Contaminants and Sea Ducks in Alaska and the Circumpolar Region

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We review nesting sea duck population declines in Alaska during recent decades and explore the possibility that contaminants may be implicated. Aerial surveys of the surf scoter (*Melanitta perspicillata*), white-winged scoter (*M. fusca*), black scoter (*M. nigra*), oldsquaw (*Clangula hyemalis*), spectacled eider (*Somateria fischeri*), and Steller's eider (*Polysticta stelleri*) show long-term breeding population declines, especially the latter three species. The spectacled eider was recently classified threatened under the Endangered Species Act. In addition, three other diving ducks, which commonly winter in coastal areas, have declined from unknown causes. Large die-offs of all three species of scoters during molt, a period of high energy demand, were documented in August 1990, 1991, and 1992 at coastal reefs in southeastern Alaska. There was no evidence of infectious diseases in those scoters. The die-offs may or may not be associated with the long-term declines. Many scoters had elevated renal concentrations of cadmium (high of 375 µg/g dry weight [dw]). Effects of cadmium in sea ducks are not well understood. Selenium concentrations in livers of nesting white-winged scoters were high; however, the eggs they laid contained less selenium than expected based on relationships for freshwater bird species. Histological evaluation found a high prevalence of hepatocellular vacuolation (49%), a degenerative change frequently associated with sublethal toxic insult. Cadmium and selenium mean liver concentrations were generally higher in those birds with more severe vacuolation; however, relationships were not statistically significant. We do not know if sea duck population declines are related to metals or other contaminants. — Environ Health Perspect 103(Suppl 4):41–49 (1995)

Key words: Alaska, eiders, scoters, oldsquaw, cadmium, selenium, metals, population declines, endangered species

Introduction

Contamination of the environment with organic pollutants and metals is worldwide; however, only limited information is available on the relationship between contaminants and effects on individual animals or animal populations, especially for the arctic. Changes in population size, age and sex composition, and reproductive success should be monitored to provide baseline data against which to evaluate possible impacts on populations caused by contaminants (*1*). The sea ducks discussed in this report have all experienced serious population declines in Alaska and perhaps elsewhere during the last several decades; the cause is unknown. The locations of sites discussed in Alaska are shown in Figure 1.

Surf scoters wintering in Oregon and Washington in 1984 to 1985, which perhaps nest in Alaska, contained elevated concentrations of cadmium (*2*). Surf scoter body weights in late January were negatively correlated with cadmium concentrations, and this initially focused our attention on cadmium. Sublethal effects of cadmium toxicity include growth retardation, anemia, testicular damage, hypertrophy of the heart, and renal dysfunction (*3*). Organic compounds received less attention in this evaluation because in 1992, 19 addled spectacled eider eggs from the Yukon Delta, Alaska, showed organochlorine pesticides (< 0.05 µg/g dry weight [dw]) and polychlorinated biphenyls (PCBs; < 0.30 µg/g dw) below detection limits (K Trust, personal communication).

Benthic feeding surf scoters eat bivalves along with gastropods and crustaceans, some plants, algae, insects, polychaetes, and fish. This diet is similar to that of the benthic feeding spectacled eider which was recently classified as a threatened species by the United States Fish and Wildlife Service (USFWS) throughout its range in Alaska and Russia (*4*). About 50,000 pairs of spectacled eider, half the estimated world population, nested on the Yukon–Kuskokwim Delta in 1971; in 1992, the population was estimated at 1721 pairs (*5*). The Steller's eider shares the same breeding range as the spectacled eider (Alaska and Russia), is also declining in Alaska and is a candidate for endangered species status. Possible reasons for the eider declines, in addition to contaminants, include parasites and disease, subsistence harvest, predation during broodrearing, habitat change, and alteration of Bering Sea food resources (*5,6*).

The purpose of this paper is to *a*) review the status of breeding populations of scoters, eiders, and oldsquaws in Alaska and document the large die-offs of scoters at coastal areas during molt; *b*) evaluate the

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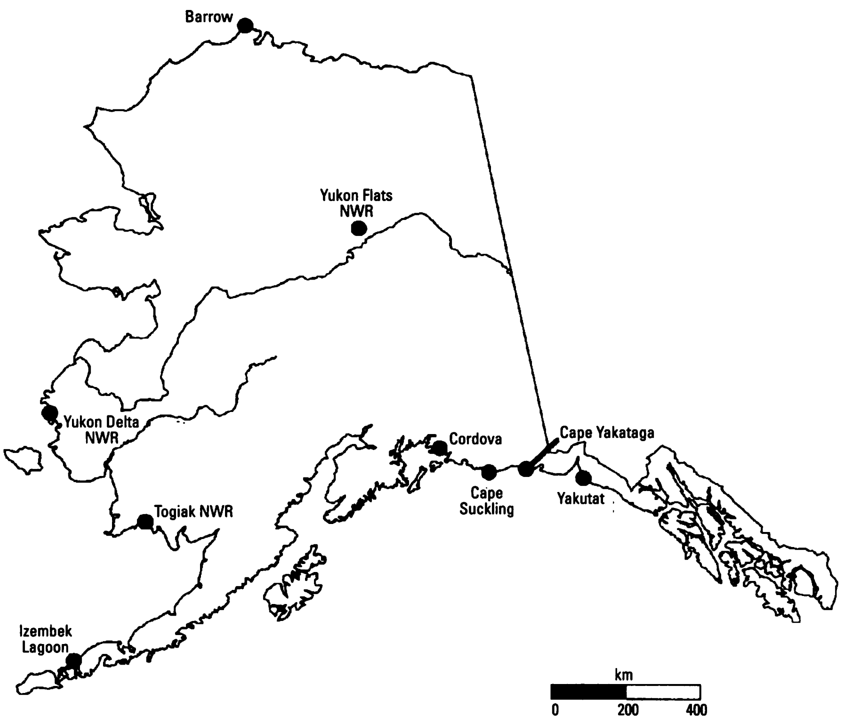

