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

By:
Alvin G. Ott, Phyllis K. Weber-Scannell,
and Matthew H. Robus

Technical Report No. 91-4

Alaska Department of Fish & Game
Division of Habitat

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Mr. John Rense and Mr. Walter Sampson of NANA also supported our efforts to learn more about the effects of the Red Dog Mine on the Wulik River fisheries. Mr. Joe Swan (Kivalina) provided samples of adult Dolly Varden to the department. Mr. Swan and Mr. Alan Butera (Kivalina) expressed interest in our study results and assisted in several public meetings held in Kivalina. Staff from both the Kivalina and Noatak school districts applied for and received a grant for heavy metals analyses for adult Dolly Varden from the Noatak and Wulik rivers.

Phil Driver and Jim Rood greatly assisted our efforts by providing on-site reports concerning the condition of the Wulik River and Ikalukrok Creek. In the summer of 1990, Jim Rood (Northwest Aviation) provided air support which enabled us to collect samples in Ikalukrok Creek.

Positive and constructive technical review of the report were provided by Mr. Fred DeCicco and Mr. Bill Arvey (Sport Fish Division). Final typing and editing of the report was done by Ms. Nancy Ihlenfeldt.

EXECUTIVE SUMMARY

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. Between early 1988 and late 1989, overburden was stripped from the ore deposit. During the fall of 1989 and the summer of 1990, heavy metals concentrations in Red Dog and Ikalukrok creeks greatly exceeded concentrations reported prior to mining activities. In late winter 1991, a clean/dirty water bypass system was installed and water quality conditions in Red Dog and Ikalukrok creeks improved dramatically. To assess the effects of heavy metals concentrations in receiving waters, we began a fishery study in 1990. The study focuses on heavy metals concentrations in adult Dolly Varden in the Wulik River, distribution of adult chum salmon in Ikalukrok Creek, use of the North Fork of Red Dog Creek by Arctic grayling, distribution of overwintering Dolly Varden in the Wulik River upstream and downstream of its confluence with Ikalukrok Creek, and relative abundance and seasonal use patterns of juvenile Dolly Varden in selected waterbodies.

We determined that heavy metals concentrations in adult Dolly Varden tissues collected in the Wulik River in 1990 and 1991 did not differ substantially from baseline data collected in 1982 and 1983. Furthermore, concentrations of heavy metals were similar for Dolly Varden wintering in the Noatak and Wulik river drainages.

We counted and assessed the 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. Our hypothesis that 90 percent of the overwintering adult Dolly Varden continue to use the Wulik River downstream of the mouth of Ikalukrok Creek in numbers comparable to baseline data appeared valid.

Distribution and use of Ikalukrok Creek by adult chum salmon was determined in both 1990 and 1991. Chum salmon spawned in Ikalukrok Creek in 1991 in the same areas used historically, although the number of fish was lower.

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 were determined. Highest use by Dolly Varden juveniles was documented in Anxiety Ridge Creek supporting findings of researchers collecting baseline data.

Dolly Varden use of Ikalukrok Creek during the summer of 1990 was virtually non-existent. However, with improved water quality in 1991, juvenile Dolly Varden were present in Ikalukrok Creek.

Finally, we determined that Arctic grayling continue to spawn in the North Fork of Red Dog Creek and young-of-the-year Arctic grayling were present. Patterns of use and relative abundance were consistent with observations made by previous investigators.

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 at the mine site include the tailings impoundment on the South Fork of Red Dog Creek, airstrip, mill, living quarters, solid waste site, and a freshwater impoundment on Bons Creek (Figure 2). The mine site is linked to the coast via a 52 mile haul road called the Delong Mountains Regional Transportation System (DMRTS). Zinc (Zn) and lead (Pb) are processed at the mill, transported by truck to a concentrate storage building at the port site, and loaded on ships during the ice-free season. The haul road system, including access roads to material sites, crosses streams tributary to the Wulik, Omikviorok, and Noatak rivers and the New Heart Creek system which drains directly into Ipiavik Lagoon. Dolly Varden (*Salvelinus malma*), Arctic grayling (*Thymallus arcticus*), and slimy sculpin (*Cottus cognatus*) occur in many of the streams crossed by the haul road. Adult Dolly Varden spawning areas are documented in the Omikviorok River and Tutak, Dudd, and Anxiety Ridge creeks.

The Red Dog Mine is a world-class lead-zinc mine. The ore body straddles the mainstem of Red Dog Creek (Figure 2). Ore rich in heavy metals is directly exposed on the ground surface. Vegetation is nearly absent; the ground surface is multicolored (e.g., red, yellow, white, black, orange), and high concentrations of heavy metals [2.6 to 16.5 mg/L Zn (Ward and Olson 1980 and Peterson 1983, respectively)] were apparent in the mainstem of the Red Dog Creek drainage immediately upstream of the North Fork of Red Dog Creek before any development activity occurred . The Red Dog ore deposit and other highly mineralized areas (e.g., the Hill Top Deposit) in the Red Dog Creek

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

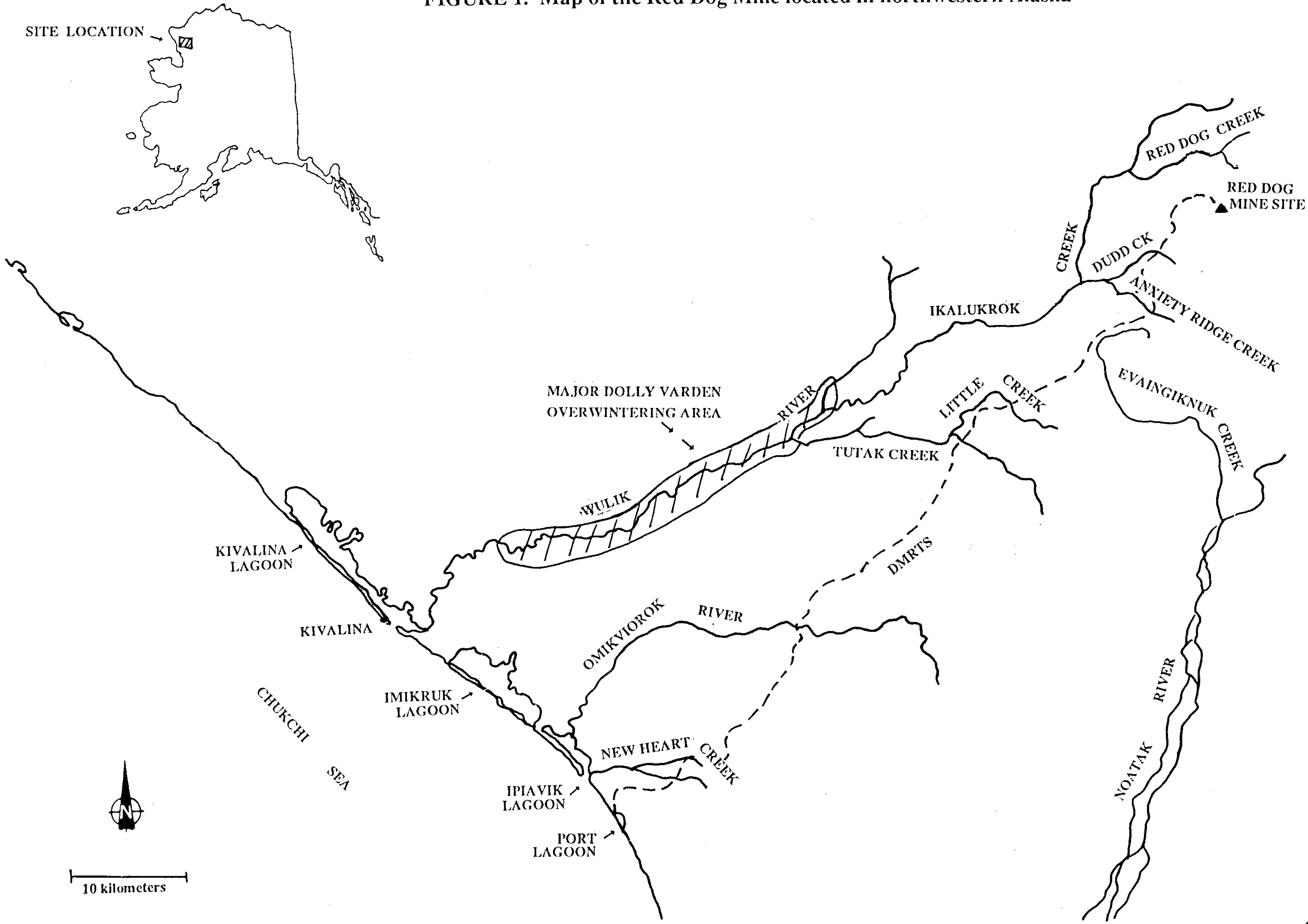
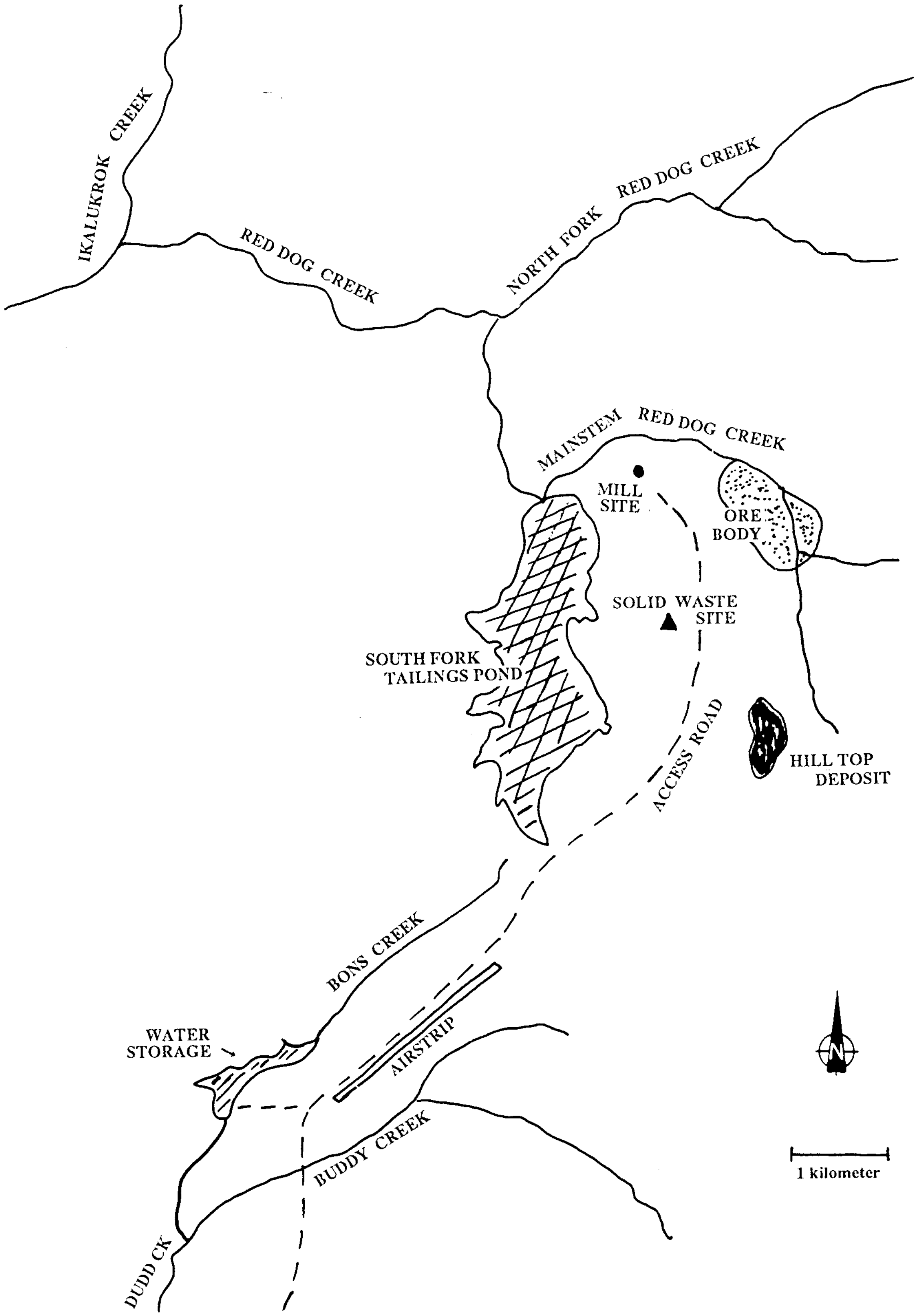


FIGURE 2. Major facilities, including the mill, airstrip, tailings impoundment, solid waste site, and freshwater impoundment at the Red Dog Mine.



drainage also contain aluminum (Al), copper (Cu), iron (Fe), cadmium (Cd), silver (Ag), and nickel (Ni).

Between early 1988 and late 1989, overburden was stripped from the ore deposit. In late fall of 1989, ore production activities began. Elevated concentrations of heavy metals in Red Dog and Ikalukrok creeks were reported in the fall of 1989 and again during the summer and fall of 1990 (Weber-Scannell 1992, In Prep.). Concentrations of Zn reached as high as 1,500 mg/L in Red Dog Creek and 60 mg/L in Ikalukrok Creek. Heavy metals concentrations greatly exceeded those reported in baseline data collected by Dames and Moore (1983). Discoloration of receiving waters was noticeable in the fall of 1989 and summer and fall of 1990. Orange and/or green/white colored water was visible throughout the entire length of Ikalukrok Creek with effects visible in the Wulik River immediately downstream of the mouth of Ikalukrok Creek.

Highly acidic ground and subsurface waters carried heavy metals from the ore body into surface waters of Red Dog Creek. Based on field observations and heavy metals data gathered during 1989 and 1990 by Cominco Alaska, Inc., the Alaska Department of Fish and Game (ADF&G), and the Alaska Department of Environmental Conservation (ADEC), agreement was reached in August of 1990 to develop and implement an engineering solution that would decrease heavy metals concentrations in Red Dog Creek. As a result of these efforts, a clean/dirty water bypass system was designed by Cominco Alaska, Inc. and the system was constructed during late winter of 1991. The clean/dirty water bypass system was functional throughout the summer of 1991. In 1991, water in Ikalukrok Creek was clear and substrate materials were covered with algae.

Ikalukrok Creek, a major tributary to the Wulik River system, is the first receiving waterbody downstream of the Red Dog Mine. Ikalukrok Creek contains both anadromous and resident fish species including Arctic grayling, slimy sculpin, chum salmon (*Oncorhynchus keta*), and Dolly Varden. The Wulik River is one of northwestern Alaska's most important fish streams, and is especially prominent for its Dolly Varden population. The estimated number of overwintering Dolly Varden in the Wulik River between 1968 and 1991 has ranged from 30,000 to 297,000 adult fish (Alt 1978, Yanagawa 1969). Humpback (*Coregonus pidschian*) and round whitefish (*Prosopium cylindraceum*), least (*Coregonus sardinella*) and Bering (*Coregonus laurettae*) cisco, Alaska blackfish (*Dallia pectoralis*), Arctic grayling, slimy sculpin, chum salmon, pink salmon (*O. gorbuscha*), sockeye salmon (*O. nerka*), coho salmon (*O. kisutch*), chinook salmon (*O. tshawytscha*), and ninespine stickleback (*Pungitius pungitius*) also occur in the Wulik River. Chum salmon and Dolly Varden spawn in Ikalukrok Creek downstream of its confluence with Red Dog Creek. An estimated 85 percent of the Dolly Varden in the Wulik River overwinter in the Wulik River immediately downstream of its confluence with Ikalukrok Creek.

Any heavy metals released into the upper mainstem of Red Dog Creek, whether from natural causes or from mining, have the potential to affect fish use of Ikalukrok Creek and the Wulik River drainage. Because of the significant subsistence fishery and the prominence of the sport fishery for Dolly Varden, there was intense local, regional, and statewide interest in ensuring the long-term health of the Wulik River fisheries. During the first year of mining at Red Dog, Habitat Division of the ADF&G received a number of requests for information concerning what, if any, effects from mining were occurring.

We initiated a fishery study of those streams directly affected by waters emanating from the Red Dog Mine because of the significant numbers of fish present in the Wulik River drainage downstream of the Red Dog Mine, the location of the major overwintering habitat in the Wulik River downstream of Ikalukrok Creek, the importance of fisheries to subsistence and sport users, and the high concentrations of heavy metals documented during the fall of 1989 and the summer and fall of 1990 (Weber-Scannell 1992, In Prep.).

We gathered preliminary data, with substantial logistical support from Cominco Alaska, Inc. in 1990. A more formalized study design was developed during the winter of 1990-91 and funding was obtained from Cominco Alaska, Inc. to conduct three years of fisheries work with field sampling commencing during the summer of 1991. Future work will be decided after completion of the first three years of field sampling and data analyses. Our progress report includes data collected during 1990 and data gathered during the first year (i.e., 1991) of the three year study.

