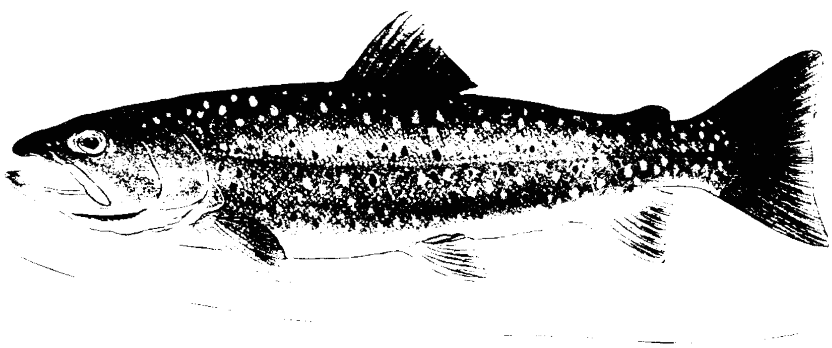
FISH MONITORING STUDY, RED DOG MINE IN THE WULIK RIVER DRAINAGE, EMPHASIS ON DOLLY VARDEN (*SALVELINUS MALMA*), SUMMARY REPORT 1990-1993

By

Alvin G. Ott and Phyllis Weber Scannell

Technical Report 94-1



Alaska Department of Fish and Game

Habitat and Restoration Division

June 1994

Alaska Department of Fish and Game

Habitat and Restoration Division
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MISSION STATEMENT

Our role is to maintain or enhance valued fish and wildlife resources and habitats to the extent possible as Alaska grows and develops its other resources.

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We thank Cominco Alaska Inc. for their logistical and financial support for the fish monitoring study since 1991. Without their assistance the fish study would not have been possible. Mr. Ralph Hargrave (President, Cominco Alaska Inc.) and Ms. Charlotte MacCay (Manager, Environmental Affairs, Cominco Alaska Inc.) continued to be very supportive of our work.

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INTRODUCTION

The Red Dog Mine operated by Cominco Alaska Inc. is located in northwestern Alaska near the headwaters of Red Dog Creek in the Wulik River drainage (Figure 1). Major facilities include a tailings impoundment, freshwater reservoir, airstrip, mill, living quarters, and a solid waste site (Figure 2). Background information on mine operations, streams, fisheries resources, and water quality conditions in Red Dog and Ikalukrok Creeks, between 1988 and 1991, were summarized by Ott et al. (1992). Data on fish use of streams, heavy metals concentrations in selected Dolly Varden tissues, the number of Dolly Varden overwintering in the Wulik River, and water quality collected and/or analyzed in 1992 were reported by Ott and Weber Scannell (1993).

Acidic metal-laden surface and subsurface waters emerging from the ore body that were a major source of heavy metals contamination to Red Dog Creek in 1989 and 1990 were successfully controlled from summer 1991 to the present. Discoloration of receiving waters was documented in fall 1989 and summer 1990 (Figure 3). Orange, green, and white colored water was observed throughout Ikalukrok Creek below the confluence with Red Dog Creek and as far downstream as the Wulik River. A clean water bypass and mine seepage water pumpback system were installed in early 1991 prior to breakup and waters in Ikalukrok Creek were clear in summers 1991, 1992, and 1993 (Figure 4). The clean water ditch bypasses uncontaminated water through a lined channel past the ore body while the mine seepage channel collects both surface and subsurface flow from the ore body. Water high in heavy metals is directed toward a sump where it is then pumped to the tailings impoundment and treated before release to Red Dog Creek. A

FIGURE 1. Map of the Red Dog Mine located in northwestern Alaska

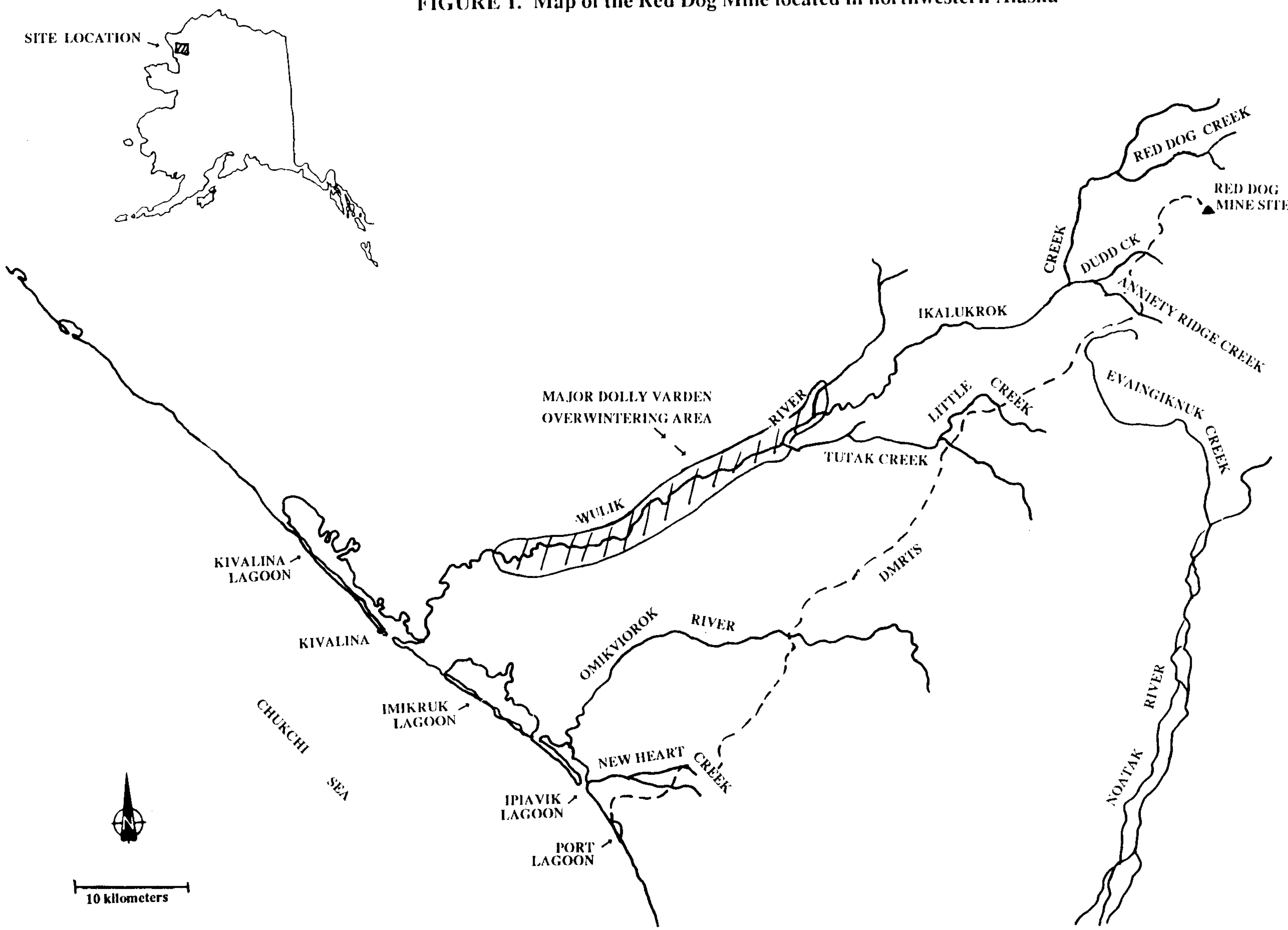
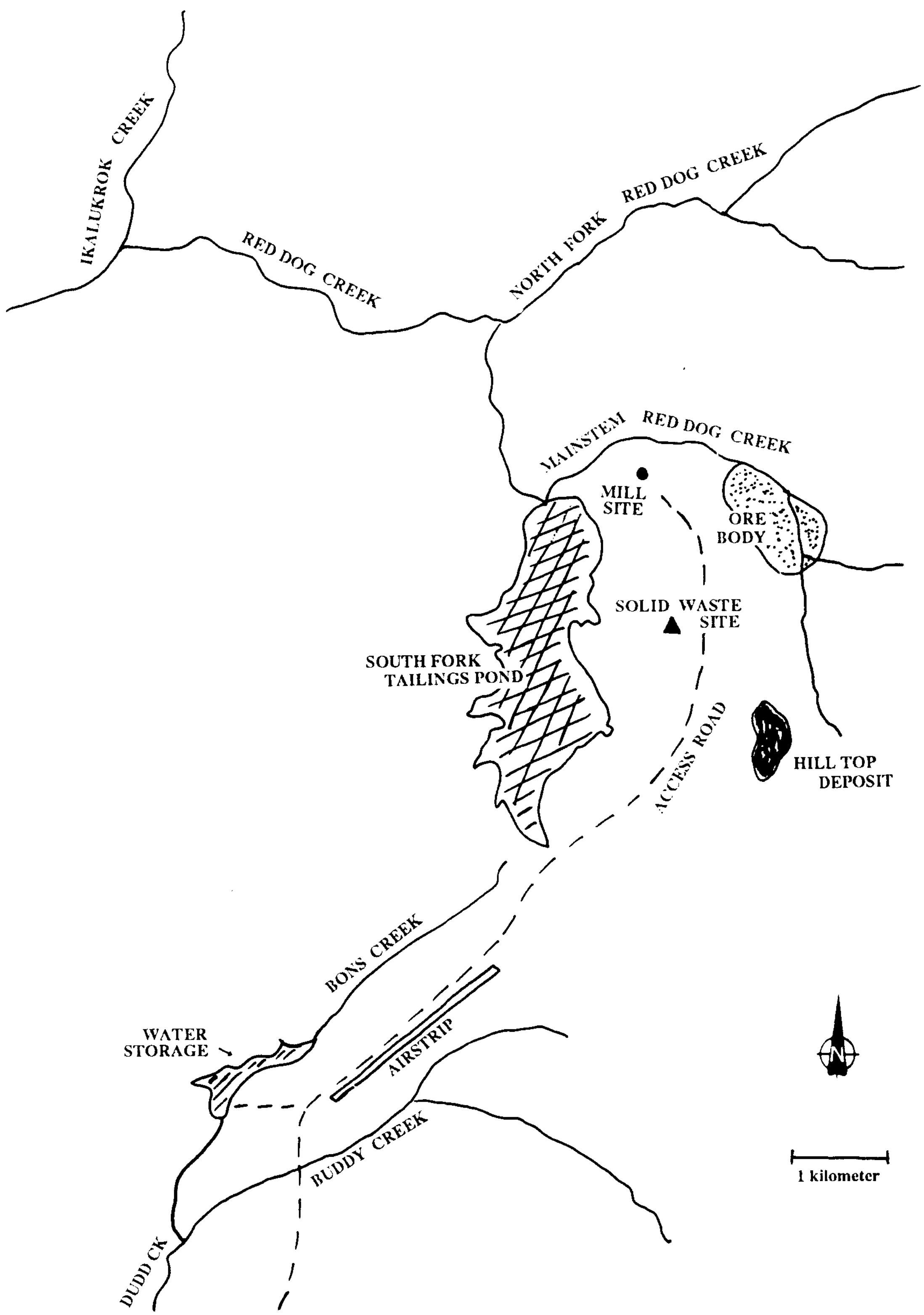


FIGURE 2. Major facilities, including the mill, airstrip, tailings impoundment, solid waste site, and freshwater impoundment at the Red Dog Mine.



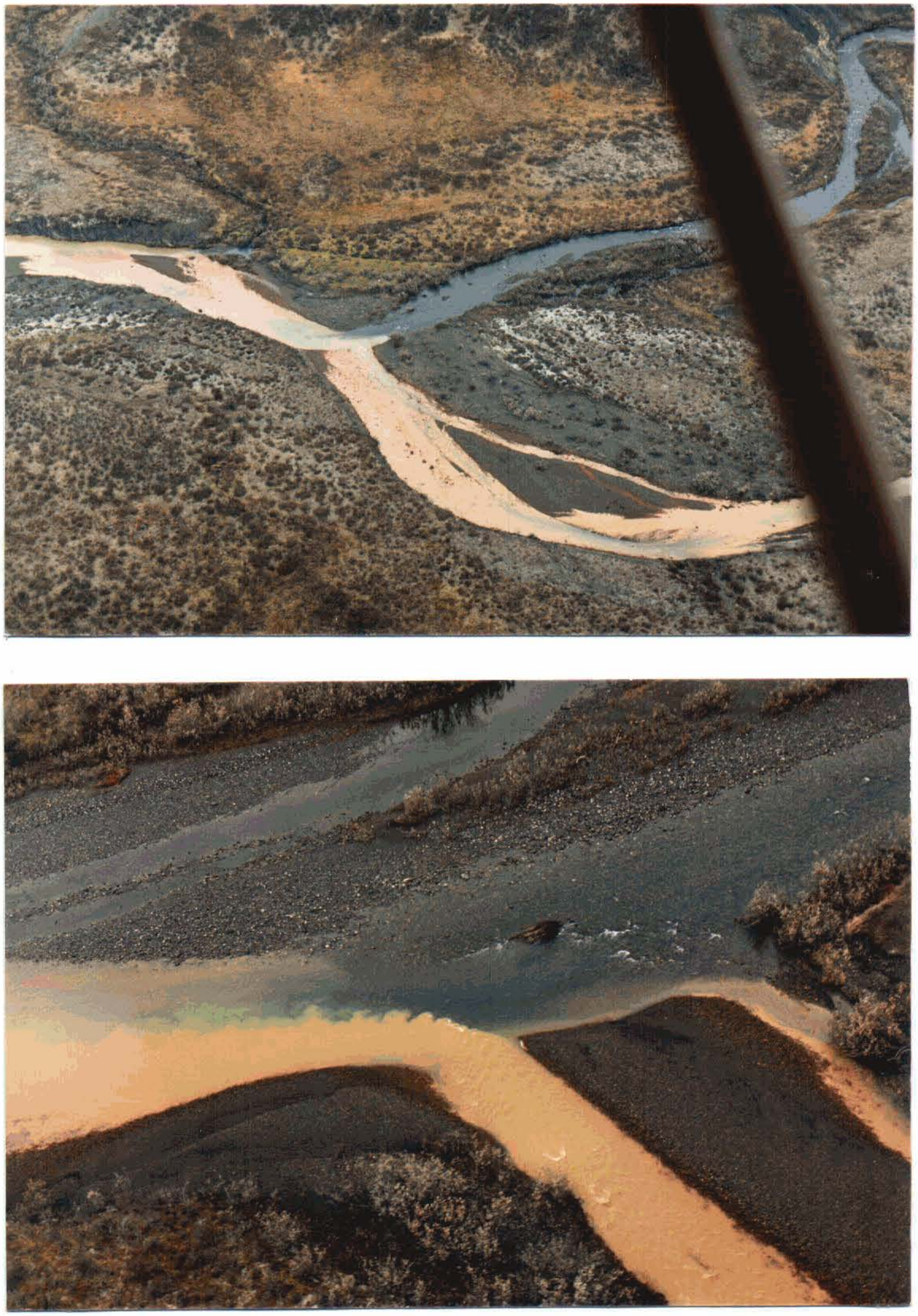


Figure 3. Confluence of Red Dog (orange-colored water) and North Fork of Red Dog Creeks (clear water) on October 4, 1989 (top photo). Confluence of Red Dog (orange-colored water) and Ikalukrok Creeks (clear water) on October 4, 1989 (bottom photo).

Figure 4. Rock-lined clean-water bypass ditch on right, road in middle, and dirty-water collection trench on left (top photo - July 1992). Clear water is documented at the confluence of Red Dog and Ikalukrok Creeks in July 1992 (bottom photo).

description of the clean water bypass system was presented by Ott and Weber Scannell (1993).

