Multi-elements, Radionuclides and Persistent Organics in Tissues of Mountain Goats in Northwest Territories

NICHOLAS C. LARTER,[1] *Department of Environment & Natural Resources, Government of the Northwest Territories, P.O. Box 240, Fort Simpson, NT X0E0N0, Canada*
COLIN R. MACDONALD, *Northern Environmental Consulting & Analysis, Inc., Box 374, Pinawa, MB R0E 1L0, Canada*
DEREK MUIR, *Environment Canada, 867 Lakeshore Road, Burlington, ON L7S 1A1, Canada*
BRETT T. ELKIN, *Department of Environment & Natural Resources, Government of the Northwest Territories, P.0. Box 1320, Yellowknife, NT X1A 2L9, Canada*
XIAOWA WANG, *Environment Canada, 867 Lakeshore Road, Burlington, ON L7S 1A1, Canada*

ABSTRACT There has been limited study on mountain goats (*Oreamnos americanus*) inhabiting the Mackenzie Mountains of the Northwest Territories (NT), Canada. As part of a larger study on sympatric ungulates of the area, we collected kidney, liver, and muscle samples from adult male mountain goats to document concentrations of heavy metals and other elements, persistent organic pollutants (POPs), and radionuclides, as well as stable isotope signatures. Most elemental concentrations were higher in kidney; only aluminum, magnesium, potassium and antimony were higher in muscle tissue. Cadmium had the highest kidney:muscle (251) ratio; mean concentration in kidney was 28.3 mg/kg (dry weight). Mean total mercury in kidney was 0.3 mg/kg (dry weight). ^{137}Cs and ^{40}K levels were relatively consistent, with means of 6.46 and 108 Bq/kg, respectively. ^{134}Cs presence in only the 2011 samples is a clear marker of deposition from the 2011 Fukushima nuclear accident in Japan. POPs were present at sub-ng/g (wet weight, ww) concentrations in liver similar to measurements in other ungulates in the NT. Chlorobenzenes (0.49 ± 0.12 ng/g ww), toxaphene (0.40 ± 0.32 ng/g ww), and DDT-related compounds (0.29 ± 0.21 ng/g ww) were the major POPs detected. Mean stable isotope signatures for δ^{13}C (-24.8‰) and δ^{15}N (1.53‰) reflect the generalist diet composition. Based upon the low reported concentrations of trace elements and radionuclides, no concerns about consumption of mountain goats were identified in an assessment of the data by health authorities.

Biennial Symposium of the Northern Wild Sheep and Goat Council 19:98-107; 2014

KEY WORDS cadmium, kidney, *Oreamnos americanus*, Mackenzie Mountains, mercury, muscle, Northwest Territories, persistent organic pollutants, radiocesium, radionuclide, stable isotope.

In the Northwest Territories (NT), Canada, mountain goats (*Oreamnos americanus*) are distributed in the southern portion of the 130,000-km^2 Mackenzie Mountains, which are located along the Yukon-NT border generally south of 63°00' N latitude (Fig. 1). Studies of mountain goats in the NT have been extremely limited (Veitch et al. 2002). More recently, aerial surveys have been conducted in different parts of the range to estimate population size; the current best estimate of the population is 1,200-1,500 animals (N. Larter, Government of the Northwest Territories, unpublished report). Because of the inaccessibility of the area,

[1] *E-mail: nic_larter@gov.nt.ca*

harvest is limited and is almost exclusively by non-resident trophy hunters. From 1967-2013, non-residents harvested 313 goats; there is no annual quota (N. Larter, unpublished data).

The concentration of Cd in organs of moose inhabiting the study area is high (Gamberg et al. 2005, Larter 2009) and has previously resulted in consumption advisories by Health Canada (Larter and Kandola 2010). These consumption advisories are based on maintaining the concentrations of Cd in the human diet below levels at which histological effects may develop in the human kidney. The World Health Organization has recommended a provisional tolerable monthly intake of 25 µg Cd/kg body weight or 1,500 µg/month for a 60 kg person (Joint FAO/WHO Expert Committee on Food Additives 2010), while the European Food Safety Authority has recommended a weekly intake of 2.5 µg Cd/kg body weight (European Food Safety Authority 2012). These recommendations are based on an assessment of the total intake of Cd from all sources and improved understanding of the possible adverse effects in the human kidney. Histological samples of moose (*Alces alces*) kidneys from the Mackenzie Mountains showed cellular changes that could be attributed to Cd exposure (N. Larter, unpublished data). To our knowledge, mountain goats have not previously been analyzed for persistent organic pollutants (POPs). Concentrations of POPs in other northern ungulates, such as caribou (*Rangifer tarandus*) and moose, are generally very low (Muir et al. 2013). Kelly and Gobas (2001) reported total polychlorinated biphenyls (ΣPCBs) of about 0.4 ng/g (wet weight (ww)) in female caribou liver from the Bathurst Inlet area of Nunavut. ΣPCBs averaged 0.86 ± 0.78 ng/g (ww) in liver of moose in the southwestern NT (N. Larter et al. unpublished data). Mountain goat meat from harvested animals is provided to residents of local communities for consumption; however, the concentrations of contaminants in mountain goat in the study area are unknown. The objectives of this study were to 1) document the levels of various elements, POPs, and radionuclides in tissues of mountain goat; 2) compare the levels to those of sympatric wildlife; 3) assess the reported levels from a human consumption perspective; and 4) document stable isotope levels to provide some baseline information on the diet of mountain goats relative to other large mammals in the area.

