Technical Report No. 23-02

Aquatic Biomonitoring at Red Dog Mine, 2022

A requirement under Alaska Pollution Discharge Elimination System Permit No. AK0038652

by

Chelsea M. Clawson

April 2023

Alaska Department of Fish and Game **Habitat Section**

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by Habitat Section and the Divisions of Sport Fish, and Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, Technical Reports and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

TECHNICAL REPORT NO. 23-02

AQUATIC BIOMONITORING AT RED DOG MINE, 2022

A REQUIREMENT UNDER ALASKA POLLUTION DISCHARGE ELIMINATION SYSTEM PERMIT NO. AK0038652

By

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April 2023

Cover: Freshly tagged Arctic grayling in Bons Creek June 6, 2022. Photograph by Chad Bear.

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Acknowledgements

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Nora Foster (NRF Taxonomic Services) was responsible for sorting and identification of aquatic invertebrates. Al Ott, Olivia Edwards, Audra Brase, and Robert Napier provided constructive reviews of this report.

Executive Summary

●In 2022, median element concentrations (lead, zinc, aluminum, cadmium) in Buddy Creek and Bons Pond were consistent with past years' results, and were lower when compared with pre-mining data. Cadmium increased slightly in North Fork Red Dog Creek, and zinc decreased slightly. Aluminum, cadmium, nickel, and lead remained stable or decreased slightly in Mainstem Red Dog Creek from 2021 levels. Zinc levels increased in Mainstem Red Dog Creek, but were still lower than the peak observed in 2020. Total dissolved solids (TDS) in Mainstem Red Dog Creek increased, which may be related to increasing naturally occurring TDS throughout the drainage.

●Periphyton standing crop, as estimated by chlorophyll-a concentration, is determined each year in drainages near the Red Dog Mine. In 2022, chlorophyll-a concentrations were highest in Bons Creek below the pond (Sta 220) and lowest in upper Ikalukrok Creek (Sta 9), Mainstem Red Dog Creek (Sta 10), Middle Fork Red Dog Creek (Sta 20), and lower Ikalukrok Creek (Sta 160). Chlorophyll-a concentration in Ikalukrok Creek at Station 9 continues to have an inverse relationship with zinc and cadmium in the water. The major source of cadmium and zinc at Station 9 is the Cub Creek natural seep.

●Aquatic invertebrate densities are used as an index of stream productivity and health. In 2022, ten sites were sampled, and the aquatic invertebrate density was highest at Bons Creek below the pond (Sta 220) and Buddy Creek below the falls. Overall taxa richness varied from 5 to 22 taxa per site. Sampling method was changed from drift nets to Hess samplers in 2022 to better depict the in-situ aquatic community and evaluate potential changes.

●Juvenile Arctic grayling from Bons Pond have been analyzed for selected whole body elements in 2004, 2007, 2010, and 2014 – 2022. Average cadmium, lead, mercury, and selenium concentrations in Arctic grayling juveniles in 2022 were consistent with past years' levels. The average selenium concentration in juvenile Arctic grayling in 2022 decreased from the peak observed in 2021. The mean zinc concentration was higher than previous years, but the standard deviation overlapped with previous years' results.

●Juvenile Dolly Varden from Mainstem Red Dog, Buddy, and Anxiety Ridge creeks have been analyzed for selected whole body elements from 2005 to 2011 and from 2014 to 2022. Juvenile Dolly Varden median whole body concentrations of cadmium and zinc are consistently highest in Mainstem Red Dog Creek. Lead concentrations in fish from Mainstem Red Dog have decreased while concentrations in fish from Buddy Creek have increased. Buddy Creek fish had the highest mean lead concentration since 2020. Mean selenium concentrations were nearly equal among the three sites in 2022.

●In 2022, adult Dolly Varden captured in the Wulik River during spring and fall were analyzed for cadmium, copper, lead, selenium, zinc, and mercury in kidney, liver, ovary, testes, and muscle tissues. Various elements concentrate in specific tissues. None of the analytes measured appear to concentrate in muscle.

●Aerial surveys are used each fall to estimate the number of overwintering Dolly Varden in the Wulik River. In 2022, a total of 74,482 Dolly Varden were counted in the Wulik River, although this should be considered a minimum estimate due to reduced visibility from turbidity.

●Only 208 chum salmon were observed in Ikalukrok Creek in 2022, although this should be considered a severe underestimate as visibility was severely impeded by turbidity in Ikalukrok Creek.

●In spring 2022, six resident Dolly Varden were captured with fyke nets in North Fork Red Dog Creek, averaging 159 mm FL. Juvenile Dolly Varden sampling with minnow traps was conducted in late summer 2022. The total number of juvenile Dolly Varden captured at all sample sites in the Ikalukrok drainage was 499 fish with an average size of 92 mm FL. The highest catch was in Buddy Creek (202 fish).

