HEAVY METALS IN SEADUCKS AND MUSSELS FROM MISTY FJORDS NATIONAL MONUMENT IN SOUTHEAST ALASKA*

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Abstract. Quartz Hill, in Misty Fjords National Monument near Ketchikan, Alaska, is the site of a proposed molybdenum-producing mine. To provide baseline data for use in post-development comparisons, we analyzed tissues of Barrow's goldeneyes (*Bucephala islandica*), common mergansers (*Mergus merganser*), and blue mussels (*Mytilus edulis*) for seven heavy metals that could potentially be released into the environment as a result of mining operations. Specimens were collected in 1980, 1981, and 1982 from two fjords likely to be used for discharge of tailings from the proposed mine and from two control fjords. Concentrations of arsenic, cadmium, copper, chromium, molybdenum, lead, and zinc were measured in soft tissues of mussels and in kidney, liver, and muscle of birds. The highest mean concentrations of metals found in bird tissues were 55.7 ppm dry weight cadmium in kidneys and 154 ppm dry weight zinc in livers of Barrow's goldeneyes. Concentrations of several metals in blue mussels differed among seasons and locations, but the most significant finding in mussels was a maximum mean cadmium concentration of 9.6 ppm dry weight, a level higher than normally found in undisturbed areas. With the exception of 104 ppm dry weight cadmium in the kidney of one common merganser and 12.7 ppm dry weight lead in the kidney of another, concentrations of other metals in seaduck and mussel tissues were low, consistent with what would be expected for a pre-development environment. Molybdenum was found in low concentrations (<10 ppm dry weight) in all avian kidney samples and most liver samples, but was not detected in blue mussels.

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1. Introduction

Molybdenum deposits were discovered in 1974 at Quartz Hill, in Misty Fjords National Monument near Ketchikan, Alaska. The final Environmental Impact Statement (EIS) and Record of Decision for the Quartz Hill mining development project have been completed (USDA Forest Service, 1988), but it is unknown when production will begin. Of environmental concern is the potential discharge of heavy metal components of the ore, particularly arsenic, cadmium, copper, lead, molybdenum, manganese, and zinc (USDA Forest Service, 1988) into surface and marine waters during mining and deep-water disposal of mine tailings. The "preferred alternative" for tailings disposal identified in the EIS is local marine disposal. At full production, about 80 000 tons of tailings will be discharged per day over the estimated 55-year lifetime of the mining project (USDA Forest Service, 1988).

Background data on water quality, freshwater and marine invertebrate populations, physical oceanography, and concentrations of heavy metals in salmonid tissues in the Quartz Hill area have been previously reported (USDA Forest Service, 1988; Elliot, 1980). Here, we report the results of monitoring initiated in 1980 to develop baseline data useful in later assessments of potential impacts of mining and tailings disposal on biological indicators of heavy metals contamination. Our primary objective was to determine pre-development concentrations of several heavy metals in tissues of marine ducks that use different prey and feeding strategies, and in tissues of a major prey species. We selected the most abundant and accessible species available: the Barrow's goldeneye (*Bucephala islandica*), the common merganser (*Mergus merganser*), and blue mussels (*Mytilus edulis*). Barrow's goldeneyes and common mergansers are abundant fall, winter, and early spring residents of coastal southeast Alaska. During the winter months in Misty Fjords, Barrow's goldeneyes consume primarily blue mussels (Koehl *et al.*, 1984), filter-feeding invertebrates recognized as biological indicators of contaminants (National Research Council, 1980; Phillips, 1976). The common merganser is the most abundant fish-eating seaduck in Misty Fjords and also one of the most common nesting species in the area (VTN, 1983). Bioaccumulation of metals in fish near Quartz Hill may result from their ingestion of vertically migrating zooplankton that carry suspended sediment particles from tailings (USDA Forest Service, 1988). We expect, therefore, that concentrations of heavy metals in tissues of blue mussels, Barrow's goldeneyes, and common mergansers will provide an index to the overall burden of metals in the area of proposed development.

2. Materials and Methods

2.1. Study Areas

The molybdenum deposits at Quartz Hill are located in Misty Fjords National Monument about 75 km east of Ketchikan, Alaska (Figure 1). Boca de Quadra and Wilson Arm were chosen as experimental study sites because several tailings disposal options in the EIS designate those fjords as potential receiving waters. We selected Rudyerd Bay and Nakat Inlet as control fjords because of their topographic and spatial separation from Quartz Hill, making transport of tailings sediments to these locations unlikely.

The four fjords are long narrow inlets with steep rock shores and central troughs over 100 m deep. Boca de Quadra is approximately 50 km long, extending 20 km inland from Behm Canal. It has five lateral bays of different sizes, a central trough that is divided by sills into several deep basins, and its greatest depth is over 350 m. Freshwater inputs are from numerous small drainages, including Humpback Creek and the Marten and Keta rivers. Sand and silt tidal flats are found at the mouths of these drainages as well as at the heads of Vixen and Badger bays. Smeaton Bay diverges into Bakewell and Wilson arms and extends 23 km to the mouth of the Blossom/Wilson River system, 18 km inland. Vegetated sand and silt tidal flats are found at the heads of both arms but, like Boca de Quadra, most of the shoreline is near-vertical rock with some rubble from slides.