STUDY AREA

The Mackenzie Mountains cover both the western NT and eastern Yukon Territory (YT) of northwestern Canada. The NT portion of the range covers approximately 130,000 km^2 between the Mackenzie River and the border with the YT (Fig. 1). The Mackenzies are a system of irregular mountain masses resulting primarily from deformation and uplift (Simmons 1968). Because they are comprised primarily of limestone, dolomite,

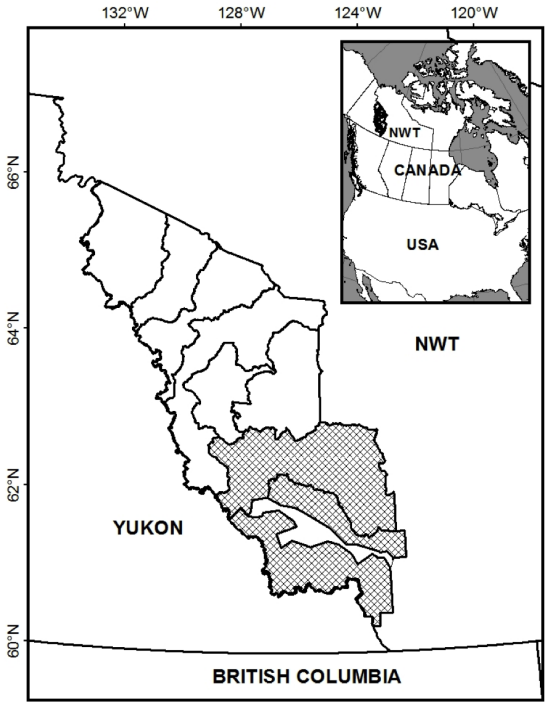

Figure 1. Location of the study area in the Mackenzie Mountains, Northwest Territories, Canada. Samples were collected in the hatched area.

and shale, they have been heavily eroded, producing unstable rubble slopes over large areas (Simmons 1982) and many spectacular canyons, ravines, and rock outcrops. Along the YT-NT border, some peaks reach 2,700 m and a few active glaciers occur (the Backbone Range), whereas along the eastern front range (the Canyon Range), the topography is generally more gentle (1,000-2,000 m). The average frost-free season lasts only 70-75 days and total annual precipitation is between 25 and 30 cm (Simmons 1968). Mountain goats occur almost exclusively below 63°00'N (Veitch et al. 2002), being most numerous in high relief terrain between 61°00' and 62°00'N. The other major large mammal species that occur across most of the mountain range include: Dall's sheep (*Ovis dalli*), northern mountain caribou, moose, grizzly bear (*Ursus arctos*), wolf (*Canis lupus*), and wolverine (*Gulo gulo*).

METHODS

We requested licensed outfitters to voluntarily submit a sample of muscle and liver tissue and a whole kidney from mountain goats harvested by their clients during the August and September hunting seasons in 2011, 2012, and 2013. All goats were harvested during the 3 August to 17 September time period annually. We provided outfitters with sampling kits and sampling instructions for the different tissues being collected. Data on sex, age (based upon counting horn annuli), and general location were also collected. Samples were kept cool or frozen at the main guide camps before being transported to the Fort Simpson regional office where we prepared and stored samples frozen prior to shipping to the various laboratories for analysis.

Following Larter (2009), a bilateral sample of kidney and a sample of muscle tissue (50 g ww) were analyzed for 33 elements by Inductively Coupled Plasma-Sector Field spectrometry (ICP-SFMS Instrumental) at the National Laboratory for Environmental Testing (NLET) at National Water Research Institute in Burlington, Ontario (National Laboratory for Environmental Testing 2003). Total mercury (NLET Method 02-2802) was analyzed by cold vapor atomic absorption spectrometry. The detection limit for most elements is 0.0001 mg/kg ww, but varied for other specific elements (Table 1). We reported data on a ww basis and converted it to a dry weight basis using tissue-specific moisture values. Accuracy and recovery rates were monitored using dogfish liver (DOLT-4), dogfish muscle (DORM-2), and lobster hepatopancreas (TORT-2) standards from the National Research Council of Canada. Using direct gamma spectrometry, Becquerel Laboratories (Mississauga, ON) analyzed gamma-emitting natural and anthropogenic radionuclides in muscle samples (≥ 100 g ww). The radioactivity in samples was counted using a 50% relative efficiency hyper-pure germanium detector, with samples as fresh weight, for count times of 7-24 hours, and occasionally longer, to quantify the low levels of ^{134}Cs. We report concentrations backdated to the day of collection using standard decay constants for the individual nuclides. The methods quantified ^{134}Cs and ^{137}Cs, which were known to be released from the 2011 Fukushima nuclear accident in Japan, and ^{40}K, a radioactive isotope of potassium that is present in all biological material.

