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Lead poisoning and trace elements in common eiders *Somateria mollissima* from Finland

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We collected carcasses of 52 common eider *Somateria mollissima* adults and ducklings and blood samples from 11 nesting eider hens in the Gulf of Finland near Helsinki in 1994, 1995 and 1996. Samples of liver tissue were analysed for arsenic, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, selenium and zinc. Blood was analysed for lead, mercury and selenium. Most of the 21 adults examined at necropsy were emaciated with empty gizzards, and no ingested shotgun pellets or other metal were found in any of the birds. Three adult females had a combination of lesions and tissue lead residues characteristic of lead poisoning. Two of these birds had acid-fast intranuclear inclusion bodies in renal epithelial cells and high concentrations of lead (73.4 and 73.3 ppm; all liver residues reported on dry weight basis) in their livers. The third was emaciated with a liver lead concentration of 47.9 ppm. An adult male had a liver lead concentration of 81.7 ppm, which is consistent with severe clinical poisoning. Two other adults, one male and one female, had liver lead concentrations of 14.2 and 8.03 ppm, respectively. Lead concentrations in the blood of hens ranged from 0.11 to 0.63 ppm wet weight. Selenium residues of ≥60 ppm were found in the livers of five adult males. Selenium concentrations in the blood of hens ranged from 1.18 to 3.39 ppm wet weight. Arsenic concentrations of 27.5-38.5 ppm were detected in the livers of four adult females. Detectable concentrations of selenium, mercury and molybdenum were found more frequently in the livers of adult males arriving on the breeding grounds than in incubating females, while the reverse was true for arsenic, lead and chromium. Mean concentrations of selenium, copper and molybdenum were higher in the livers of arriving males than in the livers of incubating hens, but hens had greater concentrations of iron and magnesium. Concentrations of trace elements were lower in the livers of ducklings than in the livers of adults.

Key words: common eider, Finland, lead, Somateria mollissima, trace elements

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The breeding population of common eiders *Somateria mollissima* in the Finnish archipelago doubled during the 1970s, reaching an estimated 350,000 pairs by about 1980 (Stjernberg 1982). Although the outer islands are still preferred for nesting, the breeding range has extended to the inner zone of islands (Laurila 1989) and the common eider is now the most frequent waterfowl species in the Finnish archipelago (Kilpi 1985). At the Söderskär research station, near Helsinki, the number of breeding eiders grew rapidly from 1975 to 1985, and stabilised in 1986 (Hario & Selin 1988). However, concern regarding the health of the eider population arose in the late 1980s, when duckling survival at Söderskär dropped to as little as 1-3% (Hario & Selin 1991). In recent years, duckling survival has remained low and an increased number of adult female eiders have also been found dead (Hario, Lehtonen & Hollmén 1995).

Predation by gulls is a well-known cause of mortality for eider ducklings (Mendenhall & Milne 1985), but that alone may not account for the extensive losses in the Finnish archipelago (Hario & Selin 1991, Hillström, Kilpi & Lindström 1994). Intestinal helminths, primarily the Acanthocephalan worms *Polymorphus minutus* and *Profilicollis botulus*, have long been implicated in large-scale mortality of eiders (Grenquist 1951, Clark, O'Meara & van Weelden 1958, Persson 1974). However, no definitive evidence for parasite-induced mortality of eiders has been found at the Söderskär research station (Hario et al. 1995, Hollmén, Hario & Lehtonen 1996).

Recently, there has been increased concern regarding contamination in the Baltic Sea (Haahti 1991), including the introduction of trace elements into the ecosystem (Mukherjee 1989, Schneider 1996). Some of these trace elements may be accumulated by the blue mussel *Mytilus edulis* (Ostapczuk, Burow, May, Mohl, Froning, Süßenbach, Waidmann & Emons 1997), the primary food item of common eiders in the Baltic Sea. Several trace elements are known to cause harm to aquatic birds. Selenium and mercury, for example, may cause reproductive impairment, acute mortality, and have been linked to more subtle sublethal effects, including immunosuppression (Fairbrother, Fix, O'Hara & Ribic 1994, Albers, Green & Sanderson 1996, Heinz 1996, Thompson 1996). Exposure to lead shot is a well-known cause of mortality in waterfowl (Pain 1992), although few cases have been reported in the common eider and spectacled eider *Somateria fischeri* (Clausen & Wolstrup 1979, Franson, Petersen, Meteyer & Smith 1995a). Lead exposure has caused immunotoxic effects in mallards *Anas platyrhynchos* (Rocke & Samuel 1991) and reduced survival of immature canvasbacks *Aythya valisineria* (Hohman, Moore & Franson 1995). During the spring and summer of 1994-1996, we examined carcasses and collected tissues of common eiders from the Gulf of Finland. Our objective was to evaluate the toxicological significance of trace element concentrations in tissues of adult eiders and ducklings.