Rudyerd Bay has the steepest walls and least amount of littoral habitat of the four fjords. Its maximum length is about 17 km, reaching 14.5 km inland. Tidal flats are present at the head of Punchbowl Cove and the distant ends of the eastern bays. In contrast, Nakat Inlet has the gentlest sloping topography and the most numerous gravel and sand intertidal areas, primarily at its head and in south Nakat Harbor. Although vertical rock is the most common shoreline type, the intertidal zone is less steep and cobble beaches are more prevalent than in the other fjords.

2.2. Seaduck collection

We used the U.S. Fish and Wildlife Service motorvessel M/V *Curlew* as a base to collect seaducks in February 1980 and 1981. Twenty-two Barrow's goldeneyes were collected at Boca de Quadra in 1980, but none from the other sites. In 1981 seven Barrow's goldeneyes were collected at each of the four fjords. Eight common mergansers were also collected in 1981, including three at Boca de Quadra, one at Nakat Inlet, two at Wilson Arm, and two at Rudyerd Bay. We collected ducks by shooting with lead shot in 1980 and steel shot in 1981. Carcasses were dissected on the *Curlew* within 3 h of collection using stainless steel instruments. Samples (10–20 g) of liver, kidney, and pectoralis minor from each bird were frozen in acid-washed glass jars for metals analysis.

2.3. Mussel collection

Blue mussels were collected in February and July 1981 and March 1982 at all fjords, with the exception of Nakat Inlet in February 1981. We used a total of 12 sites (Boca de Quadra, 5; Rudyerd Bay, 3; Wilson Arm, 4) in February 1981, 40 (Boca de Quadra, 14; Nakat Inlet, 6; Rudyerd Bay, 7; Wilson Arm, 13) in July 1981,

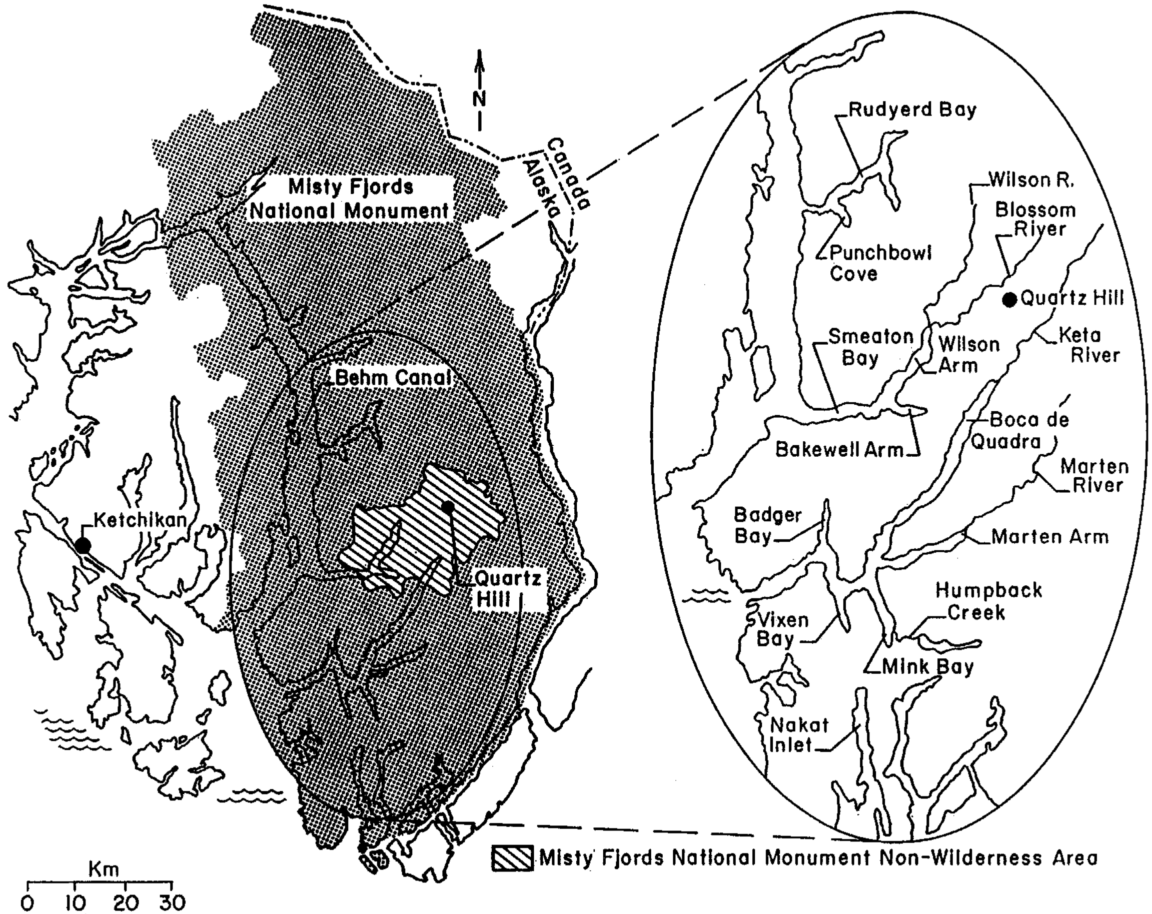

Fig. 1 Misty Fjords National Monument including location of proposed molybdenum mine and fjords where Barrow's goldeneyes (*Bucephala islandica*), common mergansers (*Mergus merganser*), and blue mussels (*Mytilus edulis*) were collected for metals analyses.

and 34 (Boca de Quadra, 11; Nakat Inlet, 5; Rudyerd Bay, 6; Wilson Arm, 12) in March 1982. We attempted to collect mussels from large boulders in apparently well-established beds, but used fallen, anchored trees when necessary. At each site about 25 specimens of 30 to 40 mm shell length (approximately 30 g of soft tissue) were collected for metals analysis from the intertidal zone near the mid-region of the bed.

