Arch. Environ. Contam. Toxicol. 41, 491–500 (2001)
DOI: 10.1007/s002440010276

ARCHIVES OF
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Contamination
and Toxicology

Trace Elements in King Eiders and Common Eiders in the Canadian Arctic

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Received: 7 February 2001/Accepted: 14 May 2001

Abstract. We determined concentrations of selected trace elements in tissues of king and common eiders at three locations in the Canadian arctic. Renal and hepatic cadmium concentrations in king eiders at a location in the eastern arctic were among the highest ever recorded in eider ducks: there, they were higher in king eiders than in common eiders. Cadmium concentrations were lower in king eiders from the western arctic than in those from the east. In the western arctic, cadmium concentrations did not differ between species. Hepatic mercury and zinc were higher in king eiders than in common eiders. Zinc and selenium were higher in eiders from the western arctic than in those from the eastern arctic. Trace element concentrations in these two duck species were below published toxicity thresholds. Positive correlations in trace element concentrations in both species were found between total and organic hepatic mercury, renal and hepatic cadmium as well as hepatic zinc, copper, mercury, and cadmium. Body mass of common but not king eiders and spleen mass of both species were negatively correlated with mercury concentrations. In common eiders, the number of nematode parasites was positively correlated with total and organic mercury. Histopathological evidence of kidney or liver lesions that are typical of trace metal poisoning was not found. We did not find evidence to support the hypothesis that trace metal exposure may be contributing to adverse effects on the health of individuals of these species.

King eiders (*Somateria spectabilis*) and common eiders (*S. mollissima*) are sea ducks (Mergini) found principally in arctic and subarctic coastal areas. Like many sea ducks in North America (Canadian Wildlife Service *et al.* 1997), their populations have declined precipitously over the past several decades (Gratto-Trevor *et al.* 1998; Robertson and Gilchrist 1998; Suydam *et al.* 2000). The causes of these declines have not been identified.

It has been postulated that contaminants may be one of several risk factors for North American sea duck populations (Canadian Wildlife Service *et al.* 1997). Trace elements, in particular cadmium and selenium, have been found at elevated concentrations in eider ducks in arctic and subarctic areas (Norheim 1987; Nielsen and Dietz 1989; Henny *et al.* 1995; Dietz *et al.* 1996; Trust *et al.* 2000). However, with the exception of Braune *et al.* (1999), who reported concentrations of selected trace elements in pooled samples of eider muscle, published information is lacking on trace elements in the two eider species in the Canadian arctic, which is an important part of their respective breeding ranges.

A paucity of useful information exists concerning the possible toxic effects of trace elements on sea ducks. Most information comes from laboratory-based, captive-feeding experiments wherein surrogate species, such as the mallard (*Anas platyrhynchos*), were exposed to relatively high levels of single trace elements (DiGiulio and Scanlon 1985; Heinz *et al.* 1989; Bennett *et al.* 2000). The results of such studies are difficult to interpret in terms of potential effects on sea ducks for the following reasons: first, sea ducks and experimental species (mainly the mallard) may differ in their sensitivities to a contaminant. Second, sea ducks in the wild are exposed simultaneously to varying levels of multiple trace elements, some of which may reduce (Magos and Webb 1980; Friberg *et al.* 1986) or increase (Gochfeld 1997) the toxic effects of others. Typically, such variation is not represented in laboratory studies. Finally, natural environmental stressors, of the type that wild animals routinely encounter (*e.g.*, adverse weather), may act together with contaminants to produce physiological impairment (Forsyth 2001). Such natural stressors are rarely considered in laboratory-based studies.

To minimize the risk of incorrectly extrapolating the results of laboratory-based studies to wild sea ducks, it is important to examine trace element concentrations while simultaneously examining the health of these birds under natural conditions. From the perspective of sea duck conservation, it would be best to examine health-related biomarkers that may have a bearing on population dynamics. One such biomarker is body condition. In waterfowl, various measures of body condition have been linked to reproductive effort (Milne 1976) and success (Blums *et al.* 1997) and to survival rates (Bergan and Smith 1993). If exposure

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to elevated concentrations of certain trace elements is related to reduced body condition, as has been alluded to by Henny *et al.* (1991), then population dynamics could ultimately be affected. The incidence and severity of disease may also impact wild populations of sea ducks. Poor health and large die-offs of common eiders have been attributed to infestations of acanthocephalan parasites (Persson *et al.* 1974; Hollmén *et al.* 1999). Thus, parasitic infestations could impact eider populations. Furthermore, it has been shown experimentally that exposure to certain trace elements can increase the severity of parasitic infestations (Borošková *et al.* 1995), providing a possible mechanism by which such exposure could impact eider populations.

In this study, we compared concentrations of selected trace elements in livers and kidneys of king and common eiders at three locations in the Canadian arctic. We also determined whether tissue concentrations of these elements were correlated, because the coaccumulation of many trace elements may affect the bioaccumulation and toxicity of individual elements (Magos and Webb 1980). Additionally, we assessed whether relationships existed between tissue concentrations of trace elements and physiological biomarkers, including body condition indices and the numbers of gastrointestinal parasites. Finally, because exposure to trace elements has been associated with tissue damage in some seabirds (Nicholson *et al.* 1983), we examined the livers and kidneys of these birds for histopathological lesions.