Methods

Study areas and sample collection

We collected specimens from four locations along the coast of southwestern Finland (Fig. 1). Most of the specimens came from the Söderskär archipelago (60°06'N, 25°25'E) about 25 km southeast of Helsinki. This group of small wooded islets and open skerries is described in more detail by Hario & Selin (1988). We also collected carcasses from three locations west of Helsinki: Rymättylä (60°25'N, 21°55'E), Tvärminne (59°50'N, 23°15'E) and Rönnskär (59°56'N, 24°22'E). These archipelagos consist of many small, rocky, wooded and treeless islands physiographically similar to Söderskär.

At Söderskär, 15 adult male eiders were shot soon after their arrival in April and May 1994. In June 1994, blood samples were collected from wing veins

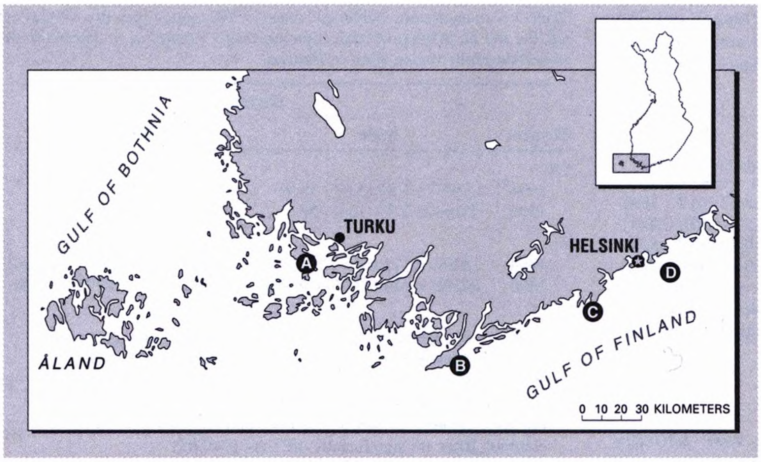

Figure 1. Locations in the Gulf of Finland where common eider *Somateria mollissima* carcasses and blood samples were collected for trace element analysis: Rymättylä (A), Tvärminne (B), Rönnskär (C), and Söderskär (D).

of 11 incubating eider hens with plastic syringes and stainless steel needles and placed in evacuated glass tubes containing anticoagulant (EDTA). Twenty-seven eider carcasses were recovered at Söderskär, consisting of nine adult females and one duckling in 1994, 10 ducklings in 1995, and four hens and three drakes in 1996. One dead eider hen was found at Rymättylä in 1995, three hens and five ducklings were found dead at Tvärminne in 1996, and one dead hen was found at Rönnskär in 1996. All dead birds were found in June and July of each year. Only intact carcasses exhibiting little decomposition were collected. Carcasses were stored chilled or frozen until necropsy and tissue and blood samples were frozen for later chemical analysis.

Necropsy

A portion of the liver was removed from each of the 52 carcasses with stainless steel instruments and frozen in a plastic bag for trace element analysis. Complete necropsies were performed on carcasses of 21 adult (3 males, 18 females) eiders including 16 from Söderskär, three from Tvärminne, one from Rönnskär and one from Rymättylä. Carcasses were examined for the presence of gross abnormalities and the body condition was evaluated on the basis of pectoral muscle development and fat reserves. Tissues for histopathology were fixed in 10% buffered formalin, embedded in paraffin, and sectioned for light microscopy. Tissue sections were stained with hematoxylin and eosin for routine examination and Ziehl-Neelsen acid-fast stain to search for renal inclusion bodies.

