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CONTAMINANT EXPOSURE AND REPRODUCTIVE HEALTH OF SANDHILL CRANES IN THE CENTRAL PLATTE RIVER VALLEY, NEBRASKA.

Photo by Lee Robinson 3/14/05

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ABSTRACT

The central Platte River Valley provides crucial staging habitat for the endangered whooping crane (*Grus americana*) and the mid-continent population of sandhill cranes (*Grus canadensis*). Platte River flow depletions and the conversion of native wet meadows for agriculture and other purposes has decreased the cranes natural habitat in the central Platte River Valley, and waste corn now makes up most of the cranes diet while they are in the Valley.

The purpose of this research was to measure organochlorine, elemental contaminant, and pesticide exposure to sandhill cranes from the central Platte River Valley, and to evaluate their reproductive condition. Pesticides and organochlorines were measured in soil and waste corn samples collected from cornfields where sandhill cranes foraged. Elemental and/or organochlorine contaminants were measured in sandhill crane carcass, liver, brain, muscle, and kidney tissues. Reproduction in sandhill cranes was evaluated by measuring sex steroids in blood plasma and by histological examination of gonads.

Sandhill cranes collected from the central Platte River Valley in 1999 and 2001 appeared to be in normal reproductive condition and concentrations of organochlorines in their tissues were not at levels considered harmful. In addition, pesticides in corn and soil from cornfields were all below detection. Elemental contaminants measured in crane tissues also were generally low, with the exception of boron. Concentrations of boron in sandhill crane livers ($n = 7$) averaged 43.60 ± 3.59 mg/kg dw and exceeded reproductive toxicity thresholds established for mallards. Boron concentrations also were detected at higher concentrations than previously reported in sandhill crane livers analyzed ten years earlier in the same study area. More research is needed to identify sources of boron in the area and further evaluate whether boron exposure to sandhill cranes may be adversely affecting their reproductive potential.

Key Words: Nebraska, sandhill cranes, Platte River, contaminants, boron, metals, organochlorines, elemental contaminants, pesticides.

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ACRONYMS AND ABBREBIATIONS

<	less than	n	sample size
µg/g	micrograms per gram	NAS	National Academy of Sciences
ACF	Analytical Control Facility	NEFO	Nebraska Ecological Services Field Office
BRD	Biological Resources Discipline	OC	organochlorine
CB	carbamates	OP	organophosphates
DDT	dichlorodiphenyltrichloroethane	p	level of significance
dw	dry weight	PACF	Patuxent Analytical Control Facility
E	estradiol	PCBs	polychlorinated biphenyls
e.g.	example given	pers. comm.	personal commentary
E/T	estrogen to testosterone ratio	pg/ml	picograms per milliliter
et al.	and others	QA/QC	quality assurance and quality control
FCSC	Florida Caribbean Science Center	RIA	radioimmunoassay
fw	fresh weight	Service	U.S. Fish and Wildlife Service
g	gram	T	testosterone
GC/MS	gas chromatography/mass spectrometry	USDA	U.S. Department of Agriculture
mg/kg	milligrams per kilogram	USFWS	U.S. Fish and Wildlife Service
mg/L	milligrams per liter	USGS	U.S. Geological Survey
ml	milliliter	ww	wet weight

INTRODUCTION

The central Platte River Valley provides crucial staging habitat for the endangered whooping crane (*Grus americana*) and 80 percent of the mid-continent population of sandhill cranes (*Grus canadensis*) (Tacha et al., 1984). A 53-mile reach of the Platte River in this area has been federally designated as critical habitat for the endangered whooping crane (USFWS, 1978) and a recent evaluation by the National Research Council indicated that the proportion of the whooping crane population that uses the central Platte River as a stopover each year has been increasing (NRC, 2004). Approximately 500,000 sandhill cranes spend six to eight weeks along the central Platte River from February to early April before continuing to their breeding grounds (U.S. Fish and Wildlife Service, 1981). During this staging period, sandhill cranes increase their body mass by 30 - 34 percent (Krapu et al., 1985). Approximately 40 percent of the accumulated fat reserves are utilized during migration to their breeding grounds and the remaining reserves sustain them during nesting (U.S. Fish and Wildlife Service, 1981).

Landscape changes in the central Platte River Valley caused by flow depletions of the Platte River and conversion of native wet meadows for agriculture and other purposes have resulted in the concentration of cranes along river reaches that still satisfy their habitat needs (Reinecke and Krapu, 1986). Intensive agriculture surrounds much of the existing river and wet meadow habitat in the central Platte River Valley. More than 45 percent of the land area around the Platte River from Lexington to Chapman is planted to corn (Stamer and Huntzinger, 1994). Cranes forage in cornfields, alfalfa fields, and wet meadows and their diet typically consists of 97 percent corn and 3 percent invertebrates (Reinecke and Krapu, 1986).

Sandhill cranes foraging in cornfields and alfalfa fields may be exposed to pesticides by ingestion of food items and grit. In 1999, 98 percent of the corn crop in Nebraska received herbicide treatment, and 31 percent received insecticides (Nebraska Agricultural Statistics Service, 1999). In addition to modern pesticides that are designed to quickly breakdown in the environment, sandhill cranes may be exposed to contaminants that are environmentally persistent such as organochlorines and elemental contaminants. Mid-continent sandhill cranes have been documented to live over 19 years in the wild (Tacha et al., 1994), and although their diets consist mainly of items low on the food chain, their relatively long life could result in significant accumulation of persistent chemicals.

Only a few studies have investigated contaminant exposure to sandhill cranes. Most of these studies have focused on lead toxicity to cranes that ingest lead objects (Wallace et al., 1983; Windingstad et al., 1984; Franson and Hereford, 1994). Mullins et al. (1979) reported that concentrations of organochlorine pesticides in sandhill cranes were generally low; however, older paired and breeding cranes had significantly higher concentrations of mercury and dichlorodiphenyltrichloroethane (DDT). Fannin (1992) evaluated pesticide, organochlorine, and elemental contaminant exposure to sandhill cranes in Nebraska during the spring migration of 1989. Exposure to organophosphate and carbamate pesticides was evaluated by measuring brain acetylcholinesterase inhibition, and all cranes tested (n = 57) had brain acetylcholinesterase activity within the expected normal range. Stomach contents of five cranes tested (the five cranes with the lowest acetylcholinesterase activity) did not have detectable concentrations of pesticides. Concentrations of oxychlordane, heptachlor epoxide, and p,p'-DDE (a metabolite of DDT) in sandhill crane carcasses also were low. However, boron and lead were detected in crane liver at concentrations of concern. The concentration of lead in the liver of one crane was 55 micrograms per gram (μg/g dw), a concentration indicative of lead toxicity in avian species (Kendall and Scanlon, 1985). However, this high lead concentration may have resulted from contamination when the crane was collected by shooting it with a rifle (Fannin, 1992). The highest concentration of boron (2.42 μg/g dw) was near a 3 μg/g dw threshold for delayed growth and behavioral effects in mallards (Hoffman et al., 1990).

Research Objectives

The purpose of this research was to determine organochlorine, elemental contaminant, and pesticide exposure to sandhill cranes from the central Platte River Valley (Figure 1) and evaluate their reproductive condition. This was accomplished by performing the following subordinate objectives:

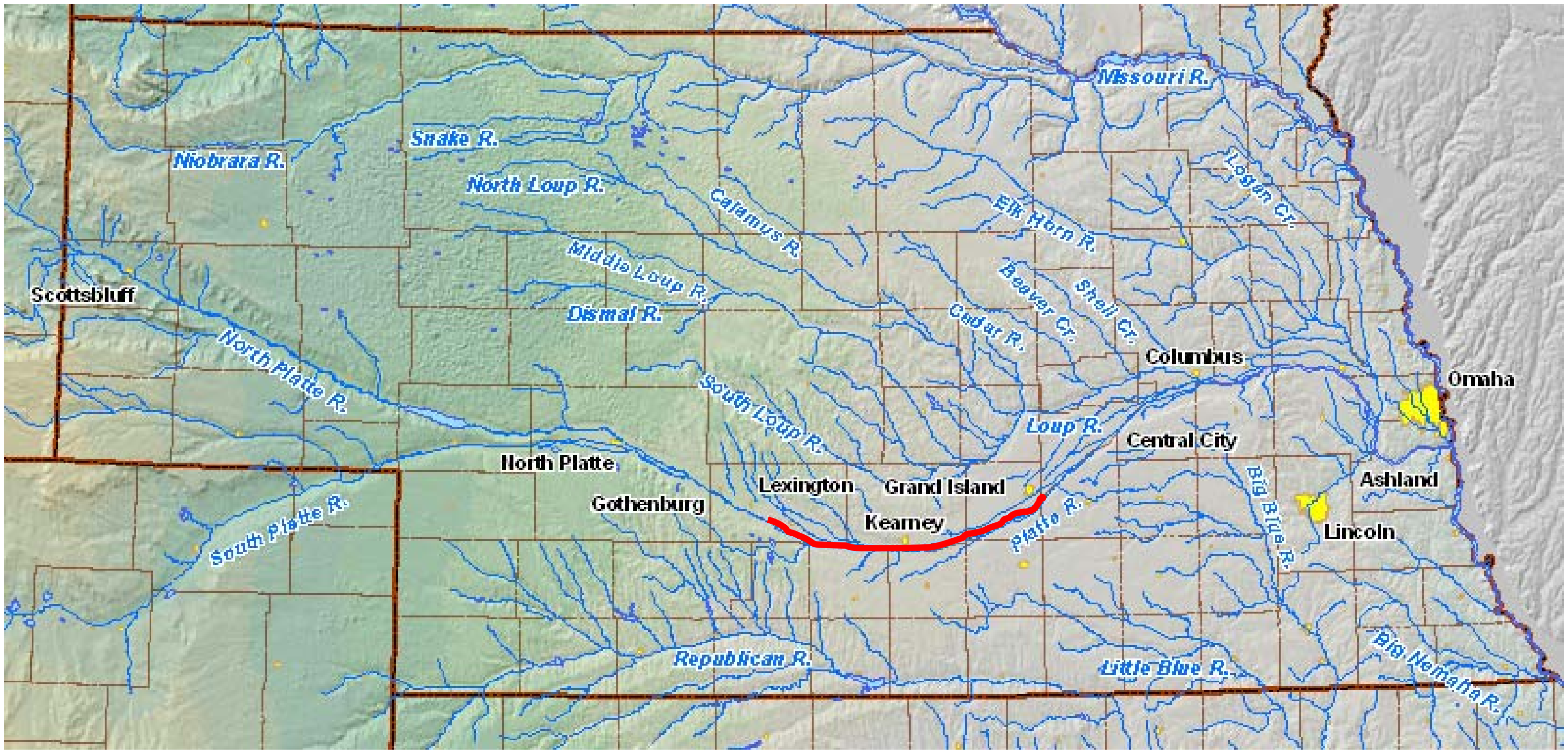
1) Evaluate the reproductive condition of sandhill cranes captured in Nebraska by comparing hormone levels in blood and fecal samples to those of a reference population of Florida sandhill cranes housed at the U.S. Geological Survey (USGS) Patuxent Wildlife Research Center in Laurel, Maryland.

2) Evaluate reproductive health of sandhill cranes by histological examination of gonads for sexual maturation and morphological abnormalities.

3) Measure elemental contaminants, organochlorine pesticides, and polychlorinated biphenyls (PCBs) in crane carcass, liver, brain, muscle, and/or kidney tissues.

4) Measure pesticide concentrations in waste-corn and soil samples collected from foraging areas to evaluate potential dietary uptake.

5) Screen gizzard contents for lead shot to determine whether cranes are ingesting spent lead while foraging.



= study site

Figure 1. Location of the study site in the central Platte River Valley of south-central Nebraska.

METHODS

Sample Collection

Cranes were collected along the central Platte River by USGS Biological Resources Discipline (BRD) personnel from the Northern Prairie Wildlife Research Center as part of their ongoing study on long-term changes in spatial and temporal use of habitat, nutrient storage, and carrying capacity of sandhill cranes in the Platte Valley, Nebraska. Cranes were collected either by shotgun at dusk when they were returning to their roost sites or by accidental mortality from rocket nets used to capture and band sandhill cranes. Sandhill cranes were identified to subspecies by BRD personnel using morphometric measurements of the tarsus, wing chord, culmen, and toe.

When time permitted, BRD personnel collected blood samples from recently killed birds or live birds that were captured, banded, and released. All blood samples were collected by syringe with a heparinized 20-gauge needle. Blood samples were stored in 5 milliliter (ml) heparinized vacutainers and kept on wet ice until U.S. Fish and Wildlife Service (Service) personnel arrived within 8 hours. Blood samples were then centrifuged at 1,000 revolutions per minute for 10 minutes to obtain a plasma fraction, which was aspirated by pipette into 2 ml cryo-vials. Fecal samples (approximately 0.5 - 1.0 gram) from recently killed birds also were collected into cryo-vials using a stainless steel spatula. Blood plasma and fecal samples were stored frozen at the Nebraska Ecological Services Field Office (NEFO) in Grand Island, Nebraska.

Gonads from shotgun-collected cranes were removed, weighted to the nearest 0.01 gram (g) and stored in 10 percent buffered formalin. The remainder of the carcass was frozen and shipped to the University of Western Ontario where it was homogenized. A 100 g sub-sample of crane homogenate (whole crane minus feathers, gonads, and ingesta) from each crane was shipped frozen to NEFO where the samples were stored frozen until shipped to the appropriate lab for residue analysis.

Cranes accidentally killed by rocket nets were necropsied by Service personnel. Reproductive tracts were removed and stored in 10 percent buffered formalin. Liver, muscle, brain, and kidney tissues were measured to the nearest 0.01 gram (g), collected into certified clean glass containers, and stored frozen for chemical analyses. Gizzards were collected whole and kept frozen for lead shot examination. Fecal samples (approximately 0.5 - 1.0 g) were collected opportunistically and frozen until time of shipment.

In February of 1999, Service biologists collected waste corn and soil from cornfields where cranes foraged. Twenty cornfields representing 20 different farms were chosen for sampling. Approximately 500 g of corn was collected uniformly across each cornfield into a certified clean glass jar. An acid cleaned and acetone rinsed stainless steel sieve was used to remove soil that may have been collected with the waste corn sample and then each sample was transferred into a new chemically clean container. Surface soil (approximately 1,500 g) also was collected uniformly across five of the 20 cornfields into a certified clean glass jar using a stainless steel spoon. Both corn and soil samples were kept cold and then stored frozen at NEFO until shipped for chemical analyses.

Hormones and Gonad Histology

Crane blood plasma and fecal samples were shipped frozen by overnight delivery to the USGS Florida Caribbean Science Center (FCSC) in Gainesville, FL. Concentrations of the sex steroid hormones estradiol and testosterone were measured in plasma and fecal samples using radioimmunoassay (RIA) procedures. These concentrations were compared to a hormone profile established from a reference population of sandhill cranes kept at the USGS Patuxent Wildlife Research Center in Laurel, Maryland. The hormone profile for the reference population was established by the same RIA procedure used in our study and included 55 samples collected intermittently during a one-year period (Sheryl Leffer, Hood College, pers. comm., 2000).

Crane gonad samples also were shipped to FCSC by overnight delivery. Gonadal sections were stained with hematoxylin and eosin prior to histological examination. Stained gonads were then examined with a compound light microscope to identify reproductive stage and screen for lesions or abnormalities. Gonads from female birds were classified according to four stages: undeveloped/immature (stage 0), previtellogenic (stage 1), early vitellogenic (stage 2), and late vitellogenic (stage 3). Male gonadal tissues also were classified to four stages of maturation: inactive/immature (stage 0), early spermatogenic (stage 1), mid-spermatogenic (stage 2), and late spermatogenic (stage 3).

Gizzard Lead Shot Screen

A FALCON MD-10 metal detector (Falcon Prospecting Equipment, Mesa, AZ) was used to screen gizzard contents for lead shot or other metal objects. Samples spiked with No. 7 lead shot were screened at the beginning of each day as a quality assurance and quality control (QA/QC) measure.

Chemical Analyses

Quantification of contaminant residues in cornfield soil, waste corn, and crane tissues was performed by several different laboratories (Appendix Table A.1). All samples, except those for the pesticide scan in corn, were submitted to the Patuxent Analytical Control Facility (PACF), since renamed the Analytical Control Facility (ACF) (Appendix Table A.2). Detailed descriptions of lab methods including sample preparation, sample digestion, QA/QC results, and detection limits are provided in the ACF catalogs, which are available upon request (ACF phone: 304-876-7336). In brief, the analysis of duplicate samples, spiked samples, and standard reference materials indicated acceptable levels of precision and accuracy, and limits of detection were within ACF's contract requirements (ACF, 2005). Corn samples were submitted directly to the Technical Services Division of the U.S. Department of Agriculture (USDA), Kansas City, Missouri. The QA/QC methods for the pesticide scan included 2 reagent blanks, 2 spikes at 0.02 µg/g, two spikes at 0.1 µg/g, and 4 randomly selected duplicate samples. Detection limits for pesticides in corn ranged from 0.02 – 0.1 µg/g and the mean percent recoveries were generally above 80 percent (Appendix Table A.3). All statistical calculations were performed with JMP® Version 5 software (JMP, 2002). Where means are provided, the "±" refers to a standard error unless otherwise noted.

Elemental Contaminants

For elemental analyses, crane carcass, liver, muscle, and kidney samples were freeze dried, percent moisture was determined, and results were provided as wet weight (ww) and dry weight (dw) concentrations. Inductively coupled plasma atomic emission spectrometry was used to determine concentrations of aluminum, boron, barium, beryllium, cadmium, chromium, copper, iron, magnesium, manganese, molybdenum, nickel, lead, strontium, vanadium, and zinc. Mercury concentrations were determined by cold vapor atomic absorption, and graphite furnace atomic absorption was used to measure arsenic, selenium, and small concentrations of lead and cadmium.