Materials and Methods

Field Collection

Between June 9–21, 1997, adult king and common eiders were collected at the East Bay Migratory Bird Sanctuary (EB) on Southampton Island, Nunavut (64°04′N, 82°00′W) and near the village of Holman (HOL) on Victoria Island, Northwest Territories (70°39′N, 117°43′W) (Figure 1). With the exception of four king eiders collected at EB, all birds were females. Also, adult, female common eiders were collected at the Belcher Islands (BEL), Nunavut (56°15′N, 79°15′W) on July 21, 1997. Common eiders at HOL and all king eiders were shot with lead shot. Common eiders at EB were captured in mist nets and killed by cervical dislocation within 15 min of capture. Common eiders at BEL were captured on nests and killed immediately. Carcasses were weighed (precision: 20 g) and measured (wing length, culmen length, total bill length, tarsal length; precision: 1 mm for wing length and 0.01 mm for others) prior to dissection. Keel length (0.01 mm) was also measured after removal of the breast muscles. At HOL and EB, liver, kidneys, spleen, heart, and stored fat in the abdominal cavity (abdominal fat) were removed, using nitric acid–rinsed dissecting tools, and weighed (0.1 g). At BEL, these tissues were not weighed. Thin slices of liver and kidneys were stored in 10% neutral buffered formalin. The remaining liver and kidney was placed in acid and solvent-rinsed glassware and frozen. The gizzard, proventriculus, and small and large intestines were removed from each bird, stored in sealed plastic bags, and frozen for subsequent examination of helminth parasites. All procedures were completed within 24 h of collection.

Residue Analysis

Total mercury, organic mercury, and selenium in liver and cadmium in kidney were analyzed at the National Wildlife Research Centre (NWRC) of Environment Canada in Hull, Quebec. Briefly, tissue samples were homogenized and weighed into preweighed, acid-washed test tubes, freeze-dried, and their dry masses recorded. Deionzed H_2O (0.5 ml) and HNO_3 (either 0.5 ml or 1.0 ml) were added to each test tube. For mercury analyses, samples were heated at 70°C for 1 h. After cooling, 1.0 ml of H_2SO_4 (95–97%) followed by 0.5 ml HCl (37%) was added to each sample. They were heated again at 70°C for 2 h. After cooling, the volumes were adjusted to 10 ml with 2 mM $K_2Cr_2O_7$ in 3% HCl. Volumes were then adjusted to 20 ml with 9.9 ml HCl (1.5%) and 100 μl octanol. Total mercury was analyzed by cold vapor atomic absorption spectrometry (CVAAS) using a 3030 AAS by Perkin-Elmer equipped with a Varian VGA-76 hydride generator and a PSC-55 Varian autosampler.

Organic mercury was extracted into toluene as methyl mercuric bromide following the method of Shum *et al.* (1979). The bromide was then partitioned into the aqueous phase as a thiosulfate complex. Then, after acid digestion, organic mercury was analyzed by CVAAS as described above.

For cadmium in kidney and selenium in liver, samples treated with deionized H_2O and HNO_3 as described above, were allowed to sit overnight at room temperature. The following day they were heated at 100°C in dry baths for 6 h. Samples were allowed to cool overnight, then their volumes were adjusted to 4.0 ml with deionized H_2O. Cadmium in kidney was analyzed by flame AAS, using a Perkin-Elmer 3030b spectrophotometer. Selenium was analyzed by graphite furnace AAS using the Perkin-Elmer 3030b equipped with a deuterium background corrector, HGA-300 graphite furnace, and AS-40 autosampler.

Cadmium, zinc, and copper in liver were analyzed at Philip Analytical Services (PAS) in Halifax, Nova Scotia. Samples were digested in mineral acids and analyzed by inductively coupled plasma mass spectrometry according to US EPA method 200.8 (US EPA 1998). Values were converted from wet to dry weight by using percent moisture values for liver samples. These values were determined as part of the AAS procedures done at NWRC.

Quality Assurance

Recovery of the analytes from spiked samples and standard reference materials (DORM-2 and DOLT-2 from the National Research Council) ranged from 88–112% and averaged 102%. Repeatability, determined as the percent residual standard deviation of duplicate and triplicate analyses, ranged from 1–11% and averaged 5.7%. Quality assurance results for cadmium in kidney, done at NWRC and cadmium in liver, done at PAS, compared favorably. Recovery of cadmium from DOLT-2 was 100% at NWRC and averaged 102% at PAS. Repeatability estimates for cadmium analyses were 11% and 1.2% at NWRC and 8% at PAS. Detection limits were 0.2 μg/g for Hg and organic Hg, 0.4 μg/g for Cd in kidney and Se in liver, 0.3 μg/g for Cd in liver and 1.6 μg/g for Cu and Zn.

Parasites

In the laboratory, sections of the gastrointestinal tract (gizzard, proventriculus, ileum, jejunum, and duodenum) were thawed and opened, and all macroscopic helminths (nematodes, large cestodes, acanthocephalans) were removed and stored in glycerine alcohol for later identification and tabulation. The tissues were searched with the aid of a stereomicroscope. Several birds were infected with high numbers of hymenolepid cestodes that were not readily visible by gross examination. Estimates of their numbers were made using the following method: total intestinal contents were scraped off the lining of each section and suspended in 200 ml distilled water. Five aliquots of 10 ml were removed, and all cestode scoleces were counted in each aliquot. The average count for the five aliquots was determined. The final estimate of cestodes was obtained by multiplying the average count by

