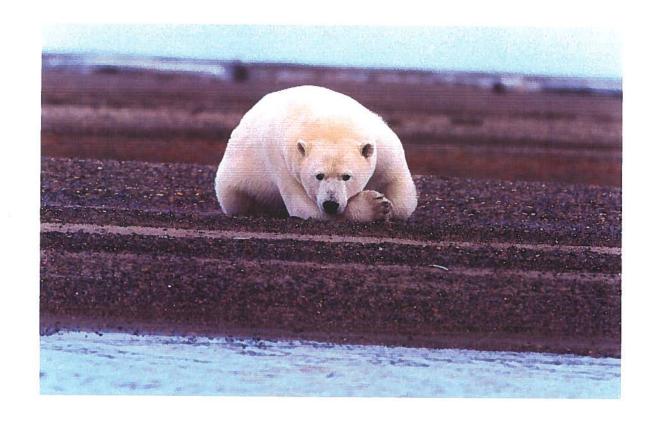# Concentrations of Selected Essential and Non-Essential Elements in Adult Male Polar Bears (*Ursus maritimus*) from Alaska

Thomas J. Evans

Marine Mammals Management
Fish and Wildlife Service
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ABSTRACT

Concentrations of selected essential and non-essential elements, [including mercury, cadmium,] lead, arsenic, selenium, copper, zinc, and vanadium were measur[ed in liver, kidney, and muscle] tissues from 36 adult male polar bears from the Southern Beaufort Sea and the Chukchi/Bering Seas in Alaska. Concentrations of Hg, Se, Cd, Pb, Se, and V generally decreased in the order of kidney>liver>muscle. Mercury, Se, and Cd concentrations were significantly higher in liver tissues in polar bears from the Southern Beaufort Sea (Hg $\bar{x}$ = 30.91 µg/g dw, Se $\bar{x}$ = 14.39 µg/g dw, Cd $\bar{x}$ = 1.42 µg/g dw) than the Chukchi/Bering Seas (Hg $\bar{x}$ =10.07 µg/g dw, Se $\bar{x}$ = 6.60 µg/g dw, Cd $\bar{x}$ = 1.21 µg/g dw). Mercury, Se, and Cd concentrations were significantly higher in kidney tissues in polar bears from the Southern Beaufort Sea (Hg $\bar{x}$ = 63.95 µg/g dw, Se $\bar{x}$ = 29.154 µg/g dw) than the Chukchi/Bering Seas (Hg $\bar{x}$ = 23.68 µg/g dw, Se $\bar{x}$ = 15.92 µg/g dw).

Based on regression analysis Hg to Se ratios in polar bear liver tissues were close to 1:1 for both Alaskan populations, which suggest that Se has a role in protecting polar bears from Hg toxicity. Mercury concentrations in liver tissues of polar bears in the Southern Beaufort Sea were about half of those found in the Amundsen Gulf, Canada in the eastern Beaufort Sea. Hepatic levels of copper, although very high ($\bar{x}$ = 103.05 µg/g dw), were within ranges reported from other Arctic polar bear populations. Although low, vanadium concentrations in polar bear kidneys were significantly higher in the Chukchi/Bering Seas ($\bar{x}$ = 0.871 µg/g dw) than in the Southern

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Ex. $\bar{x}$

Beaufort Sea ($\bar{x}$ = 0.245 µg/g dw).

MANAGEMENT RECOMMENDATIONS

This study presents additional information on selected essential and non-essential elements in adult polar bears from Alaska. Some of the highest Hg levels in the Arctic are from western Canada and the eastern Beaufort Sea, as indicated by the high Hg concentrations relative to Se concentrations, in polar bears, ringed seals, and bearded seals. Based on the polar bear data from this study mercury concentrations generally decreased in the order Western Canada > eastern Beaufort Sea (Canada, Alaska) > Southern Beaufort Sea (Alaska) > Chukchi/Bering Seas (Alaska/Russia). As mercury concentrations continue to increase in the Arctic (Asmund and Nielsen 2000), continued effort should be taken to monitor marine mammals species, including polar bears and the ice (*Phoca sp.*) seals, to see if they can continue to be able to detoxify the increased mercury burdens. Apparently enough Se is currently available in environment for polar bears to detoxify the more toxic methylmercury, thus preventing Hg poisoning. Thus Se concentrations and the other elements discussed in this study, which may have synergistic effects, should also continue to be monitored. The sample sizes for this study were relatively small and focused on only adult males. To look at temporal trends and variation in the sex, age, reproductive status, habitat, location, diet, and nutritional status of polar bears we need to

increase our sample size and include all the sex and age cohorts of both polar bears and their prey. For example very little information is known about bearded seals in northern and western Alaska and more extensive contaminant information is required for ringed seals, the two primary prey species of polar bears. Aside from documenting concentrations of toxic elements more research needs to be conducted to look at the effects and relationship of these toxic elements to polar bear physiology, disease, and population dynamics. Additional individual information that should be collected along with the polar bear contaminant data should be basic biological information such as accurate location information, weight, length, age, general health assessment and with more time and money additional data could be collected to examine hormone levels, P450 enzymes, blood chemistry, genetics, as well as histology samples. In trying to elucidate why there were differences in contaminant loading between the two Alaskan polar bear populations, it became apparent that more information was needed on the relative importance of various prey items in the polar bear diet. One approach would be to collect information on fatty acids, contaminants, and combine this with an isotopic analysis to look at marine mammal trophic ecology (Kelly 2000). (e.g. what proportion of the polar bear diet comes from feeding on marine mammals below ringed seals in the food web?). In addition detailed information on polar bear habitat use, contaminant sources, and habitat quality would assist in evaluating the impacts and potential solutions to environmental contamination problems. Contaminant studies are generally very expensive to conduct so maximum use should be made of long-term cryogenic archival storage facilities for banking specimens for future use.

Concentrations of Selected Essential and Non-Essential Elements in Adult Male Polar Bears (*Ursus maritimus*) from Alaska

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ABSTRACT

Concentrations of selected essential and non-essential elements, including mercury, cadmium, lead, arsenic, selenium, copper, zinc, and vanadium were measured in liver, kidney, and muscle tissues from 36 adult male polar bears from the Southern Beaufort Sea and the Chukchi/Bering Seas in Alaska. Concentrations of Hg, Se, Cd, Pb, Se, and V generally decreased in the order of kidney>liver>muscle. Mercury, Se, and Cd concentrations were significantly higher in liver tissues in polar bears from the Southern Beaufort Sea (Hg $\bar{x}$ = 30.91 μg/g dw, Se $\bar{x}$ = 14.39 μg/g dw, Cd $\bar{x}$ = 1.42 μg/g dw) than the Chukchi/Bering Seas (Hg $\bar{x}$ =10.07 μg/g dw, Se $\bar{x}$ = 6.60 μg/g dw, Cd $\bar{x}$ = 1.21 μg/g dw). Mercury, Se, and Cd concentrations were significantly higher in kidney tissues in polar bears from the Southern Beaufort Sea (Hg $\bar{x}$ = 63.95 μg/g dw, Se $\bar{x}$ = 29.154 μg/g dw) than the Chukchi/Bering Seas (Hg $\bar{x}$ = 23.68 μg/g dw, Se $\bar{x}$ = 15.92 μg/g dw). Based on regression analysis Hg to Se ratios in polar bear liver tissues were close to 1:1 for both Alaskan populations, which suggest that Se has a role in protecting polar bears from Hg toxicity. Mercury concentrations in liver tissues of polar bears in the Southern Beaufort Sea were about half of those found in the Amundsen Gulf, Canada in the eastern Beaufort Sea. Hepatic levels of copper, although very high ($\bar{x}$ = 103.05 μg/g dw), were within ranges reported from other Arctic polar bear populations. Although low, vanadium concentrations in polar bear kidneys were significantly higher in the Chukchi/Bering Seas ($\bar{x}$ = 0.871 μg/g dw) than in the Southern Beaufort Sea ($\bar{x}$ = 0.245 μg/g dw).

INTRODUCTION

Increased development in the Arctic, release from natural deposits, and the long-range transport of pollutants from areas of high use to the Arctic and sub-Arctic regions have raised concerns about the potential effects of heavy metals on the Arctic marine ecosystem, including marine mammals (Lentfer 1976, Stirling and Calvert 1983, Wagemann and Muir 1984, Norstrom et al. 1986, Braune et al. 1991, Norheim et al. 1992, Dietz et al. 1995, Pacyna and Keeler 1995, Pacyna 1996, Lindberg et al. 2002). Polar bears (*Ursus maritimus*) in the Southern Beaufort Sea and the Chukchi/Bering Seas populations remain on the Arctic ice covered areas for most of the year and move with the polar pack ice and depend on the polar pack ice for food, shelter, and survival. Comiso (2003) reported changes in the minimum sea ice extent in the Arctic between the periods 1979-1989 and 1990-2000 were greatest in the northern Chukchi and southern Beaufort seas. Consequently it is expected that polar bears in the Southern Beaufort Sea and the Chukchi/Bering Seas will experience greater changes than polar bears from other Arctic populations, in prey availability and accessibility, in the abundance, distribution, and movement of the sea ice habitat, and in the uptake and exposure to heavy metal contamination. Potential outcomes of these events would be an overall decline in heath and fitness and abundance. The international Arctic Monitoring and Assessment Programme (Macdonald et al. 2003) recently reviewed how climate

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change may alter contaminant pathways, chemical fate and accumulation of contaminants within the Arctic ecosystem.

Polar bears are ideally suited for monitoring the level and distribution of metals in the Arctic ecosystem because of their position at the top of the Arctic marine food chain and their wide distribution. The Arctic ecosystem is particularly sensitive to environmental contamination due to the presence of long-lived organisms with low rates of growth and reproduction. The Arctic food web is simple and fragile. In the spring, eponic algae blooms on the underside of the sea-ice in the Beaufort, Chukchi, and Bering seas (Hood and Kelley 1974). The eponic algae is eaten by zooplankton, which are eaten by fish, mostly Arctic cod (*Boreogadus saida*). Arctic cod are eaten by seals, which are then eaten by polar bears. Humans consume whales, fish, seals, walrus, and polar bears. Snyder-Conn et al. (1997) noted substantial increases in Ba, Cd, Pb, Hg, and V with increasing latitudes from the Brooks Range to the Arctic coast in Alaska. The presence of metals and trace elements has been investigated in sediments (Varanasi 1992), in snow associated with sea ice (Garbarino et al. 2002), whales (Becker et al. 1992, Becker et al. 1995, Becker 2000, Woshner et al. 2001a), seals (Varanasi 1992), walrus (Warburton and Seagars 1993), and birds (Stout et al. 2002, Wilson et al. 2004) in Alaska, but has been studied very little in polar bears, the principle mammalian predator at the top of the Arctic food chain. Existing data on essential and non-essential elements from Alaska polar bears is limited (Lentfer 1976, Lentfer and Galster 1987, Woshner et al. 2001b).

Polar bears are widely distributed throughout the Arctic and sub-Arctic region and range over

large areas in search for food (Garner et al. 1990, Amstrup et al. 2000). Data collected through

satellite telemetry indicates that there are two polar bear population stocks in Alaska, one in the

southern Beaufort Sea and the other in the Chukchi/Bering Seas (Amstrup et al. 2000). An area

of overlap occurs east of Point Barrow to Point Hope on the land, shorefast ice, and moving

offshore sea ice. Seasonal movements are closely associated with movements of the sea ice,

which in turn influences the distribution and concentration of their primary prey, ringed (*Phoca

hispida*) and bearded seals (*Erignathus barbatus*) (Stirling et al. 1982, Kingsley et al. 1985).