Liver samples were analyzed for PCBs, organochlorine pesticides (OCPs), and other chlorinated organics (OCOs), following US Environmental Protection Agency Method 1699 (US Environmental Protection Agency 2007) by ALS Global Laboratories (Burlington, ON). In brief, samples were thawed, thoroughly homogenized in a small stainless steel blender. Subsamples (3.5 g ww) were Soxhlet extracted with dichloromethane and lipid was removed by gel permeation chromatography. Percent lipid was determined gravimetrically on a subsample of the extract. Extracts were cleaned up on a silica gel column. Final extracts were analyzed

Table 1. Mean concentrations (mg/kg wet weight) of elements (with standard deviation and range) for muscle (n = 9) and kidney (n = 13) samples collected from mountain goats in the Mackenzie Mountains, Northwest Territories, Canada. Kidney:muscle concentration ratios calculated on a dry weight basis. Detection limits (DL) indicated for each element.

		Muscle			Kidney			
Element	**DL**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**Ratio**
Total Mercury	0.002	0.0048	0.0039	< DL-0.011	0.03	0.04	0.006-0.16	7.18
Antimony	0.001	0.03	0.05	0.003-0.165	0.01	0.01	< DL-0.05	0.26
Aluminum	0.02	7.19	13.5	0.11-41.4	0.28	0.28	0.05-1.15	0.04
Arsenic	0.002	0.03	0.029	0.005-0.08	0.022	0.02	< DL-0.07	0.82
Barium	0.001	0.69	1.14	0.02-3.44	0.39	0.28	0.14-1.14	0.56
Beryllium	0.0001	0.00039	0.001	< DL-0.002	< DL		< DL-0.0004	0.33
Bismuth	0.0001	0.00021	0.002	< DL-0.0006	< DL		< DL-0.0003	0.52
Cadmium	0.001	0.02	0.014	0.004-0.05	5.78	6.32	1.07-22	252
Calcium	0.001	118	125	22.8-359	76.8	14.5	59.5-116	0.65
Cobalt	0.001	0.02	0.03	0.002-0.10	0.04	0.02	0.02-0.08	2.44
Chromium	0.002	0.23	0.35	0.015-1.15	0.06	0.07	0.005-0.21	0.28
Cesium	0.001	0.23	0.16	0.08-0.57	0.20	0.18	0.02-0.59	0.87
Copper	0.001	1.54	0.66	0.67-3.03	2.76	0.39	2.27-3.4	1.79
Iron	0.001	41.29	29.2	17-116	44.0	18.8	22.9-81.3	1.07
Gallium	0.0001	0.0028	0.01	< DL-0.016	0.0002	0.0002	< DL-0.0007	0.08
Lanthanum	0.0002	0.02	0.02	0.0003-0.07	0.0013	0.0013	0.0003-0.0048	0.09
Lithium	0.02	0.03	0.04	0.01-0.12	0.08	0.06	0.01-0.19	3.01
Magnesium	0.0001	221	19.4	199-245	130	10.6	117-149	0.59
Manganese	0.0001	0.46	0.72	0.11-2.35	0.84	0.21	0.53-1.3	1.82
Molybdenum	0.0001	0.01	0.01	0.001-0.024	0.32	0.14	0.15-0.64	40.4
Nickel	0.01	0.06	0.08	0.009-0.27	0.05	0.03	0.01-0.10	0.85
Lead	0.001	0.11	0.27	0.003-0.84	0.03	0.02	0.005-0.08	0.25
Palladium	0.01	< DL		< DL	< DL		< DL	1.46
Platinum	0.001	< DL		< DL	< DL		< DL	1.46
Potassium	0.001	3456	461	2770-4310	2237	181	2060-2580	0.65
Rubidium	0.001	8.48	2.97	3.64-12.9	6.91	2.54	2.43-10.2	0.81
Selenium	0.001	0.30	0.23	0.02-0.64	1.16	0.58	0.43-2.24	3.87
Silver	0.0001	< DL		< DL-0.0003	0.0014	0.0014	0.0003-0.005	14.7
Tin	0.02	0.14	0.13	0.01-0.33	0.13	0.10	< DL-0.35	0.96
Strontium	0.001	0.16	0.24	0.018-0.751	0.09	0.03	0.03-0.13	0.59
Thallium	0.0001	0.0013	0.00	< DL-0.01	0.02	0.0242	0.0025-0.09	12.5
Uranium	0.0001	0.0012	0.00	< DL-0.01	0.0016	0.0019	0.0002-0.0064	1.29
Vanadium	0.001	0.04	0.08	0.001-0.25	0.0017	0.0009	< DL-0.003	0.05
Zinc	0.0001	39.8	13.5	27.8-72.5	24.8	6.02	19.3-39.9	0.62

