**1.13E-01**	**7.69E-02**	**58**			
Northern Fur Seal									
Goldblatt and Anthony, 1983	1975	Alaska	L	1.07E+01	6.53E+00	37			
Derived Mean, Derived SD, N (Alaska)				**1.07E+01**	**4.94E+00**	**37**			
Harbor Seal									
Miles et al., 1992	1976-78	Alaska	L	5.00E+00	*5.00E+00*	23			
Anas, 1974	1971	Alaska	L	4.23E+00	4.25E+00	3			
Derived Mean, Derived SD, N (Alaska)				**4.91E+00**	**4.94E+00**	**26**			
Polar Bear									
Lentfer, 1976	1972	Alaska	L	4.80E+00	1.46E+00	9			
Lentfer, 1976	1972	Alaska	L	3.92E+00	1.28E+00	16			
Norheim et al., 1992	1978-89	Norway	L	2.60E+00	2.00E+00	16			
Norheim et al., 1992	1978-89	Norway	L	1.90E+00	1.30E+00	6			
Derived Mean, Derived SD, N (Alaska)				**4.24E+00**	**1.33E+00**	**25**			
Derived Mean, Derived SD, N (Other)				**2.41E+00**	**1.85E+00**	**22**			
Norheim et al., 1992	1978-89	Norway	K	4.90E+00	6.60E+00	7			
Norheim et al., 1992	1978-89	Norway	K	1.90E+00	1.30E+00	3			
Derived Mean, Derived SD, N (Other)				**4.00E+00**	**5.57E+00**	**10**			
Lentfer, 1976	1972	Alaska	M	4.00E-02	1.39E-02	12			
Lentfer, 1976	1972	Alaska	M	4.00E-02	2.60E-01	4			
Derived Mean, Derived SD, N (Alaska)				**4.00E-02**	**1.31E-01**	**16**			

Table 6: Mercury and methylmercury (MeHg) in bowhead whale and walrus.

Reference	Date Collected	Sampling Location	Tissue	Mean Hg (µg/g),ww	SD Hg	Hg N	Mean MeHg (µg/g), ww	SD MeHg	MeHg N
Bowhead Whale									
Byrne et al., 1985	1979-80	Alaska	B	7.00E-03	*7.00E-03*	7			
Bratton et al., 1990	1986	Alaska	B	3.00E-03	5.00E-03	6			
Derived Mean, Derived SD, N (Alaska)				**5.15E-03**	**6.16E-03**	**13**			
Byrne et al., 1985	1979-80	Alaska	K	5.50E-03	*5.50E-03*	2			
Bratton et al., 1990	1986	Alaska	K	5.00E-03	1.00E-03	6			
Bratton et al., 1990	1988	Alaska	K	7.00E-03	1.00E-03	4			
Derived Mean, Derived SD, N (Alaska)				**5.75E-03**	**2.06E-03**	**12**			
Byrne et al., 1985	1979-80	Alaska	L	5.00E-03	*5.00E-03*	2			
Bratton et al., 1990	1986	Alaska	L	8.00E-03	1.00E-03	6			
Bratton et al., 1990	1988	Alaska	L	7.00E-03	1.00E-03	4			
Becker, 1995	1992-93	Alaska	L	1.70E-01	1.10E-01	3			
Derived Mean, Derived SD, N (Alaska)				**3.97E-02**	**4.69E-02**	**15**			
Byrne et al., 1985	1979-80	Alaska	M	5.00E-04	*5.00E-04*	2			
Bratton et al., 1990	1986	Alaska	M	3.00E-03	1.00E-03	6			
Bratton et al., 1990	1988	Alaska	M	2.00E-03		1			
Derived Mean, Derived SD, N (Alaska)				**2.33E-03**	**9.35E-04**	**9**			
Pacific (Alaska) and Atlantic (Other) Walrus									
Taylor et al., 1989	1981-84	Alaska	L	1.50E+00	3.18E+00	62			
Galster, 1971		Alaska	L	4.90E-01	1.00E-01	7			
Born et al., 1981	1975-77	Greenland	L	1.78E+00	1.54E+00	46	1.00E-01	8.00E-02	56
Derived Mean, Derived SD, N (Alaska)				**1.40E+00**	**3.03E+00**	**69**			
Derived Mean, Derived SD, N (Other)				**1.78E+00**	**1.54E+00**	**46**	**1.00E-01**	**8.00E-02**	**56**
Galster, 1971		Alaska	M	2.00E-02	5.00E-03	6			
Born et al., 1981	1975-77	Greenland	M	8.00E-02	5.00E-02	58			
Derived Mean, Derived SD, N (Alaska)				**2.00E-02**	**5.00E-03**	**6**			
Derived Mean, Derived SD, N (Other)				**8.00E-02**	**5.00E-02**	**58**			

Table 7: Summary tissue trace metal concentrations for all species.