In February 1981, mussels were frozen intact in acid-washed glass jars and opened later at the laboratory with plastic knives after removal of byssal threads and byssal glands. Soft parts were rinsed with distilled water and frozen in acid-washed glass jars until metals analysis. In July 1981 and March 1982, mussels were placed in plastic bags or buckets and depurated in clean seawater for 24 h to allow for excretion of gut contents before soft parts were removed.

2.4. Metals Analyses of Seaduck and Mussel Tissues

After homogenation in a Virtis blender, a 5 g portion of tissue was ashed in a Vycor crucible for lead, copper, zinc, cadmium, chromium, and molybdenum determinations; for arsenic, a 1 g portion was used. Analytical methods followed Haseltine *et al.* (1981) except that residues in the 5 g sample were measured with a Perkin Elmer Model 5000 atomic absorption spectrophotometer (AAS) and arsenic concentrations were determined with a Perkin Elmer Model 403 AAS equipped with a MHS-20 hydride generator. Average recoveries from chicken livers containing known concentrations of metals ranged from 81 to 110%. Residue concentrations were not corrected for percentage recovery. The lower limits of reportable residues on a wet weight (ww) basis were 0.1 ppm for lead, copper, zinc, and cadmium; 0.05 ppm for chromium and arsenic; and 0.5 ppm for molybdenum. Tissue lead residues from birds collected with lead shot (1980 only) were not reported because of possible contamination. Moisture content was determined for each sample and residues were converted to ppm dry weight (dw) to avoid potential errors due to moisture loss from specimens during transport and storage (Adrian and Stevens, 1979; Franson, 1984).

2.5. Statistical Analysis of Residue Data

For metals detected in more than 50% of the samples, we tested normality and homogeneity of variances to determine if data required log transformation. Site, year, and gender differences in residues in seaduck tissues and site and sampling time differences in mussel residues were evaluated with analysis of variance (ANOVA). Differences detected by multi-factor ANOVA were described with Bonferroni multiple comparisons, and Tukey's method was applied to results from one-factor ANOVA (Neter and Wasserman, 1974). We tested for correlations between metal concentrations using Spearman's rank correlation procedure (Zar, 1984). For samples that contained no detectable residues of a particular metal, a concentration

TABLE I

Frequencies of occurrence (%)[a] of metals in tissues of Barrow's goldeneyes (*Bucephala islandica*) from southeast Alaska

Metal	Kidney ($N = 50$)	Liver ($N = 45$)	Muscle ($N = 48$)
As	4	0	0
Cd	100	100	17
Cu	100	100	100
Cr	96	93	94
Mo	100	100	0
Pb	48	31	43
Zn	100	100	100

[a] Detection limits = 0.05 ppm wet weight for Cr and As; 0.1 ppm wet weight for Pb, Cd, Cu, and Zn; and 0.5 ppm wet weight for Mo.

of one-half the detection limit was assigned. Those values were converted to dry weight basis using the percent moisture of the sample. We chose to report arithmetic means of metal residues.

3. Results

3.1. Metals in Barrow's Goldeneyes

Cadmium, copper, molybdenum and zinc were above detectable limits in all kidneys and livers, and copper and zinc were found in all muscle samples from Barrow's goldeneyes (Table I). Two-factor (year-location and gender) ANOVA revealed significant gender differences for concentrations of cadmium in kidney samples and zinc in muscle, as well as significant year-location differences for zinc concentrations in muscle. In general, males had higher concentrations of cadmium in their kidneys than did females, while females had greater levels of zinc in muscle than did males. Zinc concentrations in muscle tissue of goldeneyes collected at Boca in 1980 and 1981 were higher than those of birds collected at Wilson (Table II). Spearman correlations were positive for concentrations of cadmium and zinc ($r = 0.41, N = 50, P = 0.001$), cadmium and copper ($r = 0.24, N = 50, P < 0.05$), and zinc and copper ($r = 0.60, N = 50, P < 0.005$) in goldeneye kidney tissue.

No gender differences occurred for the remaining metals and tissues, so we combined results for males and females and used one-factor ANOVA to compare goldeneye data among year-location groups. Significant differences among sites occurred for zinc in kidney, copper, cadmium and chromium in liver, and copper in muscle (Table III). There was no consistent pattern for site differences, but goldeneyes from Rudyerd Bay often had lower concentrations of metals in their

TABLE II

Concentrations (arithmetic means ± SD (*N*); ppm dry weight) of cadmium in kidney and zinc in muscle of Barrow's goldeneyes (*Bucephala islandica*) from southeast Alaska according to year and location. Mean percent moisture ± SD (*N*): kidney = 80.2 ± 1.3 (50), muscle = 77.6 ± 1.7 (48)

Tissue	Metal	Gender[a]	Boca 1980	Boca 1981	Nakat 1981	Rudyerd 1981	Wilson 1981
Kidney	Cd	M	49.8±18.5(14)	47.8±35.5(3)	55.7±37.1(4)	39.6±19.7(5)	36.3±17.1(5)
		F	53.2±38.0(8)	28.5±32.8(4)	18.8±11.8(3)	18.8±8.8(2)	13.6±1.8(2)
Muscle[b]	Zn	M	37.8±6.6(12)	35.1±4.4(3)	32.5±9.0(4)	26.1±4.1(5)	21.0±11.0(5)
		F	33.8±4.9(8)	39.6±4.9(4)	39.4±4.9(3)	32.7±8.4(2)	30.4±1.2(2)

[a] Two-factor (year-location and gender) ANOVA revealed significant gender differences for cadmium ($P = 0.0330$) and zinc ($P = 0.0390$).