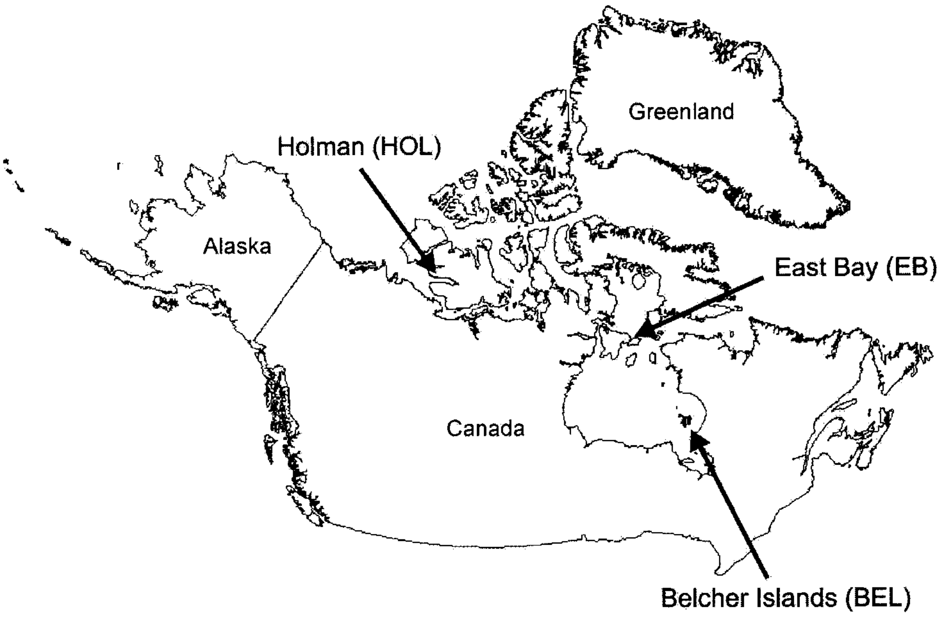

Fig. 1. Locations in the Canadian arctic, where king and common eiders were collected. Only common eiders were collected at the Belcher Islands

the ratio of the total sample volume to the aliquot sample volume (*i.e.*, 20). Estimates of the total numbers of nematodes, cestodes, and acanthocephalans in each gastrointestinal tract were recorded.

Histopathology

Slices of liver and kidney preserved in 10% neutral buffered formalin were processed routinely for light microscopic examination (Riddell 1987). Five-micrometer paraffin embedded sections stained with hemotoxylin and eosin were examined for histological lesions without prior knowledge of metal concentrations in tissues. Lesions were described and then scored with a scale from 0 to 4, with 0 indicating normal and 4 indicating marked change.

Statistics

Trace element, body condition and morphometry data were log-transformed prior to analysis. Normality of log-transformed data was tested using the W statistic of PROC UNIVARIATE (SAS Institute 1988). Homogeneity of variances was tested using the $F_{\max}$ test. Two-way multivariate analysis of variance (MANOVA) was used to test for differences between species and locations (EB and HOL) in concentrations of all trace elements considered simultaneously. Because only common eiders were collected at BEL, one-way MANOVA was used to test for among-location differences in trace element concentrations in that species. Significant MANOVAs ($p < 0.05$) were followed by univariate analysis of variance (ANOVA). Where required, *a posteriori* comparisons of mean values among locations were made using the Tukey-Kramer method.

Relationships among tissue concentrations of trace elements were examined in two ways. First, simple correlations were done across species and locations. These analyses made no attempt to partial out variation that was attributable to species and location. Second, partial correlations were determined following the example of Braune *et al.* (1991). Briefly, residual trace element values were calculated by subtracting the mean value for each species and location from the observed value. These correlations represent relationships among trace elements after adjustment for any covariation with species or location.

Before examining relationships between trace element concentrations and body/organ masses, an index of structural size for each species was developed from our morphometric measurements by using principal components analysis. In these analyses, the first principal component accounted for 39% (king eiders) and 59% (common eiders) of the total variability in morphometric data. Morphometric variables were generally positively related to the first principal component, indicating that high principal component scores represented structurally large birds.

We examined relationships between body/organ masses and trace element concentrations for each species separately by calculating partial correlations based on residual values after correcting for variation among locations as described above. Additionally, residuals of body/organ masses were calculated as the differences between observed values and those that were predicted by a structural size index as represented by principal component one scores. The structural size index was included only when it accounted for a significant ($p < 0.05$) amount of the variation in body/organ mass. Implicit in these analyses is that relationships between trace element concentrations and body/organ masses are consistent among locations regardless of the actual differences among locations in their values. A similar approach was used to examine the relationships between residuals for parasite counts (nematodes, cestodes, and acanthocephalans) and trace element concentrations, except that in such analyses, covariation due to structural size was not considered. Because of the large number of correlation analyses in this study, we used the sequential Bonferroni method (Rice 1989), unless otherwise indicated, to adjust the α level in order to reduce the probability of committing Type I error.

Logistic regression was used to determine whether tissue metal concentrations could differentiate between tissues with "normal" histopathology and those exhibiting mild to moderate lesions. Histopathology scores were analyzed separately for each species.

Results

Trace Element Concentrations

Fifty-three adult, eider ducks, including 33 female common eiders and 16 female and 4 male king eiders were analyzed in this study.

Hepatic concentrations of total mercury ($p = 0.0007$), copper ($p = 0.02$), and zinc ($p = 0.007$) were significantly higher in king eider males than in females while concentrations of cadmium in liver ($p = 0.34$) and kidney ($p = 0.43$) and of selenium in liver ($p = 0.79$) did not differ between the two genders (Table 1). Due to significant differences between genders in some of these trace elements, all subsequent analyses are based only on females.

A significant interaction between species and location was found in trace element concentrations (MANOVA: $p = 0.02$). This was primarily attributable to the significant interaction between species and location in cadmium concentrations in liver (ANOVA: $p = 0.02$) and in kidney (ANOVA: $p = 0.0008$). Cadmium concentrations were generally elevated, ranging from 4–42 μg/g in liver and from 32–225 μg/g in kidney. They were higher in king eiders at EB than at HOL, the opposite was true for common eiders (Table 1). Cadmium concentrations in common eiders at BEL were statistically indistinguishable from those in conspecifics at HOL and EB (p values > 0.05). At EB, concentrations of cadmium were higher in king eiders than in common eiders, and at HOL, they were similar in the two species (Table 1). Significant interactions between species and location were not found for other trace elements (all p values > 0.05).