Trace element analysis

Blood and liver samples were analysed at the New Bolton Center, University of Pennsylvania, Kennett Square, PA, USA. Inductively coupled plasma-atomic emission spectroscopy (ICP-AES) analyses were conducted on a GBC Integra XM2® (GBC Scientific Equipment, Inc., Arlington Heights, Illinois) sequential spectrophotometer, utilising dual 750 mm focal length Czerny-Turner monochromators with a 2KW 40.68 MHZ RF generator. Atomic absorption (AA) analyses were performed on a GBC 906AA® operating in the graphite furnace, flame, or flameless mode. In a typical ICP analysis, 2.50 g liver was weighed into a Teflon® container, 5.0 ml concentrated nitric acid was added, and the top of the container was loosely closed. The sample was placed in a 90°C oven overnight, cooled to room temperature, diluted to 25.0 ml with distilled water in a volumetric flask, and then extracted with 10 ml isooctane to remove undigested lipid prior to analysis. Standard reference material (0.50 g National Institute of Standards and Technology 1577b bovine liver) was prepared in a like fashion and analysed with the samples.

Because of small sample size, we analysed blood only for Se, Hg and Pb, in priority order. Despite the use of anticoagulant, blood samples were clotted. In a typical analysis, 0.70 g blood was weighed into a Teflon® container, 2.0 ml concentrated nitric acid was

Table 1. Frequencies of detection (%)[a] of trace elements in livers of adult common eiders *Somateria mollissima* from Söderskär Field Station, Gulf of Finland, 1994 and 1996 combined.

	Gender	
Metal	Male (N = 18)	Female (N = 13)
As[b]	0	31
Cd	100	100
Cr[b]	6	100
Cu	100	100
Fe	100	100
Hg[b]	50	8
Mg	100	100
Mn	100	100
Mo[b]	94	46
Pb[b]	11	38
Se[b]	100	77
Zn	100	100

[a] Detection limits (ppm wet weight): Cd, Cu, Fe, Zn = 0.10; Cr = 0.20; Mo = 0.30; As, Pb = 0.50; Hg, Se = 1.00.
[b] Significant differences between genders ($P < 0.05$).

Table 2. Concentrations (arithmetic means ± SE (range); ppm dry weight) of Cu, Mg, Mo and Se in livers of adult common eiders *Somateria mollissima* from Söderskär Field Station, Gulf of Finland, 1994 and 1996 combined.

	Gender[a]	
Element	Male (N = 18)	Female (N = 13)
Cu	1540 ± 176 (728 - 3230)	209 ± 84.2 (16.2 - 1190)
Mg	692 ± 16.5 (573 - 864)	838 ± 39.4 (557 - 1141)
Mo	3.15 ± 0.33 (ND[b] - 6.24)	1.62 ± 0.40 (ND[b] - 5.14)
Se	47.0 ± 6.16 (17.1 - 119)	15.3 ± 3.14 (ND[b] - 42.3)

[a] Two-way ANOVA revealed significant (P<0.05) gender differences for each metal, but no differences between years and no gender*year interaction.
[b] Not detected.

Table 3. Concentrations (arithmetic means ± SE (range); ppm dry weight) of Cd, Fe, and Zn in livers of adult common eiders *Somateria mollissima* from Söderskär Field Station, Gulf of Finland.

	Gender	
Element	Male	Female
Cd		
1994[a]	15.9A[b] ± 1.83 (5.87 - 28.9)	27.5B ± 4.13 (11.6 - 46.6)
1996	24.6A ± 7.57 (12.8 - 38.7)	17.1AB ± 2.39 (12.1 - 22.5)
Fe		
1994	1320A ± 171 (617 - 2940)	15700BC ± 1680 (7970 - 24200)
1996	8030B ± 1140 (5750 - 9370)	12400C ± 801 (10700 - 14500)
Zn		
1994	147A ± 8.96 (75.1 - 197)	327B ± 23.3 (238 - 444)
1996	443B ± 69.6 (366 - 582)	285B ± 53.4 (215 - 443)

[a] N: 1994 (16 males, 9 females); 1996 (3 males, 4 females).
[b] For each element, means within rows and columns that do not share a common letter are significantly different (P<0.05).