Polar bears move south with the ice in the fall and winter and move north as the pack ice melts in

the spring and summer. Except for the parturient females, polar bears from the two Alaskan

populations remain on the ice year-round and are considered to be some of the most pelagic bears

in the arctic polar basin (Amstrup 2003). During the spring and fall polar bears from the

Southern Beaufort Sea population preferred shallow water areas over the continental shelf and

areas with > 90% ice cover (Durner et al. 2004). It is likely polar bears move to this area during

the spring and fall to take advantage of the abundance and accessibility of ringed seals. This

parallels the findings of Stirling et al. (1982) that ringed seal densities in the Beaufort Sea were

greatest in areas with >80% ice cover and at depths of 50-100 m. Annual ice is used primarily

during the spring and fall, and areas of active ice, caused by the formation of fast-ice and

consolidation of offshore ice, are used primarily during the winter. Multi-year ice is used only

during the summer when the annual ice melts (Durner et al. 2004). Polar bears feed primarily on

ringed seals, which in turn feed on Arctic cod and large amphipods (Stirling and Archibald

1977). Bearded seals, which are more common over the shallow coastal shelf in Chukchi Sea

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than the Beaufort Sea, are another important prey item. Polar bears are opportunistic feeders and will also feed on Pacific walrus (*Odobenus rosmarus divergens*) and scavenge on bowhead whale (Balaena mysticetus), grey whale (*Eschrichtius robustus*), beluga whale, and Pacific walrus carcasses (Norstrom et al. 1998). Differences in the origin and movements of currents, rates of atmospheric or geological deposition of metals, and differences in the feeding ecology of polar bears between the Beaufort and the Chukchi/Bering Seas could affect the uptake of contaminants in polar bears. Pacific walrus and bearded seals feed primarily on benthic organisms whereas bowhead whales (*Balaena mysticetus*) feed primarily on euphausiid, copepod, mysid, and amphipod species in the water column (Lowry 1993). For example Pacific walrus and bearded seals make up a greater proportion of the polar bear diet in the Chukchi/Bering Seas. The Arctic Monitoring and Assessment Programme (AMAP) has identified the polar bear as a key indicator species of the Arctic ecosystem. Under the 1973 International Agreement on the Conservation of Polar Bear, the United States has the responsibility to protect polar bears and their habitat in Alaska. Identification of metal concentrations in polar bears and comparison with contaminant levels in other populations will provide one indirect measure of the health of polar bears and the marine ecosystem within Alaska.

Although trace elements and heavy metal concentrations have been well documented in Canada, Norway, and Greenland polar bear populations (Norstrom et al. 1986, Norheim et al 1992, Dietz et al. 1995, Dietz et al. 2000b), relatively little information is available for populations in Alaska. Lentfer (1976) documented elevated mercury in polar bears, sampled prior to the major oil and gas development on the North Slope. Hunting and utilizing marine mammals remains an

important part of the Alaska Native subsistence lifestyle. Alaska Natives are concerned about contamination levels in the marine mammals they eat, primarily ringed, spotted (*Phoca largha*), and bearded seals, Pacific walrus, bowhead whales, and polar bears. The objectives of this study are to provide more information, to compare trace element and heavy metal concentrations between the two Alaskan polar bear populations, and to compare these data with other Arctic populations. This assessment will include evaluation of: selected elements of polar bears harvested by Alaska Native subsistence hunters; whether these elements differ with age, tissue type, and population; evaluation of potential element interactions; and report of the observed ranges of essential elements.

METHODS

Study Area

Alaska has two polar bear populations, the Southern Beaufort Sea population, shared with Canada, and the Chukchi/Bering Seas population, shared with Russia (Figure 1). Polar bears from these two populations remain primarily offshore on the sea-ice throughout the year (Garner et al. 1990, Amstrup et al. 2000). Movement of the sea ice in the southern Beaufort Sea is primarily east-west whereas the movement of the sea ice in the Chukchi/Bering Seas is primarily north-south. The sea ice in the southern Beaufort Sea may recede from the coast up to 160 km in late summer. Some of the most extensive movements of the pack ice occur in the Chukchi/Bering Seas where the difference between the maximum (winter) and minimum (late summer) ice extent may be over 1400km (Garner et al. 1994). Polar bears are most abundant

along the edges of the pack-ice, over the shallow water areas near shorelines, and polynyas (Durner et al. 2004). Parturient females often visit coastal areas and river drainages in the fall looking for suitable den sites. Approximately 50% of the female bears from the Southern Beaufort Sea population den within 25 miles of the coast in northern Alaska and 50% den on the sea ice (Amstrup and Gardner 1994). Most of the denning in the Chukchi/Bering Seas population occurs on land on Wrangel Island, Herald Island, and along the Chukotka coast.

Sample Collection

Liver, kidney, muscle, and fat tissues from adult male polar bears were collected by Alaska Native subsistence hunters for contaminant analysis. Hunters were instructed to collect both kidneys, a lobe of the liver, two large muscle samples from a major muscle group such as quadriceps, and a large fat sample from the top of the rump above the tail. Samples were collected for both elemental and organochlorine analysis from the same individual. Adult males were chosen because: organochlorine concentrations are more variable in females, cubs, and subadults due to off-loading during lactation (Polischuk 1995); males are harvested at approximately twice the rate as females and thus samples should be easier to obtain; and because we didn't want to encourage the hunting of adult females the most important age class with respect to the population dynamics of this K-selected species.

All tissue samples were frozen in the field and stored at -80°C in ultra-cold freezers at the U.S. Fish and Wildlife Service Regional Office in Anchorage, Alaska. Core samples were prepared using the clean techniques described by Becker et al. (1988, 1991) and sent to the labs for

analysis. Briefly, organs were thawed to a semi-frozen state, and tissue samples were taken using Teflon dissection tools on Teflon lab surface sheeting. Samples were placed in Teflon bottles or pre-cleaned glass jars (I-CHEM 300) and shipped frozen to independent analytical laboratories through the Service's Division of Environmental Contaminants. Samples were also collected for long-term storage at the National Institute of Standards and Technology as part of the Alaskan Marine Mammal Tissue Archival Project (AMMTAP) for use in future analyses as analytical techniques improve and to assist in the development of spatial and temporal trends of contaminant concentrations in the Arctic.

Laboratory Methods

A summary of the methods is described below and a more detailed description of the analytical methods is available from Patuxent Analytical Control Facility (PACF), Patuxent Wildlife Research Center, U.S. Fish and Wildlife Service, Laurel, Maryland. Elemental analyses were performed by Research Triangle Institute in Research Triangle Park, North Carolina. Liver, kidney, and muscle tissues were analyzed for the following analytes: aluminum, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, mercury, magnesium, manganese, molybdenum, nickel, selenium, strontium, vanadium, and zinc. In addition, eight liver samples were analyzed for silver. Prior to the analysis all the tissue samples were homogenized and then freeze dried for determination of percent moisture, extraction, and further analysis. Each sample (0.25 to 0.5g) was digested in 5 ml of Baker Instra-Analyzed nitric acid in a CEM microwave oven for 3 minutes each at 120, 300, and 450 watts. The final reside was then diluted to 50ml with laboratory pure water.

Concentrations of arsenic, selenium, and silver were analyzed using graphite furnace atomic absorption (GFAA) and a Perkin-Elmer Zeeman 3030 or 4100ZL atomic absorption spectrometer. Mercury concentrations were determined using Cold Vapor Atomic Absorption (CVAA) analysis with a tin chloride ($SnCl_4$) reduction. Concentrations of Hg were determined on a Leeman PS200 Hg Analyzer using CVAA and $SnCl_4$ as a reducing agent on a Leeman PS200 Hg Analyzer. The remaining elements were measured using inductively coupled/plasma spectroscopy with a Leeman Labs Plasma Spec 1 sequential or ES2000 simultaneous spectrometer.

Muscle tissues were also analyzed for methylmercury. Methylmercury was extracted from each sample using 10ml of 5mol/l HCL into 3 20ml aliquots of toluene. The combined toluene aliquots were diluted to 100ml with toluene. The methylmercury was extracted from the toluene solution with a cysteine acetate solution. The sample was digested using EPA method 7470 and the resulting solution analyzed using CVAA spectrometry with a stannous chloride and hydroxylamine hydrochloride (2/1) reduction. The CVAA measurements were made using an automated mercury analyzer, the Leeman Labs PS2000.

Quality Assurance/Quality Control (QA/QC)

Quality assurance/quality control standardized procedures included analysis of procedural blanks, standard reference materials, spiked samples, duplicates, and evaluation of the data by a senior chemist at Patuxent Analytical Control Facility (PACF). Prior to analysis the data was reviewed

for acceptance relative to QA/QC guidelines (Quakenbush and Snyder-Conn 1993, K. Mueller, pers. comm.). These guidelines include spike recovery data, comparison of duplicates, procedural blanks, and analysis of Standard Reference Material (SRM) samples. Approximately 10% of the samples were tested for analytical accuracy and precision. For accuracy, an average spike recovery between 80-120% was considered acceptable. For precision, an average relative percent difference (RPD) was calculated based on a comparison of duplicates and was acceptable if the average RPD was <20% (RPD= ([D1-D2]/[(D1+D2)/2]*100); where D1 = the concentration measured in the first analysis and D2 = the concentration measured in the second analysis). For procedural blanks, a concentration <15% of the mean sample was considered acceptable. An SRM (lobster hepatopancreas, NRCC TORT-2) was included in the analyses for quality assurance purposes for all trace elements except for methylmercury. Dogfish liver (NRCC DOLT-2) was used as the SRM for methylmercury. Elements or compounds not meeting QA/QC criteria were eliminated from further statistical analyses.

Statistical Analysis

In addition to the QA/QC procedures the following criteria, based on percent detections, were used to determine which elements should be included and whether non-parametric or parametric testing was appropriate for comparative analyses: (a) no statistical tests were performed on analytes detected in <10% of the samples in any group; (b) only ranges are presented for those analytes detected in >10% and <50% of the samples; (c) non-parametric (univariate KruskalWallis rank sum) testing for analytes detected in >50% and <90% of the samples; and (d) parametric testing to compare populations where analytes were detected >90% of the

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samples; the remaining samples below the detection limit defaulted to 0.5 the detection limit for these analyses. In order to minimize the potential effects of desiccation due to length of time samples were stored prior to analysis, dry wights (ug/g) are reported. Wet weights may be more meaningful from a toxicological standpoint as these better reflect physiological processes in polar bears, and consumers normally eat fresh moist tissue. Wet weights are included in the hard copies of the data provided by the lab and are available from the author upon request.

We examined differences in the concentration of trace elements between the Southern Beaufort Sea and Chukchi/Bering Seas population using descriptive statistics (percent detections, geometric means, and ranges) and a combination of parametric and non-parametric tests. For the non-parametric analyses, concentrations of trace elements were compared using the Kruskal-Wallis test. The trace element data was $\log_e$.transformed to achieve normality. We used multivariate analysis of variance (MANOVA) to examine variation in the concentration of trace elements between the two populations and to reduce the number of variables. Only those variables with univariate p-values <0.15 were used to test for differences between the two populations in the final model. A Spearman rank correlation was used to examine the relationship between mercury and selenium in all individuals sampled. The ratio of hepatic Hg to Se was determined using regression analysis. For all tests, a P-value of < 0.05 was used to test for significant differences. We examined the relationships between individual elements with age using regression and correlation. Parametric and non-parametric statistical programs from SAS 6.12 (SAS 1999) were used for data analysis.

