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HEAVY METAL CONCENTRATIONS IN AQUATIC BIOTA OF GREENS CREEK, ZINC CREEK, AND HAWK INLET

Volume 1 - Text

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SUMMARY

Aquatic biota collected in the Greens Creek area of Admiralty Island, Alaska, in August 1980 were analyzed for metals content. Objectives were to determine the tissue metals burdens of resident organisms and to establish statistically sound baseline values of metals concentrations in organisms for assessing impacts of the proposed Noranda mine. Samples taken comprised freshwater invertebrates and resident Dolly Varden char from Greens and Zinc creeks; juvenile coho salmon and sculpin from Zinc Creek; anadromous Dolly Varden char from Greens Creek; and mussels, cockles, and polychaete worms from near the mouth of Greens Creek. Tissue samples were sent to three laboratories for analysis. Quality control analyses identified the reliable set of determinations to be used in assessment. The following conclusions were drawn based on the valid analytical results:

- Resident fish (juvenile coho, sculpin, Dolly Varden char) in Zinc and Greens creeks have, in general, similar levels of tissue metals concentrations.
- Metals levels in freshwater invertebrates are higher than those in fish.
- Metals concentrations in tissues of freshwater fish and invertebrates do not suggest that these organisms have been exposed to high ambient metals levels.
- Metals levels in mussels do not suggest the existence of high ambient metal levels in marine waters near Greens Creek.

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I. INTRODUCTION

Noranda Mining, Inc., is currently developing a mine in the Greens Creek area of Admiralty Island in southeastern Alaska. Numerous environmental studies have been conducted in the project area since 1978 to provide the baseline data for preparation of the Environmental Impact Statement required by the U.S. Forest Service. Several of these studies included an examination of heavy metals concentrations in aquatic biota of Greens and Zinc creeks and Hawk Inlet (Noranda Exploration, Inc. 1978; IEC, 1980a; IEC, 1980b). Although water quality studies in Greens Creek indicated that metals concentrations in the fresh water were quite low (IEC, 1980c), analyses of biological samples suggested relatively high metals burdens, particularly in organisms taken from the two creeks.

A field sampling program was conducted in 1980 to provide additional data on metals concentrations in biota. Samples of fish and invertebrates were taken in Greens and Zinc creeks, and from Hawk Inlet near the mouths of the creeks. Metals concentrations in these organisms are presented here, and are discussed in relation to literature values. Survey results relating to abundance of biota and stream characteristics are also presented in this report.

II. METHODS

A. FIELD METHODS

Field collections were carried out from 11-20 August 1980. Fish in Zinc and Greens creeks were collected by angling and with plastic minnow traps (0.5-cm mesh; 60 cm in length x 22 cm in diameter) baited with salmon roe. Invertebrate samples were collected using kick samplers (PVC pipe frame; 0.5-mm Nitex mesh) and by manually picking insect larvae from stones. Because the primary objective of sampling was to obtain sufficient biomass for heavy metals analysis, data relating to abundance (e.g., catch per unit time) were not rigorously recorded. Marine invertebrate samples were collected with nonmetallic instruments.

Sampling locations are shown in Fig. 1. Samples were collected in many different locations along each stream, but for the purpose of analysis and discussion, freshwater samples were grouped into three categories representing three general areas: Zinc Creek [in areas 35 - 40 ft (30.3-m) elevations, where the stream meanders through the coastal meadow and hemlock-spruce forest], lower Greens Creek [from the mouth at Hawk Inlet upstream to an area with an elevation of approximately 400 ft (121 m)], and upper Greens Creek (at the confluence of Greens Creek and Big Sore Creek). Organisms collected here were exposed to Big Sore water, which may carry higher metal concentrations than Greens Creek. Marine invertebrate samples were collected from the Greens Creek delta and the shoreline just south of the mouth of Greens Creek.

All biological samples were placed in polyethylene bags immediately upon capture. Samples were then placed on ice in coolers in the field and frozen within 6 hours of capture. All samples were kept frozen until they were processed in the laboratory.

