# ESSENTIAL AND NON-ESSENTIAL ELEMENTS IN EIGHT TISSUE TYPES FROM SUBSISTENCE-HUNTED BOWHEAD WHALE: NUTRITIONAL AND TOXICOLOGICAL ASSESSMENT

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## ABSTRACT

**Objectives**. To assess essential/non-essential elements in bowhead whale.
**Study Design**. Analyzes of tissues for key elements and comparing them to published food guidelines.
**Methods**. Using national and international guidelines calculate percent (%) "Recommended Daily Allowance" of essential elements in 100 g portion of bowhead tissues. For non-essential elements, determine maximal tissue consumption based on average element concentrations and provisional tolerable weekly intake; and minimal risk level.
**Results**. Liver and kidney are rich in essential/non-essential elements and have the greatest concentration of cadmium (Cd) among tissues studied, while mercury (Hg), lead (Pb) and arsenic (As) are relatively low. Kidney of bowhead whale is consumed in very limited amounts (limited tissue mass compared to muscle and *maktak*); liver is consumed rarely. Other tissues, except blubber, are excellent sources of many essential elements, without the abundance of liver and kidney Cd.
**Conclusions**. Renal Cd concentrations are most restrictive for consumption on a tissue mass basis. Better understanding of Cd bioavailability, food processing, and actual consumption rates and patterns, are critical to providing improved guidance. Compared to store-bought meat, bowhead whale had comparable concentrations of elements in the tissues studied, with a few noted differences. The occasional blubber substitute, Crisco, was nearly devoid of trace element content.
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**Keywords**: *Balaena mysticetus*, bowhead whale, cadmium, elements, nutrients, subsistence

## INTRODUCTION

Bowhead whales (*Balaena mysticetus*) inhabit many regions of the Arctic year-round. The consumption of tissues from marine mammals, including the bowhead whale, by humans has occurred for centuries. While the actual magnitude of benefits are still not well documented (1), bowhead tissues provide basic nutrients and are important to the maintenance of healthy communities (omega 3 fatty acids)(2-5); yet the whales are a known source of contaminants (e.g. 6, 7). The Arctic Monitoring and Assessment Programme (AMAP) has termed this situation the "Arctic Dilemma." Sources of non-essential, potentially toxic elements and other contaminants are both global (8) and local (9-11). Industrial concerns in the Northern Alaska region include Red Dog Mine (W 162°49'04", N 68°04'11'') a zinc (Zn)/lead (Pb)/silver (Ag) mine (9-11). The proximity of the mine, port and haul road to the coast has incited apprehension among local communities regarding the potential for environmental contamination, including subsistence resources. Oil activities within and surrounding Prudhoe Bay, Alaska, also represent a source of concern related to the mobilization of heavy metals (12, 13).

Dependence upon a subsistence-based diet has typically been expressed as "need" (14, 15). These "need" assessments do not directly address the nutrients (e.g. essential elements) provided to the people. Many coastal Alaskan communities depend on marine mammals for nutritional, cultural, health, medicinal, economic and spiritual well-being (6, 16). These communities know these benefits, but, in most cases, a well-designed quantitative assessment of these critical food sources and their actual essential element contents has not been made. With respect to elements, this "nutritional" assessment must be balanced with an evaluation of non-essential elements that have no known physiologic function. Past studies of element interactions (17, 18) were limited to classical tissues (liver, kidney, muscle, blubber), and did not consider human consumers. Hoekstra et al. (7) offered a comprehensive assessment of bowhead whale-based subsistence diets with respect to organochlorines in various tissues.

Daily requirements criteria come in many forms, including Recommended Daily Allowances (RDA), Adequate Intakes (AI), Dietary Reference Intakes (DRI) and, for upper limits of consumption, as Tolerable Upper Intake Levels (UL), as described by the National Academy of Sciences (19), and the provisional tolerable weekly intake (PTWI). For nutritional needs the reference values are intended to indicate the amount of a particular essential element required daily. Using these values, one can determine what percentage of the "daily requirement" is met by a standard meal mass, or portion weight (i.e., 100g or 3 ounces of meat) of a food item. Nutritional needs of consumers can vary according to age, reproductive status, body weight, gender, specific physiological or disease conditions, and other factors. It is not the intent of this paper to cover this wide range of human conditions or life stages (i.e., fetal to geriatric). Some studies have described subsistence diets in Alaska (e.g., 20, 21), but not in detail for the bowhead whale and the numerous types of tissues consumed; nor specifically for essential and non-essential trace elements. With respect to non-essential elements, the Joint Food and Agricultural Organization and World Health Organization (FAO/WHO) (22)

have established the Provisional Tolerable Weekly Intake (PTWI) level, which is defined as an upper intake limit above which adverse effects might be expected. The term 'provisional' is used to emphasize the lack of safety data on contaminants; consequently, the levels of PTWIs are continually re-evaluated. The minimal risk level (MRL) set forth by the US Health and Human Services Agency for the Toxic Substances and Disease Registry (ATSDR) (23) applies to oral exposure of chronic duration (≥ 365 days), and is defined as "an estimate of daily human exposure to a substance that is likely to be without an appreciable risk of adverse effects (noncarcinogenic) over a specified duration of exposure" (23). We use both criteria to provide a range of consumption advice calculations.

For nutritional needs the reference values are intended to indicate the amount of a particular essential element required daily. This study provides nutrient information on a variety of tissue types from the bowhead whale to develop a quantitative measure of the nutritive value for humans for vital elements. Such data illustrate the relevance of these food items, and the specific elements therein, for health maintenance and disease prevention in humans. We recognize elemental interactions are complex, such that: 1) a non-essential element may interfere with the absorption or function of an essential element, or 2) an essential element may be protective with respect to toxic elements (24). These complexities are not addressed here, as we consider each element individually.

Using an approach similar to other studies that have addressed public health considerations of a subsistence-based diet from both nutritional and toxicological perspectives (6, 7, 16, 25), we report on the essential and non-essential trace element status of eight bowhead whale tissues (e.g., mean concentrations), provide an assessment of their nutrient value (e.g., %RDA), and calculate tissue weights relevant to suggested maximal intakes (mass of food consumed per unit time) of specific non-essential elements (Cd, Hg and Pb). The benefits of essential trace elements as well as the potential risks of non-essential (potentially toxic) trace metals, associated with the consumption of bowhead whale tissue are discussed.