●The spring Arctic grayling spawning migration into North Fork Red Dog Creek was monitored. Spawning time in Mainstem Red Dog Creek could not be determined as green and ripe females were still being captured when sampling concluded. The 2021 population of Arctic grayling in North Fork Red Dog Creek could not be estimated as no fish that were captured in 2021 were recaptured in 2022.

●The estimated Arctic grayling population in Bons Pond in 2021 was 747 fish $\geq$ 200 mm FL. The population has been stable at around 700 fish since 2019.

●Pre-mining slimy sculpin abundance is unknown. Baseline reports indicated that this species was numerous in the Ikalukrok Creek drainage, but uncommon in the Red Dog Creek drainage. Slimy sculpin catches were low again in 2022, with three sculpin captured in Ikalukrok Creek and one captured in Mainstem Red Dog Creek.

Introduction

The Red Dog zinc (Zn) and lead (Pb) deposit is located in northwestern Alaska, about 130 km north of Kotzebue and 75 km inland from the Chukchi Sea coast (Figure 1). Mine operations, facilities, the surrounding vegetation, and wildlife are described in the Alaska Department of Fish and Game (ADF&G) technical report: *Fisheries Resources and Water Quality, Red Dog Mine* (Weber Scannell and Ott 1998). A chronology of development and operations at the Red Dog Mine for 2014 through 2022 is presented in Appendix 1. The summary of previous years of mine development and operations (1982 to 2013) can be found in Ott and Morris 2014. Aquatic resources in the Wulik River drainage are described in the ADF&G technical report: *Fish and Aquatic Taxa Report at Red Dog Mine, 1998-1999* (Weber Scannell et al. 2000).

Aquatic biomonitoring has occurred annually at the Red Dog Mine since 1995 and has included periphyton, aquatic invertebrate, and fish sampling. Tissue and whole body element analyses for Dolly Varden (*Salvelinus malma*) and spawning season monitoring for Arctic grayling (*Thymallus arcticus*) are performed annually. In 2017, the Alaska Department of Environmental Conservation (ADEC) issued Alaska Pollution Discharge Elimination System Permit (APDES) No. AK0038652 to Teck Alaska Incorporated (Teck) which allowed the discharge of up to 2.418 billion gallons of treated effluent per year into Middle Fork Red Dog Creek. The APDES Permit required the continuation of a bioassessment program that included periphyton, aquatic invertebrates, and fish in selected streams near the Red Dog Mine (Tables 1 and 2). The current bioassessment program became fully effective and enforceable on September 1, 2017.

On September 23, 2021, the ADEC issued Waste Management Permit No. 2021DB0001 (WMP) for the Red Dog Mine that included a condition that Teck adhere to the requirements of the monitoring plan contained in the Integrated Waste Management Plan submitted by Teck in September 2021. Teck's Monitoring Plan includes sample sites, sampling frequency, and parameters for all aquatic sites, including those required by the APDES Permit (Table 1). To satisfy conditions in the ADEC permit, the ADF&G submitted Technical Report #17-09 Methods for Aquatic Life Monitoring at the Red Dog Mine Site: A requirement of the 2017 APDES Permit AK0038652.

Under APDES Permit No. AK0038652, the Total Dissolved Solids (TDS) load discharged from Outfall 001 is limited from July 25 through the end of the discharge season to maintain total in-stream TDS concentrations at or below 500 mg/L at Station 160 on Ikalukrok Creek. This provision is included to properly protect chum salmon spawning in Ikalukrok Creek. In 2019 and 2020, discharge was paused for part of the discharge season due to background TDS levels at Station 160 approaching or exceeding the 500 mg/L threshold. Based on field measurements made by Teck, the elevated TDS concentrations were due to natural input from drainages in Ikalukrok Creek upstream of Mainstem Red Dog Creek. This inability of the Red Dog Mine to discharge at typical levels led to an increase in water elevation within the Tailings Storage Facility (TSF) and required Red Dog to take special actions throughout the winter of 2019 – 2020 to ensure the TSF water level remained within the criteria established in the State's (Department of Natural Resources) certificate to operate the dam. During the summer of 2020, Red Dog completed an Interim Dam Raise, increasing the freeboard limit in the TSF by five feet, and commissioned a new Reverse Osmosis water treatment system. However, background TDS levels at Station 160 have continued to exceed the 500 mg/L threshold, requiring a permit modification to continue discharging throughout the 2021 and 2022 season.

Red Dog Operations received a minor permit modification to APDES Permit No. AK0038652 on May 19, 2021. The permit modification allows continued discharge of high quality treated wastewater when the TSF approaches within 15 feet of the freeboard limit, even though the natural TDS concentration of the receiving waterbody may exceed the 1,000 mg/L (prior to July 25th) or 500 mg/L (July 25th and later) thresholds. The TDS concentration in treated water discharge remains the same; it is the naturally occurring background TDS in Ikalukrok Creek that has increased. The permit modification includes a Compliance Schedule, which requires various aquatic studies, technical evaluations, and reports that are needed to establish compliance with the TDS water quality based effluent limits of the permit.