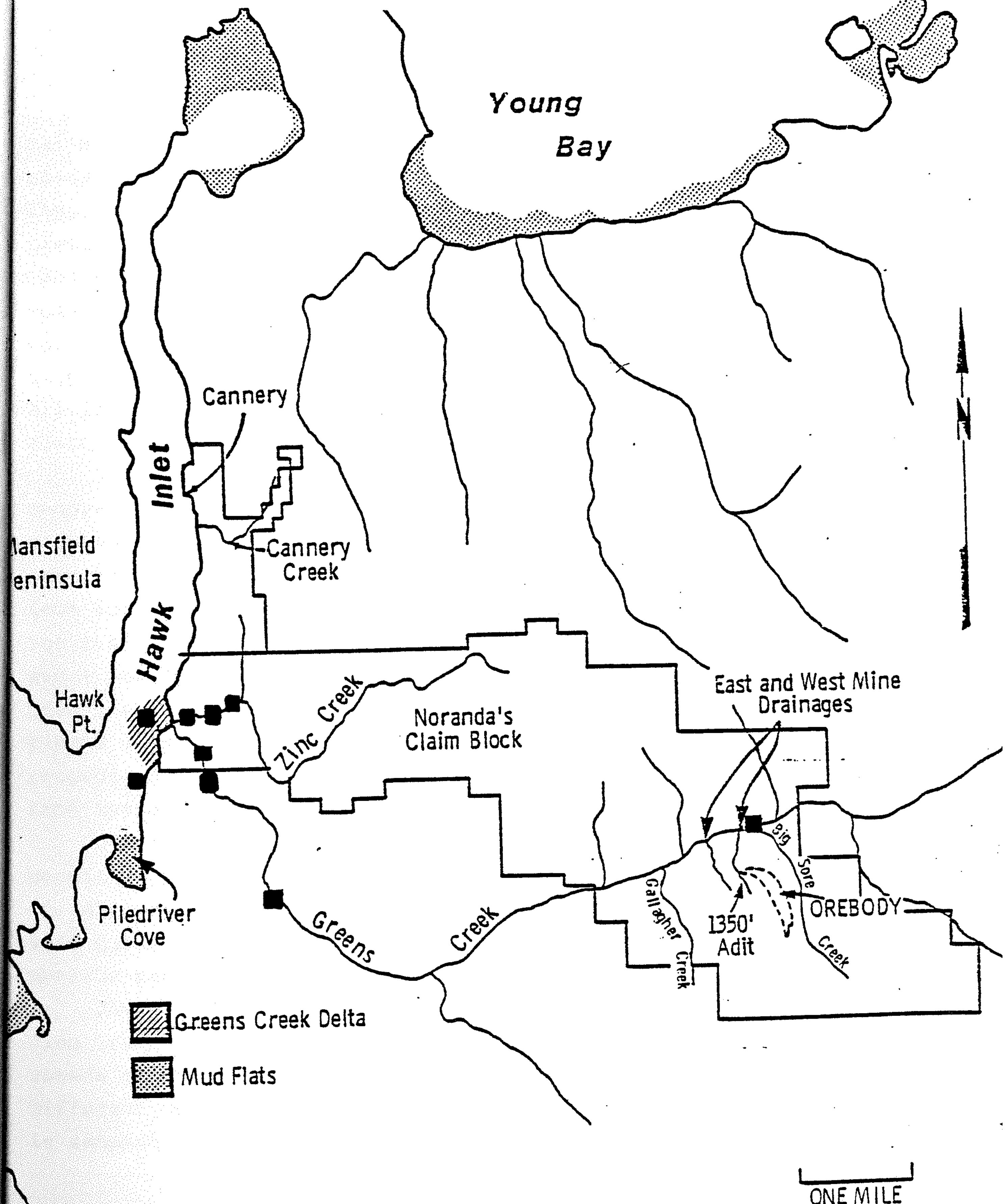

Fig. 1. Locations in the Admiralty Island area of Alaska from which biological samples were collected for metals analysis in August 1980; black squares indicate general locations of sampling.

B. PROCESSING METHODS

All metals analyses were performed on freeze-dried biological material. However, different types of organisms were processed in different ways prior to homogenization for freeze drying. For Greens Creek Dolly Varden char samples, where various tissue types were to be analyzed, the fish were thawed in the laboratory and rinsed with double-distilled water. Lengths and weights were measured and dissection was carried out on laboratory tables covered with disposable polyethylenecoated paper. Dissection tools included stainless steel and teflón-coated instruments. All instruments were soaked in 4N reagent-grade nitric acid overnight and rinsed with double-distilled water prior to use.

Gills (including arches) and livers of the Dolly Varden were removed from each fish and placed in polyethylene bottles. Intestinal tracts and gonads of fish were removed and discarded. Samples of fillet (muscle tissue with skin removed) were taken from the upper right side of each fish and placed in polyethylene bottles, and all remaining tissue from each fish (bone, muscle, etc.) was placed in another polyethylene bottle. All bottles had been soaked in 4N reagent-grade nitric acid overnight and triple rinsed with double-distilled water. Weights of all tissues were recorded so that whole-body metals levels could be calculated from the metals levels of each of the four tissue types.

Lower Greens Creek Dolly Varden were sufficiently large to permit each of the five replicate samples of each tissue type to be taken from a single fish. Upper Greens Creek Dolly Varden were quite small, however, and 34 individuals were required to provide each of the five replicate samples.

Juvenile coho salmon, sculpin, and Dolly Varden char from Zinc Creek were processed as whole fish with digestive tract and gonads removed. Lengths and weights of all fish were recorded. Different numbers of fish, depending on their size, were included in samples within each sample set.

Freshwater invertebrate samples were thawed in the laboratory, placed in porcelain pans, and covered with double-distilled water. Organisms were than sorted from debris, sediment, and pebbles using forceps, and placed in acid-washed polyethylene bottles. After a sufficient weight of organisms had been accumulated, the sample was again rinsed with double-distilled water to eliminate any possible contamination by sediments.

Marine invertebrates were thawed in the laboratory, placed in porcelain pans, and covered with double-distilled water. Shellfish were removed from their shells using stainless steel instruments. Because of the sandy and muddy sediments from which these organisms were taken, fine-grained sediment adhered to them and may have been present in the gut, since they were not allowed to clear their guts. Although they were washed three to five times, the possibility of sediment contamination remains. This means that values presented here are at worst overestimates of tissue metal burdens.

All biological samples were homogenized using acid-washed glass or polyethylene blender containers with stainless steel and teflon blade assemblies. Triple-distilled water was added to each sample to provide sufficient fluid for blending. Blended samples were then poured back into the original bottle, along with rinsing water from the blender container. Where the bone and muscle samples were large, all material was blended, but only a subsample was taken for freeze drying.

Homogenized samples were frozen, bottle caps were loosened, and the samples were freeze dried for at least 96 hours at a temperature of -5°C or lower. Samples were weighed daily, and freeze drying was continued until no additional weight loss was observed. Sample bottle caps were then tightened, and the samples were shipped to analytical laboratories.

C. ANALYTICAL METHODS

Metals analyzed for included zinc, copper, lead, manganese, nickel, chromium, silver, cadmium, mercury, arsenic, and selenium. Two types of blind standards were included in each set of samples sent out for analysis to permit some evaluation of the accuracy of the analyses performed. The standards were obtained from stocks of freeze-dried biological tissues maintained by the United States National Bureau of Standards. These tissues have been analyzed by many different laboratories, and NBS provides estimates of their heavy metals contents with specific confidence limits. One NBS standard and one NBS reference material were purchased -- albacore tuna (NBS Research Material 50) and bovine liver (NBS Standard Reference Material 1577) -- and placed in numbered bottles sent with each sample set. Although NBS values for albacore are not certified, and are thus of questionable accuracy, they do provide a benchmark for comparisons. To determine the precision of the analytical laboratory work, a number of single samples were split, and each half was placed in a different numbered bottle.

Only a number was used to mark the polyethylene bottles containing the freeze-dried samples. Replicates of the same material and halves of split samples were not numbered sequentially. Thus, the analytical laboratory technicians did not know the type of tissue being analyzed or which samples were replicates or splits. This procedure complicated the analysis of samples but ensured unbiased results.

Sample analysis was performed by three organizations: Princeton Testing Laboratory (PTL) Princeton, New Jersey (33 samples); Energy Resources Co., Inc. (ERCO), Cambridge, Massachusetts (54 samples); and Ecological Analysts, Inc. (EAI), Baltimore, Maryland (23 samples). Samples sent to each laboratory are indicated in Table 1. Based on quality control results (i.e., findings reported for NBS standards and split samples

Table 1. Types and sources of Admiralty Island samples analyzed for metals content; ERCO = Energy Resources Company, Inc.; PTL = Princeton Testing Laboratory; EAI = Ecological Analysts, Inc.

Species	Area	Tissue Type	Individuals Per Sample	Number of Samples	Analytical laboratory
Polycheates	Greens Creek delta	Whole body	21	5	ERCO
Mussels	Greens Creek	Whole body less shell	≈ 18	5	ERCO
Cockles	Greens Creek delta	Whole body less shell	≈ 8	5	PTL EAI
Anadromous Dolly Varden Char	Lower Greens Creek	Gills	1	5	PTL
		Liver	1	5	PTL
		Fillet	1	5	PTL
		Whole body less gills, liver, fillet, gonads and alimentary canal	1	5	PTL ERCO
Aquatic Invertebrates (larvae of mayflies, stone-flies, caddis flies, and dipterans)	Upper Greens Creek	Whole body	Not known	3	ERCO

Table 1. Continued.