In 1990, concentrations of Zn were as high as 1510 mg/L in Red Dog Creek below the mine effluent (Station 21) and 76 mg/L in Ikalukrok Creek (Station 8) below its confluence with Red Dog Creek (Ott and Weber Scannell 1993). Concentrations of Zn at Station 20 (located in mainstem Red Dog Creek immediately upstream of its confluence with the North Fork of Red Dog Creek) reached maximum levels of 32.40, 18.7, and 3.83 mg/L during the ice-free season in 1991, 1992, and 1993, respectively (Table 1). The median, maximum, and minimum concentrations for aluminum (Al), cadmium (Cd), copper (Cu), and lead (Pb) also decreased or remained nearly the same from 1991 through 1993 (Table 1). The median concentration of Zn at Station 8 during the ice-free season was 3.1 mg/L in 1989, 18.15 in 1990, 1.62 in 1991, 0.865 in 1992, and 0.203 in 1993 (Table 2). Zinc concentrations have steadily decreased in Ikalukrok Creek since completion of the clean water bypass system in March/April 1991. Overall, water quality improved from 1991 through 1993 at Stations 20 and 8.

In summer 1993, the third and final lift on the tailings dam was constructed to contain water in the tailings impoundment. Water accumulated in the tailings impoundment more rapidly than anticipated due to the following factors: (1) construction of the dirty water ditch and transfer of these waters to the tailings impoundment; (2) greater rainfall/snowmelt than predicted; and (3) intermittent operation of the wastewater treatment facility during the first four years of mine operation. Discharge of water from the water treatment plant was intermittent due to operational problems (e.g., loss of the seed stock in the clarifier), metals concentrations in the effluent that exceeded permit limits, periodic spikes in cyanide at downstream sample stations and in the effluent, high total dissolved

Table 1. Median, maximum, and minimum concentrations of Al, Cd, Cu, Pb, and Zn in Red Dog Creek below the mine discharge (Station 20) during the ice-free season (June 1 through October 15). No data are available for Cu concentrations in 1993.

Year		Al mg/L	Cd mg/L	Cu mg/L	Pb mg/L	Zn mg/L
1991	median	<0.05	0.13	<0.01	0.161	21.75
	maximum	0.48	0.19	<0.01	0.295	32.40
	minimum	<0.05	0.06	<0.01	0.044	8.28
	count	12	12	12	12	12
1992	median	<0.05	0.045	<0.01	0.0405	6.38
	maximum	0.226	0.147	0.012	0.23	18.7
	minimum	<0.05	0.013	<0.01	0.015	1.6
	count	30	30	30	30	30
1993	median	<0.05	0.026		0.049	3.29
	maximum	0.38	0.032		0.348	3.83
	minimum	<0.05	0.013		0.016	1.64
	count	17	17		17	17

Table 2. Median, maximum, and minimum concentrations of Al, Cd, Cu, Pb, and Zn in Ikalukrok Creek (Station 8) during the ice-free season (June 1 through October 15). Data for 1993 were collected at Station 73 on Ikalukrok Creek (about five miles downstream of Station 8). No data are available for Cu concentrations in 1993.

Year		Al mg/L	Cd mg/L	Cu mg/L	Pb mg/L	Zn mg/L
1989	median	0.30	0.02	<0.01	0.037	3.10
	maximum	3.86	0.10	0.05	0.110	10.00
	minimum	0.16	<0.01	<0.01	0.018	0.94
	count	16	17	16	17	17
1990	median	0.67	0.080	<0.01	0.070	18.15
	maximum	1.80	0.410	0.03	0.340	76.00
	minimum	0.10	0.040	<0.01	<0.02	5.46
	count	24	26	14	23	28
1991	median	<0.05	0.012	<0.01	0.008	1.62
	maximum	<0.05	0.040	<0.01	0.023	3.61
	minimum	<0.05	0.007	<0.01	<0.001	1.07
	count	12	12	12	12	12
1992	median	<0.05	0.007	<0.01	<0.002	0.865
	maximum	0.73	0.024	<0.01	0.094	3.120
	minimum	<0.05	<0.003	<0.01	<0.002	0.305
	count	28	28	28	28	28
1993	median	<0.05	<0.003		<0.002	0.203
	maximum	0.28	<0.003		0.009	0.389
	minimum	<0.05	<0.003		<0.002	0.143
	count	17	17		17	17

solids (primarily $CaSO_4$), the requirement by the state to freeze waters discharged during the winter months, and the addition of mine seepage water high in metals and total dissolved solids.

In November 1990, Cominco Alaska Inc. requested an amendment to the NPDES permit to allow a year-round discharge from the water treatment plant to decrease the water level in the tailings impoundment. In the interim, winter discharges were authorized by the Alaska Department of Environmental Conservation with limits placed on the effluent (e.g., metals, cyanide) and the requirement to ensure that winter discharge waters did not reach Ikalukrok Creek in the vicinity of Dudd Creek. Reasons for ensuring discharge waters from the mine did not reach lower Ikalukrok Creek included the following: (1) Dolly Varden and chum salmon spawn in lower Ikalukrok Creek; (2) some fish probably overwinter in lower Ikalukrok Creek; and (3) over 90 percent of the Dolly Varden in the Wulik River drainage overwinter in the Wulik River downstream of Ikalukrok Creek. The entire winter discharge in the Wulik River below Ikalukrok Creek has been documented at less than 0.5 cubic meters per second (m^3/s) [(15 cubic feet per second (cfs)] (Lamke et al. 1990); therefore, the potential effects of waters from the Red Dog Mine wastewater treatment plant [(0.175 to 0.28 m^3/s (5 to 8 cfs)] could have considerable effects on fisheries resources if an upset occurred and these waters reached lower Ikalukrok Creek and the Wulik River.

Occasional elevated concentrations of Zn in the effluent were believed to be related to minute particles of flocculated metal hydroxides not precipitated in the clarifier. A sand filter was designed and constructed to remove particulate metal hydroxides. The sand filter became operational in January 1994.

The high concentrations of total dissolved solids and sulfate in the effluent result from mine seepage water, the unplanned inability to remove and dispose of sludge from the clarifier, and from recycling of the treated discharge. Cominco Alaska Inc. continues to work on a solution to the disposal of sludge but in the interim has requested a mixing zone in receiving waters for total dissolved solids and sulfate. Baseline data for total dissolved solids and sulfate are minimal as sampling for these components was initiated in 1991 when the problem was first identified (Table 3). Total dissolved solids in the effluent have reached 2,230 mg/L (Table 3) and are projected to rise to no more than 4,000 mg/L. If a sludge disposal program is developed and implemented and treated water is discharged (i.e., not recycled), Cominco Alaska Inc. anticipates that total dissolved solids will decrease with time.

Cyanide levels in the wastewater treatment plant discharge are detected occasionally. High concentrations of cyanide also are detected intermittently during the winter season in lower Red Dog Creek. Cyanide measurements at sample points don't always correlate with cyanide concentrations in the effluent or with dilution gradients downstream. Sources of elevated cyanide are unknown but it is possible that interfering agents are being measured as cyanide. Currently, there is no treatment for cyanide in the wastewater treatment process.

Fisheries investigations in waters affected by the Red Dog Mine were initiated in 1990 due to observed water quality degradation in Ikalukrok Creek. The three-year fisheries investigation which started in 1991 was designed to monitor and evaluate project impacts to fisheries resources. The study was funded by Cominco Alaska Inc. Results of work conducted in 1990 and 1991 were reported by Ott et al. (1992) and findings in 1992 were documented by Ott and Weber Scannell (1993). We report herein results from year three of the study, a discussion which

Table 3. Median, maximum, and minimum total dissolved solids, sulfate, and pH at Stations 8 and 20. Station 8 is located in Ikalukrok Creek immediately downstream of the mouth of the mainstem of Red Dog Creek. Station 20 is in mainstem Red Dog Creek immediately upstream of the North Fork of Red Dog Creek. Data were collected during the ice-free season (June 1 through October 15).

Year		Station 8 TDS mg/L	Station 8 Sulfate mg/L	Station 8 pH	Station 20 TDS mg/L	Station 20 Sulfate mg/L	Station 20 pH
1981	median						
	maximum	174					
	minimum	124					
	n	2					
1982	median		62				
	maximum		72			108	
	minimum		36			66	
	n		3			2	
1989	median			7.3			
	maximum			7.9			
	minimum			6.8			
	n			16			
1990	median			7.1			
	maximum			7.8			
	minimum			6.5			
	n			18			
1991	median	271		7.2	598		
	maximum	406		7.5	1310		
	minimum	174		6.8	346		
	n	12		12	12		
1992	median	209		7.47	815		
	maximum	548		8.20	2230		
	minimum	64		6.15	50		
	n	21		28	31		
1993	median	181		7.7	235		
	maximum	229		8.2	961		
	minimum	68		6.7	57		
	n	17		17	17		

summarizes field work conducted from 1990 to 1993, and our recommended work scope for the next five years.

OBJECTIVES

We initiated a three-year study in the Wulik River drainage in 1991 to document whether short-term and long-term changes in fish distribution, species composition, or heavy metal concentrations of select fish tissues would result from changes in water quality at the Red Dog Mine. Objectives of the three-year study including the stated null hypothesis for each objective follow:

Objective 1 - Estimate heavy metal concentrations (Zn, Cu, Pb, Al, and Cd) in gill, liver, muscle, and kidney tissue of adult Dolly Varden (*Salvelinus malma*) taken in the fall and spring from the Wulik River.

> H_0: Heavy metal concentrations in adult Dolly Varden tissues are not substantially different from baseline concentrations measured in 1982 and 1983.

Objective 2 - Count and assess distribution of overwintering adult Dolly Varden in late September/early October using aerial surveys of the Wulik River from the mouth to approximately five river miles upstream of the confluence of the Wulik River and Ikalukrok Creek.

> H_0: Ninety percent of overwintering adult Dolly Varden continue to use the Wulik River downstream of the mouth of Ikalukrok Creek and abundance is not substantially different from prior year estimates.

Objective 3 - Count and assess distribution of adult chum salmon (*Oncorhynchus keta*) during mid-August in Ikalukrok Creek using aerial surveys from the mouth of Ikalukrok Creek to Dudd Creek.

H_0: Chum salmon continue to spawn in the lower 24 km of Ikalukrok Creek in numbers comparable to numbers reported by Dames and Moore and the ADF&G in baseline data.

Objective 4 - Measure relative abundance (catch) and seasonal use patterns of juvenile Dolly Varden during the ice-free season in Ikalukrok, Dudd, Anxiety Ridge, Evaingiknuk, and Little Creeks.

H_0: Relative abundance (catch) and seasonal use patterns of juvenile Dolly Varden are not substantially different in Ikalukrok, Dudd, Anxiety Ridge, Evaingiknuk, and Little Creeks.

Objective 5 - Determine Arctic grayling (*Thymallus arcticus*) use of North Fork of Red Dog Creek.

H_0: Arctic grayling continue to spawn in the North Fork of Red Dog Creek and young-of-the-year Arctic grayling are present.

METHODS

With assistance from Cominco Alaska Inc. and residents of Kivalina, we collected adult Dolly Varden by angling in the Wulik River during 1993. Wulik River Dolly Varden were collected in the lower river during late winter before breakup and in the fall before freezeup. Each Dolly Varden was placed in a clean plastic container which was labeled with the sample date and location. Fish were frozen and shipped to ADF&G in Fairbanks, Alaska. We collected a minimum of six adult fish per sample period. We also collected six juvenile Dolly Varden from Anxiety Ridge Creek and six from the North Fork of Red Dog Creek. Juvenile Dolly Varden were placed directly into pre-cleaned jars (EPA protocol C, Series 300), frozen, transported to Fairbanks, and later shipped directly to a private analytical laboratory for whole body analyses (i.e., entire fish was digested and analyzed, no organs were removed).

We removed the adult Dolly Varden from the freezer and measured and weighed each fish. Tissue samples from muscle (muscle was removed below the dorsal fin and above the lateral line), gill, kidney, and liver were removed from partially thawed fish using standard procedures to minimize contamination (Crawford and Luoma 1993). Tissue was placed in pre-cleaned jars (EPA protocol C, Series 300) and refrozen. We attempted to remove at least 10 g of each tissue. We cleaned each dissection instrument (i.e., tweezers, knives) in ultra-pure nitric acid with a rinse in double-distilled water before we began work on a new tissue. We also recorded sex and removed otiliths from each fish. Tissue and whole body samples were submitted to a private analytical laboratory. Samples were digested, freeze-dried, and analyzed for Al, Cu, Cd, Pb, and Zn using U.S. Environmental Protection Agency standard methods (Table 4).

Table 4. Method and method detection limit used to analyze fish tissues for various metals. All samples were reported as mg/Kg, dry weight basis.

Metal	Method[1]	MRL
Al	200.8	0.2
Cd	200.8	0.02
Cu	200.8	0.05
Pb	200.8	0.02
Zn	200.8	0.5

[1]EPA Method 200.8 - "Methods for Chemical Analysis of Water and Wastes" EPA 600/4-79-020

Results from the analytical laboratory were sent to us and the laboratory provided Quality Assurance/Quality Control information pertinent to each sample set. Statistical analyses of heavy metals data among sample years for adult Dolly Varden were not performed due to a small sample size (n = 5 to 9). We elected to display the median and range for each sample set. We qualitatively compared the 1990, 1991, 1992, and 1993 heavy metal concentrations in adult Dolly Varden with baseline data collected by Dames and Moore (1983). A two-sample T test (Zar 1974) was used to test the hypothesis that lead and cadmium in juvenile Dolly Varden from Anxiety Ridge and the North Fork of Red Dog Creek were equal. The two-sample T test was employed to compare heavy metal concentrations in adult Dolly Varden between the spring (i.e., pre-breakup) and fall (pre-freezeup) sample periods. A two-sample T test also was used to compare adult Dolly Varden samples collected prior to and after construction of the clean water bypass system.

We flew aerial surveys using fixed-wing aircraft in September 1993 in the Wulik River. The September survey covered the Wulik River from its mouth near the village of Kivalina to a point approximately five river miles above its confluence with Ikalukrok Creek. No aerial overflights were made of Ikalukrok Creek in 1993 and therefore an estimate of adult chum salmon was not made. From the Wulik River September flight, we estimated the number of overwintering Dolly Varden in the Wulik River.

We collected juvenile Dolly Varden and other fish species (e.g., Arctic grayling, slimy sculpin) in Ikalukrok, Dudd, Anxiety Ridge, North Fork of Red Dog, Evaingiknuk, and Little Creeks with minnow traps baited with salmon roe contained in perforated plastic containers. We allowed the minnow traps to actively fish for approximately 24 hours for each sample period. Each time traps were checked, fish were identified, measured, and released. In August 1993, six

Dolly Varden juveniles from Anxiety Ridge Creek and six from the North Fork of Red Dog Creek were retained for whole body heavy metals analyses. The 1991 and 1992 established sample areas and fixed minnow trap sites were used in 1993 and 10 minnow trap sites were established and marked on the North Fork of Red Dog Creek. The number of minnow traps per sample area was ten. We reflagged and replaced identification markers on streambank vegetation where needed for the permanent minnow trap fish sites. Number of fish captured, fork length of fish (mm), and time fished were recorded for each minnow trap. Number of fish per trap (catch) was compared among sample areas and times (One-Way Analysis of Variance, $p<0.05$).

We conducted visual stream surveys for Arctic grayling in the North Fork of Red Dog, Red Dog, Dudd, Ikalukrok, and Anxiety Ridge Creeks. Angling was used to collect Arctic grayling in the North Fork of Red Dog Creek.