Figure 1. Reference locations for sea ducks in Alaska.

availability of metals in the arctic and their accumulation in sea ducks; *c*) evaluate results of histological examinations of liver, kidney, and testes to reveal indications of tissue damage associated with elevated levels of metals; and *d*) lay out a research strategy to further investigate the cause(s) of the population declines.

Materials and Methods

The USFWS has studied waterfowl populations throughout much of North America using strip transect aerial surveys since 1955 (*7,8*) and in Alaska since 1957, as well as using field studies of individual populations.

Waterfowl survey information was obtained from published reports and an unpublished manuscript prepared by personnel of the USFWS. Established strata (routes) flown in Alaska since 1957 provide the long-term data set used to assess population changes in this report (*9*). Scoter numbers in Alaska and Yukon Territory were not separated into species during aerial surveys. The survey plane was changed in 1977 to a Turbo-Beaver which flies slower and has much better visibility. Aerial counts were adjusted for observer visibility and for the change in aircraft type.

In 1990, 1991, and 1992, we responded to reports of scoters dying during the August molt at Cape Yakataga and Cape Suckling in southeastern Alaska. Dead scoters were counted, and fresh carcasses were collected for necropsy and residue analyses. The number of live scoters in each region was also documented.

Analyses of water and sediment indicate the extent of metal contamination, but reveal little about the bioavailability of metals to biota. Quantification of metal concentrations in indigenous relatively sessile, benthic organisms such as mussels, can be used to assess the bioavailability of metals (*10*). Mussels become particularly meaningful when they form a substantial portion of the diet of the species of interest, which they do for scoters (*2,11*). Blue mussels (*Mytilus trossulus*) were collected at five sites between Cordova and Yakutat, Alaska, in 1992 where scoters were dying during the molt. Usually three pools of mussels varying from 19 to 33 individuals each were analyzed for residues (without the shell), since shells contain very low cadmium concentrations (*12*).

We collected (shot) 37 white-winged scoters from a nesting population on the Yukon Flats National Wildlife Refuge (NWR) in interior Alaska (early June 1993) to *a*) evaluate metals in liver and kidneys; *b*) identify and evaluate metals in stomach contents; and *c*) evaluate metals with respect to hepatic, renal, and testicular condition as determined by histopathology.

Liver and kidney samples were analyzed at Environmental Trace Substances Research Center, Columbia, Missouri. Samples were weighed and frozen prior to homogenization. An aliquot of each sample was weighed, freeze-dried, and rehomogenized. Tissue subsamples were digested by nitric acid reflux for mercury using cold vapor atomic absorption with a Perkin-Elmer Model 403 AA. Hydride generation required nitric-perchloric digestion for arsenic and selenium. Samples analyzed by inductively coupled plasma (ICP) using a Jarrell-Ash Model 1100 Mark III were also acid digested. Three times the standard deviation of the mean was used as the detection limit for each sample; Al 3.0, As 0.2, B 2.0, Ba 0.1, Be 0.01, Cd 0.02–0.03, Cr 0.1, Cu 0.2–0.3, Fe 0.9–1.0, Hg 0.01–0.04, Mg 0.3–0.4, Mn 0.2, Mo 1.0, Ni 0.1, Pb 0.4-0.5, Se 0.2-2, Sr 0.09–0.1, V 0.3–0.4, Zn 0.9–1.0. All trace elements are reported as µg/g dry weight.

Three- to 4-millimeter cross-sections of kidney and testes, and similar sections through the liver lobe, were preserved in Bouin's solution (accessions 1–7) or 10% buffered neutral formalin (accessions 8–37). Sections were paraffin-embedded, sectioned at 5 µ, and stained with hematoxylin and eosin (H&E). Oil-red-O stain was applied to fresh cut formalin-fixed tissues where H&E indicated potential lipid inclusions. The relationship between histopathologic findings and metal concentrations (cadmium, selenium, copper, zinc) were analyzed using univariate analysis of variance (ANOVA) for each metal. All metals were transformed to geometric scale ($\log_{10}$). Trends between degree of vacuolation and metal concentrations were evaluated using linear contrasts with ANOVA.

The first eider carcasses were obtained for residue analyses in 1991. These included three birds confiscated after they were illegally shot and an eider that flew into a tower during a storm.