Species	Area	Tissue Type	Individuals Per Sample	Number of Samples	Analytical Laboratory
Resident Dolly Varden Char	Upper Greens Creek	Gills	34	5	ERCO
		Liver	34	5	ERCO
		Fillet	34	5	ERCO EAI
		Whole body less gills, liver, fillet, gonads and alimentary canal	34	5	ERCO EAI
Aquatic Invertebrates (amphipods, isopods)	Zinc Creek	Whole body	≈ 200	5	PTL
Sculpin	Zinc Creek	Whole body less alimentary canal	9	5	PTL ERCO EAI
Dolly Varden	Zinc Creek	Whole body less alimentary canal	7	2	EAI
Coho Salmon (large juveniles)	Zinc Creek	Whole body less alimentary canal	5	5	ERCO
Coho Salmon (large juveniles)	Zinc Creek	Whole body less alimentary canal	4	1	EAI

Table 1. Continued.

Species	Area	Tissue Type	Individuals Per Sample	Number of Samples	Analytical Laboratory
Coho Salmon (small juveniles)	Zinc Creek	Whole body less alimentary canal	20	7	ERCO
Bovine Liver	--	U.S. National Bureau of Standards	--	3	ERCO PTL EAI
Albacore	--	U.S. National Bureau of Standards	--	3	ERCO PTL EAI

presented in Appendix B), only ERCO data were considered completely reliable. For this reason, these data were used as the basis for this report. ERCO's analytical procedures and in-house quality control results are presented in Appendix A of this report.

III. FIELD OBSERVATIONS

Nonquantitative field observations made during these August surveys augment information presented in other reports (Noranda Exploration, Inc., 1978; IEC, 1980b). One primary observation, previously unreported, is the markedly different aquatic habitats offered by Zinc and Greens creeks. This observation is documented in more detail in reports currently in preparation by Dr. James Beull.

Zinc Creek waters were highly colored (a dark tea shade), though transparent, suggesting a high tannin content. Many of the numerous small tributaries feeding into Zinc Creek in the coastal plain drain bog and muskeg areas at low elevations just north of the creek. Flow in Zinc Creek is relatively low, and organic debris is abundant in its pools and eddies. Sediments in many pools are very fine sand and silt. A major portion of the stream meanders in the coastal plain area. Where it begins to ascend the ridge to the east, flow is very low volume. Observations reported here were made during a period of very low flow and may thus not be representative of average conditions.

The waters of Greens Creek, in contrast, are uncolored and flow at a much higher volume than those in Zinc Creek. A relatively short portion of the stream occupies the coastal plain area and no small tributaries enter there. Very little organic debris or fine sediment can be found, even in major pools.

Another difference between the streams is in the distribution and density of salmon runs. During the sampling period, Greens Creek contained large numbers of pink and chum salmon, relative to Zinc Creek, in which only sparse schools could be found in the largest pools. The abundant fish and frequent spawning activity of fish in Greens Creek kept most of the gravel stream bottom continually disturbed. Such a situation was not noted in Zinc Creek. This may have accounted for the apparent difference in density of benthic invertebrates.

A. INVERTEBRATE SAMPLES

Kick sampling in lower Greens Creek yielded essentially no invertebrates. This result could have been due partly to the disruption of bottom substrate by spawning salmon. However, in upper Greens Creek, where no salmon occur, kick sampling also produced few organisms. Samples in that area had to be obtained by manually picking insect larvae from the undersides of stones in the stream. Although detailed taxonomic identifications were not made, these larvae were almost entirely mayflies, stoneflies, caddis flies, and dipterans. The surveys suggested a very low level of insect production in Greens Creek -- only about 20 g of invertebrates were collected in approximately 20 man-hours of sampling.

Kick sampling in Zinc Creek, just above the limit of tidal influence, yielded large quantitites of invertebrates. Amphipods and isopods dominated these collections. Taxonomy of these organisms was not established, but they may represent estuarine forms. As much as 500 g of invertebrates were collected in less than 4 man-hours, suggesting a very high level of invertebrate productivity in Zinc Creek.

B. FINFISH SAMPLES

Fourteen minnow traps, baited with fresh salmon roe, were set in Zinc Creek in various pools from the limit of tidal influence upstream for about 1 km. Because of the numerous small tributaries entering the creek over this distance, flow in the pools farthest upstream was about one fourth the flow at the tide line.

Traps were first tended 1 hour after deployment, and the traps were checked several times on the same day before being left overnight. Catch rates were not rigorously recorded, but as many as 39 juvenile coho were taken in a single trap in a single hour. Since our collecting permit limited our coho sample to 200 individuals, many were released. Large numbers of sculpin, Cottus aleuticus, (as many as 24 per hour) were also taken, and 187 were retained for metals analysis. Only 26 Dolly Varden char were taken in the traps, the largest 16 cm long. Three small (<8-cm) cutthroat trout were also taken in the traps. Some juvenile salmon in the trap catches that were initially believed to be chinook were later identified as 2-year-old coho. Angling in Zinc Creek was relatively unsuccessful, yielding a few small Dolly Varden and three additional small cutthroat.

Twenty minnow traps were set in Greens Creek in the vicinity of the tidal line on three separate days. Catches of juvenile coho were low: fish appeared in only 6 of the 20 traps daily, with a maximum capture rate of about 1 fish per hour. Small numbers of sculpin were also taken. In general, catches and catch rates were much lower than in Zinc Creek. Fourteen traps were also deployed approximately 3 km upstream of the tide line in Greens Creek for about 4 hours; approximately 40 juvenile coho were taken. In all traps set in lower Greens Creek, no Dolly Varden, rainbow trout, or cutthroat trout were taken.

Angling in lower Greens Creek was highly productive. Dolly Varden catches were as large as 30 fish per man-hour. The majority of fish ranged in size from about 22 to 50 cm, and no fish smaller than 13 cm were taken. Sufficient fish were kept for the heavy metals analysis, and the remainder were released. Total estimated catch of Dolly Varden char (including those released) for 12 angler days was about 400. Ten cutthroat, averaging about 25 cm long, were also taken on hook and line.

Traps set in upper Greens Creek yielded only Dolly Varden char, with a maximum size of about 15 cm. Catch rates were as high as 25 fish in the 15 minutes following initial trap deployment. Two hundred of these were kept for metals analysis.