DESCRIPTION OF STUDY AREA AND STREAMS

The study area includes Red Dog Creek, North Fork of Red Dog Creek, Ikalukrok Creek, Anxiety Ridge Creek, Dudd Creek, Evaingiknuk Creek, Little Creek, and the lower Wulik River (Figure 1). A brief description of each sample reach follows:

Red Dog Creek

Red Dog Creek, upstream of the North Fork, has a 24.2 km^2 drainage with an estimated 0.25 m^3s^{-1} Q^2 3-day summer low flow (Ashton and Carlson 1984). The mainstem of Red Dog Creek, similar in size to the North Fork, is mineralized with high concentrations of heavy metals, particularly in the vicinity of the ore body upstream of the South Fork of Red Dog Creek. The ore is in the form of metal sulfides of the Mississippian chert formation (Dames & Moore 1981). In numerous surveys, no fish were collected or observed in Red Dog Creek above the North Fork confluence (Houghton and Hilgert 1983). Periodic fish kills (young-of-the-year Arctic grayling, Dolly Varden juveniles) were observed in lower Red Dog Creek below the North Fork confluence (Houghton and Hilgert 1983). According to Peterson (1983), some surface water does exist in portions of Red Dog Creek during the winter months. However, it is unlikely that suitable overwintering habitat for fish exists in Red Dog Creek. Our current program does not include fish sampling of Red Dog Creek.

North Fork of Red Dog Creek

The North Fork of Red Dog Creek has a 36.9 km^2 drainage with an estimated 0.34 m^3s^{-1} Q^2 3-day summer low flow (Ashton and Carlson 1984). The North Fork of Red Dog Creek joins the mainstem of Red Dog Creek approximately 3 km upstream of the confluence of Red Dog and Ikalukrok creeks. Arctic grayling spawn in the North Fork of

Red Dog Creek and young-of-the-year Arctic grayling fry generally are present by the first week of July (Houghton and Hilgert 1983). With the exception of one Dolly Varden collected in the upper North Fork of Red Dog Creek, other fish species (e.g., sculpin) and juvenile Arctic grayling (>age 0+) are absent (Houghton and Hilgert 1983). The North Fork of Red Dog Creek is a small, clearwater stream with high dissolved oxygen concentrations and low levels of suspended sediments. In comparison with the mainstem of Red Dog Creek, heavy metals concentrations were low (Peterson 1983). Our sample reach included a 3 km section beginning at the mouth of the North Fork of Red Dog Creek. It appears that overwintering habitat for fish is absent and that outmigrating fish travel to lower Ikalukrok Creek or the Wulik River for wintering.

Ikalukrok Creek

Ikalukrok Creek has a 485.8 km^2 drainage with an estimated 2.24 m^3s^{-1} Q^2 3-day summer low flow (Ashton and Carlson 1984). Ikalukrok Creek, a major tributary to the Wulik River, enters the Wulik River immediately upstream of the reach of the Wulik River where most of the Dolly Varden overwinter (Figure 1). Spawning Dolly Varden and chum salmon and rearing juvenile Dolly Varden, Arctic grayling, and slimy sculpin occur in Ikalukrok Creek. Moderate water quality degradation occurs in Ikalukrok Creek immediately downstream of its confluence with Red Dog Creek. Ikalukrok Creek was selected as a sample area because of its importance for chum salmon and Dolly Varden spawning and waters from Ikalukrok Creek enter the Wulik River system immediately upstream of where over 90 percent of the Dolly Varden overwinter. Overwintering habitat probably occurs in Ikalukrok Creek immediately downstream of the mouth of Dudd Creek, in a reach about 6 to 8 km below the mouth of Dudd Creek (Houghton and Hilgert 1983), and in the lower 20 km of the stream. Our sample reach included Ikalukrok Creek from its mouth to its confluence with Red Dog Creek.

Anxiety Ridge Creek

Anxiety Ridge Creek, upstream of the DMRTS, has a 14.7 km^2 drainage with an estimated 0.17 m^3s^{-1} Q^2 3-day summer low flow (Ashton and Carlson 1984). Anxiety Ridge Creek is a small, clearwater stream with a cobble and gravel substrate. In September 1982, 10 Dolly Varden redds were observed in Anxiety Ridge Creek immediately upstream from its confluence with Buddy/Bons Creek (Dames and Moore 1984). Dames and Moore (1984) characterized Anxiety Ridge Creek as the most productive system sampled, with high Dolly Varden densities. Overwintering habitat may exist in the vicinity of the Dolly Varden spawning habitat. Our sample reach included portions of the stream immediately upstream and downstream of the haul road crossing. Anxiety Ridge Creek was selected as a sample area because of past documentation regarding high fishery productivity. Although Anxiety Ridge Creek is not directly affected by point or non-point source runoff from the mine site, fish using Anxiety Ridge Creek probably migrate to and from overwintering habitats in the Wulik River and Ikalukrok Creek.

Dudd Creek

Dudd Creek has a 47.4 km^2 drainage with an estimated 0.41 m^3s^{-1} Q^2 3-day summer low flow (Ashton and Carlson 1984). Dudd Creek is formed by the confluence of Buddy/Bons and Anxiety Ridge creeks. Approximately 20 Dolly Varden spawned in Dudd Creek immediately below the confluence of Buddy/Bons and Anxiety Ridge creeks in September 1982 (Houghton and Hilgert 1983). A school of several hundred Dolly Varden (estimated length range from 235 mm to 257 mm) were observed in Dudd Creek in September 1982 (Houghton and Hilgert 1983). Dudd Creek is a small stream tributary to Ikalukrok Creek with a cobble and gravel substrate. Dudd Creek occupies a single channel with small gravel bars on the inside of bends and vegetated, undercut banks on the outside of the bends. Dudd Creek is generally clear, carries little suspended sediments, and the water is highly oxygenated (Peterson 1983). In 1982, the pH was neutral and the highest water temperature recorded was 11.4°C (Peterson 1983). Mineralization is low (Peterson 1983) and Dudd Creek is not directly affected by either non-point or point source waters from the Red Dog Mine (i.e., tailings impoundment, ore body, water treatment effluent). Our sample reach (i.e., minnow trap sites) encompassed the lower .5 km of Dudd Creek immediately upstream from Ikalukrok Creek. Documentation of juvenile Dolly Varden in late fall in lower Dudd Creek and the fact that Dolly Varden spawn in the system strongly indicate that overwintering habitat is present.

Evaingiknuk Creek

Evaingiknuk Creek, upstream of the access road to Material Site 12 (MS 12), has a 7.7 km^2 drainage with an estimated 0.11 m^3s^{-1} Q^2 3-day summer low flow (Ashton and Carlson 1984). The drainage area for the entire creek is 243 km^2 with an estimated 1.34 m^3s^{-1} Q^2 3-day summer low flow (Ashton and Carlson 1984). Evaingiknuk Creek is a tributary to the Noatak River system. The creek was selected for sampling because of accessibility and because juvenile Dolly Varden could not have been affected by non-point or point source waters from the Red Dog Mine. Dolly Varden fry (55 to 64 mm) and juveniles (119 mm) and slimy sculpin were collected in Evaingiknuk Creek in August 1984 (Dames and Moore 1984). Evaingiknuk Creek is a small, single channel stream with a cobble and gravel substrate and vegetated stream banks. Our sample reach (i.e., minnow trap sites) is located approximately 1 km upstream of where Dames and Moore sampled in 1984. We spaced minnow traps over a stream distance of about 0.5 km with traps placed upstream and downstream of the access road crossing of

Evaingiknuk Creek. Extensive overflow (i.e., aufeis) exists in Evaingiknuk Creek about 10 stream km downstream of the MS 12 access road crossing. Small numbers of anadromous Dolly Varden spawn in Evaingiknuk Creek in the vicinity of an aufeis field (DeCicco 1991, pers. comm.). Therefore, habitat to support overwintering fish probably exists in Evaingiknuk Creek.

Little Creek

Little Creek is a tributary to Tutak Creek which flows into the Wulik River approximately 3.5 km downstream of the mouth of Ikalukrok Creek. Little Creek, upstream of the DMRTS road, has a 16.9 km^2 drainage with an estimated 0.19 m^3s^{-1} Q^2 3-day summer low flow (Ashton and Carlson 1984). The drainage area upstream from the confluence of Little and Tutak creeks is 65.2 km^2 drainage with an estimated 0.51 m^3s^{-1} Q^2 3-day summer low flow (Ashton and Carlson 1984). Little Creek is a small, deeply incised stream with a gravel/cobble substrate and vegetated stream banks. We selected Little Creek as a sample site because it is similar in size to Evaingiknuk Creek and while in the Wulik River drainage it is not directly affected by either point or non-point source waters from the Red Dog Mine. We have not identified nor do we suspect fish overwintering habitat in Little Creek in the vicinity of our sample reach. Our sample reach (i.e., minnow trap sites) encompasses about 0.5 km of stream immediately downstream of the Red Dog haul road. The nearest known overwintering habitat for fish is in the Wulik River approximately 28 km from our sample sites.

Lower Wulik River

The Wulik River system provides overwintering habitat for Dolly Varden from a number of river systems. Estimates have ranged from 30,000 to 225,000 Dolly Varden overwintering in the Wulik River, most of which occur in the Wulik River downstream of the mouth of Ikalukrok Creek. As many as 5,000 chum salmon and several thousand pink salmon spawn in the Wulik River and Arctic grayling are found throughout the system. Our sample reach in the Wulik River covered from its mouth to upstream of the confluence of the Wulik River and Ikalukrok Creek. Fish in the Wulik River drainage, particularly Dolly Varden, are important for both subsistence and sport fishing (Burch 1985).

Stream Summary

Fish use (migration, spawning, rearing, overwintering) of each waterbody, drainage area in km^2, and comments relative to effects (direct or indirect) from waters leaving the Red Dog Mine area (includes ore body, mill, tailings impoundment) are summarized in Table 1. Resource summary information for fish includes only Arctic grayling and Dolly Varden.

Table 1. The drainage area (km^2), fish use [Arctic grayling (AGR) and Dolly Varden (DV)], and location of the waterbody relative to effects from heavy metals emanating from the Red Dog ore body and facilities directly associated with mining and processing of zinc and lead.

Stream Name	Fish Use	Drainage Area	Comments
Red Dog	migration (AGR)	24.2	elevated heavy metals (natural and non-point from mine)
North Fork	migration (AGR) spawning (AGR) rearing (AGR)	36.9	control stream, no direct effects from mine; however, fish move through Red Dog to reach North Fork
Ikalukrok	migration (AGR, DV) spawning (DV) rearing (AGR, DV) overwintering	485.8	elevated heavy metals fall 1989 and summer 1990, reduced heavy metals in 1991, some elevated metals in 1991 immediately below Red Dog
Anxiety Ridge	migration (AGR, DV) rearing (AGR, DV)	14.7	control stream, no direct effects from mine; however, fish move through Ikalukrok to reach Anxiety Ridge
Dudd	migration (AGR, DV) spawning (DV) rearing (AGR, DV) overwintering	47.4	control stream, no direct effects from mine; however, fish move through Ikalukrok to reach Dudd Creek
Evaingiknuk	migration (AGR, DV) rearing (AGR, DV)	7.7	control stream, no direct effects from mine, a Noatak River tributary
Little	migration (AGR, DV) rearing (AGR, DV)	16.9	control stream, no direct effects from mine, Tutak River tributary

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 content of fish tissues would result from changes in water quality and quantity 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 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 during mid-August in Ikalukrok Creek using aerial surveys from the mouth of Ikalukrok Creek to Dudd Creek.

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

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_O: 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 use of North Fork of Red Dog Creek.

H_O: 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 and Noatak, we collected adult Dolly Varden by angling in the Wulik and Noatak rivers during 1990 and 1991. Wulik River Dolly Varden were collected near the confluence of Tutak Creek and the Wulik River during the spring (i.e., after breakup) and in the fall (i.e., prior to freezeup). Each Dolly Varden was placed in a clean plastic container which was labeled with 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.

In 1990, we also collected juvenile Dolly Varden from Tutak, Anxiety Ridge, Dudd, Ikalukrok, and Evaingiknuk creeks and the Kelly River using minnow traps baited with salmon roe. Juvenile Dolly Varden were placed in clean plastic sample containers, labeled, frozen, and shipped to ADF&G in Fairbanks.

We removed the adult Dolly Varden from the freezer and measured and weighed each fish. We dissected the fish when they were partially thawed. Tissue samples from muscle (muscle was removed below the dorsal fin and above the lateral line), gill, kidney, and liver were removed and placed in precleaned 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, scalpels) 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 both otiliths from each fish. We placed the frozen samples in a small cooler and after prenotification we mailed the sample container to an analytical laboratory.

Three juvenile Dolly Varden per sample area, with the exception of Ikalukrok Creek where only one juvenile Dolly Varden was captured, were placed in plastic sample containers and shipped to an analytical laboratory for whole body analyses. Internal organs were not removed.

All samples, including adult tissue samples and whole body juvenile samples were digested, freeze-dried, and analyzed for total Al, Cu, Cd, Pb, and Zn using the methods and method reporting limits (MRL) listed below -- whole bodies of the juvenile Dolly Varden were blended into a single sample:

Metal	Method[1,2]	MRL mg/kg (dry weight basis)
Al	202.2	0.1
Cd	7131.0	0.01
Cu	6010.0	0.5
Pb	7421.0	0.1
Zn	6010.0	0.5

[1]EPA Method 202.2 - "Methods for Chemical Analysis of Water and Wastes" EPA 600/4-79-020

[2]EPA Methods 7131, 7421, 6010 - "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods" SW-846, 3rd Edition, 1986

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 were not performed due to an inadequate sample size ($n = 5$ to 9). We elected to display the median and range for each sample set. We qualitatively compared the 1990 and 1991 heavy metal concentrations in adult Dolly Varden with baseline data collected by Dames and Moore (1983).

We flew aerial surveys using fixed-wing aircraft in August and September of 1990 and

1991 in the Wulik River from its mouth near the village of Kivalina to its confluence with Ikalukrok Creek. Aerial overflights also were made of Ikalukrok Creek from its mouth to the confluence of Dudd Creek and Ikalukrok Creek. From these flights, we estimated the number of overwintering Dolly Varden in the Wulik River and chum salmon spawners in Ikalukrok Creek.

We collected juvenile Dolly Varden and other fish species (e.g., Arctic grayling, slimy sculpin) in Ikalukrok, Dudd, Anxiety Ridge, Evaingiknuk, and Little creeks with minnow traps baited with salmon roe. Salmon roe was placed in perforated plastic containers. Aquatic habitat data such as water depth, estimated water velocity, stream substrate, and stream bank vegetation were recorded for each minnow trap site. We allowed the minnow traps to fish for approximately 24 hours with the exception of sample stations in Dudd and Ikalukrok creeks where traps fished for periods up to 72 hours for logistical reasons (i.e., access was by walking four miles across the tundra). In general, fresh salmon roe was added each time the traps were checked and all fish were removed from the traps, identified, measured, and released. In 1990, several Dolly Varden juveniles from Ikalukrok, Dudd, Anxiety Ridge, Tutak, and Evaingiknuk creeks and the Kelly River were retained for heavy metals analyses, and in 1991 juveniles greater than 70 mm were marked with an adipose fin clip. We established sample areas in each creek system and fixed the location of each minnow bucket for the 1991 sample season. We flagged and placed identification markers in stream bank vegetation for the permanent minnow trap fish sites. The number of fish captured, the fork length of fish (mm), and time fished were recorded for each minnow trap. Number of fish per trap (catch) was tabulated and used to compare catches among sample areas and time. Statistical tests were performed at the 95 percent level of confidence using an one-way Analysis of Variance. Catch-per-unit-of-effort was not used to compare catches of Dolly Varden (Appendix 1).

We conducted visual stream surveys for Arctic grayling in the North Fork of Red Dog and Anxiety Ridge creeks. Angling and electrofishing also were used to sample fish in the North Fork of Red Dog Creek.

RESULTS

Dolly Varden Tissue Heavy Metals Concentrations

Heavy metal concentrations in adult Dolly Varden tissues from 1990 and 1991 do not appear to be substantially different from baseline data collected in 1982 and 1983 (Figures 3 through 7). Heavy metals concentrations (Zn, Cu, Al, Pb, and Cd) expressed in mg/kg dry weight in the liver, gill, muscle, and kidney of adult Dolly Varden are presented in Appendix 2 and quality control/assurance in Appendix 3. Baseline data on heavy metals concentrations collected by Dames and Moore (1983) are included in Figures 3 through 7. A description of each sample group follows:

Sample Group #1 (Wulik River, Dames & Moore 1983) - Dolly Varden collected by Dames and Moore (variable numbers of fish, depending upon tissue);

Sample Group #2 (Wulik River, October 1990) - Six Dolly Varden collected and prepared for analyses by ADF&G;

Sample Group #3 (Wulik River, April 1991) - Four Dolly Varden collected by Cominco Alaska, Inc. and five collected by residents of Kivalina; fish prepared for analyses by ADF&G;

Sample Group #4 (Noatak River, April 1991) - Five Dolly Varden collected by residents of Noatak; fish prepared for analyses by ADF&G;

Sample Group #5 (Wulik River, June 1991) - Eight Dolly Varden collected by Cominco Alaska, Inc.; fish prepared for analyses by ADF&G; and

Sample Group #6 (Wulik River, October 1991) - Six Dolly Varden collected by Cominco Alaska, Inc. and ADF&G; fish prepared for analyses by ADF&G.