## MATERIAL AND METHODS

### Sampling

Sampling of the bowhead whale has been described previously (18, 26). Full thickness blubber cores and various tissues (epidermis, liver, kidney, skeletal muscle, diaphragm, tongue, intestine and heart) from bowhead whales were provided by Native subsistence hunters in Barrow, Alaska, USA, from 2002-2003. Samples were collected by staff at the Department of Wildlife Management with the endorsement of the Alaskan Eskimo Whaling Commission (AEWC) and the Barrow Whaling Captains Association (Barrow, Alaska, USA). Epidermal and blubber cores from approximately the same location on each whale (dorsal midline, 1 meter caudal to the blowhole) were collected. Life history information was recorded from each whale harvested (body length, baleen length, sex, etc.). Relationships among elements and life history parameters have been well described previously by Bratton et al. (27) and Woshner et al. (18) and will not be repeated here. Store-bought foods were

collected as described in O'Hara et al. (28). Samples were temporarily stored at -20°C at the Arctic Research Facility (Barrow, Alaska, USA) and temperature was maintained during transport to Texas A and M University (College Station, TX), via provision of the U.S. Marine Mammal Protection Act (Permit No. 932-1489 to Dr. Teri Rowles) for marine mammal samples.

**Sample collection for store-bought foods**

Various commercially available foods [boneless pork loin chop, beef shank and tongue, honeycombed tripe (rumen), reindeer steak (*Rangifer tarandus*), and Crisco® (J. M. Smucker Company, made entirely of vegetable oil)] were obtained by residents in 2002, from a local market in Barrow, Alaska, USA. Samples were selected based on their availability and potential dietary importance as a substitute for subsistence foods (i.e. country-based diet). Samples were transported as described above for the bowhead whale samples.

**Statistics and calculations**

Summary statistics were calculated using 0.5 of MDL to represent concentrations of elements below the level of detection (Tables III-IV). Representative samples of uncooked bowhead whale *maktak* were determined using the 1:2 ratio of epidermis-to-blubber that is typically consumed (7) and converting the respective concentrations in the epidermis and blubber accordingly.

The PTWI is set at 7 $\mu$g/kg body weight for Cd (22). For Pb, the PTWI is 25 $\mu$g/kg body weight (29), or 1.75 mg for a 70 kg individual. The PTWI established for THg is 300 $\mu$g per person (30), of which no more than 200 $\mu$g should be present as the readily bioavailable form, methylmercury. For Cd, the minimal risk level (MRL) for chronic-duration (≥ 365 days) oral exposure to Cd, proposed by the United States Department of Health and Human Services' Agency for Toxic Substances and Disease Registry (ATSDR), is somewhat lower, at 0.0002 mg/kg/day (23). Using the ATSDR's MRL, a 70 kg person could safely consume 98 $\mu$g Cd per week, but, according to the WHO/FAO's PTWI, should consume no more than 490 $\mu$g Cd per week for their lifetime. We use both criteria to provide a range of consumption advice calculations. We applied current Recommended Daily Allowances (RDAs) to assess the proportion (%) of nutrient daily intake provided by a standard 100 g (3 ounce) portion for each tissue type (Tables V-VI). Table VII presents analytic data and published concentrations.

**Elements analysis**

This analytical work was performed under the standard QA Plan prepared from the Pocket Guide for Quality Assurance Plans (Category III. Guy F. Simes, Quality Assurance Manager, EPA Reduction Engineering Laboratory, Cincinnati, Ohio 45268, PP 36-51) at the Texas A&M University Trace Element Research Laboratory (TERL).

Samples were received frozen, checked against accompanying chains of custody, assigned unique TERL file numbers, entered into our LIMS program, and stored in a restricted access -20°C freezer until prepared for analysis. Prior to digestion, samples were thawed, chopped and homogenized in plastic weigh boats. Approximately 0.8-1.0 grams of wet sample homogenate was weighed into

tared, acid-washed, 50-ml Corning© centrifuge tubes. Three ml of trace metal grade 69-71% nitric acid (Fisher Scientific A509-212) was added to each tube and the samples were allowed to stand overnight at room temperature. The next day, samples were vortexed and digested in a microwave oven (CEM Mars5), following the program shown in Table I. Samples were allowed to cool and were vortexed between stages. Ultrapure $H_2O_2$ (JT Baker UltrexII, 30%, 2 ml) was added to samples following Stage 2, and trace metal grade HCl (EMD Chemicals Omni Trace, 37-38%, 1 ml) was added following Stage 3. Following digestion, samples were diluted to 20 ml with 18-MegOhm/cm deionized water.

Samples were digested and analyzed in sets of 20 along with a blank, a spiked blank (laboratory control sample, LCS), a sample duplicate, a spiked sample, and three certified reference materials (Bovine Liver 1577b, NIST; Dogfish Muscle DORM-2, Research Council of Canada; and Dogfish Liver DOLT-2, Research Council of Canada). Spiking solution for LCS and sample spikes was prepared from single element standards obtained from Inorganic Ventures.

Tissue digests were analyzed for Hg using a Cetac QuickTrace 7500 cold vapor – atomic absorption spectrometer. Digest solution was diluted as necessary with 7% HCl, and combined with $SnCl_2$ to reduce $Hg^{2+}$ to $Hg^0$. $Hg^0$(g) was separated from the liquid sample matrix in a gas-liquid separator and carried by a stream of argon gas through a Nafion drying membrane and into the absorption cell, where Hg peak absorbance was measured. Selenium was analyzed on a PSA Millennium Excalibur hydride generation – atomic fluorescence spectrometer. Prior to analysis, aliquots of digest solutions were heated at 90°C in the CPI block digester with HCl, in order to reduce Se(VI) to the Se(IV) form that forms a hydride species quantitatively. This solution was then mixed with a solution containing $NaBH_4$ to form $SeH_2$, and passed into a gas-liquid separator. Volatile hydride species were atomized in an air-hydrogen flame, and Se was quantified by atomic fluorescence. Cadmium and Pb were analyzed on a Perkin-Elmer/Sciex DRC 2 inductively coupled plasma – mass spectrometer following 10-fold dilution with deionized water. Signals were measured in pulse mode, using a peak-hopping technique that incorporated internal standards ($^{103}$Rh for $^{111}$Cd and $^{209}$Bi for $^{208}$Pb) to compensate for physical matrix effects and slight instrument behavior changes.

Remaining elements were analyzed on a Spectro CirOs inductively coupled plasma – optical emission spectrometer. Digest solutions were analyzed undiluted, using an axial plasma and an internal standard (Yb) to compensate for matrix effects and instrument drift. Final calculations utilized off-peak background correction and interelement

**Table I.** Microwave digestion program.

| Stage | Temperature (°C) | Pressure (atm) | Power (%) | Time (min) |
|---|---|---|---|---|
| 1 | 100 | 1 | 40 | 30 (ramp 10, hold 20) |
| 2 | 100 | 1 | 40 | 30 (ramp 10, hold 20) |
| 3 | 80 | 1 | 40 | 30 (ramp 10, hold 20) |
| 4 | 80 | 1 | 40 | 30 (ramp 10, hold 20) |

correction equations. Calibration on all instruments utilized a blank and three calibration standards that bracketed the measured sample concentrations. Instrument response was evaluated immediately following calibration and, thereafter, following every 10 samples and at the end of each analytical run, by running a check standard and a check blank. Table II outlines the results of the QA/QC data.

