ORIGINAL ARTICLE

INORGANIC NUTRIENTS AND CONTAMINANTS IN SUBSISTENCE SPECIES OF ALASKA: LINKING WILDLIFE AND HUMAN HEALTH

Sara K. Moses [1], Alex V. Whiting [2], Gerald R. Bratton [3], Robert J. Taylor [3], Todd M. O'Hara [1]

[1]Department of Biology and Wildlife and Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, USA
[2]Native Village of Kotzebue, Kotzebue, Alaska, USA
[3]Department of Integrated Biosciences, Texas A&M University, College Station, USA

Received 8 May 2008; Accepted 24 September 2008

ABSTRACT

Objectives. To determine inorganic nutrient and contaminant concentrations in subsistence foods consumed by Alaska Natives, concentration changes related to common preparation methods and provide a basic risk-benefit analysis for these foods.
Study design. Eleven essential and six non-essential elements were measured in foods derived from spotted seals and sheefish.
Methods. Essential nutrients in foodstuffs were compared to Daily Recommended Intake (DRI) criteria. Non-essential elements were compared to Tolerable Daily Intake Limits (TDIL). These comparisons serve as a risk-benefit analysis, not as consumption advice.
Results. Cooking altered nutrient and contaminant concentrations. Spotted seal muscle and kidney are rich in Fe and Se; liver in Cu, Fe, Mo and Se; and sheefish muscle in Se. TDIL was exceeded in a 100 g serving of seal for THg in raw and fried liver and boiled kidney; MeHg in dried muscle and raw and fried liver; Cd in raw and boiled kidney; and As in raw and rendered blubber. Arsenic exceeded TDIL in sheefish muscle. However, toxicity potential is likely reduced by the element form (i.e., organic As, inorganic Hg) and the presence of protective nutrients such as Se.
Conclusions. Preparation methods alter wildlife tissues from their raw state, significantly affecting element concentrations. Direct evaluation of actual food items is warranted to determine risk-benefit ratios of traditional diets. Traditional foods provide many essential nutrients with a very limited risk from contaminants. We encourage continued consumption of traditional foods, and urge public health agencies to develop applicable models for providing consumption advice, incorporating food processing considerations.
(Int J Circumpolar Health 2009; 68(1):53–74)

Keywords: spotted seal, sheefish, essential elements, heavy metals, subsistence

INTRODUCTION

Marine mammals and fish are well-known resources for subsistence users of Northwest Alaska (AK). Residents of these communities depend on these and other wildlife species for nutritional, economic, cultural and spiritual reasons. However, several issues threaten food security in this region, including contaminants, climate change, access to animals, industrial development and integration of Western culture into traditional life-styles (1,2).

Until recently, obesity, cardiovascular disease (CVD) and diabetes were rarely reported among AK Natives. Today, chronic disease is emerging as a major concern in this population. Over the past decade, the prevalence of obesity has increased among AK Natives (3,4). Diet and physical activity, both linked to subsistence activities, are key factors in the prevention or development of obesity and other chronic diseases. Potential consequences of a shift from traditional subsistence-based diets to Western store-bought foods include decreased nutritive value and increased risk of obesity, diabetes and CVD. Biomedical professionals have documented that negative impacts have, or will likely, result (5–9), but these relationships are largely unknown.

Changes to traditional diets in AK result from both local and global factors. Local choices are significantly altered by the availability of store-bought foods, which can often be less nutritious than subsistence alternatives. At the same time, global sources are "contaminating" the arctic food chain with various chemicals (e.g., chlorinated pesticides, heavy metals, radioisotopes). Although known health benefits are associated with the consumption of traditional foods, there is concern about the presence of environmental contaminants.

Northwest AK receives contaminants from both local and global sources. These contaminants have been detected in fish, wildlife and local store-bought foods (10–12). Although the impact on local health has not been fully determined, fear of contaminants may be steering residents away from traditionally healthy subsistence diets to store-bought, processed foods (13–15). It has been suggested that changes in diet as a result of such fears may be more harmful than the contaminants themselves (16). Further study must be completed before these relationships can be soundly determined.

Although reports document the presence of contaminants in wildlife tissues, they are incomplete in many ways. Few account for the nutritive value of the tissues in which the contaminants are measured or how food processing affects chemical composition. Most wildlife contaminants studies have focused on tissues that are convenient to sample or biomagnify contaminants and are not conducted from the perspective of a consumer (i.e., do not included tissues specifically utilized as food). Nutrients have rarely been addressed, or they have been addressed only in raw tissues for basic nutrients. Although some did examine nutrients and contaminants in subsistence use (17–22), these studies dealt primarily with the North Slope of AK and did not focus on the consumer. Studies on actual marine food items, as they are consumed by AK Natives, are limited (12,23). Without these data, intake of contaminants and nutrients cannot be adequately estimated for subsistence communities consuming these foods.

Here, we examine nutrients and contaminants in two species commonly consumed

by subsistence users in Kotzebue, AK. We expand previous studies by evaluating additional tissues (foods) and including the effects of food processing. Both animal health and human intake perspectives are employed by intensively examining animals taken and consumed by subsistence hunters. We emphasize that animal health and human health are intimately linked in this scenario. The unique focus of this study is measuring contaminants and nutrients in an integrated fashion, utilizing both the raw product and the actual food items consumed. We evaluate changes in food composition as a result of various preparation methods. Such research is necessary to provide the balanced information regarding nutrients and contaminants that is needed to develop integrated, quantitative models that public health officials can use for effective interventions based on actual food items consumed. The information presented here is intended to serve as a basic risk-benefit analysis. We do not intend to provide consumption advice, as that is the responsibility of public health agencies.

Spotted seal (*Phoca largha*) and sheefish (*Stenodus leucicthys*) were selected based on availability of subsistence animals with input from local project participants, the community and hunters regarding the most frequently consumed species. Fish and marine mammals comprise the majority of subsistence harvested foods in Kotzebue. The Native Village of Kotzebue 2002–2004 Harvest Survey (24) reports that fish represent 27% of the subsistence harvest by weight, with sheefish making up 45% of the total fish harvest. Marine mammals account for another 26% of the total harvest by weight, with ice seals (spotted, ringed, bearded) accounting for 98% of this harvest.

MATERIAL AND METHODS

Sample collection

Samples were collected in October 2004 and March 2005 at Kotzebue, AK (66.90ºN, 162.59ºW) under Marine Mammal Health and Stranding Response Program (MMHSRP) permit #932-1489-05. Blubber, muscle, liver and kidney samples from spotted seals (*Phoca largha*; n=5) and muscle from sheefish (*Stenodus leucicthys*; n=8) were collected from legally subsistence harvested animals for chemical analyses using Whirl-Pak or Scienceware polyethylene bags. Blubber and liver subsamples were provided to the Alaska Marine Mammal Tissue Archival Project (AMMTAP) according to the methods of Becker et al. (25). Skin samples (1 cm^2) were provided to the Alaska Department of Fish and Game Arctic Marine Mammal Program for genetic analyses, including confirmation of species identification.

All animals were assessed for gross general health prior to sampling to allow for data interpretation in the context of animal condition. Collection of nutrient and contaminant samples was performed as previously described (19). Samples were immediately frozen at -20ºC, shipped to the University of Alaska Fairbanks (UAF) and stored at -80ºC until analysis.

Morphometrics and age estimation

Spotted seal and sheefish morphometrics appear in Table I. Seal length was measured as the straight line distance from the tip of the nose to both the base and the tip of the tail. Girth was measured at the axillary and umbilical positions. Blubber thickness was measured as the distance from below the epidermis to the blubber-muscle interface at the axillary

and umbilical positions via an incision along the ventral midline from the thoracic inlet to anus. Sheefish length was measured as the straight line distance from tip of mandible to fork of tail. Sex and body mass were determined for both species.

Seal age was estimated by counting annual growth layers in the cementum of teeth as described by Dehn et al. (17). Sheefish were aged by counting otolith annual growth increments as described in Brown et al. (26). Each slide was read in triplicate by each of three independent readers.

Food processing

A portion of each tissue was "food processed" to mimic traditional cooking methods.

Spotted Seal

Spotted seal blubber (ventral midline) was rendered to produce oil. 125 g of full thickness blubber from each individual was wrapped in cheese cloth and suspended within a 1,000 mL glass beaker at room temperature. Oil was allowed to drip from the blubber until no further appreciable oil was produced (approximately 30 days). Rendered oil was transferred to 40 mL clear borosilicate trace clean I-Chem vials (Chase Scientific Glass) and stored at -20ºC. Muscle and kidney were boiled by placing approximately 125 g into 600 mL of ultrapure water in a 1000 mL glass beaker, and boiling for 20 minutes on a VWR model 355 hotplate. Muscle was also dried by placing 125 g of muscle strips (1x3x15 cm) in a Precision model

Table I. Animal identification (ID), AMMTAP[a] ID, harvest date, sex, age, mass, length, girth and blubber thickness of spotted seals and sheefish sampled in Kotzebue, Alaska (2004–2005).

Animal ID	Species	AMMTAP ID	Harvest date	Sex	Age in years [median (range)]	Mass (kg)	Length (cm)[b]	Girth (cm)[c]	Blubber thickness (cm)[d]
KOTZ-01-04	Spotted Seal	692-SPSL-015	25-Oct-2004	Male	6 (3–8)	95.2	122/129	92/90	5.5 / 5.2
KOTZ-02-04	Spotted Seal	692-SPSL-016	25-Oct-2004	Female	5 (4–6)	87.1	119/125	93/80	3.5 / 3.6
KOTZ-03-04	Spotted Seal	692-SPSL-017	25-Oct-2004	Male	5 (4–7)	105.2	131/137	98/89	5.2 / 6.0
KOTZ-04-04	Spotted Seal	692-SPSL-018	25-Oct-2004	Male	6 (5–8)	57.0	NA[e]	NA[e]	4.0 / 4.0
KOTZ-05-04	Spotted Seal	692-SPSL-019	25-Oct-2004	Male	3 (2–4)	60.3	106/115	70/68	4.4 / 4.8
KOTZ-01-05	Sheefish	NA	22-Mar-2005	Male	14 (14–19)	5.2	83.0	NA	NA
KOTZ-02-05	Sheefish	NA	22-Mar-2005	Male	15 (15–18)	5.0	79.9	NA	NA
KOTZ-03-05	Sheefish	NA	22-Mar-2005	Female	20 (19–21)	5.2	81.0	NA	NA
KOTZ-04-05	Sheefish	NA	22-Mar-2005	Male	22 (22–25)	5.5	83.1	NA	NA
KOTZ-05-05	Sheefish	NA	22-Mar-2005	Female	20 (19–23)	6.5	87.7	NA	NA
KOTZ-06-05	Sheefish	NA	22-Mar-2005	Female	22 (20–25)	6.7	90.1	NA	NA
KOTZ-07-05	Sheefish	NA	22-Mar-2005	Female	23 (23–23)	4.8	86.6	NA	NA
KOTZ-08-05	Sheefish	NA	22-Mar-2005	Female	17 (17–18)	5.6	79.8	NA	NA

[a] Alaska Marine Mammal Tissue Archival Project (AMMTAP).
[b] Spotted seal length is the straight line distance from tip of nose to base of tail/tip of the tail. Sheefish length was measured from tip of mandible to fork of tail.
[c] Girth is reported here as axillary/umbilical (cm).
[d] Blubber thickness is reported here as axillary/umbilical (cm), measured along the ventral midline.
[e] No length or girth measurements available because body was distorted during transport and storage (could not be appropriately positioned for measurement).