The maximum and minimum (i.e., range) and median values for each heavy metal are presented for each tissue. Data from Dames and Moore (1983) (Sample Group #1) are expressed as a range and mean because individual data points could not be obtained. The concentrations of heavy metals in muscle are generally equal to or less than the metals

Figure 3. Concentrations (median, maximum, and minimum) of Zinc (mg/kg dry weight) in adult Dolly Varden tissues (gill, kidney, liver, and muscle) collected in the Noatak (N) and Wulik Rivers in 1982, 1990, and 1991. Median values for 1982 fish were not available -- 1982 concentrations are expressed as a mean.

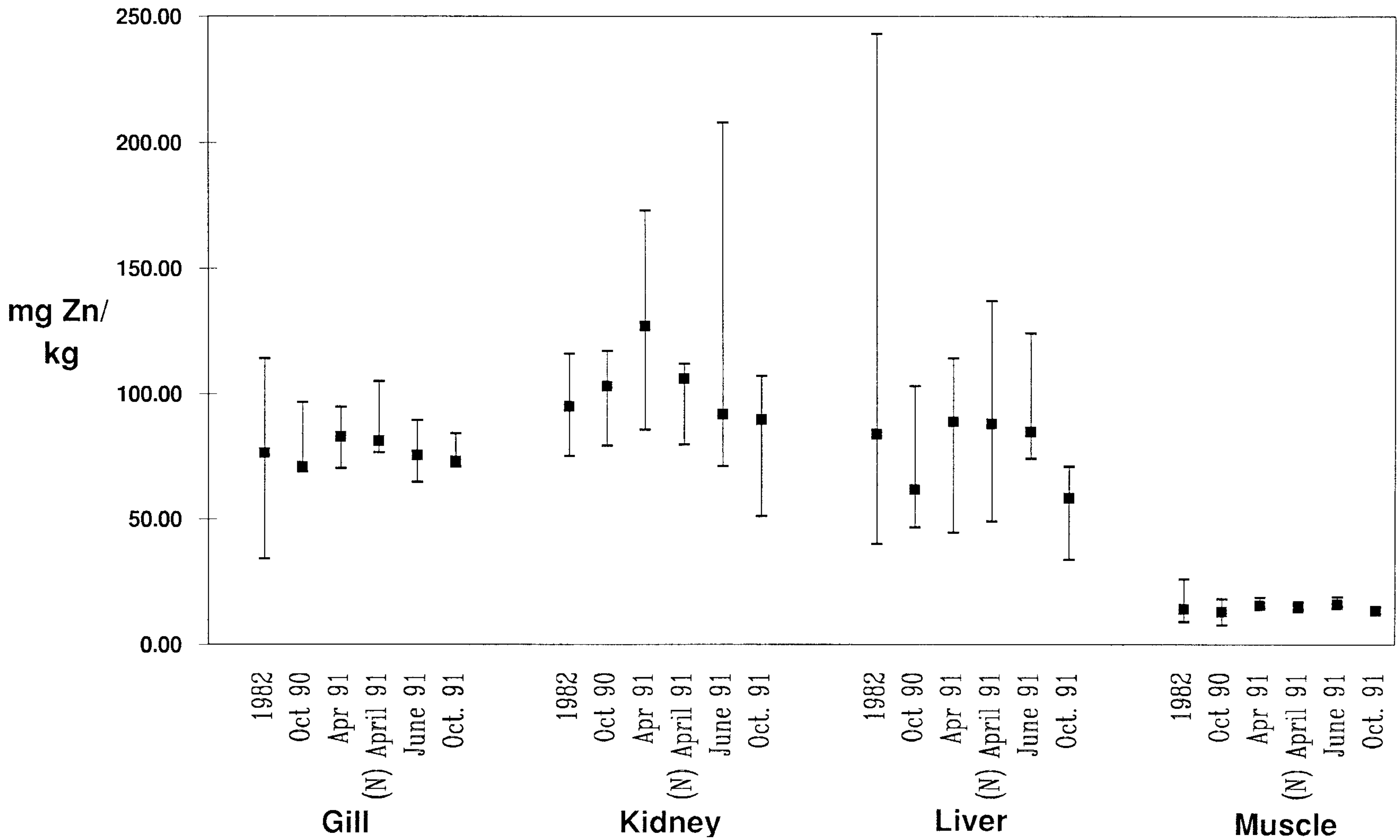


Figure 4. Concentrations (median, maximum, and minimum) of Copper (mg/kg dry weight) in adult Dolly Varden tissues (gill, kidney, liver, and muscle) collected in the Noatak (N) and Wulik Rivers in 1982, 1990, and 1991. Median values for 1982 fish were not available -- 1982 concentrations are expressed as a mean.

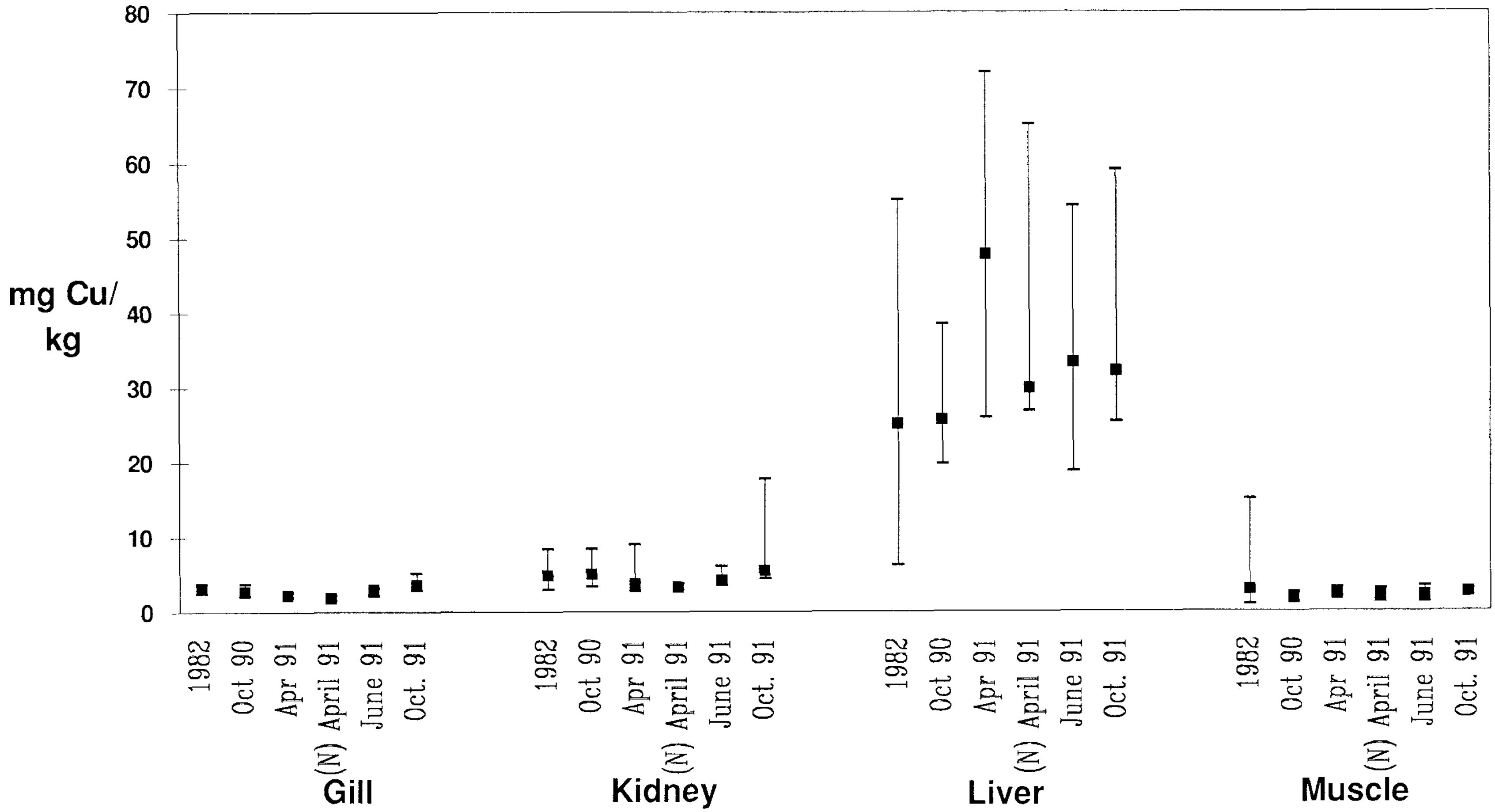


Figure 5. Concentrations (median, maximum, and minimum) of Aluminum (mg/kg dry weight) in adult Dolly Varden tissues (gill, kidney, liver, and muscle) collected in the Noatak (N) and Wulik Rivers in 1982, 1990, and 1991. Median values for 1982 fish were not available -- 1982 concentrations are expressed as a mean.

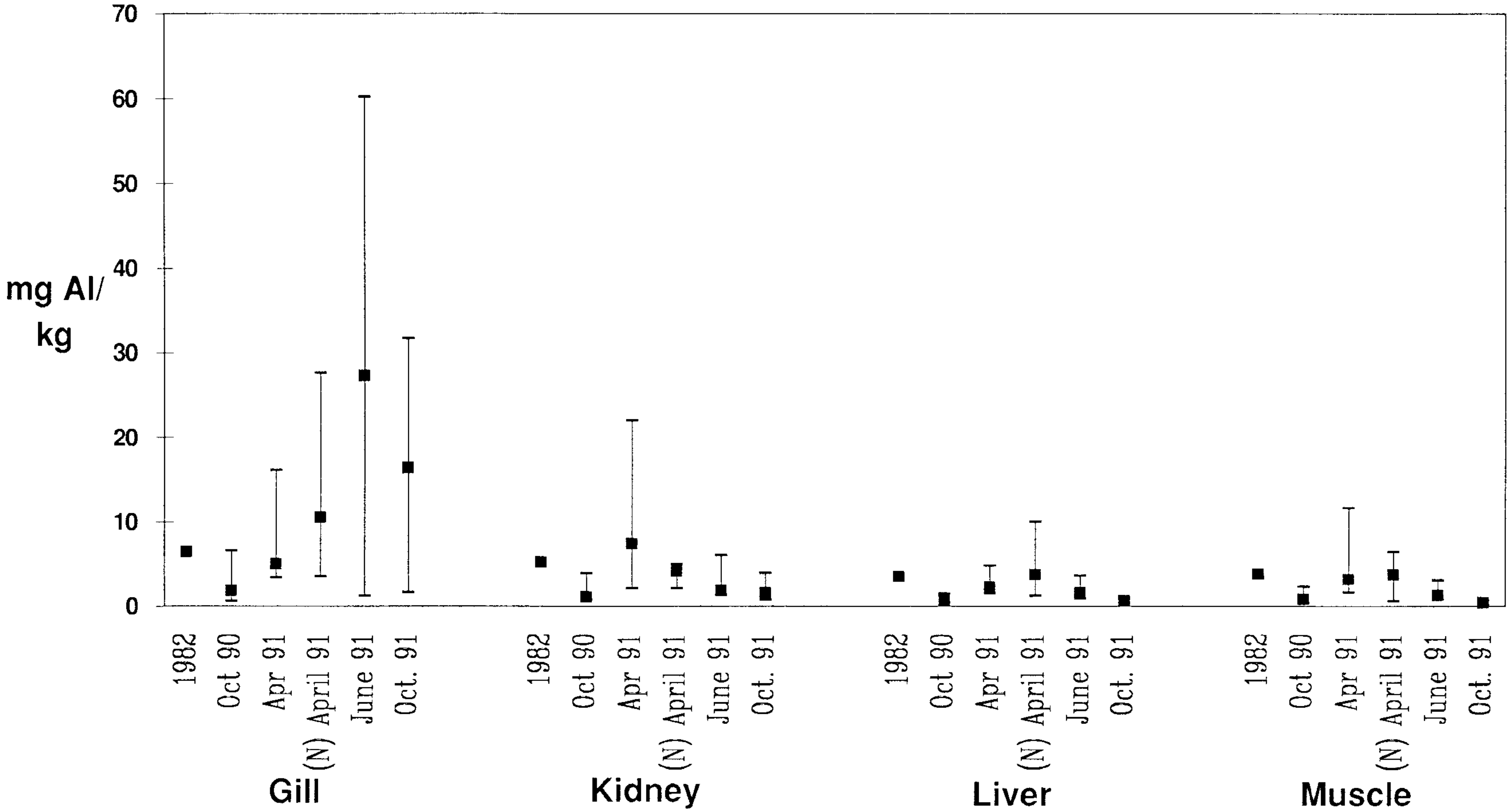


Figure 6. Concentrations (median, maximum, and minimum) of Lead (mg/kg dry weight) in adult Dolly Varden tissues (gill, kidney, liver, and muscle) collected in the Noatak (N) and Wulik Rivers in 1982, 1990, and 1991. Median values for 1982 fish were not available -- 1982 concentrations are expressed as a mean.