RESULTS AND DISCUSSION

Essential elements, such as Cu, Fe, Mg, Mn, Se, and Zn, occur naturally and play an integral role in the biochemical systems necessary for life. Usually only small amounts of the essential elements are required physiologically and excess amounts are regulated in animals by a variety of homeostatic mechanisms. Elevated levels of even essential elements may become toxic. Nonessential elements, such as As, Ag, Cd, Hg, and Pb, have no known biological function and are considered toxic. Those elements which are of most concern with respect to polar bear health will be discussed. Element concentrations, comparisons between tissue types, and geographic comparisons with other Arctic polar bear populations will be discussed for each element.

We examined liver, kidney, and muscle tissues from 36 adult male polar bears taken in northern and western Alaska for 19 trace elements (Table 1). We focused our analysis on the non-essential elements that were considered most toxic (As, Cd, Hg, and Pb) and the essential elements that at high levels could be potentially toxic (Cu, Zn, Se, and V). Although we received a complete set of samples (i.e. liver, kidney, muscle) from most polar bears, several incomplete sample sets were received and thus the discrepancy between the total number of bears from which samples were collected and those reported in the tables. We present the means, standard deviations, ranges, and 95% confidence intervals in Tables 2 and Table 3. In this study Cd, Cu, Fe, Hg, Mn, Se, and Zn were detected in greater that 90% of the kidney, liver, and muscle samples. Molybdenum in livers and kidneys and Sr in kidneys were detected in greater than 90% of the samples. Aluminum, Pb, V in kidneys and Cr in kidneys and muscle were

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detected in >50% of the samples. Several elements (As, Ag, B, Ba, Be) that were near the detection limit in all tissues were not included in Table 2. Although arsenic was near the detection level in 96% of the samples, one muscle sample from Savoonga had a high concentration of As (21.9 ug/g dw). Cadmium, Cu, Fe, Hg, Mn, Mo, Se, Sr, and Zn, were tested for differences between the Alaskan populations for each tissue type (Table 3).

Comparisons of concentrations of elements between different studies should be treated with caution as there may variation due to analytical methods, sampling years, tissues sampled, sex, age, and/or nutritional status of bears. Most of the results from other studies have combined male and female bears from the same population or have weighted the results to account for age and sex differences. Thus, unless males are specifically mentioned, our results on adult male polar bears did not account for the effects of age and are being compared to results from studies on both male and female polar bears. Previous studies have indicated that element concentrations in polar bears are not significantly different between the sexes (Norstrom et al 1986, Braune et al. 1991, Dietz et al. 1995, Dietz et al. 2000b) and thus these comparisons seem justified. Although information on essential and non-essential element concentrations from this study can be used to monitor the arctic ecosystem, a comparison between the two Alaskan populations should be viewed with caution as overlap occurs. Recent population modeling indicates that approximately 50% of the bears harvested in the vicinity of Barrow may be from the Chukchi/Bering Sea population (Amstrup et al. 2004 in press). In contrast all the bears indicated as being harvested from the Chukchi/Bering Sea population were well outside the area of overlap between the two populations (Amstrup et al. 2004 in press).

For those analytes detected in >90% of the kidney samples, Hg, Se, and Cd contributed significantly to the final multivariate model (MANOVA, Wilks' $\lambda = 0.656$, $F_{4, 27} = 3.55$, p<0.019). Adult male polar bears from the Southern Beaufort Sea population had significantly higher concentrations of mercury ($F_{1, 30} = 13.40$, P<0.001) and selenium ($F_{1, 30} = 9.31$, P<0.005) in kidney tissues than bears from the Chukchi/Bering Seas population. There were no significant differences between populations for Pb (Kruskal-Wallis test statistic = 1.1503, P=0.2835, df=1) and Cr in kidney (Kruskal-Wallis test statistic = 1.0649, P=0.3021, df=1). Although renal concentrations of Cd were significantly greater in the Southern Beaufort Sea population than in the Chukchi/Bering Seas population, Cd was less significant that either Hg or Se in the final multivariate model ($F_{1, 30} = 2.63$, P<0.115).

Mercury ($F_{1, 29} = 22.30$, P<.0001) and Se ($F_{1, 29} = 12.97$, P<.0012), and Fe ($F_{1, 29} = 6.58$, P<.0157) concentrations in liver tissues were significantly greater in polar bears from the Southern Beaufort Sea population than the Chukchi Sea population (MANOVA, Wilks' $\lambda = 0.448$, $F_{3, 27} = 11.10$, p<.0001). Concentrations of Fe, although significant in the final model, were above the significance value of P<0.15 chosen for comparisons between the two Alaskan populations. Hepatic concentrations of Cu, which were relatively high (≈ 103 μg/g dw), were not significantly different between the Alaskan populations.

No significant differences between the two Alaskan populations were detected for any of the elements in muscle tissue.

Comparison between Tissue Types

Concentrations by tissue type for Cd, Hg, Pb, Se, and V generally decreased in the order kidney>liver>muscle (Figure 1). Liver tissues had the highest Cu, Fe, Mn, and Mo concentrations and muscle tissues had the highest concentrations of Mg and Zn. Except for lead, the element concentrations were significantly different ($p<0.05$) between the polar bear kidney and liver tissues in the Southern Beaufort Sea and Chukchi/Bering Seas populations. Although there were significant differences between concentrations Hg and Se in kidney and liver tissues, no significant differences were detected in muscle tissues.

Elemental Residues and Geographic Comparisons

Mercury

Mercury is a nonessential element that occurs naturally in the environment and is released to the environment, through weathering of rocks and volcanic activity, and augmented by significant anthropogenic emissions. Mercury is highly volatile and natural and anthropogenic sources may be released into the atmosphere and deposited back into the snow pack or oceans (Kim and Fitzgerald 1986, Lindberg et al. 2002, Ebinghaus et al. 2002, and Skov et al. 2004). The major sources of Hg in Alaska are from south-central Eurasia and Eastern Europe (Garbarino et al. 2002) whereas North America and Europe are the main Hg sources for eastern Canada (Kahl, et al. 1989). Comparisons of Hg concentrations in ringed seals, in Canada (Wagemann et al. 1996),

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lake sediment cores in Alaska (Landers et al. 1995), and in Beluga teeth the Beaufort Sea

between the 16th century (pre-industrial) and the 1990s (post industrial) (AMAP 2004), indicate

that Hg concentrations are considerably higher today than before the beginning of the industrial

era. In addition to natural geological sources of mercury, there is evidence that Hg is continuing

to be released into the environment by human activities such as burning coal and fossil fuels to

meet increasing energy demands (Pacyna 1996, Dietz et al. 1998b, Asmund and Nielsen 2000,

AMAP 2004). Recent studies in Barrow have documented enhanced Hg deposition in the snow

pack from the transformation of gaseous elemental Hg to reactive gaseous Hg during the polar

sunrise in the spring (Lindberg et al. 2002). This enhanced loading of the Hg during the spring is

concurrent with the increase of biological activity in the spring (Lindberg et al. 2002). Mercury

can increase through bio-magnification and is known to be toxic at relatively low concentrations.

Despite the high concentrations of Hg often found in marine mammals relative to the terrestrial

mammals, most marine mammals have evolved effective biochemical mechanisms to tolerate the

high concentrations of Hg.

Two adult male polar bears from Barrow and one from Point Lay had the highest hepatic Hg

concentrations (> 36 ug/g dw or > 10 ug/g ww). The polar bear from Point Lay (western Alaska

– Chukchi Sea) was harvested near Kasegaluk Lagoon, an area Alaska Natives traditionally use

for hunting Beluga whales. Polar bears feeding on Beluga whales in this area could be exposed

to high levels of Hg, since beluga whales from Kasegaluk Lagoon had very high Hg

concentrations in liver (24.6-72.9 ug/g ww or 102-288 dw) (Zeisler et al. 1993). High Hg

concentrations were also recorded in the snow over the sea ice in Kasegaluk Lagoon (Garbarino

et al. 202).

Mercury levels were three times greater in hepatic tissues from polar bears in the Southern Beaufort Sea than from polar bears in the Chukchi/Bering Seas population. Although Hg concentrations were greater in polar bear kidney and liver tissues from the Southern Beaufort Sea population than the Chukchi/Bering Seas popualtion, Hg concentrations were not significantly different in the muscle tissues. Mean Hg concentrations in liver from polar bears collected in 1972 were about eight times higher in the Southern Beaufort Sea population ($\bar{x} = 38.08$ μg/g ww, n=15) than the Chukchi/Bering Seas population ($\bar{x} = 4.80$ μg/g ww, n=9) (Lentfer and Galster 1987) whereas our results were only three times higher ($\bar{x} = 9.93$ μg/g ww, n=11 vs. $\bar{x} = 3.23$ μg/g ww, n=20). Comparison of hepatic Hg concentrations from 1972 (Lentfer and Galster 1987) with our data suggests that the Hg concentrations in polar bears have decreased fourfold in the Southern Beaufort Sea whereas Hg concentrations from the Chukchi/Bering Seas have remained relatively constant at low levels. Whether these changes reflect a shift in feeding behavior or changes anthropogenic exposure is unknown. Prior to 1972, sport hunting caused population declines in both Alaskan populations. One hypothesis is that during the sport hunting era from the 1950s to the 1970s the distribution of polar bears that survived was further out on the pack ice as bears closer to the coastline and villages were more susceptible to being hunted. An increase of polar bears denning on land versus the pack ice (Amstrup and Gardner 1994) and the use of bowhead whale carcasses from subsistence harvested whales over the past 20 years suggest that sport hunting could have affected the polar bear distribution and accessibility to prey and carcass remains on the shore, shorefast ice, or sea ice near the coastline. Evidence for this is

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also supported by an analysis of the bioaccumulation factors (polar bear/ringed seal persistent organochlorine pollutants) in ringed seals and five adult male polar bears harvested near Barrow, Alaska which suggested that polar bears in northern Alaska were preying on marine mammals at lower trophic levels (i.e. bowhead whale, Pacific walrus, bearded seal) relative to polar bears from other locations in the Canadian Arctic (Kucklick et al. 2002).

Differences in the Hg concentrations between the two Alaskan populations could be due to differences in the source and turnover rate of marine and freshwater input to the Chukchi/Bering Seas and the Beaufort Sea, different natural deposits of Hg in marine sediments or ocean floor, and/or differences in the prey availability and utilization between the two areas. The water in the Chukchi/Bering Sea is more heavily influenced by sea water originating in the North Pacific Ocean and passing through the Bering Straits and freshwater runoff from western Alaska and eastern Russia (Li et al. 2002). The turnover rate in the Chukchi Sea, which is relatively shallow, is thought to be less than one year whereas the turnover rate for interior seas, such as the relatively deep Beaufort Sea, is around 10 years (McDonald 2000). Sources of fresh water for the waters in the Beaufort Sea are primarily from western Canada and northeastern Alaska.