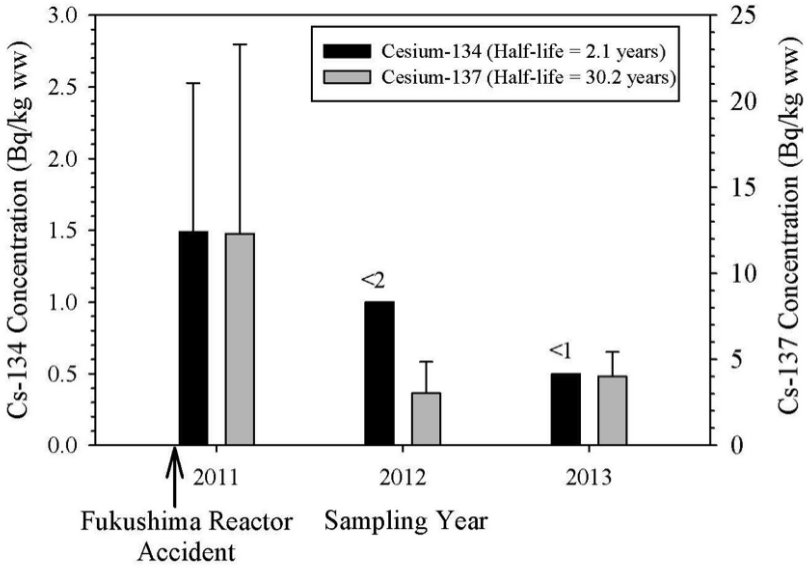

Figure 2. Mean (with error bars indicating SD) concentrations of ^{134}Cs and ^{137}Cs (Bq/kg wet weight) in muscle tissue of mountain goats collected in the Mackenzie Mountains, Northwest Territories, Canada, 2011-2013. "<" indicates below detection in all samples collected that year. The Fukushima nuclear accident occurred 6-7 months prior to sampling in 2011.

by GC-high resolution mass spectrometry. All 209 PCB congeners were determined (representing 162 gas chromatographic peaks due to coelutions). The dioxin-like PCBs (CB 81, 77, 126, 169) were included in the analysis. A total of 31 OCP related compounds (isomers and metabolites of DDT, chlordane, toxaphene, hexachlorocyclohexanes, and endosulfan, as well as mirex, dieldrin, aldrin, endrin, methoxychlor, dacthal, pentachloronitrobenzene, chlorpyrifos and dicofol) were determined. Nine OCOs (hexachlorobutadiene, tetra-, penta- and hexachlorobenzenes, pentachloroanisole, tetrachloroveratrole) were also determined.

Muscle samples (1.0-1.5 mg dry weight) were analyzed for ^{15}N and ^{13}C using a Micromass Optima (Waters, Milford, MA, USA) continuous-flow isotope-ratio mass spectrometer directly coupled to a Carlo Erba NA1500 elemental analyzer (Elemental Microanalysis, Okehampton, UK) at the Environmental Isotope Laboratory (Waterloo, ON). Samples were standardized against atmospheric nitrogen or Canyon Diablo PeeDee Belemnite (National Institute of Standards and Technology, Gaithersburg, MD, USA) using the equation ^{15}N or ^{13}C (‰) = $[(R_{sample}R_{reference})/(R_{reference})] \cdot 1{,}000$, where $R^{15}N{:}^{14}N$ or $^{13}C{:}^{12}C$. Replicate samples had a precision of 0.05‰ (Houde et al. 2008). Ratios of stable isotopes of carbon and nitrogen can be used to assess herbivore diets (Ben-David and Flaherty 2012).

We analyzed data using Systat 11.00.01. We made statistical comparisons on a dry weight basis, converted from ww basis using moisture content or using log transformed dry weight to maintain normality. We reported tissue elemental concentrations as arithmetic means. Sample sets with >50% samples below detection are summarized as < detection limit.

RESULTS

All samples came from males. We conducted multi-elemental analyses on kidneys (n = 13)

Table 2. Mean concentrations (ng/g ± SD) of persistent organic pollutants in liver samples (n = 3) collected from mountain goats in the Mackenzie Mountains, Northwest Territories, Canada. Concentrations on a wet weight (ww) and lipid weight (lw) basis. Mean % lipid = 0.72 ± 0.19.