Results

Review of Sea Duck Status in Alaska

Black scoters, surf scoters, white-winged scoters, and oldsquaw nest at freshwater lakes and ponds in Alaska, with the breeding range of the latter three species extending into adjacent Canada, and with all species wintering along the Pacific and Atlantic coasts (*13*). Spectacled eiders breed discontinuously along the coast of Alaska, historically on St. Lawrence Island,

and along the Arctic coast of Russia from the Chukotsk Peninsula west to the Yana Delta (*14*). Spectacled eiders apparently winter in the central and northwestern Bering Sea. The king eider (*S. spectabilis*), common eider (*S. mollissima*), and Steller's eider also nest near the Alaska coast.

According to Hodges et al. (*9*), scoter populations have declined since the aerial survey began in 1957, with an estimated decline of 30% during the 36-year period. Oldsquaw numbers were probably unchanged prior to 1977 and then declined precipitously. In this 16-year period, oldsquaw declined an estimated 75%. The eider breeding population on the Yukon–Kuskokwim Delta (spectacled, Steller's, and a few common eiders) decreased 93% from 1957 to 1992. The spectacled eider is now classified as threatened under the Endangered Species Act with a 94 to 98% decline in its principal breeding range (*5*), and the Steller's eider is also a candidate species. The Steller's eider was apparently extirpated in 1975 as a breeding bird on the Yukon–Kuskokwim Delta, one of two areas in Alaska where it was a regular breeder, and it is now restricted to a small breeding area near Barrow (*6*). Monthly Steller's eider counts in winter at Izembek Lagoon on the Aleutian Islands (mostly breeding birds from Siberia) averaged for the period 1986 to 1990, when compared with the same monthly averages during 1975 to 1985, show an overall population decline of more than 50% (*6*). Thus, the Steller's eider decline is more widespread than North American breeding populations.

Alaska breeding populations of three other diving ducks that commonly winter in coastal areas, the common goldeneye (*Bucephala clangula*), Barrow's goldeneye (*B. islandica*), and bufflehead (*B. albeola*) have declined. The two goldeneye species declined 45% and the bufflehead 42% since 1977 (*9*).

Scoter Die-offs on Alaska Molting Grounds

Citizens reported on 20 August 1990 that scoters had been dying at Cape Yakataga (located in southeastern Alaska between Cordova and Yakutat) for about 2 weeks. A beach survey of about 2.5 km was made at Cape Yakataga on 21–22 August and revealed carcasses of 235 white-winged scoters, 28 surf scoters, and 5 unidentified scoters. About 20 obviously weakened scoters were observed on the beach and 150 to 200 live scoters were seen offshore. Much higher numbers of dead birds had been observed by D. Leishman 2 days before the Alaska Department of Fish and Game visit; high tides apparently refloated and removed many carcasses. On 25 August, an Alaska Law Enforcement Agent recorded at least 200 dead scoters on the beach at two locations between the Tsiu and Kallakh Rivers west of Cape Yakataga.

Seven emaciated carcasses were collected for necropsy. No gross lesions or evidence of infectious diseases were found. Bacterial and viral isolations from multiple tissues were negative. Cape Yakataga is a reef area that seems to attract molting scoters in August, perhaps because scoter prey (mussels, clams, crustaceans, etc.) associate with rocky outcroppings.

Scoters again were reported dead and dying on 7 August 1991 at Cape Yakataga. Tim Bowman, a USFWS wildlife biologist, Cordova, found 100 dead scoters and another 100 obviously weak scoters near shore. All were molting and flightless, and all scoters had died within the previous 2 days. About 90% were white-winged scoters and 10% were black scoters. Several hundred scoters were alive and apparently healthy offshore at the Cape. On 19 August 1991, 200 dead scoters were found on the beach at Cape Yakataga.

On 15 August 1991, Bowman flew to Cape Suckling, which is similar to Cape Yakataga, and captured by hand 10 molting white-winged scoters. The birds were emaciated, weak, and relatively easy to capture. Six dead scoters were found by walking about 3 km of shoreline. More than 1000 live scoters were observed offshore at Cape Suckling.

Scoters were reported dying at Cape Yakataga on 18 August 1992. Weather did not permit us to visit the region until 26 August, when 58 dead scoters were counted at Cape Suckling (56 white-winged scoters, 1 surf scoter, and 1 unidentified scoter). Fifty-one of the birds had molted and were flightless and five had retained their primaries. During a beach survey at Cape Yakataga and north of the Cape, we counted 53 dead white-winged scoters, 2 surf scoters, and 9 unidentified scoters. They were all emaciated and some had been dead for many days. At Cape Yakataga, 275 to 300 live scoters were offshore. Between Cape Suckling and Cape Yakataga, an additional 1870 live scoters were counted.

No dead scoters were reported in southeastern Alaska in 1993. A visit to Cape Yakataga and Cape Suckling on 18–19 August 1993 revealed about 400 and 1200 live scoters, respectively, with no dead birds along the shoreline. All scoters could fly and had not yet initiated the molt.

Metals Accumulation in Sea Ducks and Prey

Molting Scoters from Southeast Alaska. Scoters found moribund or dead in southeastern Alaska in 1990, 1991, and 1992 were analyzed for a series of metals (Table 1). Most of these scoters were molting in late summer at reef areas associated with Capes and died shortly after their arrival. Cadmium concentrations were especially high in kidneys from Cape Suckling scoters in 1991.