added, and the top of the container was loosely closed. The sample was placed in a 90°C oven overnight, cooled to room temperature, and diluted to 10.0 ml with distilled water in a volumetric flask. Aliquots of this sample were removed for Se, Hg and Pb analyses. For Se analysis, 5.0 ml of the sample was treated with 10.0 ml concentrated nitric acid containing 20% magnesium nitrate, reduced to dryness on a hot plate, and placed in a 500°C muffle furnace for one hour. The cooled sample was then dissolved and diluted to 25.0 ml in a volumetric flask with 30% HCL/water prior to quantitation by AA in the flame mode using hydride generation. For Hg analysis, 4.0 ml of the sample was placed in a Teflon® container, 2.0 ml concentrated sulfuric acid and 1.0 ml concentrated nitric acid were added, the top was tightened, and the sample was placed in a 90°C oven for three hours. A solution of 10% potassium permanganate in water was added dropwise to the cooled sample until the purple colour persisted, and the sample was returned to the 90°C oven for 30 minutes. After cooling, 10% hydroxylamine hydrochloride was added dropwise until the purple colour disappeared, and the sample was diluted to 100 ml in a volumetric flask with 30% HCL/water prior to quantitation by AA in the flameless mode using hydride generation. DORM-2, certified reference material consisting of dogfish muscle and liver, from the National Research Council, Canada, was analysed for Se and Hg with the samples. Lead was analysed in the remaining sample by graphite furnace AA, using standard reference material from the Wisconsin State Laboratory of Hygiene, Madison, WI, USA.

Minimum detection limits (ppm wet weight) for ICP were: Mg = 0.01; Mn = 0.05; Cd, Cu, Fe, Zn = 0.10; Cr = 0.20; Mo = 0.30; As, Pb = 0.50; Hg, Se = 1.0. Minimum detection limits (ppm wet weight) for AA were: Pb = 0.02; Se, Hg = 0.025. Residues were not adjusted for recoveries from standard reference materials, which were greater than 90% for all analytes. We determined the moisture content of liver samples (average = 72%) and converted residues to ppm dry weight to avoid potential errors due to moisture loss from soft tissues (Adrian & Stevens 1979, Franson 1984). For comparison of our results to the literature expressed in terms of wet weight, when no moisture content was reported, we used the wet weight/dry weight ratio of 0.33 reported for mallard liver (Scanlon 1982). We report trace elements in blood as ppm wet weight of whole blood.

Table 4. Concentrations (arithmetic means, range: ppm dry weight) of As, Cr, Hg and Pb in livers of adult common eiders *Somateria mollissima* from Söderskär Field Station, Gulf of Finland, 1994 and 1996 combined.

	Element			
Gender	As	Cr	Hg	Pb
Male (N = 18)	ND[a]	1.65	5.12	48.0
Range	0	1.65	3.15 - 9.34	14.2 - 81.7
Number[b]	0	1	9	2
Female (N = 13)	32.4	2.58	4.14	13.6
Range	27.5 - 38.5	1.11 - 4.24	4.14	2.97 - 47.6
Number	4	13	1	5

[a] Not detected.
[b] Number of samples above minimum detectable level.

Table 5. Concentrations (ppm wet weight) of Se, Pb and Hg in blood samples collected from adult female common eiders *Somateria mollissima* at Söderskär Field Station, Gulf of Finland, in 1994.

	Element		
	Se	Pb	Hg
Number analysed	11	5	7
Number above detection limit[a]	11	5	1
Mean concentration	1.98	0.37	-[b]
Range	1.18 - 3.39	0.11 - 0.63	<0.025 - 0.22

[a] Detection limits = 0.025 ppm for Se and Hg, 0.02 ppm for Pb.
[b] No mean could be calculated.

Statistical analysis

Because of limited sample sizes at Rymättylä, Tvärminne, and Rönnskär, and the low frequency of detectable concentrations in duckling livers, our statistical evaluation was restricted to the results of liver analyses from adults collected at Söderskär in 1994 and 1996. We used logistic regression to compare the frequency of detectable concentrations of trace elements by gender and year. For elements that were detected in about 50% or more of the livers of both sexes (Cd, Cu, Fe, Mg, Mn, Mo, Se, and Zn), we used two-way analysis of variance (ANOVA) to identify gender and year differences in mean concentrations. For that analysis, we assigned a concentration of one-half of the minimum detection limit to those samples that contained no detectable residues of a particular element. When ANOVA revealed significant interactions, we evaluated gender and year differences with Student's t-test. We used a probability level of $P < 0.05$ to determine statistical significance.