Analyte	Abbreviation	wet weight	lipid weight
Hexachlorobutadiene	HCBD	0.05 ± 0.02	6.8 ± 1.5
Tetrachlorobenzenes[a]	ΣTeCBz	0.06 ± 0.03	8.8 ± 1.8
Pentachlorobenzene	PeCBz	0.05 ± 0.03	6.8 ± 2.4
Hexachlorobenzene	HxCBz	0.31 ± 0.07	44 ± 7.3
Polychlorinated biphenyls[b]	ΣPCBs	0.03 ± 0.02	4.9 ± 2.3
Dioxin-like PCBs[c]	DL-PCBs	< 0.010	< 1.09
Dichlorodiphenyltrichloroethane and metabolites[d]	ΣDDT	0.29 ± 0.21	41 ± 31
Hexachlorocyclohexanes[e]	ΣHCH	< 0.05	< 8.97
Chlordane related compounds[f]	ΣCHL	0.09 ± 0.08	13 ± 13
Endosulfans[g]	ΣEndo	< 0.12	< 29
Dieldrin, aldrin and endrin	Σdrins	< 0.10	< 15
Dicofol	dicofol	< 10	< 3500
Octachlorostyrene	OCS	0.03 ± 0.01	5.0 ± 2.5
Mirex	mirex	< 0.13	23 ± 3.5
Pentachloroanisole	PeCA	0.03 ± 0.04	4.1 ± 3.7
Pentachloronitrobenzene	PCNBz	0.02 ± 0.02	3.1 ± 2.7
Dacthal	Dacthal	< 0.019	< 3.3
Methoxychlor	Methoxychlor	< 0.16	< 55
Chlorpyrifos	Chlorpyrifos	< 0.11	< 25.8
Toxaphene[h]	Toxaphene	0.40 ± 0.32	54 ± 47

[a]Sum of 1234- and 1245-tetrachlorobenzene
[b]Sum of 209 PCB congeners represented by 162 gas chromatographic peaks
[c]Sum of PCBs 77, 81, 126 and 169
[d]Sum of 4,4'-DDE,- DDD, -DDT and 2,4-DDE, -DDD, DDT.
[e]Sum of alpha, beta and gamma isomers
[f]Sum of heptachlor, heptachlor epoxide B, oxychlordane, trans-chlordane, cis-chlordane, trans-nonachlor, cis-nonachlor
[g]Sum of alpha and beta-endosulfan and endosulfan sulphate
[h]Sum of toxaphene congeners (Parlar 26, 50 and 62)

from animals with the mean age of 6.5 years (range 3-11 years) and muscle tissue (n = 9) from animals with mean age 6.0 years (range 3-9 years). We conducted radionuclide analyses on muscle tissue (n = 12) from animals with mean age 6.1 years (range 2-9 years) and stable isotope analyses on muscle tissue (n = 9) from animals with mean age 6.0 years (range 3-9 years). We conducted the analyses for POPs on liver tissue (n = 3) with mean age 7.0 years (range 5-9 years).

Most element concentrations were higher in kidney than in muscle; only Al, Mg, K, and Sb had higher concentrations in muscle tissue. Cd had the highest kidney:muscle (251) ratio; the kidney:muscle ratio for total Hg was 7.2. Concentrations of Cd and Hg in goat kidneys ranged from 1.07-22.00 mg/kg ww (mean 28.3 mg/kg dry weight) and 0.006-0.160 mg/kg ww (mean 0.3 mg/kg dry weight), respectively (Table 1).

Mean ^{134}Cs concentrations decreased over time, being below detection limits in 2012

and 2013 (Fig. 2). In 2011, shortly after the Fukushima reactor accident, mean ^{134}Cs levels were 1.49 Bq/kg ww. ^{137}Cs remained relatively consistent in most samples with a mean value of 6.46 Bq/kg ww, though the 2 highest values were observed in the 2011 collection. Concentrations of ^{40}K were relatively constant (mean 108 Bq/kg ww).

Very low or non-detectable concentrations of the PCBs, OCPs, and OCOs were found in mountain goat liver (Table 2). The major OCP was toxaphene, consisting of the octachlorobornane (P26) and nonachlorobornane (P50), which averaged 0.40 ± 0.32 ng/g ww. Hexachlorobenzene was prominent in all 3 livers sampled (0.31 ± 0.02 ng/g ww). Combined with the tetra- and pentachlorobenzenes, the total chlorobenzenes (ΣCBz) were present at the highest concentration of all the POPs that were measured (ΣCBz = 0.49 ± 0.12 ww). DDT-related compounds, mainly 4,4' – and 2,4' – DDE, were found in all samples (0.29 ± 0.21 ng/g ww). All other POPs were present at < 0.01 ng/g ww. Consistently detected were chlordane-related compounds (ΣCHL = 0.09 ± 0.08 ng/g ww; consisting of oxychlordane and heptachlor epoxide), as well as pentachloroanisole (PeCA), hexachlorobutadiene (HCBD), and octachlorostyrene (Table 2). PCBs averaged 0.03 ± 0.02 ng/g ww, with trichlorobiphenyl congeners CB-18/30 and CB-20/28 predominating. Dioxin-like congeners were not detected (< 0.01 ng/g ww).