Mussels from Southeast Alaska. Mussels, prey species for scoters, were analyzed from the region of the August die-offs (between Cordova and Yakatat, Alaska) as were mussels and whelks from Oregon in 1992 (Table 2). Geometric mean cadmium concentrations (whole body, without shell) of blue mussels (*Mytilus trossulus*) in this study were 2.5 to 5.9 µg/g dw. *M. trossulus* collected at Cape Yakataga in 1975 (*15*) had nearly identical concentrations of cadmium as in 1992 (5 µg/g vs 5.9 µg/g). Whelks (*Nucella emarginata*) from Waldport Bay, Oregon, contained five times more cadmium than mussels at the same site. The whelks analyzed included mostly foot rather than whole body, but Streit and Winter (*16*) reported in *Anodonta anatina* that the lowest concentrations were found in the foot, gut/gonad complex, and muscle tissue, which would tend to minimize the real species difference.

Nesting Scoters from Interior Alaska. Thirty-seven nesting white-winged scoters collected on the Yukon Flats NWR in early June 1993 were analyzed for a series of metals (Table 3). The 11 females contained eggs at various stages of development, including eggs in the oviduct ready to be laid in two birds. Fourteen of 18 scoters analyzed in southeastern Alaska also were white-winged scoters (Table 1), and residue comparisons can be made. In general, the livers of scoters that died during the molt (Table 1) contained higher concentrations of cadmium, copper, mercury, iron, and zinc. Magnesium and manganese were similar in both series, while selenium was higher in the livers of breeding birds on the Yukon Flats NWR (geometric mean 54 vs 22 µg/g dw). The selenium concentrations from the Yukon Flats are potentially troublesome.

Eiders from Alaska. Three adult spectacled eiders were shot illegally on St. Lawrence Island in November 1991 and were seized by law enforcement personnel.

Table 1. Concentrations (µg/g, dw) of metals in livers and cadmium in kidneys of after hatch year (AHY) scoters at Cape Yakataga and Cape Suckling, Alaska in August 1990, 1991, and 1992, and AHY eiders collected at St. Lawrence Island and Togiak National Wildlife Refuge in 1991.

Species/sex	Cd	Se	Cu	Hg	Fe	Mg	Mn	Zn
1990								
Cape Yakataga[a]								
SS10 M	15.0	NA	110	1.3	8500	1200	15	200
WW12 M	8.0	NA	98	1.8	8400	840	11	180
WW13 M	67.0	NA	99	2.2	16000	950	20	320
WW14 M	6.0	NA	56	0.75	9500	990	16	360
1991								
Cape Yakataga[b]								
WW01 M	48.2	45	117	2.3	20600	781	15	301
WW02 M	21.3 (43.6)[c]	18	135	3.9	8410	789	17	312
BS03 M	30.3 (59.3)[c]	32	165	3.2	9620	819	11	287
BS04 M	33.4 (68.7)[c]	24	245	2.5	5550	892	10	199
SS05 M	5.0 (16.5)[c]	14	75	7.2	14400	937	23	193
1991								
Cape Suckling[b]								
WW06 M	20.7 (78.9)[c]	22	61	1.2	5360	831	16	164
WW07 M	95.3 (375)[c]	12	69	1.6	2630	734	20	173
WW08 M	60.9 (110)[c]	39	172	12	17700	846	14	371
WW09 M	57.1 (123)[c]	25	167	2.1	17300	949	18	327
WW10 F	8.6 (18.2)[c]	24	44	2.1	20200	730	13	137
1992								
Cape Yakataga[d]								
WW01 F	2.8 (7.1)[c]	12	20	4.9	9340	476	10	63
WW02 M	15.8 (99.4)[c]	12	55	1.6	4420	581	13	111
WW03 M	14.2 (29.2)[c]	16	54	1.7	12400	707	12	205
WW04 F	20.1 (53.6)[c]	53	56	2.6	5660	649	15	139
1990–1992 Combined (scoters)								
Geometric mean	19.6 (52.6)[c]	22	85	2.4	8320	800	14.5	205
St. Lawrence Island[e]								
SPE01 M	30.1 (53.1)[c]	75	17	0.5	1440	540	14	112
SPE02 F	5.2 (5.8)[c]	35	12	0.4	1040	511	12	95
SPE03 M	30.2 (113)[c]	77	345	1.1	2300	799	21	146
Togiak NWR[f]								
STE F	13.3 (97)[c]	14	26	1.1	1930	576	12	84

Abbreviations: SS, surf scoter; WW, white-winged scoter; BS, black scoter; SPE, spectacled eider; STE, Steller's eider. [a]Three weak and live-captured with a net, the other was dead. [b]All weak and live-captured with a net. [c]Parentheses indicate cadmium concentration in kidney. [d]All found dead. [e]All shot. [f]Collided with tower in storm and broke neck.

An additional Steller's eider collided with a tower at Togiak NWR in September 1991. These four carcasses provide the only carcass residue data available for the species (Table 1).

Mercury in 19 addled spectacled eider eggs collected on the Yukon Delta in 1992 ranged from nondetection (< 0.03) up to 0.41 (geom. mean 0.07) µg/g dw, while selenium ranged from 1.8 to 5.3 (geo mean 3.3) µg/g dw (K Trust, personal communication).