Observed differences in mercury concentration could also be influenced by polar bear feeding ecology. Polar bears from the Chukchi/Bering Seas have greater access to bearded seals and Pacific walrus carcasses whereas ringed seals make up a greater proportion of the diet of polar bears from the Southern Beaufort Sea. Pacific walrus from the Chukchi/Bering Seas (Warburton and Seagars 1993) and Bowhead whales from the southern Beaufort Sea (Woshner et al. 2001a)

have lower Hg hepatic concentrations than ringed seals from the same area whereas bearded seals from the Amundsen Gulf in the eastern Beaufort Sea, Canada (Burns 1977, Smith and Armstrong 1978, Wagemann et al. 1996) and beluga whales from the Chukchi Sea and southern Beaufort Sea (*Delphinapterus leucas*) (Woshner et al. 2001a) have greater Hg concentrations in liver tissue than ringed seals (Woshner et al. 2001b) from the same area. This finding is consistent with the data that indicated Hg residues were often higher in benthic organisms than pelagic organisms in the same trophic level (Leonzio et al. 1981). Although high Hg concentrations in liver tissues were found in bearded seals in central (Smith and Armstrong 1978) and western Canadian Arctic (Wagemann et al. (1996), Hg concentrations in three bearded seals from Norton Sound, Nome, Alaska (i.e. Chukchi Sea) were relatively low ($\bar{x}$ =4.15 μg/g ww, range 1.40-9.43 μg/g ww, n=3), which suggests that Hg concentrations, even among benthic feeders, in the Chukchi/Bering Seas may be lower than the Southern Beaufort Sea. Differences in the feeding habits of ringed seals may also account for some of the differences in Hg concentrations between the two populations. Ringed seals in the Chukchi Sea were found to feed more heavily on fish than ringed seals from the Beaufort Sea which consume a higher proportion of amphipods and euphausids in their diet (Lowry et al. 1978, 1980). However, it seems unlikely that differential prey selection is the primary source of the higher Hg concentrations found in polar bears from the Southern Beaufort Sea population, as polar bears are known to feed on bowhead whale carcasses, which have very low Hg concentrations, and there is no indication that bearded seals, which may have high Hg concentrations, are eaten more frequently than ringed seals. More likely, the Beaufort Sea probably contains greater concentrations of natural and/or anthropogenic sources of Hg than either the Chukchi Sea or Bering Sea.

Mercury concentrations in muscle and liver tissue from polar bears in the Southern Beaufort Sea and the Chukchi/Bering Sea were about half the Hg concentrations found in polar bears from the eastern Beaufort Sea and Amundson Gulf region in western Canada (Norstrom et al. 1986, Braune et al.1991). Mean hepatic Hg concentrations from both Alaskan populations were similar to values reported for adult bears from Svalbard, Norway (Norheim et al 1992). Overall the lowest Hg concentrations of Hg have been found in Svalbard, Norway and the Chukchi Sea (Norstom et al. 1986, Lentfer and Galster 1987, Norheim et al. 1992). Polar bears from western Canadian Arctic and southwest Melville Island, Canada (Braune et al. 1991, Norstrom et al. 1986) and ringed seals from the western Canadian Arctic (Wagemann et al. 1996, Dietz et al. 1998b) have some of the highest known mercury concentrations.

Methylmercury (organic mercury) is more toxic than inorganic mercury and more readily bioaccumulated. Thus the percentage of organic mercury to the total mercury is more important biologically. Mercury poisoning is characterized by neurological impairment, compromised immune response, and damage to the central nervous system, liver, and kidney (WHO 1989, 1990, 1991). Also, fetuses and cubs may be particularly susceptible to methylmercury during development of the central nervous system (Dietz et al. 1998b). Although intake of as little as $4\mu g$ of Hg per kilogram of body weight in humans sensitive to methylmercury can elicit clinical signs of Hg poisoning (Clarkson 1987), evidence of Hg poisoning in wild marine mammals is rare. Rawson et al. (1993) found liver abnormalities in Atlantic bottlenose dolphins stranded associated with mercury levels of (61-443 ug/g ww). By comparison the range of hepatic

mercury levels in Alaskan polar bears was much lower (0.94-69.2 ug/g ww). Dietz et al. (1990) noted that sick marine mammals often have higher concentrations of methylmercury which suggests that these animals may no longer be able to efficiently detoxify methylmercury. Polar bears may become more susceptible to Hg poisoning if they become more stressed due to the effects of global climatic change. The low concentrations of methyl mercury and the ratio of organic mercury to total mercury in muscle tissue in our study (Alaska - 65%) was similar to the 62% found in polar bears from Greenland (Dietz et al.1990) and slightly lower than the 72.5% reported by Woshner et al. (2001b) for polar bears from the Southern Beaufort Sea population in Alaska. The highest concentrations of Hg were found in the kidneys and it has been suggested that kidneys are perhaps more capable of storing larger quantities of mercury after demethylation which in turn may account for the low concentrations found in the muscle tissues (Dietz et al. 1990, Woshner 2001b).

Exposure to elevated levels of Hg have been shown to cause neurophysiological problems, such as loss of coordination, loss of vision, reduced memory and language skills, and a lower attention span in humans from the Faeroe Islands (Grandjean et al. 1997). High levels of Hg and Cd have been associated with the consumption of marine mammals by Greenlanders from villages in the Disko Bay region (Bjerregaard and Hansen 2000, Johansen et al. 2000). Polar bear livers are not consumed by humans due to high and potentially toxic levels of Vitamin A and due to the association with livers, kidneys are likewise not consumed. However polar bear meat is consumed by Alaska Natives. Total mercury concentrations in ringed seal muscle tissue from Barrow, Alaska (Woshner et al. 2001b) and beluga whales from northern and western Alaska

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(Woshner et al. 2001a) were 5.1 and 26.9 times greater than concentrations found in polar bear muscle tissue in this study ($\bar{x}$ = 0.0432 μg/g ww, n=32), respectively. Although not high, Hg concentrations in polar bear muscle tissue were 2.5 times greater than muscle tissue of bowhead whales (Woshner 2001a). The polar bear data from this paper can be used as part of a larger and more comprehensive study to assess the dietary risk of metal contaminants to human consumers of marine mammals.

Selenium

The major source of Se in the environment is from the natural weathering of rock. Although an essential element at low concentrations it can be toxic at higher concentrations causing reproductive, congenital, and developmental and impairment of the central nervous system (Eisler 1985b, Dietz et al. 1998b). Se concentrations in the liver ($\bar{x}$ =14.39 μg/g dw, range 7.26-28.20 μg/g dw, n=11) and kidneys ($\bar{x}$ =29.15 μg/g dw, range 0.49-113.0 μg/g dw, n=11) of polar bears from the Southern Beaufort Sea were within the ranges reported by (Norstom et al. 1986, Braune et al. 1991, Wagemann et al. 1996 and Woshner et al. 2001b). Despite the high concentrations that would be toxic for terrestrial mammals such as cattle and dogs (Puls 1994), the polar bears appeared healthy when taken by the Alaska Native subsistence hunters. Given the high correlation between Hg and Se, it is not surprising that comparison of Se concentrations across geographical areas paralleled that of Hg. Selenium is thought to be able to detoxify Hg, particularly methyl mercury, by forming insoluble Hg-Se complexes in the liver (Nigro and Leonzio 1996, Dietz et al. 2000a). This mercury-selenium correlation has been reported for various vertebrate species, and there is evidence that seabirds and marine mammals have the

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metabolic ability to de-methylate organic mercury, converting it to less toxic inorganic mercury, and storing it in tissues at relatively high levels within metallothionein or selenium complexes, eventually excreting it (Andre et al. 1990, Becker 2000, Dietz et al 2000a). Selenium has also been shown as an antagonist to counteract the toxicity of other elements such as Cu, Cd, As, and Ag.

Mercury/Selenium Correlation

We found significant correlations between Hg and Se (kidney, r=0.94, p<0.0001, liver, r= 0.89, p<0.0001), Hg and Cd (kidney, r=0.72, p<0.0001, liver, r= 0.44, p<0.014), and Se with Cd (kidney, r=0.79, p<0.0001, liver, r= 0.53, p<0.0020) in kidney and liver tissues The high correlation between Hg and Se was similar to the combined results from male and female polar bears in the eastern area of the Southern Beaufort Sea population in Canada (Norstrom et al. 1986, Braune et al. 1991) and other marine mammals and birds (Koeman et al. 1975). Results from regression analyses of Hg to Se in liver tissue for the Southern Beaufort Sea (SBS) and the Chukchi/Bering Seas (CBS) populations in Alaska indicated that both had similar slopes and molar ratios (SBS= 1.03, CBS=0.99). The ratio of Hg to Se as indicated by the regression coefficients was close to one in liver tissues in polar bears from the Chukchi/Bering Seas and in liver and kidney tissues from the Southern Beaufort Sea and < 1 in kidney tissues from polar bears in the Chukchi/Bering Seas. A 1:1 molar ratio of Hg to Se and the high correlation coefficient (0.92) between Hg and Se in liver, and lack of evidence of Hg toxicity suggests that Se has a role in protecting against mercury toxicity (Koeman et al. 1975, Nigro and Leonzio 1996).

Although we did not analyzed MeHg in kidney and liver tissues, there seems to be enough Se present to detoxify the organic Hg. Mercury and Se contaminant levels in polar bears and seals should be closely monitored as there is potential that the ability of these species to detoxify increased Hg levels could become compromised, resulting in mercury poisoning (Dietz et al 1998a, Dietz et al. 2000a). It might be interesting to see if the Hg/Se ratios change if polar bears from the Alaskan populations are forced to spend more time on land, particularly during the summer, due to the loss of the sea ice habitat from global warming.

Copper

Copper concentrations in adult male polar bear livers and kidneys from the Southern Beaufort Sea were similar to those reported by Woshner et al. (2001b), well within the ranges reported for Canada by Norstrom et al. (1986), and higher than those in Norway (Norheim 1992). There were no significant differences between Cu concentrations in liver or kidneys between polar bears from the Southern Beaufort Sea and Chukchi Sea populations. The mean hepatic copper concentration although high ($\bar{x}$ =33.10 μg/g ww) was close to the range, 3-30 mg/kg ww, thought to represent the normal range of homeostatic control in marine mammals (Law et al. 1991). Although hepatic Cu concentrations in marine mammals are generally lower than 20 ug/g ww (Thompson 1990, Wagemann et al. 1996) individual fur seals and beluga whales had very high concentrations (Zeisler et al. 1993) that approached some of the levels reported for the leopard seal (Thompson 1990) and Ross seal (*Ommatophoca rossii*) (McGlurg 1984) in the Antarctic. The lack of clear geographical trends between Cu concentrations in marine mammals

in areas with known high copper concentrations (Thompson et al. 1990) suggests that diet is important in determining copper concentrations. For example, high Cu concentrations in squid, the principle prey of Ross seals, are thought to be the primary source of copper (McClurg 1984). Copper concentrations in liver tissue from adult male polar bears in the Southern Beaufort Sea ($\bar{x}$ = 33.61 μg/g ww, sd = 1.47, n=11) were about four times higher than ringed seals from the same area (Woshner et al. 2001b). Although very high concentrations of copper have been found in livers of northern fur seals from St Paul Island (17-56 μg/g ww) (Zeisler et al. 1993), and beluga whales from Point Lay, Alaska (16-41 ug/g/ww) (Zeisler et al. 1993, Becker et al. 1995, Woshner et al. 2001b), these prey items are not thought to be major food items in the polar bear diet. High copper concentrations may also be attributed to the common binding of Cu in addition to Cd and Zn to metallothionein (MTH). The significant correlations between Cd, Zn and Cu is most likely due to the common binding with MTH, a small molecular weigh metal-binding protein important for both homeostasis and the detoxification of various metals, especially Hg, Cd, Zn, and Cu (Lee et al. 1977). Copper concentrations typically decrease with age in marine mammal livers but this trend was not evident from our data. Woshner et al. (2001b) suggested that metallothionein may be more important for Hg detoxification in polar bears than Se and the increase of metallothionein would in turn account for the higher concentrations of Cu and Zn in polar bear livers. The high Cu concentrations in polar bear liver tissue and the higher concentrations of Hg and Pb in kidneys, compared to livers, are more typical of terrestrial mammals (Dietz et al 1995) than marine mammals and this may be related to the fairly recent evolution of polar bears from brown bears about 200,000 to 250,000 years ago (Talbot and Shields 1996).