Hepatic concentrations of total mercury were relatively low in these eiders, ranging from 0.7–3.7 μg/g. They were higher in king eiders than in common eiders (ANOVA: $p = 0.04$) and higher in eiders from EB than in those from HOL (Table 1), although the difference was not significant (ANOVA: $p = 0.08$). Hepatic mercury concentrations in common eiders from BEL were not significantly different from those in their conspecifics from HOL and EB ($p > 0.05$). Organic mercury did not differ between species or locations (ANOVA: $p_{\text{species}} = 0.13$; $p_{\text{location}} = 0.15$).

Hepatic selenium concentrations ranged from 8–62 μg/g. They did not differ between species ($p = 0.5$) but were higher in eiders at HOL than in those at EB ($p < 0.0001$) while common eiders from BEL had concentrations that were lower than in their conspecifics from HOL and EB ($p < 0.05$) (Table 1).

Hepatic zinc concentrations ranged from 86–333 μg/g. They were significantly higher in king eiders than in common eiders ($p = 0.0002$) and were significantly higher in eiders at HOL than in those at EB ($p = 0.02$) (Table 1). Zinc concentrations in common eiders did not differ significantly among the three locations ($p = 0.13$).

Hepatic copper concentrations ranged from 12–805 μg/g with no significant differences between species ($p = 0.43$) or locations ($p = 0.53$) (Table 1). Furthermore, copper concentrations in common eiders did not differ significantly between HOL, EB, and BEL ($p = 0.70$).

Interrelationships Among Trace Elements

Eleven of 21 simple correlations between log-transformed concentrations of trace elements were significant ($p < 0.05$) (Table 2). These correlations included variation that was attributable to species and location as well as to intrinsic chemical and physiological factors related to bioaccumulation of these elements. Total and organic mercury concentrations were highly correlated ($r = 0.91$). Cadmium concentrations in liver were correlated with those in kidney ($r = 0.79$) and with hepatic zinc ($r = 0.72$), total mercury ($r = 0.53$), and organic mercury ($r = 0.44$) concentrations. In addition to their high correlations with cadmium in liver and kidney (Table 2), zinc concentrations were correlated with those of copper ($r = 0.46$) and total ($r = 0.53$) and organic mercury ($r = 0.38$). Selenium concentrations were not highly correlated with those of any of the other trace elements (Table 2).

Seven of 21 simple correlations between residuals of trace element concentrations were significant ($p < 0.05$) (Table 2). Such correlations excluded variation attributable to species and location and more closely reflected intrinsic chemical and physiological factors related to the bioaccumulation of these trace elements. Residuals of total mercury were highly correlated with those of organic mercury ($r = 0.84$) and zinc ($r = 0.57$). Residuals of hepatic cadmium concentrations were significantly correlated with those of renal cadmium ($r = 0.61$) and with those of hepatic zinc ($r = 0.57$). Zinc and copper residuals were correlated ($r = 0.44$). Residuals of selenium concentrations were not significantly correlated with those of other trace elements ($p > 0.05$) (Table 2).

Trace Elements and Body Condition/Organ Mass

The two most important indices of body condition, total body mass and abdominal fat mass, were generally not negatively correlated with trace element concentrations, although for common eiders, a significant negative correlation was found between the residual of cadmium in liver and residual total body mass ($r_{\text{spearman}} = -0.44$, $p_{\text{unadjusted}} = 0.01$). In both species, residual spleen mass was negatively correlated with the residual of total hepatic mercury (common eider: $r_{\text{spearman}} = -0.47$, $p_{\text{unadjusted}} = 0.02$; king eider: $r_{\text{spearman}} = -0.49$, $p_{\text{unadjusted}} = 0.05$) (Figure 2), while in common eiders it was negatively correlated with the residual of renal cadmium ($r_{\text{spearman}} = -0.62$, $p < 0.05$).

Parasites

Nematodes and cestodes were found in 18 and 17 of 20 king eiders, respectively, and in 30 of 33 common eiders; acanthocephalans were found in 8 king eiders and 25 common eiders. Only cestode numbers were high (KIEI: 125.1 ± 53.2; COEI: 1,759.5 ± 549.8, mean ± 1 SE), whereas those of acanthocephalans were low (KIEI: 0.9 ± 0.4; COEI: 57.0 ± 23.8). Mean (± 1 SE) numbers of nematodes were 18 (± 3.9) and 31 (± 3.8) in king and common eiders, respectively. Nematodes were dominated by *Echinuria sp.*, *E. borealis*, and *Amidostomum acutum* and included a few *Tetrameres, Streptocara*, and *Capillaria*. Cestodes were comprised principally of *Microsomacanthus, Dicranotaenia fallax*, and *Lateriporus teres*. The small number of acanthocephalans were comprised principally of *Profilicollis botulus*, *Polymorphus phippsi*, and *Corynosoma*.