45EG gravity convection oven for 12 hours at 65˚C. Liver was fried by placing 14 g of butter into a stainless steel frying pan and heating it on a VWR model 355 hot plate on the highest setting. When the butter was melted, 125 g of liver was placed in the pan for ten minutes, flipping it every two minutes with a stainless steel spoon. Processed muscle, liver and kidney were subsampled and stored at -80ºC until analysis.

Sheefish

Sheefish muscle was baked, dried and smoked both with and without skin on the filets. Baking was carried out at 425ºF (218ºC) for 20 minutes in a conventional oven (Kenmore Model 911.9349180). Muscle was dried as described above for seals. Finally, muscle was smoked with 50/50 mesquite/hickory wood chips in an electric smoker (Brinkman Model 810-7080-K) for two hours. Processed sheefish muscle was subsampled and stored at -80ºC until analysis.

Elements analyses

Raw and food processed tissues were analysed for essential elements [calcium (Ca), chromium (Cr), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), molybdenum (Mo), potassium (K), selenium (Se), sodium (Na), zinc (Zn)] and non-essential elements [arsenic (As), cadmium (Cd), lead (Pb), total mercury (THg), methyl mercury (MeHg), silver (Ag)]. Elements in tissues are reported on a ppm (μg/g) or ppb (ng/g) ww basis.

Elements were analysed at Texas A&M University (TAMU) and/or the UAF according to U.S. Environmental Protection Agency (EPA) procedures (27) as previously described (18) with minor modifications. Briefly, 0.8 g (ww) of homogenized, subsampled tissue was digested by a microwave procedure using nitric acid (HNO_3), hydrogen peroxide (H_2O_2) and hydrochloric acid (HCl). In preparation for Se analysis, an aliquot of each digest was heated (95˚C, 1 hour) with excess HCl to reduce all Se(VI) to Se(IV).

Ag, As, Cd, Cr, Cu, Mn, Mo and Pb in seals and Ag, As, Cd, Cr, Cu, Fe, Mn, Mo, Pb, Se and Zn in sheefish were analysed at TAMU using a Perkin Elmer Sciex Elan Model 6100 DRC-II inductively coupled plasma mass spectrometer (ICP-MS). Ca, Fe, K, Mg, Na and Zn in seal samples were analysed at TAMU using a Spectro Ciros Vision ICP optical emissions spectrometer (ICP-OES). Ca, K, Mg, and Na in sheefish were analysed at the UAF on a Perkin Elmer AAnalyst 800 atomic absorption spectrometer (AAS) using flame ionization. Finally, Se in seals was determined at TAMU by hydride generation with a PSA Millennium System atomic fluorescence (AF) detector.

An aliquot of each digest was diluted 1:4 with 7% HCl for THg analysis. THg in seal tissues was measured at TAMU with a CETAC Quick Trace Mercury Analyzer. THg in sheefish was analysed at the UAF using a purge-and-burn technique with cold vapour atomic fluorescence spectrometric (CVAFS) detection on an Amalgamation Control Module equipped with a Model III detector (Brooks Rand) as previously described (10,11,17,18).

MeHg analyses of seals and sheefish were carried out at the UAF using a purge-and-burn technique with CVAFS detection, as established previously by Bloom (28). In short, approximately 0.25 g dry weight (dw) of tissue was digested in 25% KOH in methanol. Aqueous phase ethylation was activated using 1% sodium tetraethylborate ($NaB(C_2H_5)_4$) to

produce methylethyl mercury. Methylethyl mercury was purged from solution with N_2 gas and collected on Tenax® traps (Brooks Rand). MeHg was thermally desorbed from the traps, analogs separated using isothermal (100˚C) gas chromatography, and detected via CVAFS on a Model III detector.

The proportion of THg present as MeHg (%MeHg) in each tissue was determined according to the equation:

%MeHg = MeHg (ng/g)/THg (ng/g) x 100 %

Detection limits

The minimum detection limit (MDL) for each element was determined in terms of tissue ww concentrations. In spotted seal tissues, the MDL (ng/g) were 500 (Ca, Mg, K, Na), 125 (Fe), 50 (Cu, Zn), 25 (Mo), 12.5 (Cr, As), 10 (Mn, Se), 8 (THg), 7 (MeHg), 5 (Cd), 2.5 (Ag) and 1.25 (Pb). In sheefish tissues, the MDL (ng/g) were 200,000 (Na), 4,000 (Ca), 3,000 (Mg), 750 (K), 200 (Fe), 80 (Cu, Mn, Zn), 40 (Mo), 20 (Cr, Se, As, Pb), 8 (Cd), 7 (MeHg) and 4 (THg, Ag).

QA/QC

Element analyses were held to strict QA/QC standards to assure the accuracy and precision of the results. For every twelve samples, at least five QA/QC samples were run, including a method blank, method blank spike, sample spike, sample duplicate and standard reference materials (SRM). SRM were DOLT-2 dogfish liver tissue (Institute for Environmental Chemistry, National Research Council), 1577b Bovine Liver and 1946 Lake Superior Fish Tissue (National Institute of Standards and Technology). Method blanks were held <10% of MDL for the element analysed. Method blank spikes, sample spikes and SRM were kept within 80–120% recovery. Sample duplicate validation criterion was percent difference <20%.

Calculations and statistics

Concentration changes due to food processing

Element concentrations were determined in tissues before and after food processing, as described above. Concentration changes due to food processing were calculated as:

$$\% \text{ Change} = \frac{(C_p - C_r)}{(C_r)} \times 100\ \%$$

where C_r is the concentration (ppm) of the raw tissue, and C_p is the concentration (ppm) of the processed tissue. Thus, $(C_p - C_r)$ represents the absolute concentration change due to food processing, where positive values indicate an increase and negative values indicate a decrease. To account for changes in water content during food processing, absolute and percent change were calculated on both a ww and dw basis. Significance was determined using a paired t-test ($p<0.05$). Water content was determined by freeze drying a 1 g sample to a constant mass on a Labconco FreeZone 4.5 L Benchtop Freeze Dryer.

Daily recommended intakes (DRI) and upper limits (UL) for essential elements

Essential element concentrations (ww) in raw and food processed tissues were compared to Daily Recommended Intakes (DRI) and Upper Limits (UL) (29). The contribution (%) of one serving (100 g) of each food product to element DRI/UL was determined. Serving size was chosen as an intermediate to the serving sizes for meats and fish established by the United

States Department of Agriculture (57–85 g) and the Food and Drug Administration (140 g). K and Na were not included in this analysis since these macronutrients do not have DRIs. The reference group for DRI/UL calculations was adult men, ages 31–50 years. It should be noted that recommended intakes vary by cohort (i.e., age, sex, pregnancy/lactation status).

Tolerable daily intake limits (TDIL) for non-essential elements

Non-essential element concentrations (ww) in raw and processed tissues were compared to the provisional tolerable daily intake (PTDI) for As, Cd, Pb, THg and MeHg and to the reference dose (RfD) established by the U.S. EPA for Ag (30–34).

Assuming a reference consumer body weight (BW) of 70 kg, tolerable daily intake limits (TDIL) of food products for each non-essential element were calculated according to:

$$\text{TDIL (g)} = \frac{\text{PTDI or RfD (µg/kg/day) x BW (kg)}}{C_t \text{ (µg/g, ww)}}$$

where C_t is the mean concentration of the contaminant in the food tissue. The TDIL represents the amount of a particular food a 70 kg consumer could safely eat daily throughout their entire lifespan without risk of adverse effect from a given contaminant.

RESULTS

Essential and non-essential element concentrations and changes due to food processing

Concentrations of essential (Ca, Cr, Cu, Fe, Mg, Mn, Mo, K, Se, Na, Zn) and non-essential (As, Cd, Pb, THg, MeHg, Ag) elements in raw and food processed spotted seal and sheefish tissues are summarized in Tables II and III. Changes in element concentrations as a result of food processing on a ww and dw basis are shown in Tables IV and V. Statistically significant changes ranged from -96.4% (K with rendering of seal blubber) to +217% (As with drying of seal muscle) on a ww basis and from -96.4% (K with rendering of seal blubber) to -13.9% (Mg with frying of seal liver) on a dw basis.

Contribution to daily reference intakes (DRI) and upper limits (UL)

The contribution of a 100 g serving of each food product to the DRI for essential elements is shown in Table VI. Elements present at >100% of DRI in spotted seal tissues included Cu and Mo in raw and fried liver, and Fe and Se in all raw and processed muscle, liver and kidney. In sheefish, Se exceeded 100% in muscle dried with skin.

In two cases tissues exceeded the UL for an element for a single serving. Dried seal muscle contributes 122% of the UL for Fe. Raw kidney provides 132% of the UL for Se. No element exceeded the UL in a serving of sheefish prepared by any method investigated.

Contribution to tolerable daily intake limit (TDIL)

Tolerable daily intake levels (TDIL) for non-essential elements are shown in Table VII. In spotted seal tissues, elements present above the TDIL in a 100 g serving were THg in raw and fried liver, MeHg in dried muscle and raw and fried liver, Cd in raw and boiled kidney, and As in raw and rendered blubber. In sheefish muscle, As was above the TDIL in all raw and processed samples.

Table IIa. Mean (±SD), median and range of essential elements (ppm[a] or ppb[b] ww) in various raw and processed tissues of spotted seals (n=5) harvested in Kotzebue, Alaska (2004)[c].