Tissue concentrations of the following elements were determined: aluminum (Al), arsenic (As), boron (B), barium (Ba), beryllium (Be), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), potassium (K), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na), nickel (Ni), phosphorous (P), lead (Pb), sulfur (S), selenium (Se), strontium (Sr), titanium (Ti), vanadium (V), and zinc (Zn). For tissues in which > 50% of the samples submitted had concentrations below the level of detection, we do not report a concentration for that element

**Table II.** Quality assurance and quality control (QA/QC) data for element analyses.

| Element | MDL (ppm) | Blank (ppm) | Duplicate (RPD) | LCS Recovery (%) | Spike Recovery (%) | SRM Recovery (%) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 1577b | DOLT-3 | DORM-2 |
| Al | 1 | 0.2 | 3.9 (1) | 91 (7) | 91 (10) | | | |
| As | 0.42 | 0.08 | 3.6 (1) | 99 (7) | 103 (11) | | 77 (7) | 95 (6) |
| B | 0.21 | 0.08 | 9.8 (3) | 88 (7) | 90 (11) | | | |
| Ba | 0.021 | 0.00 | 7.7 (2) | 101 (7) | 101 (11) | | | |
| Be | 0.011 | 0.00 | | 93 (7) | 95 (11) | | | |
| Ca | 0.42 | 0.9 | 14.4 (11) | 101 (7) | 101 (10) | 95 (1) | | |
| Cd | 0.023 | 0.005 | 9.3 (18) | 97 (7) | 99 (10) | 94 (1) | 84 (7) | 105 (1) |
| Co | 0.11 | 0.02 | | 101 (7) | 102 (11) | | | |
| Cr | 0.11 | 0.03 | | 104 (7) | 104 (11) | | | 75 (6) |
| Cu | 0.11 | 0.02 | 6.3 (9) | 101 (7) | 102 (10) | 92 (1) | 96 (7) | 79 (5) |
| Fe | 0.21 | 0.09 | 11.1 (11) | 104 (7) | 106 (5) | 90 (1) | 96 (7) | 90 (6) |
| Hg | 0.003 | 0.002 | 4.9 (8) | 109 (7) | 95 (8) | | 90 (7) | 86 (6) |
| K | 2.1 | 0.6 | 4.1 (11) | 96 (7) | | 90 (1) | | 82 (6) |
| Mg | 0.21 | 0.1 | 5.0 (11) | 101 (7) | 102 (8) | 90 (1) | | |
| Mn | 0.042 | 0.001 | 15.2 (6) | 103 (7) | 105 (11) | 92 (1) | | |
| Mo | 0.21 | 0.04 | | 100 (7) | 100 (11) | 102 (1) | | |
| Na | 42 | 0.5 | 3.1 (10) | 106 (7) | | 92 (1) | | |
| Ni | 0.11 | 0.03 | | 98 (7) | 99 (11) | | 94 (7) | 74 (6) |
| P | 9.2 | 0.1 | 5.1 (11) | 105 (1) | | 94 (1) | | |
| Pb | 0.005 | 0.003 | | 102 (7) | 103 (9) | 106 (1) | 94 (7) | 89 (3) |
| S | 9.4 | 0.5 | 6.1 (11) | 90 (7) | | 84 91) | | |
| Se | 0.005 | 0.004 | 6.0 (10) | 97 (6) | 93 (10) | 92 (1) | 86 (7) | 93 (5) |
| Si | 2.1 | 0.04 | | | | | | |
| Sr | 0.011 | 0.001 | 7.7 (8) | 101 (7) | 101 (10) | 94 (1) | | |
| Ti | 0.11 | 0.02 | | 100 (7) | 98 (10) | | | |
| V | 0.21 | 0.003 | | 98 (7) | 99 (11) | | | |
| Zn | 0.11 | 0.1 | 4.0 (10) | 99 (7) | 101 (7) | 83 (1) | 93 (7) | 78 (6) |

(n) number of valid observations; Duplicate values are valid when average concentration is not less than 3 x MDL; LCS values are valid when the observed concentration is not less than 3 x MDL; Spike values are valid when spike level added is not less than the original concentration; SRM values are valid when the SRM is certified and when the observed concentration is not less than 3 x MDL.

and tissue combination. The following elements were not reported Al, Co, Cr and Ni. For kidney, the elements not reported include As, B, Ba, Mo, Ti and V. For liver, As, B, Ba, Be and Ti are not reported. For muscle, the elements not reported include As, B, Ba, Be, Mo, Pb, Ti and V. For heart, the elements not reported are As, B, Ba, Be, Mo, Pb, Ti and V. For intestine, the elements not reported are As, B, Ba, Be, Mo, Ti and V. For tongue, the elements not reported are B, Ba, Be, Mn, Mo and V. For blubber, the elements not reported are B, Ba, Be, Mn, Mo, Ti and V. For epidermis, the elements not reported are As, Be, Cd, Mn, Mo, Ti and V.

## RESULTS

### Metals analyses

Summary statistics for concentrations of essential and non-essential elements detected in at least 50% of the samples for each tissue type are compiled in Tables III-IV. Current RDAs for each element are shown in Tables V-VI, along with the percentage (%RDA) of the daily requirement met by consuming 100 g, or 3 ounces, of a given tissue for an adult male 31-50 years of age.

### Elemental nutrient value of tissues studied

Among the tissues we analyzed, kidney and liver are the most elementally rich (Table III and V). On average, kidney (100g) provides > 10% of the RDA for the following elements: Cr (88%), Cu (13%), Fe (42%), Mo (42%), P (17%), Se (236%), Na (45%) and Zn (14%) (Table V); whereas 100g of liver supplies > 10% of the RDA for Cr (88%), Cu (33%), Fe (566%), Mo (20%), P (29%), K (11%), Se (200%), Na (32%) and Zn (230%) (Table V).

Skeletal muscle provides > 10% of the RDA for the elements Fe, Mo, P, K, Se and Zn (Table V). Heart provides > 10% of the RDA for Fe, P, K, Na, Se and Zn, while tongue supplies > 10%

**Table III.** Bowhead whale (*Balaena mysticetus*) kidney, liver, muscle and heart element concentrations (ppm w.w.) summary statistics (arithmetic mean, or "ar mean", and range).