In both species, residuals of cestode numbers and acanthocephalan numbers were not correlated with those of trace element concentrations ($p > 0.05$). However, in common eiders, but not in king eiders, residual total and organic mercury

Table 1. Geometric means, 95% confidence intervals, and ranges (μg/g dry weight) of selected trace elements in livers and kidneys of king and common eiders from three locations in the Canadian arctic[a]

Location	Species[b]	Sex	Se	Tot-Hg	Org-Hg	Cu	Zn	Cd (L)	Cd (K)
EB	COEI	F	19.4	1.6	1.4	109.3	120.5	10.5	68.1
		(n = 13)	15.5–24.2	1.3–2.0	1.2–1.7	54.1–221.1	109.4–132.7	8.5–12.8	57.8–80.3
			10.7–31.5	0.9–3.7	0.9–3.2	12.5–805.4	85.6–157.2	6.5–17.8	47.1–113.5
	KIEI	F	18.7	2.1	1.7	86.7	135.3	27.1	154.5
		(n = 6)	14.1–24.8	1.7–2.5	1.3–2.3	59.4–26.6	114.9–159.3	18.3–40.2	123.3–193.6
			14.4–26.1	1.5–2.5	1.2–2.2	56.6–152.9	106.9–161.0	15.7–41.1	116.2–213.3
		M	19.9	3.8	3.0	224.5	188.2	33.5	173.7
		(n = 4)	11.1–35.5	3.2–4.5	2.3–3.8	86.9–580.0	166.5–212.6	26.9–41.7	131.4–229.6
			15.7–37.1	3.4–4.4	2.6–3.8	92.6–434.8	166.7–202.7	26.7–38.0	146.8–232.5
HOL	COEI	F	29.1	1.5	1.3	82.0	123.6	15.8	117.2
		(n = 10)	22.1–38.3	1.2–1.7	1.0–1.6	34.0–197.9	108.9–140.4	12.5–19.8	95.7–143.5
			16.4–53.3	1.0–2.2	0.8–1.9	11.7–542.2	97.1–171.7	9.4–24.4	71.4–175.3
	KIEI	F	35.6	1.7	1.4	176.4	168.8	23.3	111.7
		(n = 10)	28.2–44.9	1.4–2.0	1.1–1.7	110.2–282.4	155.3–183.4	18.0–30.2	77.0–162.0
			22.5–61.7	1.0–2.5	0.8–2.0	72.5–625.0	147.2–221.6	12.8–42.7	48.7–224.6
BEL	COEI	F	10.2	1.3	0.9	123.5	152.4	13.9	73.6
		(n = 10)	8.7–11.9	0.9–1.9	0.7–1.2	67.6–225.7	110.7–209.7	7.6–25.5	44.6–121.4
			7.6–16.1	0.7–2.8	0.5–1.7	51.4–787.7	89.2–333.3	4.5–37.0	31.8–218.3

[a] Cd concentrations in both liver (Cd(L)) and kidney (Cd(K)) are reported. Concentrations of the other trace elements were determined only in liver.
[b] COEI = common eider, KIEI = king eider.

Table 2. Pearson (above diagonal) and Spearman (below diagonal) correlation coefficients for log-transformed and residual trace element concentrations, respectively, in 53 king and common eiders from three locations in the Canadian arctic

	Se	Tot-Hg	Org-Hg	Cu	Zn	Cd (L)[a]	Cd (K)[a]
Se	—						
Tot-Hg		—	0.91**		0.53**	0.53**	0.51**
Org-Hg		0.84**	—		0.38*	0.44*	0.43*
Cu				—	0.46*		
Zn		0.57**	0.48**	0.44*	—	0.72**	0.51**
Cd (L)[a]					0.57**	—	0.79**
Cd (K)[a]					0.48**	0.61**	—

Residual trace elements were calculated as actual value minus mean value (by species and location). Only significant ($P \leq 0.05$ after sequential Bonferroni adjustment) correlation coefficients are shown.
[a] Cd(L) refers to Cd in liver; Cd(K) refers to Cd in kidney.
* $p \leq 0.05$ after Bonferroni adjustment; ** $p \leq 0.01$ after Bonferroni adjustment.

concentrations were positively correlated with residual nematode numbers (total Hg: $r_{\text{spearman}} = 0.42$, $p_{\text{unadjusted}} = 0.02$; org- Hg: $r = 0.53$, $p < 0.05$) (Figure 3).

Histopathology

Tissues were collected from 22 common eiders and 20 king eiders from which 40 kidneys, 41 livers, 12 ovaries, 5 tests, and 15 spleens were examined histologically. All tissues were considered normal or had very mild to mild nonspecific lesions that could not be associated with elevated metal concentrations and were most likely attributable to bacteria, parasitic migration, or some other antigenic stimulation. In both species, the presence of kidney and liver lesions were not related to trace element concentrations (p values ≥ 0.09).

Discussion

Trace Element Concentrations

Cadmium concentrations in king eiders from EB were among the highest ever recorded in eider ducks. Cadmium concentrations in both species at HOL were also relatively high in comparison to other published studies. The geometric mean renal cadmium concentrations in king eiders were 162 (range: 116–232) and 112 μg/g (range: 49–225) at EB and HOL,

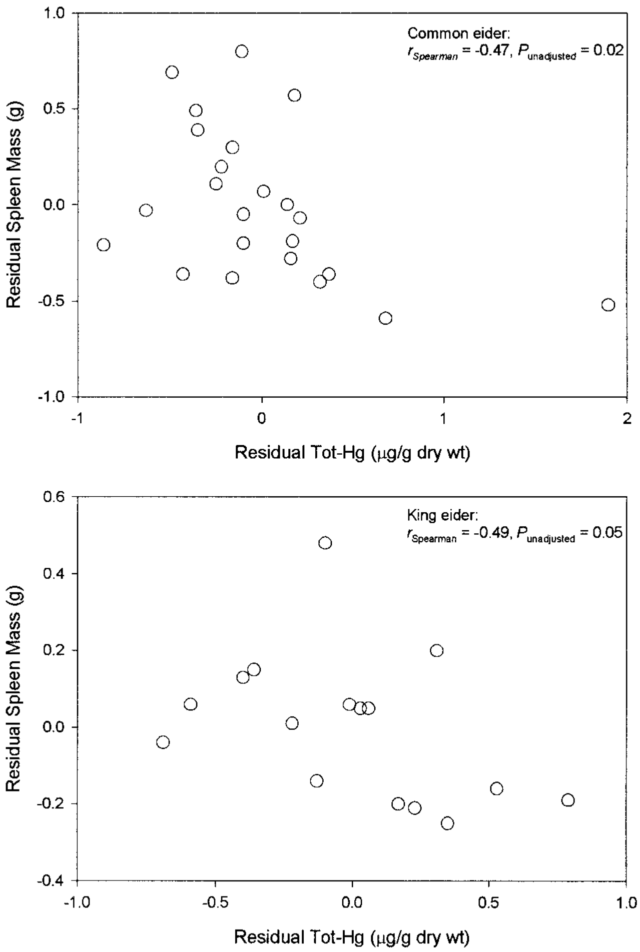

Fig. 2. Relationship between residuals of total hepatic mercury and those of spleen mass in common (top graph) and king eiders (bottom graph). Residuals were calculated as the difference between observed values and the location mean value