RESULTS

Dolly Varden Tissue Heavy Metals Concentrations

Since 1990 ADF&G has sampled Dolly Varden from the Wulik River for concentrations of selected metals (Ott et al. 1992, Ott and Weber Scannell 1993) (Table 5). Metal concentrations in muscle, liver, gill, and kidney were compared to pre-mining concentrations reported by Dames and Moore (1983). Metals concentrations expressed in mg/Kg dry weight in the liver, gill, muscle, and kidney of adult Dolly Varden are presented in Appendix 1 and quality control/quality assurance data are presented in Appendix 2.

The concentrations of Zn, Cu, Al, Pb, and Cd in adult Dolly Varden tissues collected in 1993 do not appear to be substantially different from pre-mining fish samples collected in 1982 and 1983. A summary of our results follows:

(1) Zinc concentrations in the gill, kidney, liver, and muscle of Dolly Varden in 1993 were similar to those reported by Dames and Moore (1983), (Figure 5).

(2) Copper concentrations in the kidney, liver, and muscle of Dolly Varden in 1993 were similar to those reported by Dames and Moore (1983). The highest copper concentrations occurred in the liver. One of the Dolly Varden collected in October 1993 had elevated copper in gill tissue (Figure 6).

(3) Aluminum was highly variable in the gills of Dolly Varden and several fish collected in October 1993 contained elevated aluminum in the gill tissue. Concentrations of aluminum in kidney, liver, and muscle in 1993 were similar to and slightly lower than baseline concentrations (Figure 7).

Table 5. Fish samples tested for concentrations of selected metals by Dames and Moore and ADF&G, 1982 to 1993. All fish collected since 1990 were dissected by ADF&G and analyzed by a private analytical laboratory according to the methods listed in Table 3.

Date Collected	Site	No. of Fish	Collector
1982	Wulik River	Varies with tissue	Dames and Moore
[1]October 1990	Wulik River	6	ADF&G
[2]April 1991	Wulik River	4	Cominco
[2]April 1991	Wulik River	5	Kivalina
[3]April 1991	Noatak River	5	ADF&G
[4]June 1991	Wulik River	8	Cominco
[5]October 1991	Wulik River	6	Cominco and ADF&G
[6]April 1992	Wulik River	8	Cominco and ADF&G
[7]September 1992	Wulik River	6	ADF&G
[8]April 1993	Wulik River	6	Cominco and ADF&G
[9]October 1993	Wulik River	6	ADF&G

[1]Sample Group A - Six adult Dolly Varden collected from the Wulik River (downstream of the mouth of Ikalukrok Creek) by Fred DeCicco (ADF&G) on October 3, 1990, prior to freezeup.

[2]Sample Group B - Nine adult Dolly Varden collected from the Wulik River (three by Cominco Alaska Inc. on 3/9/91, five by Kivalina on 4/6/91, one by Cominco Alaska Inc. on 4/26/91) between Driver's Camp (Station 2) and Umiivaq (lower Wulik River) during late winter prior to breakup.

[3]Sample Group C - Five adult Dolly Varden collected from the Noatak River by local residents during winter 1990/1991. Date and exact location in the Noatak River are unknown.

[4]Sample Group D - Eight adult Dolly Varden collected from the Wulik River (lower Wulik River immediately upstream of Kivalina) by Cominco Alaska Inc. and local residents from Kivalina on June 16, 1991, immediately following breakup.

[5]Sample Group E - Six adult Dolly Varden collected from the Wulik River (Station 2) by Matt Robus (ADF&G) and Hank Brown and John Martinesko (Cominco Alaska Inc.) on October 5, 1991, prior to freezeup.

[6]Sample Group F - Eight adult Dolly Varden collected from the Wulik River (about five miles upstream of Kivalina) between April 28 and 30, 1992, by Al Townsend (ADF&G) and Hank Brown (Cominco Alaska Inc.) during late winter prior to breakup.

Table 5 (Concluded)

[7]Sample Group G - Six adult Dolly Varden collected from the Wulik River (Station 2) by Al Townsend (ADF&G) on September 29, 1992, prior to freezeup.

[8]Sample Group H - Six adult Dolly Varden collected from the Wulik River (about five miles upstream of Kivalina) between April 19 and 23 by 1993, by Al Townsend (ADF&G) and Jake Wells (Cominco Alaska Inc.) during late winter prior to breakup.

[9]Sample Group I - Six adult Dolly Varden collected from the Wulik River (Station 2) by Al Townsend (ADF&G) on October 20, 1993, prior to freezeup.

Figure 5. Median, maximum, and minimum concentration of zinc (mg/Kg dry weight) in adult Dolly Varden tissues (gill, kidney, liver, and muscle) collected in the Wulik River in 1982, 1990, 1991, 1992, and 1993. Median values for 1982 fish were not available; 1982 data are expressed as mean concentration.

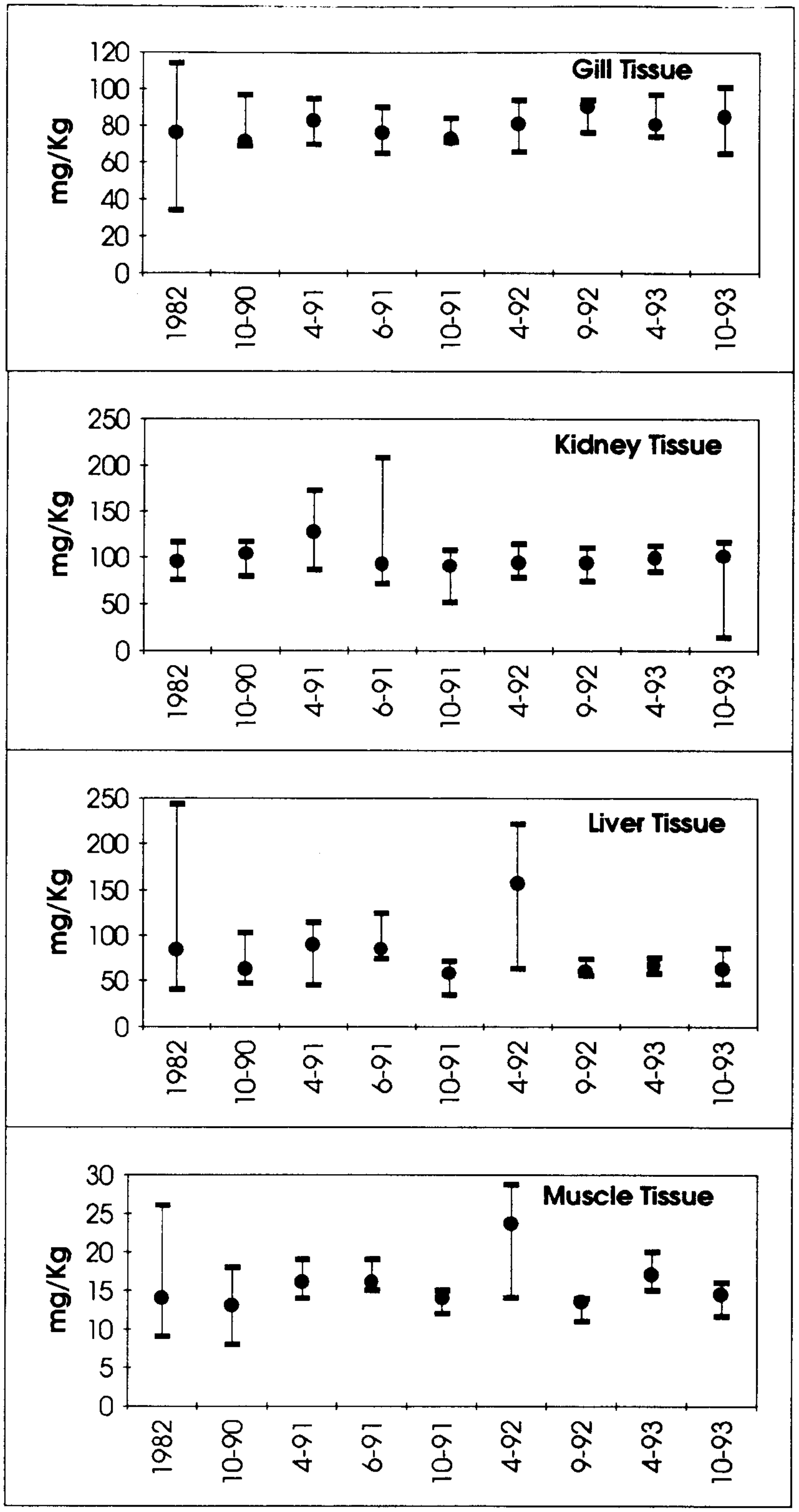


Figure 6. Median, maximum, and minimum concentration of copper (mg/Kg dry weight) in adult Dolly Varden tissues (gill, kidney, liver, and muscle) collected in the Wulik River in 1982, 1990, 1991, 1992, and 1993. Median values for 1982 fish were not available; 1982 data are expressed as mean concentration.

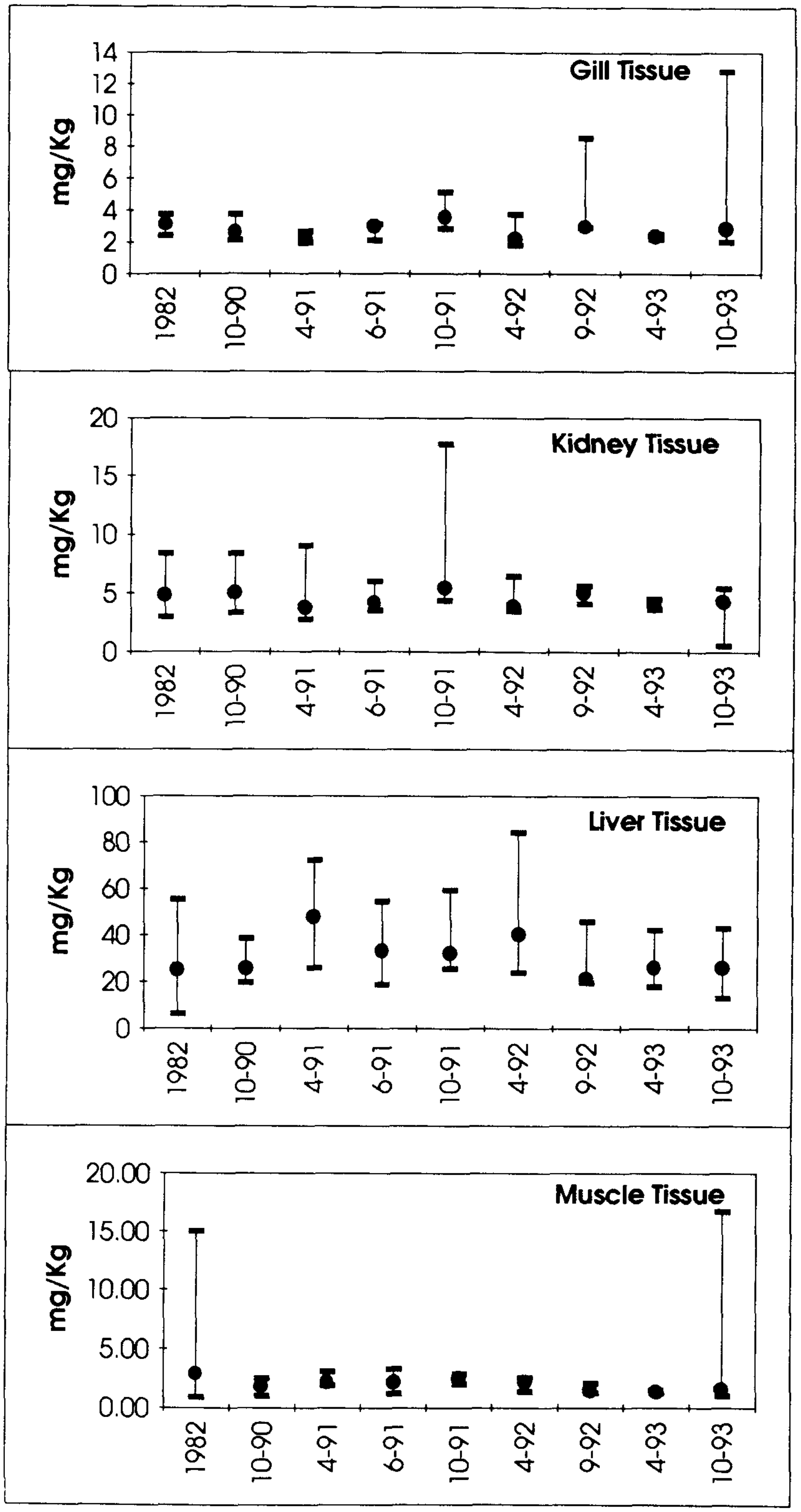
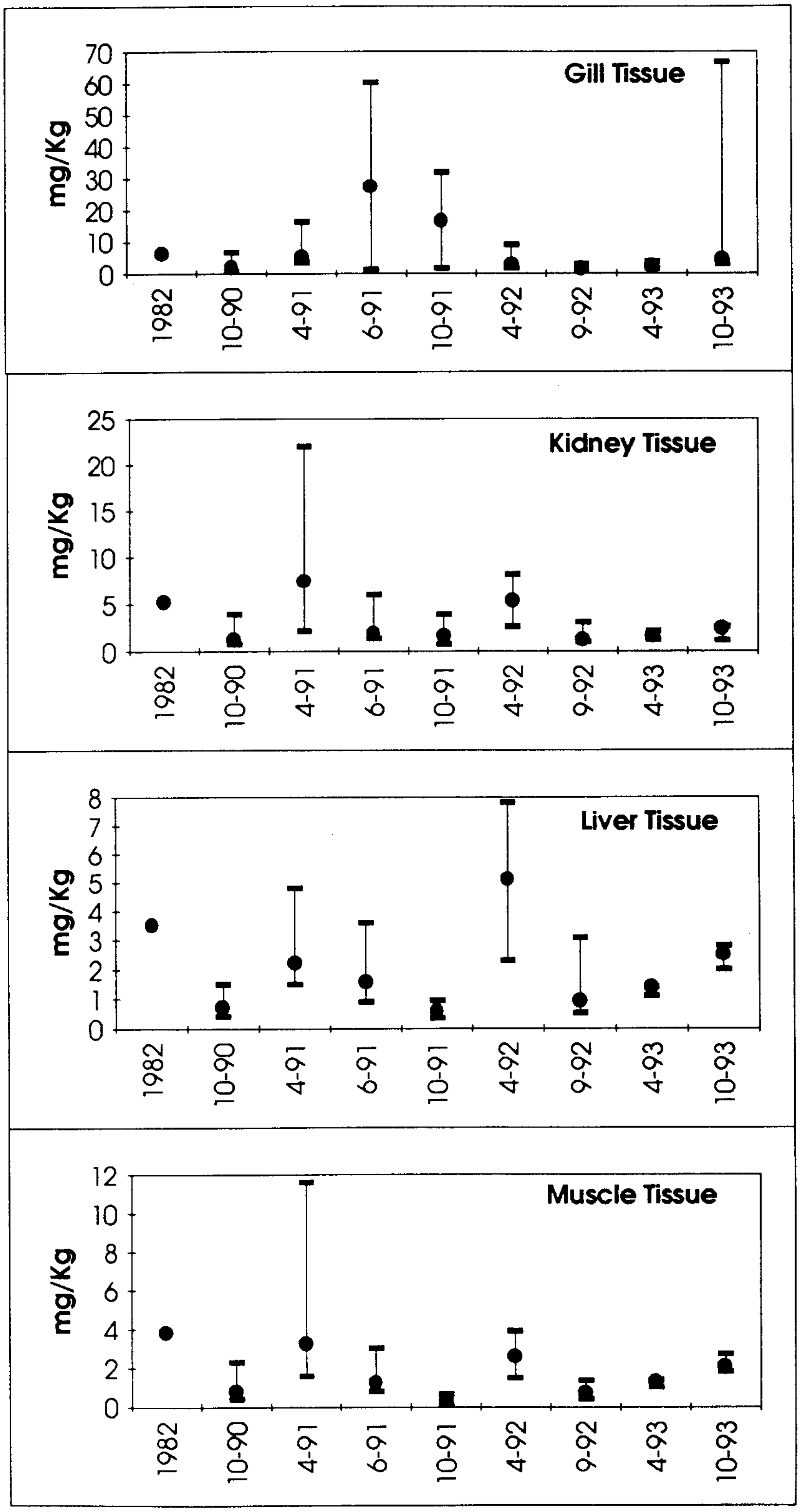


Figure 7. Median, maximum, and minimum concentration of aluminum (mg/Kg dry weight) in adult Dolly Varden tissues (gill, kidney, liver, and muscle) collected in the Wulik River in 1982, 1990, 1991, 1992, and 1993. Median values for 1982 fish were not available; 1982 data are expressed as mean concentration.