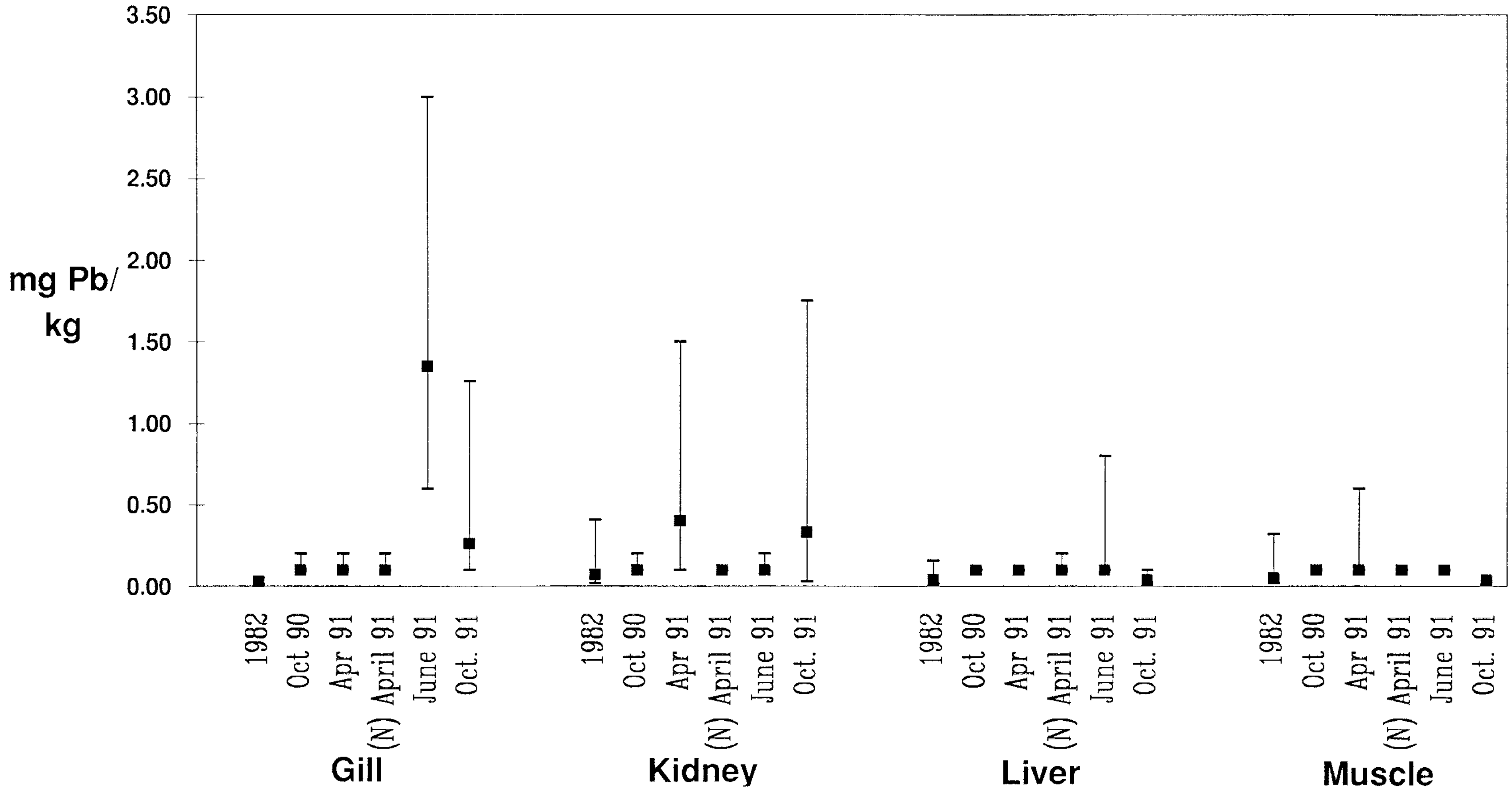
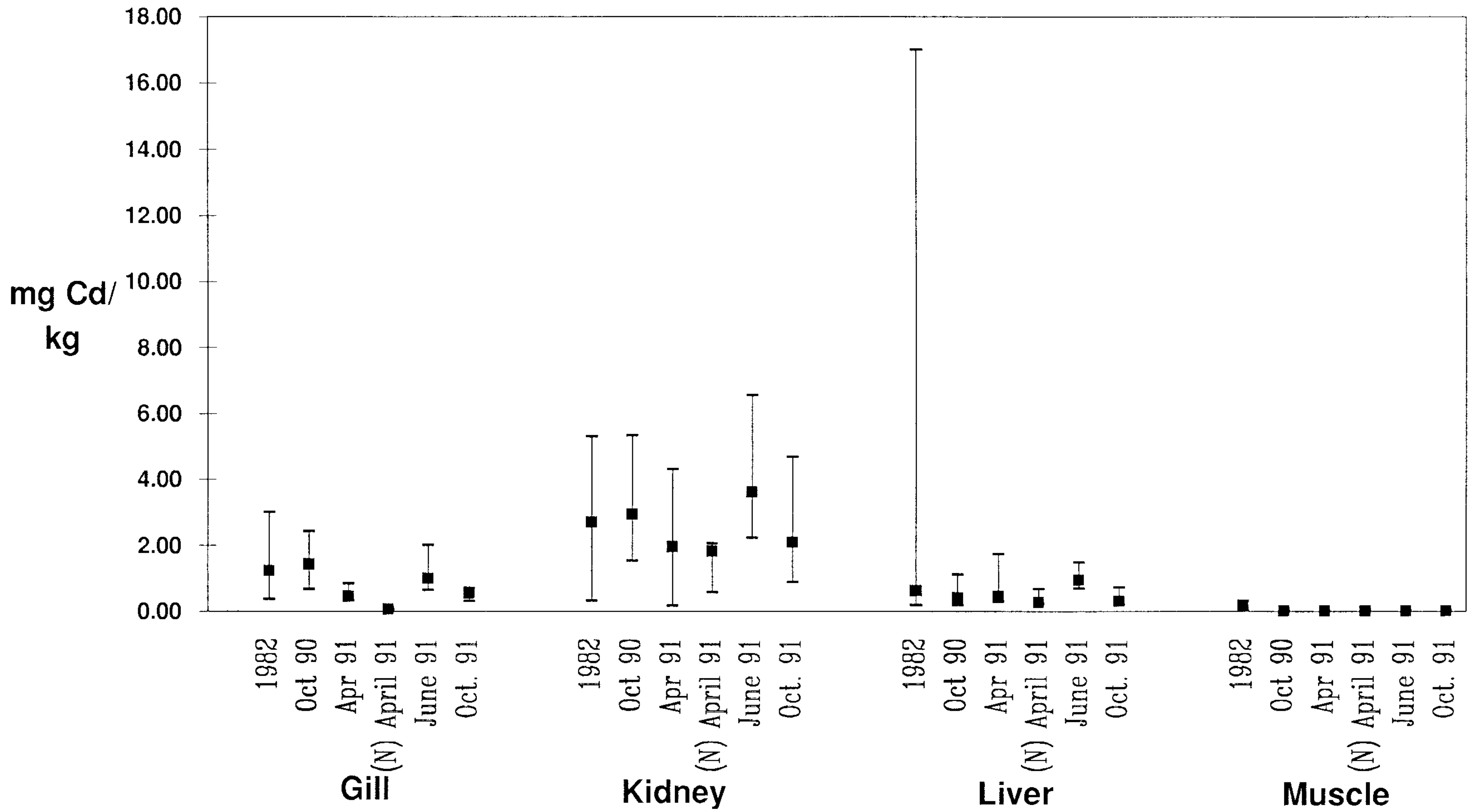


Figure 7. Concentrations (median, maximum, and minimum) of Cadmium (mg/kg dry weight) in adult Dolly Varden tissues (gill, kidney, liver, and muscle) collected in the Noatak (N) and Wulik Rivers in 1982, 1990, and 1991. Median values for 1982 fish were not available -- 1982 concentrations are expressed as a mean.



concentrations in the liver, kidney, and gill (Figures 3 through 7). There is no apparent trend (i.e., increase or decrease) in heavy metals concentrations in Dolly Varden tissues in the Wulik River drainage based on comparisons of the 1982 with the 1990 and 1991 data.

The lead concentration in gill tissue was higher in the June 1991 sample (n=8) from the Wulik River than in any previous set of samples from either the Wulik or Noatak drainages (Figure 6). Lead concentrations in gill tissue in the October 1991 Wulik River sample (n=6) were lower than those measured in the June 1991 sample. Lead concentrations from gills were lowest in fish collected by Dames and Moore (1983).

Aluminum concentrations in gill tissue were higher in the June 1991 sample from the Wulik River than in the baseline data (Dames and Moore 1983) and higher than concentrations from the Wulik and Noatak drainages at other sample dates (Figure 5). However, aluminum in gill tissue was lower in the October 1991 sample than the measured concentration in the June 1991 sample.

Zinc was measured at similar concentrations in the gill, kidney, and liver, but was lower in muscle tissue (Figure 3). Copper concentration in the liver was higher than in the gill, kidney, and muscle (Figure 4). Aluminum concentrations were relatively low in the kidney, liver, and muscle but fluctuated widely in the gill (Figure 5). Cadmium was concentrated in the kidney (Figure 7).

In 1990, juvenile Dolly Varden (80 to 125 mm) from Tutak, Anxiety Ridge, Dudd, Ikalukrok, and Evaingiknuk creeks and the Kelly River were analyzed for heavy metals concentrations in whole body samples (Table 2). The concentrations of all five analytes (Al, Cd, Cu, Pb, and Zn) were higher in the single Dolly Varden collected in Ikalukrok Creek than in any of the composite samples of Dolly Varden from any of the other

Table 2. Concentrations (mg/kg dry weight) of total Al, Cd, Cu, Pb, and Zn in whole body samples of juvenile Dolly Varden from the Wulik River and Noatak River drainages collected in July-August 1990. Samples are a composite of three fish, except Ikalukrok Creek, which is one fish.

	Al	Cd	Cu	Pb	Zn
Wulik River Drainage					
Tutak Creek	18.1	0.1	3.8	0.9	128
Anxiety Ridge Creek	25.8	0.8	3.7	1.1	136
Dudd Creek	11.9	0.2	2.9	0.3	89.8
Ikalukrok Creek	42.1	2.4	5.6	5.4	391
Noatak River Drainage					
Evaingiknuk Creek	6.3	0.4	2.9	0.1	135
Kelly River	10.6	0.1	5.0	0.3	112

Overwintering Dolly Varden Surveys, Wulik River

Aerial surveys to count the number of overwintering adult Dolly Varden in the Wulik River system have been made periodically in the fall since 1968. In September 1991, 127,000 Dolly Varden were counted in the Wulik River. Numbers of adult Dolly Varden in the Wulik River upstream and downstream of the mouth of Ikalukrok Creek are presented in Table 3.

On October 3, 1990, an aerial survey (helicopter) was made in the Wulik River and Ikalukrok Creek drainages. Visibility was poor due to overcast skies. Ikalukrok Creek was greenish-gray for its entire length and no fish were observed (DeCicco 1990). A turbid plume of water from Ikalukrok Creek was visible in the Wulik River, numerous Dolly Varden were present in the Wulik River downstream of Ikalukrok Creek, and an estimated 5,000 to 8,000 Dolly Varden were present in the Wulik River upstream of the mouth of Ikalukrok Creek (DeCicco 1990). Most of the Dolly Varden in the Wulik River immediately below the mouth of Ikalukrok Creek were located along the right (north) bank away from the turbid plume of water emerging from Ikalukrok Creek (DeCicco 1990).

On August 18, 1991, a fixed-wing aerial survey of the Wulik River from its mouth to Ikalukrok Creek was conducted. An estimated 30,000 to 40,000 Dolly Varden were present in the lower 21 km of the Wulik River (DeCicco 1991). Estimates of Dolly Varden also were made using a fixed-wing aircraft on August 27, 1991. Areas surveyed included Ikalukrok Creek, Wulik River (5 mi reach upstream of the mouth of Ikalukrok Creek), Wulik River (Ikalukrok Creek to Driver's Camp located immediately downstream of the confluence of Tutak Creek and the Wulik River), and lower Wulik River to within one mile of Kivalina. Six Dolly Varden were observed in Ikalukrok Creek, 18 in the

Table 3. Number of overwintering adult Dolly Varden in the Wulik River, including percentage 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).

Year	Wulik River (upstream) Ikalukrok Creek	Wulik River (downstream) Ikalukrok Creek	Percent of Fish
1979	3,305	51,725	94
1980	12,486	101,067	89
1981	4,125	97,136	96
1982	2,300	63,197	97
1984	370	30,483	99
1987	893	60,397	99
1988	1500	78,644	98
1989	2,110	54,274	96
1991	7,930	119,055	94

Wulik River upstream of Ikalukrok Creek, and 98,648 in the Wulik River downstream of Ikalukrok Creek (Lean 1991). In mid-September, an aerial survey of the Wulik River was made and 127,000 Dolly Varden were estimated in the Wulik River mainly downstream of the confluence of the Wulik River and Ikalukrok Creek (DeCicco 1992).

Chum Salmon Surveys, Ikalukrok Creek

We were unable to count fish in Ikalukrok Creek during a late July 1990 aerial survey due to turbid (orange colored) water; however, one dead chum salmon was observed on a gravel bar. On August 24, 1990, a foot survey (visual) from the mouth of Ikalukrok Creek upstream for about 4 km was made. Only one scavenged chum salmon carcass was observed.

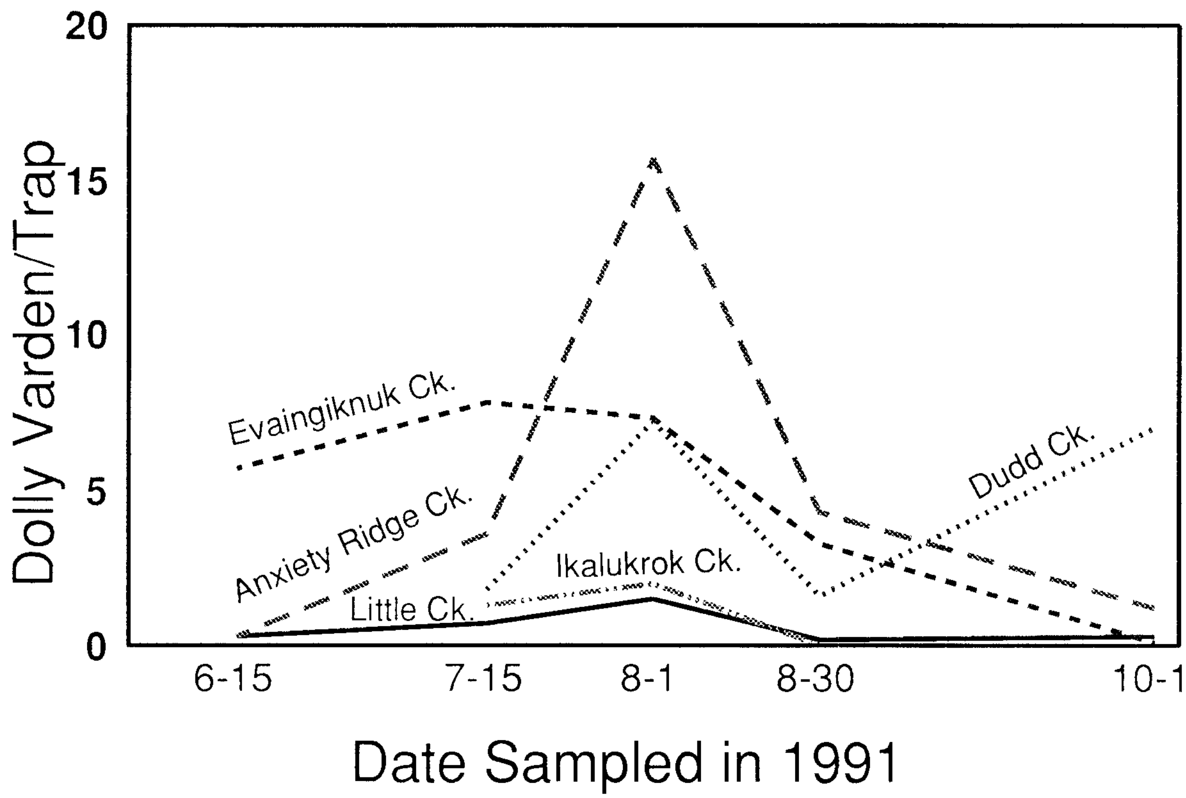
We conducted an aerial survey (fixed-wing) of Ikalukrok Creek from the mouth of Red Dog Creek to its confluence with the Wulik River on August 29, 1991. Approximately 60 chum salmon were observed in lower Ikalukrok Creek near Iyichoruk Mountain. Similar findings (i.e., 58 chum salmon) were reported by Lean (1991) on August 27, 1991.

Juvenile Dolly Varden, Relative Abundance and Distribution

In 1990 and 1991, minnow traps were fished in Ikalukrok, Anxiety Ridge, Dudd, Little, and Evaingiknuk creeks. Sample effort, number of Dolly Varden juveniles captured, their length (range and average), and the number of fish (average, standard deviation) per trap were recorded (Appendices 4 through 8).

In 1991, the catch of juvenile Dolly Varden increased in sample creeks from early June through August with a peak catch per trap recorded in all streams except Evaingiknuk Creek in early August (Figure 8). Catch decreased by late August and continued to

Figure 8. Catch of Dolly Varden per minnow trap in Evaingiknuk, Little, Tutak, Anxiety Ridge, and Ikalukrok creeks, 1991.



decrease in the October sample period with the exception of Dudd Creek (Figure 8).

The total number of Dolly Varden captured per minnow trap was compared for Anxiety Ridge, Dudd, Ikalukrok, Evaingiknuk, and Little creeks for 1991 samples. Comparisons in catch per trap were made for the early August, late August, and early October 1991 sample period. Significant differences among the creeks in total catch per trap of juvenile Dolly Varden were determined during early August ($F = 4.28$; $df = 4,20$; $P < 0.05$), late August ($F = 3.86$; $df = 4,20$; $P < 0.05$); however, there was no significant difference in the catch in October ($F = 1.58$; df 4,20; $P = 0.05$). Highest catches were recorded in Anxiety Ridge Creek - lowest catches were recorded in Little and Ikalukrok creeks (Figure 8).

In 1990 when water quality was degraded in Ikalukrok Creek (Weber-Scannell 1992, In Prep.), only one Dolly Varden was collected in minnow traps in Ikalukrok Creek whereas in 1991, 29 Dolly Varden were collected (Appendix 8). Dolly Varden juveniles were present in Ikalukrok Creek during July and early August 1991, but were absent in the sample area located immediately above Dudd Creek by late August (Figure 8). During mid-July, two size groups (45-65 mm and 105-115 mm) of Dolly Varden dominated the catch and by early August, 90 percent of the catch consisted of Dolly Varden between 55 and 65 mm (Appendix 9).

In 1990 and 1991 Dolly Varden juveniles were collected with minnow traps during late July and late August in Anxiety Ridge Creek (Appendix 6). In 1990 (July 27 to 30) and in 1991 (July 20 to 23) with similar sample effort, the total number of juvenile Dolly Varden collected was 19 and 54, respectively. In 1990 (August 24 to 25) and in 1991 (August 27 to 30) the total numbers of juvenile Dolly Varden collected were 24 and 64, respectively. Sample effort in 1991 (August) was greater than in 1990.

Length frequency data for juvenile Dolly Varden collected in 1991 in Evaingiknuk Creek are presented in Appendix 10. In mid-June the catch was dominated by juvenile Dolly Varden in the 65 to 85 mm range. By mid-July, most Dolly Varden were between 85 and 105 mm. Fish in the 55 to 65 mm range first appeared in the catch in early August and their relative percentage increased in the late August sample.