| | Kidney | Liver | Muscle | Heart |
|---|---|---|---|---|
| Ca | 132.9 (77.5 - 287) | 57.8 (26.7 - 101) | 39.8 (26.4 - 61.5) | 65.4 (46.2 - 93.8) |
| Cd | 13.9 (0.47 - 70.2) | 9.47 (0.28 - 42.2) | 0.04 (0.007-0.212) | 0.87 (0.03 - 3.64) |
| Cu | 1.65 (1.13 - 2.2) | 4.91 (3.08 - 8.96) | 0.57 (0.36 - 0.76) | 1.20 (0.90 - 1.36) |
| Fe | 60.1 (26.9 - 110) | 791.6 (72.2-3690) | 169.7 (97.1 - 286) | 70.6 (50.9 - 98.7) |
| Hg | 0.032 (0.003 - 0.18) | 0.05 (0.01 - 0.19) | 0.02 (0.003 - 0.04) | 0.016 (0.006 - 0.031) |
| Mg | 91.5 (72.2 - 132) | 122.9 (90.5 - 178) | 232.0 (180 - 268) | 190.8 (165 - 211) |
| Mn | 0.36 (0.20 - 0.55) | 1.24 (0.45 - 2.43) | 0.12 (0.05 - 0.18) | 0.21 (0.16 - 0.271) |
| Se | 1.30 (0.77 - 2.04) | 1.07 (0.50 - 1.79) | 0.20 (0.13 - 0.25) | 0.41 (0.24 - 0.92) |
| Zn | 21.1 (12.7 - 57.2) | 34.5 (23.6 - 65.1) | 36.3 (24.7 - 62.8) | 27.1 (21.8 - 30.3) |

Pb in kidney was ar mean = 0.008, range = 0.005-0.015. Pb in liver was ar mean 0.015, range = 0.006-0.03;
Mo in liver was ar mean = 0.46, range 0.29-0.99.V in liver was ar mean = 0.69, range = 0.23-1.76;
n = 33 (33 samples analyzed) and reported except for Pb: n = 21 (12 < detection level or DL) for kidney;
n=34 (analyzed) and reported except V: n = 31 (3 < DL), and Mo: n = 33 (1 < DL) for liver;
n = 33 (analyzed) and reported except Cd: n = 22 (11 < DL) for muscle. n = 10 for heart;
Mean (ppm ww) K for kidney = 1441.6, liver = 2222.6, muscle = 2793.0, heart = 3098.0;
Mean (ppm ww) Na for kidney = 2227.6, liver = 1581.7, muscle = 478.5, heart = 1325;
Mean (ppm ww) P for kidney = 1361.6, liver = 2312.1, muscle = 2021.5, heart = 1732;
Mean (ppm ww) S for kidney = 1465.1, liver = 2109.4, muscle = 1795.8, heart = 1791;
Mean (ppm ww) Sr for kidney = 0.34, liver = 0.13, muscle = 0.04, heart = 0.12.

of the RDA for Cr, Fe, Se and Na (Table IV). Intestine provides > 10% of the RDA for P, K, Na, Se and Zn (Table VI).

As expected, blubber is a poor source of elements, providing 10% or more of the RDA for Cr, Se and Na only (Table VI). Epidermis (Table V) supplies > 10% of the RDA for Cr, P, K, Mo, Na and Se. Blubber and epidermis comprise 66% and 33% of *maktak*, respectively. Using the same proportions to assess the nutrient quality of *maktak*, > 10% of the RDA for Cr, Se, Zn and Na are provided in a 100-g serving (Table VI).

**Non-essential elements**

For bowhead whale kidney, Cd concentrations allow for consumption rates of 7- 35 g per week (Table V), or 364 g to 1,820 g per year, and much higher rates of consumption for the other non-essential elements (Hg up to 9.4 kg and Pb 219 kg per week). With respect to liver (rarely consumed), Cd content allows for consumption rates of 10.3-51.7 g per week (Table V), and much higher rates of consumption for the other non-essential elements (Hg up to 6.0 kg and Pb 117 kg per week).

For heart, allowable consumption rates are 113-563 g per week for Cd, and much higher rates for the other non-essential elements (for Hg up to 18.8 kilograms per week). For intestine and tongue, allowable consumption rates based on Cd concentrations are 204-1021 g per week and 1633 g (1.6 kg) to 8167 g (8.2 kg) per week, respectively, and much higher rates for the other non-essential elements. Skeletal muscle and epidermis (as well as maktak) are not significant sources of non-essential elements and weekly consumption rates in excess of 2.5 or 18 kg, respectively, are required to reach levels of concern (Table V).

**Table IV.** Bowhead whale (*Balaena mysticetus*) intestine, tongue, blubber and epidermis element concentrations (ppm w.w.) summary statistics (arithmetic mean or "ar mean", and range).

| | Intestine | Tongue | Blubber | Epidermis |
|---|---|---|---|---|
| Ca | 99.0 (57.5-137) | 47.5 (13.6-113) | 26.8 (16.5-37) | 89.3 (44.8-142) |
| Cd | 0.48 (0.04-1.52) | 0.06 (0.005-0.22) | 0.02 (0.009-0.015) | - |
| Cu | 0.86 (0.45-1.47) | 0.25 (0.11-0.35) | 0.13 (0.10-0.16) | 0.34 (0.22-0.72) |
| Fe | 13.3 (5.67-44.4) | 40.3 (2.39-186) | 4.29 (1.95-13.8) | 3.42 (0.94-16.6) |
| Hg | 0.007 (0.004-0.014) | 0.012 (0.003-0.046) | 0.006 (0.005-0.008) | 0.017 (0.004-0.037) |
| Mg | 119.7 (94-144) | 30.8 (9.1-85.9) | 14.5 (9.42-18.6) | 171.8 (136-202) |
| Pb | 0.03 (0.01-0.05) | 0.008 (0.005-0.011) | 0.008 (0.006-0.012) | 0.008 (0.004-0.016) |
| Se | 0.364 (0.18-0.63) | 0.10 (0.045-0.18) | 0.10 (0.06-0.14) | 0.64 (0.39-0.86) |
| Zn | 21.6 (14.3-31.7) | 5.22 (1.10-15.7) | 0.93 (0.70-1.16) | 12.5 (9.88-18.7) |

Mn in intestine was ar mean = 0.21, range = 0.06-0.87. Ti in tongue was ar mean 0.18, range = 0.11-0.22;
Ba in epidermis was ar mean = 0.04, range 0.02-0.10,. B in epidermis was ar mean = 0.73, range = 0.38-1.15;
As in tongue was ar mean = 1.44, range = 0.89 – 2.6, in blubber and ar mean = 1.31, range = 0.77-1.77;
Intestine n = 8 (analyzed) Pb n = 6 (2 < DL), and Hg n = 7 (1<DL);
Tongue n = 8 (analyzed); As, Cd and Hg n = 6 (2 < DL), and Cu, Pb and Ti n = 4 (4 < DL);
Blubber n = 6 (analyzed), Cd and Hg n = 5 (1 < DL) and Pb n = 4 (2 < DL);
Epidermis n = 33 (analyzed); Ba n = 26 (7 < DL), Hg n = 29 (4 < DL), and Pb n = 19 (14 < DL);
Mean (ppm ww) K for intestine = 2441.3, tongue = 489.8, blubber = 211.7, epidermis = 3567. 9;
Mean (ppm ww) Na for intestine = 1853.8, tongue = 1029.5, blubber = 624.7, epidermis = 631.5;
Mean (ppm ww) P for intestine = 1402, tongue = 308.9, blubber = 168.3, epidermis = 1744.2;
Mean (ppm ww) S for intestine = 1790, tongue = 583, blubber = 362.5, epidermis = 3087.2;
Mean (ppm ww) Sr for intestine = 0.58, tongue = 0.09, blubber = 0.06, epidermis = 0.32.