Metals and Histopathology of Nesting White-winged Scoters

Kidney sections often contained tissue changes associated with parasitism. These lesions were characterized by small, well defined granulomatous or pyogranulomatous foci containing central debris and larval nematode remains and were distributed throughout the renal cortex. Syncytia were common. The lesions varied from mild to severe and may have hampered observation of degenerative changes that could potentially be associated with metals. Degenerative and necrotic lesions not associated with parasitic lesions occurred in six sections and were very localized and minor. These changes did not correlate with the tissue residue levels of contaminants we examined.

Vacuolation of hepatic cytoplasm was common (18/37 = 49%). Vacuoles varied from an indistinct mildly foamy cytoplasm to clear, distinct, round, singular to multiple vacuoles. Oil-red-O stain indicated lipid was responsible for only a small portion of the vacuolation in some scoters. The degree of vacuolation varied from mild to severe. Generally, mean liver concentrations of cadmium and selenium were higher in birds with more severely affected liver sections. However, no significant relationship was found between cadmium concentration and hepatocellular vacuolation and only a marginally significant relationship was found between selenium and vacuolation (F 2.84, $p = 0.10$) (Table 4). There was no relationship between presence and severity of vacuolation and sex of the bird, mean liver copper concentration, or mean liver zinc concentration. Occasional granulomatous parasitic foci were observed in liver sections.

No significant lesions were observed in sections of testes.

Table 2. Concentrations (µg/g, dw) of metals in mussels and whelks from Alaska and Oregon, August–September 1992.

Location (# pools)	Length cm, mean ± SD	Cd	Se	Cu	Hg	Fe	Mg	Mn	Zn	Al
Mytilus trossulus										
Sitkagi Bluffs, AK (3)	2.2 ± 0.3	4.0 (5.4)[a]	11 (27)	29 (51)	0.23 (0.33)	5700 (11000)	7100 (9800)	94 (170)	130 (180)	3200 (6500)
Cape Yakataga, AK (3)	2.4 ± 0.3	5.9 (7.0)	14 (18)	26 (39)	0.27 (0.36)	3900 (6900)	7900 (11000)	72 (120)	180 (240)	2400 (5700)
Kayak Island, AK (3)	3.0 ± 0.5	2.5 (2.9)	13 (18)	15 (20)	0.23 (0.27)	1100 (1500)	6600 (7300)	22 (31)	110 (150)	480 (700)
Cape Suckling, AK (3)	3.0 ± 0.5	3.7 (4.7)	12 (15)	15 (16)	0.21 (0.24)	1500 (1900)	5300 (5700)	30 (32)	120 (140)	690 (860)
Yakutat, AK (2)	2.5 ± 0.7	4.1 (5.1)	8.1 (12)	25 (29)	0.44 (1.1)	3500 (4900)	9400 (10000)	55 (73)	160 (161)	2000 (2800)
Waldport Bay, OR and Seal Rock, OR (2)	2.5 ± 0.4	5.9 (6.6)	5.4 (6.6)	7.1 (8.2)	0.07 (0.09)	370 (420)	4000 (4700)	6.4 (6.5)	93 (100)	200 (220)
Nucella emarginata[b]										
Waldport Bay, OR (1)	2.4 ± 0.2	30	4.1	24	0.08	120	7900	19	190	85

[a]First value geometric mean (highest pool value). [b]Mostly foot muscle extracted from shell.

Table 3. Geometric mean concentrations (µg/g, dw) of metals in livers of after hatch year white-winged scoters nesting on the Yukon Flats National Wildlife Refuge, Alaska, June 1993.

Element	Geometric mean	Range
Ba	0.42	0.05–2.9
Cd	7.0	2.92–29.5
Cd (Kidney)	41.8	18–141
Cr	0.51	0.2–0.98
Cu	60.8	25–132
Fe	6570	1300–14400
Hg	0.99	0.28–4.02
Mg	769	626–869
Mn	15.7	10–21.6
Mo	3.2	2–7.5
Ni	0.21	0.05–14.8
Pb	1.5	0.2–2.9
Se	54	24–85
Sr	0.37	0.05–2.9
Zn	108	77–215

Table 4. Geometric mean concentrations (µg/g, dw) of cadmium and selenium in nonvacuolated and mildly, moderately, and severely vacuolated white-winged scoter liver sections from Yukon Flats National Wildlife Refuge, Alaska, June 1993.

Hepatic vacuolation (*n*)	Cadmium mean	Selenium mean
None (19)	7.3	51.5
Mild (6)	6.3	49.9
Moderate (6)	6.2	64.4
Severe (6)	7.9	60.1