Teck's monitoring plan is incorporated by reference into the Alaska Department of Natural Resources (ADNR) Reclamation Plan Approval (F20169958) dated September 28, 2016. On March 10, 2010, the U.S. Department of Army issued permit POA-1984-12-M45 to Teck which authorized development of the Aqqaluk Pit. Active mining in the Aqqaluk Pit began during 2012. In addition to mine drainage, certain waste rock from Aqqaluk and Qanaiyaq and treated water were placed in the mined out main pit. This report presents data collected during summer 2022 and where applicable, these data are compared with previous years.

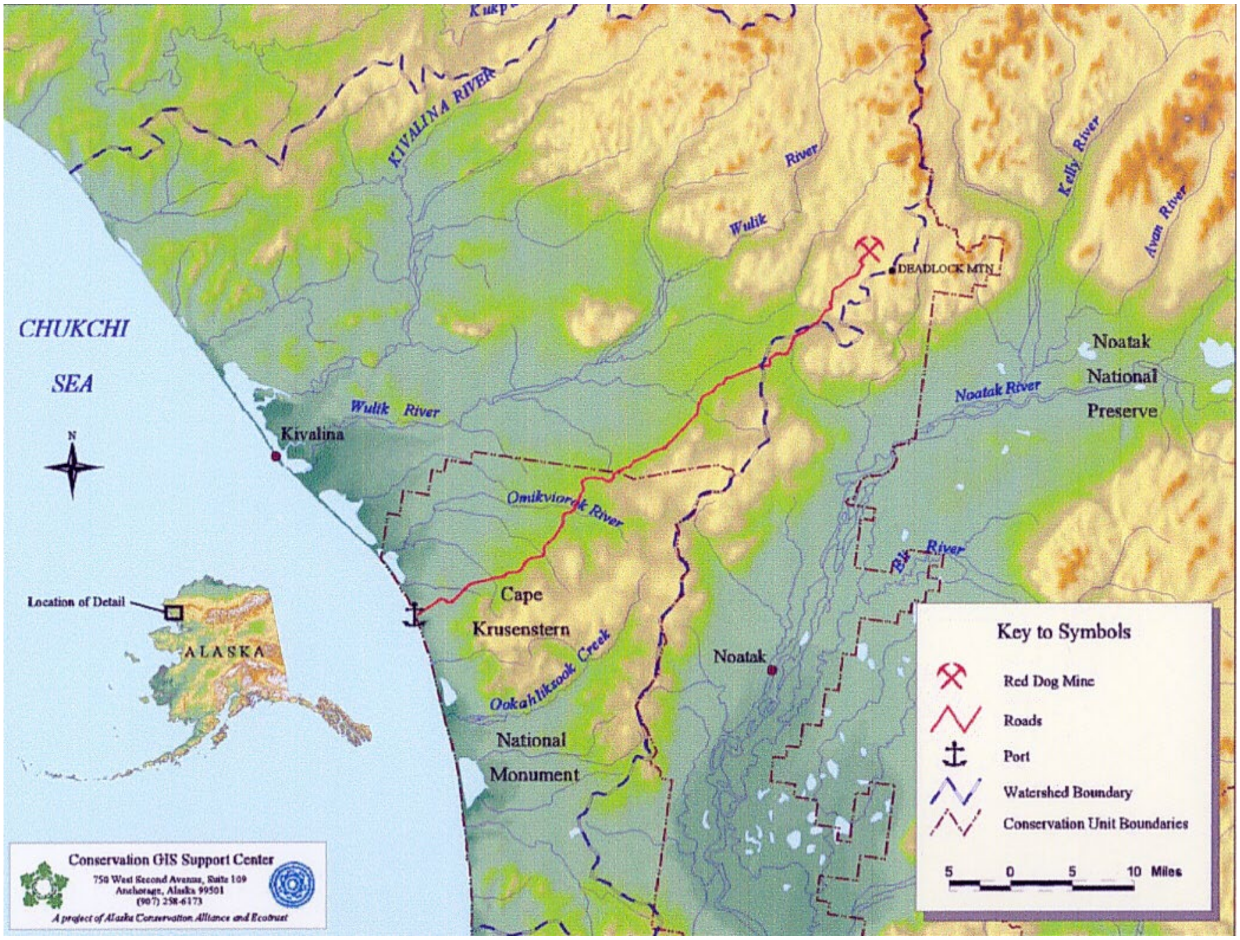


Figure 1. Location of the Red Dog Mine in northwestern Alaska.[1]

[1] Map used with permission of Conservation GIS Support Center, Anchorage, Alaska.

Table 1. Location of biological sample sites and factors measured at the Red Dog Mine, 2022.