(4) Lead concentrations in the kidney, liver, and muscle of Dolly Varden in 1993 were similar to and slightly lower than lead levels reported by Dames and Moore (1983). Dolly Varden in the June 1991 sample contained a higher concentration of lead in gill tissue than reported by Dames and Moore (1983), (Figure 8).

(5) Cadmium concentrations in the 1993 Dolly Varden samples were similar to and slightly lower in all tissues than levels documented by Dames and Moore (1983), Figure 9.

Dolly Varden collected in the fall after summer rearing in salt water were compared with Dolly Varden collected in spring after overwintering in the Wulik River to determine differences in tissue metals concentrations. The method reporting limit was used for censored data. The fall sample included Dolly Varden from Groups A, E, G, and I (N = 24, Table 5) and the spring sample included Groups B, F, and H (N = 23, Table 5). Overall, concentrations of Al and Zn were significantly higher (two sample T-test, $p < 0.05$, Table 6) in all tissues from spring-caught fish except gill tissue, where there was no significant difference between spring- and fall-caught fish. Concentrations of Cu were significantly higher (two sample T-test, $p < 0.05$, Table 6) in liver tissue from spring-caught fish. However, Cd and Cu were significantly higher in gill tissue from fall-caught fish. Concentrations of Pb were at or near the method reporting limit in all tissues from both sample groups, and no significant differences (Table 6) could be shown between spring- and fall-caught fish.

Dolly Varden collected before and after construction and operation of the clean water bypass were compared to determine differences in tissue metals concentrations. A two-sample T-test, assuming unequal sample variances was used

Figure 8. Median, maximum, and minimum concentration of lead (mg/Kg dry weight) in adult Dolly Varden tissues (gill, kidney, liver, and muscle) collected in the Wulik River in 1982, 1990, 1991, 1992, and 1993. Median values for 1982 fish were not available; 1982 data are expressed as mean concentration.

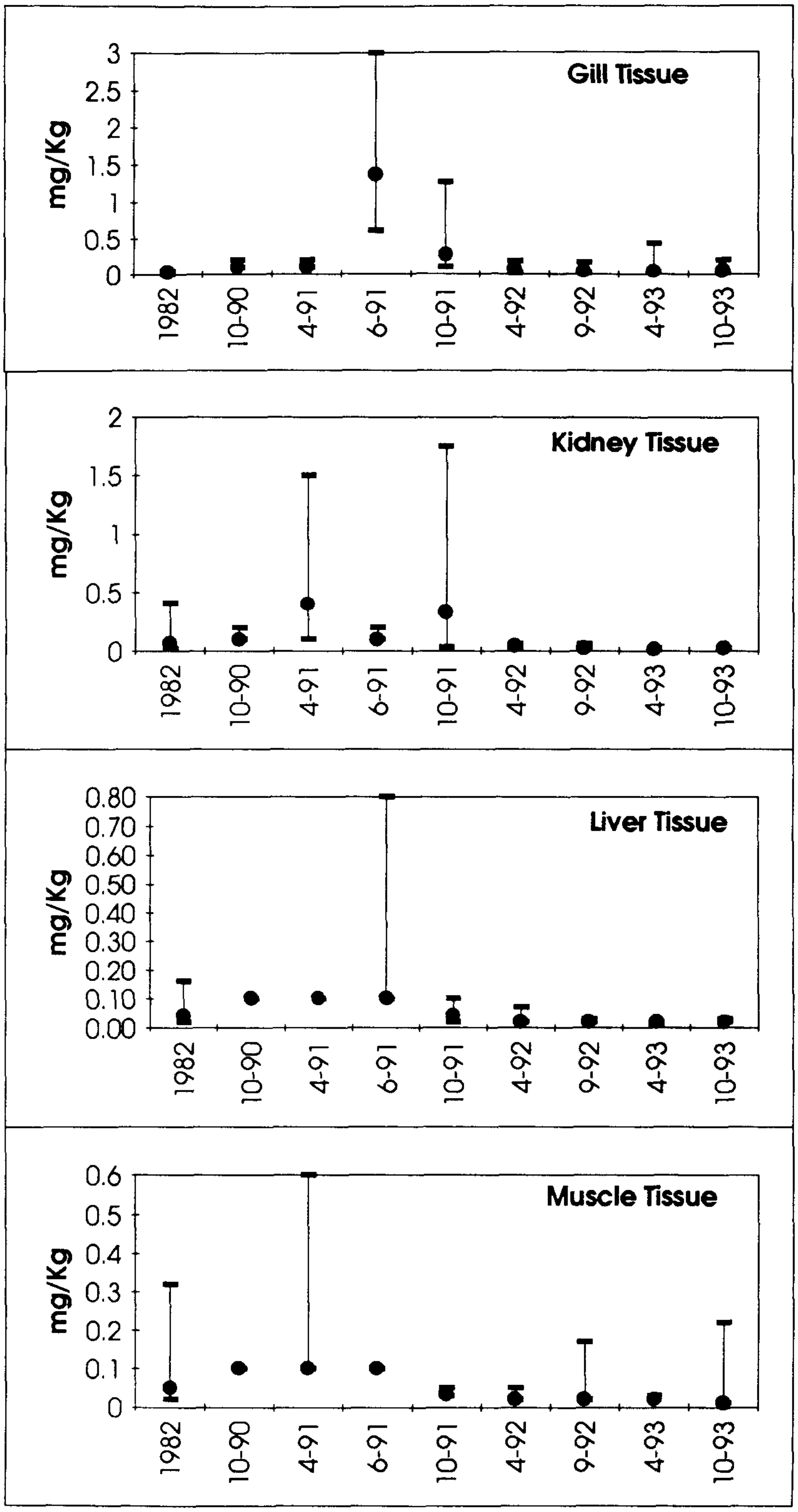


Figure 9. Median, maximum, and minimum concentration of cadmium (mg/Kg dry weight) in adult Dolly Varden tissues (gill, kidney, liver, and muscle) collected in the Wulik River in 1982, 1990, 1991, 1992, and 1993. Median values for 1982 fish were not available; 1982 data are expressed as mean concentration.

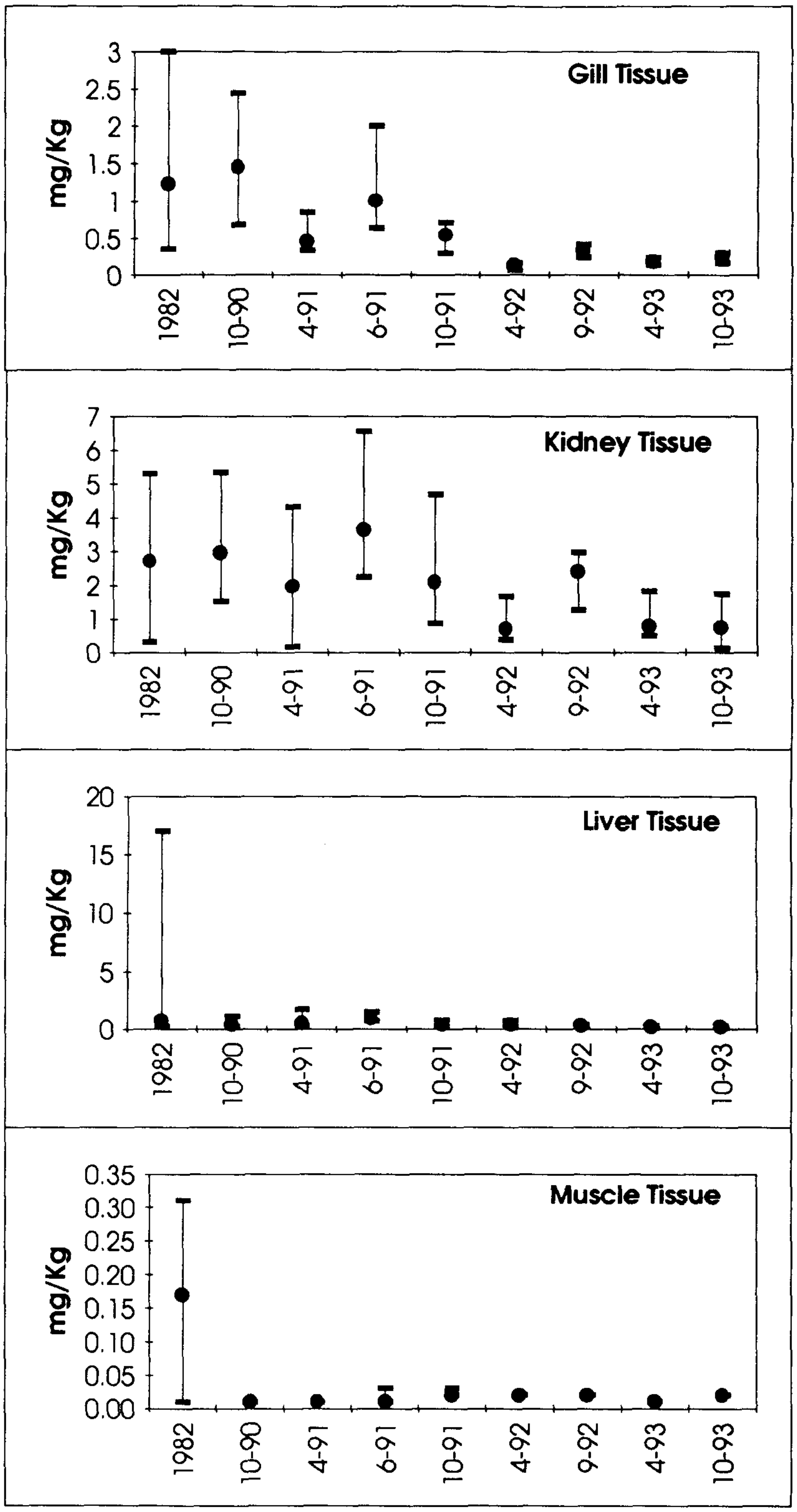


Table 6. Comparisons of metals concentrations in tissues of Dolly Varden collected from the Wulik River in the fall and in the spring. Comparisons were made with a two sample T-test, assuming unequal variances, with $p < 0.05$.

Analyte	Tissue	Fall Caught Fish mg/Kg	Spring Caught Fish mg/Kg	Significantly Different $p < 0.05$
Al	Muscle	1.05	2.66	yes
	Liver	1.28	3.12	yes
	Gill	9.78	5.03	no
	Kidney	1.77	4.68	yes
Cd	Muscle	0.02	0.01	no
	Liver	0.32	0.50	no
	Gill	0.64	0.33	yes*
	Kidney	2.10	1.68	no
Cu	Muscle	2.43	2.00	no
	Liver	29.49	40.41	yes
	Gill	3.66	2.30	yes*
	Kidney	5.14	4.44	no
Pb	Muscle	0.06	0.08	no
	Liver	0.05	0.05	no
	Gill	0.16	0.15	no
	Kidney	0.16	0.15	no
Zn	Muscle	13.5	18.3	yes
	Liver	63.0	102.0	yes
	Gill	80.4	81.7	no
	Kidney	92.3	106.7	yes
n		24	23	

*The mean concentration in fall-caught fish is higher than in spring-caught fish.

to compare concentrations of each metal by tissue with $p < 0.05$. The method reporting limit was used for censored data. Dolly Varden from Groups A, B, and D (N = 23, Table 5) were compared with Groups E, F, G, H, and I (N = 32, Table 5). Dolly Varden from Group D were included in the pre-construction sample because the bypass was not fully functional until mid-summer 1991.

Significant decreases in the concentration of Cd in liver, gill, and kidney were recorded in Dolly Varden collected after the clean water bypass was constructed (Table 7). The concentration of lead also decreased significantly in Dolly Varden samples in the muscle, liver, and gill (Table 7). A significant decrease in Zn concentrations in kidney tissue from Dolly Varden post-ditch was recorded. In all remaining comparisons significant changes were not detected.

Overwintering Dolly Varden Surveys, Wulik River

Aerial surveys to count the number of overwintering Dolly Varden in the Wulik River were made periodically from fall 1979 to present. In 1993 an aerial survey was conducted on September 29. Adult Dolly Varden were present from the mouth of the Wulik River to above Ikalukrok Creek. DeCicco (1993) counted 144,138 Dolly Varden in the Wulik River, the most Dolly Varden observed in the Wulik River upstream and downstream of the confluence of Ikalukrok Creek since 1979 (Table 8). Survey conditions were excellent and more Dolly Varden were observed in the river below Driver's Camp than in previous surveys (DeCicco 1993).

Chum Salmon Surveys, Ikalukrok Creek

Aerial surveys for adult chum salmon in Ikalukrok Creek were not conducted in 1993. We observed Ikalukrok Creek immediately above and below the confluence

Table 7. Comparisons of metals concentrations in tissues of Dolly Varden collected from the Wulik River before and after construction and operation of the clean water bypass system. Comparisons were made with a two sample T-test, assuming unequal variances, with $p < 0.05$.

Analyte	Tissue	Before Bypass Fish mg/Kg	After Bypass Fish mg/Kg	Significantly Different $p < 0.05$
Al	Muscle	2.10	1.50	no
	Liver	1.73	2.39	no
	Gill	14.24	8.46	no
	Kidney	3.46	2.78	no
Cd	Muscle	0.011	0.018	no
	Liver	0.789	0.285	yes
	Gill	1.04	0.27	yes
	Kidney	3.23	1.42	yes
Cu	Muscle	2.12	2.26	no
	Liver	35.40	34.23	no
	Gill	2.54	3.28	no
	Kidney	4.69	4.78	no
Pb	Muscle	0.12	0.04	yes
	Liver	0.130	0.028	yes
	Gill	0.643	0.144	yes
	Kidney	0.20	0.11	no
Zn	Muscle	15.26	16.32	no
	Liver	84.17	82.27	no
	Gill	79.00	81.16	no
	Kidney	110.04	92.63	yes
n		23	32	

Table 8. Number of overwintering adult Dolly Varden in the Wulik River, including percent of total count located in the Wulik River downstream of Ikalukrok Creek during late-fall (prior to freezeup). Surveys conducted by the ADF&G (DeCicco 1989, 1991, 1992, and 1993).

Year	Wulik River upstream of Ikalukrok Creek	Wulik River downstream of Ikalukrok Creek	Wulik River (Total Fish)	Percent of Fish downstream of Ikalukrok Creek
1979	3,305	51,725	55,030	94
1980	12,486	101,067	113,553	89
1981	4,125	97,136	101,261	96
1982	2,300	63,197	65,497	97
1984	370	30,483	30,853	99
1987	893	60,397	61,290	99
1988	1500	78,644	80,144	98
1989	2,110	54,274	56,384	96
1991	7,930	119,055	126,985	94
1992	750	134,385	135,135	99
1993	7,650	136,488	144,138	95

of Dudd Creek in late June and late August. Chum salmon adults were not observed but at least six (6) adult Dolly Varden were present in a pool in Dudd Creek on August 25, 1993. The adult Dolly Varden were located at the head of a pool located about one mile below the confluence of Anxiety Ridge and Buddy/Bonns Creeks. Active spawning behavior was not observed; however, adult fish were in spawning coloration.