Organochlorine Chemical Residues

Crane muscle, brain, and carcass samples were analyzed for 21 organochlorine (OC) contaminants including hexachlorobenzene, total polychlorinated biphenyls, lindane (alpha, beta, and gamma), chlordane (alpha and gamma), cis- and trans-nonachlor, dieldrin, endrin, heptachlor epoxide, mirex, oxychlordane, toxaphene, and DDT p,p' and o,p' isomers and their metabolites (o,p'-DDD, o,p'-DDE, p,p'-DDD, and p,p'-DDE). Concentrations were measured by gas chromatography/mass spectrometry (GC/MS). Detection limits for the OC analysis of brain, muscle and carcass samples were 0.05 milligrams per kilogram (mg/kg) ww for total PCBs and toxaphene, and 0.01 mg/kg ww for all other OCs.

Pesticides in Soil and Corn

Soil samples were sent to the Mississippi State Chemical Laboratory in Mississippi State, Mississippi, for a herbicide scan that included atrazine, cyanazine, metribuzin, propazine, and simazine. Soil samples were also tested at ACF for OCs and other pesticides classified as either organophosphates (OP) or carbamates (CB). For the herbicide scan, samples were desiccated overnight, extracted in a PRQ Accelerated Solvent Extractor and quantified by a Varian Model 3400 Gas Chromatograph. Gas chromatography (GC) was used to quantify OP and CB pesticides by following standard operating procedures (PACF, 1989). Megabore capillary columns were used for the GC separations and a flame photometric detector and a nitrogen phosphorus detector were used for determinations of OPs and CBs, respectively. Analytical methods for measuring OCs in soil included Soxhlet extraction and lipid removal as described by Cromartie et al. (1975) followed by quantification with a gas-liquid chromatograph equipped with a 63Ni electron capture detector. Residues in 10 percent of the samples were confirmed by GC/MS. Detection limits for OCs and pesticides in soil samples were generally 0.01 and 0.05 mg/kg ww, respectively (Appendix Table A.4). Corn samples were analyzed by GC/MS for 42 pesticides which included OCs, CBs, OPs, and triazines (Appendix Table A.4).

RESULTS AND DISCUSSION

Sample Collections

A total of 51 sandhill cranes were collected in 1999 (n = 44) and 2001(n = 7) from four Nebraska counties in the central Platte River Valley (Figure 2). In addition, 14 sandhill cranes were sub-lethally sampled for blood plasma in 1999. Sampling was suspended in 2000 due to changes in the contaminants personnel at the Service’s Grand Island Field Office.

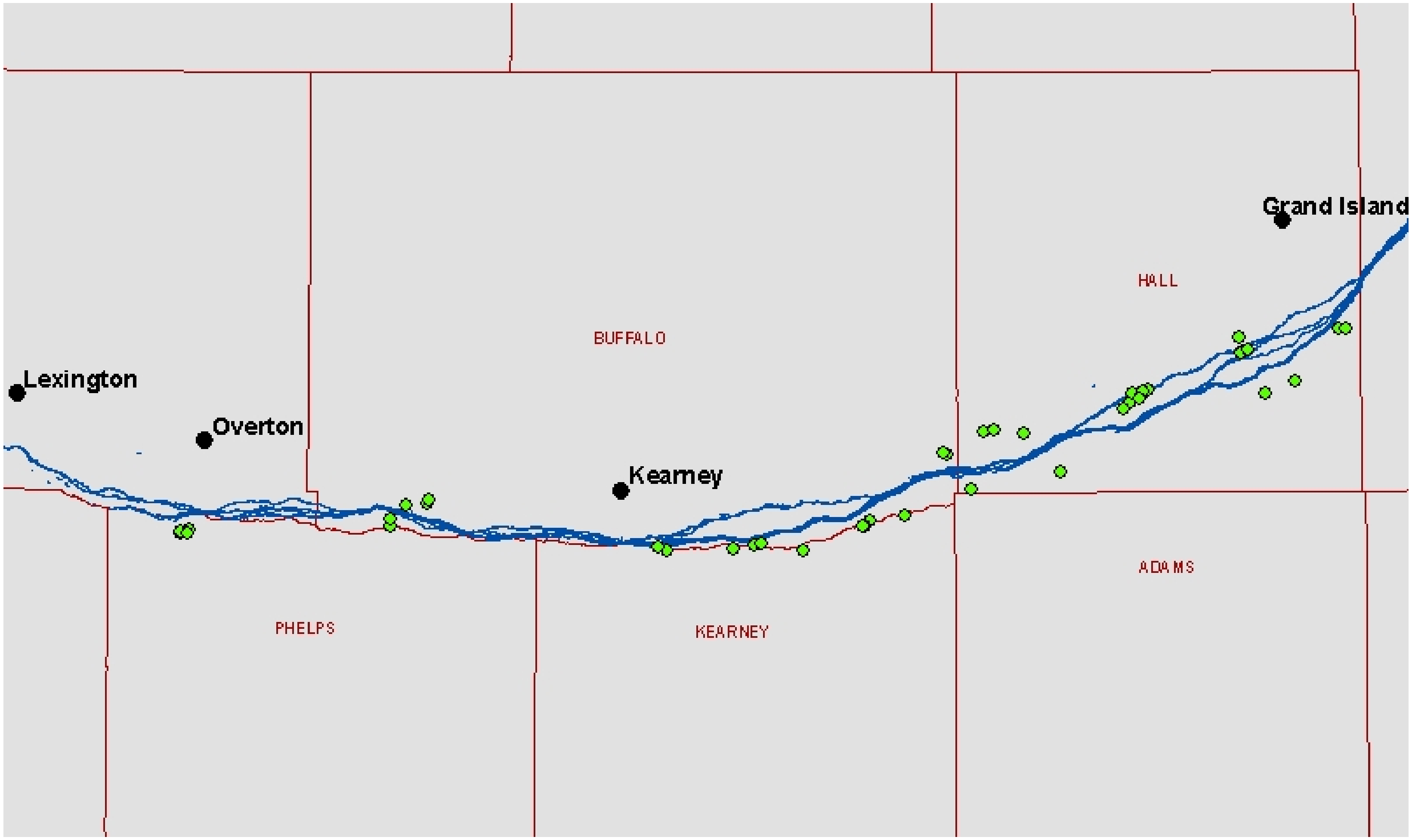


Figure 2. Location of sandhill cranes collected near the central Platte River in Phelps, Buffalo, Kearney, and Hall counties of South Central, Nebraska. Note: each green dot represents a collection site for one or more sandhill cranes.

Hormones

Concentrations of estradiol (E) and testosterone (T) in sandhill cranes were measured in 57 blood plasma samples and 20 fecal samples from *canadensis*, *rowani*, and *tabida* subspecies (Appendix Table 5). Blood E averaged 656 ± 37 and 873 ± 91 picograms per milliliter (pg/ml) in male and female cranes, respectively. Testosterone in blood averaged 1029 ± 74 and 364 ± 28 pg/ml in male and female cranes, respectively. Concentrations of E and T in fecal samples averaged 2,188 ± 259 and 1,634 ± 152 pg/ml in females and 849 ± 133 and 2,165 ± 274 pg/ml in males, respectively. Female cranes had significantly ($p < 0.05$) greater concentrations of E in blood and fecal samples than males (Figure 3). Males had significantly ($p < 0.05$) greater concentrations of T in blood than females, but gender differences in fecal T were not significant (Figure 3). There also was no significant difference in blood T or E between male *rowani* and *canadensis* (data not shown).

The estrogen to testosterone ratio (E/T) in blood plasma and fecal samples from wildlife has been used as an indicator of physiological responses to environmental conditions including potential exposure to endocrine disrupting chemicals (Culotta, 1995; Goodbred et al., 1997; Washburn et al., 2004). Females generally have a higher E/T than males. In our study, the E/T ratio for females was greater than one in 21/22 blood plasma samples and 7/8 fecal samples. Males had an E/T of less than one in 28/35 blood plasma samples and 12/12 fecal samples. Concentrations of estradiol can peak in male sandhill cranes during the spring (Sheryl Leffer, Hood College, pers. comm., 2000) and may explain why some of the males had an E/T ratio greater than one. Abnormal estrogen to testosterone ratios have been linked to potential endocrine disruption in carp from exposure to pesticides in water (Goodbred et al., 1997) and feminization of male alligators exposed to p,p'-DDE (Culotta, 1995). However, there are no known studies that have linked abnormal E/T ratios in avian species to exposure to environmental contaminants.