Discussion

Long-term Metals Availability in the Arctic

If cadmium, selenium, or other metals are currently affecting sea duck populations, the question we immediately ask becomes, why at this time? Of course, the population data for scoters and eiders provide evidence of long-term population declines and not strictly a recent event. What is the source and long-term pattern of pollution in Alaska sea ducks? Norheim (*17*) studied seabirds and reported the presence of cadmium in both the arctic and antarctic environments, but did not know to what extent long-distance transport of air pollution contributed to this load. In arctic terrestrial ecosystems lichens constitute a large portion of the tundra vegetation, and they readily absorb atmospheric contaminants, including cadmium (*18*). Therefore, barren-ground caribou (*Rangifer tarandus*) with a preferred food in arctic Canada of lichens, were evaluated (*19*). Gamberg and Scheuhammer (*19*) reported elevated concentrations of cadmium in caribou kidneys (high of 166 µg/g dw, and most above 40 µg/g, especially older animals) but with no significant differences among the three herds sampled. They suggested that it was unlikely that herds were exposed to cadmium from point-source pollution. Gamberg and Scheuhammer further pointed out that in more pristine areas, contamination is primarily from long-range transport with large air masses, but in some locations, differences in buffering capacity and degree of environmental acidification may also contribute to site differences in cadmium accumulation by herbivorous wildlife. Plants accumulate cadmium, especially where soil acidification has occurred. In addition, acidification increases concentrations of cadmium in surface waters (*20*). Cadmium enrichment of food chains caused by acid rain may be important in portions of the arctic. Like Norheim (*17*) for seabirds, Gamberg and Scheuhammer (*19*) did not know whether the cadmium was primarily of natural origin in the terrestrial arctic ecosystem or whether it was mainly from atmospheric deposition.

Increased cadmium in remote ice fields seems to coincide with human industrialization (*21,22*). Cadmium in wheat samples from 1972 was found to be twice that reported in samples from 1916 at the same location near Uppsala, Sweden (*23*). However, Boutron et al. (*24*) more recently observed decreased concentrations of lead, cadmium, and zinc in the central Greenland snows from 1967 to 1989, and suggested that pollution of the troposphere of the northern hemisphere has significantly decreased for the three metals. However, Furness et al. (*25*) reported that attempts to quantify changes in heavy metal concentrations with ice cores or snow samples have been hindered by extremely low concentrations. They recommended using plants and animals because metal concentrations are increased by five to nine orders of magnitude over those of snow or ice. Unfortunately, few long-term suitable series of biological samples are available for analysis, especially for cadmium, which concentrates in the liver and kidney (*26*).

Metals and Their Source in Migratory Sea Ducks

Migratory sea ducks present another confounding issue in that the accumulation of metals may occur at a number of places including both the breeding and wintering grounds. When cadmium concentrations in kidneys of hatch-year (HY) birds collected in October (1.13 µg/g, dw) were compared with adults (after hatch year, AHY) collected at the same time (33.8 µg/g), it was apparent that surf scoters wintering in Oregon and Washington accumulated cadmium during their life (*2*). Data showed that cadmium increased significantly ($p < 0.001$) in kidneys from October to January in HY surf scoters collected at two of the sites in Oregon and Washington (0.94 vs 5.18 µg/g dw) (*2*). No HYs were collected at the third site in January. Thus, it is important to recognize that cadmium was accumulated by HY surf scoters at a rate of about 1.4 µg/g per month on the wintering grounds. The maximum longevity for surf scoters is unknown, but for the similar-sized white-winged scoter, it is 15 years 7 months (*27*), and cadmium is generally believed to accumulate throughout life (*28*). However, cadmium did not increase in the liver or kidney tissue of herring gulls (*Larus argentatus*) between 4 and 11 years of age (*29*).

Hontelez et al. (*30*) reported cadmium concentrations in common eiders from the Netherlands and reviewed European literature. He reported median concentrations (dw) in livers and kidneys, respectively, as follows: Netherlands, 6.5 and 15.3 µg/g; Norway, 13 and 25 µg/g; Denmark, 12.6 and 38.1 µg/g; Sweden, 6.7 and 21.8 µg/g; Svalbard, 13.2 and 48.7 to 59.8 µg/g. Differences between studies may possibly be explained by differences in age of the birds investigated. For example, the HY eiders from Denmark contained 9 and 26 µg/g cadmium in liver and kidney respectively, while AHYs contained 17 and 52 µg/g (*31*). Oldsquaws from Sweden contained even higher median levels of cadmium in kidneys (est. 41.4 µg/g dw, max. 90 µg/g) than eiders (*32*).

Residue concentrations of cadmium in eiders from Alaska were similar to those in scoters (Table 1); however, common eiders from Europe seemed to contain slightly lower concentrations. Common eiders were recommended for biomonitoring cadmium in the aquatic environments of Sweden and the Netherlands (*30,32*).

Interpretation of Metals Concentrations

Nicholson et al. (*33*) studied seabirds at St. Kilda with mean cadmium kidney concentrations of 100 to 200 µg/g dw and mean mercury concentrations of 5 to 13 µg/g dw and concluded that cadmium concentrations at which damage began and at which biochemical changes could be detected were below those presently considered relatively safe for humans (200 µg/g wet weight [ww] renal cortex, i.e., >600 µg/g dw). In humans, cadmium is stored mainly in the renal cortex, the metal level of which is about twice as high as the medulla (*34*). Elinder et al. (*35*) found histopathological changes in horse kidneys associated with cadmium as low as 75 to 125 μg/g ww. Elliott et al. (*36*) reported Leach's storm petrels (*Oceanodroma leucorhoa*) with similar kidney cadmium concentrations (129–183 μg/g dw) to Nicholson's seabirds but observed few histological lesions in the tissues examined; none were similar to the lesions previously associated with poisoning by or high residue concentrations of cadmium or mercury. We did not find histopathological changes associated with the level of cadmium in scoter livers and kidneys. On the basis of broad ecological judgments, Nicholson et al. (*33*) concluded that animals exposed to high levels of metals for a long time have evolved mechanisms to minimize the effects on breeding potential. Tolerance to high tissue cadmium levels is thought to be made possible by the cellular production of the metal binding protein metallothionein (*36*). Metallothionein is thought to be important in the normal metabolism of essential trace metals (zinc and copper) and to afford protection against nonessential metals (cadmium and mercury) by sequestering them in a form that renders them incapable of interacting with enzymes and other macromolecules (*36*). In their study, Elliott et al. (*36*) observed a highly significant positive correlation between renal cadmium and metallothionein.