Juvenile Dolly Varden, Relative Abundance and Distribution

In 1993, minnow traps were set in Evaingiknuk, Dudd, Anxiety Ridge, Little, Ikalukrok, and the North Fork of Red Dog Creeks. Number of Dolly Varden captured, their length (range and average), and the number of fish (average, standard deviation) per trap were recorded (Appendices 3 through 8).

In 1993, the catch of Dolly Varden increased in sample creeks from late June to late August with the exception of Evaingiknuk Creek. The average catch/trap for Dolly Varden in Anxiety Ridge Creek in late June and late August was 5.5 and 29.5, respectively. Numbers of Dolly Varden captured per minnow trap was compared for sample creeks. Comparisons in catch/trap were made for each sample period (June 29/30 and August 23/25). Significant differences among the creeks in total catch per trap of juvenile Dolly Varden were determined for late June ($F = 5.71$; $df = 5,54$; $P < 0.05$) and late August ($F = 66.8$; $df = 5,54$; $P < 0.05$) sample periods. Highest catches were recorded in Anxiety Ridge Creek during late June and late August. The average number of juvenile Dolly Varden per minnow trap in Anxiety Ridge Creek in late August was 29.5. The total number of Dolly Varden captured in Evaingiknuk (26), Ikalukrok (38), Dudd (20), and the North Fork of Red Dog Creek (31) were similar in late August.

Juvenile Dolly Varden, Metals Concentrations

The average concentration of cadmium in juvenile Dolly Varden from the North Fork of Red Dog and Anxiety Ridge Creeks was 0.96 and 0.24 mg/Kg, respectively (Table 9). The average lead levels were 1.83 and 0.32 mg/Kg in juvenile Dolly Varden collected in Anxiety Ridge and North Fork of Red Dog Creeks, respectively. Cadmium levels were significantly higher in North Fork of Red Dog fish whereas lead concentrations were significantly higher in Anxiety Ridge fish. Dolly Varden from Anxiety Ridge Creek and the North Fork of Red Dog Creek were collected on the same day. Dolly Varden from Anxiety Ridge Creek ranged from 122 to 136 mm while fish taken from the North Fork of Red Dog Creek were between 117 and 136.

Arctic Grayling Surveys, North Fork of Red Dog Creek

Fisheries surveys were conducted along the lower 1.2 km of the North Fork of Red Dog Creek on June 29 and August 25, 1993. Water was clear in late June and late August and the water temperature was 10.6°C and 7.3°C, respectively.

Arctic grayling were present in late June and 25 were collected (angling effort of two hours), measured and released (130, 140, 152, 152, 159, 162, 180, 186, 188, 194, 195, 197, 204, 205, 214, 215, 218, 218, 222, 228, 255, 264, 265, 405, and 410 mm). Average length of the 25 Arctic grayling was 214 mm with a standard deviation of 68. Young-of-the-year Arctic grayling were not observed and adult fish had regained good condition after spawning.

In early August heavy rains occurred in the vicinity of the Red Dog Mine. By late August discharge in the North Fork of Red Dog Creek had decreased but flows were higher than in late June. Numerous young-of-the-year Arctic grayling were

Table 9. Comparisons of metals concentrations in tissues of juvenile Dolly Varden (N = 6) collected from the North Fork of Red Dog and Anxiety Ridge Creeks. Comparisons were made with a two sample T-test, assuming equal variances, with $p < 0.05$.

Analyte	Anxiety Ridge Fish mg/Kg	North Fork Fish mg/Kg	Significantly Different $p < 0.05$
Cadmium	0.26	0.80	
	0.24	0.79	
	0.28	0.35	
	0.24	2.37	
	0.20	0.67	
	0.24	0.75	
Cadmium (average)	0.24	0.96	yes
Lead	1.52	0.26	
	2.12	0.18	
	2.51	0.25	
	1.52	0.32	
	0.69	0.34	
	2.60	0.58	
Lead (average)	1.83	0.32	yes

present in backwater areas and along the creek margins. Three young-of-the-year Arctic grayling were collected in minnow traps (48, 51, and 52 mm).

Visual surveys of Red Dog Creek between the mine and the North Fork of Red Dog Creek were made in late June and late August and survey conditions were excellent. Fish were not observed in Red Dog Creek. In late August filamentous green algae was prevalent in several side channels of Red Dog Creek. These side channels are fed by surface flow from Red Dog Creek and subsurface flow in the floodplain of the creek.

DISCUSSION AND CONCLUSIONS

Dolly Varden Tissue Heavy Metals Concentrations

Comparisons of metal concentrations in fish tissues that were reported as less than the method reporting limit were set at the method reporting limit for comparative purposes. Using the method reporting limit for censored data is the most conservative approach and is more likely to indicate higher levels than actually occur than to indicate no metal accumulation where it has occurred.

We compared heavy metals concentrations in adult Dolly Varden tissues (muscle, liver, gill, and kidney) collected since the startup of the Red Dog Mine. Sample groups of Dolly Varden from spring (pre-breakup) and fall (pre-freezeup) and Dolly Varden from preconstruction and postconstruction of the clean water bypass system were compared.

There was no significant difference in the concentration of Pb between fish caught in the fall after returning from salt water and fish that had overwintered in the Wulik River and were collected in the spring. However, concentrations of Al and Zn were significantly higher in muscle, liver, and kidney tissues in fish caught in the spring. Copper concentrations were significantly higher in the liver of spring-caught Dolly Varden than in fish collected in the fall. In contrast, Cd and Cu in gill tissue was significantly higher in fall-collected fish. Results were identical to those reported by Ott and Weber Scannell (1993) with the exception of Cd in the liver where no significant difference was found after the addition of 1993 samples (Groups H and I, Table 5).

The comparison of adult Dolly Varden collected before and after the construction and operation of the clean water bypass system revealed significant differences.

In all cases there was either no change in heavy metals concentrations or a significant decrease was reported. Significant decreases in cadmium (liver, gill, and kidney), lead (muscle, liver, and gill), and zinc (kidney) occurred after the clean water bypass system was operational. The clean water bypass system began to function efficiently during July 1991 following initial flushing of the work area and minor repairs and modifications to the bypass. It appears, based on data collected since 1990, that measures to minimize introduction of heavy metals into Red Dog Creek by Cominco Alaska Inc. have had an effect on actual heavy metals concentrations in adult Dolly Varden tissues.

Overwintering Dolly Varden Surveys, Wulik River

Objective #2 of our study was to estimate the number of overwintering Dolly Varden in the Wulik River from its mouth to a point five miles upstream of the confluence of the Wulik River and Ikalukrok Creek. Our null hypothesis was that 90% of the overwintering Dolly Varden continue to use the Wulik River downstream of the mouth of Ikalukrok Creek and abundance is not substantially different from prior year estimates. In 1991, 1992, and 1993 over 90% of the Dolly Varden were observed in the Wulik River downstream of Ikalukrok Creek.

The number of overwintering Dolly Varden in the Wulik River has been estimated for the years 1979 through 1982, 1984, 1987 through 1989, and 1991 through 1993. Prior to development of the mine, the number of overwintering Dolly Varden ranged from 30,853 to 113,553 (average = 72,518). Numbers of Dolly Varden estimated in the Wulik River from 1989 to 1993 ranged from 56,384 to 144,138 (average = 115,661). Many factors contribute to the variability in the number of Dolly Varden wintering in the Wulik River including the subsistence and commercial harvest, differential survival due to environmental conditions, and the fact that Dolly Varden stocks from multiple drainages including streams in Russia use the Wulik River for overwintering (DeCicco 1985 and 1990). It is apparent however that the number of overwintering Dolly Varden has not decreased since the opening of the Red Dog Mine and that the fish still use habitat in the Wulik River downstream of Ikalukrok Creek.

<u>Chum Salmon Surveys, Ikalukrok Creek</u>

Objective #3 of our study was to count and assess distribution of adult chum salmon during mid-August in Ikalukrok Creek using aerial surveys from the mouth of Ikalukrok Creek to Dudd Creek. Surveys were not conducted in 1992 and 1993.

<u>Juvenile Dolly Varden, Relative Abundance and Distribution</u>

Our objective was to measure relative abundance (catch) and seasonal use patterns of juvenile Dolly Varden during the ice-free season in Evaingiknuk, Dudd, Anxiety Ridge, Little, and Ikalukrok Creeks. In 1993, a sample reach was established in the North Fork of Red Dog Creek based on preliminary surveys documenting use of the creek by juvenile Dolly Varden in 1992. Our null hypothesis that the relative abundance of juvenile Dolly Varden are not significantly different in sample creeks was rejected for all 1992 and 1993 summer sample periods.

Our highest catch rates in 1992 excluding the early July period were in Anxiety Ridge Creek (Ott and Weber Scannell 1993). Similar results were obtained in 1990 and 1991 (Ott et al. 1992). In 1993 the catch rates were again higher in Anxiety Ridge Creek. Researchers conducting baseline studies reported that the most productive creek for juvenile Dolly Varden was Anxiety Ridge Creek (Dames and Moore 1984). Our results on juvenile Dolly Varden use of Anxiety Ridge Creek continue to support the findings made by Dames and Moore prior to mine development.

Hougton and Hilgert (1983) repeatedly sampled the North Fork of Red Dog Creek in 1981/1982 and reported finding only one Dolly Varden near the headwaters of the creek. They assumed the Dolly Varden was a non-migratory resident. In late July 1992 during a visual survey of the North Fork of Red Dog Creek, we observed fish in riffle areas which we believed were juvenile Dolly Varden. Minnow traps were placed in the North Fork of Red Dog Creek in late July and late August 1992 and juvenile Dolly Varden were captured. In 1993 a sample reach was established using ten minnow traps in the North Fork of Red Dog Creek. In late June 1993 Dolly Varden were not collected but in late August 1993, 31 juvenile anadromous Dolly Varden were captured. The length and coloration of these Dolly Varden were similar to those collected in Anxiety Ridge Creek. Furthermore, the timing of use by juvenile Dolly Varden was similar between Anxiety Ridge Creek and the North Fork of Red Dog Creek. Catches of Dolly Varden in Anxiety Ridge and the North Fork of Red Dog Creeks increased from late June to late August. We speculate that the presence and use of the North Fork of Red Dog Creek by Dolly Varden juveniles is occurring because of decreased heavy metals concentrations in the mainstem of Red Dog Creek, particularly during low flow periods.

Patterns of juvenile Dolly Varden use of Evaingiknuk, Dudd, Anxiety Ridge, Little, and Ikalukrok Creeks during the summer months remained similar to those reported in 1990 and 1991 (Ott et al. 1992) and 1992 (Ott and Weber Scannell 1993). Catch rates for juvenile Dolly Varden are low early in the summer with peak catches occurring from late July to late August and catch rates declining to zero by late fall. Seasonal use patterns of Dolly Varden juveniles in the North Fork of

Red Dog Creek followed the same pattern in the summer of 1993. We believe that the increased catches of juvenile Dolly Varden in the North Fork of Red Dog Creek and Anxiety Ridge Creek later in the summer represents a gradual dispersal of the juveniles from overwintering to rearing habitats.

Overwintering habitat for juvenile Dolly Varden and other fish species that use the Ikalukrok Creek drainage is believed to be restricted to the lower portion of Ikalukrok Creek, the Wulik River immediately upstream and downstream of its confluence with Ikalukrok Creek, and in isolated springs (e.g., Dudd Creek immediately below the confluence of Anxiety Ridge and Buddy/Bonns Creeks). Arctic grayling, burbot, and adult and juvenile Dolly Varden have been collected in the Wulik River during the winter months. Winter discharge data collected by the USGS and Cominco Alaska Inc. indicate that free water does not exist in the winter in the North Fork of Red Dog Creek or in Ikalukrok Creek in the vicinity of its confluence with Red Dog Creek.

Dolly Varden use of Ikalukrok Creek was virtually non-existent in summer 1990 but increased in 1991 (Ott et al. 1992). Seasonal distribution of juvenile Dolly Varden in Ikalurkok Creek in the vicinity of Dudd Creek was similar to distributions documented in Anxiety Ridge Creek with peak use occurring during late summer. Peak catches of Dolly Varden were 0.0 ± 0.0 in 1990, 2.0 ± 2.5 in 1991, 5.8 ± 5.8 in 1992, and 3.8 ± 3.8 in 1993. The clean water bypass system was constructed during March/April 1991 and has functioned from mid-July 1991 through the present. Water quality improved in Red Dog and Ikalukrok Creeks below the confluence of Red Dog Creek (Station 8) during late summer 1991 and throughout summers 1992 and 1993.

Juvenile Dolly Varden, Metals Concentrations

Significant differences in Pb and Cd concentrations were found for juvenile Dolly Varden collected in Anxiety Ridge and the North Fork of Red Dog Creeks. We do not know why the metals concentrations are different.

Arctic Grayling Surveys, North Fork of Red Dog Creek

Our objective from 1991 through 1993 was to evaluate Arctic grayling use of the North Fork of Red Dog Creek. In 1991 and 1992, we found that Arctic grayling continued to spawn in the North Fork of Red Dog Creek and young-of-the-year Arctic grayling were present (Ott et al. 1992; Ott and Weber Scannell 1993). In 1993, adult Arctic grayling in good post-spawning condition were collected and released in the North Fork of Red Dog Creek in late June. Young-of-the-year Arctic grayling were collected and released in late August 1993. Numerous young-of-the-year Arctic grayling were documented in the North Fork of Red Dog Creek in all sample years (1991 through 1993).

Prior to mine development, high heavy metals concentrations in Red Dog Creek, particularly during low flow periods, limited use of the North Fork of Red Dog Creek to adult, young-of-the-year, and large sub-adult Arctic grayling (Hougton and Hilgert 1983). Presumably the larger Arctic grayling migrated up Red Dog Creek during spring when flows were high and metals concentrations low. Movement of adult Arctic grayling into spawning streams prior to juvenile movement has been documented in specific Arctic streams (McCart et al. 1972; Craig and Poulin 1975). Few, if any, age 1+ and 2+ Arctic grayling used the North Fork of Red Dog Creek (Hougton and Hilgert 1983). They documented adult Arctic grayling in the North Fork of Red Dog Creek up to 360 mm in length with subadults ranging from 210 to 245 mm.

In 1992 and 1993, we collected by angling and measured and released Arctic grayling in the North Fork of Red Dog Creek. Nine Arctic grayling with an average length of 277.6 mm (range 100 to 407) were caught and released in 1992. In 1993, we collected and released 25 Arctic grayling with an average length of 214.0 mm (range 130 to 410). Twelve of the 25 Arctic grayling were less than 200 mm fork length. It was apparent that smaller Arctic grayling are using the North Fork of Red Dog Creek than before mine development. Improved water quality in Red Dog Creek during summers of 1992 and 1993 may account for the presence of smaller Arctic grayling in the North Fork of Red Dog Creek.

FUTURE STUDY RECOMMENDATIONS

Our past studies have focused on distribution and relative abundance of juvenile Dolly Varden, heavy metals concentrations in selected tissues of adult Dolly Varden, and Arctic grayling use of the North Fork of Red Dog Creek. Changes in fish distribution and habitat have been observed and appear to coincide with changes in water conditions downstream of the Red Dog Mine. We believe that it is essential to continue to conduct fisheries studies to document both short-term and long-term changes in fish distribution, relative abundance, fish species composition, and heavy metal content of fish tissues. Furthermore, fisheries data can be used, as applicable, to predict impacts and provide mitigation options for other mine operations in Alaska. Based on results of work to date, we have identified the following objectives for future field investigations:

(1) Determine heavy metal concentrations (zinc, copper, lead, aluminum, cadmium) in muscle, gill, liver, and kidney tissue of adult Dolly Varden taken in the spring and fall from overwintering habitat in the Wulik River. Trends in heavy metals concentrations in selected Dolly Varden tissues were not detected in samples collected in 1991 (Ott et al 1992) and 1992 (Ott and Weber 1993).