Lengths and weights of all fish processed for metals analysis were recorded. Length frequency distributions of fish analyzed by ERCO and EAI are presented in Appendix C. Size distributions of the 34 resident Dolly Varden char from upper Greens Creek in each of the five replicate samples were very similar (Table C-1). Size differences among and within replicate samples of small and large coho juveniles are seen in Table C-2. Relative similarity of length distributions of groups of sculpin constituting replicate samples from Zinc Creek is evident in Table C-5.

IV TISSUE METAL CONCENTRATIONS

A. FRESHWATER BENTHIC INVERTEBRATES

Benthic invertebrates from upper Greens Creek are the major food source of resident Dolly Varden char in that section of the stream. Thus, invertebrates provide a major pathway for metals in the environment to enter fish tissue. Mean metals concentrations from three replicate samples of upper Greens Creek invertebrates are presented in Table 2. Raw data are presented in Table D-1 in Appendix D. Metals in highest concentrations are zinc, copper, manganese, silver, and cadmium. These values can be compared with literature values for freshwater invertebrates from other river systems, also presented in Table 2. Wet weight Greens Creek values for zinc, nickel, arsenic, selenium, cadmium, and mercury are substantially lower than invertebrate values reported for several streams in Ketchican, Alaska (Elliot, 1980). Values for the remaining metals may also be lower, but degree of variability and detection limits prohibit comparison.

Dry weight values can be compared to values reported for a contaminated stream in Virginia (Van Hassel et al., 1980). Greens Creek values for zinc and cadmium are higher, while lead is much lower and nickel is similar. This comparison is less meaningful than the first since the environments and the species of organisms analyzed differ.

These comparisons, though limited, suggest that Greens Creek values are not unusual or abnormal. Indeed, the most comparable data from Alaskan streams (Elliot 1980) imply that Greens Creek values are very low. The fact that Elliot indicates that several samples were contaminated may suggest that the high values reflect general contamination of most samples.

Phillips (1980), in an extensive review and discussion of trace metals pollution, noted that invertebrates normally have

Table 2. Metals concentrations (mean ±2SD for dry weight) in freshwater invertebrates from Greens Creek, and literature data on aquatic invertebrates from other river systems. (NA - not analyzed)

Species	Reference	Location	Comments	Analytical Technique	Tissue	Basis for Concentration	Metals Concentration (ppm)										
							Zn	Cu	Pb	Mn	Ni	Cr	As	Se	Ag	Cd	Hg
Aquatic Invertebrates	Sample Nos. 71, 72, 108N	Upper Greens Creek	--	Atomic absorption spectrophotometry	Whole body	Dry Weight	570 ±330	36 ±3.1	0.60 ±0.55	85 ±16	4.1 ±0.3	2.00 ±0.40	0.84 ±0.92	1.40 ±2.27	19 ±21	12.0 ±6.4	0.57 ±0.57
						Wet Weight	99.9	6.3	0.11	15	12.0	0.35	0.15	0.25	3.30	2.1	0.10
Aquatic Insects (grouped taxa)	Elliot, 1980	Hill Creek (Ketchikan, Alaska)	Unpolluted	Same as above	Whole body	Wet Weight	174.0	<5.4	<1.25	NA	<40.2	<3.30	10.30	33.00	<3.40	13.1	3.90
Same as above	Elliot, 1980	Lower Keta River (Ketchikan, Alaska)	Unpolluted	Same as above	Whole body	Wet Weight	129.9	<3.7	<1.00	NA	<24.4	<3.90	<5.10	36.20	<4.10	<7.1	10.00
Same as above	Elliot, 1980	North Creek (Ketchikan, Alaska)	Unpolluted	Same as above	Whole body	Wet Weight	152.0	<1.9	<1.00	NA	75.8	<3.00	1.00	16.00	2.9	6.4	0.04
Aquatic Insects hydropsychidae	Elliot, 1980	Beaver Creek (Ketchikan, Alaska)	Unpolluted	Same as above	Whole body	Wet Weight	140.0	<1.9	<3.00	NA	35.6	<3.00	2.00	12.00	3.70	8.6	1.50
Aquatic Insects (grouped taxa)	Elliot, 1980	Upper Keta River (Ketchikan, Alaska)	Unpolluted	Same as above	Whole body	Wet Weight	126.60	<4.80	<2.70	NA	<38.10	<3.10	4.40	32.00	<4.50	<6.80	1.90
Aquatic Insects Tipulidae (dipteran family)	Van Hassel et al.,1980	Back Creek, Roanoke River, Southwest Virginia	Contaminated	Same as above	Whole body	Dry Weight	93.70	NA	12.20	NA	4.10	NA	NA	NA	NA	0.78	NA

Table 2. Continued

Species	Reference	Location	Comments	Analytical Technique	Tissue	Basis for Concentration	Metals Concentration (ppm)										
							Zn	Cu	Pb	Mn	Ni	Cr	As	Se	Ag	Cd	Hg
Aquatic Insects Perlidae (plecopteran family)	Van Hassel et al.,1980	Back Creek, Roanoke River, Southwest Virginia	Contaminated	Atomic absorption spectrophotometry	Whole body	Dry Weight	222.00	NA	21.70	NA	6.80	NA	NA	NA	NA	0.80	NA
Aquatic Insects Pteronarcidae (plecopteran family)	Van Hassel et al.,1980		Contaminated	Same as above	Whole body	Dry Weight	242.00	NA	14.60	NA	2.70	NA	NA	NA	NA	0.88	NA

relatively high levels of metals in their tissues. He also stated that the majority of crustacean invertebrates could physiologically regulate most heavy metals, particularly copper, manganese, and zinc, over a broad range of ambient metals concentrations, up to some threshold breakdown level. In the crab, Carcinus maenas, the threshold for zinc is about 100 μg/l. Concentrations of most metals in Greens Creek water seldom exceed several μg/l, and average zinc values do not exceed 23 μg/l (Table 3). Thus, based on Phillips (1980) discussion, we would expect invertebrates to regulate the metals rather than accumulate them to abnormal levels. The tissue metals concentrations determined from the present work support this contention.

B. FINFISH

Although resident Dolly Varden char from upper Greens Creek may exhibit net movement downstream, they do not exhibit major migrations (J. Beull, personal communication). They would thus be exposed to ambient metals levels for their entire lifetime -- over 4 years. For this reason, concentrations of metals accumulating in their tissues might be expected to be higher than levels found in juvenile coho, and anadromous Dolly Varden, which spend less time in the same waters. Mean metals concentrations found in gill, liver, muscle, and remainder tissue are presented in Table 4. Raw data are presented in Tables D-3, D-4, D-5, and D-6 in Appendix D. It can be seen that concentrations of copper were much higher in liver than in other tissues. Likewise, zinc exhibited higher concentrations in liver and remainder tissue. Muscle tissue tended to have the lowest levels of all metals. Whole body metals concentration levels were calculated based on the remainder values and the total weight of each type of tissue.