Results

Concentrations of trace elements in liver and blood

Cadmium, Cu, Fe, Mg, Mn, and Zn in concentrations above the detection limits were found in the livers of all adults from Söderskär (Table 1). The frequencies of detectable levels of As, Cr, and Pb were greater in females, while Hg, Mo, and Se were found more frequently in males (see Table 1). Analysis of variance showed a significant gender difference, but no year difference and no gender*year interaction for Cu, Mg, Mo, and Se (Table 2). Mean concentrations of Cu, Mo and Se were higher in males, and Mg was higher in females (see Table 2). Concentrations of Cd, Fe, and Zn were compared both by gender and year because ANOVA revealed a significant gender*year interaction (Table 3). Females had higher levels of Cd and Zn in 1994 and higher concentrations of Fe in both 1994 and 1996. Males collected in 1996 had higher Fe residues than males collected in 1994. The concentration of Mn in the livers of adults collected at Söderskär did not vary by gender or year, so all results were combined (mean = 19.5 ppm, SE = 0.98, range = 6.88 - 35.0 ppm).

Detectable concentrations of As, Cr, Hg, and Pb were found in adult eiders from Söderskär but, except for Pb and As, levels were generally low (Table 4). Lead was detected in the livers of two males (14.2 and 81.7 ppm) and five females (2.97, 4.39, 4.59, 8.03 and 47.9 ppm). Arsenic was detected in the livers of four females (27.5, 30.4, 33.3 and 38.5 ppm).

A mean Se concentration of nearly 2 ppm wet weight was found in the blood of adult female eiders, and detectable concentrations of Se were found in each of the 11 blood samples tested (Table 5). Lead was found in all of the five blood samples tested (maximum 0.63 ppm), and Hg was found in one (0.22 ppm) of seven samples.

Concentrations of trace elements in the livers of

Table 6. Concentrations (mean ± SE (range; number above detection limit)) in ppm dry weight of trace elements in the livers of adult female common eiders *Somateria mollissima* from Rymättyla, Tvärminne, and Rönnskar and eider ducklings from Tvärminne and Söderskär Field Station, Gulf of Finland, 1994-1996.

Metal	Adult females (N = 5)	Ducklings (N = 16)
As	ND[a]	ND[a]
Cd	19.4±1.55 (7.42-32.5; 5)	1.34±0.22 (0.45-3.02; 12)
Cr	1.54±0.02 (1.32-2.06; 4)	1.16±0.31 (0.86,1.47; 2)
Cu	137 ±86.2 (27.1-481; 5)	265 ±67.9 (22.7-751; 16)
Fe	6808±1010 (2830-8350; 5)	2350±455 (337-6740; 16)
Hg	ND[a]	ND[a]
Mg	746 ±19.8 (694-808; 5)	815 ±37.0 (662-1200; 16)
Mn	15.2±1.64 (9.34-18.7; 5)	17.8±0.85 (11.7-24.0; 16)
Mo	1.45±0.28 (1.16,1.73; 2)	ND[a]
Pb	73.4±0.06 (73.3,73.4; 2)	2.16 (1)
Se	12.4±1.29 (8.68-15.6; 5)	7.35±0.91 (4.10-10.8; 6)
Zn	277 ±58.5 (158-428; 5)	186 ±22.9 (124-490; 16)

[a] Not detected.

Table 7. Frequencies of gross lesions in 21 (18 females, 3 males) adult common eiders *Somateria mollissima* from the Gulf of Finland with and without (Others) elevated concentrations of Pb, Se, and As in their livers (ppm dry weight).