   H_0: Heavy metal concentrations in adult Dolly Varden tissues are not substantially different from baseline data collected in 1982 and 1983.

(2) Estimate abundance and assess distribution of overwintering adult Dolly Varden in late-September/early-October using aerial surveys of the Wulik River from its mouth to approximately five river miles upstream of the confluence of the Wulik River and Ikalukrok Creek. Since 1966, the

number of overwintering Dolly Varden has ranged from 30,000 to 225,000. The estimated number of Dolly Varden in the Wulik River in late fall of 1991, 1992, and 1993 was 126,985; 135,135; and 144,138; respectively (DeCicco 1991, 1992, and 1993a). In 1991, 1992, and 1993, over 90 percent of the Dolly Varden were located in the Wulik River downstream of Ikalukrok Creek (Ott and Weber-Scannell 1993, DeCicco 1993a).

> H_0: Ninety percent of overwintering adult Dolly Varden continue to use the Wulik River downstream of the mouth of Ikalukrok Creek in numbers comparable to baseline data.

(3) Determine relative abundance (catch per unit of effort) of juvenile Dolly Varden during the ice-free season in Ikalukrok, Anxiety Ridge, Evaingiknuk, Red Dog, and North Fork of Red Dog Creeks. The most productive creek for juvenile Dolly Varden during baseline surveys in 1983 was Anxiety Ridge Creek in the vicinity of the proposed Haul Road crossing (Dames and Moore 1984).

> H_0: Relative abundance of juvenile Dolly Varden are not significantly different in Ikalukrok, Anxiety Ridge, Evaingiknuk, Red Dog, and North Fork of Red Dog Creeks.

(4) Determine Arctic grayling use of the North Fork of Red Dog Creek. On July 6, 1982, spawned-out Arctic grayling were abundant in the North Fork of Red Dog Creek and on July 9, 1982, numerous young-of-the-year Arctic grayling were observed (Dames and Moore 1983).

> H_0: Arctic grayling continue to spawn in the North Fork of Red Dog Creek and young-of-the-year Arctic grayling are present.

(5) Determine juvenile Dolly Varden use of the North Fork of Red Dog Creek. Juvenile Dolly Varden were first documented in the North Fork of Red Dog Creek during the ice-free season in 1992 (Ott and Weber-Scannell 1993) and 1993 (Ott 1993).

H_0: Juvenile Dolly Varden continue to rear in the North Fork of Red Dog Creek during the ice-free season.

(6) Determine Dolly Varden and Arctic grayling use of Red Dog Creek between its mouth and the Red Dog Mine site. Historical data indicate that fish use was limited to migration in Red Dog Creek downstream of its confluence with the North Fork of Red Dog Creek. Some rearing fish were observed in Red Dog Creek within the influence of the North Fork of Red Dog Creek (Dames and Moore 1983) and fish mortalities were documented in Red Dog Creek (E.V.S. Consultants Ltd. 1983).

H_0: Dolly Varden and Arctic grayling continue to use Red Dog Creek as a migratory corridor.

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Appendix 1. Concentrations of Al, Cd, Cu, Pb, and Zn in adult Dolly Varden muscle, liver, gill, and kidney tissues, 1990 through 1993 from the Wulik River. Baseline fish tissue data from Dames and Moore (1983) are included. All concentrations are expressed as mg/Kg, dry weight basis.

Sample Group	Matrix	Collector	Date	Sex	Weight grams	Length mm	age (fresh/ salt)	Al mg/kg	Cd mg/kg	Cu mg/kg	Pb mg/k	Zn mg/kg	% Solids
DM	Gills	D&M	6/1/81	a					0.77	3.00	< 0.03	67.2	
DM	Gills	D&M	6/1/81	a					1.20	3.20	< 0.02	68.6	
DM	Gills	D&M	8/1/81	a					0.36	3.20	< 0.04	34.1	
DM	Gills	D&M	9/1/81	a					0.79	3.10	< 0.04	67.4	
DM	Gills	D&M	6/1/82	a					5.75	0.75	3.18	0.0	24.8
A	Gills	ADF&G	10/5/90	f		538		1.80	1.63	2.20	0.20	90.4	22.3
A	Gills	ADF&G	10/5/90	f		615		1.30	0.68	3.10	< 0.10	70.9	25.8
A	Gills	ADF&G	10/5/90	m		608		1.40	1.44	2.60	< 0.10	68.7	24.0
A	Gills	ADF&G	10/5/90	f		430		2.00	1.20	3.30	0.10	70.5	26.2
A	Gills	ADF&G	10/5/90	f		452		0.60	1.22	2.10	< 0.10	70.2	21.6
A	Gills	ADF&G	10/5/90	f		528		2.20	2.44	2.60	0.20	96.6	24.1
B	Gills	Cominco	3/9/91					6.10	0.39	2.30	< 0.10	87.4	19.2
B	Gills	Cominco	3/9/91					7.80	0.66	2.30	< 0.10	87.6	22.0
B	Gills	Cominco	3/9/91					10.80	1.02	2.30	< 0.10	77.8	22.1
B	Gills	KIVALINA	4/6/91	m		300		5.00	0.45	2.60	< 0.10	94.8	19.5
B	Gills	KIVALINA	4/6/91	m	197	294		13.90	0.36	1.90	< 0.10	74.4	18.6
B	Gills	KIVALINA	4/6/91	f	201	303		3.40	0.82	2.20	< 0.10	88.4	19.3
B	Gills	KIVALINA	4/6/91	f	237	355		4.20	0.33	2.50	0.20	70.3	19.0
B	Gills	KIVALINA	4/6/91	f	751	434		16.10	0.85	1.90	< 0.10	83.0	19.8
B	Gills	Cominco	4/26/91	f	1279	518		3.20	0.79	1.70	1.10	79.8	20.4
D	Gills	Cominco	6/16/91	m	962	489		36.60	1.51	3.10	1.00	75.6	18.2
D	Gills	Cominco	6/16/91	f	1426	538		56.30	0.78	3.00	3.00	79.3	21.1
D	Gills	Cominco	6/16/91	m	1361	541		21.20	1.15	2.70	0.60	75.5	18.8
D	Gills	Cominco	6/16/91	f	762	461		18.40	2.00	3.10	1.50	89.6	22.2
D	Gills	Cominco	6/16/91	f	672	417		20.50	0.64	2.10	0.80	64.7	21.4
D	Gills	Cominco	6/16/91	f	745	430		33.30	0.83	2.80	1.50	75.3	20.8
D	Gills	Cominco	6/16/91	f	680	443		60.20	0.85	2.90	2.40	67.7	21.5
D	Gills	Cominco	6/16/91	f	654	430		1.20	1.82	3.10	1.20	78.5	20.2
E	Gills	Cominco	10/5/91	F	1162	480		1.61	0.55	3.39	0.10	70.8	21.0
E	Gills	Cominco	10/5/91	M	1262	480		23.40	0.30	2.92	0.16	75.2	19.3
E	Gills	Cominco	10/5/91	M	2551	614		10.60	0.63	2.82	0.29	71.4	20.3
E	Gills	Cominco	10/5/91	F	2188	589		2.08	0.54	3.64	0.23	72.3	23.0
E	Gills	Cominco	10/5/91	F	1616	525		22.10	0.50	4.23	1.26	73.6	19.8
E	Gills	Cominco	10/5/91	M	2233	563		31.70	0.71	5.10	0.33	84.1	21.7
F	Gills	ADF&G	4/29/92	F	180	291		3.10	0.13	3.34	0.18	93.3	20.8
F	Gills	ADF&G	4/29/92	F	670	424	(2+2)	2.10	0.16	1.78	0.07	65.5	25.9
F	Gills	ADF&G	4/29/92	F	1420	530	(2+3)?	9.00	0.07	1.79	0.11	65.7	27.8
F	Gills	ADF&G	4/29/92	undet	180	294	(2+1)?	2.30	0.13	1.92	0.07	84.2	21.0
F	Gills	ADF&G	4/29/92	F	140	275	(3+1)	2.70	0.12	3.73	0.04	93.7	19.9
F	Gills	ADF&G	4/29/92	M	160	276		4.40	0.14	2.21	0.02	81.3	19.2

Sample Group	Matrix	Collector	Date	Sex	Weight grams	Length mm	age (fresh/ salt)	Al mg/kg	Cd mg/kg	Cu mg/kg	Pb mg/k	Zn mg/kg	% Solids
F	Gills	ADF&G	4/29/92	M	140	264	(4+1)	5.90	0.08	2.24	0.06	80.2	20.3
F	Gills	ADF&G	4/29/92	F	150	259	(3+1)	1.70	0.09	2.13	0.03	77.7	19.9
G	Gills	ADF&G	9/30/92	F	4120	706	9	2.79	0.24	3.22	0.04	76.0	21.2
G	Gills	ADF&G	9/30/92	M	2820	620	(3+4)	2.29	0.42	8.50	0.16	90.0	18.8
G	Gills	ADF&G	9/30/92	F	3410	674	(3+5)	1.25	0.41	2.92	< 0.02	86.0	19.8
G	Gills	ADF&G	9/30/92	M	2630	600	(4+4)	1.28	0.33	2.90	0.04	91.0	20.3
G	Gills	ADF&G	9/30/92	F	2110	564	(3+4)	1.39	0.33	2.92	< 0.02	94.0	19.8
G	Gills	ADF&G	9/30/92	M	2920	595	(2+4)	1.02	0.36	2.34	0.04	73.0	21.6
H	Gills	ADF&G	4/21/93		673	407		1.80	0.24	2.42	0.36	87.0	20.2
H	Gills	ADF&G	4/21/93		1032	480	(2+3)	1.60	0.15	2.50	0.03	97.0	20.7
H	Gills	ADF&G	4/21/93		717	414	(4+2)	2.50	0.18	2.35	0.43	84.0	20.8
H	Gills	ADF&G	4/21/93		701	421	(3+2)	3.70	0.14	2.33	0.04	74.0	21.7
H	Gills	ADF&G	4/21/93		685	398	6	3.10	0.16	2.19	0.04	75.0	22.4
H	Gills	ADF&G	4/21/93		611	407	(2+3)	1.40	0.17	2.31	0.03	77.0	22.8
I	Gills	ADF&G	10/20/93	F	2168	575	(3+3)	42.40	0.18	2.68	0.06	101.0	25.5
I	Gills	ADF&G	10/20/93	M	1352	491	(4+3)	3.90	0.26	12.80	0.20	88.5	24.8
I	Gills	ADF&G	10/20/93	M	1551	498	(3+3)	3.70	0.31	3.93	< 0.02	80.1	22.2
I	Gills	ADF&G	10/20/93	F	1188	456	(3+3)	66.70	0.28	2.90	0.08	88.5	25.8
I	Gills	ADF&G	10/20/93	M	1324	473	(3+3)	2.90	0.16	2.64	0.03	81.2	21.7
I	Gills	ADF&G	10/20/93	M	2204	556	(3+4)	4.30	0.23	2.02	0.02	64.7	24.8
DM	Kidney	D&M	6/1/81	a					0.32	4.90	0.02	80.1	
DM	Kidney	D&M	6/1/81	a					5.30	4.00	< 0.02	75.9	
DM	Kidney	D&M	8/1/81	a					2.90	5.20	< 0.05	74.6	
DM	Kidney	D&M	9/1/81	a					3.00	5.80	< 0.03	109.0	
DM	Kidney	D&M	6/1/82	a				3.00	2.53	5.28	0.03	94.4	
A	Kidney	ADF&G	10/5/90	f		538		1.50	5.34	3.30	0.20	117.0	21.4
A	Kidney	ADF&G	10/5/90	f		615		1.10	2.22	4.80	< 0.10	96.4	21.9
A	Kidney	ADF&G	10/5/90	m		608		0.70	1.53	4.80	< 0.10	79.3	24.0
A	Kidney	ADF&G	10/5/90	f		430		3.00	2.93	5.20	< 0.10	100.0	23.7
A	Kidney	ADF&G	10/5/90	f		452		0.90	3.30	5.00	< 0.10	106.0	21.9
A	Kidney	ADF&G	10/5/90	f		528		1.10	2.63	5.30	< 0.10	103.0	18.5
B	Kidney	Cominco	3/9/91					2.30	3.59	4.80	< 0.10	143.0	23.1
B	Kidney	Cominco	3/9/91					4.70	3.48	5.20	< 0.10	103.0	22.9
B	Kidney	Cominco	3/9/91					2.10	3.20	4.90	< 0.10	118.0	23.6
B	Kidney	KIVALINA	4/6/91	m		300		2.40	4.31	3.70	< 0.20	127.0	20.3
B	Kidney	KIVALINA	4/6/91	m	197	294		8.80	0.85	2.70	< 0.40	85.6	23.4
B	Kidney	KIVALINA	4/6/91	f	201	303		22.00	1.96	4.10	1.50	173.0	23.7