Mean values for two samples of anadromous Dolly Varden remainder tissue are shown in Table 5. When these values are compared to values for remainder tissue of resident Dolly Varden char from upper Greens Creek (Table 4), it can be seen that

Table 3. Average heavy metals concentration (mg/l) in filtered Greens Creek water - April 1978 to May 1980 (from IEC, 1980c); values preceded by L are detection limits; thus, actual values may be much less than the number entered in the table.

Station	No. of Samples	Hg M.±S.D.	As M.±S.D.	Se M.±S.D.	Pb M.±S.D.	Cu M.±S.D.	Zn M.±S.D.	Cd M.±S.D.	Cr M.±S.D.	Ni M.±S.D.	Ag M.±S.D.
GCBA 1	4	L.0020±L.0020	L.0050±L.0050	L.0100±L.0100	L.0100±L.0100	.0030±.0020	.0050±.0030	.0020±.0020	.0020±.0020	L.0050±L.0050	.0004±.0004
GCBA 2	4	L.0020±L.0020	L.0050±L.0500	L.0100±L.0100	L.0100±L.0100	.0300±.0470	.0070±.0050	.0020±.0030	.0060±.0100	.0060±.0080	.0017±.0029
GCBA 6	23	L.0020±L.0020	L.0050±L.0050	L.0100±L.0100	L.0100±L.0100	.0030±.0040	.0100±.0080	L.0020±L.0020	L.0020±L.0020	.0050±L.0050	.0009±.0009
Near GCBA 3	23	L.0020±L.0020	L.0050±L.0050	L.0100±L.0100	L.0100±L.0100	.0030±.0030	.0230±.0140	L.0020±L.0020	.0040±.0090	L.0050±L.0050	.0010±.0011
GCBA 5	21	L.0020±L.0020	L.0050±L.0500	L.0100±L.0100	L.0100±L.0100	.0040±.0040	.0090±.0130	L.0020±L.0020	L.0040±L.0080	L.0050±L.0050	.0008±.0008
Near BSBA 7	11	L.0020±L.0020	L.0050±L.0050	L.0100±L.0100	L.0100±L.0100	.0030±.0040	.0180±.0110	L.0020±L.0020	.0030±.0030	.0050±L.0050	.0010±.0013

M.±S.D. = Mean ± Standard Deviation
L = less than

Table 4. Mean metals concentrations (+2SD) found in various tissue types and whole body of resident Dolly Varden char from upper Greens Creek, as measured by ERCO.

Tissue Type		Metals Concentrations in Dry Material (ppm)										
		Zn	Cu	Pb	Mn	Ni	Cr	As	Se	Ag	Cd	Hg
Gill		144	3.6	<0.12	9.3	<0.71	2.1	<0.44	2.0	6.0	0.69	0.11
		+11	+1.2		+0.9		+0.5		+2.2	+6.5	+0.23	+0.005
	Wet wt. $\bar{x}$ =	36.7	0.92	<0.03	2.4	<0.18	0.53	<0.01	0.51	1.53	0.18	0.03
Liver		218	44.6	<0.19	9.3	<0.98	0.89	<0.32	2.3	10.1	3.9	0.30
		+36	+19.3		+0.93		+0.58		+1.7	+ 8.3	+0.86	+0.05
	Wet wt. $\bar{x}$ =	58	11.9	<0.05	2.5	<0.26	0.24	<0.09	0.61	2.69	1.0	0.08
Muscle		59	2.0	<0.11	1.7	<0.61	2.4	<0.20	2.1	10.9	0.29	0.33
		+ 4.0	+0.31		+0.56		+1.2		+2.0	+16.5	+0.08	+0.16
	Wet wt. $\bar{x}$ =	13	0.46	<0.03	0.39	<0.14	0.55	<0.05	0.48	2.49	0.07	0.08
Remainder		204	2.9	<0.12	8.8	<0.73	2.7	<0.43	1.8	6.0	0.46	0.14
		+22.8	+0.58		+2.1		+1.9		+1.7	+6.7	+0.08	+0.05
	Wet wt. $\bar{x}$ =	43.5	0.62	0.03	1.9	<0.16	0.58	<0.09	0.38	1.3	0.10	0.03
Whole Body	Wet wt. $\bar{x}$ =	31.3	1.29	<0.03	1.37	<0.15	<0.54	<0.06	0.41	1.84	0.14	0.05

Table 5. Mean metals concentrations (ppm) in remainder tissue of anadromous Dolly Varden char from lower Greens Creek as measured by ERCO.

	Metals Concentration (ppm)										
	Zn	Cu	Pb	Mn	Ni	Cr	As	Se	Ag	Cd	Hg
Dry wt. $\bar{x}$ =	49	1.8	<0.10	2.2	<0.55	0.48	<0.23	0.65	0.60	<0.02	0.10
Wet wt. $\bar{x}$ =	11	0.40	<0.02	0.48	0.12	0.11	0.05	0.14	0.13	<0.01	0.02

values of zinc, manganese, silver, and cadmium for the resident fish are significantly higher than for the anadromous stock.

Juvenile coho from Zinc Creek consisted of two basic size groups: 90 mm mean length and 60 mm mean length (Appendix C). If we assume these groups to represent two year classes of juveniles, then, any metals being accumulated may be expected to be found in higher concentrations in the larger (i.e., older) size group. Mean metal concentrations in small and large juvenile coho are presented in Table 6. Raw data are presented in Tables D-12 and D-13 in Appendix D. There is no indication of increased metals concentrations with size (i.e., age) for any metal.

Values for all metals for both size categories are similar to reconstituted whole body values for upper Greens Creek Dolly Varden (Table 4). The two exceptions are copper which appears somewhat higher in the Dolly Varden, and manganese which is lower in the char.

Sculpin are another totally resident species, but one which may occupy a different niche in the stream ecosystem. Although sculpin age was not determined, they can be expected to have rather short lifetimes. Metals levels in sculpin are shown in Table 7. It is evident that values for all metals except manganese and silver are comparable to those found in juvenile coho. Silver concentrations are two orders of magnitude lower, while manganese is double the coho value. Quality control results indicate that these values are accurate and not a result of analytical error. No explanation for these differences is evident.

Several interesting contrasts are evident when data from different species or size groups included in this study are compared. Values for zinc, manganese, silver, and cadmium are significantly lower in remainder tissue from anadromous Dolly Varden (Table 5) than in remainder tissue from resident Dolly Varden from upper Greens Creek (Table 4). These findings could be interpreted as indicating bioaccumulation in the resident stock (the anadromous Dolly Varden would be present in the creek only for relatively short portions of their lifetime).