Element	Blubber raw	Blubber rendered	Muscle raw	Muscle boiled	Muscle dried	Liver raw	Liver fried	Kidney raw	Kidney boiled
Ca[a]	7.34 (±0.60)	1.09 (±0.16)	32.0 (±4.8)	35.1 (±8.2)	85.0 (±15.8)	36.8 (±4.2)	67.6 (±25.2)	65.1 (±2.4)	73.3 (±22.9)
	7.41	1.02	31.9	36.9	77.1	39.5	51.7	65.1	83.9
	7.02-8.11	0.97–1.37	25.5–38.7	21.8–44.3	74.4–112	32.1–40.4	46.5–95.9	62.8–68.8	35.1–92.3
Cu[a]	0.12 (±0.01)		1.30 (±0.20)	1.48 (±0.22)	3.13 (±0.75)	16.4 (±8.6)	17.4 (±7.2)	4.09 (±0.42)	3.52 (±1.83)
	0.11	BDL[c]	1.23	1.38	3.18	12.6	16.6	4.15	3.55
	0.10–0.13		1.08-1.55	1.31-1.84	1.90-3.93	7.07-26.4	10.3-26.1	3.43-4.46	0.92-6.02
Fe[a]	4.83 (±2.80)		204 (±53)	271 (±74)	549 (±146)	392 (±151)	431 (±149)	136 (±30)	182 (±39)
	3.58	BDL[c]	217	297	579	389	468	119	186
	3.01-9.68		115-257	163-357	323-705	170-543	198-591	107-181	139-238
Mg[a]	8.10 (±0.91)	1.13 (±0.39)	233 (±12)	214 (±25)	602 (±115)	200 (±9)	225 (±15)	154 (±10)	141 (±47)
	7.76	1.04	228	204	618	201	225	154	167
	7.43-9.67	0.75-1.78	221-252	186-248	411-724	188-212	210-248	140-167	62.7-177
Mn[b]	38.4 (±2.3)	16.7 (±2.1)	169 (±48)	173 (±31)	381 (±12)	5306 (±469)	6408 (±407)	1066 (±92)	1027 (±359)
	38.6	17.1	165	178	421	5340	6490	1080	1070
	34.9-41.4	13.5-19.2	109-240	126-211	166-481	4700-5780	5750-6800	919-1170	425-1320
Mo[b]						552 (±63)	801 (±89)	122 (±12)	152 (±78)
	BDL[c]	BDL[c]	BDL[c]	BDL[c]	BDL[c]	560	822	118	179
						472-633	664-900	109-135	147-232
K[a]	140 (±35)	4.66 (±1.62)	3234 (±253)	2120 (±377)	8922 (±1628)	3084 (±246)	3172 (±325)	2568 (±211)	1344 (±401)
	147	3.81	3100	2190	9140	2940	3290	2560	1550
	102-191	3.34-7.12	2970-3520	1620-2610	6360-10900	2900-3470	2740-3560	2280-2800	860-1690
Se[b]	138 (±25)	14.4 (±10.0)	649 (±191)	700 (±202)	1655 (±606)	2992 (±1010)	3806 (±1053)	5274 (±652)	3776 (±1407)
	142	10.7	605	643	1810	2820	3850	5240	4040
	107-173	7.94-32.0	414-801	517-1030	906-2240	2000-4300	2540-5030	4360-5960	1480-5250
Na[a]	150 (±13)	48.1 (±5.2)	569 (±129)	357 (±78)	1592 (±326)	883 (±69)	1044 (±186)	1858 (±133)	1036 (±337)
	152	46.6	565	341	1500	905	971	1920	1170
	129-165	42.3-56.4	375-708	271-463	1170-2030	790-948	841-1320	1700-1980	538-1350
Zn[a]	3.30 (±0.68)	1.82 (0.54)	19.6 (±3.6)	27.6 (±5.8)	54.4 (±10.0)	42.1 (±4.8)	54.3 (±3.1)	26.2 (±1.4)	35.8 (±11.5)
	3.25	1.67	19.2	28.0	51.4	40.2	54.9	26.5	37.0
	2.43-4.22	1.34-2.74	15.5-25.3	21.1-34.9	41.8-68.5	37.6-47.6	49.7-58.2	23.8-27.6	16.9-46.3

[a]Ca, Cu, Fe, Mg, K, Na and Zn are reported in ppm ww.
[b]Mn, Mo and Se are reported in ppb ww.
[c]BDL = Below Detection Limit. All samples were BDL for Cr.

Table IIb. Mean (±SD), median and range of essential elements (ppm[a] or ppb[b] ww) in raw and processed muscle tissue of sheefish (n=8) harvested in Kotzebue, Alaska (2005)[c].

Element	Raw	Baked no skin	Baked with skin	Dried no Skin	Dried with Skin	Smoked no Skin	Smoked with Skin
Ca[a]	32.6 (±40.0)	15.4 (±5.8)	12.3 (±4.5)	43.6 (±64.6)	100 (±39)	13.0 (±4.8)	21.2 (±24.3)
	21.2	15.2	11.4	20.3	103	12.0	13.2
	5.9-129	6.8-23.4	7.9-22.1	16.3-203	20.2-303	7.8-23.1	8.7-81.1
Cu[b]	323 (±96)	480 (±199)	394 (±130)	675 (±296)	836 (±904)	482 (±141)	430 (±165)
	304	430	352	614	468	460	415
	246-544	245-731	262-623	385-1151	365-3007	309-716	239-770
Fe[a]	2.85 (±1.11)	3.75 (±1.33)	4.39 (±3.75)	6.51 (±3.13)	4.35 (±2.15)	3.30 (±2.19)	3.39 (±1.40)
	2.45	3.87	3.13	5.99	3.68	2.43	3.19
	1.92-5.20	1.44-5.67	2.22-13.5	2.18-11.7	3.11-9.58	1.95-8.48	1.72-6.46
Mg[a]	414 (±58)	431 (±74)	389 (±51)	704 (±162)	815 (±151)	511 (±136)	374 (±33)
	385	435	386	751	843	529	373
	368-538	269-509	318-462	431-875	601-1067	353-736	337-432
Mn[b]	188 (±56)	219 (±43)	208 (±40)	307 (±82)	386 (±227)	252 (±66)	253 (±20)
	165	232	211	298	278	237	253
	123-300	144-264	160-278	179-416	213-883	186-378	211-274
K[a]	5486 (±379)	5760 (±550)	5394 (±587)	9474 (±1343)	10968 (±1860)	6884 (±1139)	6499 (±1407)
	5536	5630	5320	9541	11011	6549	5953
	4481-5957	5167-6676	4802-6394	7495-11301	8708-14595	5510-9163	5100-9182
Se[b]	293 (±30)	320 (±36)	301 (±32)	513 (±134)	584 (±50)	385 (±47)	368 (±42)
	286	317	295	474	594	372	362
	265-344	277-379	251-354	347-730	505-655	333-476	310-452
Na[a]	565 (±118)	658 (±180)	623 (±168)	1063 (±328)	1026 (±319)	640 (±158)	610 (±143)
	605	607	565	989	981	603	609
	414-704	449-920	439-856	765-1825	642-1717	493-980	360-825
Zn[a]	3.81 (±0.34)	4.83 (±0.79)	4.40 (±0.55)	7.87 (±1.61)	8.07 (±1.35)	5.07 (±0.54)	5.27 (±0.94)
	3.81	4.63	4.20	8.34	7.62	5.29	4.93
	3.47-4.47	4.01-6.15	3.78-5.42	4.95-9.52	6.73-10.4	4.24-5.64	4.31-7.26

[a]Ca, Fe, Mg, K, Na and Zn are reported in ppm ww.
[b]Cu, Mn and Se are reported in ppb ww.
[c]BDL = Below Detection Limit. All samples were BDL for Cr and Mo.

Table III. Mean (±SD), median and range of non-essential elements (ppb ww) in various raw and processed tissues of spotted seals (n=5) and sheefish (n=8) harvested in Kotzebue, Alaska (2004–2005).

	THg	MeHg	%MeHg	Cd	As	Ag	Pb
Spotted Seal					2704 (±254)		41.5 (±13.4)
Blubber	BDL[a]	BDL[a]	-----	BDL[a]	2630	BDL[a]	36.1
Raw					2410-3060		26.1-60.2
Spotted Seal					2580 (±348)		33.1 (±9.3)
Blubber	BDL[a]	BDL[a]	-----	BDL[a]	2570	BDL[a]	30.6
Rendered					2110-3070		25.3-49.3
Spotted Seal	182 (±46)	149 (±17)	86.4 (±23.9)		197 (±70)		5.73 (±0.95)
Muscle	196	146	72.0	BDL[a]	172	BDL[a]	5.13
Raw	133-242	128-172	64.9-119		141-319		4.96-6.89
Spotted Seal	261 (±74)	179 (±42)	71.2 (±21.0)		200 (±21)		4.34 (±0.89)
Muscle	294	182	61.4	BDL[a]	209	BDL[a]	4.41
Boiled	161-343	112-226	57.8-108		175-219		3.32-5.65
Spotted Seal	406 (±111)	415 (±125)	103 (±17)		583 (±249)		7.82 (±6.65)
Muscle	413	430	110	BDL[a]	532	BDL[a]	5.13
Dried	248-559	289-596	73.0-116		370-991		4.34-19.7
Spotted Seal	1991 (±1170)	314 (±35)	22.9 (±15.2)	478 (±155)	415 (±154)	43.0 (± 21.1)	10.5 (±4.4)
Liver	2500	326	13.6	374	362	44.1	8.94
Raw	615-3140	253-340	10.4-41.1	349-671	304-686	20.9-69.3	6.93-17.9
Spotted Seal	2510 (±1524)	415 (±60)	26.4 (±21.3)	456 (±111)	557 (±159)	61.8 (±32.1)	16.1 (±9.8)
Liver	3440	442	12.9	440	493	60.6	15.2
Fried	835-3730	336-482	9.91-57.8	351-626	432-828	24.9-112	4.91-30.8
Spotted Seal	444 (±132)	83.9 (±13.2)	19.9 (±5.8)	3488 (±538)	281 (±58)		16.5 (±4.4)
Kidney	437	84.4	19.0	3740	296	BDL[a]	15.9
Raw	336-661	63.8-99.8	13.6-29.4	2830-4040	182-333		11.1-21.3
Spotted Seal	576 (±200)	113 (±26)	20.4 (±4.4)	2417 (±1273)	541 (±559)		7.79 (±1.45)
Kidney	526	100	21.1	2270	279	BDL[a]	7.47
Boiled	399-908	90.9-151	15.2-25.1	616-4090	245-1540		6.66-10.2
Sheefish	87.7 (±34.5)	69.0 (±23.9)	80.0 (±13.9)		6236 (±3030)		
Muscle	76.7	64.5	76.2	BDL[a]	6466	BDL[a]	BDL[a]
Raw	62.5-169	45.5-117	64.1-99.8		2059-10547		
Sheefish	103 (±39)	93.8 (±28.2)	95.8 (±23.9)		5563 (±2437)		
Muscle	94.8	87.7	85.5	BDL[a]	6147	BDL[a]	BDL[a]
Baked (No Skin)	58.2-185	66.3-160	76.2-148		1979-8309		
Sheefish	102 (±40)	91.9 (±35.4)	90.0 (±7.3)		5810 (±2949)		
Muscle	96.9	81.7	89.6	BDL[a]	6086	BDL[a]	BDL[a]
Baked (With Skin)	62.5-191	56.4-169	79.7-98.5		1695-10455		
Sheefish	158 (±63)	161 (±66)	104 (±17)		10175 (±4863)		
Muscle	133	159	108	BDL[a]	10978	BDL[a]	BDL[a]
Dried (No Skin)	97.8-268	102-306	75.7-125		3326-16697		
Sheefish	161 (±66)	156 (±46)	99.8 (±15.2)		10945 (±5720)		
Muscle	140	153	97.5	BDL[a]	11543	BDL[a]	BDL[a]
Dried (With Skin)	106-311	94.5-256	82.3-123		2816-18962		
Sheefish	108 (±39)	85.6 (±28.5)	80.6 (±14.6)		6772 (±3658)		
Muscle	101	83.5	76.5	BDL[a]	7101	BDL[a]	BDL[a]
Smoked (No Skin)	68.4-195	49.1-148	65.9-109		2120-11827		
Sheefish	105 (±43)	84.6 (±27.5)	82.4 (±7.8)		5735 (±2646)		
Muscle	95.8	80.0	84.8	BDL[a]	5819	BDL[a]	BDL[a]
Smoked (With Skin)	70.0-198	57.4-135	68.4-92.2		2486-10272		