Sample Group	Matrix	Collector	Date	Sex	Weight grams	Length mm	age (fresh/ salt)	Al mg/kg	Cd mg/kg	Cu mg/kg	Pb mg/k	Zn mg/kg	% Solids
B	Kidney	KIVALINA	4/6/91	f	237	355		7.40	0.17	9.00	0.40	139.0	21.8
B	Kidney	KIVALINA	4/6/91	f	751	434		2.10	2.79	3.50	< 0.10	102.0	22.4
B	Kidney	Cominco	4/26/91	f	1279	518		1.00	5.40	6.20	0.20	112.0	21.0
D	Kidney	Cominco	6/16/91	m	962	489		6.00	6.56	6.00	0.10	83.3	18.3
D	Kidney	Cominco	6/16/91	f	1426	538		2.40	4.87	4.10	< 0.10	89.2	23.0
D	Kidney	Cominco	6/16/91	m	1361	541		1.70	4.14	4.00	0.20	76.6	22.3
D	Kidney	Cominco	6/16/91	f	762	461		2.10	3.09	4.50	< 0.10	94.5	22.4
D	Kidney	Cominco	6/16/91	f	672	417		1.50	2.47	3.50	< 0.10	208.0	15.2
D	Kidney	Cominco	6/16/91	f	745	430		1.60	2.23	4.20	< 0.10	71.1	21.9
D	Kidney	Cominco	6/16/91	f	680	443		1.90	4.01	4.90	< 0.10	108.0	22.5
D	Kidney	Cominco	6/16/91	f	654	430		1.30	3.23	4.10	< 0.10	95.9	21.2
E	Kidney	Cominco	10/5/91	F	1162	480		0.96	1.27	4.54	0.06	87.1	22.7
E	Kidney	Cominco	10/5/91	M	1262	480		1.86	1.66	4.89	0.62	92.4	22.8
E	Kidney	Cominco	10/5/91	M	2551	614		3.93	0.87	17.70	1.75	51.2	23.0
E	Kidney	Cominco	10/5/91	F	2188	589		1.30	2.54	6.18	0.03	104.0	22.3
E	Kidney	Cominco	10/5/91	F	1616	525		1.86	4.68	5.94	0.04	107.0	21.5
E	Kidney	Cominco	10/5/91	M	2233	563		0.75	2.81	4.37	0.06	86.4	22.9
F	Kidney	ADF&G	4/29/92	F	180	291		6.60	0.62	5.04	0.04	114.0	36.4
F	Kidney	ADF&G	4/29/92	F	670	424	(2+2)	5.00	1.51	3.57	0.04	78.1	24.2
F	Kidney	ADF&G	4/29/92	F	1420	530	(2+3)?	5.70	1.28	3.43	0.02	86.6	24.5
F	Kidney	ADF&G	4/29/92	undet	180	294	(2+1)?	4.70	0.53	3.83	0.04	91.7	20.8
F	Kidney	ADF&G	4/29/92	F	140	275	(3+1)	4.30	0.38	6.43	0.06	99.7	21.4
F	Kidney	ADF&G	4/29/92	M	160	276		8.10	1.67	3.88	0.05	95.5	19.8
F	Kidney	ADF&G	4/29/92	M	140	264	(4+1)	2.60	0.40	3.50	0.04	82.2	17.4
F	Kidney	ADF&G	4/29/92	F	150	259	(3+1)	5.90	0.80	4.22	0.03	114.0	21.3
G	Kidney	ADF&G	9/30/92	F	4120	706	9	3.08	2.74	4.49	< 0.02	85.0	22.5
G	Kidney	ADF&G	9/30/92	M	2820	620	(3+4)	2.30	2.97	5.00	< 0.02	110.0	22.6
G	Kidney	ADF&G	9/30/92	F	3410	674	(3+5)	1.13	2.37	4.09	< 0.02	74.0	28.0
G	Kidney	ADF&G	9/30/92	M	2630	600	(4+4)	0.97	1.26	5.64	< 0.02	93.0	24.2
G	Kidney	ADF&G	9/30/92	F	2110	564	(3+4)	1.00	2.14	5.24	0.06	105.0	24.3
G	Kidney	ADF&G	9/30/92	M	2920	595	(2+4)	1.66	1.64	3.69	0.24	81.0	24.1
H	kidney	ADF&G	4/21/93	F	673	407		1.40	0.76	3.85	0.02	88.0	23.8
H	kidney	ADF&G	4/21/93		1032	480	(2+3)	1.70	1.33	4.53	0.02	106.0	23.5
H	kidney	ADF&G	4/21/93		717	414	(4+2)	1.50	1.82	4.44	0.01	112.0	24.8
H	kidney	ADF&G	4/21/93		701	421	(3+2)	1.20	0.79	3.66	0.01	84.0	26.9
H	kidney	ADF&G	4/21/93		685	398	6	2.10	0.51	4.05	< 0.01	100.0	22.9
H	kidney	ADF&G	4/21/93		611	407	(2+3)	4.10	0.53	3.61	< 0.01	99.0	22.3
I	kidney	ADF&G	10/20/93	F	2168	575	(3+3)	2.30	1.37	4.67	< 0.02	103.0	25.6
I	kidney	ADF&G	10/20/93	M	1352	491	(4+3)	1.10	0.13	0.54	< 0.02	13.8	24.6
I	kidney	ADF&G	10/20/93	M	1551	498	(3+3)	2.30	0.77	4.51	< 0.02	110.0	23.0

Sample Group	Matrix	Collector	Date	Sex	Weight grams	Length mm	age (fresh/ salt)	Al mg/kg	Cd mg/kg	Cu mg/kg	Pb mg/k	Zn mg/kg	% Solids
I	kidney	ADF&G	10/20/93	F	1188	456	(3+3)	2.60	0.73	4.01	< 0.02	95.5	24.0
I	kidney	ADF&G	10/20/93	M	1324	473	(3+3)	2.60	0.71	3.93	< 0.02	116.0	23.5
I	kidney	ADF&G	10/20/93	M	2204	556	(3+4)	2.50	1.76	5.45	< 0.02	98.9	22.7
DM	Liver	D&M	6/1/81	a					0.58	33.00	< 0.02	72.3	
DM	Liver	D&M	6/1/81	a					0.54	16.50	< 0.02	50.8	
DM	Liver	D&M	8/1/81	a					0.77	11.00	< 0.02	91.0	
DM	Liver	D&M	9/1/81	a					0.97	18.00	0.02	78.2	
DM	Liver	D&M	6/1/82	a				2.50	0.67	27.75	0.03	69.6	
A	Liver	ADF&G	10/5/90	f		538		1.50	1.11	25.60	0.10	103.0	26.1
A	Liver	ADF&G	10/5/90	f		615		0.70	0.25	19.70	< 0.10	46.6	46.6
A	Liver	ADF&G	10/5/90	m		608		0.70	0.19	38.40	< 0.10	58.7	50.9
A	Liver	ADF&G	10/5/90	f		430		0.80	0.46	22.60	< 0.10	79.3	29.0
A	Liver	ADF&G	10/5/90	f		452		0.70	0.40	24.20	< 0.10	74.6	34.6
A	Liver	ADF&G	10/5/90	f		528		0.40	0.37	29.90	< 0.10	61.8	55.9
B	Liver	Cominco	3/9/91					1.50	1.81	40.30	< 0.10	164.0	27.1
B	Liver	Cominco	3/9/91					3.10	0.53	30.70	< 0.10	65.8	44.4
B	Liver	Cominco	3/9/91					2.00	0.73	46.60	< 0.10	84.8	38.8
B	Liver	KIVALINA	4/6/91	m		300		4.80	1.73	51.90	< 0.10	88.8	33.8
B	Liver	KIVALINA	4/6/91	m	197	294		1.50	0.29	47.70	< 0.10	87.2	34.9
B	Liver	KIVALINA	4/6/91	f	201	303		1.80	0.45	41.10	< 0.10	95.8	33.1
B	Liver	KIVALINA	4/6/91	f	237	355		2.20	0.63	72.00	< 0.10	114.0	25.2
B	Liver	KIVALINA	4/6/91	f	751	434		2.90	0.38	25.90	0.10	44.6	35.0
B	Liver	Cominco	4/26/91	f	1279	518		1.30	0.76	25.40	< 0.10	56.1	38.2
D	Liver	Cominco	6/16/91	m	962	489		1.30	1.25	32.40	< 0.10	74.0	31.9
D	Liver	Cominco	6/16/91	f	1426	538		1.80	0.71	18.70	< 0.10	75.2	30.8
D	Liver	Cominco	6/16/91	m	1361	541		3.60	0.86	37.50	< 0.10	83.2	33.7
D	Liver	Cominco	6/16/91	f	762	461		2.00	1.18	34.10	< 0.10	96.6	27.4
D	Liver	Cominco	6/16/91	f	672	417		1.80	1.48	38.30	0.80	124.0	24.0
D	Liver	Cominco	6/16/91	f	745	430		1.20	0.69	54.20	< 0.10	85.4	28.9
D	Liver	Cominco	6/16/91	f	680	443		1.20	1.04	26.00	< 0.10	84.3	33.3
D	Liver	Cominco	6/16/91	f	654	430		0.90	0.84	31.00	< 0.10	88.0	30.1
E	Liver	Cominco	10/5/91	F	1162	480		0.94	0.29	33.60	0.04	70.8	45.6
E	Liver	Cominco	10/5/91	M	1262	480		0.34	0.21	27.40	0.02	50.2	43.1
E	Liver	Cominco	10/5/91	M	2551	614		0.44	0.72	39.00	0.10	61.7	37.7
E	Liver	Cominco	10/5/91	F	2188	589		0.87	0.32	59.00	0.05	65.6	45.7
E	Liver	Cominco	10/5/91	F	1616	525		0.40	0.53	25.40	0.04	55.1	41.5
E	Liver	Cominco	10/5/91	M	2233	563		0.70	0.21	30.60	0.04	33.8	47.6

Sample Group	Matrix	Collector	Date	Sex	Weight grams	Length mm	age (fresh/ salt)	Al mg/kg	Cd mg/kg	Cu mg/kg	Pb mg/k	Zn mg/kg	% Solids
F	Liver	ADF&G	4/29/92	F	180	291		3.20	0.41	40.30	< 0.02	152.0	27.0
F	Liver	ADF&G	4/29/92	F	670	424	(2+2)	7.20	0.31	23.80	< 0.02	62.8	46.7
F	Liver	ADF&G	4/29/92	F	1420	530	(2+3)?	4.70	0.26	47.80	0.02	66.2	39.6
F	Liver	ADF&G	4/29/92	undet	180	294	(2+1)?	7.60	0.37	32.40	0.03	142.0	27.7
F	Liver	ADF&G	4/29/92	F	140	275	(3+1)	7.80	0.21	71.80	0.07	222.0	26.4
F	Liver	ADF&G	4/29/92	M	160	276		2.30	0.74	39.90	< 0.02	162.0	26.5
F	Liver	ADF&G	4/29/92	M	140	264	(4+1)	5.50	0.45	84.10	0.04	176.0	27.0
F	Liver	ADF&G	4/29/92	F	150	259	(3+1)	4.50	0.35	36.20	0.02	160.0	25.3
G	Liver	ADF&G	9/30/92	F	4120	706	9	1.64	0.27	21.50	0.02	60.0	45.0
G	Liver	ADF&G	9/30/92	M	2820	620	(3+4)	3.07	0.37	19.50	0.03	67.0	41.8
G	Liver	ADF&G	9/30/92	F	3410	674	(3+5)	0.92	0.24	19.70	0.02	56.0	50.1
G	Liver	ADF&G	9/30/92	M	2630	600	(4+4)	0.51	0.16	40.20	< 0.02	60.0	48.1
G	Liver	ADF&G	9/30/92	F	2110	564	(3+4)	0.61	0.32	45.60	0.02	74.0	41.4
G	Liver	ADF&G	9/30/92	M	2920	595	(2+4)	0.55	0.15	20.00	< 0.02	59.0	41.4
H	liver	ADF&G	4/21/93		673	407		1.20	0.24	29.80	< 0.01	75.0	39.5
H	liver	ADF&G	4/21/93		1032	480	(2+3)	1.40	0.16	37.30	0.02	73.0	37.4
H	liver	ADF&G	4/21/93		717	414	(4+2)	1.40	0.19	42.30	< 0.01	63.0	46.0
H	liver	ADF&G	4/21/93		701	421	(3+2)	1.40	0.13	23.00	0.02	58.0	42.2
H	liver	ADF&G	4/21/93		685	398	6	1.40	0.15	21.00	0.01	66.0	38.7
H	liver	ADF&G	4/21/93		611	407	(2+3)	1.10	0.18	18.10	0.02	67.0	36.8
I	liver	ADF&G	10/20/93	F	2168	575	(3+3)	2.80	0.18	23.60	< 0.02	46.5	48.4
I	liver	ADF&G	10/20/93	M	1352	491	(4+3)	2.80	0.23	22.10	0.03	67.6	41.4
I	liver	ADF&G	10/20/93	M	1551	498	(3+3)	2.00	0.12	13.20	< 0.02	51.0	46.3
I	liver	ADF&G	10/20/93	F	1188	456	(3+3)	2.30	0.23	42.90	< 0.02	86.0	37.4
I	liver	ADF&G	10/20/93	M	1324	473	(3+3)	2.60	0.14	28.90	< 0.02	60.9	44.4
I	liver	ADF&G	10/20/93	M	2204	556	(3+4)	2.40	0.27	35.20	< 0.02	62.4	35.6
DM	muscle	D&M	6/1/81	a					0.16	1.30	< 0.02	9.9	
DM	muscle	D&M	6/1/81	a					0.20	2.00	< 0.02	9.2	
DM	muscle	D&M	7/1/81	a					0.21	2.50	< 0.04	13.9	
DM	muscle	D&M	8/1/81	a					0.19	2.00	0.03	13.6	
DM	muscle	D&M	9/1/81	a					0.12	2.10	< 0.02	16.8	
DM	muscle	D&M	6/1/82	a				3.40	0.17	1.56	0.02	12.1	
A	muscle	ADF&G	10/5/90	f		538		1.60	< 0.01	2.50	< 0.10	18.1	24.9
A	muscle	ADF&G	10/5/90	f		615		0.40	< 0.01	1.00	< 0.10	7.6	42.4
A	muscle	ADF&G	10/5/90	m		608		0.80	< 0.01	1.80	< 0.10	11.5	38.1
A	muscle	ADF&G	10/5/90	f		430		0.50	< 0.01	1.90	< 0.10	12.9	32.5
A	muscle	ADF&G	10/5/90	f		452		0.50	< 0.01	1.70	< 0.10	15.3	30.1

Sample Group	Matrix	Collector	Date	Sex	Weight grams	Length mm	age (fresh/ salt)	Al mg/kg	Cd mg/kg	Cu mg/kg	Pb mg/k	Zn mg/kg	% Solids
A	muscle	ADF&G	10/5/90	f		528		0.90	< 0.01	1.70	< 0.10	12.1	39.5
B	muscle	Cominco	3/9/91	f		560	7(3+4)	2.20	< 0.01	3.50	< 0.10	18.6	24.7
B	muscle	Cominco	3/9/91	f		380	5(3+2)	2.80	< 0.01	2.40	< 0.10	14.5	27.0
B	muscle	Cominco	3/9/91	f		387	4(2+2)	1.60	< 0.01	2.50	< 0.10	15.5	26.8
B	muscle	KIVALINA	4/6/91	m		300		1.60	0.01	2.00	0.10	17.4	24.9
B	muscle	KIVALINA	4/6/91	m	197	294		6.10	< 0.01	2.20	< 0.10	15.0	23.6
B	muscle	KIVALINA	4/6/91	f	201	303		11.60	< 0.01	3.10	0.60	15.5	24.7
B	muscle	KIVALINA	4/6/91	f	237	355		3.20	< 0.01	1.90	< 0.10	18.8	19.3
B	muscle	KIVALINA	4/6/91	f	751	434		1.90	< 0.01	2.20	< 0.10	14.2	28.4
B	muscle	Cominco	4/26/91	f	1279	518		1.20	< 0.01	1.70	< 0.10	14.1	29.1
D	muscle	Cominco	6/16/91	m	962	489		1.40	0.01	3.30	< 0.10	16.0	29.7
D	muscle	Cominco	6/16/91	f	1426	538		1.80	< 0.01	2.20	0.10	15.3	26.4
D	muscle	Cominco	6/16/91	m	1361	541		3.00	< 0.01	2.60	< 0.10	15.6	25.4
D	muscle	Cominco	6/16/91	f	762	461		0.80	< 0.01	2.40	< 0.10	16.0	23.7
D	muscle	Cominco	6/16/91	f	672	417		0.90	< 0.01	1.20	< 0.10	16.4	22.4
D	muscle	Cominco	6/16/91	f	745	430		1.10	< 0.01	1.50	< 0.10	15.1	23.6
D	muscle	Cominco	6/16/91	f	680	443		1.20	0.03	1.50	< 0.10	18.9	23.0
D	muscle	Cominco	6/16/91	f	654	430		1.20	< 0.01	2.00	< 0.10	16.6	24.0
E	muscle	Cominco	10/5/91	F	1162	480		0.55	< 0.02	2.55	0.03	14.9	27.7
E	muscle	Cominco	10/5/91	M	1262	480		0.66	< 0.02	2.85	0.03	13.9	26.9
E	muscle	Cominco	10/5/91	M	2551	614		0.43	< 0.02	2.02	0.04	14.5	27.4
E	muscle	Cominco	10/5/91	F	2188	589		0.13	0.03	2.68	0.04	13.1	30.4
E	muscle	Cominco	10/5/91	F	1616	525		0.22	< 0.02	2.03	0.03	12.8	27.5
E	muscle	Cominco	10/5/91	M	2233	563		0.32	< 0.02	2.42	0.05	12.2	29.1
F	muscle	ADF&G	4/29/92	F	180	291		2.50	< 0.02	2.27	< 0.05	16.5	24.7
F	muscle	ADF&G	4/29/92	F	670	424	(2+2)	2.20	< 0.02	1.46	0.02	14.6	24.4
F	muscle	ADF&G	4/29/92	F	1420	530	(2+3)?	1.80	< 0.02	1.35	< 0.02	14.1	25.9
F	muscle	ADF&G	4/29/92	undet	180	294	(2+1)?	2.60	< 0.02	2.12	0.03	25.9	23.6
F	muscle	ADF&G	4/29/92	F	140	275	(3+1)	1.50	< 0.02	2.08	< 0.02	28.7	20.5
F	muscle	ADF&G	4/29/92	M	160	276		2.60	< 0.02	2.38	0.02	22.9	22.6
F	muscle	ADF&G	4/29/92	M	140	264	(4+1)	3.00	< 0.02	2.57	< 0.02	24.3	21.8
F	muscle	ADF&G	4/29/92	F	150	259	(3+1)	3.90	< 0.02	1.99	0.02	26.1	22.8
G	muscle	ADF&G	9/30/92	F	2820	620	9	1.35	< 0.02	1.74	< 0.02	14.0	23.5
G	muscle	ADF&G	9/30/92	M	3410	674	(3+4)	0.47	< 0.02	1.27	< 0.02	11.0	31.7
G	muscle	ADF&G	9/30/92	F	2630	600	(3+5)	0.72	< 0.02	1.27	< 0.02	13.0	34.4
G	muscle	ADF&G	9/30/92	M	2110	564	(4+4)	0.74	< 0.02	1.26	0.03	13.0	26.2
G	muscle	ADF&G	9/30/92	F	2920	595	(3+4)	0.42	< 0.02	1.59	< 0.02	14.0	30.7
G	muscle	ADF&G	9/30/92	M	673	407	(2+4)	1.26	< 0.02	2.08	0.17	14.0	35.5
H	muscle	ADF&G	4/21/93		1032	480		1.00	< 0.01	1.38	0.02	16.0	25.4
H	muscle	ADF&G	4/21/93		717	414	(2+3)	1.40	< 0.01	1.45	0.03	18.0	27.4

Appendix 1, concluded.