Location	APDES[1]/WMP[2]	Location Description	Parameters
Wulik River	WMP	Kivalina Lagoon to 10 km past mouth of Ikalukrok Creek	Fall aerial surveys for overwintering Dolly Varden
Ikalukrok Cr	WMP	Lower Ikalukrok Creek to mouth of Dudd Creek	Fall aerial surveys for adult chum salmon
Station 9	APDES/WMP	Ikalukrok Creek upstream of confluence with Red Dog Creek	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates Fish presence and use
Station 160	WMP	Lower Ikalukrok Creek	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates Fish presence and use
Station 20	WMP	Middle Fork Red Dog Creek	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates
Station 10	APDES/WMP	Mouth of Red Dog Creek	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates Fish presence and use Juvenile Dolly Varden elements in tissue
Station 12	APDES/WMP	North Fork Red Dog Creek	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates Fish presence and use Record of spawning activity Capture/mark Arctic grayling
Upper NF	APDES	Upper North Fork Red Dog Creek, above Aqqaluk	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates Fish presence and use
Station 151	APDES	Mainstem Red Dog Creek	Fish presence and use
Buddy Creek	WMP	Below falls, about 1.5 km downstream of haul road	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates Fish presence and use Juvenile Dolly Varden elements in tissue
Buddy 221	WMP	Buddy Creek above haul road	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates
Bons 220	WMP	Bons Creek below pond	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates
Bons	WMP	Bons Creek above pond	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates
Anxiety Ridge	WMP	Anxiety Ridge Creek below haul road	Fish presence and use Juvenile Dolly Varden elements in tissue
Evaingiknuk	WMP	Evaingiknuk Creek east of haul road	Fish presence and use
Bons Pond	WMP	Above reservoir spillway	Juvenile Arctic grayling elements in tissue Arctic grayling population estimate

[1]APDES – Alaska Pollutant Discharge Elimination System [2]WMP – Waste Management Permit

Structure of Report

This report is presented in several sections as follows:

1) Overview of sampling sites and general methods;
2) Water quality;
3) Periphyton standing crop;
4) Aquatic invertebrates;
5) Element concentration data for juvenile Dolly Varden and juvenile and adult Arctic grayling collected from streams and Bons Pond, and adult Dolly Varden collected from the Wulik River;
6) Aerial survey estimates of overwintering Dolly Varden in the Wulik River and chum salmon (*Oncorhynchus keta*) spawners in Ikalukrok Creek; and
7) Biological monitoring data for Dolly Varden juveniles, Arctic grayling, and slimy sculpin (*Cottus cognatus*).

Location and Description of Sample Sites

Biomonitoring is conducted annually in streams in the vicinity of the Red Dog Mine as required under the APDES Permit No. AK0038652 (Table 1 and Figure 2) and by the ADEC Waste Management Permit and the ADNR Reclamation Plan Approval. All streams in the study area including Red Dog, Ikalukrok, Bons and Buddy creeks are in the Wulik River drainage, except for Evaingiknuk Creek, which is in the Noatak River drainage. Station numbers correspond either to those used by Dames and Moore (1983) during baseline work or to the current water quality program being conducted by Teck. Water quality and fish data collected during four years of baseline studies (1979 to 1982) represent pre-mining conditions. Comparisons of existing conditions relative to baseline data should consider that there is a much longer time series of data since mining began (1990 to 2022) when compared to the pre-development baseline data.