Zinc

Zinc concentrations livers and kidneys were not significantly different between the two Alaskan polar bear populations. Zinc concentrations were highest in the muscle tissues, intermediate in liver tissues, and lowest in kidney tissues. The hepatic Zn concentrations of the adult male polar bears in this study ($\bar{x}$ = 50.22 μg/g ww) were well within the normal range of Zn concentrations (20-100 ug/g ww) required for homeostatic control in marine mammals. Zinc concentrations are within the same range as results previously reported for Canada, Svalbard, and Greenland (Norstrom, et al. 1986, Braune et al. 1991, Norheim et al. 1992, Dietz et al. 1995, Dietz et al. 2000b). The similarities of zinc concentrations between different populations are consistent with the bear's physiological ability to regulate and maintain the essential elements at the required concentrations. Norstrom et al. (1986) postulated that elevated concentrations of Cu in the liver could disturb the homeostatic control, resulting in high concentrations of both Cu and Zn.

Cadmium

Cadmium, a non-essential and potentially toxic element, occurs naturally and is a byproduct of incineration of fossil fuels, mining and smelting operations, and battery production (Eisler 1985a). Cadmium has a very long half-life (30 yrs in humans) and similar to Hg, shares the protective action of metallothionein proteins in the kidneys and liver against Cd toxicity (Dietz et al 1998a). Cadmium concentrations were highest in the kidney tissues, with much lower concentrations in the liver and muscle tissues. Concentrations of Cd were below the detection limit for many of the muscle samples. Cadmium concentrations in the kidney tissues from the

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Southern Beaufort Sea were similar to those reported by Woshner (2001b) (this study - $\bar{x}$ = 7.11 μg/g ww, sd = 2.84, n=11, Woshner et al. - $\bar{x}$ = 8.69 μg/g ww, sd = 5.05, n=24). Woshner et al (2001b) found that Cd concentrations in kidneys were significantly lower in polar bears than ringed seals from the Southern Beaufort Sea. Dietz et al (1995) also reported similar findings for polar bears in east central Greenland.

The mean Cd concentration in polar bear kidney samples from the Southern Beaufort Sea population ($\bar{x}$ =24.72 μg/g dw, range 6.25-47.40 μg/g dw, n=11) was approximately 20 times greater than the next highest tissue (liver). Similarly, mean Cd kidney concentrations in the Chukchi/Bering Seas population ($\bar{x}$ =16.52 μg/g dw, range 1.53-41.00 μg/g dw, n=21) were approximately 11 times greater than liver tissue concentrations. Cadmium concentrations in polar bear liver tissues were less than concentrations reported from eastern Canada (Norstrom et al. 1986, Braune et al. 1991) and below toxic threshold levels ($\approx$200 ug/g ww) associated with kidney damage in mammals (Law 1996, Dietz et al 1998a). Cadmium concentrations in polar bears from the Southern Beaufort Sea population and the Chukchi/Bering Seas population were approximately two times greater than concentrations found in polar bears in at Melville Island in western Canada (Norstrom et al 1986) but similar to concentrations found in the Eastern Beaufort Sea and Amundsen Gulf (Dietz et al. 1998b). The relatively low cadmium concentrations found in Alaska are most likely due to the geologic gradient of cadmium which decreases from east to west across the arctic regions in North America (Wagemann et al. 1996).

The effects of elevated cadmium concentrations in marine mammals are largely unknown (Deitz et al. 1998). Cadmium is a known carcinogen (Eisler, 1985a) and elevated Cd levels in marine birds and mammals is known to cause sever kidney damage, disruption of calcium and vitamin D metabolism, bone loss, depress growth, anemia, and affect metabolism and concentration of essential elements such as Fe, Zn, and Cu (Furnass 1996). The toxicity of Cd may be determined by the capacity of the kidneys and livers to synthesize metallothionein.

There is some evidence that in the absence of anthropogenic contamination the feeding habits of marine mammals may represent a major pathway for metal accumulation. For example there is evidence that Ross seals (McClurg 1984) and crabeater seals (*Lobodon carcinophagus*) (Szefer et al. 1993, Szefer et al. 1994) accumulated high concentrations of Cd from eating squid, which in turn have high Cd concentrations in their organs. Also, it is thought that Pacific walrus obtain a significant portion of the cadmium from eating certain species of mollusks (*Mya sp.*) (Miles and Hills 1994). The differences in the habitat, with respect to natural and anthropgenic sources of Cd, and diet determine the uptake of Cd and variation between the polar bear populations.

Lead

Although mean concentrations of Pb in muscle, kidneys, and livers were low overall there is potential for polar bears to accumulate high Pb concentrations. For example, high concentrations of Pb were detected in one bear from St Lawrence Island, Alaska (Liver - 16.9 μg/g dw, Kidney - 14.2 μg/g dw) and one male cub from Nuiqsut (Liver – 14.7 μg/g dw, Kidney – 10.0 μg/g dw). Concentrations above 15 μg/g dw have been associated with the clinical signs of lead toxicosis

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(Ma 1996). Although there is the possibility that these samples may have been contaminated by lead shot we believe that the Pb concentrations are accurate due to the extreme care taken during the sub-sampling, the normal range of values for other elements and tissues tested, and acceptable QA/QC results. Lead concentrations, which are normally higher in surface waters, were relatively low from the Beaufort Sea continental shelf in the western Arctic Ocean (<20-40 ng/l) (Muir et al. 1992, Pacyna et al. 1995) relative to concentrations found in surface waters from the North Atlantic and the Norwegian Sea (80-400 ng/l) (Mart and Nurnberg, 1984). There is potential for high concentrations of Pb to accumulate in marine mammals that feed on benthic organisms, such as pacific walrus and bearded seals as relatively high concentrations of lead have been found in benthic organisms (e.g. bivalve mollusks - *Mya truncata*), adjacent to the Nanisivik mine in Strathcona Sound, North Baffin Island, Canada (Muir et al 1992). Although Pb concentrations in ringed seals in the Canadian Arctic were generally higher than belugas or narwhals lead concentrations from liver, kidney, and muscle tissues of ringed seals collected near Barrow, Alaska were low ($\bar{x}$ = 0.04 μg/g ww, sd = 0.03, n=17, Woshner et al. 2001b). High lead concentrations in individual polar bears is probably a result of feeding near industrial sites (e.g. lead/zinc mines) that have extremely elevated lead concentrations from industrial waste, sewage outfall, or atmospheric emissions from smelters, smoke stacks, and exhaust (Pacyna and Keeler 1995, Pacyna 1996).

Vanadium

The concentration of V in kidney (Kruskal-Wallis test statistic = 3.8578, P=0.0495, df=1) was significantly greater in polar bears from the Chukchi/Bering Seas population ($\bar{x}$ =0.871 μg/g dw,

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range 0.25-3.2 μg/g dw, n=21) than the Southern Beaufort Sea population ($\bar{x}$ =0.439 μg/g dw, range 0.25-0.85 μg/g dw, n=11).

Vanadium was found to be higher in Alaskan cetacean and pinnipeds, relative to marine mammals from the eastern United States (Mackey et al. 1996). The highest concentrations of vanadium in adult male polar bears from Alaska were in the kidney tissues ($\bar{x}$ =0.688 μg/g dw, range 0.245-3.20 μg/g dw, n=32). The highest concentrations of vanadium reported in marine mammal tissues from the Arctic were from Pacific walrus liver tissues colleted in the Bering Sea ($\bar{x}$ =6.04 μg/g dw, range 0.96-14.55 μg/g dw, n=53). Similar high hepatic levels of vanadium were not however detected in polar bears from the Chukchi/Bering Seas ($\bar{x}$ =0.309 μg/g ww, n=20). Only 16% of the liver tissues sampled from adult male polar bears from Alaska were above the detection limit (Table 3). Hepatic vanadium concentrations in polar bears from Alaska ($\bar{x}$ =0.095 μg/g ww, n=32) were similar to those reported by Norstrom et al. 1986 ($\bar{x}$ =0.07 μg/g ww, n=32) and within the range of those reported (range 0.02-1.2 μg/g ww) for ringed seals (n=13), bearded seals (n=3), Bowhead whales (n=3), and beluga whales (n=15) from Alaska.(Mackey et al. 1996). Concentrations of vanadium in seals from industrial Northern Europe (Frank et al. 1992) were similar to those results from the Alaskan marine mammals (Mackey et al. 1996). The presence of vanadium in the oil from Prudhoe Bay (Hughes and Holba 1988) and natural oil seepages (Becker and Manen 1989) are potential sources of vanadium in the Arctic. The source of relatively high concentrations of vanadium in polar bears and other Alaskan marine mammals (Mackey et al. 1996) is currently not known.

Age Accumulation

The mean ages of adult polar bears sampled from the Southern Beaufort Sea ($\bar{x}$ = 12.0 years, range 5-21, n=7) and the Chukchi/Bering Seas ($\bar{x}$ =10.8 years, range 5-30, n=24) were not significantly different (t-test, P>0.670). Ages were determined from all bears sampled from the Chukchi/Bering Seas population and only seven bears from the Southern Beaufort Sea population. We found significant, but relatively weak, relationships between the following elements and age in kidney, liver, and muscle tissues pooled from both populations and age: mercury (r^2=0.13, p<0.05) and selenium (r^2=0.15, p<0.04) in muscle tissue; cadmium (r^2=0.14, p<0.05) in kidney tissue; iron in liver (r^2=0.40, p<0.0004) and muscle (r^2=0.14, p<0.05) tissue; and vanadium(r^2=0.13, p<0.06) in kidney tissue.

Comparisons between the elemental concentrations and age were also determined for each population separately. Significant relationships between the following elements and age in the Chukchi/Bering Seas population were: selenium (r^2=0.17, p<0.07) in muscle tissue; mercury in kidney (r^2=0.15, p<0.09) and muscle (r^2=0.17, p<0.06) tissue; cadmium (r^2=0.18, p<0.06) in kidney tissue; iron in liver (r^2=0.46, p<0.001) and muscle (r^2=0.17, p<0.06) tissue. In the Southern Beaufort Sea population significant relationships were found only between vanadium concentrations and age in kidney tissue (r^2=0.15, p<0.04) and arsenic concentrations and age in liver tissue (r^2=0.41, p<0.09). There were no significant correlations between concentrations of Pb, Mg, Mo, Mn, Zn, Mehg, Cu and age in any tissue. The lack of more significant relationships

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between element concentrations, particularly Cd and Hg, and age for polar bear tissues from the Southern Beaufort Sea is most likely due to the small sample size and lack of complete age information from the Southern Beaufort Sea population.

Although concentrations of Cd, Hg, and Se in polar bear liver tissues have been found to be significantly correlated with age (Norstrom et al. 1986, Braune et al. 1991, Dietz et al. 1995) our results did not show a similar pattern. Dietz (2000) found significant correlations of cadmium with kidney, liver, and muscle tissues. Mercury was only weakly correlated with age in kidney tissues from Alaskan polar bears. The lack of many old and young adult bears in our study may also contribute the lack of correlations of heavy metals with age in this study. Polar bears in our study ranged from 5-30 years with the majority of individuals between 9 and 17 years (n=15).