Species	Tissue	Mean As	SD As	As No.	Mean Hg	SD Hg	Hg No.	Mean MeHg	SD MeHg	MeHg No.	Mean Se	SD Se	Se No.	Mean Cd	SD Cd	Cd No.
Bearded Seal	L	3.86E-1	2.02E-1	3	*3.40E+1*	*5.260E+1*	*69*	1.88E-1	1.62E-1	16	*2.23E+1*	*2.12E+1*	*19*	1.03E+0	9.90E-1	3
Bearded Seal	M				*1.22E-1*	*8.65E-2*	*65*									
Beluga Whale	B				8.00E-2	9.00E-2	11									
Beluga Whale	K				2.50E-3	2.50E-3	37				3.40E-1	3.40E-1	37	7.50E-3	7.50E-3	36
Beluga Whale	L	1.75E-1	1.42E-1	15	*9.08E+0*	*1.29E+1*	*66*	9.23E-1	6.40E-1	22	*5.77E+0*	*9.26E+0*	*55*	*5.48E-1*	*4.77E-1*	*55*
Beluga Whale	M				7.08E-1	6.10E-1	103				1.00E-1	1.00E-1	41	7.50E-3	7.50E-3	41
Bowhead Whale	B	1.00E-3	1.00E-3	13	5.15E-3	6.16E-3	13				2.58E-3	3.39E-3	13	3.62E-2	3.67E-2	17
Bowhead Whale	K	1.26E-1	1.20E-1	12	5.75E-3	2.06E-3	12				1.39E+0	2.72E-1	12	8.63E+0	2.15E+0	12
Bowhead Whale	L	2.56E-1	1.40E-1	15	3.97E-2	4.69E-2	15				1.06E+0	2.83E-1	15	9.42E+0	5.11E+0	14
Bowhead Whale	M	7.13E-2	7.39E-2	9	2.33E-3	9.35E-4	9				3.61E-1	1.55E-1	9	5.89E-2	5.51E-2	9
Fur Seal	L				1.07E+1	6.53E+0	37									
Harbor Seal	K													6.60E+0	6.60E+0	23
Harbor Seal	L	8.00E-2	8.00E-2	23	4.91E+0	4.94E+0	26				1.60E+0	1.60E+0	23			
Polar Bear	K	3.70E-2	1.80E-2	10	4.00E+0	5.57E+0	10				3.97E+0	2.89E+0	10	6.81E+0	6.39E+0	10
Polar Bear	L	5.45E-2	3.30E-2	22	*3.38E+0*	*1.59E+0*	*47*				2.29E+0	8.19E-1	22	5.18E-1	2.78E-1	22
Polar Bear	M				4.00E-2	1.31E-1	16									
Ringed Seal	K	3.12E+0	3.12E+0	2	2.32E+0		1				3.15E+0	3.15E+0	2	*3.51E+1*	*3.32E+1*	*32*
Ringed Seal	L	1.03E+0	7.22E-1	14	*1.16E+1*	*1.50E+1*	*458*	*3.32E-1*	*3.93E-1*	*94*	*1.03E+1*	*6.53E+0*	*198*	*5.54E+0*	*2.74E+0*	*53*
Ringed Seal	M				1.75E+1	2.31E-1	337							6.10E-2	8.51E-2	42
Walrus	K	1.30E-1	2.00E-2	3							9.53E+0	6.32E+0	3	4.65E+1	2.02E+1	42
Walrus	L	1.00E-2	4.00E-2	57	*1.55E+0*	*2.54E+0*	*115*	1.00E-1	8.00E-2	56	2.32E+0	1.96E+0	65	9.47E	8.26E+0	65
Walrus	M				*7.44E-2*	*4.79E-3*	*64*									

Summary data are taken from Tables 1-6. When both Alaskan and non-Alaskan samples were available for a particular species and tissue, summary weighted means and standard deviations were calculated according to the number of species analyzed (see Methods); these results are presented in italics.