The mean stable isotope signatures for (n = 9) muscle samples was -24.8 ‰ for δ^{13}C and 1.53 ‰ for δ^{15}N.

DISCUSSION

Concentrations of elements in mountain goat were generally higher in kidney than muscle tissue and most elements did not show a positive correlation with age. Total Hg levels were more than 7 times higher in kidney than muscle but were relatively low and similar to those reported for co-habiting Dall's sheep (N. Larter, unpublished data). Cd had the highest kidney:muscle ratio at 251, showing the ability of the metal to accumulate in the kidney. The Cd concentrations we report for mountain goat kidney ranged from 1.07-22.00 mg/kg ww and were substantially lower than the range of 8.9-624.0 mg/kg ww (n = 18) reported for co-habiting moose, which resulted in a human health advisory (Larter and Kandola 2010). Hg concentrations reported for moose kidneys ranged from 0.018-0.076 mg/kg ww and were similar to those we report for mountain goat (0.006-0.160 mg/kg ww). The low concentration of Cd we report in mountain goat kidneys were below levels reported to be associated with observed changes in other animal species (Aughey et al. 1984, Outridge et al. 1994, Beiglböck et al. 2002). An assessment of Cd and other metal data from a human health consumption perspective did not identify any concerns given the low levels.

^{134}Cs and ^{137}Cs were released during the Fukushima nuclear accident and deposited from the atmosphere roughly 1-2 weeks later in North America (Wetherbee et al. 2012). We report detectable concentrations of ^{134}Cs in the muscle tissue of mountain goats samples in the 2011 hunting season but not in subsequent years. ^{134}Cs has a rapid decay (half-life 2.1 years) and had fallen below detectable levels in mountain goats by 2012. ^{134}Cs was also detected in muscle from Dall's sheep sampled in the 2011 hunting season but not in caribou or moose. Differences in dietary items could explain the differences in ^{134}Cs detection between animals as has been observed for Cd (Vandecasteele et al. 2002). Our stable isotope results were consistent with mountain goat and Dall's sheep having a more generalist and diverse diet; they likely ingested specific food items that accumulated the nuclide. Although ^{137}Cs remained relatively consistent in muscle tissue over the 3-year sampling period, the 2 highest values were observed in the 2011

collection. The mean concentration of the naturally occurring ^{40}K (108 Bq/kg ww) we report was similar to the ~100 Bq/kg reported in other large mammals (Macdonald et al. 1996) and similar to that found in co-habiting Dall's sheep, northern mountain caribou, and moose (N. Larter, unpublished data). In general, the concentrations of concern for nuclides are based on levels that result in an incremental dose of 1 mSv/y above background for humans (Health Canada 2014) or 40 µGy/h for mammals (Anderson et al. 2009). The radionuclide concentrations we report were low and did not raise concerns for mountain goat health or from a consumption perspective.

Stable isotope signatures for $\delta^{13}C$ and $\delta^{15}N$ from muscle tissue reflect diet composition (Ben-David et al. 2001). Although food species vary seasonally, all goats were harvested in August and September of each year, reducing seasonality as a potential source of variation in the data. Mean $\delta^{13}C$ value (-24.8 ‰) for mountain goats were intermediate to higher values observed in sympatric northern mountain caribou and lower values observed in moose. Caribou and moose have more restrictive diets with high lichen (Gustine et al. 2012) and willow (*Salix* spp., Risenhoover 1989) dietary components, respectively. This isotopic pattern has been observed in ungulates in Alaska (Ben-David et al. 2001) and eastern Canada (Drucker et al. 2010). The stable isotope signatures we report were consistent with the interpretation that mountain goats are generalist feeders (Rideout 1978).