Foulkes (*37*) points out that the rate at which cadmium can be sequestered in the presumably inert metallothionein complex depends upon the rate of cadmium uptake by the kidney and the net rate of renal metallothionein synthesis. It is likely, a priori, that following acute exposure to cadmium, a higher fraction of tissue cadmium will be present in nonmetallothionein and therefore probably a more toxic form than is the case after more chronic low-level exposure. Cadmium-induced metallothionein has been shown to bind not only cadmium, but also copper and zinc, which can lead to increased concentrations of these metals in kidney and liver tissue (*38–40*). As predicted, we found significant positive correlations between $\log_{10}$ cadmium and $\log_{10}$ copper ($r^2 = 0.41$, $p = 0.004$) and between $\log_{10}$ cadmium and $\log_{10}$ zinc ($r^2 = 0.29$, $p = 0.02$) in the livers of scoters found dead during the molt (Table 1) and in scoters collected on the breeding grounds (Table 5). However, neither copper nor zinc were positively correlated with increasing hepatic vacuolation.

Several protective mechanisms may operate to diminish effects of metals. For 10 seabird species, the highest correlation coefficients were observed when the molar concentrations of cadmium plus mercury and selenium plus zinc were used in the calculations (*17*). Norheim (*17*) cited several papers where selenium and zinc reduced the toxic effect of cadmium and mercury and concluded that the penguins and other birds studied have protective mechanisms that most probably diminish any effect of metals.

Adult mallards fed 15 μg/g dietary cadmium for 90 days had 54.3 μg/g ww in their kidneys or about 175 μg/g dw, and no lesions were found in the kidneys. A few males showed slight to moderate gonad alterations, and spermatogenesis appeared to have ceased (*41*). Mild to severe kidney lesions were found in mallard ducklings fed 14.6 μg/g (*42*). But perhaps more important is the altered avoidance behavior in the form of hyperresponsiveness observed in young black ducks (*Anas rubripes*) produced from parents fed only 4 μg/g dietary cadmium for about 4 months before egg laying (*43*). Most mussels collected in coastal Alaska and Oregon contained at least 4 μg/g cadmium (Table 2). Cadmium mainly accumulates in soft body parts of mussels by means of metallothioneins, and excretion appears to be very slow in contrast to that of other metals (*44*). The giant snail (*Neptunea* spp.) collected near Yakutat in 1975 contained much higher cadmium concentrations that ranged from 49.5 to 142.5 μg/g dw (*15*).

Selenium concentrations in livers of nesting white-winged scoters collected on the Yukon Flats NWR were high. The 54 μg/g dw selenium (geometric mean) was higher than in scoters found dead during the molt in southeast Alaska (Table 1), lower than in surf scoters collected on the wintering grounds in Oregon and Washington (*2*),

Table 5. Correlation matrix between trace element concentrations in the liver of after hatch year white-winged scoters nesting at Yukon Flats National Wildlife Refuge, Alaska, June 1993. Values represent logged residue data for 37 individuals.

	Ba	Cd(K)	Cd	Cr	Cu	Fe	Hg	Mg	Mn	Mo	Ni	Pb	Se	Sr
Cd(K)	–0.424**													
Cd(L)	–0.518#	0.779##												
Cr	–0.014	0.043	–0.013											
Cu	–0.525#	0.561#	0.695##	0.196										
Fe	0.080	–0.022	–0.094	0.971##	0.100									
Hg	–0.041	0.163	0.127	0.146	0.172	0.108								
Mg	0.104	0.018	0.045	–0.145	–0.111	–0.128	–0.166							
Mn	–0.392*	0.057	0.093	–0.088	0.103	–0.134	–0.222	0.172						
Mo	–0.271	0.215	0.207	0.793##	0.403*	0.719##	0.234	–0.289	0.071					
Ni	0.004	0.069	–0.112	0.642##	0.064	0.626##	0.221	0.221	–0.134	0.408*				
Pb	0.004	0.022	–0.022	0.926##	0.167	0.968##	0.083	0.083	–0.098	0.712##	0.506**			
Se	0.028	–0.253	–0.118	0.170	0.023	0.206	0.026	0.026	0.004	0.101	–0.030	0.228		
Sr	0.860##	–0.261	–0.355*	0.002	–0.406*	0.061	0.080	0.080	–0.451**	–0.232	0.065	–0.013	–0.184	
Zn	–0.276	0.490**	0.619##	0.217	0.723##	0.132	–0.106	–0.106	0.147	0.317	0.020	0.157	0.080	–0.096

The Cd(K) represents kidney. *$p < 0.05$; **$p < 0.01$; #$p < 0.001$; ##$p < 0.0001$.

but similar to surf scoters collected on wintering grounds in San Francisco Bay, California (*45,46*). Mallards with relatively low liver selenium concentrations are known to have impaired reproductive success (*47*). We also found an apparent relationship between liver selenium concentrations and hepatocellular pathology (vacuolation) that warrants further investigation.