[b] Two-factor (year-location and gender) ANOVA revealed significant differences among year-location groups ($P = 0.0101$).

TABLE III

Concentrations (arithmetic means ± SD; ppm dry weight)[a] of metals in tissues of Barrow's goldeneyes (*Bucephala islandica*) from southeast Alaska according to year and location. Males and females combined. Mean percent moisture ± SD (*N*): kidney = 80.2 ± 1.3 (50), liver = 75.5 ± 1.3 (45), muscle = 77.6 ± 1.7 (48)

Metal	Boca 1980	Boca 1981	Nakat 1981	Rudyerd 1981	Wilson 1981
Kidney					
Cu	19.0±4.3	21.1±3.7	20.1±5.6	14.9±5.9	16.9±5.1
Cr	6.0±7.8	4.6±4.2	3.0±2.4	2.9±2.2	2.5±3.3
Mo	6.7±1.7	7.3±1.0	6.2±2.2	7.8±1.6	5.2±2.8
Zn	111.0±16.0A[b]	117.0±19.6A	125.0±15.4A	89.5±8.3B	89.3±11.4B
Liver					
Cd[c]	7.6±3.1	4.8±2.2	5.2±2.2	4.7±1.6	4.8±2.2
Cu	43.6±11.0AB	40.9±6.0AB	51.2±12.2A	31.1±4.6B	44.5±14.7AB
Cr	1.3±0.9A	1.1±0.8A	2.9±1.8	0.6±0.4A	0.5±0.3A
Mo	5.2±1.2	4.7±0.6	6.2±1.2	4.8±1.4	5.1±2.0
Zn	154.0±35.5	151.0±21.4	154.0±24.3	126.0±8.5	133.0±23.7
Muscle					
Cu	22.3±4.8A	14.2±10.6AB	10.5±9.4B	8.6±5.3B	10.7±2.5B
Cr	2.7±1.5	6.3±7.2	2.8±1.6	2.4±2.2	2.3±2.9

[a] $N = 22$ (Boca 1980 kidney), 17 (Boca 1980 liver), 20 (Boca 1980 muscle), 7 (all others). [b] Means in same row not sharing a common letter are significantly different ($P<0.05$). Comparisons were done only when the F-test indicated a difference. [c] Although Tukey's method (Neter and Wasserman, 1974) found no differences, a linear contrast indicated that cadmium concentrations at Boca in 1980 were higher than in 1981 ($P = 0.0012$).

tissues than did those from other locations. Zinc residues in livers were relatively consistent among sites and ranged from 126 to 154 ppm dw (Table III).

Arsenic was not detected in liver or muscle and was found in only two kidney samples (3.3 and 3.7 ppm dw). Molybdenum was not found in any muscle samples. Maximum concentrations and frequencies of lead in all tissues and cadmium in muscle are listed by location in Table IV. The concentrations of lead in kidney ranged from not detectable in 71% of the goldeneyes from Wilson Arm to 4.9 ppm dw in a bird from Rudyerd Bay. The maximum lead concentration in both liver and muscle was 3.0 ppm dw.

TABLE IV

Maximum concentrations (ppm dry weight) and frequencies of occurrence (%)[a] of lead in all tissues and cadmium in muscle of Barrow's goldeneyes (*Bucephala islandica*) from southeast Alaska according to year and location. Males and females combined; $N = 7$, except for Boca 1980 muscle ($N = 20$). Mean percent moisture ± SD (N): kidney = 80.2 ± 1.3 (50), liver = 75.5 ± 1.3 (45), muscle ± 77.6 ± 1.7 (48)

		Location				
		Boca	Boca	Nakat	Rudyerd	Wilson
Metal	Tissue	1980	1981	1981	1981	1981
Pb	Kidney	–[b]	3.0	3.6	4.9	1.0
	%		43	43	43	29
Pb	Liver	–	1.1	1.6	3.0	1.0
	%		57	14	43	43
Pb	Muscle	–	2.1	1.1	3.0	1.0
	%		43	43	43	43
Cd	Muscle	0.8	ND[c]	0.9	ND	ND
	%	35	0	14	0	0

[a] Detection limit = 0.1 ppm wet weight. [b] Lead concentrations not reported for birds collected with lead shot. [c] Not detected.

3.2. METALS IN COMMON MERGANSERS

Copper and zinc were above detectable limits in all common merganser tissues (Table V). Molybdenum was present in all kidneys and all but one liver sample, but was not detected in muscle. We found 104 ppm dw cadmium in the kidney of one merganser, but concentrations in others were low (<20 ppm dw). Lead residues occurred infrequently and at quite low concentrations except for 12.7 ppm dw in the kidney from a merganser collected at Wilson Arm. Arsenic was not detected in any merganser tissues. Because of small sample sizes, metals concentrations in mergansers were not statistically compared among locations.