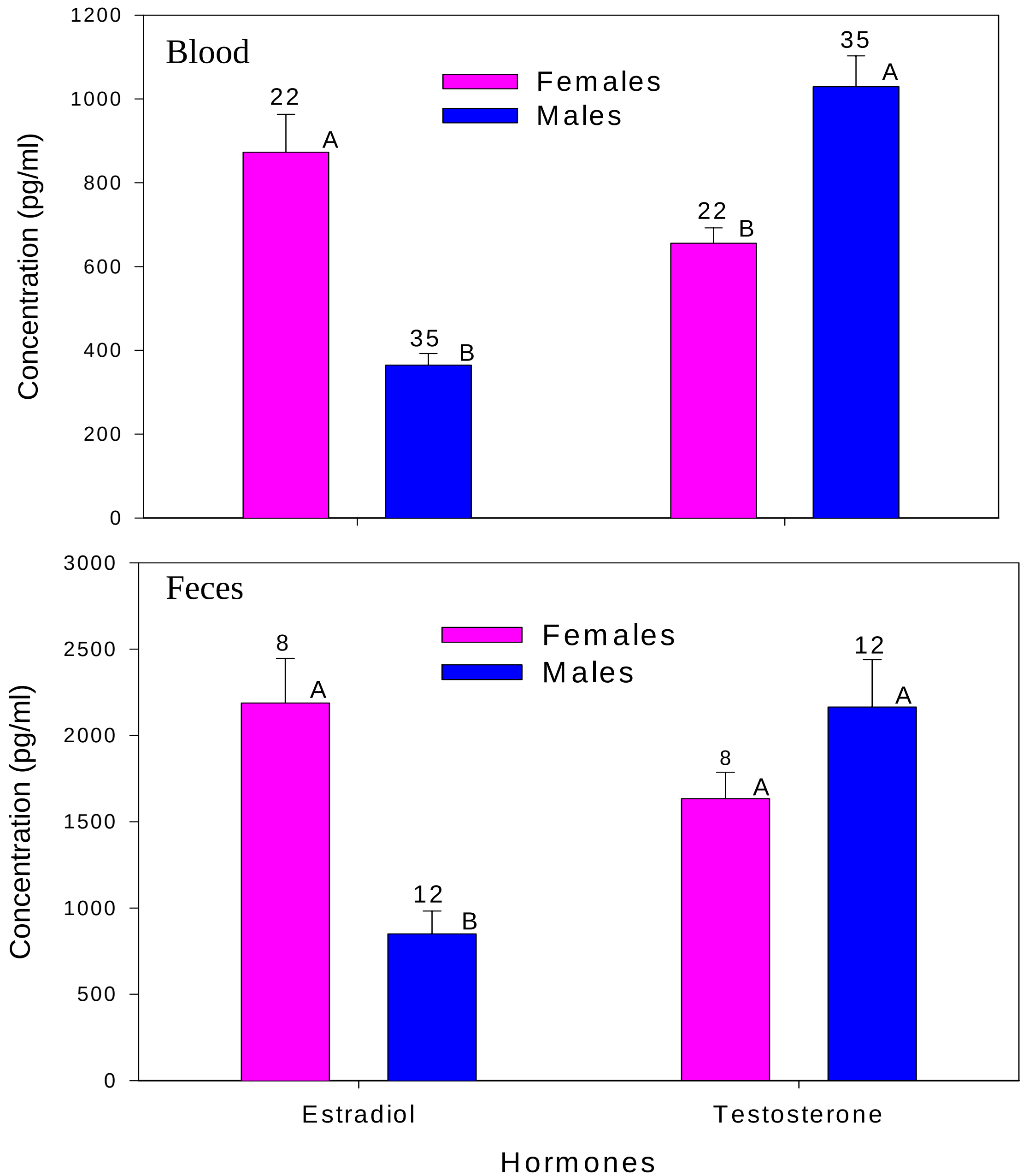


Figure 3. Concentrations of estradiol and testosterone in blood plasma and fecal samples from sandhill cranes collected from the Platte River Valley, Nebraska, 1999. The sample size is above each standard error bar and different letters indicate significant differences ($p < 0.05$) as determined by a Wilcoxon test.

Gonad Histology

Gonadal histology for 44 cranes (28 males and 16 females) collected in 1999 indicated that all males were moderately spermatogenic (stage 2) and all females were between stages 1 and 2 (previtellogenic/early vitellogenic). In 2001, an additional 5 gonad samples (3 females and 2 males) were examined. Both males were stage 1 (early spermatogenic) with no mature sperm and the females were all stage 2 (early vitellogenic) with small follicles. No reproductive abnormalities were observed.

Elemental Contaminants

A total of 24 carcass samples and seven samples each of liver, kidney, and muscle were analyzed for elemental contaminants (Appendix Tables A.6 and A.7). Concentrations of arsenic, beryllium, mercury, and Mo were below detection limits in all samples analyzed. All other elemental contaminants examined in this study were detected in one or more of the tissue samples submitted for analysis.

With the exception of boron, concentrations of elemental contaminants in the sandhill cranes were generally below levels of concern. Boron concentrations in sandhill crane livers were much greater than those reported previously by Fannin (1992) (Table 1). Concentrations of boron in livers of sandhill cranes in our study (n = 7) ranged from 32 to 57 mg/kg dw and averaged 44 ± 4 mg/kg dw. In comparison, liver samples (n = 20) from mallards (*Anas platyrhynchos*) fed 1,000 mg/kg dw boron in their diet had a mean concentration of 33 mg/kg dw (Smith and Anders, 1989). Ducks fed this ration of boron also had a significantly ($p < 0.05$) lower hatching success of fertile eggs (Smith and Anders, 1989). Furthermore, dietary concentrations of 300 - 400 mg boron/kg of feed fresh weight (fw) adversely affect mallard growth, behavior, and brain biochemistry (Eisler, 1990). Mean concentrations of boron in liver samples from ducks fed 300 - 400 mg boron/kg fw in their diet were 15 mg/kg dw (maximum of 24 mg/kg dw) and 17 mg/kg dw (maximum of 36 mg/kg dw) for adults and ducklings, respectively (Smith and Anders, 1989). Dietary levels of 100 mg boron/kg fw resulted in reduced growth of

Table 1. Detections and mean concentrations of elemental contaminants in liver samples of sandhill cranes from the central Platte River Valley, 2001 compared to 1989 -1990.

Element	Aluminum		Barium		Boron		Cadmium	
N_D/N_A	7/7	2/17	1/7	2/17	7/7	8/17	7/7	11/17
Mean	16.2	3.17*	0.9	0.09*	43.6	1.22*	0.54	0.31
SE	1.2	1.6	NA	1.4	3.6	0.5	0.08	0.05
Max	20.4	14.0	NA	0.6	57.4	2.4	0.84	0.80
Min	10.9	1.5	NA	0.1	32.3	1.0	0.24	0.05
Max LOD	3.3	4.1	0.7	0.7	1.3	1.7	0.07	0.25
Element	**Chromium**		**Copper**		**Iron**		**Lead**	
N_D/N_A	7/7	8/17	7/7	17/17	7/7	17/17	0/7	11/17
Mean	3.3	0.42*	12.8	7.7	1656	1379	NA	0.2*
SE	0.1	0.5	1.1	0.5	344	149	NA	1.7
Max	3.5	0.5	17.7	11.1	3259	2850	NA	55.0
Min	2.9	0.1	8.9	4.4	761	631	NA	0.1
Max LOD	0.3	0.4	0.3	0.4	3	4	0.3	2.0
Element	**Selenium**		**Vanadium**		**Zinc**		**Mercury**	
N_D/N_A	7/7	17/17	0/7	2/17	7/7	17/17	0/7	14/17
Mean	1.3	3.6	NA	0.14*	118	95	NA	0.03*
SE	0.1	0.2	NA	1.0	10	5	NA	0.001
Max	1.8	5.8	NA	0.4	168	125	NA	0.3
Min	1.0	2.0	NA	0.1	85	53	NA	0.0
Max LOD	0.3	0.4	0.3	0.2	0.7	0.8	0.1	0.1
Element	**Magnesium**		**Manganese**		**Molybedum**		**Nickel**	
N_D/N_A	7/7	17/17	7/7	17/17	6/7	17/17	4/7	1/17
Mean	693	569	8.72	8.49	2.07	2.13	4.18	0.40
SE	45	21	0.6	0.5	0.4	0.2	1.7	1.6
Max	869	734	10.4	12.2	4.3	3.9	9.4	1.3
Min	547	348	6.1	5.4	0.7	1.0	0.2	0.3
Max LOD	3	4	0.7	0.4	1.3	1.6	0.3	0.5

Note: Data in columns not shaded is from this study. Data in the shaded columns is from Fannin (1992) and PACF catalog 6050014. N_D = number of samples above detection limits, N_A = number of samples analyzed, SE = standard error, Max = maximum concentration detected, Min = minimum concentration detected, Max LOD = the highest limit of detection reported. * indicates a geometric mean. Arsenic and Beryllium were not frequently detected in this study (0/7 for each element) or in Fannin, (1992) (1/17 for each element).

female mallard ducklings, especially under conditions of low protein (Hoffman et al., 1990), and ducklings exhibited reduced growth when their parents were fed boron at 30 mg/kg fw (Smith and Anders, 1989). The actual concentrations of boron that are harmful to cranes are not known and may be different to those in ducks due to philological differences between the species.