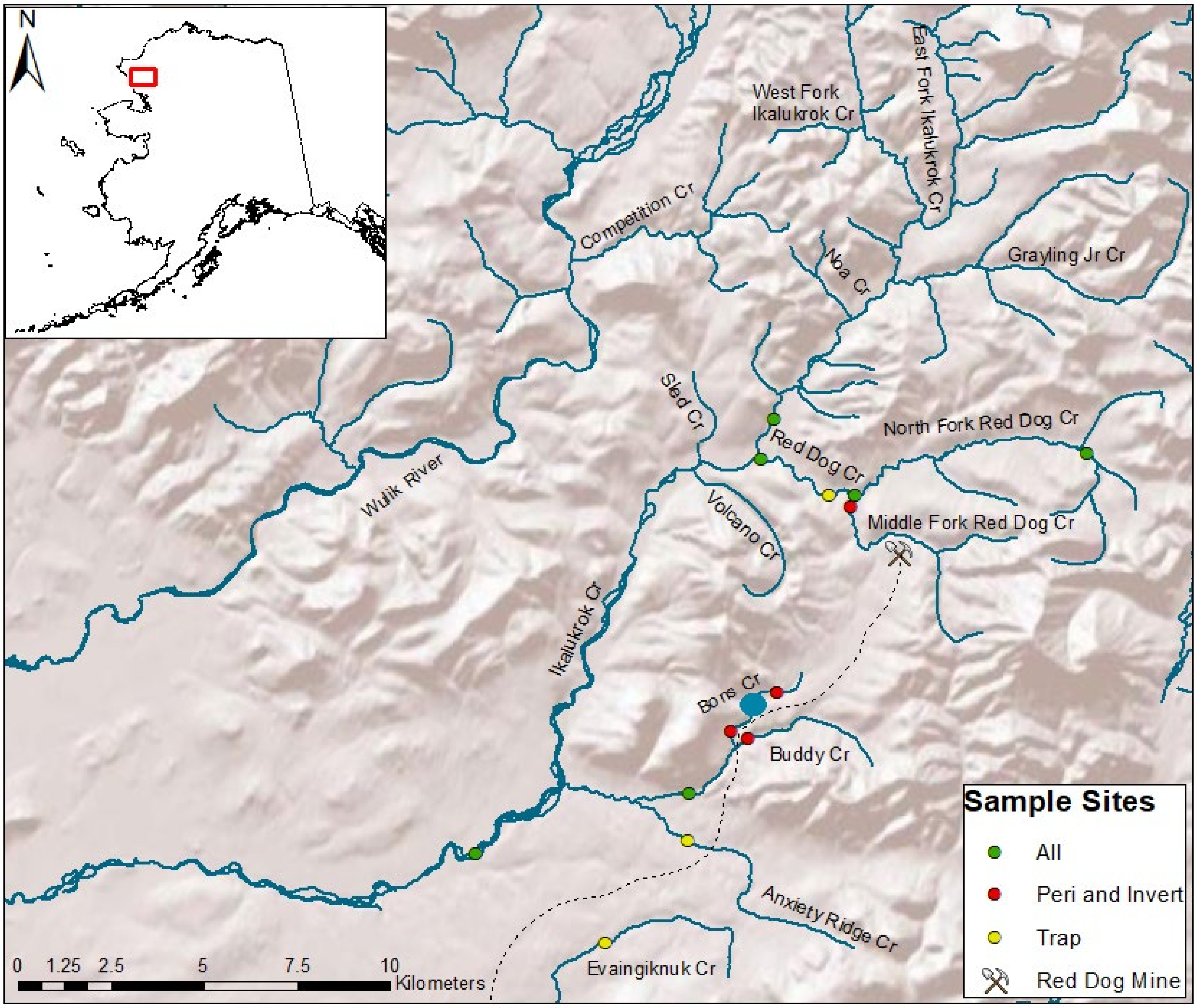


Figure 2. Location of sample sites in the Ikalukrok Creek drainage (tributary of the Wulik River) and Evaingiknuk Creek (a tributary of the Noatak River) drainage.

Methods

Five sampling events occurred in the Red Dog vicinity in 2022 including spring Arctic grayling gamete collection and sampling and adult Dolly Varden sampling (June 2 – June 9), mid-summer aquatic invertebrates and periphyton (July 7 – 14), late-summer juvenile Dolly Varden sampling (August 1 – 6), and fall aerial surveys of Dolly Varden in Wulik River and chum salmon in Ikalukrok Creek (October 1 – 3). The gamete collection in spring was part of the additional studies commissioned to meet requirements of the 2021 minor permit modification TDS Compliance Schedule. These studies are intended to identify potential effects from Red Dog Mine treated water discharge to the environment, given the recent and rapidly changing background water quality.

Owl Ridge Natural Resource Consultants is the project lead on these studies, with logistical support from ADF&G Habitat staff.

Methods used for the 2022 Red Dog Mine aquatic biomonitoring study are fully described by ADF&G (2017) in Technical Report No. 17-09 Methods for Aquatic Life Monitoring at the Red Dog Mine Site, a requirement of the 2017 APDES Permit AK0038652.

In 2022, invertebrate sampling at all sites was conducted with Hess samplers instead of drift nets. The Hess stream bottom sampler has a 0.086 m^2 sample area and material is captured in a 200 mL cod end – both constructed with 300 µm mesh net. Rocks within the sample area were scoured by hand, and gravel, sand, and silt were disturbed to about 10 cm depth to dislodge macroinvertebrates into the net. After samples were collected, methods for preservation and identification of invertebrates were identical to those used for drift net invertebrate samples. Hess samplers are potentially more accurate at identifying the in-situ benthic community, rather than the drifting invertebrate community. This provides a more accurate baseline for evaluating changes at each site, rather than changes occurring upstream. However, since sampling methodology is different, previous years' invertebrate results are not directly comparable to the 2022 results.

All 2022 water quality sampling was performed by Red Dog Mine personnel following their standard methodology. Water quality analysis was performed by laboratories and results provided to ADF&G for inclusion in this report. All water quality presented in this report are for "total recoverable" unless otherwise specified. The number of water quality samples taken each year varies depending upon duration of the open water season, but are collected according to Red Dog Mine's APDES permit and WMP. Baseline water quality pre-mining data presented in the report were collected from 1979 to 1982.

In 2022, the abundance of Arctic grayling in Bon's Pond and North Fork Red Dog Creek was estimated using Chapman's modification of the Lincoln-Petersen two-sample mark-recapture model (Chapman 1951),

$$\widehat{N}_c = \left\{\frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)}\right\} - 1$$

where $\widehat{N}_c$ = estimated population, n_1 = fish marked in first capture event, n_2 = fish captured during recapture event, and m_2 = fish captured during recapture event that were marked in the capture event.