	Pb[a]				Se[b]	As[c]				Others
	73.3	73.4	47.9	8.03	72.3	38.5	33.3	30.4	27.5	(N = 12)
Pectoral muscle atrophy	+	+	+	-	+	+	+	+	+	12
Absence of fat reserves	-	-	+	+	+	+	+	-	+	11
Liver atrophy	+	+	+	+	-	+	+	+	+	8
Engorged gall bladder	+	-	+	+	-	+	+	+	+	3
Bile (green) staining of										
Liver	+	-	+	+	-	+	+	+	+	0
Gizzard Lining	-	+	-	-	-	-	-	-	-	0
Vent	-	-	-	-	+	-	-	+	-	0

[a] 73.3 and 73.4 ppm = consistent with severe clinical poisoning; 47.9 ppm = clinical poisoning; 8.03 = subclinical poisoning (Pain 1996), based on wet weight:dry weight ratio of 0.33 (Scanlon 1982).
[b] Indicative of probable sublethal effects (Heinz 1996).
[c] Above normal background levels (Eisler 1988).

adult females from Rymättylä, Tvärminne, and Rönnskär and for all ducklings are presented in Table 6. No As or Hg were detected in any of these birds. Two of the five adult females had high concentrations of Pb in their livers (73.3 and 73.4 ppm), and Pb was detected in one of 16 ducklings (2.16 ppm).

Necropsy findings

Most of the carcasses examined were emaciated, with severe pectoral muscle atrophy, little or no fat reserves, and atrophied livers (Table 7). Gizzards were empty, or contained only grit and small amounts of plant material, pieces of sticklebacks (Gasterosteidae), or mussel *Mytilus* sp. shell fragments. No Pb or other metal was found in the gizzards of any of the birds. Two hens that had liver Pb concentrations of 73.3 and 73.4 ppm also had acid-fast inclusion bodies in proximal epithelial cell nuclei in their kidneys. Another hen was emaciated with 47.9 ppm Pb and 33.3 ppm As in its liver. These three hens were diagnosed with lead poisoning. Four birds with 27.5-38.5 ppm of As in their livers exhibited additional lesions characteristic of emaciation, including engorged gall bladders and green staining of the liver, gizzard lining, and vent (see Table 7).

Discussion

Lead, selenium, arsenic and mercury

Lead concentrations in liver or blood samples from 10 adult eiders were above the levels associated with normal background exposure (about 6 ppm dry weight and 0.2 ppm whole blood, respectively) in waterfowl (Pain 1996). These 10 adult eiders included three hens that were found dead and diagnosed with lead poisoning on the basis of high liver Pb concentrations (73.3, 73.4, and 47.6 ppm) and additional observations of emaciation or acid-fast intranuclear inclusion bodies in kidney epithelium. One drake had 81.7 ppm Pb in its liver, which is evidence of severe clinical poisoning (Pain 1996), but it was not examined at necropsy. Six additional eiders exhibited tissue Pb concentrations indicative of clinical or subclinical lead poisoning (Pain 1996). These included four hens with blood Pb concentrations of 0.28-0.63 ppm and one male and one female that had liver Pb concentrations of 14.2 and 8.03 ppm, respectively. Females may have had a higher frequency of detectable Pb concentrations because laying hens generally have higher Pb concentrations in their tissue than males (Finley, Dieter & Locke 1976). We were unable to determine the source of Pb, because the gizzards contained no lead shot or metal fragments. Although lead shot is a common source of lead poisoning in waterfowl, pellets may have passed through the intestinal tract or eroded within about 20 days after ingestion, and may not be present when the bird dies (Sanderson & Bellrose 1986). Waterfowl may also be exposed to Pb from local environmental sources other than shots (Blus, Henny, Hoffman & Grove 1991).

Lead poisoning has been previously diagnosed in at least one common eider from Denmark and one from Alaska (Clausen & Wolstrup 1979, Franson et al. 1995a) but, to our knowledge, this is the first report of acid-fast intranuclear inclusion bodies in kidneys of eiders. In comparison with surveys of common eiders from other areas, Pb concentrations in birds from the Gulf of Finland were generally higher. Of 40 common eiders examined in Denmark, three (7.5%) had liver Pb concentrations that were >7 ppm wet weight (about 21 ppm dry weight) (Karlog, Elvestad & Clausen 1983), while we found >21 ppm

Pb in livers of four of 36 (11.1%) adult eiders. In a study in the Netherlands, Hontelez, van den Dungen & Baars (1992) found low concentrations of Pb (<0.1 to 4.9 ppm dry weight) in the livers of 25 common eiders, and Pb levels in nine common eiders from Spitsbergen were below the detection limit of 0.5 ppm wet weight (Norheim 1987).