[a]BDL = Below Detection Limit.

Table IVa. Absolute (ppm[a] or ppb[b]) and percent change (%Δ) [mean (±1 SD)][c] in essential and non-essential elements on a *wet weight* basis as a result of food processing for various tissues of spotted seals (n=5) harvested in Kotzebue, Alaska (2004)[d].

Element	Blubber Δ with rendering	Muscle Δ with boiling	Muscle Δ with drying	Liver Δ with frying	Kidney Δ with boiling
Ca	**-6.25 (±0.69)**	+3.18 (±6.73)	**+53.0 (±16.5)**	**+30.8 (±23.1)**	+8.20 (±21.4)
	-85.0 (±3.1)%	+9.9 (±22.7)%	**+170 (±59)%**	**+81.8 (±55.7)%**	+12.0 (±33.4)%
Cu	NA[d]	+0.18 (±0.34)	**+1.82 (±0.69)**	+0.95 (±8.19)	**-0.57 (±1.75)**
		+16.2 (±26.8)%	**+140.5 (±56.3)%**	+20.8 (±57.6)%	**-14.2 (±41.4)%**
Fe	**-2.88 (±0.55)**	**+67.0 (±33.1)**	+345 (±106)	+38.8 (±273)	+45.8 (±35.2)
	-89.7 (±5.0)%	**+33.5 (±14.1)%**	+170.8 (±36.4)%	+43.4 (±118.9)%	+36.7 (±31.8)%
Mg	**-6.97 (±1.10)**	-19.2 (±31.6)	**+369 (±112)**	+24.8 (±20.2)	-12.3 (±40.2)
	-85.8 (±5.1)%	-7.9 (±13.2)%	**+159 (±49)%**	+12.7 (±11.0)%	-9.0 (±28.1)%
Mn	**-21.7 (±2.7)**	+4.80 (±25.5)	**+212 (±106)**	**+1102 (±464)**	-38.8 (±299)
	-56.4 (±5.5)%	+5.7 (±14.9)%	**+128 (±71)%**	**+21.3 (±9.8)%**	-4.9 (±30.9)%
Mo	NA[d]	NA[d]	NA[d]	**+249 (±72)**	+60.3 (±35.6)
				+45.7 (±15.0)%	+49.4 (±28.3)%
K	**-135 (±36)**	**-1114 (±523)**	**+5688 (±1785)**	+88.0 (±464)	**-1224 (±420)**
	-96.4 (±2.0)%	**-33.9 (±14.1)%**	**+179 (±64)%**	+3.5 (±15.0)%	**-47.5 (±16.4)%**
Se	**-124 (±26)**	+51.6 (±135)	**+1007 (±487)**	**+814 (±387)**	-1498 (±1849)
	-89.5 (±6.5)%	+9.9 (±18.0)%	**+155 (±66)%**	**+29.6 (±13.5)%**	-26.1 (±31.4)%
Na	**-103 (±11)**	**-212 (±133)**	**+1023 (±269)**	+161 (±196)	**-822 (±411)**
	-68.0 (±3.2)%	**-35.1 (±17.0)%**	**+185 (±52)%**	+18.8 (±22.3)%	**-43.6 (±19.8)%**
Zn	**-1.48 (±0.99)**	+7.98 (±6.57)	**+34.8 (±12.0)**	**+12.2 (±7.3)**	+9.62 (±12.1)
	-42.2 (±23.2)%	+44.3 (±40.4)%	**+188 (±95)%**	**+30.8 (±20.1)%**	+37.7 (±45.6)%
THg	NA[d]	**+79.4 (±62.1)**	**+225 (±103)**	**+519 (±415)**	+132 (±204)
		+47.2 (±45.2)%	**+130 (±68)%**	**+24.6 (±17.5)%**	+33.9 (±45.1)%
MeHg	NA[d]	+29.6 (±38.5)	**+266 (±130)**	**+101 (±42)**	+28.9 (±26.3)
		+19.8 (±27.3)%	**+184 (±101)%**	**+32.2 (±12.8)%**	+36.5 (±33.8)%
Cd	NA[d]	NA[d]	NA[d]	+21.8 (±207)	+1071 (±1624)
				+4.2 (±43.0)%	-27.0 (±43.4)%
As	-124 (±473)	+2.60 (±64.6)	**+386 (±254)**	+142 (±279)	+261 (±551)
	-3.8 (±15.7)%	+8.2 (±25.7)%	**+217 (±163)%**	+51.9 (±76.8)%	+91.8 (±180.1)%
Ag	NA[d]	NA[d]	NA[d]	+18.9 (±29.7)	NA[d]
				+54.9 (±69.6)%	
Pb	-8.40 (±18.3)	**-1.39 (±1.58)**	-2.09 (±7.12)	+5.64 (±12.2)	**-5.35 (±7.50)**
	-12.3 (±38.3)%	**-36.1 (±22.2)%**	-46.0 (±53.7)%	+118.0 (±191)%	**-40.1 (±26.3)%**

[a]Ca, Cu, Fe, Mg, K, Na and Zn are reported in ppm ww.
[b]Mn, Mo, Se, THg, MeHg, As, Ag, Cd and Pb are reported in ppb ww.
[c]**Bold** text represents statistically significant changes ($p < 0.05$).
[d]NA = Not available because both raw and processed samples were below the analytical detection limit. All samples NA for Cr.

Table IVb. Absolute (ppm[a] or ppb[b]) and percent change (%Δ) [mean (±SD)][c] in essential and non-essential elements on a *wet weight* basis as a result of food processing for muscle tissue of sheefish (n=8) harvested in Kotzebue, Alaska (2005)[d].

Element	Δ with baking (no Skin)	Δ with baking (with skin)	Δ with drying (no skin)	Δ with drying (with skin)	Δ with smoking (no skin)	Δ with smoking (with skin)
Ca	-17.1 (±37.4)	-20.3 (±36.2)	11.0 (±27.1)	67.4 (±101)	-19.6 (±40.5)	-11.4 (±51.4)
	-7.14 (±88.4)%	-34.2 (±40.8)%	+48.8 (±107.2)%	+436 (±702)%	-21.8 (±60.6)%	+48.2 (±205.8)%
Cu	+157 (±229)	+70.5 (±185)	**+352 (±297)**	+513 (±906)	+159 (±213)	+106 (±193)
	+58.5 (±83.7)%	+31.2 (±58.9)%	**+116 (±92)%**	+164 (±267)%	+62.7 (±72.6)%	+39.6 (±60.0)%
Fe	+899 (±1778)	+1543 (±4352)	**+3658 (±3187)**	+1502 (±2818)	+457 (±2091)	+542 (±1782)
	+48.4 (±82.2)%	+91.0 (±210)%	**+144 (±136)%**	+80.7 (±136)%	+19.8 (±62.9)%	+30.9 (±62.9)%
Mg	+16.7 (±75.3)	-25.2 (±74.5)	**+290 (±154)**	**+401 (±151)**	+97.5 (±134)	**-39.9 (±40.5)**
	+4.90 (±19.6)%	-4.73 (±17.2)%	**+71.4 (±41.7)%**	**+99.0 (±41.9)%**	+24.5 (±35.0)%	**-8.92 (±8.38)%**
Mn	+31.1 (±47.8)	+20.0 (±35.7)	**+119 (±46)**	**+198 (±219)**	**+63.6 (±72.2)**	**+65.3 (±52.0)**
	+21.6 (±29.7)%	+14.4 (±21.0)%	**+65.9 (±28.5)%**	**+112 (±139)%**	**+39.9 (±43.7)%**	**+43.3 (±36.1)%**
K	+274 (±751)	-92.8 (±538)	**+3988 (±1325)**	**+5482 (±1770)**	**+1397 (±1181)**	**+1012 (±1450)**
	+5.63 (±14.5)%	-1.58 (±9.39)%	**+73.2 (±26.2)%**	**+100 (±32)%**	**+25.9 (±22.2)%**	**+18.9 (±27.1)%**
Se	+26.3 (±35.2)	+7.50 (±27.5)	**+220 (±118)**	**+291 (±66)**	**+91.3 (±39.7)**	**+75.0 (±31.0)**
	+9.4 (±12.4)%	+2.9 (±9.4)%	**+74.1 (±36.9)%**	**+101 (±29)%**	**+31.5 (±13.1)%**	**+25.9 (±10.8)%**
Na	+93.3 (±124)	+58.9 (±130)	**+499 (±296)**	**+461 (±284)**	+75.0 (±138)	+45.6 (±145)
	+16.9 (±20.3)%	+11.0 (±20.3)%	**+91.5 (±51.0)%**	**+84.8 (±47.4)%**	+15.3 (±24.2)%	+11.0 (±33.1)%
Zn	**+1.02 (±0.87)**	**+0.59 (±0.67)**	**+4.06 (±1.47)**	**+4.26 (±1.56)**	**+1.25 (±0.74)**	**+1.46 (±0.89)**
	+27.7 (±24.6)%	**+16.3 (±17.7)%**	**+106 (±38)%**	**+114 (±49)%**	**+34.3 (±22.1)%**	**+38.6 (±23.3)%**
THg	**+15.0 (±14.3)**	**+14.8 (±9.8)**	**+69.8 (±38.4)**	**+73.8 (±32.8)**	**+20.3 (±10.2)**	**+17.3 (±13.8)**
	+17.9 (±19.7)%	**+16.9 (±11.9)%**	**+80.4 (±37.9)%**	**+83.9 (±19.2)%**	**+24.3 (±14.0)%**	**+19.2 (±15.1)%**
MeHg	**+24.8 (±12.5)**	**+22.9 (±17.1)**	**+91.8 (±47.7)**	**+87.0 (±33.9)**	**+16.6 (±14.0)**	**+15.6 (±15.2)**
	+39.9 (±24.8)%	**+33.8 (±21.5)%**	**+134 (±52)%**	**+137 (±64)%**	**+26.6 (±24.2)%**	**+25.2 (±25.4)%**
As	-0.67 (±1.17)	-0.43 (±0.77)	**+3.94 (±1.97)**	**+4.71 (±3.27)**	+0.54 (±1.57)	-0.50 (±0.78)
	-8.28 (±14.3)%	-7.70 (±10.4)%	**+64.0 (±15.5)%**	**+72.5 (±32.5)%**	+6.50 (±22.2)%	-4.99 (±12.7)%