respectively. For common eiders at HOL, this value was 117 µg/g (range: 71–175). In comparison, Dietz *et al.* (1996) reported geometric mean renal cadmium concentrations of 74 and 53 µg/g in adult king and common eiders, respectively, in Greenland. An earlier study in Greenland found renal cadmium concentrations in the range of 12–258 µg/g (geometric mean: 58 µg/g) in adult king eiders (Nielsen and Dietz 1989). For common eiders, those values were 14–244 µg/g (geometric mean: 47). Other published values for renal cadmium concentrations in eider ducks are as follows: for common eiders, 5–44 µg/g (median: 15) in The Netherlands (Hontelez *et al.* 1992); 36–109 µg/g (mean: 59) in Svalbard, Norway (Norheim 1987); 52 µg/g in Denmark (Karlog *et al.* 1983); 3–189 µg/g (median: 21) in Sweden (Frank 1986); and 10–135 µg/g in the Finnish archipelago (Franson *et al.* 2000); and for spectacled eiders (*S. fischeri*) in Alaska, 5–30 µg/g (Henny *et al.* 1995) and 50–137 µg/g (mean: 96) (Trust *et al.* 2000). Although high in comparison to other published studies, renal cadmium concentrations in this study were below the published toxicity threshold for birds (100 µg/g wet weight, @ 400 µg/g dry weight, Furness 1996).

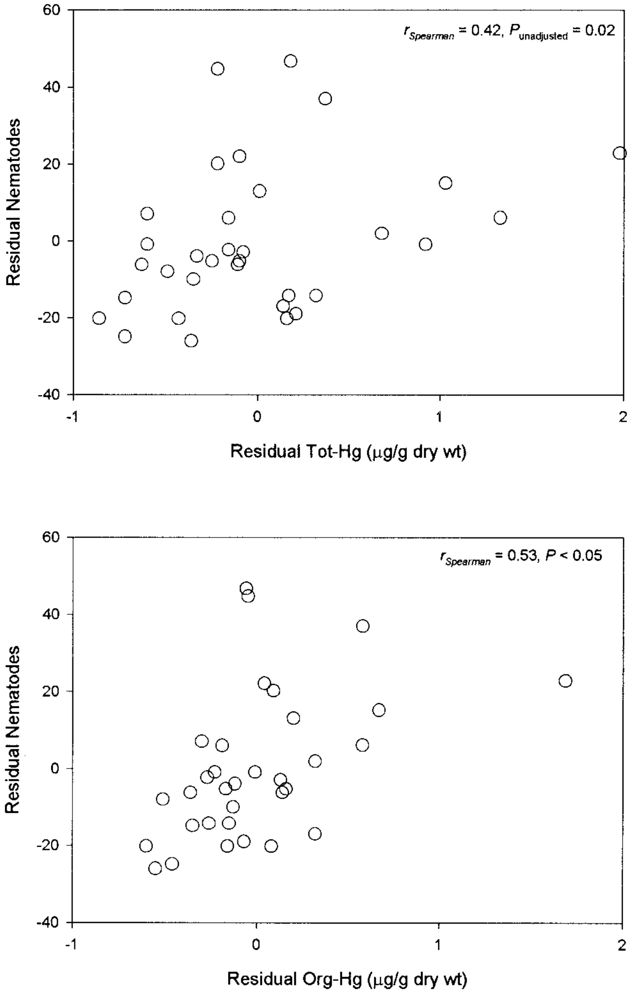

Fig. 3. Relationship between residuals of nematode numbers and those of total (top graph) and organic mercury (bottom graph) in common eiders. Residuals were calculated as the difference between observed values and the location mean value

Concentrations of other trace elements were similar to or lower than those reported in other studies of eider ducks. For example in this study, total hepatic mercury ranged from 0.7–4.4 µg/g, while zinc ranged from 86–333 µg/g. These values are similar to the collective range of values reported in other studies (Hg: < 1–9 µg/g; Zn: 71–615 µg/g, Norheim 1987; Nielsen and Dietz 1989; Henny *et al.* 1995; Hollmén *et al.* 1998; Franson *et al.* 2000; Trust *et al.* 2000). Selenium concentrations in this study were similar to those reported in some other studies of eider ducks (Norheim 1987; Nielsen and Dietz 1989; Franson *et al.* 2000) but were lower than selenium concentrations in apparently healthy, spectacled eiders from western Alaska (range: 78–171 µg/g, Trust *et al.* 2000). In this study, selenium concentrations in several eiders were higher than published toxicity thresholds for birds (10 µg/g wet weight, @ 30 µg/g dry weight, Heinz 1996). However, the interaction of selenium with other trace elements may modify its toxicity; thus this published toxicity threshold may not be broadly applicable to all species and situations (Heinz 1996). For example, mercury, copper, and cadmium are believed to protect against selenium toxicity (Hill 1974; Magos and Webb 1980). Thus, the relatively high concentrations of copper and cadmium in eiders, as shown in this and other studies (Norheim 1987; Nielsen and Dietz 1989; Franson *et al.* 2000; Trust *et al.* 2000) may provide protection against high concentrations of selenium. The maximum copper concentration in this study (805 μg/g) was somewhat higher than that in spectacled eiders in a study of sea ducks in Alaska (345 μg/g, Henny *et al.* 1995) but was lower than maximum concentrations reported in other studies of eiders (1,333, 2,740, and 4,182 μg/g in studies by Trust *et al.* 2000, Franson *et al.* 2000, and Norheim 1987, respectively). Norheim and Borch-Iohnsen (1990) concluded that hepatic copper concentrations as high as 1,050 μg/g wet weight (@ 3,800 μg/g dry weight) were not harmful to eiders. Thus, in this study, copper concentrations were probably not harmful.