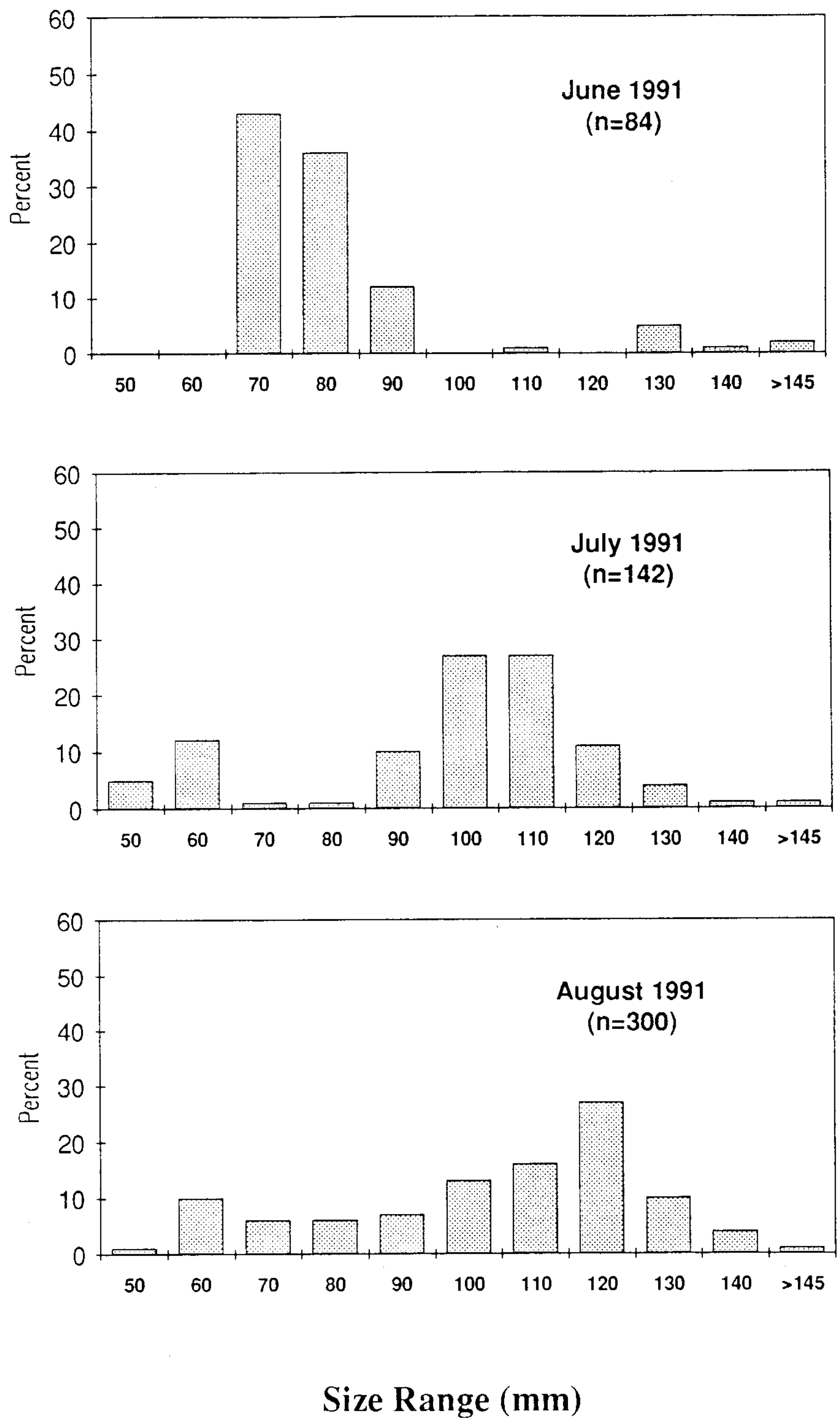
Small Dolly Varden (45-55 mm) were first collected in Little Creek in 1991 during the early August sample (Appendix 11). While only small numbers of fish were collected in Little Creek, some Dolly Varden were still present in October (Appendix 7).

Dolly Varden between 75 and 95 mm dominated the catch in Anxiety Ridge Creek in mid-June 1991 (Appendix 12). Dolly Varden between 55 and 75 mm were present in Anxiety Ridge Creek in the July 20 to 23 sample period and although none were caught in early August, fish between 65 and 85 mm reappeared in late August.

In Dudd Creek (i.e., the lower portion of Anxiety Ridge Creek), Dolly Varden between 45 and 65 mm were collected in mid-July (Appendix 13). By late August 1991, most juvenile Dolly Varden in Dudd Creek were between 65 and 95 mm. Dolly Varden between 75 and 85 mm and between 115 and 125 mm represented nearly 80 percent of the catch by early October (Appendix 13).

We pooled length frequency data for juvenile Dolly Varden collected in Anxiety Ridge, Dudd, Ikalukrok, Evaingiknuk, and Little creeks for the summer of 1991 (Figure 9). In June, fish between 65 and 85 mm represented nearly 80 percent of the catch. Smaller fish (45 to 65 mm) first appeared in mid-July. In mid-July most juvenile Dolly Varden captured were between 85 and 125 mm. In August, two peaks in length frequency were observed -- Dolly Varden between 55 and 65 mm and 115 and 125 mm (Figure 9).

Figure 9. Length frequencies (mm) of juvenile Dolly Varden caught in minnow traps in Little, Anxiety Ridge, Ikalukrok, Dudd, and Evaingiknuk creeks during the ice-free season, 1991.



Arctic Grayling Surveys, North Fork of Red Dog Creek

On May 23, 1991, we conducted a foot survey of the lower 1.2 km of the North Fork of Red Dog Creek. The North Fork was high, stained, and still contained some bottom-fast ice. Fish were not observed on May 23, 1991. An identical survey was conducted on June 19, 1991. Three Arctic grayling (two about 180 mm and one 300 mm plus) were observed. Water was clear; however, visibility was limited in deeper waters due to wind.

Portions of the North Fork of Red Dog Creek within our sample area were fished on July 21, 1991 with an electroshocker. Numerous (hundreds) Arctic grayling fry were collected in slow, shallow reaches. One adult Arctic grayling (410 mm) was captured by angling and was released. We observed no fish in the mainstem of Red Dog Creek but young-of-the-year Arctic grayling were seen in Red Dog Creek immediately downstream of the North Fork. Young-of-the-year Arctic grayling were located along the right (north) bank of Red Dog Creek where waters from the North Fork entered the mainstem of Red Dog Creek.

DISCUSSION

Dolly Varden Tissue Heavy Metals Concentrations

Objective 1 of our study was to estimate heavy metal concentrations (Zn, Cu, Pb, Al, and Cd) in gill, liver, muscle, and kidney tissue of adult Dolly Varden taken in the fall and spring from the Wulik River. Additional Dolly Varden tissue samples from the Noatak River were obtained as a result of a grant awarded to the Northwest Arctic Borough School District. Heavy metal concentrations in adult Dolly Varden tissues from 1990 and 1991 did not differ substantially from the baseline data even though heavy metals concentrations in Ikalukrok Creek were high in the fall of 1989 and summer of 1990. Furthermore, similar concentrations of heavy metals were present in Dolly Varden wintering in the Noatak and Wulik river drainages.

Fish eyes accumulate the highest concentrations of Zn, followed by gill, bone (especially opercular bone), intestine, liver, kidney, and skin while muscle does not accumulate the metal (Holcombe et al. 1979). We found similar concentrations of Zn in the gill, kidney, and liver and the lowest concentration occurred in the muscle (Figure 3). Furthermore, low concentrations of Zn in muscle were reported for Dolly Varden collected pre- and post-mining and for adult Dolly Varden from the Noatak and Wulik rivers.

Copper usually is more toxic to freshwater fish than any other heavy metal, except mercury. Copper accumulates primarily in the liver and gill tissue (Solbe and Cooper 1976). We found Cu to be concentrated primarily in the liver of Dolly Varden with low median concentrations in the gill, kidney, and muscle (Figure 4).

Aluminum is thought to accumulate primarily in the gills of fish (Moore and Ramamoorthy 1984). We also found the highest Al concentrations in the gills of Dolly

Varden, with low concentrations in kidney, liver, and muscle (Figure 5). We detected elevated levels of Al in all tissues for the April 1991 samples, including Noatak River fish, indicating that adult fish may have accumulated Al during the summer of 1990. During fall of 1990, Al concentrations in Red Dog Creek immediately upstream of its confluence with Ikalukrok Creek were higher than during pre-mining concentrations (Weber-Scannell 1992, In Prep.), while during the summer of 1991, Al concentrations in Red Dog Creek were reduced due to the completion of the clean/dirty water bypass system in April of 1991. By the fall of 1991, concentrations of Al in kidney, liver, and muscle in samples were lower than previously measured (Figure 5).

During July of 1990 several dead fish (two Dolly Varden adults, one adult chum salmon) were collected in Ikalukrok Creek (Ott 1990). Al concentrations (mg/kg dry weight) in gills of the two adult Dolly Varden and one chum salmon (unspawned adult female) were 148, 10, and 1,120, respectively.

Holcombe et al. 1976 subjected brook trout (*Salvelinus fontinalis*) to waters containing elevated levels of Pb and determined that Pb was concentrated in the liver and kidney where levels reached equilibrium with the water. However, they reported that Pb continued to increase in gill tissue, reaching concentrations higher than in surrounding waters. Concentrations of Pb in liver and kidney considered to be detrimental (68 and 50 mg/kg for liver and 215 and 179 mg/kg kidney) (Holcombe et al. 1976) to brook trout greatly exceed the maximum concentrations we found in Dolly Varden (Figure 6).

Fish primarily accumulate Cd in major organ tissues, not in muscle (Moore and Ramamoorthy 1984). Cadmium was not detected in the muscle of Arctic char collected from an unpolluted Arctic lake but was present in the liver at concentrations up to 2.5 mg/kg dry weight (Bohn and Fallis 1978). Our findings indicate that Dolly Varden accumulate Cd in the kidney (Figure 7); however, Dames and Moore (1983) reported a level of 17 mg/kg dry weight in the liver of one adult Dolly Varden. Possible contamination of the tissue sample may account for Dames and Moore's (1983) finding as the sample mean was low. Virtually no Cd was detected in our samples in the muscle tissue of adult Dolly Varden (Figure 7). Furthermore, our reported concentrations of Cd in the liver for all samples except the Dames and Moore in 1982 are less than those reported by Bohn and Fallis (1978) for Arctic char from an uncontaminated lake.

The life history patterns of adult Dolly Varden in the Wulik River drainage are complex and are directly relevant to the length of exposure (i.e., time) of individual fish to heavy metals in the water. Overwintering Dolly Varden in the Wulik River are from a number of stream systems (e.g., Kivalina and Noatak rivers) and a relatively small percentage actually spawn in the Wulik River drainage (DeCicco 1985). Furthermore, with the exception of summer spawners, all post-smolt Dolly Varden leave the Wulik River to forage in marine waters and to migrate to other stream systems (e.g., Noatak and Kivalina rivers) to spawn (DeCicco 1985). Adult Dolly Varden exhibit fidelity to spawning streams but not to overwintering habitats. Therefore, the total time individual Dolly Varden are actually exposed to heavy metals concentrations from the Red Dog mine is quite limited. Limited exposure time is related both to the life history pattern of the fish and to the fact that natural and man-induced heavy metal contamination is principally restricted to the ice free season. During the winter months, free water to convey heavy metals to downstream receiving aquatic habitat do not exist (i.e., flows cease in the vicinity of the Red Dog ore deposit).

Patterns of heavy metal presence in Dolly Varden tissues of the Wulik and Noatak river drainages appear to be consistent with those reported in the literature. Certain metals are concentrated in particular organs and in general very little metal accumulates in muscle tissue. Concentration levels in all tissues from the Wulik and Noatak rivers appear to be within background levels reported for other fish species (Jenkins 1980).

Overwintering Dolly Varden Surveys, Wulik River

Our second objective was to estimate abundance 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. Our hypothesis that 90 percent of the overwintering adult Dolly Varden continue to use the Wulik River downstream of the mouth of Ikalukrok Creek in numbers comparable to baseline data appears valid (Table 2). We have 10 years of data between 1979 and 1991 and in only one year (1980) is the percentage of adult fish downstream of Ikalukrok Creek less than 90 percent (Table 2).

On October 9, 1989 an estimated 56,384 overwintering Dolly Varden were observed in the Wulik River (DeCicco 1989b). Two surveys (October 4 and 9) were made with similar estimates of the total number of Dolly Varden. However, between the 4th and 9th some of the Dolly Varden moved from upstream of the mouth of Ikalukrok Creek presumably downstream in the Wulik River (DeCicco 1992). As in previous years, virtually all of the fish were located downstream of the mouth of Ikalukrok Creek. However, the lateral distribution of Dolly Varden in the Wulik River downstream of Ikalukrok Creek was abnormal. All of the adult Dolly Varden were located along the right (i.e., north) bank away from the influence of waters emerging from Ikalukrok Creek (DeCicco 1989b). Metals concentration in Ikalukrok Creek immediately upstream of its mouth on the 4th of October for Al was 0.12 mg/L, Cd 0.017 mg/L, Cu not detectable, Pb 0.01 mg/L, and Zn 3.46 mg/L.

An estimate of the number of overwintering Dolly Varden in the Wulik River in 1990 could not be made due to weather conditions. It was reported; however, that a fairly large number of fish (5,000 to 8,000) were in the Wulik River upstream of the mouth of Ikalukrok Creek (DeCicco 1990a). Furthermore, fish appeared to be avoiding the turbid water emerging from Ikalukrok Creek. We surmise that in the fall of 1990, adult Dolly Varden avoided waters of Ikalukrok Creek based on the unusually high numbers of fish upstream of the mouth of Ikalukrok Creek and the fact that fish were located along the right bank of the Wulik River downstream of Ikalukrok Creek.

In 1991, with significant improvements in water quality and no observable discoloration in Ikalukrok Creek, an estimated 127,000 Dolly Varden were in the Wulik River. Over 90 percent were located downstream of the mouth of Ikalukrok Creek based on Lean's (1991) aerial survey counts. Total numbers of fish were within the historical range of between 20,000 and 225,000 overwintering Dolly Varden. Furthermore, there was no reported avoidance by Dolly Varden of waters from Ikalukrok Creek.

Chum Salmon Surveys, Ikalukrok Creek

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. We found that chum salmon continued to spawn in the lower 24 km of Ikalukrok Creek; however, the number of chum salmon documented in Ikalukrok Creek was substantially lower than previous estimates using similar survey methods. In September 1981, the estimated number of spawning chum salmon in Ikalukrok Creek ranged from 3,520 to 6,960 (Houghton and Hilgert 1983). In August and September of 1982, chum salmon adults were estimated at 353 and 1,400, respectively (Houghton and Hilgert 1983). ADF&G aerial surveys on August 28, 1984 and August 25, 1986 documented the presence of 994 and 1,975 adult chum salmon, respectively in Ikalukrok

Creek (DeCicco pers. com. 1990). In 1990 and 1991, less than 70 adult chum salmon were observed during aerial surveys along lower Ikalukrok Creek. However, in 1991, chum salmon were present in the same general area of Ikalukrok Creek as was used by spawners during previous surveys. Given the fact that chum salmon in the Wulik River drainage are near the northern limit of their distribution, a number of environmental factors (e.g., severity of the winter) can dramatically affect the number of returning adult salmon. Normally, four year old fish represent the major component of chum salmon escapement and therefore run strength in 1989, 1990, and 1991 is directly associated with run class strength and spawning success in the years 1985, 1986, and 1987, prior to start-up of the Red Dog Mine.

Water quality conditions were degraded in Ikalukrok Creek during the fall of 1989 and during the summer and fall of 1990 as a result of non-point source pollution from the Red Dog ore body (Weber-Scannell 1992, In Prep.). Water quality conditions in lower Ikalukrok Creek may have caused chum salmon to avoid the system in 1989 and 1990; however, water quality conditions were within background levels during the summer and fall of 1991 (Weber-Scannell 1992, In Prep.); therefore, water quality in 1991 should not have affected the number of adult chum salmon using Ikalukrok Creek.

Juvenile Dolly Varden, Relative Abundance and Distribution

Our objective was to 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. Our null hypothesis that the relative abundance of juvenile Dolly Varden are not significantly different in Ikalukrok, Dudd, Anxiety Ridge, Evaingiknuk, and Little creeks was rejected for the August 1991 sample periods ($P < 0.05$) but not for the October sample ($P = 0.05$). Our highest catches of juvenile Dolly

Varden in 1991 generally were recorded in Anxiety Ridge Creek. Researchers conducting baseline fisheries work along the DMRTS haul road stated that the most productive system for juvenile Dolly Varden was Anxiety Ridge Creek (Dames and Moore 1984). Our results confirm their previous work.