[a]Ca, Fe, Mg, K, Na, Zn and As are reported in ppm ww.
[b]Cu, Mn, Se, THg and MeHg are reported in ppb ww.
[c]**Bold** text represents statistically significant changes ($p < 0.05$).
[d]NA = Not available because both raw and processed samples were below the analytical detection limit. All samples were NA for Cr, Mo, Cd, Ag and Pb.

Table Va. Absolute (ppm[a] or ppb[b]) and percent change (%Δ) [mean (±SD)][c] in essential ad non-essential elements on a *dry weight* basis as a result of food processing for various tissues of spotted seals (n=5) harvested in Kotzebue, Alaska (2004)[e].

Element	Spotted Seal blubber Δ with Rendering[d]	Spotted Seal muscle Δ with Boiling	Spotted Seal muscle Δ with Drying	Spotted Seal liver Δ with Frying	Spotted Seal kidney Δ with Boiling
Ca	**-6.25 (±0.69)**	-12.1 (±21.5)	-6.53 (±11.9)	+45.9 (±52.6)	-66.2 (±79.9)
	-85.0 (±3.1)%	-11.3 (±21.1)%	-5.4 (±11.9)%	+38.6 (±40.9)%	-23.6 (±27.9)%
Cu	NAe	-0.42 (±0.94)	-0.72 (±0.74)	-9.90 (±24.4)	**-8.12 (±5.67)**
		-6.9 (±19.7) %	-15.5 (±14.8)%	-8.04 (±44.3)%	**-43.9 (±29.7)%**
Fe	**-2.88 (±0.55)**	+39.1 (±114)	-58.4 (±116)	-204 (±794)	-58.9 (±171)
	-89.7 (±5.0)%	+8.0 (±17.6)%	-2.6 (±24.2)%	+11.9 (±99.6)%	-7.10 (±26.4)%
Mg	**-6.97 (±1.10)**	**-211 (±88)**	-74.6 (±91.1)	**-89.9 (±65.6)**	**-245 (±145)**
	-85.8 (±5.1)%	**-26.1 (±8.9)%**	-9.2 (±10.8)%	**-13.9 (±10.2)%**	**-37.8 (±23.1)%**
Mn	**-21.7 (±2.7)**	-104 (±105)	**-132 (±104)**	-1294 (±1568)	**-1503 (±1061)**
	-56.4 (±5.5)%	-14.8 (±14.1)%	**-21.6 (±10.0)%**	-7.36 (±8.70)%	**-34.2 (±26.1)%**
Mo	NA[e]	NA[e]	NA[e]	+190 (±231)	-89.5 (±212)
				+11.4 (±14.0)%	-17.4 (±40.8)%
K	**-135 (±36)**	**-5149 (±852)**	-287 (±1356)	-2090 (±1245)	**-7485 (±1090)**
	-96.4 (±2.0)%	**-47.3 (±8.5)%**	-2.7 (±12.5)%	-21.0 (±11.8)%	**-66.5 (±9.9)%**
Se	**-124 (±26)**	-314 (±404)	-296 (±392)	-194 (±1284)	**-12559 (±6779)**
	-89.5 (±6.5)%	-11.4 (±16.6)%	-10.6 (±15.4)%	-1.06 (±11.2)%	**-51.6 (±21.8)%**
Na	**-103 (±11)**	-948 (±355)	26.1 (±269)	-272 (±509)	**-5110 (±1602)**
	-68.0 (±3.2)%	-48.3 (±11.4)%	+0.7 (±13.9)%	-9.16 (±18.5)%	**-62.6 (±13.9)%**
Zn	**-1.48 (±0.99)**	+7.31 (±20.3)	-1.21 (±34.5)	-2.11 (±20.5)	-13.9 (±44.5)
	-42.2 (±23.2)%	+16.7 (±35.8)%	+10.0 (±63.6)%	-0.19 (±15.4)%	-10.3 (±36.2)%
THg	NA[e]	+85.2 (±209)	-137 (±245)	-155 (±361)	-628 (±966)
		+20.8 (±46.5)%	-13.9 (±43.4)%	-5.10 (±11.7)%	-21.6 (±35.8)%
MeHg	NA[e]	-25.2 (±107)	-17.6 (±133)	+9.95 (±111)	-47.8 (±108)
		-4.51 (±21.1)%	-2.37 (±26.7)%	+1.00 (±11.0)%	-10.5 (±27.3)%
Cd	NA[e]	NA[e]	NA[e]	-0.41 (±0.64)	**-9.25 (±5.86)**
				-19.7 (±36.3)%	**-53.5 (±30.1)%**
As	-124 (±473)	-112 (±158)	+34.4 (±218)	+40.3 (±813)	+127 (±1070)
	-3.8 (±15.7)%	-13.7 (±18.1)%	+7.1 (±34.8)%	+17.4 (±65.2)%	+9.54 (±78.1)%
Ag	NA[e]	NA[e]	NA[e]	+14.9 (±83.3)	NA[e]
				+19.1 (±57.6)%	
Pb	-8.40 (±18.3)	**-7.75 (±6.23)**	-9.85 (±11.4)	+5.51 (±30.3)	**-54.5 (±25.7)**
	-12.3 (±38.3)%	**-36.1 (±22.2)%**	-46.0 (±53.7)%	+37.3 (±114)%	**-68.0 (±14.7)%**

[a]Ca, Cu, Fe, Mg, K, Na, Zn and Cd are reported in ppm dw.
[b]Mn, Mo, Se, THg, MeHg, As, Ag and Pb are reported in ppb dw.
[c]**Bold** text represents statistically significant changes ($p < 0.05$).
[d]Changes in blubber are based on ww values which are assumed to be essentially equivalent to dw values (i.e., 0% water content).
[e]NA = Not available because either raw or processed samples were below the analytical detection limit. All samples were NA for Cr.

Table Vb. Absolute (ppm[a] or ppb[b]) and percent change (%Δ) [mean (±SD)][c] in essential and non-essential on a *dry weight* basis as a result of food processing for muscle tissue of sheefish (n=8) harvested in Kotzebue, Alaska (2005)[d].

Element	Δ with baking no skin	Δ with baking with skin	Δ with drying no skin	Δ with drying with skin	Δ with smoking no skin	Δ with smoking with skin
Ca	-82.0 (±165)	-94.6 (±159)	**-51.2 (±60.1)**	+76.5 (±220)	-96.2 (±175)	-70.4 (±205)
	-22.7 (±70.6)%	-50.4 (±27.4)%	**-31.0 (±46.1)%**	+168 (±311)%	-44.8 (±39.9)%	+10.6 (±159.9)%
Cu	+251 (±732)	-62.2 (±703)	-83.7 (±578)	+276 (±1373)	+121 (±776)	-3.60 (±715)
	+30.1 (±68.0)%	+4.88 (±51.2)%	-1.24 (±39.2)%	+27.0 (±101)%	+21.9 (±61.1)%	+5.26 (±46.7)%
Fe	+829 (±6051)	+2462 (±14822)	+190 (±6582)	-2414 (±6900)	-1601 (±7044)	-1133 (±6536)
	+21.3 (±66.7)%	+54.9 (±179)%	+11.3 (±58.4)%	-8.29 (±60.0)%	-12.1 (±47.8)%	-2.20 (±47.8)%
Mg	-208 (±344)	**-420 (±238)**	**-353 (±274)**	+79.0 (±366)	-150 (±423)	**-518 (±125)**
	-11.8 (±20.7)%	**-23.4 (±13.5)%**	**-21.4 (±16.4)%**	+4.51 (±23.0)%	-8.63 (±26.8)%	**-31.9 (±8.3)%**
Mn	-31.8 (±154)	-92.4 (±114)	**-178 (±178)**	+56.7 (±400)	-11.3 (±217)	+4.85 (±230)
	-0.17 (±18.5)%	-10.8 (±12.8)%	**-22.4 (±18.2)%**	+8.66 (±57.7)%	+1.21 (±26.5)%	+7.14 (±27.8)%
K	-2695 (±3377)	**-4755 (±2272)**	**-4276 (±3363)**	+1363 (±4521)	-1641 (±3733)	-2196 (±5363)
	-11.9 (±15.0)%	**-22.5 (±11.2)%**	**-19.5 (±14.8)%**	+5.40 (±21.1)%	-7.72 (±17.6)%	-10.6 (±24.6)%
Se	-109 (±203)	**-227 (±129)**	**-231 (±168)**	+59.7 (±271)	-45.2 (±186)	-76.3 (±129)
	-8.3 (±16.5)%	**-19.0 (±9.2)%**	**-19.8 (±15.2)%**	+6.6 (±25.5)%	-3.3 (±16.6)%	-5.9 (±10.4)%
Na	-100 (±445)	-269 (±599)	-269 (±703)	-108 (±693)	-391 (±487)	**-450 (±378)**
	-2.95 (±17.58)%	-11.7 (±23.0)%	-9.56 (±30.7)%	-1.01 (±31.38)%	-15.2 (±21.9)%	**-18.5 (±16.9)%**
Zn	+0.71 (±3.19)	-1.35 (±3.06)	-0.78 (±3.21)	+1.73 (±4.50)	-0.41 (±3.12)	+0.59 (±3.46)
	+6.27 (±22.9)%	-8.01 (±18.5)%	-4.10 (±22.2)%	+13.3 (±32.8)%	-1.35 (±21.7)%	+4.07 (±21.3)%
THg	-1.54 (±63.6)	-23.2 (±50.2)	-56.1 (±103)	-0.26 (±56.5)	-28.6 (±44.3)	-29.9(±40.6)
	-1.3 (±21.7)%	-7.7 (±15.7)%	-15.5 (±26.3)%	-3.3 (±17.6)%	-9.2 (±13.9)%	-11.2 (±12.8)%
MeHg	+39.2 (±53.9)	+18.6 (±71.1)	+20.2 (±73.2)	+59.1 (±86.7)	-23.1 (±49.2)	-17.9 (±58.6)
	+15.9 (±18.4)%	+6.29 (±23.3)%	+9.18 (±29.4)%	+24.2 (±36.6)%	-7.8 (±16.4)%	-6.1 (±21.2)%
As	**-6.28 (±6.51)**	**-6.14 (±3.48)**	**-5.33 (±3.23)**	-1.36 (±5.13)	**-4.81 (±4.44)**	**-7.07 (±4.61)**
	-23.0 (±17.0)%	**-27.1 (±12.8)%**	**-23.8 (±10.8)%**	-9.44 (±18.9)%	**-22.1 (±16.9)%**	**-28.9 (±11.0)%**