3.3. METALS IN MUSSELS

Residues of copper, zinc, and cadmium were found in all blue mussels and chromium was found in all but one sample. Concentrations of several metals differed among seasons and locations (Table VI). The highest mean cadmium concentrations in mussels included 9.6 ppm dw at Boca de Quadra, 7.4 ppm dw at Nakat Inlet, and 6.9 ppm dw at Wilson Arm. Cadmium concentrations at Boca were significantly different at each sampling time (March > July > February) and in March were higher than those at all other locations. At Nakat Inlet, the July cadmium concentration in mussels was higher than that in March, but the reverse was true

TABLE V

Concentrations (ppm dry weight) of metals in tissues of common mergansers (*Mergus merganser*) collected in southeast Alaska in February 1981. Mean percent moisture ± SD (*N*): kidney = 79.4 ± 2.2 (8), liver = 75.0 ± 1.4 (8), muscle = 77.3 ± 1.6 (8)

Location	Gender	Tissue	Pb	Cu	Zn	Cd	Cr	Mo
Boca	M	Muscle	1.5	1.0	48.3	ND[a]	3.0	ND
		Liver	ND	39.6	119.0	0.4	0.6	5.7
		Kidney	ND	1.6	107.0	7.5	0.9	7.5
Boca	M	Muscle	0.5	13.8	193.0	ND	3.0	ND
		Liver	ND	25.2	118.0	3.2	ND	3.7
		Kidney	ND	11.0	116.0	17.1	2.4	8.0
Boca	F	Muscle	ND	23.0	39.4	ND	1.6	ND
		Liver	ND	24.1	119.0	2.1	1.3	5.5
		Kidney	ND	14.2	89.7	9.5	11.1	6.3
Nakat	M	Muscle	ND	20.0	53.1	ND	4.5	ND
		Liver	ND	20.0	102.0	0.7	ND	5.8
		Kidney	0.5	22.6	116.0	3.8	5.8	7.2
Wilson	F	Muscle	1.3	6.3	35.0	ND	2.5	ND
		Liver	ND	16.4	82.0	0.4	ND	4.5
		Kidney	12.7	9.8	68.6	1.5	3.1	3.5
Wilson	M	Muscle	ND	6.3	36.2	ND	0.6	ND
		Liver	ND	19.2	86.3	2.8	0.4	3.3
		Kidney	ND	14.3	105.0	17.7	1.0	5.2
Rudyerd	M	Muscle	ND	3.0	28.9	ND	3.5	ND
		Liver	ND	23.2	99.1	9.9	1.3	1.9
		Kidney	ND	12.0	104.0	104.0	0.6	2.4
Rudyerd	M	Muscle	ND	5.4	30.5	ND	0.6	ND
		Liver	ND	14.8	74.1	0.8	0.7	ND
		Kidney	ND	10.6	65.9	9.7	0.9	3.6

[a] Not detected.

at Wilson Arm. In July, the zinc concentration in mussels at Nakat Inlet was higher than at the other three locations. Within Nakat Inlet the zinc concentration in mussels was higher in July than it was in March, but there were no seasonal differences in zinc levels at the other locations. Copper concentrations in mussels were significantly lower in March than in July at all sampling locations. No differences occurred among locations or seasons for chromium.

We detected no molybdenum in mussel samples. Maximum concentrations and frequency of detection for lead and arsenic are listed in Table VII. Low frequencies prevented statistical analysis of these data, but concentrations of lead and arsenic in mussels were usually higher in July than in February or March based on samples with concentrations above the detection limit.

TABLE VI

Concentrations (arithmetic means ± SD; ppm dry weight) of metals in mussels (*Mytilus edulis*) from southeast Alaska. Data were log transformed for statistical analysis. Mean percent moisture ± SD (N): 89.8 ± 1.3 (50)

Metal	Time	Location Boca	Nakat	Rudyerd	Wilson
Cu	Feb[a]	6.5±0.6	NS[b]	5.0±1.0	5.6±0.9
	N[c]	5	–	3	4
	July	6.8±1.3	8.7±3.1	7.6±1.3	7.2±4.0
	N	14	6	7	13
	Mar	4.8±1.4[d]	5.1±1.2[d]	5.7±0.8[d]	5.2±0.8[d]
	N	11	5	6	12
Zn	Feb	61.4±6.4	NS	52.6±3.4	52.4±8.3
	N	5	–	3	4
	July	60.0±10.9A[e]	86.0±29.9B	56.9±4.2A	53.6±2.8A
	N	14	6	7	13
	Mar	51.6±6.6	60.2±16.5[d]	58.3±3.1	57.2±4.1
	N	11	5	6	12
Cd	Feb	3.4±0.5A	NS	5.5±2.5B	4.1±0.3AB
	N	5	–	3	4
	July	6.5±1.1	7.4±2.6	5.4±0.9	5.5±0.8
	N	14	6	7	13
	Mar	9.6±2.3A[f]	5.1±1.0B[d]	6.3±0.9B	6.9±0.8B[g]
	N	11	5	6	12
Cr	Feb	2.7±1.5	NS	4.0±3.6	2.6±1.6
	N	5	–	3	4
	July	6.5±6.2	2.4±0.9	1.8±1.2	2.4±2.0
	N	14	6	7	13
	Mar	2.0±0.9	4.4±4.9	3.0±2.8	1.8±1.0
	N	11	5	6	12

[a] February and July 1981; March 1982. [b] No samples collected from Nakat in February 1981. [c] Number of sites from which mussels were collected. [d] Significantly less than July value ($P<0.05$). [e] Means within a row not sharing letters in common are significantly different ($P<0.05$). [f] Boca Cd concentrations significantly different; March > July > February ($P<0.05$). [g] Wilson Cd concentrations significantly different; March > July and February ($P<0.05$).