Boron exposure to sandhill cranes likely occurred within the study area, because boron is rapidly accumulated and eliminated. Adult mallards fed a diet of 1,600 mg boron/kg accumulated equilibrium levels of boron in liver and blood within 2 – 15 days and completely eliminated boron from these tissues within one day after removing boron from their diet (Pendleton et al., 1995). Sources of boron could include municipal wastewater effluent, irrigation drain water, fertilizers, and emissions from a coal fired power plant. Laundry detergents originating from household use may contribute as much as 50 percent of the boron loadings in effluents discharged into aquatic environments (Eisler, 1990). Approximately 30 percent of boron in coal is released into the atmosphere by coal-fired power plants (Eisler, 1990). Fly-ash from coal fired power plants can be used as a soil amendment in agriculture (Petruzzelli, 1989) and may result in an increased uptake of boron by corn (Kukier et al., 1994). Boron fertilization is not recommended in corn fields of the central Platte River Valley; however, it is recommended for alfalfa fields if soil concentrations of boron are less than 0.25 mg/kg (Knudsen and Frank, 1974).

Waterborne concentrations of boron are generally less than 0.1 milligrams per liter (mg/L) in natural freshwater ecosystems (Adriano, 1986, as cited by USDOI, 1998), but can be much greater, especially in pumped groundwater (USDOI, 1998). In the heavily irrigated western San Joaquin Valley of California, concentrations of boron in surface water ranged from 11- 65 mg/L (USDOI, 1998). Invertebrates from wetlands that receive irrigation drainage water can accumulate high concentrations of boron (Hothem and Ohlendorf, 1989; Tuttle et al., 1996).

In Nebraska, concentrations of boron in 19 irrigation water samples collected in 2004 averaged 0.14 mg/L and ranged from 0.59 - 1.5 mg/L (R. Ferguson, Department of

Agronomy and Horticulture, University of Nebraska, pers. comm., 2005). Furthermore, concentrations of boron in 49 soil samples from Nebraska ranged from 0.59 – 1.5 mg/kg and averaged 0.9 mg/kg (R. Ferguson, Department of Agronomy and Horticulture, University of Nebraska, pers. comm., 2005). These data indicate that sandhill cranes may not be exposed to high concentrations of boron in river water or soils from cornfields; however, site specific data for areas used by the cranes is needed.

No lead shot was found in the 73 gizzards that were analyzed during this study. Wallace et al. (1983) also reported a low incidence of lead shot in gizzards of sandhill cranes. However, ingestion of lead objects (e.g., unspent .22 caliber shell cartridges and fishing sinkers) by wild cranes can cause mortality (Windingstad et al., 1984; Franson and Hereford, 1994).

Organochlorines and Pesticides

Concentrations of OCs and pesticides were generally below detection limits and were not detected at levels of concern. A total of 24 carcass samples and 7 samples each of brain, muscle, and liver tissue were analyzed for OCs. Only endrin, lindane, p,p'-DDD, and p,p'-DDE were detected (Table 2). A total of 5 soil samples and 24 corn samples were analyzed for pesticides and all were below detection limits. Since agricultural pesticides are generally not applied while the cranes are in the area between February and late March, the lack of residues detected in February indicate that pesticide residues may not persist over winter in soil and corn and pesticide exposure to cranes is probably low.

Table 2. Concentrations of organic contaminants detected in sandhill cranes collected from the central Platte River Valley, Nebraska, 1999 and 2001.

Tissue Type	Contaminant	N_D/N_A	Concentration in mg/kg wet weight	
			Mean ± Standard Error	Range
Carcass	endrin	4/24	NC	0.011 - 0.017
Carcass	lindane	1/24	NC	0.012 - 0.012
Carcass	p,p'-DDD	1/24	NC	0.014 - 0.014
Carcass	p,p'-DDE	17/24*	0.030 ± 0.008	0.005 - 0.148
Brain	p,p'-DDE	3/5*	0.023 ± 0.008	0.005 - 0.043
Muscle	p,p'-DDE	7/7	0.046 ± 0.013	0.025 - 0.122

Note: * indicates that half the detection limit was used to calculate the mean and standard error for samples that were below detection limits. N_D/N_A = number of detections over the number of samples analyzed, NC = not calculated because more than 50 percent of the samples analyzed were below detection.

Management Recommendations

More research is needed to evaluate boron exposure and effects to sandhill cranes that use the central Platte River Valley as a staging area during the spring migration. The results of this study included high concentrations of boron in sandhill crane liver samples; however, the number of samples analyzed was small (n = 7). Future evaluations should include a more robust sampling for boron in sandhill crane livers. In addition, sources of boron exposure to sandhill cranes should be evaluated by measuring concentrations of boron in waste corn, invertebrate food items, water, and soil/sediments from wet meadows and/or cornfields.

Conclusions

Sandhill cranes collected from the central Platte River Valley in 1999 and 2001 did not have harmful concentrations of organochlorines contaminants. In addition, pesticides in corn and soil from cornfields where cranes foraged were all below detection at the beginning of the staging period in February. Elemental contaminants measured in crane tissues also were generally low with the exception of boron. Boron concentrations in sandhill crane liver tissues were higher than previously reported for the area and exceeded toxicity thresholds for mallards. It is unclear why concentrations of boron in cranes increased within the 10 years between 1989 and 1999. More research is needed to identify sources of boron to the area and determine whether boron exposure to sandhill cranes may be adversely affecting their reproductive potential.

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APPENDIX: ADDITIONAL TABLES

Table A.1. Summary of samples collected for analytical residue analysis from sandhill cranes and cornfields in the central Platte River Valley, Nebraska, 1999 and 2001.

Date	Sample Type	Analysis	N	Laboratory	PACF Catalog ID
03/99	Sandhill crane carcass	Elemental contaminants	23	GERG	6050071
03/99	Sandhill crane carcass	OCs	23	PACF	6050071
03/01	Sandhill crane brain	OCs	5	PACF	6050092
03/01	Sandhill crane liver	Elemental contaminants	7	PACF	6050092
03/01	Sandhill crane kidney	Elemental contaminants	7	PACF	6050092
03/01	Sandhill crane muscle	OCs	7	PACF	6050092
03/01	Sandhill crane muscle	Elemental contaminants	7	PACF	6050092
04/99	Cornfield soil	OCs, Pesticides	5	PACF	6050061
04/99	Cornfield soil	Herbicides	5	MSCL	6050061
04/99	Waste corn	Pesticides	24	USDA	NA

GERG = Geochemical and Environmental Research Group, PACF = Patuxent Analytical Control Facility, MSCL = Mississippi State Chemical Lab, USDA = U.S. Department of Agriculture, OCs = organochlorine compounds, NA = not applicable, N = the number of samples analyzed.

Table A.2. Mass, percent moisture and percent lipid results for sandhill crane and cornfield soil samples collected from the central Platte River Valley, Nebraska, 1999 and 2001.

ACF Catalog and Analysis	Sample ID	Sample Mass (grams)	Percent moisture	Percent Lipid
Catalog 6050061	AH281	350	18	NA
Herbicides in soil	GST	366	17	NA
	H10G	368	22	NA
	KH10	378	19	NA
	WRATNC	400	20	NA
Catalog 6050061	AH281	1000	18	NA
	GST	1000	16	NA
Organochlorines and	H10G	1000	23	NA
modern insecticides in soil	KH10	1000	16	NA
	WRATNC	1000	19	NA
Catalog 6050071	CH315	100	50	NA
Elemental contaminants	CH316	100	62	NA
in crane carcasses	CH321	100	55	NA
	CH322	100	54	NA
	CH327	100	53	NA
	CH328	100	54	NA
	CH329	100	52	NA
	CH338	100	49	NA
	CH343	100	48	NA
	CH346	100	58	NA
	CH348	100	45	NA
	CH401	100	60	NA
	CH402	100	58	NA
	CH408	100	52	NA
	CH603	100	61	NA
	CH605	100	56	NA
	CH606	100	53	NA
	CH609	100	61	NA
	CH610	100	54	NA
	CH613	100	53	NA
	CH705	100	55	NA
	CH706	100	54	NA
	CH709	100	62	NA
Catalog 6050071	CH315	99	58	14
Organochlorines	CH316	102	64	8
in crane carcasses	CH321	100	64	9
	CH322	100	57	15
	CH327	101	59	13
	CH328	101	59	15
	CH329	109	59	16
	CH338	103	55	16
	CH343	110	53	22
	CH346	97	61	12
	CH348	99	51	21
	CH401	103	65	5
	CH402	115	62	6
	CH408	116	59	13
	CH603	109	66	2
	CH605	119	56	12
	CH606	116	59	15
	CH609	112	63	10
	CH610	107	56	15
	CH613	100	58	12
	CH705	100	60	11
	CH706	97	54	14
	CH709	118	63	9

Table A.2. Continued.