Concentrations of POPs in mountain goat liver were comparable to those in moose and caribou in the NT. Lipid weight concentrations (Table 2) are provided because most previous studies on terrestrial animals in the NT and Nunavut have reported POPs concentrations on this basis. The POPs consisted mainly of semi-volatile compounds such as HCBz, HCBD, PeCA, DDT, chlordane and trichlorobiphenyls – all of which are known to undergo global atmospheric transport and deposition. Similar to mountain goats, ΣCBz was the most prominent group between the OCPs and OCOs in moose liver from the southwestern NT with average concentrations of 0.16 ± 0.03 ng/g ww (N. Larter et al. unpublished data); ΣCBz was also predominant in caribou (Elkin and Bethke 1995, Kelly and Gobas 2001). However, mountain goats differed from moose and caribou in the proportions of other POPs. For example, HCH isomers were non-detectable (< 0.05 ng/g ww) in mountain goat but averaged 0.12 ± 0.02 ng/g in moose liver. A factor influencing the comparison among species that have been analyzed infrequently, as is the case for ungulates, is the year of collection. Samples reported by Kelly and Gobas (2001) and Elkin and Bethke (1995) were collected in the early 1990s and atmospheric concentrations of legacy POPs have been declining. Air measurements at Alert (Nunavut) have shown ΣHCH declined with a half-life of 3.9 years over the period 2002-2009 (Hung et al. 2013), thus HCH concentrations in diets of ungulates were likely higher in 1990s than in recent years. Seasonal variation in POPs has been documented in caribou (Kelly and Gobas 2001) and could affect comparisons between and within species. While the PCB, OCPs, and OCOs were present at sub-ng/g (ww) concentrations, other POPs, such as perfluorooctane sulfonate and related substances, as well as decabromo diphenyl ether, have been detected at somewhat higher concentrations in moose (N. Larter et al. unpublished data) and caribou liver (Müeller et al. 2011, Morris et al. unpublished data) and should be considered for future baseline monitoring in mountain goats.

ACKNOWLEDGMENTS

We thank J. and C. Lancaster of Nahanni Butte Outfitters and W. Aschbacher and S. Petersen of South Nahanni Outfitters for coordinating the collection of all tissue samples from their clients and for verifying the ages of

harvested mountain goats. Tissue samples were analyzed for elemental concentrations at Environment Canada's National Laboratory for Environmental Testing (Burlington, ON). Radionuclides were determined by Becquerel Laboratories Inc. (Mississauga, ON). Muscle samples were analyzed for stable isotopes at the Environmental Isotope Laboratory, University of Waterloo (Waterloo, ON). Liver samples were analyzed for persistent organic pollutants by ALS Global Laboratories (Burlington ON). D. Allaire drafted the study area figure. Funding came from Northwest Territories Western Biophysical Program (GNWT) and the Department of Environment and Natural Resources.

LITERATURE CITED

Andersson, P., J. Garnier-Laplace, N. A. Beresford, D. Copplestone, B. J. Howard, P. Howe, D. Oughton, and P. Whitehouse. 2009. Protection of the environment from ionising radiation in a regulatory context (PROTECT): proposed numerical benchmark values. Journal of Environmental Radioactivity 100: 1100-1108.

Aughey, E., G. S. Fell, R. Scott, and M. Black. 1984. Histopathology of early effects of oral cadmium in the rat kidney. Environmental Health Perspectives 54: 153-161.

Beiglböck, C., T. Steineck, F. Tataruch, and T. Ruf. 2002. Environmental cadmium induces histopathological changes in kidneys of roe deer. Environmental Toxicology and Chemistry 21: 1811-1816.

Ben-David, M., and E. Flaherty. 2012. Stable isotopes in mammalian research: a beginner's guide. Journal of Mammalogy 93: 312-328.

Ben-David, M., E. Shochat, and L. G. Adams. 2001. Utility of stable isotope analysis in studying foraging of herbivores: examples from moose and caribou. Alces 37: 421-434.

Drucker, D. G., K. A. Hobson, J. P. Ouellet, and R. Courtois. 2010. Influence of forage preferences and habitat use on ^{13}C and ^{15}N abundance in wild caribou (*Rangifer tarandus caribou*) and moose (*Alces alces*) from Canada. Isotopes in Environmental and Health Studies 46:107-121.

European Food Safety Authority. 2012. Cadmium dietary exposure in the European population. European Food Safety Authority Journal 10: 2551.

Elkin, B. T., and R. W. Bethke. 1995. Environmental contaminants in caribou in the Northwest Territories, Canada. Science of the Total Environment 160/161: 307-321.

Gamberg, M., M. Palmer, and P. Roach, P. 2005. Temporal and geographic trends in trace element concentrations in moose from Yukon, Canada. Science of the Total Environment 351/352:530-538.

Gustine, D. D., P. S. Barboza, J. P. Lawler, L. G. Adams, K. L. Parker, S. M. Arthur, and B. S. Shults. 2012. Diversity of nitrogen isotopes and protein status in caribou: implications for monitoring northern ungulates. Journal of Mammalogy 93:778-790.

Health Canada. 2014. Canadian guidelines for the management of naturally occurring radioactive materials (NORM). Revised 2011. Federal Provincial Territorial Radiation Protection Committee. Ottawa, Canada.