Sample Group	Matrix	Collector	Date	Sex	Weight grams	Length mm	age (fresh/ salt)	Al mg/kg	Cd mg/kg	Cu mg/kg	Pb mg/k	Zn mg/kg	% Solids
H	muscle	ADF&G	4/21/93		701	421	(4+2)	1.30	< 0.01	1.49	0.02	20.0	27.4
H	muscle	ADF&G	4/21/93		685	398	(3+2)	1.30	< 0.01	1.38	0.02	16.0	26.5
H	muscle	ADF&G	4/21/93		611	407	6	1.20	< 0.01	1.23	0.02	18.0	24.8
H	muscle	ADF&G	4/21/93		2168	575	(2+3)	1.30	< 0.01	1.27	0.07	15.0	25.8
I	muscle	ADF&G	10/20/93	F	2168	575	(3+3)	2.70	< 0.02	16.70	0.22	14.6	36.7
I	muscle	ADF&G	10/20/93	M	1352	491	(4+3)	2.60	< 0.02	1.57	< 0.01	14.5	29.6
I	muscle	ADF&G	10/20/93	M	1551	498	(3+3)	2.10	< 0.02	1.51	< 0.01	14.0	31.1
I	muscle	ADF&G	10/20/93	F	1188	456	(3+3)	1.90	< 0.02	1.91	< 0.01	16.1	31.3
I	muscle	ADF&G	10/20/93	M	1324	473	(3+3)	2.10	< 0.02	1.37	< 0.01	14.7	31.4
I	muscle	ADF&G	10/20/93	M	2204	556	(3+4)	1.80	< 0.02	1.00	< 0.01	11.7	33.1

Appendix 2. Quality control/quality assurance data for concentrations of metals in Dolly Varden tissues collected in 1993. (Metals concentrations data presented in Appendix 1.)

Dates of Samples QA/QC applies to	Metal	Method	MRL	Duplicate Samples			Matrix Spike Results				Method Blank
				Sample A	Sample B	%Relative Difference	Spike Level	Sample Result	Spike Result	% Recovery	
4/21/93	Al	200.8	0.2	1.4	1.6	13	8.6	1.4	12.9	134	0.8
	Cd	200.8	0.01	ND	ND	<1	4.3	ND	4.28	100	ND
	Cu	200.8	0.05	1.45	1.47	1	8.6	1.45	9.76	97	ND
	Pb	200.8	0.01	0.03	0.01	100	4.4	0.03	4.26	96	ND
	Zn	7950	1	18	18	<1	43	18	59	95	ND
4/21/93	Al	200.8	0.2	1.3	1	25	8.4	1.3	9.1	93	0.6
	Cd	200.8	0.01	ND	ND	<1	4.2	ND	4.17	99	ND
	Cu	200.8	0.05	1.24	1.3	5	8.4	1.24	9.46	98	ND
	Pb	200.8	0.01	0.07	0.02	125	4.2	0.07	4.35	105	ND
	Zn	7950	1	15	15	<1	42	15	58	102	ND
10/20/93	Al	200.8	0.2	2.6	2.2	17	9.4	2.6	11	89	0.7
	Cd	200.8	0.02	ND	ND	<1	4.7	ND	4.41	94	ND
	Cu	200.8	0.05	1.57	1.78	12	9.4	1.57	10.3	93	ND
	Pb	200.8	0.02	ND	0.3	--	4.7	ND	4.43	94	ND
	Zn	200.8	0.5	14.5	13.2	9	47	14.5	56.8	90	ND
10/20/93	Al	200.8	0.2	1.8	1.5	19	10	1.8	10.9	91	0.7
	Cd	200.8	0.02	ND	ND	--	5	ND	4.89	98	ND
	Cu	200.8	0.05	1	1.12	11	10	1	10.1	91	ND
	Pb	200.8	0.02	ND	ND	--	5	ND	4.72	94	ND
	Zn	200.8	0.5	11.7	12.9	10	50	11.7	60.1	97	0.6

Appendix 3. Dolly Varden collected in Evaingiknuk Creek using minnow traps baited with salmon roe, 1990-1993.

Sample Time	Number of Traps	Hours Fished/ Trap	Total Number DV	Length Range (mm), (Average)	DV/Trap ±SD
7/27-28/90	5	30	38	58-153(99)	7.6±7.2
8/23-24/90	5	24	23	56-174(101)	4.6±5.9
6/17-18/91	5	24	27	69-129(80)	5.4±8.2
6/18-19/91	5	25	34	66-110(77)	6.8±6.4
6/19-20/91	5	23	25	69-127(77)	5.0±3.6
7/20-21/91	2	24	15	90-107(98)	7.5±10.7
7/21-22/91	2	23	16	83-115(96)	8.0±1.4
8/5-6/91	5	18	34	62-136(97)	6.8±3.5
8/27-28/91	5	20	16	64-135(96)	3.2±2.3
8/28-29/91	5	25	14	59-113(88)	2.8±1.8
8/29-30/91	5	18	20	54-116(93)	4.0±3.4
10/2-3/91	5	24	0		0.0
10/3-4/91	5	24	1	64	0.2±0.4
10/4-5/91	5	26	1	62	0.2±0.4
6/30-7/1/92	10	24	39	64-112(80)	3.9±3.7
7/28-29/92	10	24	63	70-125(90)	6.3±3.2
8/25-26/92	10	24	111	73-143(90)	11.1±9.0
6/29-30/93	10	24	29	70-114(94)	2.9±2.1
8/24-25/93	10	22	26	59-118(93)	2.6±3.1

Appendix 4. Dolly Varden collected in Dudd Creek using minnow traps baited with salmon roe, 1990-1993.

Sample Time	Number of Traps	Hours Fished/ Trap	Total Number DV	Length Range (mm), (Average)	DV/Trap ±SD
8/23-24/90	5	22	2	80,127	0.4±0.5
8/24-26/90	5	41	8	89-133(115)	1.6±3.6
9/12-13/90	5	15	1	125	0.2±0.4
9/13-14/90	5	25	0		0.0
9/14-15/90	5	23	2		0.4±0.9
7/17-18/91	5	23	8	55-118(82)	1.6±1.8
7/18-19/91	5	23	10	55-134(101)	2.0±1.6
7/19-20/91	5	21	9	59-133(84)	1.8±2.2
8/5-8/91	5	65	36	53-161(92)	7.2±5.7
8/27-30/91	5	64	8	68-136(101)	1.6±2.1
10/2-5/91	5	72	35	69-145(89)	7.0±12.0
6/30-7/1/92	10	23	0		
7/28-29/92	10	24	9	54-110(89)	0.9±1.3
8/25-26/92	10	24	48	57-138(116)	4.8±4.8
6/29-30/93	10	24	1	79	0.1±0.3
8/24-25/93	10	20	20	63-148(103)	2.0±1.6

Appendix 5. Dolly Varden collected in Anxiety Ridge Creek using minnow traps baited with salmon roe, 1990-1993.

Sample Time	Number of Traps	Hours Fished/ Trap	Total Number DV	Length Range (mm), (Average)	DV/Trap ±SD
7/27-28/90	5	27.5	7	104-152(133)	1.4±2.1
7/28-29/90	5	23	3	89-128(108)	0.6±0.9
7/29-30/90	5	16.5	9	107-146(132)	1.8±2.0
8/24-25/90	5	17	14	78-166(135)	3.5±1.9
8/25-26/90	5	22	10	75-160(140)	2.0±3.5
9/14-15/90	3	22	1	82	0.3±0.6
5/23-24/91	5	18	0		0.0
6/17-18/91	5	24	2	90,95	0.4±0.6
6/18-19/91	5	25	0		0.0
6/19-20/91	5	22	2	85,137	0.4±0.6
7/20-21/91	5	24	25	99-153(114)	5.0±8.0
7/21-22/91	5	24	18	60-131(100)	3.6±5.9
7/22-23/91	5	13	11	62-155(109)	2.2±3.8
8/5-6/91	5	19	75	88-147(118)	15.0±15.3
8/6-7/91	5	24	79	88-148(118)	15.8±11.3
8/7-8/91	5	20	81	99-147(117)	16.2±10.6
8/27-28/91	5	24	34	71-143(111)	6.8±8.8
8/28-29/91	5	25	3	71-126(90)	0.6±0.9
8/29-30/91	5	17	27	68-135(115)	5.4±4.8
10/2-3/91	4	24	6	108-137(121)	1.5±0.6
10/3-4/91	5	21	7	87-136(123)	1.4±2.6

Appendix 5 continued.

Sample Time	Number of Traps	Hours Fished/ Trap	Total Number DV	Length Range (mm), (Average)	DV/Trap ±SD
10/4-5/91	5	26	4	78-133(117)	0.8±0.8
6/30-7/1/92	10	23	11	89-131(113)	1.1±1.7
7/28-29/92	10	24	223	82-144(101)	22.3±13.4
8/25-26/92	10	24	334	60-162(102)	33.4±17.4
6/29-30/93	10	24	55	74-161(109)	5.5±6.8
8/24-25/93	10	22	295	58-159(113)	29.5±8.5

Appendix 6. Dolly Varden collected in Little Creek using minnow traps baited with salmon roe, 1990-1993.

Sample Time	Number of Traps	Hours Fished/ Trap	Total Number DV	Length Range (mm), (Average)	DV/Trap ±SD
7/29-30/90	5	17	7	97-127(107)	1.4±1.5
6/17-18/91	5	24	4	131-163(145)	0.8±1.3
6/18-19/91	5	25	0		0.0
6/19-20/91	5	22	0		0.0
7/20-21/91	5	24	2	112,113	0.4±0.9
7/21-22/91	5	24	4	99-114(107)	0.8±1.3
7/22-23/91	5	14	4	92-114(107)	0.8±1.8
8/5-6/91	5	21	7	104-142(120)	1.4±1.1
8/6-7/91	5	25	8	54-140(116)	1.6±1.1
8/7-8/91	5	19	8	54-142(116)	1.6±1.1
8/27-28/91	5	22	1	51	0.2±0.4
8/28-29/91	5	25	1	126	0.2±0.4
8/29-30/91	5	19	1	58	0.2±0.4
10/2-3/91	4	24	2	61,78	0.5±1.0
10/3-4/91	5	21	1	60	0.2±0.4
10/4-5/91	5	26	1	102	0.2±0.4
6/30-7/1/92	10	23	0		
7/28-29/92	10	24	17	88-136(100)	1.7±3.7
8/25-26/92	10	24	74	60-145(105)	7.4±5.3
6/29-30/93	10	24	1	122	0.1±0.3
8/24-25/93	10	22	8	54-132(80)	0.8±1.0

Appendix 7. Dolly Varden collected in Ikalukrok Creek using minnow traps baited with salmon roe, 1990-1993. Minnow trap sample sites included Ikalukrok Creek from upstream of the mouth of Red Dog Creek to the lower portion of Ikalukrok Creek about 20 km downstream of mouth of Dudd Creek. Sample stations (#1 - #5) in Ikalukrok Creek at Dudd Creek were the same in 1990, 1991, 1992, and 1993; however, five additional sites were established and run in 1992 and 1993.

Sample Time	Number of Traps	Hours Fished/ Trap	Total Number DV	Length Range (mm), (Average)	DV/Trap ±SD
[a]7/27-28/90	5	19	0		0.0
[b]7/27-28/90	5	23	1	107	0.2±0.4
[c]7/28-29/90	5	23	0		0.0
[d]7/28-29/90	5	22	0		0.0
[d]8/23-24/90	5	24	0		0.0
[e]8/23-24/90	5	24	0		0.0
[e]8/24-26/90	5	48	0		0.0
[f]8/24-29/90	5	120	0		0.0
[d]9/12-13/90	4	24	0		0.0
[d]9/13-14/90	4	20	0		0.0
[d]9/14-15/90	4	23	0		0.0
[f]9/13-14/90	5	24	0		0.0
[f]9/14-15/90	4	25	0		0.0
[e]9/13-14/90	5	22	0		0.0
[e]9/14-15/90	5	23	0		0.0
[e]7/17-18/91	5	23	6	53-61(57)	1.2±1.1
[e]7/18-19/91	5	23	4	52-109(72)	0.8±0.8
[e]7/19-20/91	5	21	9	82-140(112)	1.8±1.9
[e]8/5-8/91	5	65	10	60-105(66)	2.0±2.5

Appendix 7 continued.

Sample Time	Number of Traps	Hours Fished/ Trap	Total Number DV	Length Range (mm), (Average)	DV/Trap ±SD
[e]8/27-30/91	5	65	0		0.0
[e]10/2-5/91	5	73	0		0.0
[g]6/30-7/1/92	10	24	0		
[g]7/28-29/92	10	24	6	56-104(76)	0.6±1.3
[g]8/25-26/92	10	24	58	60-155(102)	5.8±5.8
[g]6/29-30/93	10	24	8	76-93(83)	0.8±1.0
[g]8/24-25/93	10	22	38	62-137(82)	3.8±3.8

[a]Ikalukrok Creek - 7 km upstream of Dudd Creek
[b]Ikalukrok Creek - 10 km downstream of Dudd Creek
[c]Ikalukrok Creek - 10 km downstream of Dudd Creek, clear back-water
[d]Ikalukrok Creek - 20 km downstream of Dudd Creek
[e]Ikalukrok Creek - Immediately upstream of Dudd Creek
[f]Ikalukrok Creek - Immediately upstream of Red Dog Creek
[g]Ikalukrok Creek - Immediately upstream and downstream of Dudd Creek

Appendix 8. Dolly Varden collected in the North Fork of Red Dog Creek using minnow traps baited with salmon roe, 1992-1993.

Sample Time	Number of Traps	Hours Fished/ Trap	Total Number DV	Length Range (mm), (Average)	DV/Trap ±SD
7/27-30/92	5	72	2	124,133	0.4±0.9
8/24-25/92	5	22	1	168	0.2±0.4
6/28-29/93	10	24	0		0.0
8/23-25/93	10	48	31	74-148(113)	3.1±3.1