**Table V.** Bowhead whale (*Balaena mysticetus*) kidney, liver, muscle and epidermis essential and non-essential element contents (arithmetic mean as mg/100g and (ppm or mg/kg w.w.) and respective consumption amounts based on daily intake (Recommended Daily Allowance, or RDA) for the essential elements, and weekly intake for the non-essential elements.

| | | Kidney | | Liver | | Muscle | | Epidermis | |
|---|---|---|---|---|---|---|---|---|---|
| Parameter | RDA mg/100g | Mean mg/100g | Mean % RDA | Mean mg/100g | Mean % RDA | mg/100g | % RDA | mg/100g | % RDA |
| Essential | | | | | | | | | |
| Ca | 800 | 13.3 | 1.7 | 5.8 | 0.7 | 4.0 | 0.5 | - | - |
| Cr | 0.125 | 0.11 | **88.0** | 0.11 | **88.0** | | | 0.07 | **56.0** |
| Cu | 1.5 | 0.2 | **13.3** | 0.5 | **33.3** | 0.06 | 3.8 | 0.03 | 2 |
| Fe | 14 | 6.0 | **42.3** | 79.2 | **565.7** | 17.0 | **121.2** | 0.3 | 2.1 |
| Mn | | 0.04 | | 12.3 | 4.9 | 0.12 | | - | - |
| Mg | 250 | 9.2 | 3.7 | 0.1 | | 23.2 | 9.3 | 17.2 | 6.9 |
| Mo | 0.25 | 0.11 | **42.0** | 0.05 | **20.0** | 0.08 | **32.0** | 0.07 | **26.0** |
| P | 800 | 136.2 | **17.0** | 231.2 | **28.9** | 202.2 | **25.3** | 174.4 | **21.8** |
| K | 2000 | 144.2 | 7.2 | 222.3 | **11.1** | 279.3 | **14.0** | 357.0 | **17.9** |
| Se | 0.055 | 0.13 | **236** | 0.11 | **200** | 0.20 | **363** | 0.06 | **109** |
| Na | 500 | 222.8 | **44.6** | 158.2 | **31.6** | 47.9 | 9.6 | 63.2 | **12.6** |
| Zn | 15 | 2.1 | **14.0** | 34.5 | **230.0** | 3.6 | **24.0** | 1.3 | 8.7 |
| Non-Essential | ug/week* | Mean (ppm) | g tissue/wk | Mean (ppm) | g tissue/wk | Mean(ppm) | g tissue/wk | Mean(ppm) | g tissue/wk |
| Cd* | 98 | 13.9 | 7.1 | 9.47 | 10.3 | 0.04 | 2,450 | <DL | >19,600 |
| Cd** | 490 | 13.9 | 35.3 | 9.47 | 51.7 | 0.04 | 12,250 | <DL | >98,000 |
| THg | 300 | 0.032 | 9375 | 0.05 | 6000 | 0.02 | 15,000 | 0.017 | 17,647.1 |
| Pb | 1,750 | 0.008 | 218,750 | 0.015 | 116,667 | | | 0.008 | 218,750 |

*ATSDR's MRL, 70 kg person safely consume 98 µg Cd per week; WHO/FAO's PTWI, consume no more than 490 µg Cd per week for their lifetime. Pb PTWI is 25 µg/kg body weight (WHO, 1993), or 1.75 mg for a 70 kg individual. THg PTWI is 300 µg per person (NRC, 2000), no more than 200 µg as methylmercury. **Bold text** >10% RDA met by a 100-g or 3-ounce serving;
For Pb > 50% of muscle samples were < 0.005 ppm ww (< DL), and were thus not reported here. For Cd > 50% of epidermal samples were < 0.005 ppm w.w. (<DL);
%RDA represents the proportion of the RDA met by consuming 100g (3 ounces) of a specific tissue based on the RDA and mean mg/100g of the essential element. g tissue/week represents the maximum suggested intake of the specific tissue based on the MRL, or the PTWI of the specific non-essential element.

**Table VI.** Bowhead whale (*Balaena mysticetus*) heart, tongue, intestine, blubber and maktak essential and non-essential element contents (arithmetic mean as per mg/100g and (ppm = mg/kg)) and respective consumption amounts based on daily intake for the essential elements and weekly intake for the non-essential elements.

| Parameter | RDA | Heart Mean mg/100g | Heart %RDA | Tongue Mean mg/100g | Tongue %RDA | Intestine Mean mg/100g | Intestine %RDA | blubber Mean mg/100g | blubber % RDA | maktak Mean mg/100g | maktak % RDA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Essential | | | | | | | | | | | |
| Ca | 800 | 6.5 | 8.1% | 4.8 | 0.6% | 9.9 | 1.2% | 2.68 | 0.3% | 4.737 | 6% |
| Cr | 0.125 | ND | N/A | 0.1 | 80% | ND | N/A | 0.08 | 61.3 | 0.0831 | 66.5% |
| Cu | 1.5 | 0.12 | 8% | 0.03 | 2.0% | 0.09 | 6% | 0.013 | 0.9% | 0.018 | 1.2% |
| Fe | 14 | 7.1 | 51% | 4.0 | 28.6% | 1.3 | 9.3% | 0.43 | 0.1% | 0.38 | 2.7% |
| Mg | 250 | 19.1 | 7.6% | 3.1 | 1.2% | 12.0 | 4.8% | 1.45 | 0.6% | 6.633 | 2.7% |
| Mn | N/A | 0.02 | N/A | N/A | N/A | 0.02 | N/A | | | | |
| Mo | 0.25 | ND | | ND | | ND | | ND | - | 0.02 | 8% |
| P | 800 | 173.2 | 21.7% | 30.9 | 3.9% | 140.2 | 17.5% | 16.8 | 2.1% | 68.64 | 8.6% |
| K | 2000 | 310 | 15.5% | 49.0 | 2.5% | 244.1 | 12.2% | 21.2 | 1.1% | 132 | 6.6% |
| Na | 500 | 133 | 26.6% | 103.0 | 20.6% | 185.4 | 37.1% | 62.5 | 12.5% | 62.073 | 12.4% |
| Se | 0.055 | 0.04 | 72% | 0.01 | 18% | 0.04 | 72% | 0.01 | 18% | 0.0266 | 48.4% |
| Zn | 15 | 2.7 | 18% | 0.5 | 3.3% | 2.2 | 14.7% | 0.09 | 0.6 | 0.489 | 13.6 |
| Non-Essential | ug/week* | Mean (ppm ww) | g /wk | Mean (ppm ww) | g /wk | Mean (ppm ww) | g /wk | Mean (ppm ww) | g /wk | Mean (ppm ww) | g /wk |
| As | | ND | | 1.44 | | | | | | | |
| Cd* | 98 | 0.87 | 112.6 | 0.06 | 1633.3 | 0.48 | 204.2 | 0.02 | 4900 | | |
| Cd (PTWI)** | 490 | 0.87 | 563.2 | 0.06 | 8166.7 | 0.48 | 1020.8 | 0.02 | 24500 | | |
| Hg | 300 | 0.016 | 18,750 | 0.012 | 25,000 | 0.007 | 4285.7 | 0.006 | 50,000 | | |
| Pb | 1,750 | ND | - | 0.008 | 218,750 | 0.03 | 58333.3 | 0.008 | 218750 | | |