[a]Ca, Fe, Mg, K, Na, Zn and As are reported in ppm dw.
[b]Cu, Mn, Se, THg and MeHg are reported in ppb dw.
[c]**Bold** text represents statistically significant changes ($p < 0.05$).
[d]NA = Not available because both raw and processed samples were below the analytical detection limit. All samples were NA for Cr, Mo, Cd, Ag and Pb.

Table VI. Mean percent (%) contribution[a,b] of one serving (100g ww) of spotted seal (n=5) and sheefish (n=8) tissue to the Daily Reference Intake (DRI)[c] for select essential elements.

		Element:	Ca	Cu	Fe	Mg	Mn	Mo	Se	Zn
		DRI:	1000 mg/day	900 µg/day	8 mg/day	420 mg/day	1.8 mg/day	45 µg/day	55 µg/day	11 mg/day
Species	Tissue	Processing								
Spotted Seal	Blubber	Raw	0.07	1.28	6.04	0.19	0.21	BDL[d]	25.1	3.00
Spotted Seal	Blubber	Rendered	0.01	BDL[d]	BDL[d]	0.03	0.09	BDL[d]	2.62	1.65
Spotted Seal	Muscle	Raw	0.32	14.5	**256**	5.54	0.94	BDL[d]	**118**	17.8
Spotted Seal	Muscle	Boiled	0.35	16.4	**339**	5.09	0.96	BDL[d]	**127**	25.1
Spotted Seal	Muscle	Dried	0.85	34.7	**686**	14.3	2.12	BDL[d]	**301**	49.5
Spotted Seal	Liver	Raw	0.37	**183**	**490**	4.77	29.5	**123**	**544**	38.3
Spotted Seal	Liver	Fried	0.68	**193**	**539**	5.36	35.6	**178**	**692**	49.4
Spotted Seal	Kidney	Raw	0.65	45.4	**170**	3.66	5.92	26.2	**959**	23.8
Spotted Seal	Kidney	Boiled	0.73	39.1	**227**	3.37	5.71	41.0	**687**	32.6
Sheefish	Muscle	Raw	0.33	3.59	3.56	9.86	1.05	BDL[d]	53.3	3.47
Sheefish	Muscle	Baked (no skin)	0.15	5.33	4.68	10.3	1.22	BDL[d]	58.2	4.39
Sheefish	Muscle	Baked (with skin)	0.12	4.38	5.49	9.26	1.16	BDL[d]	54.7	4.00
Sheefish	Muscle	Dried (no skin)	0.44	7.49	8.13	16.8	1.70	BDL[d]	93.3	7.15
Sheefish	Muscle	Dried (with skin)	1.00	9.29	5.44	19.4	2.15	BDL[d]	**106**	7.34
Sheefish	Muscle	Smoked (no skin)	0.13	5.36	4.13	12.2	1.40	BDL[d]	70.0	4.61
Sheefish	Muscle	Smoked (with skin)	0.21	4.77	4.24	8.90	1.41	BDL[d]	66.9	4.79

[a]**Bold** text highlights contributions of >100% of DRI of a given element by a 100g meal of the specified tissue.
[b]Contributions to the DRI of K and Na are not included because no DRI exists for these elements.
[c]Reference group used for DRI analysis is men ages 31-50.
[d]BDL = No contribution to DRI calculated because element was below detection limit in tissue. All samples were BDL for Cr.

Table VII. Mean percent (%) contribution of one meal (100g ww) of spotted seal (n=5) and sheefish (n=8) tissue to the toxicological reference dose for select non-essential elements[a].

		Element:	THg	MeHg	Cd	As	Ag	Pb
		PTDI/RfD[b,c] (µg/kg/day):	0.71	0.27	1.0	2.1[d]	5.0	3.57
Species	Tissue	Processing						
Spotted Seal	Blubber	Raw	BDL[e]	BDL[e]	BDL[e]	**(184)**	BDL[e]	1.7
Spotted Seal	Blubber	Rendered	BDL[e]	BDL[e]	BDL[e]	**(176)**	BDL[e]	1.3
Spotted Seal	Muscle	Raw	36.6	78.8	BDL[e]	(13.4)	BDL[e]	0.2
Spotted Seal	Muscle	Boiled	52.5	94.7	BDL[e]	(13.6)	BDL[e]	0.2
Spotted Seal	Muscle	Dried	81.7	**220**	BDL[e]	(39.7)	BDL[e]	0.3
Spotted Seal	Liver	Raw	**401**	**166**	68.3	(28.2)	1.2	0.4
Spotted Seal	Liver	Fried	**505**	**220**	65.1	(37.9)	1.8	0.6
Spotted Seal	Kidney	Raw	89.3	44.4	**499**	(19.1)	BDL[e]	0.7
Spotted Seal	Kidney	Boiled	**116**	59.8	**346**	(36.8)	BDL[e]	0.3
Sheefish	Muscle	Raw	17.7	36.5	BDL[e]	**(424)**	BDL[e]	BDL[e]
Sheefish	Muscle	Baked (no skin)	20.7	49.6	BDL[e]	**(378)**	BDL[e]	BDL[e]
Sheefish	Muscle	Baked (with skin)	20.5	48.6	BDL[e]	**(395)**	BDL[e]	BDL[e]
Sheefish	Muscle	Dried (no skin)	31.8	85.2	BDL[e]	**(694)**	BDL[e]	BDL[e]
Sheefish	Muscle	Dried (with skin)	32.4	82.5	BDL[e]	**(748)**	BDL[e]	BDL[e]
Sheefish	Muscle	Smoked (no skin)	21.7	45.3	BDL[e]	**(461)**	BDL[e]	BDL[e]
Sheefish	Muscle	Smoked (with skin)	21.1	44.8	BDL[e]	**(390)**	BDL[e]	BDL[e]

[a]**Bold** text highlights contributions of >100% of PTDI/RfD of a given element by a 100g meal of the specified tissue.
[b]THg, MeHg, Cd, As, Pb: Provisional Tolerable Daily Intake (PTDI): Joint FAO/WHO Expert Committee on Food Additives (JECFA)
[c]Ag: Reference Dose (RfD): United States Environmental Protection Agency (US EPA).
[d]() indicate that the PTDI for As refers to inorganic As, while total As was measured for this study and used for RfD contribution calculations. Because As is expected to be primarily organic in these tissues, contribution is likely overestimated here (see Discussion).
[e]BDL = No contribution to toxicological reference dose calculated because element was below detection limit in tissue.

Percent methylmercury (% MeHg)

%MeHg in raw and food processed tissues is shown in Table III. Muscle had the highest %MeHg, followed by liver and kidney. Both THg and MeHg were below the MDL in all blubber samples, thus %MeHg was not determined. %MeHg in muscle (71.2–104% for seals and sheefish) was significantly higher than both seal liver (22.9% raw and 26.4% fried) and kidney (19.9% raw and 20.4% boiled), but the %MeHg in liver and kidney were not significantly different. %MeHg did not change significantly in any spotted seal tissue when food was processed by any method. Three processing methods (baking with skin, drying without skin, and drying with skin) resulted in significant increases in %MeHg in sheefish muscle. No concurrent significant change in THg concentration was observed. There were no significant differences in %MeHg in sheefish muscle processed by the same method whether skin was present during processing or not.

DISCUSSION

Alaska is unique within the United States in that a significant proportion of its population depends on fish and wildlife as major food sources (35). Shifts from traditional subsistence diets to "Westernized," store-bought diets have coincided with increases in adverse health issues among AK Natives, including obesity, cardiovascular disease and diabetes (3,4,6–9). Although contaminants are generally lower in arctic species than their counterparts from lower latitudes, they remain a concern due to the importance of these species as food sources. The relative benefits of nutritional contributions must be weighed against potential risks posed by the presence of contaminants. Store-bought alternatives to subsistence foods are often limited, may not provide the same level of nutrition and may contain appreciable levels of contaminants themselves (12). Numerous studies have concluded that the risks of consuming nutritionally inferior commercial foods outweigh the risks posed by the contaminant intake associated with a subsistence diet (5,16,20,36,37). However, the recent release of an AK-based fish consumption advisory (38) for Hg has blurred this issue.

Contaminant and nutrient studies in AK have focused primarily on establishing baseline concentration data for use in species monitoring over space and time. Thus, the tissues studied have not necessarily been those utilized most frequently by human consumers for food. Nor have they investigated how contaminants or nutrients may change when a tissue is processed for food. Therefore, true intake of nutrients and contaminants by subsistence users, critical components of a risk-benefit analysis of traditional foods, is unknown. This study focuses on known food tissues in important subsistence species of Northwest AK and documents that these foods contain numerous important nutrients with very limited risk from contaminants, and that element concentrations can be significantly altered through food processing.

Essential and non-essential element concentrations

All elements, except As and Pb, were lower in seal blubber than in muscle, liver or kidney. Typically, either liver or kidney contained the highest concentration of a given element.