MANAGEMENT RECOMMENDATIONS

This study presents additional information on selected essential and non-essential elements in adult polar bears from Alaska. Some of the highest Hg levels in the Arctic are from western Canada and the eastern Beaufort Sea, as indicated by the high Hg concentrations relative to Se concentrations, in polar bears, ringed seals, and bearded seals. Based on the polar bear data from this study mercury concentrations generally decreased in the order Western Canada > eastern Beaufort Sea (Canada, Alaska) > Southern Beaufort Sea (Alaska) > Chukchi/Bering Seas (Alaska/Russia). As mercury concentrations continue to increase in the Arctic (Asmund and Nielsen 2000), continued effort should be taken to monitor marine mammals species, including

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polar bears and the ice (*Phoca sp.*) seals, to see if they can continue to be able to detoxify the increased mercury burdens. Apparently enough Se is currently available in environment for polar bears to detoxify the more toxic methylmercury, thus preventing Hg poisoning. Thus Se concentrations and the other elements discussed in this study, which may have synergistic effects, should also continue to be monitored. The sample sizes for this study were relatively small and focused on only adult males. To look at temporal trends and variation in the sex, age, reproductive status, habitat, location, diet, and nutritional status of polar bears we need to increase our sample size and include all the sex and age cohorts of both polar bears and their prey. For example very little information is known about bearded seals in northern and western Alaska and more extensive contaminant information is required for ringed seals, the two primary prey species of polar bears. Aside from documenting concentrations of toxic elements more research needs to be conducted to look at the effects and relationship of these toxic elements to polar bear physiology, disease, and population dynamics. Additional individual information that should be collected along with the polar bear contaminant data should be basic biological information such as accurate location information, weight, length, age, general health assessment and with more time and money additional data could be collected to examine hormone levels, P450 enzymes, blood chemistry, genetics, as well as histology samples. In trying to elucidate why there were differences in contaminant loading between the two Alaskan polar bear populations, it became apparent that more information was needed on the relative importance of various prey items in the polar bear diet. One approach would be to collect information on fatty acids, contaminants, and combine this with an isotopic analysis to look at marine mammal trophic ecology (Kelly 2000). (e.g. what proportion of the polar bear diet comes from feeding on

marine mammals below ringed seals in the food web?). In addition detailed information on polar bear habitat use, contaminant sources, and habitat quality would assist in evaluating the impacts and potential solutions to environmental contamination problems. Contaminant studies are generally very expensive to conduct so maximum use should be made of long-term cryogenic archival storage facilities for banking specimens for future use.

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Table 1. Individual animal tissue recovery information from polar bear tissues sampled in Alaska for trace elements.

Table 2. Geometric mean concentrations ± SD and lower and upper 95% confidence intervals (ug/g dry weight) of trace elements in liver, kidney, and muscle of adult male polar bears in Alaska.

Table 3. Elemental mean concentrations (ug/g dry weight) in liver, kidney, and muscle tissues of adult male polar bears in Southern Beaufort Sea and Chukchi/Bering Seas populations. Geometric means were only calculated for those analytes where >50 of the measured values were above the detection limit (values below the detection limit defaulted to 0.5 the detection limit for analyses. Only ranges are presented for those analytes where >50% of the samples were below the detection limit. N = number of samples that passed QA/QC. % = % of samples that had element concentrations above the detection limits.

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Table 1. Individual animal tissue recovery information from polar bear tissues sampled in Alaska for trace elements.

Sample No.	Age	Sex	Date Collected	Location[a]	Latitude/Longitude	ECDMS Catalogue #	Tissue Type	Analysis[b]	%Moisture
12216AK	Adult(21)	M	21-Oct-93	Barrow	71N 17' 30"/156W 47' 15"	7010024	Kidney	E	75.1
12216AL	Adult(21)	M	21-Oct-93	Barrow	71N 17' 30"/156W 47' 15"	7010024	Liver	E	69.9
MM11K540	Adult	M	19-Mar-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Kidney	E	77.8
MM11L539	Adult	M	19-Mar-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Liver	E	72.0
PB196MA	Adult	M	19-Mar-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Muscle	E	75.1
PB196MB	Adult	M	19-Mar-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Muscle	MeHg	75.1
MM11K543	Adult	M	21-Mar-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Kidney	E	72.0
MM11L542	Adult	M	21-Mar-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Liver	E	69.5
PB296MA	Adult	M	21-Mar-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Muscle	E	76.6
PB296MB	Adult	M	21-Mar-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Muscle	MeHg	76.6
MM11K575	Adult	M	30-Dec-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Kidney	E	70.4
MM11L574	Adult	M	30-Dec-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Liver	E	70.2
PB1996MA	Adult	M	30-Dec-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Muscle	E	74.0
PB1996MB	Adult	M	30-Dec-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Muscle	MeHg	74.0
MM11K572	Adult (12)	M	20-Nov-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Kidney	E	74.8
MM11L571	Adult (12)	M	20-Nov-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Liver	E	70.1
PB1896MA	Adult (12)	M	20-Nov-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Muscle	E	74.7
PB1896MB	Adult (12)	M	20-Nov-96	Barrow	71N 17' 30"/156W 47' 15"	7020042	Muscle	MeHg	74.7
MM12K645	Adult(19)	M	24-May-97	Barrow	71N 17' 30"/156W 47' 15"	7020042	Kidney	E	79.9
MM12L644	Adult(19)	M	24-May-97	Barrow	71N 17' 30"/156W 47' 15"	7020042	Liver	E	69.0
970012K	Adult(16)	M	3-Dec-97	Barrow	71N 17' 30"/156W 47' 15"	7020050	Kidney	E	74.8
970012LA	Adult(16)	M	3-Dec-97	Barrow	71N 17' 30"/156W 47' 15"	7020050	Liver	E	64.8
970012MA	Adult(16)	M	3-Dec-97	Barrow	71N 17' 30"/156W 47' 15"	7020050	Muscle	E	75.8
970012MB	Adult(16)	M	3-Dec-97	Barrow	71N 17' 30"/156W 47' 15"	7020050	Muscle	MeHg	75.8
692-033K	Adult(16)	M	6-Dec-97	Barrow	71N 17' 30"/156W 47' 15"	7020050	Kidney	E	76.6

ID	Age	Sex	Date	Location	Coordinates	Number	Tissue	Analyte	Value
692-033L	Adult(16)	M	6-Dec-97	Barrow	71N 17' 30"/156W 47' 15"	7020050	Liver	E	67.0
692-033MA	Adult(16)	M	6-Dec-97	Barrow	71N 17' 30"/156W 47' 15"	7020050	Muscle	E	72.7
692-033MC	Adult(16)	M	6-Dec-97	Barrow	71N 17' 30"/156W 47' 15"	7020050	Muscle	MeHg	72.7
990083KC	Adult(5)	M	27-Nov-99	Barrow	71N 17' 30"/156W 47' 15"	7020061	Kidney	E	67.10
990083LC	Adult(5)	M	27-Nov-99	Barrow	71N 17' 30"/156W 47' 15"	7020061	Liver	E	64.10
692050MA	Adult(5)	M	27-Nov-99	Barrow	71N 17' 30"/156W 47' 15"	7020061	Muscle	E	71.60
990083MC	Adult(5)	M	27-Nov-99	Barrow	71N 17' 30"/156W 47' 15"	7020061	Muscle	MeHg	67.10
2367KA	Adult(14)	M	8-May-00	Barrow	71N 17' 30"/156W 47' 15"	7020061	Kidney	E	70.30
2367LA	Adult(14)	M	8-May-00	Barrow	71N 17' 30"/156W 47' 15"	7020061	Liver	E	62.10
2367MA	Adult(14)	M	8-May-00	Barrow	71N 17' 30"/156W 47' 15"	7020061	Muscle	E	75.00
2367MB	Adult(14)	M	8-May-00	Barrow	71N 17' 30"/156W 47' 15"	7020061	Muscle	MeHg	75.00
970201KC	Adult(13)	M	19-Sep-97	Nuiqsut	70N 24' 00"/151W 07' 00"	7020050	Kidney	E	71.30
970201LA	Adult(13)	M	19-Sep-97	Nuiqsut	70N 24' 00"/151W 07' 00"	7020050	Liver	E	66.30
970201MA	Adult(13)	M	19-Sep-97	Nuiqsut	70N 24' 00"/151W 07' 00"	7020050	Muscle	E	74.40
970201MB	Adult(13)	M	19-Sep-97	Nuiqsut	70N 24' 00"/151W 07' 00"	7020050	Muscle	MeHg	74.40
980562KA	Adult(14)	M	19-Apr-98	L. Diomede	65N 46' 15"/168W 54' 00"	7020050	Kidney	E	77.9
980562LA	Adult(14)	M	19-Apr-98	L. Diomede	65N 46' 15"/168W 54' 00"	7020050	Liver	E	71.5
2368KB	Adult	M	29-Apr-00	L. Diomede	65N 46' 15"/168W 54' 00"	7020061	Kidney	E	74.80
2368LC	Adult	M	29-Apr-00	L. Diomede	65N 46' 15"/168W 54' 00"	7020061	Liver	E	60.20
980341KA	Adult(17)	M	28-Feb-98	Point Lay	69N 45' 45"/163W 30' 00"	702050	Kidney	E	71.0
980341LA	Adult(17)	M	28-Feb-98	Point Lay	69N 45' 45"/163W 30' 00"	702050	Liver	E	66.9
980341MA	Adult(17)	M	28-Feb-98	Point Lay	69N 45' 45"/163W 30' 00"	702050	Muscle	E	75.4
980341MB	Adult(17)	M	28-Feb-98	Point Lay	69N 45' 45"/163W 30' 00"	702050	Muscle	MeHg	75.4
010130MA	Adult(6)	M	18-Apr-01	Kivalina	67N 58' 30"/164W 32' 30"	7050001	Muscle	E	76.00
010130MB	Adult(6)	M	18-Apr-01	Kivalina	67N 58' 30"/164W 32' 30"	7050001	Muscle	MeHg	76.00
940090KA	Adult(30)	M	25-Apr-94	Gambell	63N 47' 00"/171W 45' 00"	7010024	Kidney	E	68.9
940090LA	Adult(30)	M	25-Apr-94	Gambell	63N 47' 00"/171W 45' 00"	7010024	Liver	E	64.4
97106K	Adult(16)	M	2-Mar-97	Gambell	63N 47' 00"/171W 45' 00"	7020042	Kidney	E	79.5
970106L	Adult(16)	M	2-Mar-97	Gambell	63N 47' 00"/171W 45' 00"	7020042	Liver	E	65.4