*ATSDR's MRL, 70 kg person safely consume 98 µg Cd per week.
**WHO/FAO's PTWI (µg/kg body wt), consume no more than 490 µg Cd per week for their lifetime. Pb PTWI is 25 µg/kg body weight; (WHO, 1993), or 1.75 mg for a 70 kg individual. THg PTWI is 300 µg per person (NRC, 2000), no more than 200 µg as methylmercury;
Components not detected in the 3 tissue types are not reported in the Table;
% RDA represents the proportion of the RDA met by consuming 100g (3 ounces) of a specific tissue based on the RDA and mean mg/100g of the essential element. g tissue/week represents the maximum suggested intake of the specific tissue based on the MRL, or the PTWI of the specific non-essential element.

**Comparison to store-bought products**

For the most part, store-bought meats had similar concentrations of elements as the analogous bowhead whale product (Table VII). Some interesting differences are noted. Muscle of the bowhead whale is much richer in Fe than the other muscle-based store-bought products. Beef tongue is slightly more mineral rich than bowhead whale tongue. Not surprisingly, the most dramatic difference is between Crisco (a common blubber substitute) and blubber. Crisco is very low in Cu, Fe, K, Mg, Na, P, S, Se and Zn, as compared to bowhead whale blubber. Basically, Crisco is devoid of nutritional value from a trace element perspective. Bovine calf liver is richer in Cu and Mn; while bowhead whale liver is richer in Fe and Se.

## DISCUSSION

As expected, raw bowhead whale tissues are variable sources of essential and non-essential elements. In some cases, these nutrients were below the level of detection of the assays employed, and thus cannot be reviewed here. Of course, this means that those elements and tissues are of no concern for toxicity. Of the elements evaluated, Ca, Co, Cr, Fe, K, Mg, Mn, Mo, Na, Cu, Zn, P, S and Se are the major essential elements, while As, Cd, Pb and Hg have no known function in mammals and are considered non-essential, or potentially "toxic", elements. The non-essential elements important for toxicological assessment in the arctic food chain include Cd, Hg and Pb (31). For most arctic residents Hg is a major issue

**Table VII.** Element concentrations for products purchased locally in Barrow, Alaska (USA), and from published data for food products of domestic livestock origin that are potentially analogous to the bowhead whale products studied.

| Product | Ba | Ca | Cu | Fe | Hg | Mg | Mn | Se | Zn |
|---|---|---|---|---|---|---|---|---|---|
| Barrow-Purchased Items | | | | | | | | | |
| pork loin chop | < MDL | 36.7 | 0.32 | 7.05 | 0.022 | 247 | 0.099 | 0.619 | 14.8 |
| beef shank | 0.023 | 91.1 | 0.557 | 17.1 | < MDL | 172 | 0.119 | 0.162 | 66.3 |
| reindeer steak | 0.027 | 38.0 | 1.80 | 37.2 | 0.017 | 257 | 0.265 | 0.208 | 29.8 |
| B.m. muscle mean | | 39.8 | 0.57 | 169.7 | 0.02 | 232 | 0.120 | 0.200 | 36.3 |
| beef tongue | 0.036 | 60.2 | 1.05 | 82.4 | < MDL | 170 | 0.148 | 0.069 | 33.8 |
| B.m. tongue mean | | 47.5 | 0.25 | 40.3 | 0.012 | 31 | | 0.100 | 5.22 |
| honeycombed tripe | 0.101 | 153.0 | 0.53 | 5.24 | < MDL | 115 | 0.278 | 0.257 | 22.9 |
| B.m. intestine mean | | 99.0 | 0.86 | 13.3 | 0.007 | 120 | | 0.364 | 21.6 |
| Crisco | < MDL | 19.7 | < MDL | < MDL | 0.004 | 0.4 | < MDL | < MDL | < MDL |
| B.m. blubber mean | | 26.8 | 0.13 | 4.29 | 0.006 | 14.5 | | 0.10 | 0.93 |
| Published Data | | Ca | Cu | Fe | Hg | Mg | Mn | Se | Zn |
| Calves (liver)* | - | 30-100 | 35-200 | 45-300 | - | 90-200 | 2.5-6.0 | 0.25-0.5 | 25-50 |
| B.m. liver mean | - | 57.8 | 4.91 | 791.6 | 0.05 | 122.9 | 1.240 | 1.07 | 34.5 |
| Beef (muscle)** | - | - | 0.91 | - | - | - | 0.081 | 0.14 | 27 |

< MDL indicates sample was below level reportable (or below detection);
B <0.229, except 0.279 in pork loin chop; Cr < 0.114, except 1.1 in reindeer steak; Ni < 0.114, except 0.142 in Crisco;
As <0.46, except 0.53 in pork loin chop (0.53) and Crisco (0.68); Pb < 00.00573, except in pork loin chop (0.00602) and in beef tongue (0.00579);
*Johnson et al., 1989 (40); perinatal cattle (calves) range of "normal" hepatic elemental concentrations based on Puls, 1994 (32);
**Jorhem et al., 1996 (41), mg/kg fresh weight, USA values;
K, Na, P, S and Sr were generated, but are not provided here

in fish and seals. However, Hg concentrations in bowheads are relatively miniscule compared to other marine mammals, and are below levels used by regulatory agencies for marketed animal products. Compared to other species of northern Alaska, bowhead whales of this study had similar or lower tissue concentrations of the toxic metal Hg (17, 18). The Cd concentrations are similar to those previously reported for bowhead whales (18, 27), which accumulate Cd with age in liver, and particularly in kidney (18), similar to other arctic mammals, including both terrestrial and marine species (17, 18, 32, 33, 34, 35, 36, 37, 38, 39). Other reports have addressed potential nutritional and toxic effects of such elemental concentrations in bowhead whales and domestic animals (32, 18).