In most cases, element concentrations in raw seal tissues were similar to those previously reported for northern ice seals (11,17,39–45). Concentrations of Ca, Cr, K, Na and MeHg in blubber and Ca and K in kidney were not sufficiently represented in the literature to make an adequate comparison. In this study, As was approximately twofold higher in blubber and muscle of spotted seals than previously reported for ringed and harp seals (11,44). This result could be a marker for piscivory or locally elevated As levels from geologic sources and/or activities such as mining. Mg was one-third to one-half that reported in the same studies. Very little data on elements in sheefish exists in published literature. Therefore, the data in this study fill an important gap and were not compared with existing information for this species and region.

Changes due to food processing

Significant changes in nutrient and contaminant concentrations of tissues resulted from food processing in several cases. Changes were determined not only on a ww basis but also on a dw basis to account for concentration changes resulting from changes in water content. This is a critical consideration for determining risks and benefits to human consumers, as the contribution to DRI or TDIL is subsequently affected and potential mechanisms for compositional changes can be proposed.

As an example, raw sheefish muscle provides 53.3% of the DRI for Se per serving. This value does not change significantly for baked fish, but if the fish consumed is smoked or dried, the contribution to DRI increases to 70.0/66.9% (cooked without/with skin) and 93.3/106%, respectively. Similarly, the contribution to TDIL for Cd in spotted seal kidney decreases significantly from 449% to 368% when kidney is boiled as compared to when it is raw. Therefore, the contribution to TDIL is overestimated if only raw kidney is considered.

Thus, preparation method must be considered when assessing nutrients and contaminants in traditional foods. By basing DRI and TDIL determinations only on concentrations in raw tissues, the contribution to DRI or TDIL may be grossly under- or overestimated for the actual food items consumed.

Contributions to daily reference intakes (DRI) and upper limits (UL)

As expected, traditionally prepared foods provide a number of nutrients at >100% of the DRI per 100 g serving. In addition, these foods provide many nutrients in moderate amounts (i.e., 10–100% per 100 g serving) while others, such as Ca and Cr, were not represented in any tissue at ≥10% of their respective DRI's. These results support the assertion that traditional foods represent an important, nutritious part of a balanced diet.

In addition to the danger posed by a lack of nutrition, some essential elements can become harmful at excessive doses. Therefore, UL have been developed in addition to minimal requirements. Fe in dried seal muscle and Se in raw kidney exceeded the UL for these elements. It should be noted though that UL are *daily* limits. The seasonal nature of subsistence foods makes it extremely unlikely that any given food item would be eaten every day of the year. In addition, 100 g may be an overestimate of a typical serving size for dried seal meat. Finally, raw kidney is not an abundant food item as compared to the mass of other tissues and is included in this study primarily for comparison to processed kidney. Based on

these considerations, there does not appear to be a significant threat of essential element toxicosis from consuming these traditional foods. Element interactions are another important consideration, but are beyond the scope of this work.

Contribution to tolerable daily intake limits

Although Alaskan wildlife is generally less contaminated than wildlife at lower latitudes, several contaminants are still detectable in all tissues of these animals. The non-essential elements investigated may have natural and/or anthropogenic sources. Contaminant levels approached or exceeded TDIL in some cases.

When interpreting TDIL, one must remember that these values are very conservative and represent the amount that can be consumed *every day over an entire lifetime* without risk of adverse health effects. Due to the seasonality of subsistence foods, it is extremely unlikely that any food item studied would be eaten every day of the year for an entire lifetime. On the other hand, these risks are only those originating from individual food items. Humans consume a range of foods and must also consider contaminant intake from multiple sources. Further, the above assessments do not take into account the chemical form of some elements, a critical factor for assessing potential toxicity.

It is not our intent that comparisons of element concentrations to DRI and TDIL be interpreted as consumption advice. This analysis was used to put concentration values into a useful context in terms of human consumption guidelines and to facilitate comparisons between tissues and between the current study and the available published literature. We recognize that it is the responsibility of public health agencies to consider the information presented here and to provide consumption advice accordingly. The data have been provided to public health agencies in Alaska, including the Alaska Division of Public Health, Department of Health and Social Services and the Alaska Native Tribal Health Consortium.

Arsenic speciation considerations

Only total As was measured in this study. The chemical form of the As present was not determined. Like Hg, As can exist in organic or inorganic forms, yet the PTDI does not take into consideration the relative amounts of each form present. Inorganic As is of greater concern in terms of toxic effects to a consumer. It is well known that As in marine mammals is primarily in the organic form (46). Studies have shown that >90% of the As present is organic with >70% being organic arsenobetaine (47–50). Similarly, fish muscle contains 75–100% organic As (51–53). Therefore, the fact that As was above TDIL in seal blubber and sheefish muscle should be interpreted carefully. It is likely that the levels present in this study do not pose a toxicological risk, but a complete investigation of the As speciation in these tissues is needed to make this conclusion with greater certainty.

Percent methylmercury (%MeHg)

When considering implications of Hg in foods, it is critical to take into account the chemical and physical forms represented. MeHg is the main form of concern, since it can be present in appreciable amounts, is relatively bioavailable and is a known neurotoxicant (54). This

is particularly true for the developing central nervous systems of fetuses and children (55), making them the cohort of greatest concern. Inorganic mercury is considered less toxic because it has lower bioavailability and may be bound to selenium in insoluble Hg-Se complexes. MeHg is present in fish and marine mammals, but whether it occurs at levels that may cause subtle neurotoxic effects in human consumers of these species has been widely debated. Long-term studies indicate that the benefits obtained from the nutrients (e.g., Se, ω-3 fatty acids) in these foods outweigh any danger posed by the presence of MeHg (37).

%MeHg must be considered together with the THg concentration. A tissue with low %MeHg can still contribute significant levels of MeHg if the THg concentration is substantial. For example, the %MeHg in spotted seal liver (22.9% and 26.4% for raw and fried, respectively) is much lower than that in muscle (86.4%, 71.2% and 103% for raw, boiled and dried). However, because the THg level in liver (1991 and 2510ng/g for raw and fried) is greater than in muscle (182, 261 and 406ng/g for raw, boiled and dried), a serving of liver contributes more MeHg to the diet than an equivalent serving of muscle.

Mercury–Selenium interactions

Another important consideration for determining potential toxicity of Hg in foods is the relative ratio of Hg to Se in the tissue. Studies suggest Se may be highly effective in reducing Hg toxicity, though human data are lacking (56). The exact mechanism of the protective role of Se against Hg toxicity is unknown. The leading hypothesis is that Se protects against Hg by forming insoluble complexes with Hg, rendering it non-bioavailable (57). Others suggest the mechanism may be related to the antioxidant properties of Se, for example as glutathione peroxidase (GSH-Px), which may protect against Hg toxicity and be involved in demethylation of MeHg (58). For human consumers, intake of tissues with Se in excess of Hg could potentially aid in reducing the bioavailability of Hg and/or mitigating the systemic toxic effects of Hg.

In all tissues studied, Se:THg molar ratio was significantly >1 (student t-test; $p<0.05$). In spotted seals, Se:Hg was lowest in liver (4.84–5.22), followed by muscle (7.05–10.7) and highest in kidney (17.8–31.5). Se:Hg in sheefish muscle was similar (8.35–10.3) to that found in seals. These results indicate that although these traditional foods contain Hg, they are also rich in Se, which may help to counteract any toxic effects of Hg.

Conclusions

Cooking can have significant effects on the concentration of elements in a tissue, illustrating the importance of looking at the actual food items consumed when considering the risks and benefits of a traditional diet.

Spotted seal and sheefish tissues were abundant sources of several nutrients. The consumption of these traditional foods does not appear to pose a significant threat due to essential elements exceeding their established UL. Although certain non-essential elements exceeded their respective TDIL in certain food items, considerations of element interactions (Se/Hg), bioavailabilty (Hg-Se complexes) and chemical form (organic vs. inorganic Hg or As) as well as the seasonal nature of subsistence food use, lead to the conclusion that the risk posed by contaminant intake via these items is relatively low.

Overall, the results suggest that the traditional foods investigated provide an array of nutrients accompanied by a very limited risk of contaminant toxicosis. Therefore, we encourage the continuation of traditional food consumption as a nutritious part of a balanced diet. Because the current work was interpreted in terms of a 70 kg male human consumer, the data would need to be re-evaluated for other consumer cohorts, particularly children and women of childbearing age who may have different nutrient requirements or capacity to tolerate contaminants without ill effect. The data presented here could be used by public health agencies in the future to support the development of cohort-specific consumption advice. It is our intent that the data presented here be treated as a risk-benefit analysis, not consumption advice, which should be provided only by appropriate public health agencies. Finally, we encourage public health agencies to develop models or algorithms to assess overall food safety and quality for underrepresented diets, such as the subsistence diet of many Alaska residents.

Acknowledgements

We greatly appreciate the participation and generosity of the Native Village of Kotzebue and the hunters and fishers of Kotzebue, AK, without whom this project would not have been possible. We are grateful to R. Swor, K. Knott, T. Cardona-Marek, B. Brattin and D. Perry for analytical assistance; L. Verbrugge and G. Myers for critical review of the manuscript; and R. Schaeffer and E. Schiedt for development of the project. We thank T. Rowles (NOAA) for including us as co-investigators on MMHSRP permit (#932-1489-05) for possession and shipment of marine mammal tissues. The project described was supported by Grant Numbers 5P20RR016430 and 5P20RR016466 from the National Center for Research Resources (NCRR), a component of the National Institutes of Health (NIH). Its contents are solely the responsibility of the authors and do not necessarily represent the official views of NCRR or NIH.