Patterns of juvenile Dolly Varden use in Ikalukrok, Dudd, Anxiety Ridge, Evaingiknuk, and Little creeks varied with sample time during the ice-free season. Increased use by fish occurred during the early portion of the summer in all streams with a peak in use occurring in early August. Juvenile fish appeared to move from overwintering habitats postulated to exist in lower Evaingiknuk Creek, lower Dudd Creek, Ikalukrok Creek downstream of Dudd Creek, and lower Little Creek to the upper portions of the drainages. Outmigrations occurred in August and we speculate that increased catches in Dudd Creek reflect movement of fish either into overwintering habitat in Dudd Creek or movement of fish from Anxiety Ridge Creek through the sample area in Dudd Creek. The lack of capture of any Dolly Varden in Ikalukrok Creek upstream of Dudd Creek may indicate that these fish as well as fish caught in lower Dudd Creek were actively moving to overwintering habitats located in lower Ikalukrok Creek or the Wulik River. Failure to catch juvenile Dolly Varden in Anxiety Ridge Creek until mid-July in 1991 supports our conclusion that these fish overwinter in lower Ikalukrok Creek or the Wulik River.

Dolly Varden use of Ikalukrok Creek during the summer of 1990 was virtually non-existent. Substantial effort was expended with the capture of only one juvenile Dolly Varden. Heavy metal concentrations in the Dolly Varden (whole body analyses with gut contents not removed) for Al was 42.1 mg/kg, Cd 2.39 mg/kg, Cu 5.6 mg/kg, Pb 5.4 mg/kg, and Zn was 391 mg/kg dry weight (Ott 1990). Concentrations of metals in the Ikalukrok Dolly Varden exceeded those found in juvenile fish collected in Tutak, Evaingiknuk, and Anxiety Ridge creeks (Ott 1990). We postulate that during 1990, Dolly Varden juveniles actively avoided Ikalukrok Creek due to degraded water quality conditions (e.g., Zn levels of 45 to 60 mg/L). We also assume that if some juvenile Dolly Varden did not avoid Ikalukrok Creek that some mortality occurred. In fact, when a juvenile Dolly Varden collected in Dudd Creek was placed in Ikalukrok Creek on August 24, 1991 the fish was dead when the minnow trap was checked on August 26 (Robus 1990). In 1991, with drastically improved water conditions in Ikalukrok Creek, 29 juvenile Dolly Varden were captured and released.

Furthermore, in Anxiety Ridge Creek the catch of juvenile Dolly Varden increased from 1990 to 1991. Assuming juvenile Dolly Varden overwinter mainly in lower Ikalukrok Creek and the Wulik River, juvenile Dolly Varden which normally use Anxiety Ridge Creek during the summer may have been adversely affected in 1990. Juvenile Dolly Varden probably avoided Ikalukrok Creek and therefore were unable to reach rearing habitat in Anxiety Ridge Creek. However, in 1991, with improved water quality conditions in Ikalukrok Creek, juvenile Dolly Varden were able to migrate through waters of Ikalukrok Creek and enter Anxiety Ridge Creek to rear. Increased catches of juvenile Dolly Varden in the summer of 1991 appear to support our conclusion that improved water quality in Ikalukrok Creek in 1991 resulted in an increase in numbers of juvenile Dolly Varden in Anxiety Ridge Creek. Numbers of fish using Anxiety Ridge Creek may continue to increase as the population recovers from the effects of heavy metals concentrations in the fall of 1989 and summer of 1990.

Arctic Grayling Surveys, North Fork of Red Dog Creek

Our objective was to determine Arctic grayling use of North Fork of Red Dog Creek. Our hypothesis that Arctic grayling continue to spawn in the North Fork of Red Dog

Creek and young-of-the-year Arctic grayling are present was determined to be valid. Findings during 1991 were nearly identical to observations made during biological sampling conducted during 1981 and 1982 by Dames and Moore. Houghton and Hilgert (1983) documented numerous young-of-the-year Arctic grayling fry in the North Fork of Red Dog Creek in July of both 1981 and 1982 and they collected both adult and subadult (210 to 245 mm) fish. Our surveys confirmed numerous fry and the presence of both adult and subadult Arctic grayling.

We were concerned that poor water quality (e.g., heavy metals concentrations), particularly during the summer of 1990, may have precluded adult Arctic grayling from reaching the North Fork of Red Dog Creek. Furthermore, heavy metals concentrations were elevated to the point that significant mortality to Arctic grayling could have occurred during migration to or from the North Fork of Red Dog Creek. Since Arctic grayling adults exhibit fidelity to spawning streams, there was a reasonable chance that the North Fork of Red Dog Creek population of Arctic grayling could have been seriously depleted. Our findings to date (documenting the presence of adult fish, subadults, and numerous young-of-the-year Arctic grayling in 1991) indicate that this species still uses the North Fork of Red Dog Creek in a manner nearly identical to that recorded by Houghton and Hilgert (1983).

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Appendix 1 - Experimental tests to evaluate effectiveness of minnow traps and to compare catch of Dolly Varden in minnow traps with variable fishing effort (time).

Two experimental tests were conducted in Evaingiknuk Creek to evaluate effectiveness of minnow traps in capturing juvenile fish and to determine the relationship of effort (time fished) and catch. Test 1 was designed to evaluate the effectiveness of minnow traps and the experiment was conducted between July 21 and 24, 1991. Test 2 was designed to determine the relationship between effort and catch and was performed between August 7 and 10, 1991.

In Test 1, one minnow trap was fished for three days with block nets (i.e., seines) placed upstream and downstream of the minnow trap to prevent either immigration or emigration of fish. The minnow trap was checked each day, fish were fin clipped (adipose), and released. After checking minnow traps and releasing fish on day three, we electrofished the area between the block nets. Three passes were used in an attempt to capture all fish. The purpose of Test 1 was to assess the effectiveness of minnow traps. Number of Dolly Varden captured in a minnow trap with block nets located 20 m upstream and 30 m downstream on Day 1, 2, and 3 was 15, 10, and 2, respectively. On Day 2 and 3 all fish were recaptures. In addition to the Dolly Varden, one slimy sculpin was collected. Electrofishing the sample reach between the nets resulted in the capture of four Arctic grayling, one slimy sculpin, and 11 Dolly Varden. Three additional juvenile Dolly Varden were observed but not captured and of the 11 fish collected, nine were recaptures. We concluded that minnow traps are at least as effective in collecting fish as is electroshocking with multiple passes between instream block nets.

In Test 2 the total number of Dolly Varden collected (fish were not released) in five minnow traps on Day 1, 2, and 3 was 34, 37, and 39. Dolly Varden collected on Day 1 and 2 were fin clipped and placed into the minnow trap. There was no significant difference in catch by day ($F = 0.05$; $df = 2,12$; $P < 0.05$). Number of recaptures on Day 1, 2, and 3 was 6, 25, and 36. Over 90 percent of the fish collected on Day 3 were recaptures. Some individual minnow traps lost fish (i.e., Trap #5 had 9, 5, and 3 fish on Day 1, 2, and 3, respectively) and some gained fish (i.e., Trap #4 had 6, 14, 19 on Day 1, 2, and 3, respectively). A high rate of recapture on Day 3 with similar catches (total number of fish by day) also was documented at Little and Anxiety Ridge creeks during the August 5 to 8 sample period. Total catch of Dolly Varden on Day 1, 2, and 3 in Little Creek was 7, 8, and 8, respectively with a recapture rate of 100 percent on Day 3. Total catch of Dolly Varden on Day 1, 2, and 3 in Anxiety Ridge Creek was 75, 79, and 81, respectively with a recapture rate of 88 percent on Day 3. We concluded that effort was not related to catch when minnow traps are fished between 24 and 72 hours.

Appendix 2. Concentrations (mg/kg dry weight basis) of Al, Cd, Cu, Pb, and Zn in adult Dolly Varden tissues (muscle, liver, gill, and kidney) collected in 1990 and 1991 in the Wulik and Noatak rivers. Baseline fish tissue data from Dames and Moore (1983) are included.

Collected By	Date	Location	Sex	Weight (gm)	Length (mm)	Al (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	% Solids	Spawning Condition
Muscle												
Dames &	1982	average	a				0.17	2.88	< 0.03	14.10		
Moore*	all sites,	(minimum)					(0.01)	(0.9)	(<0.02)	(9.0)		
	all dates	(maximum)					(0.03)	(15.0)	(<0.06)	(26.0)		
ADF&G	5-Oct-90	Wulik	f		538	1.60	< 0.01	2.50	< 0.10	18.10	24.90	unspawned
ADF&G	5-Oct-90	Wulik	f		615	0.40	< 0.01	1.00	< 0.10	7.60	42.40	non-spawner
ADF&G	5-Oct-90	Wulik	m		608	0.80	< 0.01	1.80	< 0.10	11.50	38.10	non-spawner
ADF&G	5-Oct-90	Wulik	f		430	0.50	< 0.01	1.90	< 0.10	12.90	32.50	non-spawner
ADF&G	5-Oct-90	Wulik	f		452	0.50	< 0.01	1.70	< 0.10	15.30	30.10	non-spawner
ADF&G	5-Oct-90	Wulik	f		528	0.90	< 0.01	1.70	< 0.10	12.10	39.50	non-spawner
Noatak	15-Apr-91	Noatak	f	274	323	6.40	0.04	2.40	< 0.10	16.10	24.10	
Noatak	15-Apr-91	Noatak	f	283	324	1.50	< 0.01	2.00	< 0.10	14.60	24.40	
Noatak	15-Apr-91	Noatak	m	714	416	3.70	0.01	2.90	< 0.10	14.10	28.60	
Noatak	15-Apr-91	Noatak	f	730	443	0.60	< 0.01	1.40	< 0.10	13.80	26.40	
Noatak	15-Apr-91	Noatak	f	449	401	4.10	0.01	1.20	< 0.10	17.00	23.60	
Cominco	9-Mar-91	Wulik				2.20	< 0.01	3.50	< 0.10	18.60	24.70	
Cominco	9-Mar-91	Wulik				2.80	< 0.01	2.40	< 0.10	14.50	27.00	
Cominco	9-Mar-91	Wulik				1.60	< 0.01	2.50	< 0.10	15.50	26.80	
Kivalina	6-Apr-91	Wulik	m		300	1.60	0.01	2.00	0.10	17.40	24.90	
Kivalina	6-Apr-91	Wulik	m	197	294	6.10	< 0.01	2.20	< 0.10	15.00	23.60	
Kivalina	6-Apr-91	Wulik	f	201	303	11.60	< 0.01	3.10	0.60	15.50	24.70	
Kivalina	6-Apr-91	Wulik	f	237	355	3.20	< 0.01	1.90	< 0.10	18.80	19.30	
Kivalina	6-Apr-91	Wulik	f	751	434	1.90	< 0.01	2.20	< 0.10	14.20	28.40	
Cominco	26-Apr-91	Wulik	f	1230	513	1.20	< 0.01	1.70	< 0.10	14.10	29.10	prespawner, small eggs
Cominco	16-Jun-91	Wulik	m	962	444.5	1.40	0.01	3.30	< 0.10	16.00	29.70	
Cominco	16-Jun-91	Wulik	f	1424	533	1.80	< 0.01	2.20	0.10	15.30	26.40	prespawner, small eggs
Cominco	16-Jun-91	Wulik	m	1361	541	3.00	< 0.01	2.60	< 0.10	15.60	25.40	
Cominco	16-Jun-91	Wulik	f	762	457	0.80	< 0.01	2.40	< 0.10	16.00	23.70	prespawner, small eggs

Collected By	Date	Location	Sex	Weight (gm)	Length (mm)	Al (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	% Solids	Spawning Condition
Cominco	16-Jun-91	Wulik	f	671	414	0.90	< 0.01	1.20	< 0.10	16.40	22.40	prespawner, small eggs
Cominco	16-Jun-91	Wulik	f	744	427	1.10	< 0.01	1.50	< 0.10	15.10	23.60	immature, no eggs
Cominco	16-Jun-91	Wulik	f	680	439	1.20	0.03	1.50	< 0.10	18.90	23.00	immature, no eggs
Cominco	16-Jun-91	Wulik	f	653	427	1.20	< 0.01	2.00	< 0.10	16.60	24.00	prespawner, small eggs
Cominco	5-Oct-91	Wulik	f	1.16	200	0.55	< 0.02	2.55	0.03	14.90	27.70	small eggs
Cominco	5-Oct-91	Wulik	m	1.26	200	0.66	< 0.02	2.85	0.03	13.90	26.90	
Cominco	5-Oct-91	Wulik	m	2.55	256	0.43	< 0.02	2.02	0.04	14.50	27.40	
Cominco	5-Oct-91	Wulik	f	2.19	246	0.13	0.03	2.68	0.04	13.10	30.40	small eggs
Cominco	5-Oct-91	Wulik	f	1.61	219	0.22	< 0.02	2.03	0.03	12.80	27.50	small eggs
Cominco	5-Oct-91	Wulik	m	2.23	235	0.32	< 0.02	2.42	0.05	12.20	29.10	

Liver

Collected By	Date	Location	Sex	Weight (gm)	Length (mm)	Al (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	% Solids	Spawning Condition
Dames &	1982	average	a			2.50	0.63	25.10	< 0.04	83.90		
Moore*	all sites,	(minimum)					(0.19)	(6.2)	(<0.02)	(40.1)		
	all dates	(maximum)					(17.00)	(55)	(0.16)	(243)		
ADF&G	5-Oct-90	Wulik	f		538	1.50	1.11	25.60	0.10	103.00	26.10	unspawned
ADF&G	5-Oct-90	Wulik	f		615	0.70	0.25	19.70	< 0.10	46.60	46.60	non-spawner
ADF&G	5-Oct-90	Wulik	m		608	0.70	0.19	38.40	< 0.10	58.70	50.90	non-spawner
ADF&G	5-Oct-90	Wulik	f		430	0.80	0.46	22.60	< 0.10	79.30	29.00	non-spawner
ADF&G	5-Oct-90	Wulik	f		452	0.70	0.40	24.20	< 0.10	74.60	34.60	non-spawner
ADF&G	5-Oct-90	Wulik	f		528	0.40	0.37	29.90	< 0.10	61.80	55.90	non-spawner
Noatak	15-Apr-91	Noatak	f	274	323	10.00	0.21	26.90	0.20	70.30	36.30	
Noatak	15-Apr-91	Noatak	f	283	324	2.60	0.43	44.40	< 0.10	110.00	28.50	
Noatak	15-Apr-91	Noatak	m	714	416	6.70	0.27	29.80	< 0.10	88.10	44.30	
Noatak	15-Apr-91	Noatak	f	730	443	1.20	0.27	26.80	< 0.10	49.00	44.20	
Noatak	15-Apr-91	Noatak	f	449	401	3.70	0.68	65.10	< 0.10	137.00	28.30	
Cominco	9-Mar-91	Wulik				1.5	1.81	40.3	< 0.10	164.00	27.1	
Cominco	9-Mar-91	Wulik				3.10	0.53	30.70	< 0.10	65.80	44.40	
Cominco	9-Mar-91	Wulik				2.00	0.73	46.60	< 0.10	84.80	38.80	
Kivalina	6-Apr-91	Wulik	m		300	4.80	1.73	51.90	< 0.10	88.80	33.80	
Kivalina	6-Apr-91	Wulik	m	197	294	1.50	0.29	47.70	< 0.10	87.20	34.90	
Kivalina	6-Apr-91	Wulik	f	201	303	1.80	0.45	41.10	< 0.10	95.80	33.10	

Collected By	Date	Location	Sex	Weight (gm)	Length (mm)	Al (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	% Solids	Spawning Condition
Kivalina	6-Apr-91	Wulik	f	237	355	2.20	0.63	72.00	< 0.10	114.00	25.20	
Kivalina	6-Apr-91	Wulik	f	751	434	2.90	0.38	25.90	0.10	44.60	35.00	
Cominco	26-Apr-91	Wulik	f	1230	513	1.30	0.76	25.40	< 0.10	56.10	38.20	prespawner, small eggs
Cominco	16-Jun-91	Wulik	m	962	444.5	1.30	1.25	32.40	< 0.10	74.00	31.90	
Cominco	16-Jun-91	Wulik	f	1424	533	1.80	0.71	18.70	< 0.10	75.20	30.80	prespawner, small eggs
Cominco	16-Jun-91	Wulik	m	1361	541	3.60	0.86	37.50	< 0.10	83.20	33.70	
Cominco	16-Jun-91	Wulik	f	762	457	2.00	1.18	34.10	< 0.10	96.60	27.40	prespawner, small eggs
Cominco	16-Jun-91	Wulik	f	671	414	1.80	1.48	38.30	0.80	124.00	24.00	prespawner, small eggs
Cominco	16-Jun-91	Wulik	f	744	427	1.20	0.69	54.20	< 0.10	85.40	28.90	immature, no eggs
Cominco	16-Jun-91	Wulik	f	680	439	1.20	1.04	26.00	< 0.10	84.30	33.30	immature, no eggs
Cominco	16-Jun-91	Wulik	f	653	427	0.90	0.84	31.00	< 0.10	88.00	30.10	prespawner, small eggs
Cominco	5-Oct-91	Wulik	f	1.16	200	0.94	0.29	33.60	0.04	70.80	45.60	small eggs
Cominco	5-Oct-91	Wulik	m	1.26	200	0.34	0.21	27.40	0.02	50.20	43.10	
Cominco	5-Oct-91	Wulik	m	2.55	256	0.44	0.72	39.00	0.10	61.70	37.70	
Cominco	5-Oct-91	Wulik	f	2.19	246	0.87	0.32	59.00	0.05	65.60	45.70	small eggs
Cominco	5-Oct-91	Wulik	f	1.61	219	0.40	0.53	25.40	0.04	55.10	41.50	small eggs
Cominco	5-Oct-91	Wulik	m	2.23	235	0.70	0.21	30.60	0.04	33.80	47.60	