4. Discussion

4.1. Metals in Seaducks

To compare our data with reports where results were expressed in ppm ww, we converted concentrations of heavy metals from those reports to ppm dw. When

TABLE VII

Maximum concentrations (ppm dry weight) and frequencies of occurrence (%)[a] for lead and arsenic in mussels (*Mytilus edulis*) from southeast Alaska. Mean percent moisture ± SD (N): 89.8 ± 1.3 (50)

	Maximum value					
	Pb			As		
Location	Feb[b]	July	Mar	Feb	July	Mar
Boca	1.1	3.3	1.2	0.6	0.8	ND[c]
%	20	50	36	20	21	0
N[d]	5	14	11	5	14	11
Nakat	NS[e]	4.0	1.2	NS	0.7	ND
%	–	67	40	–	67	0
N	–	6	5	–	6	5
Rudyerd	ND	ND	ND	0.8	ND	ND
%	0	0	0	100	0	0
N	3	7	6	3	7	6
Wilson	ND	2.4	ND	0.7	0.8	ND
%	0	23	0	75	54	0
N	4	13	12	4	13	12

[a] Detection limits = 0.1 ppm wet weight, Pb; 0.05 ppm wet weight, As. [b] February and July 1981; March 1982. [c] Not detected. [d] Number of sites from which mussels were collected. [e] No samples were collected at Nakat in February.

moisture content of tissues was not reported we used ww : dw ratios calculated for liver (0.33) and kidney (0.23) of mallards (*Anas platyrhynchos*) (Scanlon, 1982). Cadmium residues in kidneys of seaducks from Misty Fjords, particularly Barrow's goldeneyes, were higher than those reported from other species in several studies elsewhere (Table VIII).

According to Eisler (1985), cadmium residues in vertebrate liver or kidney that exceed 10 ppm ww (about 30.3 ppm dw for liver or 43.5 ppm dw for kidney) should be viewed as evidence of probable cadmium contamination. In Misty Fjords, 22 of 50 goldeneyes and one of eight mergansers had cadmium residues greater than 43.5 ppm dw in kidney. Cadmium levels in kidneys of goldeneyes and mergansers from Misty Fjords were, however, lower than concentrations (nearly 500 ppm dw) in kidneys of individual northern fulmars (*Fulmarus glacialis*) collected near Spitsbergen (Norheim, 1987). Kidneys of apparently healthy individual northern fulmars, Atlantic puffins (*Fratercula arctica*) and Leach's storm-petrels (*Oceanodroma leucorhoa*) collected near the Outer Hebrides had cadmium residues as high as 240 ppm dw, 125 ppm dw, and 128 ppm dw, respectively (Bull *et al.*, 1977). In experimental studies on dietary uptake of cadmium in mallards, White

TABLE VIII

Mean concentrations (ppm dry weight) of cadmium in bird kidneys from southeast Alaska and other study sites

Species[a]	Cd	Location	Reference
Common merganser	21.3	Misty Fjords	This study
Barrow's goldeneye	42.1	Misty Fjords	This study
Cattle egret	4.7[b]	Galveston Bay	Hulse *et al.* (1980)
Greater scaup	5.3[b]	Baltic Sea	Szefer and Falandysz (1987)
Bufflehead	5.5	Chesapeake Bay	Di Giulio and Scanlon (1984b)
Canvasback	6.0	Chesapeake Bay	Di Giulio and Scanlon (1984b)
Laughing Gull	6.6[b]	Galveston Bay	Hulse *et al.* (1980)
Greater scaup	7.4	Chesapeake Bay	Di Giulio and Scanlon (1984b)
Canvasback	10.0[b]	Chesapeake Bay	White *et al.* (1979)
Herring gull	13.0	United Kingdom	Hutton (1981)
Kelp gull	15.2[b]	New Zealand	Turner *et al.* (1978)
White-headed stilt	16.0[b]	New Zealand	Turner *et al.* (1978)
Gadwall	17.0	Chesapeake Bay	Di Giulio and Scanlon (1984b)
S. island oystercatcher	17.1[b]	New Zealand	Turner *et al.* (1978)
Greater scaup	24.9	San Francisco Bay	Ohlendorf *et al.* (1986)
Eurasian oystercatcher	27.0	United Kingdom	Hutton (1981)
Seaducks[c]	27.6	Chesapeake Bay	Di Giulio and Scanlon (1984b)
Surf scoter	28.3	San Francisco Bay	Ohlendorf *et al.* (1986)
Red-billed gull	37.7[b]	New Zealand	Turner *et al.* (1978)
Common eider	60.9[b]	Spitsbergen	Norheim (1987)
Great skua	81.4	United Kingdom	Hutton (1981)
Leach's storm-petrel	92.2	Outer Hebrides	Bull *et al.* (1977)
Atlantic puffin	103.0	Outer Hebrides	Bull *et al.* (1977)
Northern fulmar	126.0	Outer Hebrides	Bull *et al.* (1977)
Northern fulmar	239.0[b]	Spitsbergen	Norheim (1987)

[a] Common names of species follow Clements (1991). [b] Conversion from wet weight (Scanlon 1982). [c] Pooled oldsquaws and white-winged scoters.

and Finley (1978a, b) observed few pathologic alterations in birds with kidney concentrations as high as 260 ppm dw.