Sample ID	Age class	Sex	Date	Location	Coordinates	Station	Tissue	Analyte	Value
970106MA	Adult(16)	M	2-Mar-97	Gambell	63N 47' 00"/171W 45' 00"	7020042	Muscle	E	76.2
970106MB	Adult(16)	M	2-Mar-97	Gambell	63N 47' 00"/171W 45' 00"	7020042	Muscle	MeHg	76.2
970108K	Adult(8)	M	9-Mar-97	Gambell	63N 47' 00"/171W 45' 00"	7020042	Kidney	E	74.3
970108L	Adult(8)	M	9-Mar-97	Gambell	63N 47' 00"/171W 45' 00"	7020042	Liver	E	66.7
970108MA	Adult(8)	M	9-Mar-97	Gambell	63N 47' 00"/171W 45' 00"	7020042	Muscle	E	76.5
970108MB	Adult(8)	M	9-Mar-97	Gambell	63N 47' 00"/171W 45' 00"	7020042	Muscle	MeHg	76.5
970112K	Adult(16)	M	27-Mar-97	Gambell	63N 47' 00"/171W 45' 00"	7020042	Kidney	E	65.8
970112L	Adult(16)	M	27-Mar-97	Gambell	63N 47' 00"/171W 45' 00"	7020042	Liver	E	80.7
970112MA	Adult(16)	M	27-Mar-97	Gambell	63N 47' 00"/171W 45' 00"	7020042	Muscle	E	75.3
970112MB	Adult(16)	M	27-Mar-97	Gambell	63N 47' 00"/171W 45' 00"	7020042	Muscle	MeHg	75.3
990122MA	Adult(6)	M	3-May-99	Gambell	63N 47' 00"/171W 45' 00"	7020056	Muscle	E	74.2
990122MB	Adult(6)	M	3-May-99	Gambell	63N 47' 00"/171W 45' 00"	7020056	Muscle	MeHg	74.2
990127KB	Adult(6)	M	21-May-99	Gambell	63N 47' 00"/171W 45' 00"	7020056	Kidney	E	58.8
990127LC	Adult(6)	M	21-May-99	Gambell	63N 47' 00"/171W 45' 00"	7020056	Liver	E	63.4
990127MA	Adult(6)	M	21-May-99	Gambell	63N 47' 00"/171W 45' 00"	7020056	Muscle	E	74.9
990127MB	Adult(6)	M	21-May-99	Gambell	63N 47' 00"/171W 45' 00"	7020056	Muscle	MeHg	74.9
990658KA	Adult(10)	M	15-Jun-99	Gambell	63N 47' 00"/171W 45' 00"	7020056	Kidney	E	67.0
990658LA	Adult(10)	M	15-Jun-99	Gambell	63N 47' 00"/171W 45' 00"	7020056	Liver	E	68.3
990658MA	Adult(10)	M	15-Jun-99	Gambell	63N 47' 00"/171W 45' 00"	7020056	Muscle	E	74.3
990658MB	Adult(10)	M	15-Jun-99	Gambell	63N 47' 00"/171W 45' 00"	7020056	Muscle	MeHg	74.3
944090AK	Adult(30)	M	25-Apr-94	Gambell	63N 47' 00"/171W 45' 00"	7010024	Kidney	E	76.4
944090AL	Adult(30)	M	25-Apr-94	Gambell	63N 47' 00"/171W 45' 00"	7010024	Liver	E	64.4
990112KA	Adult(5)	M	5-Apr-99	Gambell	63N 47' 00"/171W 45' 00"	7020056	Kidney	E	66.50
970112LA	Adult(5)	M	5-Apr-99	Gambell	63N 47' 00"/171W 45' 00"	7020056	Liver	E	67.00
970112MA	Adult(5)	M	5-Apr-99	Gambell	63N 47' 00"/171W 45' 00"	7020056	Muscle	E	74.40
970112MB	Adult(5)	M	5-Apr-99	Gambell	63N 47' 00"/171W 45' 00"	7020056	Muscle	MeHg	74.40
010451KD	Adult(9)	M	6-Jan-02	Gambell	63N 47' 00"/171W 45' 00"	7050002	Kidney	E	68.30
010451LC	Adult(9)	M	6-Jan-02	Gambell	63N 47' 00"/171W 45' 00"	7050002	Liver	E	68.50
010451MA	Adult(9)	M	6-Jan-02	Gambell	63N 47' 00"/171W 45' 00"	7050002	Muscle	E	74.50
010451MB	Adult(9)	M	6-Jan-02	Gambell	63N 47' 00"/171W 45' 00"	7050002	Muscle	MeHg	74.50

Sample ID	Age (class)	Sex	Date	Location	Coordinates	Code	Tissue	Analyte	Value
020436KD	Adult(11)	M	5-Mar-02	Gambell	63N 47' 00"/171W 45' 00"	7050002	Kidney	E	72.10
020436LD	Adult(11)	M	5-Mar-02	Gambell	63N 47' 00"/171W 45' 00"	7050002	Liver	E	65.10
020436MA	Adult(11)	M	5-Mar-02	Gambell	63N 47' 00"/171W 45' 00"	7050002	Muscle	E	75.20
020436MB	Adult(11)	M	5-Mar-02	Gambell	63N 47' 00"/171W 45' 00"	7050002	Muscle	MeHg	75.20
020438KC	Adult(13)	M	7-Mar-02	Gambell	63N 47' 00"/171W 45' 00"	7050002	Kidney	E	72.50
020438LA	Adult(13)	M	7-Mar-02	Gambell	63N 47' 00"/171W 45' 00"	7050002	Liver	E	66.40
020438MA	Adult(13)	M	7-Mar-02	Gambell	63N 47' 00"/171W 45' 00"	7050002	Muscle	E	75.50
020438MB	Adult(13)	M	7-Mar-02	Gambell	63N 47' 00"/171W 45' 00"	7050002	Muscle	MeHg	75.50
960512K	Adult(5)	M	16-Mar-97	Savoonga	63N 42' 00"/170W 29' 00"	7020042	Kidney	E	77.1
960512MA	Adult(5)	M	16-Mar-97	Savoonga	63N 42' 00"/170W 29' 00"	7020042	Muscle	E	78.3
960512MB	Adult(5)	M	16-Mar-97	Savoonga	63N 42' 00"/170W 29' 00"	7020042	Muscle	MeHg	78.3
980367MA	Adult(21)	M	3-Mar-98	Savoonga	63N 42' 00"/170W 29' 00"	7020050	Muscle	E	75.3
980367MB	Adult(21)	M	3-Mar-98	Savoonga	63N 42' 00"/170W 29' 00"	7020050	Muscle	MeHg	75.4
980369KA	Adult(22)	M	15-Feb-98	Savoonga	63N 42' 00"/170W 29' 00"	7020050	Kidney	E	67.9
980369LA	Adult(22)	M	15-Feb-98	Savoonga	63N 42' 00"/170W 29' 00"	7020050	Liver	E	65.6
980369M	Adult(22)	M	15-Feb-98	Savoonga	63N 42' 00"/170W 29' 00"	7020050	Muscle	E	76.3
980367MB	Adult(22)	M	15-Feb-98	Savoonga	63N 42' 00"/170W 29' 00"	7020050	Muscle	MeHg	76.7
990594KA	Adult(19)	M	1-May-99	Savoonga	63N 42' 00"/170W 29' 00"	7020056	Kidney	E	77.4
990594LA	Adult(19)	M	1-May-99	Savoonga	63N 42' 00"/170W 29' 00"	7020056	Liver	E	71.4
990594MA	Adult(19)	M	1-May-99	Savoonga	63N 42' 00"/170W 29' 00"	7020056	Muscle	E	76.6
990594MB	Adult(19)	M	1-May-99	Savoonga	63N 42' 00"/170W 29' 00"	7020056	Muscle	MeHg	76.6
020318KA	Adult (16)	M	8-Feb-02	Savoonga	63N 42' 00"/170W 29' 00"	7050002	Kidney	E	75.20
020318LA	Adult(16)	M	8-Feb-02	Savoonga	63N 42' 00"/170W 29' 00"	7050002	Liver	E	64.60
020318MA	Adult(16)	M	8-Feb-02	Savoonga	63N 42' 00"/170W 29' 00"	7050002	Muscle	E	75.00
020318MB	Adult(16)	M	8-Feb-02	Savoonga	63N 42' 00"/170W 29' 00"	7050002	Muscle	MeHg	75.00
010550KC	Adult (9)	M	9-Mar-02	Savoonga	63N 42' 00"/170W 29' 00"	7050002	Kidney	E	74.40
010550LB	Adult(9)	M	9-Mar-02	Savoonga	63N 42' 00"/170W 29' 00"	7050002	Liver	E	70.40
010550MA	Adult(9)	M	9-Mar-02	Savoonga	63N 42' 00"/170W 29' 00"	7050002	Muscle	E	72.90
010550MB	Adult(9)	M	9-Mar-02	Savoonga	63N 42' 00"/170W 29' 00"	7050002	Muscle	MeHg	72.90

2629KD	Adult(18)	M	31-Mar-02	Savoonga	63N 42' 00"/170W 29' 00"	7050002	Kidney	E	69.50
2629LE	Adult(18)	M	31-Mar-02	Savoonga	63N 42' 00"/170W 29' 00"	7050002	Liver	E	66.10
2629MA	Adult(18)	M	31-Mar-02	Savoonga	63N 42' 00"/170W 29' 00"	7050002	Muscle	E	73.50
2629MB	Adult(18)	M	31-Mar-02	Savoonga	63N 42' 00"/170W 29' 00"	7050002	Muscle	MeHg	73.50
990600KA	Adult(5)	M	28-Feb-99	Savoonga	63N 42' 00"/170W 29' 00"	7020056	Kidney	E	68.20
990600LA	Adult(5)	M	28-Feb-99	Savoonga	63N 42' 00"/170W 29' 00"	7020056	Liver	E	68.00
990600MA	Adult(5)	M	28-Feb-99	Savoonga	63N 42' 00"/170W 29' 00"	7020056	Muscle	E	75.10
990600MB	Adult(5)	M	28-Feb-99	Savoonga	63N 42' 00"/170W 29' 00"	7020056	Muscle	MeHg	75.10
980390KA	Adult(5)	M	12-Apr-98	Shishmaref	66N 15' 00"/166W 04' 00"	7020050	Kidney	E	71.50
980390LA	Adult(5)	M	12-Apr-98	Shishmaref	66N 15' 00"/166W 04' 00"	7020050	Liver	E	71.00
980390MA	Adult(5)	M	12-Apr-98	Shishmaref	66N 15' 00"/166W 04' 00"	7020050	Muscle	E	76.00
980390MB	Adult(5)	M	12-Apr-98	Shishmaref	66N 15' 00"/166W 04' 00"	7020050	Muscle	MeHg	75.90

[a] Bears taken from the villages of Barrow and Nuiqsut are from the Southern Beaufort Sea population. Bears taken from Little Diomede, Point Lay, Kivalina, Gambell, and Savoonga are from Chukchi/Bering Seas Population.

[b] E = Element analysis   MeHg = Methylmercury

Table 2. Geometric mean concentrations ± SD and lower and upper 95% confidence intervals (ug/g dry weight) of selected trace elements in liver (L), kidney(K), and muscle(M) of adult male polar bears in Alaska. Sample sizes by tissue type for those elements which had greater than 10% and fewer than 90% detections. Cd (M n=13), Cr (K n=17, L n=11, M n=19), Mo (M n=3), Pb (K n=20, L n=11, M n=6), Sr (L n=16, M n=14), V (K n=25, L n=5, M n=2)

Element	Liver (n=33)			Kidney (n=32)			Muscle (n=29)		
	Mean	SD	95%CI	Mean	SD	95%CI	Mean	SD	95%CI
Ag (n=8)	0.385	0.19	(0.13-1.12)						
Al	2.27	1.52	(0.99-5.23)	3.31	2.33	(0.63-17.47)	2.72	2.20	(0.58-12.77)
Cd	1.34	2.57	(0.21-8.57)	18.97	1.98	(4.96-72.62)	0.11	3.54	(0.01-1.29)
Cr	0.57	3.45	(0.05-6.41)	1.59	6.68	(0.38-66.03)	1.47	6.35	(0.04-55.04)
Cu	103.05	1.88	(29.74-357.09)	15.12	1.67	(5.52-41.45)	5.86	1.81	(1.83-18.78)
Fe	395.77	1.97	(104.50-1498.84)	256.44	1.57	(105.49-623.05)	203.09	2.04	(50.30-819.96)
Hg	14.99	2.29	(2.96-75.87)	33.32	2.37	(6.14-152.00)	0.17	2.46	(0.029-1.01)
MeHg							0.11	0.15	(0.029-1.05)
Mg	560.20	1.15	(424.69-738.94)	454.36	1.27	(283.18-729.04)	871.37	1.16	(647.70-1172.27)
Mn	11.61	1.37	(6.24-21.64)	4.17	1.39	(2.17-8.01)	0.94	2.47	(0.16-5.52)
Mo	1.63	1.18	(1.18-2.24)	1.07	1.57	(0.44-2.60)	0.29	1.51	(0.02-4.45)
Pb	0.68	3.17	(0.10-6.52)	1.15	3.49	(0.07-13.39)	0.27	4.15	(0.02-4.45)

Se	8.71	1.98	(2.29-33.11)	19.60	1.82	(6.05-63.50)	2.34	1.45	(1.12-4.88)
Sr	0.18	2.19	(0.04-0.86)	0.86	1.96	(0.23-3.22)	0.18	3.03	(0.02-1.55)
V	0.295	1.46	(0.14-0.62)	0.688	1.90	(0.19-2.43)	0.267	1.68	(0.01-0.74)
Zn	156.35	1.33	(88.81-275.25)	94.52	1.46	(44.74-199.68)	208.40	1.23	(139.85-310.53)

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Table 3. Elemental mean concentrations (ug/g dry weight) in liver, kidney, and muscle tissues of adult male polar bears in Southern Beaufort Sea and Chukchi/Bering Seas populations. Geometric means were only calculated for those analytes where >50% of the measured values were above the detection limit (values below the detection limit defaulted to 0.5 the detection limit for analyses). Only ranges are presented for those analytes where >50% of the samples were below the detection limit. N = number of samples that passed QA/QC. % = % of samples that had element concentrations above the detection limits.