Catalog and Analysis	Sample ID	Sample Mass (grams)	Percent moisture	Percent Lipid
Catalog 6050092	01BR	19	80	28
Organochlorines in crane	02BR	14	79	30
muscle and brain	05BR	16	78	24
	11BR	14	79	27
	12BR	12	79	31
	01Bst	69	71	8
	02Bst	190	72	8
	05Bst	140	73	6
	06Bst	122	71	15
	09Bst	51	70	8
	11Bst	58	69	15
	12Bst	73	67	12
Catalog 6050092	01KD	23	76	NA
Elemental contaminants in	02KD	14	77	NA
crane kidney, liver, and	05KD	15	75	NA
muscle	06KD	14	75	NA
	09KD	14	74	NA
	11KD	20	73	NA
	12KD	14	73	NA
	01LV	75	68	NA
	02LV	29	68	NA
	05LV	22	72	NA
	06LV	46	72	NA
	09LV	31	64	NA
	11LV	60	74	NA
	12LV	50	69	NA
	01Bst	69	71	NA
	02Bst	190	72	NA
	05Bst	140	73	NA
	06Bst	122	71	NA
	09Bst	51	70	NA
	11Bst	58	69	NA
	12Bst	73	67	NA

Note: ACF = Analytical Control Facility, CH = carcass homogenate, NA = not applicable, BR = brain, Bst = breast muscle, KD = kidney, LV = liver.

Table A.3. Limits of detection (LOD) and spike recovery data for an analysis of pesticides in waste corn collected from sandhill foraging areas in the central Platte River Valley, Nebraska, 1999 and 2001.

		Spike Recovery (n=4)	
Pesticide	Detection Limit	Mean Percent	CV Percent
Alachlor	0.02	82	14
Aldrin	0.05	66	19
Atrazine	0.02	82	15
Azinophos-methyl	0.02	> 100*	NR
Lindane-alpha	0.02	70	16
Lindane-beta	0.02	80	16
Lindane-delta	0.02	78	9
Carbaryl	0.02	103	18
Carbofuran	0.02	88	12
Chlorothalonil	0.1	32	37
Chlorpyrifos	0.02	82	13
Chlorpyrifos-methyl	0.02	90	14
Cyanazine	0.05	116	24
Diazinon	0.02	79	19
Diclofop-methyl	0.02	88	14
Dieldrin	0.02	71	11
Dimethoate	0.04	84	29
Endosulfan I & II	0.02	82	9
Endrin	0.02	86	30
Fenitrothion	0.02	90	49
Fenthion	0.02	87	15
Fenvalerate-alpha	0.02	100*	62
Fenvalerate-beta	0.02	98*	69
Folpet	0.05	27	121
Fonofos	0.05	77	24
Lindane	0.02	65	33
Malathion	0.02	95	20
Methidathion	0.02	115	8
Methoxychlor	0.02	116	19
Metolachlor	0.02	85	13
p,p'-dichlorodiphenyltrichloroethane (DDT)	0.02	93	18
DDT metabolite p,p'-DDD	0.02	80	21
DDT metabolite p,p'-DDE	0.02	79	12
Parathion	0.02	98	73
Parathion-methyl	0.02	113	22
Phorate	0.05	98	11
Pirimiphos-methyl	0.02	97	16
Propachlor	0.02	69	22
Terbufos	0.05	76	32
Triallate	0.02	72	16
Trifluralin	0.05	97	21

Note: NR = not reported. * indicates that some recoveries were well over 100 percent indicating an interference in the matrix that was used for the spikes.

Table A.4. Limits of detection (LOD) for organochlorines and pesticides in soil samples collected from cornfields in the central Platte River Valley, Nebraska, 1999.

LOD = 0.01 mg/kg wet weight		LOD = 0.05 mg/kg wet weight	
Chemical Class	Compound	Chemical Class	Compound
Organochlorine	chlordane	Carbamate	aldicarb
	cis-nonachlor		carbaryl
	DDT		carbofuran
	dieldrin		methiocarb
	endrin		methomyl
	heptachlor epoxide		oxamyl
	hexachlorobenzene	Organochlorine	PCB-Total
	lindane		toxaphene
	mirex	Organophophate	acephate
	oxychlordane		azinphos-methyl
	trans-nonachlor		chlorpyrifos
Triazine Herbicide	atrazine		coumaphos
	cyanazine		demeton
	metribuzin		diazinon
	propazine		dichlorvos
	simazine		dicrotophos
			dimethoate
			disulfoton
			EPN
			ethoprop
			famphur
			fensulfothion
			fenthion
			malathion
			methamidophos
			methyl parathion
			mevinphos
			monocrotophos
			parathion
			phorate
			terbufos
			trichlorfon

Note: lindane includes alpha, beta, and gama isomers, chlordane includes alpha and gama isomers, DDT (dichlorodiphenyltrichloroethane) includes o,p' and p,p' isomers and metabolites DDD and DDE, PCB = polychlorinated biphenyls, EPN = Ethyl 4-nitrophenyl phenylphosphonothioate

Table A.5. Concentrations of estradiol and testosterone in blood plasma and feces from sandhill cranes in the central Platte River Valley, Nebraska, 1999.

				Blood Plasma			Feces		
				Concentration (pg/ml)			Concentration (pg/ml)		
Crane ID	Date	Sub Species	Gender	Estradiol	Testosterone	E/T	Estradiol	Testosterone	E/T
315	990302	canadensis	F	674	392	1.7	NC	NC	NA
316	990302	canadensis	F	671	409	1.6	NC	NC	NA
321	990310	canadensis	F	560	360	1.6	3352	2546	1.3
338	990329	canadensis	F	854	313	2.7	1365	1294	1.1
346	990407	canadensis	F	583	361	1.6	1251	1395	0.9
348	990409	canadensis	F	744	313	2.4	2431	1568	1.6
605	990308	rowani	F	727	345	2.1	NC	NC	NA
609	990309	canadensis	F	1534	429	3.6	2347	1362	1.7
613	990316	canadensis	F	613	302	2.0	NC	NC	NA
705	990309	canadensis	F	815	374	2.2	2426	1914	1.3
612	990316	canadensis	F	1586	380	4.2	NC	NC	NA
341	990401	canadensis	F	1471	292	5.0	NC	NC	NA
347	990409	canadensis	F	945	317	3.0	NC	NC	NA
324	990315	rowani	F	1583	361	4.4	NC	NC	NA
410	990323	UNK	F	1485	301	4.9	2757	1725	1.6
323	990312	canadensis	F	637	357	1.8	1574	1271	1.2
22R	990312	UNK	F	506	292	1.7	NC	NC	NA
23	990317	UNK	F	543	301	1.8	NC	NC	NA
32	990316	UNK	F	256	913	0.3	NC	NC	NA
33	990312	UNK	F	476	327	1.5	NC	NC	NA
45	990323	UNK	F	531	308	1.7	NC	NC	NA
47	990401	UNK	F	1406	279	5.0	NC	NC	NA
322	990312	canadensis	M	732	1335	0.5	NC	NC	NA
327	990321	rowani	M	483	1374	0.4	935	4660	0.2
328	990322	rowani	M	504	1397	0.4	763	2228	0.3
329	990323	rowani	M	601	1312	0.5	441	2177	0.2
343	990405	canadensis	M	482	821	0.6	1661	2361	0.7
401	990225	rowani	M	714	978	0.7	338	1463	0.2
402	990307	canadensis	M	605	804	0.8	NC	NC	NC
408	990316	rowani	M	494	535	0.9	556	2296	0.2
603	990225	tabida	M	489	1382	0.4	1258	1660	0.8
606	990308	rowani	M	603	714	0.8	771	1965	0.4
610	990311	canadensis	M	605	1431	0.4	210	943	0.2
706	990310	rowani	M	691	702	1.0	1317	1834	0.7
709	990315	canadensis	M	619	1319	0.5	1368	1406	1.0
713	990319	rowani	M	725	1595	0.5	581	2987	0.2
318	990304	canadensis	M	657	1385	0.5	NC	NC	NA
326	990318	canadensis	M	505	1303	0.4	NC	NC	NA
330	990323	canadensis	M	471	1340	0.4	NC	NC	NA
614	990318	canadensis	M	701	1357	0.5	NC	NC	NA
615	990323	canadensis	M	641	1316	0.5	NC	NC	NA
703	990308	canadensis	M	697	737	0.9	NC	NC	NA
704	990308	canadensis	M	575	543	1.1	NC	NC	NA
313	990301	rowani	M	638	1446	0.4	NC	NC	NA
331	990323	rowani	M	470	1380	0.3	NC	NC	NA
345	990406	rowani	M	613	1282	0.5	NC	NC	NA
407	990315	rowani	M	578	1384	0.4	NC	NC	NA
409	990323	rowani	M	646	1306	0.5	NC	NC	NA
314	990301	canadensis	M	609	1388	0.4	NC	NC	NA
11	990324	UNK	M	549	1386	0.4	NC	NC	NA
12	990318	UNK	M	926	318	2.9	NC	NC	NA
13	990319	UNK	M	578	328	1.8	NC	NC	NA
14	990321	UNK	M	1395	329	4.2	NC	NC	NA
21R	990312	UNK	M	654	946	0.7	NC	NC	NA
31	990329	UNK	M	874	269	3.2	NC	NC	NA
34	990320	UNK	M	412	303	1.4	NC	NC	NA
46	990325	UNK	M	1415	273	5.2	NC	NC	NA

Note: NC = not collected, NA = not applicable, UNK = unknown, M = male, F = female, Date = date collected in YYMMDD format, E/T = the estradiol to testosterone ratio.

Table A.6. Concentrations of elemental contaminants in carcass samples of sandhill cranes collected from the central Platte River Valley, Nebraska, 1999.