Variance was calculated as (Seber 1982):

$$\mathrm{var}(\hat{N}_c) = \left\{\frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)}\right\}$$

The 95% C.I. for the population estimate was calculated as:

$$95\%\ \mathrm{C.I.} = N_c \pm (1.960)\sqrt{\widehat{\mathrm{var}}(\hat{N}_c)}$$

Results and Discussion

Water Quality

Water quality data collected in Mainstem Red Dog Creek prior to 2010 were from Station 10, located near the mouth of the creek. Data from 2010 to 2022 were collected at Station 151 located about 2 km upstream from Station 10. Station 151 is at the downstream end of the mixing zone in Mainstem Red Dog Creek (Figure 3). There are no defined drainages entering Mainstem Red Dog Creek between these two water quality stations. Mainstem Red Dog Creek is directly affected by the treated mine wastewater effluent and by water from the clean water bypass. North Fork Red Dog Creek is a reference site with no direct effects from the mine.

Figure 3. Downstream end of mixing zone in Mainstem Red Dog Creek in early August 2022 (Station 151).

In 2022, Teck continued to maintain the mine's clean water bypass system which picks up non-mining impacted water (non-contact water) from Sulfur, Shelly, Connie, Rachel, and Upper Middle Fork Red Dog creeks (Figure 4). This water is moved through the mine pit area, including the currently active Aqqaluk pit, to its original channel via a combination of culverts and lined open ditches. These bypass conveyance structures serve to isolate the non-contact water from areas disturbed by mining activities.

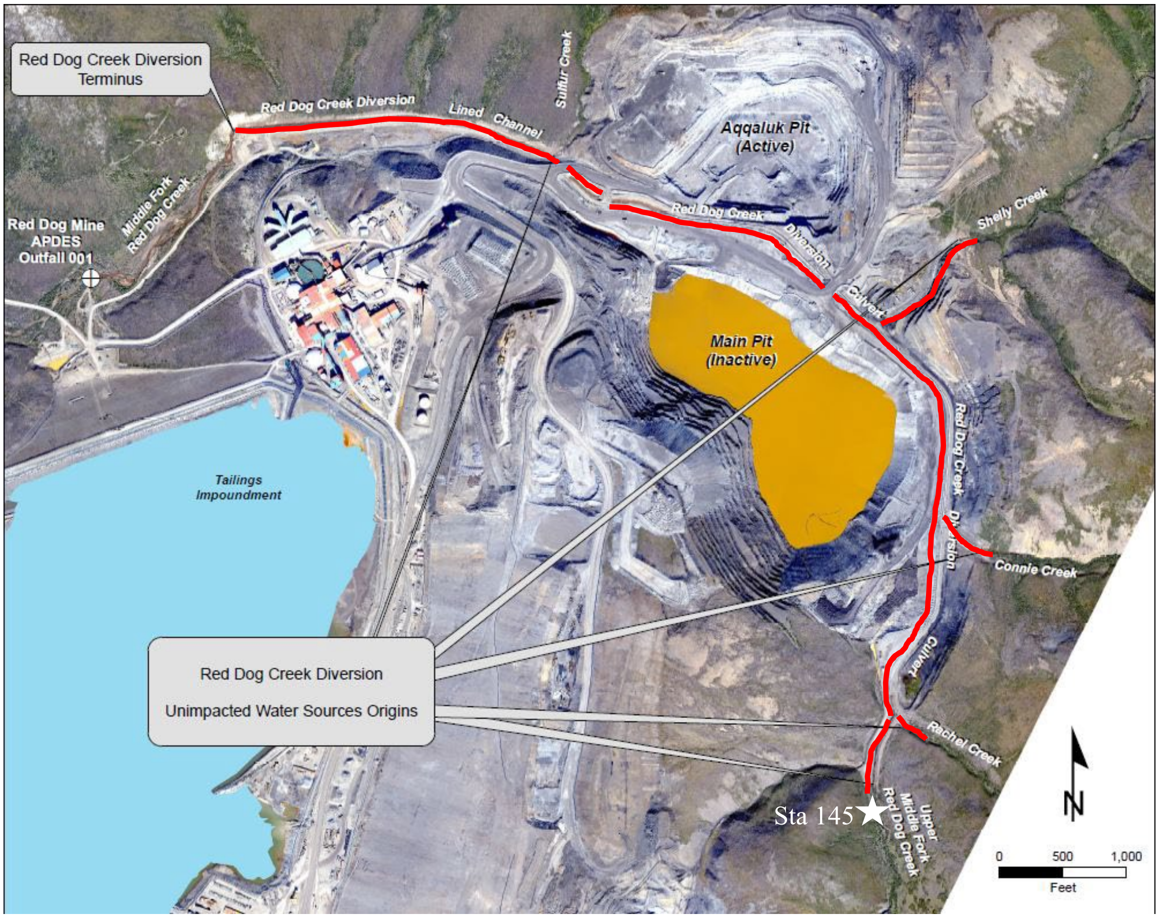


Figure 4. Clean water bypass system at the Red Dog Mine. The Red Dog Creek diversion structure (delineated by labels in the photograph and shown in red) picks up non-mining impacted waters from upstream tributaries and moves them between the Aqqaluk pit and the main pit back to the original Middle Fork Red Dog Creek streambed.[2]