Cadmium concentrations in livers of goldeneyes and mergansers were below those considered evidence of contamination (Eisler, 1985), but were higher than avian liver residues reported from some less pristine environments (Table IX). Parslow *et al.* (1982) examined 301 waterfowl of seven species from the Ouse Washes in England. They found cadmium concentrations of less than 0.6 ppm dw in 82% of liver samples. By contrast, cadmium residues in livers of 100% of goldeneyes and 75% of mergansers from Misty Fjords, an area free of any industrial or residential development or human-induced point source pollution,

TABLE IX

Mean concentrations (ppm dry weight) of heavy metals in bird livers from southeast Alaska and other study sites

Species[a]	Cd	Pb	Cu	Zn	Location	Reference
Common merganser	2.5	ND[b]	22.8	99.8	Misty Fjords	This study
Barrow's goldeneye	5.9	0.3	42.6	146.0	Misty Fjords	This study
Common goldeneye	0.4[c]	1.0[c]	31.4[c]	94.3[c]	Sweden	Eriksson *et al.* (1989)
Greater scaup	1.2[c]	0.7[c]	46.8[c]	96.2[c]	Baltic Sea	Szefer and Falandysz (1987)
Bufflehead	1.2	5.1	36.7	116.0	Chesapeake Bay	Di Giulio and Scanlon (1984b)
Ruddy duck	1.8[c]	1.1[c]	–[d]	–	Delaware River	White and Kaiser (1976)
Canvasback	1.8[c]	0.8[c]	179.0[c]	124.0[c]	Chesapeake Bay	White *et al.* (1979)
Herring gull	2.0	–	–	91.6	United Kingdom	Hutton (1981)
Canvasback	3.1	3.8	114.7	170.0	Chesapeake Bay	Di Giulio and Scanlon (1984b)
White-winged scoter	3.1	5.4	39.2	159.0	Chesapeake Bay	Di Giulio and Scanlon (1984b)
Oldsquaw	5.5	7.1	20.1	158.0	Chesapeake Bay	Di Giulio and Scanlon (1984b)
Great skua	7.5	–	–	139.4	United Kingdom	Hutton (1981)
Eurasian oystercatcher	10.5	–	–	137.9	United Kingdom	Hutton (1981)
Common eider	13.0[c]	–	818.0[c]	152.0[c]	Spitsbergen	Norheim (1987)
Common eider	13.0	–	367.0	204.0	Trondheim Fjord	Lande (1977)
Leach's storm-petrel	33.0	–	–	–	Outer Hebrides	Bull *et al.* (1977)
Atlantic puffin	20.8	–	–	–	Outer hebrides	Bull *et al.* (1977)
Surf scoter	–	0.6[c]	32.1[c]	100.0[c]	Fraser River	Vermeer and Peakall (1979)
Surf scoter	–	0.45	49.8	131.0	San Francisco	Ohlendorf *et al.* (1986)
Greater scaup	–	2.5[c]	55.2[c]	123.0[c]	Fraser River	Vermeer and Peakall (1979)
Greater scaup	–	0.71	96.8	151.0	San Francisco	Ohlendorf *et al.* (1986)
Northern fulmar	29.1	–	–	–	Outer Hebrides	Bull *et al.* (1977)
Northern fulmar	51.0[c]	–	18.6[c]	219.0[c]	Spitsbergen	Norheim (1987)

[a] Common names follow Clements (1991). [b] Not detected; detection limit = 0.1 ppm wet weight.
[c] Conversion from wet weight (Scanlon, 1982). [d] Not analyzed.

exceeded 0.6 ppm dw. In a study of more than 750 waterfowl of 15 species collected from Chesapeake Bay, Di Giulio and Scanlon (1984b) found cadmium levels greater than 7.0 ppm dw in only 4% of livers from all species tested. Among oldsquaws (*Clangula hyemalis*) and white-winged scoters (*Melanitta deglandi*), two species of seaducks, liver cadmium residues of 7.0 ppm dw or greater occurred in 18%. We found liver concentrations of cadmium exceeding 7.0 ppm dw in 36% of goldeneyes and 12% of mergansers from Misty Fjords. Di Giulio and Scanlon (1985) suggested a trend to increasing cadmium in seaducks, because of diets consisting almost entirely of animal matter.

Mean concentrations of lead and copper in livers of Barrow's goldeneyes and common mergansers from Misty Fjords were generally less than or similar to those reported for other diving ducks and seabirds (Table IX). At 146 ppm dw, the mean concentration of zinc in goldeneye livers was within the range suggested to be indicative of normal environmental exposure (<210 ppm dw; Eisler, 1993) but was higher than in several other species of seabirds collected in more contaminated environments (Table IX).