	Aluminum		Barium		Beryllium		Cadmium		Chromium	
Sample ID	D.W.	W.W.	D.W.	W.W.	D.W.	W.W.	D.W.	W.W.	D.W.	W.W.
CH315	48.20	23.90	3.56	1.77	3.56	1.77	< 0.10	< 0.05	3.28	1.63
CH316	115.00	43.50	2.63	1.00	2.63	1.00	< 0.10	< 0.04	1.83	0.69
CH321	42.50	19.00	2.25	1.01	2.25	1.01	< 0.10	< 0.05	1.82	0.81
CH322	38.20	17.60	2.30	1.06	2.30	1.06	< 0.10	< 0.05	2.21	1.02
CH327	32.10	15.10	1.71	0.81	1.71	0.81	< 0.10	< 0.05	1.46	0.69
CH328	40.40	18.60	3.60	1.65	3.60	1.65	< 0.10	< 0.05	1.23	0.57
CH329	52.40	25.10	3.13	1.50	3.13	1.50	< 0.10	< 0.05	1.20	0.57
CH338	25.80	13.30	4.00	2.06	4.00	2.06	< 0.10	< 0.05	1.82	0.93
CH343	30.10	15.70	2.90	1.51	2.90	1.51	< 0.10	< 0.05	0.57	0.29
CH346	27.50	11.50	4.36	1.82	4.36	1.82	< 0.10	< 0.04	0.96	0.40
CH348	46.40	25.70	2.39	1.33	2.39	1.33	< 0.10	< 0.06	0.64	0.36
CH401	67.30	27.00	3.53	1.42	3.53	1.42	0.11	0.04	2.26	0.91
CH402	76.60	31.80	3.58	1.49	3.58	1.49	< 0.10	< 0.04	2.39	1.00
CH408	35.40	16.90	2.34	1.11	2.34	1.11	< 0.10	< 0.05	1.63	0.78
CH603	54.70	21.50	3.15	1.24	3.15	1.24	< 0.10	< 0.04	2.60	1.02
CH605	23.80	10.40	2.29	1.00	2.29	1.00	< 0.10	< 0.04	4.44	1.94
CH606	21.40	9.99	1.96	0.91	1.96	0.91	< 0.10	< 0.05	0.97	0.45
CH609	46.30	17.90	3.76	1.45	3.76	1.45	< 0.10	< 0.04	1.27	0.49
CH610	51.10	23.40	3.29	1.51	3.29	1.51	< 0.10	< 0.05	2.05	0.94
CH613	32.40	15.10	1.88	0.88	1.88	0.88	< 0.10	< 0.05	1.31	0.61
CH705	24.60	11.00	2.99	1.34	2.99	1.34	< 0.10	< 0.05	2.34	1.05
CH706	30.80	14.20	1.42	0.66	1.42	0.66	< 0.10	< 0.05	1.50	0.69
CH709	75.50	28.50	2.70	1.02	2.70	1.02	0.17	0.06	1.48	0.56
CH713	15.70	6.65	1.94	0.82	1.94	0.82	< 0.10	<0.04	1.40	0.59

	Copper		Iron		Magnesium		Mangenese		Nickel	
Sample ID	D.W.	W.W.	D.W.	W.W.	D.W.	W.W.	D.W.	W.W.	D.W.	W.W.
CH315	3.41	1.69	172	85	1168	579	3.68	1.83	< 0.50	< 0.20
CH316	4.42	1.67	265	100	947	358	3.37	1.28	< 0.50	< 0.20
CH321	4.17	1.87	189	85	917	410	3.13	1.40	0.684	0.306
CH322	3.68	1.70	191	88	796	367	3.38	1.56	< 0.50	< 0.20
CH327	4.33	2.04	194	91	792	373	2.38	1.12	< 0.50	< 0.20
CH328	3.99	1.84	226	104	715	329	2.63	1.21	< 0.50	< 0.20
CH329	4.13	1.97	209	100	751	359	3.55	1.70	< 0.50	< 0.20
CH338	3.34	1.72	191	98	806	414	3.11	1.60	< 0.50	< .030
CH343	3.16	1.64	160	83	638	332	2.19	1.14	< 0.50	< .030
CH346	3.89	1.62	196	82	865	360	3.42	1.42	< 0.50	< 0.20
CH348	3.69	2.05	201	112	582	323	3.29	1.83	< 0.50	< 0.03
CH401	6.32	2.54	284	114	1025	411	3.74	1.50	0.522	0.21
CH402	6.50	2.71	308	128	1029	428	4.27	1.78	< 0.50	< 0.20
CH408	4.05	1.93	198	94	783	372	2.72	1.29	< 0.50	< 0.20
CH603	7.27	2.86	395	156	1070	421	4.49	1.77	< 0.50	< 0.20
CH605	4.22	1.85	245	107	885	387	3.41	1.49	0.791	0.346
CH606	4.31	2.01	226	106	662	308	2.53	1.18	< 0.50	< 0.20
CH609	3.50	1.35	245	95	802	309	3.92	1.51	< 0.50	< 0.20
CH610	4.38	2.01	285	130	727	333	2.92	1.34	< 0.50	< 0.20
CH613	4.97	2.32	258	121	691	322	3.05	1.42	< 0.50	< 0.20
CH705	3.60	1.61	201	90	891	399	2.27	1.02	< 0.50	< 0.20
CH706	3.86	1.78	191	89	741	343	1.98	0.92	0.603	0.279
CH709	6.66	2.52	275	104	793	300	3.83	1.45	0.7	0.264
CH713	3.81	1.61	176	75	769	326	2.00	0.85	< 0.50	< 0.20

Table A.6. Continued.

Sample ID	Lead D.W.	Lead W.W.	Selenium D.W.	Selenium W.W.	Strontium D.W.	Strontium W.W.	Vanadium D.W.	Vanadium W.W.	Zinc D.W.	Zinc W.W.
CH315	2.19	1.09	0.84	0.42	47.20	23.40	0.87	0.43	95.40	47.30
CH316	< 0.50	< 0.20	0.99	0.37	31.90	12.10	< 0.50	< 0.20	86.20	32.60
CH321	3.55	1.59	1.06	0.48	22.60	10.10	< 0.50	< 0.20	73.20	32.70
CH322	2.29	1.06	0.69	0.32	22.20	10.20	< 0.50	< 0.20	73.90	34.10
CH327	3.23	1.52	0.95	0.45	13.30	6.27	< 0.50	< 0.20	65.10	30.60
CH328	< 0.50	< 0.20	0.66	0.30	17.80	8.20	< 0.50	< 0.20	60.80	28.00
CH329	0.94	0.45	0.63	0.30	22.60	10.80	< 0.50	< 0.20	63.50	30.30
CH338	< 0.50	< 0.30	0.69	0.35	29.00	14.90	0.76	0.39	69.90	35.90
CH343	< 0.50	< 0.30	0.63	0.33	22.40	11.70	< 0.50	< 0.30	47.80	24.80
CH346	< 0.50	< 0.20	0.79	0.33	20.10	8.38	< 0.50	< 0.20	68.10	28.40
CH348	1.39	0.77	0.59	0.33	11.30	6.29	< 0.50	< 0.30	49.40	27.40
CH401	1.24	0.50	1.05	0.42	14.30	5.73	0.58	0.23	83.10	33.30
CH402	0.82	0.34	1.08	0.45	32.90	13.70	< 0.50	< 0.20	83.60	34.80
CH408	0.51	0.24	0.65	0.31	20.80	9.89	< 0.50	< 0.20	65.10	30.90
CH603	2.46	0.97	1.00	0.39	21.90	8.63	< 0.50	< 0.20	101.00	39.80
CH605	0.77	0.34	0.84	0.37	38.60	16.90	< 0.50	< 0.20	84.80	37.10
CH606	< 0.50	< 0.20	0.96	0.45	18.50	8.61	< 0.50	< 0.20	64.00	29.90
CH609	1.61	0.62	1.34	0.52	28.30	10.90	< 0.50	< 0.20	77.20	29.80
CH610	1.54	0.70	0.80	0.37	39.40	18.00	< 0.50	< 0.20	62.00	28.40
CH613	0.55	0.26	0.69	0.32	19.80	9.22	< 0.50	< 0.20	66.50	31.00
CH705	< 0.50	< 0.20	0.99	0.44	41.40	18.50	< 0.50	< 0.20	71.80	32.10
CH706	4.76	2.20	0.83	0.38	21.50	9.93	< 0.50	< 0.20	60.20	27.80
CH709	1.86	0.70	1.43	0.54	28.00	10.60	< 0.50	< 0.20	69.70	26.30
CH713	5.32	2.25	0.64	0.27	27.30	11.60	< 0.50	< 0.20	59.50	25.20

Note: < indicates sample was below the detection limit (value is the detection limit). D.W. = dry weight and W.W. = wet weight.

Table A.7. Concentrations of elemental contaminants in kidney, liver, and muscle samples from sandhill cranes collected from the central Platte River Valley, Nebraska, 2001.