In 2022, the median lead concentration in Mainstem Red Dog Creek (Station 151/10), downstream of the clean water bypass system, remained lower than the pre-mining (1979-83) median concentration. However, in some years the maximum lead concentration has been higher than pre-

[2] Figure provided by Teck with modifications made by ADF&G.

mining (Figure 5). Median lead concentrations increased beginning in 2017 and peaked at 18.0 µg/L in 2020, then declined in 2021 and 2022 to 7.2 µg/L and 6.3 µg/L, respectively.

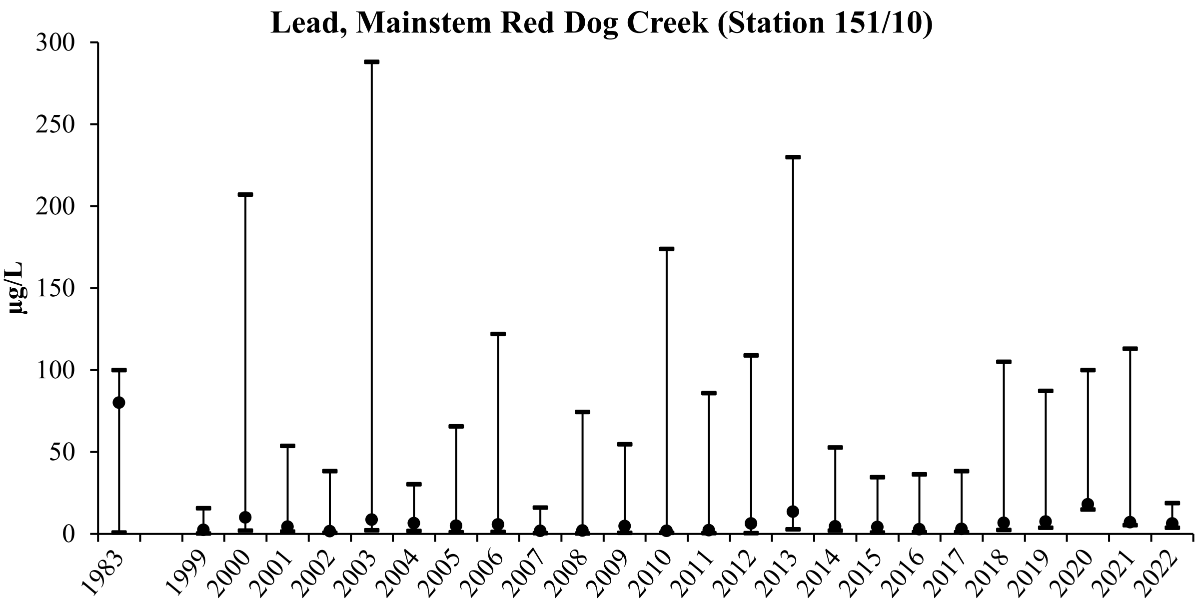


Figure 5. Median, maximum, and minimum lead concentrations at Station 151/10.

In 2022, the system with the highest concentration of lead was Sulfur Creek with a median lead concentration of 270.5 µg/L (Figure 6). Sulfur Creek often has the highest median lead concentration. Flows in Sulfur Creek are typically low, so although lead concentrations are often high in Sulfur Creek, it does not have much effect on overall lead concentrations in Mainstem Red Dog Creek. Station 145 is affected by the Kaviqsaaq Seep, which was captured and diverted to the tailings pond for eventual treatment beginning in 2021, which could have contributed to the decrease in lead levels at Station 145 from 2020 levels.