**Element nutrient value by tissues type**

Many nutrients are present in numerous tissues of the bowhead whale at adequate (>10% of the RDA or AI met by 100 g or 3 ounces of that specific tissue) to excellent (meets, or exceeds, >100% the RDA or AI for 100 g or 3 ounces of that specific tissue) levels. Among tissues from a single whale, it is obvious that the organ meats (kidney, intestine, heart) are of limited mass relative to the more abundant skeletal muscle and *maktak* (composed of epidermis and blubber), but are comparatively higher in concentrations of essential elements. Both kidney and liver are potentially very good sources (>10%) of Cr, Cu, Fe, Na, Mo, P and Zn. Kidney is more commonly consumed (highly prized), but is of limited mass compared to muscle and *maktak*, while liver is consumed rarely. Skeletal muscle (Table III) provides > 10% of the RDA for Cu, Mo, Fe, P, K and Zn, and represents a relatively massive amount of available food from a whale. Heart and intestine are both good sources of Cu, Fe, Na, K, Zn and P, while tongue supplies Cr, Cu, Na and Fe (Table IV).

While rarely eaten alone, blubber offers a very good source of Cr, Cu and Mo. Epidermis represents a good source of Cr, Mo, P, K, Na and Zn (>10%). Together (blubber and epidermis) comprising *maktak*, these tissues constitute good sources of the above elements.

**Non-essential elements**

The PTWI is set at 7 $\mu$g/kg body weight for Cd (22). However, the MRL for chronic-duration (≥ 365 days) oral exposure to Cd proposed by the ATSDR is somewhat lower, at 0.0002 mg/kg/day (23). Using the ATSDR's MRL, a 70 kg person could safely consume 98 $\mu$g of Cd per week, but according to the WHO/FAO's PTWI, should consume no more than 490 $\mu$g Cd per week for their lifetime. The WHO/FAO's guideline is more applicable here, as it represents an upper boundary for chronic intake and we are discussing many years of exposure.

Cd concentration in liver and kidney increases in conjunction with whale age (and size). Thus the level of Cd exposure to human consumers would vary correspondingly. If kidney or liver were the only source of Cd in the diet, the PTWI for Cd would be reached (on average) by consumption of 520 g of liver, or 35.3 g of kidney per week. Using the more conservative MRL, a 70 kg human could safely consume, on average, up to 10.3 g of liver, or 7.1 g of kidney per week, over the year. The ATSDR has noted the existence of a relatively narrow margin of safety with respect to Cd and renal function, especially among tobacco smokers (20). Cadmium concentrations in whale muscle and other tissues were low across all age classes and pose no appreciable exposure risk to human consumers.

For Pb, the PTWI is 25 $\mu$g/kg body weight (29), or 1.75 mg for a 70 kg individual. If there were no other sources of Pb exposure, a 70 kg person would reach the PTWI level by consuming (on average) 219 kg of bowhead liver, or 117 kg of bowhead kidney per week. The PTWI established for Hg is 300 $\mu$g per person (30), of which no more than 200 $\mu$g should be present as the readily bioavailable form, methylmercury. If no other sources of Hg are considered, on average, a person would have to consume 6.0 kg bowhead liver, or 9.4 kg bowhead kidney per week to attain the PTWI level for THg.

In other cetaceans, slightly more than 66% of total mercury comprises methylmercury, or other organic forms, whereas the mercury in liver and kidney is predominately inorganic (18). For example, in beluga whales, mean methylmercury levels expressed as a percentage of total Hg were 14.2 % in liver, 12.8 % in kidney, 96.0 % in muscle, and 97.1 % in epidermis (18). Among bowhead whales, the total Hg concentrations are typically too low to justify evaluating organic forms, and such low levels of total Hg imply that this element poses little risk to human consumers.

We recognize that some elements are not limited in most diets and may even, on occasion, be prevalent, or even supplemented, well above recommended limits (e.g., Na). Communication of nutrient data must be conducted carefully in the context of the overall diet and other health influences (i.e., smoking tobacco is a significant source of Cd and disease). Similarly, risk assessments of contaminants should not be conducted in isolation (6, 16). Rather, data pertaining to concentrations of toxic elements should be evaluated in the context of the many important nutrients these tissues contain. Not to be underestimated is the socio-cultural value of hunting and sharing, which is tremendously important to these communities. Furthermore, remote villages frequently lack healthy, affordable and desirable alternatives. The bioavailability of certain elements (i.e., Cd, Hg and Se) from organ meats as they are eaten (raw, or processed by cooking or fermentation) should be determined to better assess actual risks to subsistence users.

## Conclusions

As expected, most of the tissues from bowhead whales used as foods are rich in many elements, with the exception of blubber. As for most arctic mammals, the broad range of Cd concentrations in kidney and liver does not allow us to give precise, reassuring guidance, especially because data are lacking pertaining to bioavailability (proportion absorbed into blood circulation from diet) and the effects of food preparation techniques on Cd concentrations. The potential protective effects of concurrent essential element intake (i.e., Se) must also be considered. The very low concentrations of Hg should not be a concern for consumption of bowhead whale-based products. The bowhead whale tissues studied here had element concentrations similar to those encountered in store-bought meat products. However, the occasional blubber substitute, Crisco, was nearly devoid of trace element content and is not similar to bowhead whale blubber element concentrations.

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## REFERENCES

1. Bjerregaard P, Young TK, Hegele RA. Low incidence of cardiovascular disease among the Inuit-what is the evidence? Atherosclerosis 2003; 166: 351-357
2. Ebbesson SOE, Risica PM, Ebbesson LOE, Kennish JM, Tejero ME. Omega-3 fatty acids improve glucose tolerance and components of the metabolic syndrome in Alaskan Eskimos: The Alaska-Siberia project. Int J Circumpolar Health 2005; 64 (4): 396- 407
3. Bang HO, Dyerberg J, Hjorne N. The composition of food consumed by Eskimos. Acta Med Scand 1976; 200: 69-73.
4. Bang HO, Dyerberg J. Lipid metabolism and ischemic heart disease in Greenland Eskimos. Adv Nutr Res 1980; 3: 1-22.
5. Dyerberg J. Coronary heart disease in Greenland Inuit: a paradox. Implications for western diet patterns. Arctic Med Res 1989; 48: 47-54.
6. Egeland GM, Feyk LA, Middaugh JP. The Use of Traditional Foods in a Healthy Diet in Alasak: Risks in Perspective. Section of Epidemiology Alaska Division of Public Health Dept. of Health and Social Services State of Alaska. 1989. pp. 140.
7. Hoekstra PF, O'Hara TM, Backus SM, Hanns C, Muir DCG. Concentrations of persistent organochlorine contaminants in bowhead whale tissues and other biota from northern Alaska: Implications to human exposure from a subsistence diet. Environ Res 2005 98 (3): 329-340.
8. de Wit CA, Fisk AT, Hobbs KE, et al. Persistent organochlorine pollutants. In: de Wit, C.A., Fisk, A.T., Hobbs, K.E., Muir, D.C.G. (Eds.), Arctic Monitoring and Assessment Program (AMAP) II. Arctic Monitoring and Assessment Program, Oslo. 2004.
9. Alaska Department of Environmental Conservation. Press Release, DEC Denies Petition to Close Haul Road to Red Dog Mine (July 13, 2001), available at http://www.state.ak.us/dec/press/2001/rel_07103.htm).
10. Department of Health and Social Services, State of Alaska. Public health evaluation of exposure of Kivalina and Noatak residents to heavy metals from Red Dog Mine (October 25, 2001). Environmental Public Health Program, Section of Epidemiology, Alaska Division of Public Health, Anchorage, Alaska.
11. Ford J, Hasselbach L. Heavy metals in mosses and soils on six transects along the Red Dog Mine haul road-Alaska National Park Service, No. NPS/AR/NRTR-2001/38. 2001.
12. Snyder-Conn E, Garbarino JR, Hoffman GL, Oelkers A. Soluble trace elements and total mercury in Arctic Alaskan snow. Arctic 1997; 50 no. 3: 201-215.
13. Trefry JH, Rember RD, Trocine RP, Brown JS. Trace metals in sediments near offshore oil exploration and production sites in the Alaskan Arctic. Environ Geol 2003; 45 (2): 149-160.
14. Braund S, Moorehead EL. Contemporary Alaska Eskimo bowhead whaling villages. 2003. Pp. 253-279 in A.P. McCarteny (ed), Hunting the largest animals. Native whaling in the Western Arctic and Subarctic. Canadian Circumpolar Institute, Alberta, Canada.
15. Braund S. Quantification of subsistence and cultural need for bowhead whales by Alaska Eskimos: 2002 Update Based on 2000 U.S. Census Data. Stephen R. Braund and Associates, P.O. Box 1480, Anchorage, AK 99510 (srba@alaska.net). Prepared for the Alaska Eskimo Whaling Commission, Barrow, Alaska, May 2002. pp. 6
16. Arnold SM, Middaugh JP. Use of traditional foods in a healthy diet in Alaska: risks in perspective. Second Edition: Volume 2. Mercury. State of Alaska Epidemiology Bulletin 2005; 8:1-48.