Gills

Collected By	Date	Location	Sex	Weight (gm)	Length (mm)	Al (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	% Solids	Spawning Condition
Dames &	1982	average	a				1.23	3.07	< 0.03	76.40	24.76	
Moore*	all sites,	(minimum)					(0.36)	(2.4)	(<0.01)	(34.1)		
	all dates	(maximum)					(3.00)	(3.7)	(<0.05)	(114)		
ADF&G	5-Oct-90	Wulik	f		538	1.80	1.63	2.20	0.20	90.40	22.30	unspawned
ADF&G	5-Oct-90	Wulik	f		615	1.30	0.68	3.10	< 0.10	70.90	25.80	non-spawner
ADF&G	5-Oct-90	Wulik	m		608	1.40	1.44	2.60	< 0.10	68.70	24.00	non-spawner
ADF&G	5-Oct-90	Wulik	f		430	2.00	1.20	3.30	0.10	70.50	26.20	non-spawner
ADF&G	5-Oct-90	Wulik	f		452	0.60	1.22	2.10	< 0.10	70.20	21.60	non-spawner
ADF&G	5-Oct-90	Wulik	f		528	2.20	2.44	2.60	0.20	96.60	24.10	non-spawner
Noatak	15-Apr-91	Noatak	f	274	323	27.60	0.05	1.80	0.20	105.00	20.30	
Noatak	15-Apr-91	Noatak	f	283	324	15.60	0.06	1.60	0.10	79.80	22.30	
Noatak	15-Apr-91	Noatak	m	714	416	3.50	0.07	2.20	0.10	81.20	20.50	
Noatak	15-Apr-91	Noatak	f	730	443	6.70	0.10	1.50	< 0.10	76.60	21.30	

Collected By	Date	Location	Sex	Weight (gm)	Length (mm)	Al (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	% Solids	Spawning Condition
Noatak	15-Apr-91	Noatak	f	449	401	10.50	0.04	2.20	< 0.10	84.00	20.30	
Cominco	9-Mar-91	Wulik				6.10	0.39	2.30	< 0.10	87.40	19.20	
Cominco	9-Mar-91	Wulik				7.80	0.66	2.30	< 0.10	87.60	22.00	
Cominco	9-Mar-91	Wulik				10.80	1.02	2.30	< 0.10	77.80	22.10	
Kivalina	6-Apr-91	Wulik	m		300	5.00	0.45	2.60	< 0.10	94.80	19.50	
Kivalina	6-Apr-91	Wulik	m	197	294	13.90	0.36	1.90	< 0.10	74.40	18.60	
Kivalina	6-Apr-91	Wulik	f	201	303	3.40	0.82	2.20	< 0.10	88.40	19.30	
Kivalina	6-Apr-91	Wulik	f	237	355	4.20	0.33	2.50	0.20	70.30	19.00	
Kivalina	6-Apr-91	Wulik	f	751	434	16.10	0.85	1.90	< 0.10	83.00	19.80	
Cominco	26-Apr-91	Wulik	f	1230	513	3.2	0.79	1.7	1.1	79.80	20.4	prespawner, small eggs
Cominco	16-Jun-91	Wulik	m	962	444.5	36.60	1.51	3.10	1.00	75.60	18.20	
Cominco	16-Jun-91	Wulik	f	1424	533	56.30	0.78	3.00	3.00	79.30	21.10	prespawner, small eggs
Cominco	16-Jun-91	Wulik	m	1361	541	21.20	1.15	2.70	0.60	75.50	18.80	
Cominco	16-Jun-91	Wulik	f	762	457	18.40	2.00	3.10	1.50	89.60	22.20	prespawner, small eggs
Cominco	16-Jun-91	Wulik	f	671	414	20.50	0.64	2.10	0.80	64.70	21.40	prespawner, small eggs
Cominco	16-Jun-91	Wulik	f	744	427	33.30	0.83	2.80	1.50	75.30	20.80	immature, no eggs
Cominco	16-Jun-91	Wulik	f	680	439	60.20	0.85	2.90	2.40	67.70	21.50	immature, no eggs
Cominco	16-Jun-91	Wulik	f	653	427	1.20	1.82	3.10	1.20	78.50	20.20	prespawner, small eggs
Cominco	5-Oct-91	Wulik	f	1.16	200	1.61	0.55	3.39	0.10	70.80	21.00	small eggs
Cominco	5-Oct-91	Wulik	m	1.26	200	23.40	0.30	2.92	0.16	75.20	19.30	
Cominco	5-Oct-91	Wulik	m	2.55	256	10.60	0.63	2.82	0.29	71.40	20.30	
Cominco	5-Oct-91	Wulik	f	2.19	246	2.08	0.54	3.64	0.23	72.30	23.00	small eggs
Cominco	5-Oct-91	Wulik	f	1.61	219	22.10	0.50	4.23	1.26	73.60	19.80	small eggs
Cominco	5-Oct-91	Wulik	m	2.23	235	31.70	0.71	5.10	0.33	84.10	21.70	

Kidney

Collected By	Date	Location	Sex	Weight (gm)	Length (mm)	Al (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	% Solids	Spawning Condition
Dames &	1982	average	a			3.00	2.71	4.80	< 0.07	95.00		
Moore*	all sites,	(minimum)					(0.32)	(2.9)	(<0.02)	(74.6)		
	all dates	(maximum)					(5.30)	(8.4)	(0.41)	(116)		
ADF&G	5-Oct-90	Wulik	f		538	1.50	5.34	3.30	0.20	117.00	21.40	unspawned
ADF&G	5-Oct-90	Wulik	f		615	1.10	2.22	4.80	< 0.10	96.40	21.90	non-spawner
ADF&G	5-Oct-90	Wulik	m		608	0.70	1.53	4.80	< 0.10	79.30	24.00	non-spawner
ADF&G	5-Oct-90	Wulik	f		430	3.00	2.93	5.20	< 0.10	100.00	23.70	non-spawner

Collected By	Date	Location	Sex	Weight (gm)	Length (mm)	Al (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	% Solids	Spawning Condition
ADF&G	5-Oct-90	Wulik	f		452	0.90	3.30	5.00	< 0.10	106.00	21.90	non-spawner
ADF&G	5-Oct-90	Wulik	f		528	1.10	2.63	5.30	< 0.10	103.00	18.50	non-spawner
Noatak	15-Apr-91	Noatak	f	274	323	2.10	0.93	3.20	< 0.10	112.00	23.10	
Noatak	15-Apr-91	Noatak	f	283	324	4.60	0.57	2.90	< 0.10	79.80	22.00	
Noatak	15-Apr-91	Noatak	m	714	416	2.20	2.01	3.20	< 0.10	93.40	26.50	
Noatak	15-Apr-91	Noatak	f	730	443	4.10	2.06	3.30	< 0.10	106.00	23.20	
Noatak	15-Apr-91	Noatak	f	449	401	5.00	1.82	3.70	0.10	108.00	18.00	
Cominco	9-Mar-91	Wulik				2.30	3.59	4.80	< 0.10	143.00	23.10	
Cominco	9-Mar-91	Wulik				4.70	3.48	5.20	< 0.10	103.00	22.90	
Cominco	9-Mar-91	Wulik				2.10	3.20	4.90	< 0.10	118.00	23.60	
Kivalina	6-Apr-91	Wulik	m		300	2.40	4.31	3.70	< 0.20	127.00	20.30	
Kivalina	6-Apr-91	Wulik	m	197	294	8.80	0.85	2.70	< 0.40	85.60	23.40	
Kivalina	6-Apr-91	Wulik	f	201	303	22.00	1.96	4.10	1.50	173.00	23.70	
Kivalina	6-Apr-91	Wulik	f	237	355	7.40	0.17	9.00	0.40	139.00	21.80	
Kivalina	6-Apr-91	Wulik	f	751	434	2.10	2.79	3.50	< 0.10	102.00	22.40	
Cominco	26-Apr-91	Wulik	f	1230	513	1.00	5.40	6.20	0.20	112.00	21.00	prespawner, small eggs
Cominco	16-Jun-91	Wulik	m	962	444.5	6.00	6.56	6.00	0.10	83.30	18.30	
Cominco	16-Jun-91	Wulik	f	1424	533	2.40	4.87	4.10	< 0.10	89.20	23.00	prespawner, small eggs
Cominco	16-Jun-91	Wulik	m	1361	541	1.70	4.14	4.00	0.20	76.60	22.30	
Cominco	16-Jun-91	Wulik	f	762	457	2.10	3.09	4.50	< 0.10	94.50	22.40	prespawner, small eggs
Cominco	16-Jun-91	Wulik	f	671	414	1.50	2.47	3.50	< 0.10	208.00	15.20	prespawner, small eggs
Cominco	16-Jun-91	Wulik	f	744	427	1.60	2.23	4.20	< 0.10	71.10	21.90	immature, no eggs
Cominco	16-Jun-91	Wulik	f	680	439	1.90	4.01	4.90	< 0.10	108.00	22.50	immature, no eggs
Cominco	16-Jun-91	Wulik	f	653	427	1.30	3.23	4.10	< 0.10	95.90	21.20	prespawner, small eggs
Cominco	5-Oct-91	Wulik	f	1.16	200	0.96	1.27	4.54	0.06	87.10	22.70	small eggs
Cominco	5-Oct-91	Wulik	m	1.26	200	1.86	1.66	4.89	0.62	92.40	22.80	
Cominco	5-Oct-91	Wulik	m	2.55	256	3.93	0.87	17.70	1.75	51.20	23.00	
Cominco	5-Oct-91	Wulik	f	2.19	246	1.30	2.54	6.18	0.03	104.00	22.30	small eggs
Cominco	5-Oct-91	Wulik	f	1.61	219	1.86	4.68	5.94	0.04	107.00	21.50	small eggs
Cominco	5-Oct-91	Wulik	m	2.23	235	0.75	2.81	4.37	0.06	86.40	22.90	

m=male, f=female, a=adult fish, sex not specified

*Data from Environmental Baseline Studies, Red Dog Project by Dames and Moore, Inc. 1983, Chapter 2, Table 2-7.

Appendix 3. Quality control/quality assurance data for concentrations of metals in Dolly Varden tissues. (Metals concentrations data presented in Appendix 2.)

Dates of Samples QA/QC applies to	Metal	Method	Method Reporting Limit	Duplicate Samples: Sample A	Duplicate Samples: Sample B	Duplicate Samples: %Relative Difference	Matrix Spike Results: Spike Level	Matrix Spike Results: Sample Result	Matrix Spike Results: Spiked Sample Result	Matrix Spike Results: % Recovery	Method Blank Summary: MB1	Method Blank Summary: MB2	Method Blank Summary: MB3
10/5/90	Al	202.2	0.10	1.50	1.00	38	4.70	1.50	6.80	113	ND		
	Cd	7131	0.01	1.11	1.14	3	0.95	1.11	1.93	86	ND		
	Cu	6010	0.40	25.60	27.00	5	4.70	25.60	32.60	NC	ND		
	Pb	7412	0.10	0.10	ND		0.90	0.10	0.90	89	ND		
	Zn	6010	0.40	103.00	105.00	2	23.70	103.00	129.00	NC	ND		
10/19/90	Al	202.2	0.10	2.30	4.30	61	47.70	2.30	76.40	155	ND		
	Cd	7131	0.01	0.01	0.01	0	1.20	0.01	1.34	112	ND		
	Cu	6010	0.50	2.40	3.50	37	47.70	2.40	59.80	120	ND		
	Pb	7412	0.10	0.10	0.10	0	4.80	0.10	5.10	106	ND		
	Zn	6010	0.50	12.90	13.80	7	119.00	12.90	135.00	103	ND		
3/9/91	Al	202.2	0.10	2.20	2.30	4	10.40	2.20	10.20	77	0.2		
	Cd	7131	0.01	nd	nd		1.04	nd	1.14	110	nd		
	Cu	6010	0.50	3.50	3.70	6	41.50	3.50	47.30	106	nd		
	Pb	7412	0.10	nd	nd		4.20	nd	4.30	102	nd		
	Zn	6010	0.50	18.60	17.60	6	104.00	18.60	126.00	103	nd		
4/6/91	Al	202.2	0.10	6.40	6.80	6	9.60	6.40	16.10	101	0.2	0.2	0.2
4/15/91	Cd	7131	0.01	0.04	0.04	<1	0.96	0.04	1.10	110	nd	nd	nd
	Cu	6010	0.50	2.40	2.20	9	38.50	2.40	43.40	106	nd	nd	nd
	Pb	7412	0.10	nd	nd		3.90	nd	4.10	105	nd	nd	nd
	Zn	6010	0.50	16.10	16.40	2	96.30	16.10	113.00	101	nd	nd	nd
4/6/91	Al	202.2	0.10	4.10	3.80	8	9.70	4.10	14.70	109			
4/15/91	Cd	7131	0.01	0.01	nd		0.97	0.01	1.07	109			
continued	Cu	6010	0.50	1.20	1.20	<1	38.40	1.20	42.70	108			
	Pb	7412	0.10	nd	nd		3.90	nd	4.00	103			
	Zn	6010	0.50	17.00	16.90	<1	96.00	17.00	116.00	103			

			Duplicate Samples				Matrix Spike Results				Method Blank Summary		
Dates of Samples QA/QC applies to	Metal	Method	Method Reporting Limit	Sample A	Sample B	%Relative Difference	Spike Level	Sample Result	Spiked Sample Result	% Recovery	MB1	MB2	MB3
4/26/91	Al	202.2	0.10	1.20	1.30	8	6.70	1.20	6.40	78	0.3	0.3	
6/16/91	Cd	7131	0.01	ND	ND		0.67	ND	0.67	100	ND	ND	
	Cu	6010	0.50	1.70	1.50	12	26.90	1.70	28.80	101	ND	ND	
	Pb	7412	0.10	ND	ND		2.70	ND	2.70	100	ND	ND	
	Zn	6010	0.50	13.60	13.80	4	67.30	14.10	78.40	96	ND	ND	
4/26/91	Al	202.2	0.10	2.10	2.20	4	9.20	2.10	12.20	110	0.4	0.2	
6/16/91	Cd	7131	0.01	3.09	3.12	<1	0.92	3.09	4.01	100	ND	ND	
continued	Cu	6010	0.50	4.50	4.30	5	36.70	4.50	39.70	96	ND	ND	
	Pb	7412	0.10	ND	ND		3.70	ND	3.90	105	ND	ND	
	Zn	6010	0.50	94.50	90.70	4	91.70	94.50	178.00	91	ND	ND	
10/5/91	Al	200.8	0.05	0.55	0.59	7	4.06	0.55	3.97	84	0.5	0.56	0.51
	Cd	200.8	0.02	ND	ND	--	0.81	ND	0.88	109	ND	ND	ND
	Cu	200.8	0.05	2.55	2.15	17	16.20	2.55	18.20	97	0.08	ND	ND
	Pb	200.8	0.02	0.03	0.04	25	1.62	0.03	1.81	110	0.04	ND	ND
	Zn	200.8	0.05	14.90	14.00	6	40.60	14.90	51.60	90	0.9	0.41	0.31
10/5/91	Al	200.8	0.05	0.32	0.28	13	4.48	0.32	5.42	114			
Continued	Cd	200.8	0.02	ND	ND	--	0.90	ND	0.97	108			
	Cu	200.8	0.05	2.42	2.35	3	17.90	2.42	21.40	106			
	Pb	200.8	0.02	0.05	0.03	50	1.79	0.05	2.13	116			
	Zn	200.8	0.05	12.20	12.20	<1	44.80	12.20	56.40	99			

ND = not detected at MRL

NC = not calculated due to sample concentration greater than 4 times the spike level

Appendix 4. Dolly Varden collected in Evaingiknuk Creek using minnow traps baited with salmon roe. Minnow traps placed in waters between 0.15 and 0.61 meters deep with water velocities from 0.0 to 0.46 meters per second and a gravel and cobble substrate. Stream banks were undercut with overhanging vegetation.

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

Appendix 5. Dolly Varden collected in Dudd Creek using minnow traps baited with salmon roe. Minnow traps placed in waters between 0.30 and 0.61 meters deep with water velocities from 0.15 to 0.30 meters per second and a gravel and cobble substrate. Stream banks were undercut with overhanging vegetation.