We observed that cadmium consistently accumulated to higher concentrations in goldeneye kidneys than in livers, with the reverse true for zinc. Di Giulio and Scanlon (1984a) found highly significant positive correlations between concentrations of cadmium and copper and of cadmium and zinc in mallard kidneys in laboratory feeding trials of cadmium. They suggested that increases in dietary cadmium elicit increased kidney concentrations of copper and zinc. In goldeneye kidneys, we found significant but weaker positive correlations between concentrations of cadmium and copper and between cadmium and zinc. The weaker correlations may result from the fact that we found a narrower range and lower concentrations of cadmium in wild goldeneye kidneys than those values reported in the mallard feeding study (Di Giulio and Scanlon, 1984a).

Parslow *et al.* (1982) noted that cadmium and zinc concentrations are temporally variable and apparently at their lowest levels immediately following the molt, increasing thereafter. Male Barrow's goldeneyes complete their pre-nuptial molt by late October, while females finish molting several months later (Bellrose, 1980). This may account in part for the higher levels of cadmium we found in kidneys of male goldeneyes compared with females, but does not explain why females had more zinc in muscle than males.

4.2. Metals in Mussels

Although the gonads and mantle tissues of mussels show the least response to metals uptake (Schulz-Baldes, 1974), reductions in body weight following spawning result in greater measurable concentrations of metals (Simpson, 1979). Further complicating factors include variable onset and duration of the reproductive cycle from year to year (Seed, 1976), and differential frequencies of ripe individuals among locations (Chipperfield, 1953). The onset of spawning in mussels in Prince

TABLE X

Maximum concentrations (ppm dry weight) of heavy metals in mussels (*Mytilus edulis*) from southeast Alaska and other study sites

Location	Cd	Pb	Cu	Zn	Source
Misty Fjords	9.6	4.0	8.7	86.0	This study
Trondheimsfjorden	5.0	–[a]	88.0	359.0	Lande (1977)
Scandinavia	7.6	202.0	–	396.0	Phillips (1979)
Burrard Inlet, BC	–	413.0	25.0	662.0	Popham and D'Auria (1982)
Rupert Inlet, BC	–	–	150.0	–	Goyette and Nelson (1977)
Rupert Inlet, BC[b]	9.9	3.4	29.7	554.0	McGreer *et al.* (1980)
Baffin Island, NWT[b]	8.5	5.1	66.7	957.0	McGreer *et al.* (1980)
Marmorilik, Greenland[b]	12.8	865.0	77.0	1823.0	McGreer *et al.* (1980)

[a] Not analyzed. [b] Laboratory study.

William Sound and southeast Alaskan waters is thought to begin in April or early May and continue through July (R.T. Myren and C. E. O'Clair, Auke Bay Fisheries Laboratory, pers. comm.). Higher levels of copper in July at all our study sites are consistent with greater metals concentrations after spawning, but the general lack of significant differences in seasonal concentrations of metals may be due to other variables or to availability of only very low levels of naturally-occurring metals.

Among variables that could not be controlled by our sampling procedures are greater seasonal variations generally found in estuarine areas, probably because of changes in seasonal run-off, and variations in elevations of sample sites. Exact vertical positions on the shoreline where bivalves are sampled are considered important with respect to metals levels encountered (National Research Council, 1980). Sampling sites at Misty Fjords were located at different elevations, which may prevent meaningful comparisons between sites (Phillips, 1976). Each site, however, should accurately reflect changes in concentrations of metals over time, to the extent that the original sampling scheme is replicated.

Except for cadmium, concentrations of most metals found in mussels collected in this study were low compared with those of other reports (Table X). The maximum mean cadmium concentration of 9.6 ppm dw in mussels from Misty Fjords was as high as that reported from several other locations (Table X) and was about an order of magnitude higher than that found in clams from the Chesapeake Bay (Di Giulio and Scanlon, 1985). This, despite the fact that all Misty Fjords study sites were in undisturbed environments far from industrial developments or human settlements. Lande (1977) found a maximum mean of 5 ppm dw cadmium in mussels from Trondheim Fjord, Norway, an area described as polluted with heavy metals. Ouellette (1981) studied seasonal variation of trace metals in mussels in Monterey County, California and reported a maximum mean cadmium concentration of 10.4 ppm dw. McGreer *et al.* (1980) collected mussels from an uncontaminated site in British Columbia and conducted 30-day static bioaccumulation experiments using mine tailings effluent from three locations: the Greenex lead-zinc mine on Agfardlikavsa Fjord, Greenland, the Nanisivik Mine on Strathcona Sound in Baffin Island, and the Island Copper Mine in British Columbia. They reported maximum cadmium residues of 8.5 to 12.8 ppm dw, similar to the maximum concentrations we found at Misty Fjords.

5. Conclusions

Concentrations of heavy metals in mussels and seaducks were consistent with what might be expected from a relatively uncontaminated environment, except for somewhat elevated cadmium residues in mussels and cadmium and zinc in Barrow's goldeneyes. Cadmium levels in blue mussels, the primary prey of Barrow's goldeneyes, were as high or higher than those reported from some contaminated environments. Although cadmium concentrations in kidneys of goldeneyes were less than those associated with acute toxicity, they were in the range indicative of exposure, likely reflecting the cadmium levels in their diet of blue mussels. Differences in concentrations of metals in seaducks and mussels among Misty Fjords sampling sites were largely inexplicable. Based on descriptive comparisons, levels of metals in common mergansers were generally lower than in goldeneyes. We observed consistent seasonal differences only in concentrations of copper in blue mussels.

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