17. Woshner VM, O'Hara TM, Bratton GR, Beasley VR. Concentrations and interactions of selected essential and non-essential elements in ringed seals and polar bears of Arctic Alaska. J Wildl Dis 2001; 37(4)711-721.
18. Woshner VM, O'Hara TM, Bratton GR, Suydam RS, Beasley VR. Concentrations and interactions of selected essential and non-essential elements in bowhead and beluga whales of Arctic Alaska. J Wildl Dis 2001; 37: 693-710.
19. National Academy of Sciences. Dietary Reference Intakes. Institute of Medicine, Food and Nutrition Board. Washington, DC: National Academy Press; 1998. p. 592.
20. Jensen PG, Nobmann ED. "What's in Alaskan Foods" Chart Series. U.S. Department of Health and Human Services, Indian Health Service, Alaska Area Native Health Service, Anchorage, Alaska. Nutritional Services. 1994.
21. Nobmann E. Nutrient value of Alaska Native foods. US Dept of Health and Social Services Indian Health Service Anchorage Alaska revised October 1993.
22. WHO/FAO. Evaluation of Certain Food Additives and Contaminants. Fifty-fifth Report of the Joint WHO/FAO Expert Committee on Food Additives. WHO Technical Report Series, No 901. WHO, Geneva, Switzerland. 2001: 107 pp.
23. ATSDR. Toxicological profile for cadmium. Agency for Toxic Substances and Disease Registry, Public Health Service, US Department of Health and Human Services, Atlanta, Georgia. 1999: 439 pp.
24. Furst, A. Can nutrition affect chemical toxicity? International Journal of Toxicology 2002; 21: 419-424.
25. Hansen JC. Traditional Food – Environmental and Health Concerns. IWC/52/AS2. The Fifty-Second Annual Meeting of the International Whaling Commission Adelaide, South Australia, 3-6 July 2000 pp. 12.
26. O'Hara TM, Krahn MM, Boyd D, Becker PR, Philo LM. Organochlorine contaminant levels in Eskimo harvested bowhead whales of arctic Alaska. J Wildl Dis 1999; 35, 741-752.
27. Bratton GR, Flory W, Spainhour CB, Haubold EM. Assessment of selected heavy metals in liver, kidney, muscle, blubber, and visceral fat of Eskimo harvested bowhead whales Balaena mysticetus from Alaska's north coast. Final report submitted to the North Slope Borough Dept. of Wildlife Management, Barrow, Alaska, 1997: 233 pp.
28. O'Hara T, Hoekstra PF, Hanns C, Backus SM, Muir DCG. Concentrations of selected persistent organochlorine contaminants in store bought foods from northern Alaska: Human exposure implications. Int J Circumpolar Health 2005; 64 (4): 303-313.
29. WHO (World Health Organization). Guidelines for drinking-water quality, 2nd ed. Vol. 1. Recommendations. Geneva, Swizterland. 1993: pp. 49-50.
30. NRC/(National Research Council). Toxicological effects of methylmercury. Washington, D.C.: National Academy Press. 2000: 344 pp.
31. AMAP. Arctic Pollution 2002. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway, 2002: 111 pp.
32. Puls R. Mineral levels in animal health: Diagnostic data. Sherpa International, Clearbrook, British Columbia, Canada. 2004: 356 pp.
33. Larter NC, Nagy JA. A comparison of heavy metal levels in the kidneys of high Arctic and mainland caribou populations in the Northwest Territories of Canada. Sci Tot Environ 2000; 246: 109-119.
34. Gamberg M, Scheuhammer AM. Cadmium in caribou and muskoxen from the Canadian Yukon and Northwest Territories. Sci Tot Environ 1994; 143: 221-234.
35. Aastrup P, Riget F, Dietz R, Asmund G. Lead, zinc, cadmium, mercury, selenium and copper in Greenland caribou and reindeer (*Rangifer tarandus*). Sci Tot Environ 2006; 245: 149-159.
36. Elkin B, Bethke RW. Environmental contaminants in caribou in the Northwest Territories, Canada. Sci Total Environ 1995; 160/161: 307-321.
37. O'Hara TM, Carroll G, Barboza P, et al. Mineral and heavy metal status as related to a mortality event and poor recruitment in a moose population in Alaska. J Wildl Dis 2001; 37(3): 509-522.
38. O'Hara TM, George JC, Blake J, et al. Investigation of heavy metals in a large mortality event in caribou of northern Alaska. Arctic 2003; 56(2):125-135.
39. Wagemann R, Innes S, Richard PR. Overview and regional and temporal differences of heavy metals in arctic whales and ringed seals in the Canadian Arctic. Sci Total Environ 1996; 186:41-66.
40. Johnson JL, Schneider NR, Carlson MP, Slanker MR. Trace element concentrations in perinatal beef calves from west central Nebraska. Vet Hum Toxicol 1989; 31(6):521-4.
41. Jorhem, L, Sundstrom B, Engman J, Astrand-Yates C, Olsson I. Levels of certain trace elements in beef and pork imported to Sweden. Food Addit Contam 1996; 13 (7): 737-745.

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