Tissue	Sample ID	Aluminum D.W.	Aluminum W.W.	Boron D.W.	Boron W.W.	Barium D.W.	Barium W.W.	Cadmium D.W.	Cadmium W.W.	Chromium D.W.	Chromium W.W.
Kidney	01KD	8.44	2.03	20.30	4.88	< 0.595	< 0.143	1.67	0.40	2.95	0.71
Kidney	02KD	28.00	6.50	27.10	6.31	1.370	0.319	2.93	0.68	4.58	1.07
Kidney	05KD	12.10	3.05	34.50	8.67	< 0.667	< 0.167	2.74	0.69	5.05	1.27
Kidney	06KD	22.00	5.61	38.90	9.89	3.270	0.833	1.81	0.46	4.33	1.10
Kidney	09KD	14.10	3.74	35.20	9.30	1.050	0.278	3.33	0.88	3.99	1.05
Kidney	11KD	22.60	6.00	20.90	5.56	1.650	0.437	0.85	0.23	3.33	0.88
Kidney	12KD	25.80	6.92	24.20	6.48	1.160	0.311	2.78	0.75	3.28	0.88
Liver	01LV	15.00	4.75	32.50	10.30	< 0.658	< 0.209	0.37	0.12	3.28	1.04
Liver	02LV	20.40	6.58	32.30	10.40	< 0.667	< 0.215	0.84	0.27	3.26	1.05
Liver	05LV	16.70	4.77	50.60	14.40	< 0.667	< 0.190	0.57	0.16	3.54	1.01
Liver	06LV	18.70	5.21	46.90	13.10	< 0.658	< 0.183	0.44	0.12	3.30	0.92
Liver	09LV	18.30	6.57	57.40	20.60	< 0.602	< 0.216	0.81	0.29	3.38	1.21
Liver	11LV	10.90	2.86	38.40	10.10	< 0.667	< 0.175	0.24	0.06	2.87	0.75
Liver	12LV	13.60	4.15	47.10	14.40	0.876	0.268	0.49	0.15	3.35	1.02
Muscle	01Bst	14.30	4.20	36.10	10.60	< 0.658	< 0.193	0.31	0.09	2.99	0.88
Muscle	02Bst	13.30	3.76	32.00	9.01	< 0.610	< 0.172	0.16	0.04	2.75	0.78
Muscle	05Bst	9.82	2.68	33.10	9.04	0.872	0.238	0.22	0.06	2.61	0.71
Muscle	06Bst	8.88	2.61	26.80	7.88	< 0.658	< 0.193	0.41	0.12	2.49	0.73
Muscle	09Bst	27.60	8.17	34.80	10.30	0.962	0.285	0.36	0.11	3.26	0.97
Muscle	11Bst	17.30	5.29	36.00	11.00	< 0.658	< 0.201	1.43	0.44	3.15	0.97
Muscle	12Bst	14.80	4.94	34.50	11.50	0.880	0.294	0.44	0.15	2.78	0.93

Tissue	Sample ID	Copper D.W.	Copper W.W.	Iron D.W.	Iron W.W.	Magnesium D.W.	Magnesium W.W.	Manganese D.W.	Manganese W.W.	Molybednum D.W.	Molybednum W.W.
Kidney	01KD	13.2	3.19	904	218	743	179	6.14	1.48	1.83	0.44
Kidney	02KD	22.4	5.21	996	232	981	228	11.7	2.71	2.15	0.5
Kidney	05KD	34.1	8.56	735	185	818	205	8.78	2.2	1.72	0.432
Kidney	06KD	26.6	6.78	677	172	837	213	10.2	2.6	2.47	0.628
Kidney	09KD	24.9	6.57	894	236	855	226	8.07	2.13	2.19	0.58
Kidney	11KD	23.9	6.34	633	168	848	225	8.29	2.2	2.58	0.686
Kidney	12KD	19.1	5.12	431	115	817	219	9.37	2.51	3.72	0.995
Liver	01LV	8.93	2.83	761	241	547	173	6.14	1.95	< 1.32	< .417
Liver	02LV	11.8	3.8	1554	501	594	191	7.3	2.35	1.51	0.486
Liver	05LV	17.7	5.03	3259	929	869	248	10.4	2.97	2.17	0.617
Liver	06LV	14.8	4.13	1058	294	833	232	10.2	2.83	1.97	0.549
Liver	09LV	13.5	4.84	2515	904	658	236	10.1	3.64	2.19	0.788
Liver	11LV	12.7	3.34	1446	379	658	172	8.52	2.23	1.75	0.459
Liver	12LV	10.5	3.22	996	305	690	211	8.36	2.56	4.27	1.31
Muscle	01Bst	22.7	6.66	251	73.7	990	290	2.64	0.774	< 1.32	< 0.386
Muscle	02Bst	20.6	5.81	288	81.3	1014	286	2.71	0.766	< 1.22	< 0.344
Muscle	05Bst	15.8	4.31	294	80.3	1087	296	1.94	0.528	< 1.33	< 0.364
Muscle	06Bst	18.3	5.37	202	59.4	992	292	2.46	0.722	< 1.32	< 0.387
Muscle	09Bst	19.5	5.78	260	77	1099	326	2.61	0.773	< 1.28	< 0.380
Muscle	11Bst	21	6.42	248	76	853	261	2.55	0.782	< 1.32	< 0.403
Muscle	12Bst	19.5	6.52	229	76.7	953	319	2.7	0.904	< 1.33	< 0.446

Table A.7. Continued.

Tissue	Sample ID	Nickel D.W.	Nickel W.W.	Lead D.W.	Lead W.W.	Selenium D.W.	Selenium W.W.	Strontium D.W.	Strontium W.W.	Vanadium D.W.	Vanadium W.W.	Zinc D.W.	Zinc W.W.
Kidney	01KD	1.670	0.401	< 0.298	< 0.072	3.09	0.74	0.59	0.14	< 0.30	< 0.07	79.90	19.20
Kidney	02KD	2.250	0.524	< 0.333	< 0.078	4.30	1.00	3.06	0.71	< 0.33	< 0.08	128.00	29.90
Kidney	05KD	2.800	0.704	< 0.333	< 0.084	3.80	0.95	3.35	0.84	0.34	0.09	117.00	29.30
Kidney	06KD	3.280	0.834	< 0.333	< 0.085	2.36	0.60	3.39	0.86	< 0.33	< 0.09	97.80	24.90
Kidney	09KD	1.420	0.374	0.325	0.086	2.56	0.68	2.43	0.64	0.45	0.12	112.00	29.50
Kidney	11KD	< 0.312	< 0.083	0.475	0.126	2.64	0.70	2.72	0.72	0.64	0.17	126.00	33.40
Kidney	12KD	0.674	0.180	0.346	0.093	3.86	1.03	2.34	0.63	0.82	0.22	115.00	30.80
Liver	01LV	< 0.329	< 0.104	< 0.329	< 0.104	1.00	0.32	2.41	0.77	< 0.33	< 0.10	85.20	27.00
Liver	02LV	< 0.333	< 0.107	< 0.333	< 0.107	1.14	0.37	2.21	0.71	< 0.33	< 0.11	91.60	29.50
Liver	05LV	1.870	0.533	< 0.333	< 0.095	1.82	0.52	2.28	0.65	< 0.33	< 0.10	168.00	47.70
Liver	06LV	< 0.329	< 0.092	< 0.329	< 0.092	1.15	0.32	2.22	0.62	< 0.33	< 0.10	123.00	34.20
Liver	09LV	8.190	2.940	< 0.301	< 0.108	1.34	0.48	2.22	0.80	< 0.301	< 0.10	124.00	44.70
Liver	11LV	9.360	2.450	< 0.333	< 0.088	1.42	0.37	1.99	0.52	< 0.33	< 0.10	121.00	31.70
Liver	12LV	9.310	2.850	< 0.333	< 0.102	1.44	0.44	2.01	0.62	< 0.33	< 0.10	111.00	34.00
Muscle	01Bst	9.820	2.880	< 0.329	< 0.096	0.39	0.11	1.76	0.52	< 0.33	< 0.10	86.00	25.20
Muscle	02Bst	5.780	1.630	< 0.305	< 0.086	0.51	0.14	1.98	0.56	< 0.31	< 0.10	63.30	17.90
Muscle	05Bst	1.870	0.510	< 0.333	< 0.091	0.46	0.12	1.38	0.38	< 0.33	< 0.10	73.60	20.10
Muscle	06Bst	0.760	0.223	< 0.329	< 0.097	< 0.33	< 0.10	1.43	0.42	< 0.33	< 0.10	54.70	16.10
Muscle	09Bst	12.200	3.610	< 0.321	< 0.095	< 0.32	< 0.10	2.58	0.76	< 0.32	< 0.10	58.30	17.30
Muscle	11Bst	9.460	2.900	< 0.329	< 0.101	0.35	0.11	1.76	0.54	< 0.33	< 0.10	58.10	17.80
Muscle	12Bst	10.100	3.390	< 0.333	< 0.112	0.42	0.14	2.05	0.69	< 0.33	< 0.10	69.90	23.40

Note: < indicates sample was below the detection limit (value is the detection limit).