We anticipated selenium concentrations would be much lower on the Yukon Flats NWR by assuming levels would quickly decline if scoters were no longer in a selenium-enriched area. Liver loss of selenium (in the absence of selenium in the diet) was rapid and described by an exponential equation in mallards (*48*). Perhaps a selenium source exists on the Yukon Flats.

The interpretation of selenium concentrations in birds has been primarily based on egg concentrations. Ohlendorf et al. (*49*) showed selenium concentrations in eggs reflect dietary selenium levels, and adverse selenium effects on reproduction begin at about 10 µg/g dw in the egg, or perhaps a little lower. Heinz (*50*), under controlled laboratory conditions, reported selenium concentrations above 12 µg/g dw in eggs reduced hatching success. To better interpret the 54 µg/g dw selenium in livers at Yukon Flats NWR, we need to estimate selenium concentrations in eggs laid by the white-winged scoters. A number of paired sets of selenium concentrations (livers and eggs) of waterbirds (all freshwater species) from Kesterson NWR, California, and Carson Lake, Nevada, are available (Table 6). These freshwater species provide evidence that selenium concentrations in eggs can be estimated from selenium concentrations in livers. Based on these data, an estimated 29.2 µg/g dw was expected in the white-winged scoter eggs. Using a similar approach, but another more comprehensive database of 42 paired sets of livers and eggs (unpublished, all freshwater species), a regression equation was used to estimate 21.3 µg/g dw selenium in white-winged scoter eggs (JP Skorupa, personal communication). Eggs from two white-winged scoter hens shot on the Yukon Flats NWR with eggs in their oviducts contained 3.05 and 2.74 µg/g dw selenium; less developed eggs from other white-winged scoters collected at the same time contained 2.85, 2.99, 3.39, and 4.70 µg/g dw. These low egg values were nearly 10-fold less than concentrations predicted by the two approaches based on relationships for freshwater species (21.3–29.2 µg/g dw) and well below egg concentrations known to affect freshwater species. Therefore, the use of selenium concentration in livers (based on freshwater species) as a measure of potential reproductive problems for sea ducks and perhaps other seabirds may be in error. More selenium research is needed on liver-egg relationships for seabirds and sea ducks.

Mercury and selenium concentrations in eggs laid by spectacled eiders (geometric means 0.07 and 3.3 µg/g dw, respectively) were low. Higher concentrations of mercury in eggs (above 3 µg/g dw) were needed to show behavioral changes in mallard ducklings in controlled laboratory studies (*54*) and, as mentioned earlier, higher concentrations of selenium are also needed to reduce hatching success.

At the present stage of our investigations, we have not found evidence of cadmium, selenium, or mercury adversely impacting the sea duck populations in Alaska. We believe these contaminants were the most logical to evaluate first. Also, limited evidence (spectacled eider eggs) suggests that organochlorine pesticides and PCB concentrations were low. The need to further evaluate organochlorine pesticides and PCBs for the other sea duck species (except eider) still exist because they winter in bays and estuaries south of Alaska where these contaminants persist at higher concentrations. The eiders, with very low organochlorine pesticides and PCBs, do not migrate south of Alaska. Although all sea ducks generally feed on benthic organisms, the timing and magnitude of population declines suggest that the cause of decline is not the same for all species. Sea ducks in general, and scoters in particular, are the least understood waterfowl in North America. Little biological and ecological research has been conducted on these species. For example, we do not know if the nesting and molting scoter populations we sampled are the same population. To our knowledge, only one detailed nesting study of scoters has been conducted in North America (*55*). Nesting is generally considered one of the weakest links in the life cycle, especially with regard to contaminant effects. There are potentially many critical points and environmental exposures in the life history of sea duck species. Because of this lack of information on these species, particularly movement and migration patterns, we believe the next step is to focus on a more complete understanding of their ecology. Such information will help identify critical life stages and potentially harmful environmental exposures and will allow us to generate testable hypotheses regarding population declines.

We know that many of the sea duck species are declining, especially spectacled and Steller's eiders. The USFWS has stewardship responsibilities for these species in the United States. Additional biological, ecological, and contaminant research is required for the service to effectively discharge those responsibilities.

Table 6. A comparison of selenium concentrations (geometric means) in livers and eggs of various species of birds.[a]

	Selenium, µg/g (dry weight)		
Species, year	Liver (L)	Eggs (E)	E/L
Eared grebe, 1983	127.0	69.7	0.55
American avocet, 1985	80.0	32.2	0.40
Black-necked stilt, 1985	67.9	35.5	0.52
American coot, 1983	56.4	32.4	0.57
Black-necked stilt, 1984	46.4	24.8	0.53
Black-necked stilt, 1983	41.8	28.2	0.67
White-faced ibis, 1985	9.7	5.4[b]	0.56
White-winged scoter,1993	54.0	29.2[c]	0.54[d]

Minimum sample size required was >5. [a]Data from Kesterson NWR (*51,52*) and Carson Lake, Nevada (*53*). [b]Late laid eggs (best match with late collected birds). [c]Estimated selenium in eggs based on liver × 0.54. [d]Mean ratio of egg to liver concentration.

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