Houde, M., D. C. G. Muir, K. A. Kidd, S. Guilford, K. Drouillard, M. S. Evans, X. Wang, D. M. Whittle, D. Haffner, and H. Kling. 2008. Influence of lake characteristics on the biomagnification of persistent organic pollutants in lake trout food webs. Environmental Toxicology and Chemistry 27: 2169-2178.

Hung, H., P. Kurt-Karakus, L. Ahrens, T. Bidleman, M. Evans, C. Halsall, T. Harner, L. Jantunen, S. C. Lee, D. Muir, M. Shoeib, G. Stern, E. Sverko, Y. Su, P. Vlahos, and H. Xiao. 2013. Occurrence and trends in the physical environment. Pages 147-172 in D. C. G. Muir, P. Kurt-Karakas, and J. E. Stow, editors. Canadian arctic contaminants assessment report on persistent organic pollutants – 2013. Aboriginal Affairs and Northern Development Canada, Ottawa, Ontario, Canada.

Joint FAO/WHO Expert Committee on Food Additives. 2010. Summary report of the seventy-third meeting of the JECFA. JECFA/73/SC.

Kelly, B. C., and F. A. P. C. Gobas. 2013. Bioaccumulation of persistent organic pollutants in lichen-caribou-wolf food chains of Canada's Central and Western Arctic. Environmental Science and Technology 35: 325-334.

Larter, N. C. 2009. A program to monitor moose populations in the Dehcho Region, Northwest Territories, Canada. Alces 45: 89-99.

Larter, N. C., and K. A. Kandola. 2010. Levels of arsenic, cadmium, lead, mercury, selenium and zinc in various tissues of moose harvested in the Dehcho, Northwest Territories. Proceedings of 14th International Conference on Circumpolar Health, Circumpolar Health Supplement 7: 351-355.

Macdonald, C. R., L. L. Ewing, B. T. Elkin, and A. M. Wiewel. 1996. Regional variation in radionuclide concentrations and radiation dose in caribou (*Rangifer tarandus*) in the Canadian Arctic; 1992-94. Science

of the Total Environment 182: 53-73.

Müller, C. E., A. O. De Silva, J. Small, M. Williamson, X. Wang, A. Morris, S. Katz, M. Gamberg, and D. C. G. Muir. 2011. Biomagnification of perfluorinated compounds in a remote terrestrial food chain: lichen-caribou-wolf. Environmental Science and Technology 45: 8665-8673.

Muir, D. C. G., P. Kurt-Karakas, J. Stow, J. Blais, B. Braune, E. Choy, M. Evans, B. Kelly, N. Larter, R. Letcher, M. McKinney, A. Morris, G. Stern, and G. Tomy. 2013. Occurrence and trends in the biological environment. Pages 273-422 in D. C. G. Muir, P. Kurt-Karakas, and J. Stow, editors. Aboriginal Affairs and Northern Development Canada, Ottawa, Ontario, Canada.

National Laboratory for Environmental Testing. 2003. NLET schedule of services. National Water Research Institute, Environment Canada, Burlington, Ontario, Canada.

Outridge, P. M., D. D. MacDonald, E. Porter, and I. D. Cuthbert. 1994. An evaluation of ecological hazards associated with cadmium in the Canadian environment. Environmental Reviews 2: 91-107.

Rideout, C. B. 1978. Mountain goat. Pages 149-160 in J. L. Schmidt and D. L. Gilbert, editors. Stackbole Books, Washington, D. C., USA.

Risenhoover, K. 1989. Composition and quality of moose winter diets in interior Alaska. Journal of Wildlife Management 53: 568-577.

Simmons, N. M. 1968. Big game in the Mackenzie Mountains, Northwest Territories. Pages 35-40 in Transactions of 32nd Federal-Provincial Wildlife Conference, Whitehorse, Yukon Territory, Canada.

Simmons, N. 1982. Seasonal ranges of Dall's sheep, Mackenzie Mountains, Northwest Territories. Arctic 35: 512-518.

Vandecasteele, B., B. De Vosa, and F. Tack. 2002. Cadmium and zinc uptake by volunteer willow species and elder rooting in polluted dredged sediment disposal sites. Science of the Total Environment 299: 191-205.

Veitch, A., E. Simmons, M. Promislow, D. Tate, M. Swallow, M. and R. Popko. 2002. The status of mountain goats in Canada's Northwest Territories. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council 13:49-62.

US Environmental Protection Agency. 2007. Method 1699: pesticides in water, soil, sediment, biosolids and tissue by HRGC/HRMS, EPA-821-R-08-001. Washington, D. C., USA.

Wetherbee, G. A., D. A. Gay, T. M. Debey, C. M. B. Lehmann, and M. A. Niles. 2012. Wet deposition of fission-product isotopes to North America from the Fukushima Dai-ichi incident, March 2011. Environmental Science and Technology 46: 2574-2582.