King eiders contained higher concentrations of mercury, cadmium, and zinc than common eiders. Similarly, in Greenland, king eiders had slightly higher concentrations of cadmium and zinc than common eiders (Nielsen and Dietz 1989). Foraging habitat and dietary segregation between the two species may account at least partially for the observed differences in their trace element concentrations. Both species feed heavily on mussels. However, whereas common eiders are mussel specialists, king eiders consume a more varied diet that includes not only mussels but also echinoderms and other benthic invertebrates (Bustnes and Erikstad 1988; Frimer 1997). Furthermore, in a Norwegian study, king eiders preferred feeding in relatively deep water over bare, cobble, or corraline algal substrates, whereas common eiders preferred shallower water dominated by kelp beds or sandy substrates interspersed with rock (Bustnes and Lønne 1997). Trace element concentrations in marine invertebrates vary among species and may vary with water depth and substrate characteristics (Phillips 1980). Thus, it is possible that benthic organisms accumulate slightly higher concentrations of certain trace elements in habitats preferred by king eiders compared to those preferred by common eiders. Alternatively, king eiders, being smaller-bodied than common eiders (Dunning 1993), may have higher energy requirements, and hence energy intake rates, per unit body mass (King and Farner 1961). This may result in greater dietary contaminant intake per unit body mass in king eiders.

We found evidence of spatial variability in trace element concentrations. The high concentrations of cadmium in king eiders at EB were consistent with reports of high cadmium levels in marine mammals from the eastern Canadian arctic (Braune *et al.* 1991; Muir *et al.* 1997). This phenomenon has been attributed to elevated levels of natural cadmium in the region's bedrock (Muir *et al.* 1997). However, the relatively low concentrations of cadmium in common eiders from EB contrasted with results for marine mammals (Braune *et al.* 1991; Muir *et al.* 1997). Other factors unrelated to bedrock geology may have influenced our results. For example, after adulthood is reached, cadmium continues to accumulate with age in some species of seabirds (Furness and Hutton 1979), but not in others (Stewart and Furness 1998). If cadmium does accumulate with age in adult eiders, then some of the interspecific and interlocation variation in cadmium concentrations in this study may have been accounted for by differences in the ages of the birds that were collected.

Consistent with evidence that selenium is relatively high in biota in the western arctic (Braune *et al.* 1991; Muir *et al.* 1997), we found that selenium levels were higher in eiders from HOL than in those from other locations. Eiders from HOL spend much of the year in the Bering Sea (L. Dickson, Canadian Wildlife Service, unpublished data), some of them close to St. Lawrence Island where spectacled eiders were found to have concentrations of selenium exceeding 100 μg/g (Trust *et al.* 2000). It is possible that exposure to high levels of selenium during their prolonged period of residency in the Bering Sea may have some residual effect on tissue selenium concentrations during spring migration through HOL.

Interrelationships Among Trace Elements

After partialing out effects due to location and species, we found a number of correlations among trace elements in their tissue concentrations. The positive correlations between cadmium, mercury, and zinc have been observed in other studies of marine birds (Norheim 1987; Nielsen and Dietz 1989; Henny *et al.* 1991, 1995). These trace elements induce and bind to metallothionein in liver and kidney and the coaccumulation of zinc, mercury, and cadmium reduces cadmium toxicity (Friberg *et al.* 1986). In this study, hepatic selenium and mercury were not correlated. Mercury and selenium are often correlated in marine mammals (Braune *et al.* 1991) and in seabirds that feed at high trophic levels (Nielsen and Dietz 1989). Furthermore, their coaccumulation reduces the toxicity of each element alone (Heinz 1996). However, consistent with our results, Nielsen and Dietz (1989) reported that these two elements were not strongly correlated in eider ducks. We found that organic and total mercury were strongly correlated, with the former comprising about 83% of the latter. The relatively small proportion of mercury that was inorganic probably precluded the extensive formation of inorganic mercury-selenium complexes (Scheuhammer *et al.* 1998), resulting in the absence of a correlation between mercury and selenium in our study.

Trace Elements and Body Condition/Organ Mass

We found little evidence that trace element concentrations were related to various indices of body condition or organ mass. Notably, however, cadmium was inversely correlated with body mass in common eiders, a result similar to that reported in other studies of sea ducks (Henny *et al.* 1991; Franson *et al.* 2000). Henny *et al.* (1991) postulated that the inverse relationship between body mass and cadmium in sea ducks was a cause for concern. However, experimental studies on captive, adult mallards found that dietary cadmium did not affect body mass (DiGiulio and Scanlon 1985; Bennett *et al.* 2000) despite alterations in energy metabolism, specifically lipolysis, that can be induced by high cadmium exposure (DiGiulio and Scanlon 1985). The apparent discrepancy between the inverse relationship between cadmium and body mass found in field studies and the absence of an effect in experimental studies needs to be resolved. Perhaps the negative relationship seen in field studies can be attributed simply to smaller birds having less tissue mass in which cadmium (and other trace elements) can be distributed. If dietary exposure and uptake and elimination rates are similar between large and small birds, then smaller birds should accumulate higher concentrations.