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

Appendix 6. Dolly Varden collected in Anxiety Ridge Creek using minnow traps baited with salmon roe. Minnow traps placed in waters between 0.46 and 0.91 meters deep with water velocities from 0.15 to 0.61 meters per second and a gravel with some cobble substrate. Stream banks were undercut with overhanging vegetation and instream woody debris was present in several sites.

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

Appendix 6 continued.

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
10/4-5/91	5	26	4	78-133(117)	0.8±0.8

Appendix 7. Dolly Varden collected in Little Creek using minnow traps baited with salmon roe. Minnow traps placed in waters between 0.30 and 1.07 meters deep with water velocities from 0.15 to 0.61 meters per second and a gravel, cobble, and sand substrate. Stream was incised and banks were undercut with overhanging vegetation.

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

Appendix 8. Dolly Varden collected in Ikalukrok Creek using minnow traps baited with salmon roe. 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 in Ikalukrok Creek at Dudd Creek were the same in 1990 and 1991. Minnow traps in Ikalukrok Creek at Dudd Creek were placed in waters between 0.30 and 0.91 meters deep with water velocities from 0.15 to 0.61 meters per second and a gravel and cobble substrate. Some trap sites were adjacent to cut banks with overhanging vegetation while others were along exposed gravel bars.

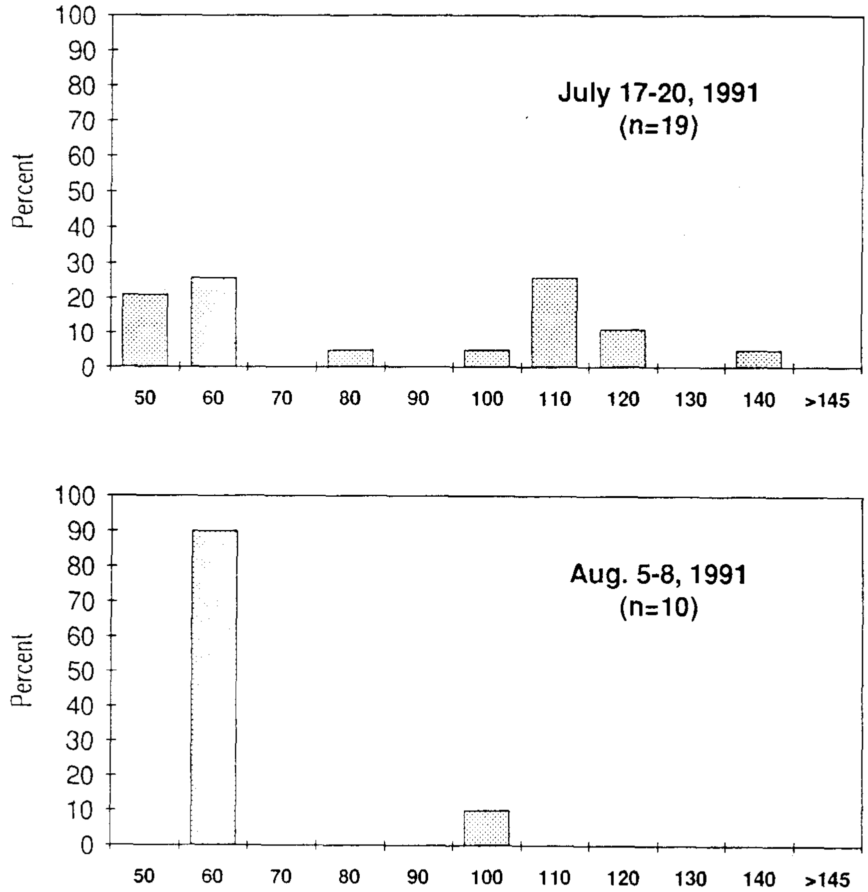
Sample Time	Number of Traps	Hours Fished/ Trap	Total Number DV	Length Range (mm), (Average)	DV/Trap ±SD
[a]7/27-28/90	5	19	0		0.0
[b]7/27-28/90	5	23	1	107	0.2±0.4
[c]7/28-29/90	5	23	0		0.0
[d]7/28-29/90	5	22	0		0.0
[d]8/23-24/90	5	24	0		0.0
[e]8/23-24/90	5	24	0		0.0
[e]8/24-26/90	5	48	0		0.0
[f]8/24-29/90	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

Appendix 8 continued.

[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
[e]8/27-30/91	5	65	0		0.0
[e]10/2-5/91	5	73	0		0.0

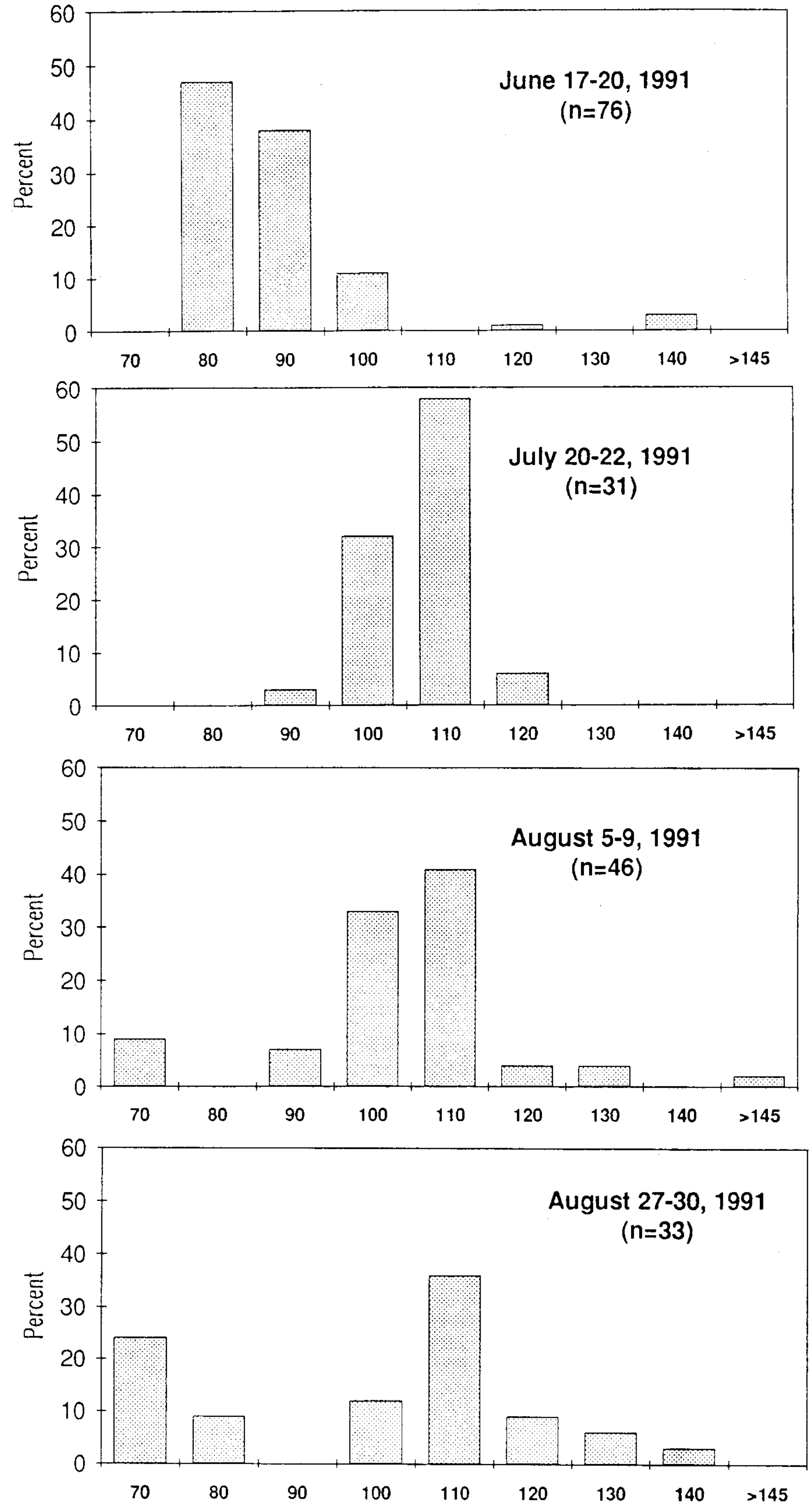
[a]Ikalukrok Creek - 7 km upstream of Dudd Creek
[b]Ikalukrok Creek - 10 km downstream of Dudd Creek
[c]Ikalukrok Creek - 10 km downstream of Dudd Creek, clear back-water
[d]Ikalukrok Creek - 20 km downstream of Dudd Creek
[e]Ikalukrok Creek - Immediately upstream of Dudd Creek
[f]Ikalukrok Creek - Immediately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

Appendix 9. Length frequencies (mm) of juvenile Dolly Varden caught in minnow traps in Ikalukrok Creek during the ice-free season, 1991.

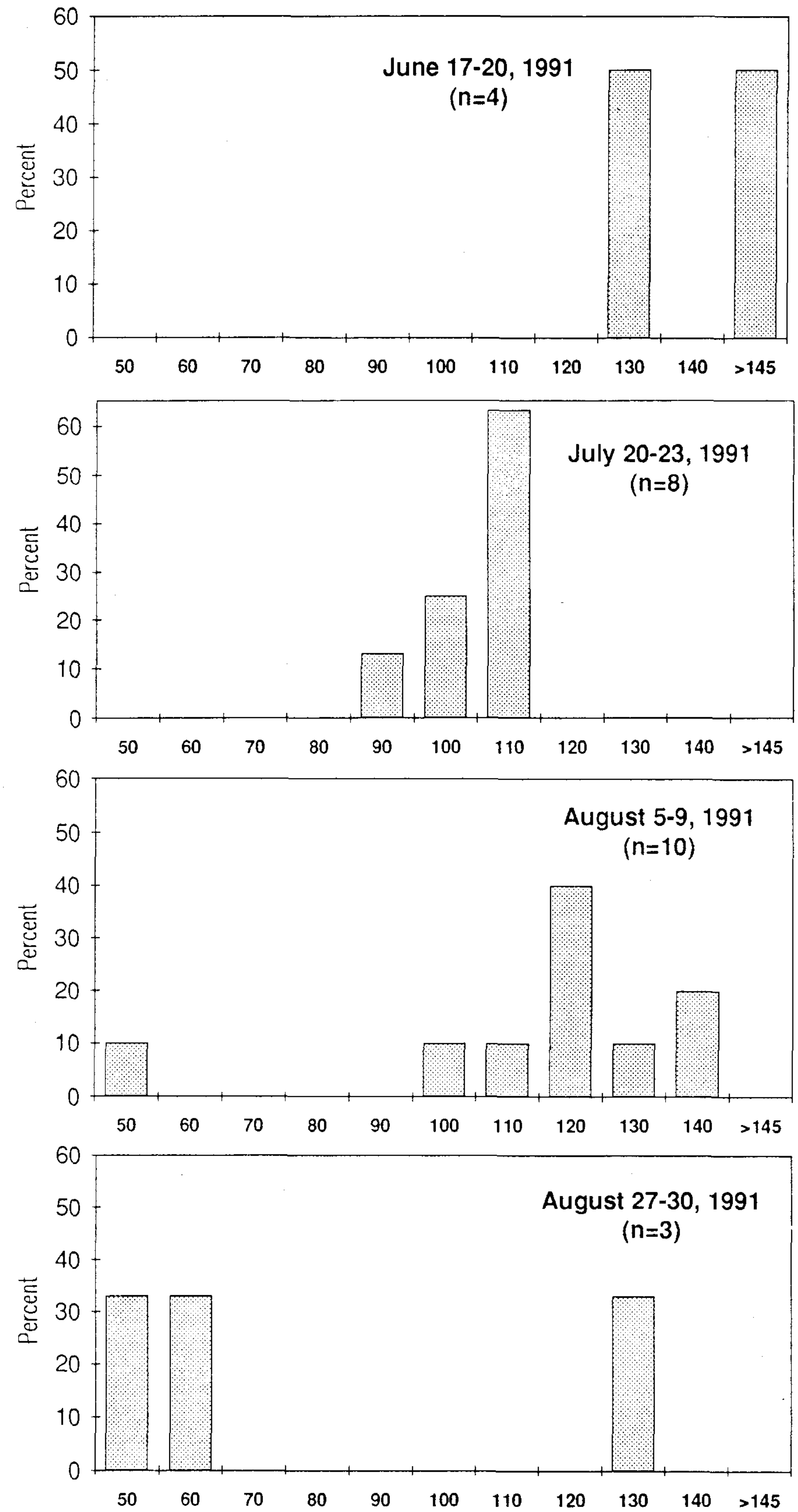


Size Range (mm)

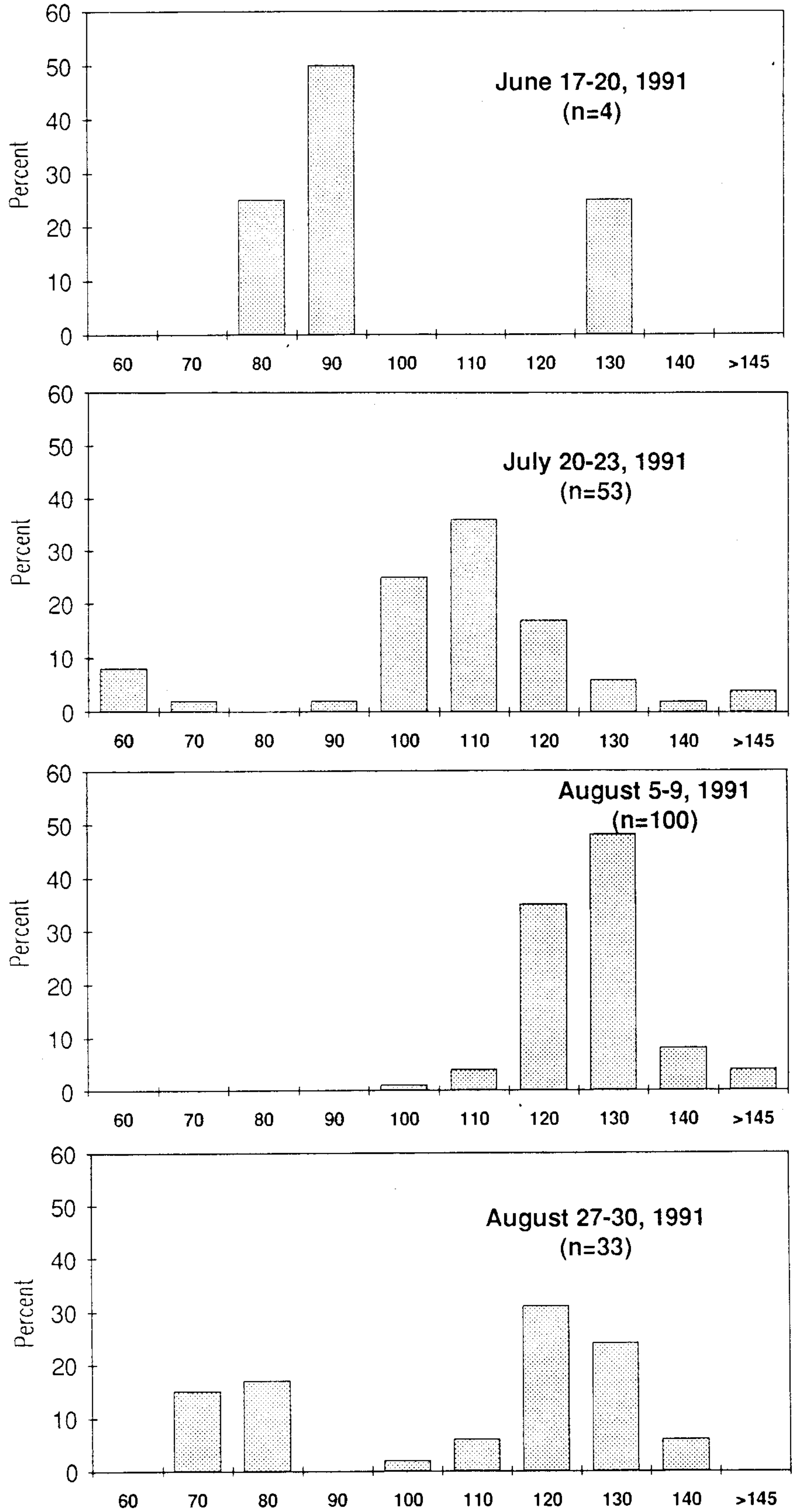
Appendix 10. Length frequencies (mm) of juvenile Dolly Varden caught in minnow traps in Evaingiknuk Creek during the ice-free season, 1991.



Appendix 11. Length frequencies (mm) of juvenile Dolly Varden caught in minnow traps in Little Creek during the ice-free season, 1991.



Appendix 12. Length frequencies (mm) of juvenile Dolly Varden caught in minnow traps in Anxiety Ridge Creek during the ice free season, 1991.



Appendix 13. Length frequencies (mm) of juvenile Dolly Varden caught in minnow traps in Dudd Creek during the ice free season, 1991.