REFERENCES

1. Caulfield RA. Food security in arctic Alaska: A preliminary assessment. In: Duhaime G, editor. Sustainable food security in the Arctic – state of knowledge. Quebec City: Canadian Circumpolar Institute Press; 2002. pp. 75–94.
2. Duhaime G. Tradition, modernity, and food among northern peoples. In: Duhaime G, editor. Sustainable food security in the Arctic – state of knowledge. Quebec City: Canadian Circumpolar Institute Press; 2002. pp. 1–12.
3. McLaughlin JB, Middaugh JP, Utermohle CJ, Asay ED, Fenaughty AM, Eberhart-Phillips JE. Changing patterns of risk factors and mortality for coronary heart disease among Alaska natives, 1979–2002. JAMA 2004;291:2545–2546.
4. Rith-Najarian SJ, Gohdes DM, Sheilds R, Skipper B, Moore KR, Tolbert B, et al. Regional variation in cardiovascular disease risk factors among American Indians and Alaska Natives with diabetes. Diabetes Care 2002;25:279–283.
5. Arnold SM, Middaugh JP. Use of traditional foods in a healthy diet in Alaska: risks in perspective. 2nd ed. Volume 2. Mercury. State of Alaska Epidemiology Bulletin 2004;8:1–48.
6. Ebbesson SO, Alder AI, Risica PM, Ebbesson LO, Yeh JL, Go OT, et al. Cardiovascular disease and risk factors in three Alaskan Eskimo populations: The Alaska-Siberia Project. Int J Circumpolar Health 2005;64: 365–386.
7. Ebbesson SO, Risica PM, Ebbesson LO, Kennish JM. Eskimos have CHD despite high consumption of omega-3 fatty acids: The Alaska-Siberia Project. Int J Circumpolar Health 2005;64:387–395.
8. Ebbesson SO, Risica PM, Ebbesson LO, Kennish JM, Telero 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;64:396–408.
9. Ebbesson SO, Ebbesson LO, Swenson M, Kennish JM, Robbins DC. A successful diabetes prevention study in Eskimos: The Alaska-Siberia Project. Int J Circumpolar Health 2005;64:409–424.

10. 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.
11. 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;37:711–721.
12. O'Hara TM, Hoekstra PF, Hanns C, Backus SM, Muir DCG. Concentrations of selected persistent organochlorine contaminants in store-bought foods from northern Alaska. Int J Circumpolar Health 2005;64: s303–313.
13. Blanchet C, Dewailly E, Ayotte P, Bruneau S. Contribution of selected traditional and market foods to the diet of Nunavik Inuit women. Can J Diet Pract Res 2000;61:50–59.
14. Blanchet C, Dewailly E, Chaumette P, et al. Diet profile of circumpolar Inuit. In: Duhaime G, editor. Sustainable food security in the Arctic – state of knowledge. Quebec City: Canadian Circumpolar Institute Press; 2002. pp. 47–60.
15. Booth S, Zeller D. Mercury, food webs, and marine mammals: implications of diet and climate change for human health. Environ Health Perspect 2005;113: 521–526.
16. Egeland GM, Feyk LA, Middaugh JP. The use of traditional foods in a healthy diet in Alaska: risks in perspective. State of Alaska Epidemiology Bulletin 1998; Bulletin 6. 140 pp.
17. Dehn LA, Sheffield GG, Follmann EH, et al. Trace elements in tissues of Phocid seals harvested in the Alaskan and Canadian Arctic: influence of age and feeding ecology. Can J Zool 2005;83:726–746.
18. Dehn LA, Follmann EH, Rosa C, Duffy LK, Thomas DL, Bratton GR, et al. Stable isotope and trace element status of subsistence-hunted bowhead and beluga whales in Alaska and gray whales in Chukotka. Mar Pollut Bull 2006;52:301–319.
19. Hoekstra PF, O'Hara TM, Pallent S, Solomon KR, Muir DCG. Bioaccumulation of organochlorine contaminants in bowhead whales (Balaena mysticetus) from Barrow, Alaska. Arch Environ Contam Toxicol 2002;42:497–507.
20. 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: 329–340.
21. Krone CA, Robisch PA, Tilbury KL, et al. Elements in liver tissues of bowhead whales (Balaena mysticetus). Mar Mamm Sci 1999;15:123–142.
22. 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.
23. Rothschild RFN, Duffy LK. Preliminary study on total mercury in the common prepared subsistence foods of a rural Alaskan village. Alaska Med 2002;44: 89–103.
24. Whiting A. Native Village of Kotzebue Harvest Survey program 2002–2003–2004: results of three consecutive years cooperating with Qikiqtagrugmiut to understand their annual catch of selected fish and wildlife. 2006. (Unpublished observation).
25. Becker PR, Wise SA, Koster BJ, Zeisler R. Alaska Marine Mammal Tissue Archival Project: Revised Collection Protocol. U.S. National Institute of Standards and Technology (NIST) Interagency Report 4529. U.S. Dept. of Commerce, NIST, Gaithersburg, MD: U.S. Dept. of Commerce (NIST) 1991; 36 pp.
26. Brown RJ, Bickford N, Severin K. Otolith trace element chemistry as an indicator of anadromy in Yukon River drainage coregonine fishes. Trans Am Fish Soc 2007;136:678–690.
27. U.S. Environmental Protection Agency. Methods for the determination of metals in environmental samples. Boca Raton, FL: CRC Press; 1992. 352 pp.
28. Bloom NS. Determination of pictogram levels of methylmercury by aqueous phase ethylation followed by cryogenic gas chromatography with cold vapor atomic fluorescence detection. Can J Fish Aquat Sci 1989;46:1131–1140.
29. Otten JJ, Hellwig JP, Meyers LD, eds. Dietary reference intakes: the essential guide to nutrient requirements. Washington, D.C.: National Academies Press; 2006. 560 pp.
30. Joint FAO/WHO Expert Committee on Food Additives (JECFA). 1978. Evaluation of certain food additives and contaminants. WHO Technical Report Series, No. 631.
31. Joint FAO/WHO Expert Committee on Food Additives (JECFA). 1989. Evaluation of certain food additives and contaminants. WHO Technical Report Series, No. 776.
32. Joint FAO/WHO Expert Committee on Food Additives (JECFA). 1999. Evaluation of certain food additives and contaminants. WHO Technical Report Series, No. 896.
33. Joint FAO/WHO Expert Committee on Food Additives (JECFA). 2005. Evaluation of certain food contaminants. WHO Technical Report Series, No. 930.
34. Joint FAO/WHO Expert Committee on Food Additives (JECFA). 2006. Evaluation of certain food additives and contaminants. WHO Technical Report Series, No. 940.
35. Verbrugge LA, Middaugh JP. Use of traditional foods in a healthy diet in Alaska: risks in perspective. 2nd ed. Volume 1. Polychlorinated biphenyls (PCBs) and related compounds. State of Alaska Epidemiology Bulletin 2004; 8:1–62.
36. Kinloch D, Kuhnlein H, Muir DCG. Inuit foods and diet: a preliminary assessment of benefits and risks. Sci Total Environ 1992;122:247–278.
37. Meyers GJ, Davidson PW, Strain JJ. Nutrient and methyl mercury exposure from consuming fish. J Nutr 2007;137:2805–2808.
38. Verbrugge LA. Fish consumption advice for Alaskans: A risk management strategy to optimize the public's health. 2007. State of Alaska Epidemiology Bulletin 11: 44 pp.

39. Becker PR, Mackey EA, Demiralp R, Schantz MM, Koster BJ, Wise SA. Concentrations of chlorinated hydrocarbons and trace elements in marine mammal tissues archived in the U.S. National Biomonitoring Specimen Bank. Chemosphere 1997;34:2067–2098.
40. Brunborg LA, Julshamn K, Nortvedt R, Froyland L. Nutritional composition of blubber and meat of hooded seal (Cystophora cristata) and harp seal (Phagophilus groenlandicus) from Greenland. Food Chem 2006;96:524–531.
41. Goessler W, Rudorfer A, Mackey EA, Becker PR, Irgolic KJ. Determination of arsenic compounds in marine mammals with high-performance liquid chromatography and an inductively coupled plasma mass spectrometer as element-specific detector. Appl Organometal Chem 1998;12:491–501.
42. Mackey EA, Becker PR, Demiralp R, Greenberg RR, Koster BJ, Wise SA. Bioaccumulation of vanadium and other trace metals in livers of Alaskan cetaceans and pinnipeds. Arch Environ Contam Toxicol 1996;30:503–512.
43. 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.
44. Yeats P, Stenson G, Hellou J. Essential elements and priority contaminants in liver, kidney, muscle and blubber of harp seal beaters. Sci Total Environ 1999;243/244:157–167.
45. Zeisler R, Demiralp R, Koster BJ, Becker PR, Burow M, Ostapczuk P, et al. Determination of inorganic constituents in marine mammal tissues. Sci Total Environ 1993;139/140:365–386.
46. Neff JM. Ecotoxicology of arsenic in the marine environment. Environ Toxicol Chem 1997;16:917–927.
47. 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 Balaene mysticetus from Alaska's north coast. Report to the North Slope Borough Department of Wildlife Management. Barrow, AK. February 6, 1997. 233 pp.
48. Ebisuda K, Kunito T, Kubota R, Tanabe, S. Arsenic concentrations and speciation in the tissues of ringed seals (Phoca hispida) from Pangnirtung, Canada. Appl Organometal Chem 2002;16:451–457.
49. Kubota R, Kunito T, Tanabe S. Arsenic accumulation in the liver tissue of marine mammals. Environ Pollut 2001;115:303–312.
50. Kubota R, Kunito T, Fujihara J, Tanabe S, Yang J, Miyazaki N. Placental transfer of arsenic to fetus of Dall's porpoises (Phocoenoides dalli). Mar Pollut Bull 2005;51:845–849.
51. Richtera P, Seguel R, Ahumada I, Verdugo R, Narvaez J, Shibatac Y. Arsenic speciation in environmental samples of a mining impacted sector of central Chile. Chil Chem Soc 2004;49:333–339.
52. Slejkovek Z, Bajc Z, Doganoc D. Arsenic speciation patterns in freshwater fish. Talanta 2003;62:931–936.
53. U.S. Environmental Protection Agency. Technical summary of information available on the bioaccumulation of arsenic in aquatic organisms. EPA-822-R-03-032; 2003. 102 pp.
54. Clarkson TW, Magos L, Meyers GJ. The toxicology of mercury – current exposures and clinical manifestations. N Engl J Med 2003;349:1731–1737.
55. Burbacher TM, Rodier PM, Weiss B. Methylmercury developmental neurotoxicity: A comparison of effects in humans and animals. Neurotoxicol Teratol 1990;12:191–202.
56. Chapman L, Chan HM. The influence of nutrition on methyl mercury intoxication. Environ Health Perspect 2000;108 Suppl 1:29-56.
57. Cuvin-Aralar MLA, Furness RW. Mercury and selenium interaction: A review. Ecotoxicol Environ Saf 1991;21:348–364.
58. Woshner V, Knott K, Wells R, Willetto C, Swor R, O'Hara T. Mercury and selenium in blood and epidermis of bottlenose dolphins (Tursiops truncatus) from Sarasota Bay, FL: interaction and relevance to life history and hematologic parameters. Ecohealth; 2008; Published online 25 Mar 2008. Available from: http://www.springerlink.com/content/11082/?K=woshner

Sara K. Moses
Institute of Arctic Biology
University of Alaska Fairbanks
P.O. Box 757000
Fairbanks, AK 99775-7000
USA
Email: ftskm1@uaf.edu