Spleen mass was negatively correlated with hepatic mercury in both species and with renal cadmium in common eiders. Although mercury concentrations were well below those normally associated with toxic effects in birds (Thompson 1996), these results are intriguing because mercury and cadmium are known to be immunotoxic (Borošková *et al.* 1995; Borošková and Dvoroznáková 1997) and spleen mass dynamics are associated with changes in the amount of lymphoid tissue in the spleen (Silverin *et al.* 1999). Perhaps one of the ways in which these metals act on the immune system is by interfering with mechanisms controlling the production of lymphoid tissue in the spleen. Further research is required to assess the robustness of our finding that mercury and cadmium were negatively correlated with spleen mass in eider ducks.

Parasites

We found that residual mercury concentrations were correlated with the residual number of nematodes in common eiders, but not in king eiders. In an experimental study on guinea pigs, the number of nematodes was 15% higher in animals dosed with mercury for 28 days and infected with eggs of the nematode *Ascaris* than they were in infected animals not dosed with mercury (Borošková *et al.* 1995). The higher number of parasites was attributed to suppressed lymphocyte production in the lymphoid organs, including spleen, caused by mercury. The spleen is considered to be an important organ for regulating the severity of nematode infections (Morand and Poulin 2000). Perhaps a complex relationship exists between mercury exposure, spleen mass dynamics, and the severity of nematode infections. This requires further investigation in wild birds.

For free-living homeotherms, information concerning the possible effects of contaminants on parasite infestations is scarce. Notably, the number of gastrointestinal nematodes was positively correlated with PCB concentrations in livers of glaucous gulls (*Larus hyperboreus*) from Svalbard, Norway (Sagerup *et al.* 2000). Dead loons in poor body condition had higher concentrations of mercury and greater numbers of intestinal trematodes than those in good body condition (Daoust *et al.* 1998). However, those authors were unable to ascertain whether the high numbers of trematodes could be directly attributed to high mercury levels. The findings of those studies, together with the results of our study, suggest that parasite infections in free-living birds may be affected by contaminants.

Acanthocephalan parasites, but not nematodes, have been associated with die-offs or poor health of eiders ducks (Persson *et al.* 1974; Hollmén *et al.* 1999). Counts of acanthocephalans were not correlated with trace element concentrations in either species. Thus, we cannot conclude that exposure of eiders to trace elements is likely to increase parasite-induced mortality in eiders.

Histopathology

No severe histological lesions were found in the tissues examined and none of the lesions were associated with elevated tissue concentrations of metals. These results are in agreement with those of Trust *et al.* (2000) who reported no significant histological lesions in 20 spectacled eiders with kidney Cd concentrations ranging from 50 to 137 μg/g and liver Se concentrations ranging from 78 to 171 μg/g. Kidney lesions have been observed in feeding trials involving pekin ducks (Bennett *et al.* 2000) and wood ducks (Mayack *et al.* 1981), but renal Cd concentrations were greater than 500 μg/g dry weight and 125 μg/g wet weight, respectively, before renal lesions were observed. In contrast, Nicholson *et al.* (1983) reported degeneration and necrosis of proximal tubular epithelial cells in nine pelagic seabirds with kidney cadmium concentrations between 60–480 mg/kg and found similar lesions in seven metal-dosed starlings with renal Cd concentrations ranging from 95–240 mg/kg. In our study the 10 highest kidney Cd concentrations ranged from 158 to 233 μg/g dry weight, which overlapped concentrations reported by Nicholson *et al.* (1983). Scattered foci of dilated proximal renal tubules with attenuated epithelium and a mild interstitial nephritis, likely a sequela to proximal renal tubular degeneration or necrosis, were identified in the kidney from a common eider, however, concentrations of renal Cd and hepatic Hg were 122 and 1.7 μg/g, respectively, and not considered significant. This type of lesion is not specific for metal intoxication (Maxie 1993).

In our study, very mild to mild hepatocellular vacuolation and/or degeneration was observed in three eiders with liver Se concentrations of 27, 29, and 42 μg/g. Hepatic vacuolation has been reported to be associated with selenium exposure (Green and Albers 1997) and has been reported in livers with mean Se concentrations as low as 50 μg/g (Henny *et al.* 1995). However, in our study, hepatic vacuolation was not observed in five livers with higher Se tissue concentrations ranging from 46 to 62 μg/g. Hepatocellular vacuolation is not specific to metal intoxication and can be influenced by reproductive hormones and nutrition (Riddell 1987). No significance was attributed to the hepatic vacuolation observed in this study.

Conclusion

Concentrations of mercury, copper, zinc, and selenium in king and common eiders in the Canadian arctic were similar to or somewhat lower than those in eiders ducks in northern Europe, Greenland, and Alaska. Cadmium concentrations in king eiders in the eastern Canadian arctic were among the highest ever recorded in eider ducks. We did not find strong evidence that the health of these ducks was adversely affected by exposure to these trace elements. However, the severity of nematode infestations in the gastrointestinal tracts of these birds was positively correlated with total and organic mercury. Further research is required to assess the plausibility of a cause-effect linkage in this result.

Acknowledgments. Many thanks to the following individuals who contributed to various aspects of this study: Lucassie Arragutainaq, T. Byers, R. MacNeil, M. Miller, E. Neugebauer, J. Nakoolak, G. Robertson, and B. Wakeford. Specimens were collected under a scientific permit issued by Environment Canada, following protocols that were approved by the University of Saskatchewan Animal Care Committee.

Funding was provided by Environment Canada and the Northern Contaminants Program of the Department of Indian and Northern Affairs (Canada).

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