Table 6. Mean metals concentrations (±2SD) in large and small juvenile coho salmon taken from Zinc Creek, as measured by ERCO.

Sample	Metals Concentrations in Dry Material (ppm)										
	Zn	Cu	Pb	Mn	Ni	Cr	As	Se	Ag	Cd	Hg
Small Juveniles	126	2.5	<0.18	14	<0.68	1.5	<0.18	0.93	9.9	0.16	0.33
	±30	±1.3		± 5.0		±0.75		±0.71	±11	±0.13	±0.26
Wet wt. $\bar{x}$ =	26.5	0.53	<0.04	2.9	<0.14	0.32	<0.04	0.20	2.1	0.03	0.07
Large Juveniles	128	2.1	<0.12	11	<1.10	2.6	<0.19	0.88	6.9	0.15	0.24
	±16.7	±0.68		± 2.3		±2.8		±1.3	±10.0	±0.16	±0.31
Wet wt. $\bar{x}$ =	31.4	0.52	<0.03	2.7	<0.27	0.64	0.05	0.22	1.7	0.04	0.06

Table 7. Mean metals concentrations (ppm) found in sculpin from Zinc Creek, as measured by ERCO.

	Metals Concentration (ppm)										
	Zn	Cu	Pb	Mn	Ni	Cr	As	Se	Ag	Cd	Hg
Dry wt. $\bar{x}$ =	118	2.0	<0.11	26	<0.73	0.98	<0.16	0.90	0.06	0.18	0.24
Wet wt. $\bar{x}$ =	29.8	0.5	<0.03	6.5	<0.19	0.25	<0.04	0.23	0.02	0.05	0.06

However, Phillips (1980), in his extensive review of literature concerning the influence of size and growth on whole body metals tissue levels in fish, concluded that the younger or smaller individuals of most fish species exhibited higher concentrations, i.e., levels decreased with size. Mean size of upper Greens Creek Dolly Varden was about 118 mm, while mean size of the anadromous Dolly Varden analyzed was about 500 mm. Thus, the difference in metals content just noted may well be a function of size difference. Of course, anadromous and resident fish would differ physiologically also, and observed differences could well reflect this physiological difference.

Metals concentration data for all three fish species (resident Dolly Varden char, juvenile coho, sculpin) from both Zinc and Greens creeks generally show good agreement. Some specific exceptions are the higher manganese values in sculpin than in the other two species (6.5 ppm vs. 1.37-2.9 ppm) and the lower silver values (0.02 ppm vs. 1.7-2.09 ppm). These differences may reflect different food preferences or physiological mechanisms controlling metals regulation. The similarity in values for fish from the different streams suggests that all species are responding to metals in the same manner (i.e., regulating some but not others), and that the ambient metals levels to which they are exposed are similar.

Some literature values of metals concentrations in several species of salmonids and their tissues are presented in Table 8. Phillips (1980) noted that reported concentrations of metals in different tissues and species of fish could be affected by sampling and analytical methods, season, age, physiological factors, environmental conditions, and ambient metals levels to which the organisms were exposed. For this reason, comparing data from various literature sources may be of questionable value. Data presented in Table 8 are only from salmonids to eliminate the grossest species differences as a factor. Of the data included, those reported by Elliot (1980) for Dolly Varden char and coho salmon from an Alaskan river system are most comparable to the

Table 8. Metals concentrations in various salmonids and their tissues, as reported in the literature.

Species	Reference	Location	Comments	Analytical Technique	Tissue	Basis for Concentration	Metals Concentration (ppm) Zn	Cu	Pb	Mn	Ni	Cr	As	Se	Ag	Cd	Hg
Dolly Varden Char (Salvelinus malma)	Elliot, 1980	Keta and Blossom rivers (Ketchikan, Alaska)	Unpolluted	Atomic absorption spectrophotometry	Whole body less viscera	Wet weight	203.25	2.15	2.33	NA	45.49	3.55	28.91	3.64	NA	8.06	NA
Dolly Varden Char + Coho Salmon	Elliot, 1980	Same as above	Unpolluted	Same as above	Gill	Wet weight	201.82	1.77	0.88	NA	61.18	2.85	2.22	NA	7.20	6.52	NA
Dolly Varden Char + Coho Salmon	Elliot, 1980	Same as above	Unpolluted	Same as above	Liver	Wet weight	92.16	24.80	1.16	NA	114.81	7.32	62.91	NA	6.38	12.00	NA
Brook Trout (Salvelinus fontinalis)	Grizzle, 1980	Buford Dam, Chattahoochee River, Georgia	Hypolimnetic water from a reservoir	Same as above	Liver	Dry weight	174.00	135.00	NA	17.00	NA	NA	NA	NA	NA	1.80	NA
Brown Trout (Salmo trutta)	Grizzle, 1980	Same as above	Same as above	Same as above	Liver	Dry weight	96.00	610.00	NA	27.00	NA	NA	NA	NA	NA	3.40	NA
Rainbow Trout (Salmo gairdneri)	Grizzle, 1980	Same as above	Same as above	Same as above	Liver	Dry weight	113.00	478.00	NA	27.00	NA	NA	NA	NA	NA	1.00	NA
Lake Trout (Salvelinus namaycush)	Lucas, et al. 1970	Lake Superior	Highly industrialized area	Activation analysis	Liver	Dry weight	48.00	28.00	NA	NA	NA	NA	0.080	NA	NA	$\leq$3.00	NA
Lake Trout (Salvelinus namaycush)	Lucas, et al. 1970	Lake Michigan	Same as above	Same as above	Liver	Dry weight	NA	21.00	NA	NA	NA	NA	0.080	NA	NA	0.06	NA

present work. These values can be contrasted to those reported here for upper Greens Creek Dolly Varden char (Table 4). For gill tissue, Greens creek values for all metals are much lower (in general by a factor of 10) than values reported by Elliot. Liver values from Greens Creek are similarly lower. Whole body values for Greens Creek fish are also much lower than Elliot's values, often by more than an order of magnitude.

Greens Creek liver values are substantially different from liver values for salmonids from other geographical areas (Table 8): zinc values in Greens Creek fish are distinctly higher. Of course, the differences in liver metal values between water bodies is evident in the two sets of data presented in Table 8 -- Great Lakes fish have very low levels of all metals. These differences illustrate the limitations on making comparisons. Conclusions must, at best, be broad generalizations. Comparisons are also complicated by the great impact which analytical methods and technique have on results reported. This widely acknowledged weakness of tissue metals burden data makes description of analytical and quality control methods an important part of any report of findings.