Kidney

Element	Southern Beaufort Sea			Chukchi/Bering Seas			Alaska		
	N	%	Mean (Range)	N	%	Mean (Range)	N	%	Mean (Range)
Ag	-	-	-	-	-	-	-	-	-
Al	11	64%	5.17 (2.51-11.10)	21	43%	- (0.505-9.38)	32	50%	3.31 (0.505-11.10)
As	11	0.0%	-	21	19%	- (0.201-0.690)	32	12.5%	- (0.196-0.690)
B	11	9%	- (<0.516)	21	4.7%	- (<0.516-0.746)	32	6.25%	- (<0.516-0.746)
Ba	11	0.0%	-	21	4.7%	- (<0.104-0.670)	32	3.12%	- (<0.104-0.670)
Be	11	0.0%	-	21	4.7%	- (<0.617-5.82)	32	50%	3.31 (0.617-5.82)
Cd	11	100%	24.72 (6.25-47.40)	21	100%	16.52 (1.53-41.00)	32	100%	18.97 (1.53-47.40)

	n	%	Value (range)	n	%	Value (range)	n	%	Value (range)
Cr	11	54%	1.44 (0.248-53.30)	21	52%	1.68 (0.251-23.40)	32	53%	1.59 (0.248-53.30)
Cu	11	100%	14.36 (8.02-28.50)	21	100%	15.54 (8.18-161.00)	32	100%	15.12 (8.02-161.00)
Fe	11	100%	272.24 (96.3-694.0)	21	100%	248.54 (95.1-450.0)	32	100%	256.44 (95.1-694.0)
Hg	11	100%	63.95 (23.20-152.0)	21	100%	23.68 (5.01-73.30)	32	50%	33.32 (5.01-152.0)
MeHg	-	-	(2.51-11.10)	-	-	(0.505-9.38)	-	-	(0.505-11.10)
Mg	11	100%	409.51 (208.0-574.0)	21	100%	479.78 (295.0-650.0)	32	100%	454.36 (208.0-697.0)
Mn	11	100%	3.64 (2.02-8.73)	21	100%	4.48 (2.13-6.50)	32	100%	4.17 (2.02-8.73)
Mo	11	91%	0.983 (0.255-1.79)	21	95%	1.12 (0.256-1.78)	32	93%	1.07 (0.255-1.79)
Ni	11	18%	- (<0.614-0.914)	21	29%	- (<0.617-5.82)	32	29%	- (<0.617-5.82)
Pb	11	64%	1.54 (0.491-113.0)	21	62%	0.987 (0.256-14.20)	32	63%	1.15 (0.256-113.0)
Se	11	100%	29.15	21	100%	15.92	32	100%	19.60

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Element	Southern Beaufort Sea			Chukchi/Bering Seas			Alaska		
	N	%	Mean (Range)	N	%	Mean (Range)	N	%	Mean (Range)
			(12.40-56.60)			(4.33-32.70)			(4.33-56.60)
Sr	11	100%	0.838 (0.302-1.68)	21	95%	0.880 (0.100-2.63)	32	97%	0.865 (0.100-2.63)
V	11	55%	0.439 (0.245-0.852)	21	90%	0.871 (0.250-3.20)	32	78%	0.688 (0.25-3.20)
Zn	11	100%	98.55 (34.8-223.0)	21	100%	92.47 (48.2-143)	32	100%	94.52 (34.8-223.0)

Liver

Element	Southern Beaufort Sea			Chukchi/Bering Seas			Alaska		
	N	%	Mean (Range)	N	%	Mean (Range)	N	%	Mean (Range)
Ag	2	100%	0.194 (0.138-0.273)	6	100%	0.484 (0.277-0.722)	8	100%	0.385 (0.138-0.722)
Al	11	18%	- (2.50-2.56)	20	30%	- (0.520-5.45)	31	25%	- (0.520-5.45)
As	11	0.0%	-	20	19%	- (0.205-0.690)	31	12.5%	- (0.196-0.690)
B	11	18%	- (<0.205-5.95)	20	10%	- (<0.206-0.942)	31	13%	- (<0.206-5.95)
Ba	11	0.0%	-	20	0.0%	-	31	0.0%	-

Element	n	%	Value (range)	n	%	Value (range)	n	%	Value (range)
Be	11	0.0%	-	20	0.0%	-	31	0.0%	-
Cd	11	100%	1.21 (0.416-2.33)	20	100%	1.42 (0.533-58.20)	31	100%	1.34 (0.416-58.2)
Cr	11	36%	0.746 (0.250-7.56)	20	35%	0.486 (0.249-7.09)	31	35%	0.566 (0.249-7.56)
Cu	11	100%	104.59 (53.20-202.00)	20	100%	102.20 (14.10-282.00)	31	100%	103.05 (14.10-282.00)
Fe	11	100%	583.17 (184.0-1384.0)	20	100%	319.78 (137.0-1521.0)	31	100%	395.77 (137.0-1521.0)
Hg	11	100%	30.91 (14.7-69.2)	20	100%	10.07 (2.72-66.60)	31	100%	14.99 (2.72-69.20)
MeHg	-	-	-	5	100%	1.89 (1.81-2.01)	5	100%	1.89 (1.81-2.01)
Mg	11	100%	577.87 (461.0-697.0)	20	100%	550.71 (370.0-659.0)	31	100%	454.36 (208.0-697.0)
Mn	11	100%	12.42 (9.28-15.0)	20	100%	11.19 (4.27-19.0)	31	100%	11.61 (4.27-19.0)
Mo	11	100%	1.61 (1.31-2.15)	20	100%	1.64 (1.16-2.57)	31	100%	1.63 (1.16-2.57)
Ni	11	18%	- (<0.614-6.54)	20	10%	- (<0.598-2.83)	31	13%	- (<0.614-6.54)

Element	Southern Beaufort Sea N	%	Mean (Range)	Chukchi/Bering Seas N	%	Mean (Range)	Alaska N	%	Mean (Range)
Pb	11	18%	- (0.50-3.24)	20	45%	- (0.114-16.9)	31	35%	- (0.114-16.9)
Se	11	100%	14.39 (7.26-28.20)	20	100%	6.60 (2.47-41.60)	31	100%	8.71 (2.47-41.60)
Sr	11	18%	- (0.100-0.33)	20	65%	0.217 (0.100-2.37)	31	52%	0.184 (0.100-2.37)
V	11	9%	0.272 (0.25-0.59)	20	20%	0.309 (0.247-1.05)	31	16%	0.295 (0.25-1.05)
Zn	11	100%	164.92 (101.0-289.0)	20	100%	151.82 (74.3-282.0)	31	100%	156.35 (74.3-289.0)

Muscle

Element	Southern Beaufort Sea N	%	Mean (Range)	Chukchi/Bering Seas N	%	Mean (Range)	Alaska N	%	Mean (Range)
Ag	-	-	-	-	-	-	-	-	-
Al	9	33%	- (2.49-11.90)	21	33%	- (0.505-11.0)	30	33%	- (0.505-11.90)
As	9	0.0%	-	21	14%	- (0.250-21.9)	30	10%	- (0.250-21.9)

	n	%	value (range)	n	%	value (range)	n	%	value (range)
B	9	0.0%	-	21	9%	- (<0.207-5.13)	30	6.6%	- (<0.207-5.13)
Ba	9	0.0%	-	21	3.3%	- (<0.984-1.20)	30	0.0%	- (<0.984-1.20)
Be	9	0.0%	-	21	0.0%	-	30	0.0%	-
Cd	9	22%	- (0.045-0.589)	21	62%	0.128 (0.049-21.5)	30	43%	- (0.045-21.5)
Cr	9	66%	3.18 (0.249-157.0)	21	76%	1.05 (0.049-17.0)	30	63%	1.47 (0.049-157.0)
Cu	9	100%	4.54 (2.83-7.66)	21	100%	6.54 (3.74-95.70)	30	100%	5.86 (2.83-95.7)
Fe	9	100%	238.77 (152.0-1084.0)	21	100%	189.48 (74.90-3989.0)	30	100%	203.09 (74.90-3989.0)
Hg	9	66%	0.174 (0.045-0.863)	21	100%	0.173 (0.050-4.42)	30	90%	0.173 (0.045-4.42)
MeHg	9	100	0.147	21	90%	0.089 (1.81-2.01)	30	93%	0.104 (0.01-0.75)
Mg	9	100%	828.99 (703.0-988.0)	21	100%	890.18 (494.0-1118.0)	30	100%	871.37 (494.0-1118.0)
Mn	9	88%	0.895 (0.20-15.20)	21	95%	0.956 (4.27-11.60)	30	93%	0.937 (0.20-15.20)

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	n	%	Value (Range)	n	%	Value (Range)	n	%	Value (Range)
Mo	9	11%	- (0.245-1.41)	21	9.5%	- (0.249-0.74)	30	10%	- (0.245-1.41)
Ni	9	22%	- (<0.528-79.60)	21	43%	- (<0.519-8.15)	30	37%	- (<0.528-79.60)
Pb	9	11%	- (0.50-1.07)	21	24%	- (0.10-1.74)	30	20%	- (0.10-1.74)
Se	9	100%	2.28 (1.12-3.09)	21	100%	2.36 (0.88-4.92)	30	100%	2.34 (0.88-4.92)
Sr	9	22%	(0.095-0.331)	21	57%	0.217 (0.100-36.4)	30	47%	- (0.095-36.4)
V	9	11%	- (0.245-0.975)	21	4.5%	- (0.049-1.58)	30	6.6%	- (0.049-1.58)
Zn	9	100%	220.26 (178.0-255.0)	21	100%	203.51 (118.0-280.0)	30	100%	208.40 (118.0-280.0)

CANADA

Beaufort Sea

ALASKA

Chukchi Sea

RUSSIA

Bering Sea

70 N

65 N

60 N

55 N

- - - - Chukchi Sea Stock

—— Southern Beaufort Sea Stock

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Geometric Mean (ug/g dw)

Analyte

Legend: Kidney, Liver, Muscle

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