Selenium concentrations in the livers of five of 18 adult males ranged from 64.0 to 119 ppm dry weight, levels associated with mortality of freshwater birds both in the laboratory and in the field (Heinz 1996, Ohlendorf, Kilness, Simmons, Stroud, Hoffman & Moore 1988). An additional seven males and one female had liver Se concentrations greater than 35 ppm, which has resulted in significant sublethal effects in experimental studies (Heinz 1996). The 3-fold higher mean concentration of Se in the livers of males than in the livers of females may be related to the timing of collection, since males were collected at least 4-6 weeks before carcasses of females were found. Perhaps the higher Se levels in males reflect exposure to Se at another location shortly before their arrival at the breeding grounds. However, because Se declines from duck tissue relatively quickly when exposure is terminated (Heinz, Pendleton, Krynitsky & Gold 1990), hens may have had lower concentrations simply because they feed very little while incubating.

The mean concentration of Se that we found in the blood of adult female eiders (1.98 ppm) was about five times higher than baseline concentrations in experimental mallards, and about one-sixth to one-eighth of the levels associated with death in mallards (Heinz et al. 1990, O'Toole & Raisbeck 1997). Little information on Se levels in blood of sea ducks is available. The interpretation of Se concentrations in sea ducks based on data from freshwater species is difficult because somewhat higher levels of Se have been reported in estuarine and marine birds, and the relationships between higher concentrations and biological effects in these species are unclear (Ohlendorf 1989). Relatively high levels of Se have been found in waders from the Dutch Wadden Sea (Goede 1985) and in common eiders and Steller's eiders *Polysticta stelleri* in Spitsbergen and Alaska, respectively (Norheim 1987, Henny, Rudis, Roffe & Robinson-Wilson 1995).

We detected Hg in only 10 of 36 livers and one of seven blood samples from adult eiders. The concentrations that we found in the livers (maximum 9.34 ppm) were much lower than those considered toxic (about 60 to 90 ppm dry weight) for non-marine birds (Thompson 1996), but were higher than levels found in eiders in Denmark, Spitsbergen and Norway (Karlog et al. 1983, Norheim 1987, Lande 1977). The fact that we found little evidence of Hg exposure, but high concentrations of Se in several eiders, is consistent with the variable and poorly established relationship of these two elements in birds (Ohlendorf 1993).

According to Eisler (1988), liver residues of As within the range of 2-10 ppm wet weight (about 6-30 ppm dry weight) should be considered elevated. The As concentrations detected in the livers of four female eiders (27.5-38.5 ppm dry weight) from Söderskär were within or above this range and were much higher than those reported from shorebirds inhabiting an industrialised coastal area (White, King & Prouty 1980). Except for one bird with over 100 ppm dry weight As in its liver, waders from the Dutch Wadden Sea generally had liver As levels of less than 15 ppm dry weight (Goede 1985). Arsenic accumulates and disappears rapidly from the tissue (Pendleton, Whitworth & Olsen 1995). The presence of elevated concentrations of As in female eiders found dead near the end of incubation, but the absence of As in drakes collected earlier in the spring, suggests that exposure may occur after arrival at the breeding grounds or that there may be some gender difference related to As. It is also possible that the As concentrations in the livers of four of the females that were found dead may have somehow contributed to the deaths of those specific birds.

Iron and copper

The mean Fe concentration in the livers of females from Söderskär was nearly 10 times greater than that of males in 1994 and 1.5 times that of males in 1996 (see Table 3). Borch-Iohnsen, Holm, Jørgensen & Norheim (1991) found nearly a 10-fold increase in the Fe concentration in the livers of female eiders near the end of incubation. They suggested that the increase could be attributed to a combination of factors, including increased Fe uptake before egg laying, and a concentration of Fe caused by liver weight loss and catabolism of blood and lean body tissue during incubation. The reason for the much higher concentration of Fe in males in 1996 than in 1994 is unknown. It may be related to a loss of body condition as described for females by Borch-Iohnsen et al. (1991), since in 1996 the males were found dead, while in 1994 they were apparently healthy birds that were shot. Iron levels in the livers of eider ducklings, also found dead, were about twice as high as those of the males collected in 1994.