Table 9 presents literature data on metals level in other species of fish of Order Salmoniformes. These values are useful primarily for placing Greens Creek values in perspective, given all the factors which might influence such values. Greens Creek values fit generally into the range of values presented and do not appear unusually high. There does appear to be a tendency, however, for fish from lakes (particularly the Great Lakes) to have lower values than stream or river fish.

Phillips (1980) discussed the manner in which different metals are handled physiologically by fish. Some metals appear to be well regulated, including copper and zinc. If ambient concentrations of copper in water do not exceed 27 to 40 μg/l, complete regulation is the rule. Since, as indicated in Table 3, copper levels in Greens Creek waters are well below 10 μg/l, complete regulation is probable. However, since fish tissues have

Table 9. Literature values of metals concentrations found in tissues of various species of fish of Order Salmoniformes taken from both polluted and unpolluted waters; values are generally averages or medians; sources of data are indicated; NA indicates analysis was not made for that metal.

Species	Reference	Location	Comments	Analytical Technique	Tissue	Basis for Concentration	Metals Concentration (ppm)										
							Zn	Cu	Pb	Mn	Ni	Cr	As	Se	Ag	Cd	Hg
Lake Whitefish (Coregonus clupeaformis)	Othe and Blegh, 1971	Moose Lake (Canada)	Non-industrial area	Perkin-Elmer atomic absorption methodology (Pb, Ni, Cd, Cu, Zn). AOAC method for As	Whole body less head and viscera	Wet weight	14.0	0.50	<0.5	0.69	<0.2	<0.033	0.09	0.24	NA	<0.05	0.07
Northern Pike (Esoxulocius)	Othe and Blegh, 1971	Moose Lake (Canada)	Non-industrial area	Same as above	Whole body less head and viscera	Wet weight	19.0	0.70	<0.5	2.98	<0.2	<0.035	<0.05	0.17	NA	<0.05	0.11
Lake Whitefish	Othe and Blegh, 1971	Lake Ontario (Canada)	Highly industrialized area	Same as above	Whole body less head and viscera	Wet weight	12.0	0.94	<0.5	0.66	<0.2	<0.017	0.70	0.38	NA	<0.05	0.17
Northern Pike	Othe and Blegh, 1971	Lake St. Pierre (Canada)	Same as above	Same as above	Whole body less head and viscera	Wet weight	19.0	0.89	<0.5	3.16	<0.2	<0.026	0.09	0.37	NA	<0.05	0.70
Northern Pike	Othe and Blegh, 1971	Lake Erie (Canada)	Same as above	Same as above	Whole body less head and viscera	Wet weight	11.0	0.70	<0.5	0.93	<0.2	<0.031	<0.05	0.19	NA	<0.05	0.49
Rainbow Smelt (Osmerus mordax)	Othe and Blegh, 1971	Same as above	Same as above	Same as above	Whole body less head and viscera	Wet weight	20.0	0.78	<0.5	0.02	<0.2	0.034	0.15	0.22	NA	0.06	0.05

Table 9. Continued

Species	Reference	Location	Comments	Analytical Technique	Tissue	Basis for Concentration	Metals Concentration (ppm)										
							Zn	Cu	Pb	Mn	Ni	Cr	As	Se	Ag	Cd	Hg
Lake Whitefish	Lucas et al, 1970	Lake Superior	Highly industrialized area	Activation analysis	Liver	Dry weight	23.0	2.40	NA	NA	NA	NA	0.006	NA	NA	0.30	NA
Lake Whitefish	Lucas et al., 1970	Lake Michigan	Same as above	Same as above	Liver	Dry weight	NA	8.50	NA	NA	NA	NA	0.021	NA	NA	0.09	NA
Bloater (Coregonus hoyi)	Lucas et al, 1970	Lake Superior	Same as above	Same as above	Liver	Dry weight	44.0	2.40	NA	NA	NA	NA	0.063	NA	NA	0.70	NA
Bloater (Coregonus hoyi)	Lucas et al, 1970	Lake Michigan	Same as above	Same as above	Liver	Dry weight	NA	7.40	NA	NA	NA	NA	0.012	NA	NA	0.40	NA
Round Whitefish (Prosopium cylindraceum)	Lucas et al, 1970	Lake Superior	Same as above	Same as above	Liver	Dry weight	11.0	3.80	NA	NA	NA	NA	0.006	NA	NA	0.40	NA
Chain Pickerel (Esox niger)	Wiener and Giesy, 1978	Skinface Pond (Jackson, S. Carolina)	Highly organic softwater pond	Atomic absorption spectrophotometry	Whole body	Dry weight	209.0	1.60	0.3	14.60	NA	NA	NA	NA	NA	NA	NA
Same as above	Wiener and Giesy, 1978	Same as above	Same as above	Same as above	Axial muscle	Dry weight	14.7	0.29	NA	1.21	NA	NA	NA	NA	NA	NA	NA
Same as above	Wiener and Giesy, 1978	Same as above	Same as above	Same as above	Liver	Dry weight	337.9	27.80	NA	1.77	NA	NA	NA	NA	NA	NA	NA
Redfin Pickerel (Esox americanus americanus)	Wiener and Giesy, 1978	Same as above	Same as above	Same as above	Whole body	Dry weight	216.0	2.77	1.1	19.30	NA	NA	NA	NA	NA	NA	NA

·arying capabilities for regulation (e.g., muscle tissue has a higher regulating capability than liver), some will accumulate metals. For this reason, metals values in liver tend to be the highest among all tissues (Table 4).

Cadmium and lead are examples of metals which are partially regulated, depending on tissue type (Phillips, 1980). For these metals, uptake is dose dependent. The low lead and cadmium values found in Greens Creek char (Table 4) indicate that these fish have not been exposed to high ambient levels, which is, of course, evident from the water quality data presented in Table 3.

Chromium is a metal which does not appear to be regulated well by any fish tissue (Phillips, 1980). Thus, tissue concentrations should reflect the concentrations to which the fish have been exposed. The low chromium levels found in Greens Creek fish (Table 3) confirm the accuracy of the low ambient levels reported for water quality and vice versa.

In summary, the metals concentrations found in fish tissues in the present work do not appear unusually high in comparison to literature information. They also suggest that resident fish in Greens and Zinc creeks have not been exposed to abnormally high ambient metals levels. This finding, in turn, suggests that resident organisms are not carrying tissue metals burdens approaching lethal or biologically adverse levels.

C. MARINE INVERTEBRATES

Metal concentrations in tissues of polychaetes and mussels collected near the mouth of Greens Creek are presented in Table 10. Raw data are presented in Tables D-17 and D-18 in Appendix D. Concentrations of zinc, selenium, silver, and arsenic shown in the table are higher in polychaetes than in mussels. Values of manganese, chromium, cadmium, and mercury are higher in mussels.

Metals levels in marine invertebrates have been studied in great detail by researchers around the world. As with fish, the observed levels are influenced by a wide range of factors

Table 10. Mean metals concentrations in marine invertebrates from Greens Creek delta, as measured by ERCO.

	Metals Concentrations in Dry Material (ppm)										
	Zn	Cu	Pb	Mn	Ni	Cr	As	Se	Ag	Cd	Hg
Polychaetes	200	12	0.69	11	2.9	3.6	3.5	1.1	5.3	0.70	<0.01
	±37	± 2.7	±0.22	± 3.6	±0.81	±1.3	±1.0	±0.81	±4.4	±0.57	
Wet wt. $\bar{x}$ =	25	1.5	0.09	1.38	0.36	0.45	0.44	0.14	0.66	0.09	<0.01
Mussels	132	8.1	0.80	27	3.0	5.9	1.3	0.68	3.1	6.3	0.46
	±16.7	±0.76	±0.67	±10	±0.51	±5.0	±0.60	±0.38	±4.0	±0.83	±0.35
Wet wt. $\bar{x}$ =	14.0	0.86	0.01	2.9	0.32	0.62	0.14	0.07	0.33	0.67	0.05

(Phillips, 1980). Polychaete worms are known to regulate zinc with high efficiency but to regulate cadmium rather poorly (Bryan and Hummerstone, 1971). Yet, for both metals, levels within organisms were found to be affected by size, season, and salinity, as well as by levels in the environment. These findings suggest that comparisons among polychaete data determined in the present work and those reported in the literature would not be meaningful.

Metals uptake in shellfish molluscs, particularly the mussel, has been studied intensively. Phillips (1980) reported that metals concentrations in molluscs tended to follow levels in their environment more so than in the case of other taxonomic groups, making them excellent indicators of metals pollution. Numerous other factors (e.g., size, season, etc.) also affect organism levels, but to a lesser degree. Thus, comparisons of Hawk Inlet data with literature values appear of value. Table 11 presents metals concentration data for mussels from Hawk Inlet, British Columbia, Ireland, and New Zealand. Silver appears to be the only metal for which Hawk Inlet values are not comparable to one of the other data sets. Hawk Inlet values for zinc, copper, and lead are the same as for British Columbia mussels from unpolluted waters, suggesting low ambient metals levels in marine waters near the Greens Creek delta. These data also suggest that the mussel may be a good baseline indicator species for detecting increases in ambient metals levels.

Table 11. Metals concentrations in the mussel, Mytilus edulis, from four locations reported in the literature and from Hawk Inlet

Location and Source	Metals Concentrations of Dry Material (ppm)										
	Zn	Cu	Pb	Mn	Ni	Cr	As	Se	Ag	Cd	Hg
Unpolluted estuary, New Zealand (Brooks and Rumsby., 1965)	91	9	12	27	7	16	--	--	0.1	<10	--
Unpolluted estuary, Ireland (Segan et al., 1971)	132	9.6	9.1	3.5	3.7	1.5	--	--	0.03	5.1	--
Hawk Inlet (1980)	132	8.1	0.8	27	3.0	5.9	1.3	0.68	3.1	6.3	0.46
British Columbia, ambient (Popham et al., 1980)	150-220	12-15	<10								
British Columbia, polluted	270-670	13-44	25-465								

V. BACKGROUND DISCUSSION OF METALS POLLUTION AND TISSUE BURDENS

A review of information on metals pollution is necessary to provide an appropriate background for the interpretation of study results. Environmental regulations dealing with toxic substances in aquatic systems generally address the concentrations of these substances allowed in the water itself. Allowable concentrations are usually based on known effects on human health or levels found from laboratory studies to be acutely toxic to aquatic organisms. The most widely used measure from such studies is the 96-hr TLm: the concentration of the substance which results in the death of 50 percent of the test organisms within 96 hours. Allowable concentrations for regulatory purposes are set at a conservative fraction of an established TLm value (e.g., one tenth).

The type of data collected in this study deals with the levels of metals found in tissues of organisms. Such metals may originally have been in solution in the water, in particulate form suspended in the water, or in organisms consumed by the organism being studied. However, no direct relationship can be established between TLm concentrations for a metal and the tissue levels that a healthy organism can sustain in the field. As noted, TLm values indicate acutely lethal levels that overwhelm the organism's physiological regulatory processes for the toxicant; tissue concentrations, on the other hand, reflect the time-integration capacity of a particular species for sublethal levels of a compound. Since regulating capacity varies among tissues within an organism, among different types of organisms, and according to metal type (Phillips, 1980), concentrations of different metals will differ among tissues and species of organisms taken from the same location and environment. For this reason, tissue metals levels cannot be and are not used for regulatory purposes except in the case of tissue consumable by man.

What then do tissue metals levels indicate about the environment from which the organism was taken? If the environment is unperturbed (as is Greens Creek), metals levels found in any tissue or organism type reflect the equilibrium between metals uptake from water and/or food and physiological regulation and depuration by the organism. For many metals and organisms or tissues, this equilibrium level will remain relatively constant even if the organism is exposed to a wide range of metals concentrations (Phillips, 1980). However, it will be affected by oxidation state of the metal, temperature, and other environmental and physiological variables.

Above some "threshold" exposure level, however, the capability of physiological mechanisms for control is exceeded, and morbidity results. The factors influencing the regulatory mechanisms include, for example, water hardness, presence of other metals or pollutants, season of the year, and diet. For this reason, the significance of levels of metals found in a particular organism or tissue is difficult to interpret and difficult to relate to ambient conditions. Some conclusions on environmental perturbations can be drawn from a comparison of levels found in tissues or organisms from a particular location with those from a similar environment. Although not rigorous, this type of analysis can indicate gross abnormalities and a possible range of causes.

The comparison of Greens Creek data to literature data suggest the absence of gross abnormalities in tissue metals levels. Thus, the data do not support the contention that organisms inhabiting this area may have a particular sensitivity to metals pollution, which contention has been raised in discussions of possible impacts of the development of a mine in the Greens Creek drainage. The data do, however, provide a good baseline for use in monitoring of the potential impact of mine development as it proceeds.

VI. OVERVIEW

The major findings of this study are:

- Resident fish (juvenile coho, sculpin, Dolly Varden char) in Zinc and Greens creeks have, in general, similar, but not abnormally high, tissue metals concentrations.
- Freshwater invertebrates exhibit much higher metals levels than do fish; however, values are not abnormally high relative to literature values.
- Metals levels in mussels from marine waters near Greens Creek appear comparable to levels in mussels in other unpolluted marine waters.
- Metals concentrations in tissues of freshwater fish and invertebrates suggest that these organisms have not been exposed to and are not adapted to high ambient metal levels.

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