Copper concentrations in livers of common eider males were over seven times higher than in females (see Table 2). Norheim & Borch-Iohnsen (1990) found a tendency toward higher Cu levels in male common eiders than in females, but the difference was not statistically significant. These authors suggested that the variation in Cu concentrations among birds was primarily the result of differences in dietary intake. Seasonal differences in Cu concentrations, as described in male surf scoters *Melanitta perspicillata* (Ohlendorf, Marois, Lowe, Harvey & Kelly 1991), may be involved, as well as differences related to the nesting cycle (Haarakangas, Hyvärinen & Ojanen 1974). The Cu levels in male eiders from Söderskär were similar to those found in males from Svalbard (Norheim & Borch-Iohnsen 1990), but higher than the concentrations reported from male eiders in Denmark (Karlog et al. 1983). The Cu concentrations in the livers of female eiders from Söderskär were about half those found in eider hens from Trondheimsfjorden, Norway (Lande 1977), and less than half of those found in mute swans *Cygnus olor* from a contaminated area in Denmark (Clausen & Wolstrup 1978). Copper concentrations in Barrow's goldeneyes *Bucephala islandica* and common mergansers *Mergus merganser* from an uncontaminated area in Alaska (Franson, Koehl, Derksen, Rothe, Bunck & Moore 1995b) were much lower than the levels we found in eiders.

Cadmium, chromium, molybdenum and zinc

The levels of Cd that we found in common eiders were somewhat higher than concentrations found in the livers of eiders from the Netherlands (Hontelez et al. 1992), Denmark (Karlog et al. 1983) and Norway (Lande 1977). Levels in eiders were also higher than those in dunlin *Calidris alpina* and curlew sandpipers *Calidris ferruginea* from the Baltic Sea (Blomqvist, Frank & Petersson 1987). However, Cd concentrations in eiders were well below the levels considered harmful in birds (Furness 1996). Chromium concentrations were below levels indicative of Cr contamination (Eisler 1986), but higher than concentrations found in eiders in Norway (Lande 1977).

Little is known about hazard levels of Mo in wild birds, but the concentrations we found in eiders were lower than those found in the livers of Barrow's goldeneyes and common mergansers from an undisturbed environment in Alaska (Franson et al. 1995b). Zinc concentrations in eiders from Söderskär were generally higher than in spectacled and Steller's eiders from Alaska (Henny et al. 1995), but were less than half the concentrations found in common eiders in Norway (Lande 1977). Liver concentrations of Zn in captive Barrow's goldeneyes that died of Zn poisoning (Zdziarski, Mattix, Bush & Montali 1994) were two to five times higher than the concentrations we found in eiders. Concentrations of Zn in the livers of mallards that died of Zn toxicosis in an experimental study (Gasaway & Buss 1972) were about four times higher than those we found in eiders. The gender and year differences in concentrations of Cd and Zn may be related to seasonal variations and differences between males and females during the course of the breeding cycle (Osborn 1979, Haarakangas et al. 1974). Although the Zn concentrations that we found in eiders were well below probable toxic levels, it should be pointed out that the males and females that were found dead had higher levels than the males that were shot.

Magnesium and manganese

Concentrations of Mg and Mn in adult common eiders from Finland were similar to those found in spectacled and Steller's eiders from Alaska (Henny et al. 1995). The higher mean concentration of Mg in the livers of female eiders than in the livers of males could be the result of seasonal differences in metabolism (Haarakangas et al. 1974).

Conclusions

Lead exposure of common eiders that nest in the Gulf of Finland is of concern, based on our findings of lead poisoning or elevated tissue residues in 10 of 31 adults. High As concentrations in the livers of four females suggest a possible point source, differential gender exposure for that element, or potential involvement of As in the deaths of those birds. The high concentrations of Se found in the livers of arriving male eiders and its occurrence in the blood of all females sampled indicate a need for Se analysis of eider eggs, to evaluate the potential for adverse reproductive effects. Although concentrations of trace elements in the livers of eider ducklings were not above those considered toxic to birds, our finding of detectable levels of Se in six, and Pb in one, of the 16 ducklings sampled supports the need for further study of these elements in relation to reproductive success. Future research should focus on identifying the sources of exposure to Pb, As and Se. The reasons for the differences in concentrations of trace elements between arriving males and females collected later in the breeding season should be identified.

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