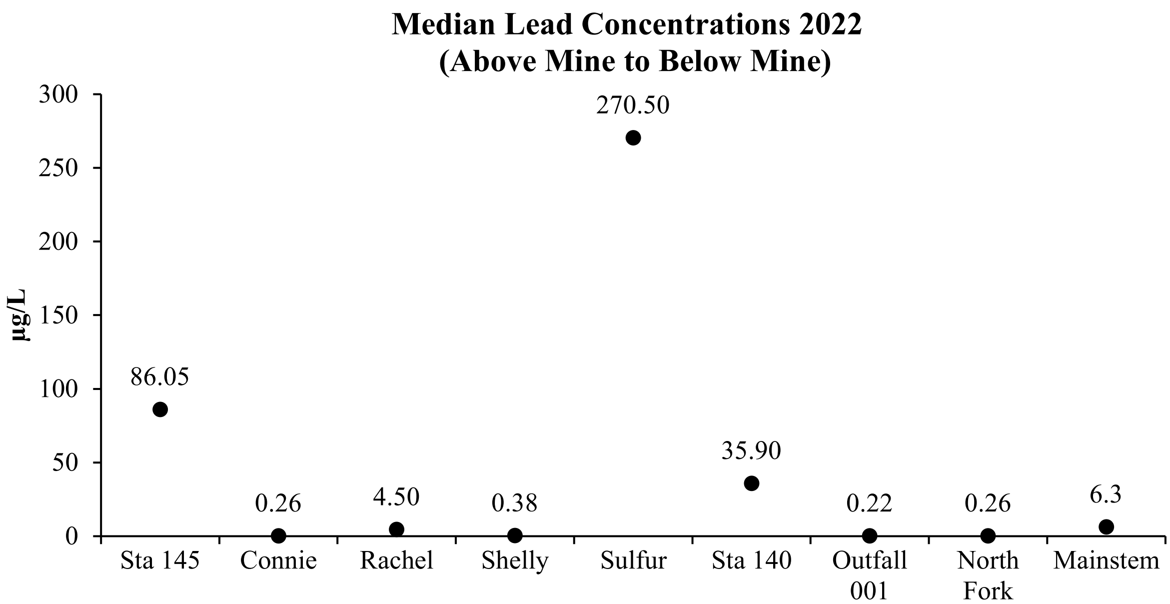


Figure 6. Median lead concentrations in 2022 from upstream (Station 145) of the clean water bypass, including tributaries to the clean water bypass (Connie, Rachel, Shelly, and Sulfur), and Station 140 (above the Outfall 001), Outfall 001, and North Fork Red Dog and Mainstem Red Dog creeks.

The median zinc concentration in Mainstem Red Dog Creek (Station 151/10) increased in 2022, although zinc levels are still lower than the spike observed in 2020 (Figure 7). Station 140 on Middle Fork Red Dog Creek, upstream of the treated mine discharge Outfall 001 and downstream of the non-contact water diversion, exhibited a similar trend (Figure 8). Zinc levels at Station 145, above the clean water bypass, decreased slightly from 2021 levels. The sharp decrease in zinc levels from the spike in 2020 is due to the diversion of Kaviqsaaq seep in early 2021. The other component creeks of the clean water bypass (Connie, Rachel, Shelly, and Sulfur) have lower zinc concentrations, although levels in Rachel Creek did increase in 2022 (Figure 9).

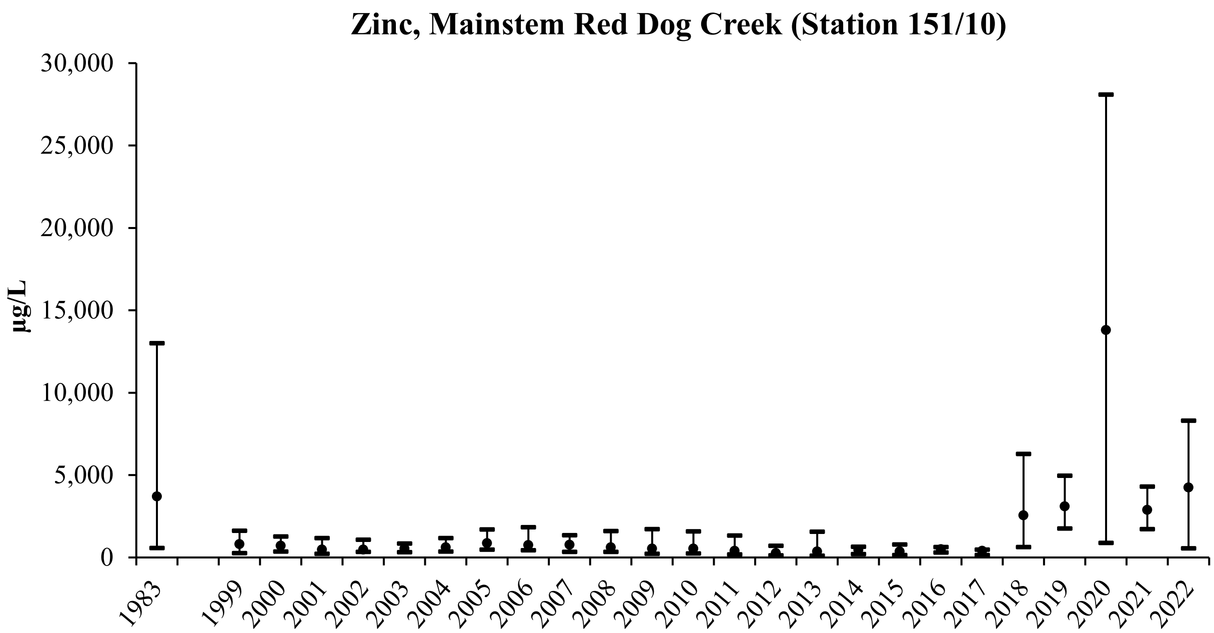


Figure 7. Median, maximum, and minimum zinc concentrations at Station 151/10.

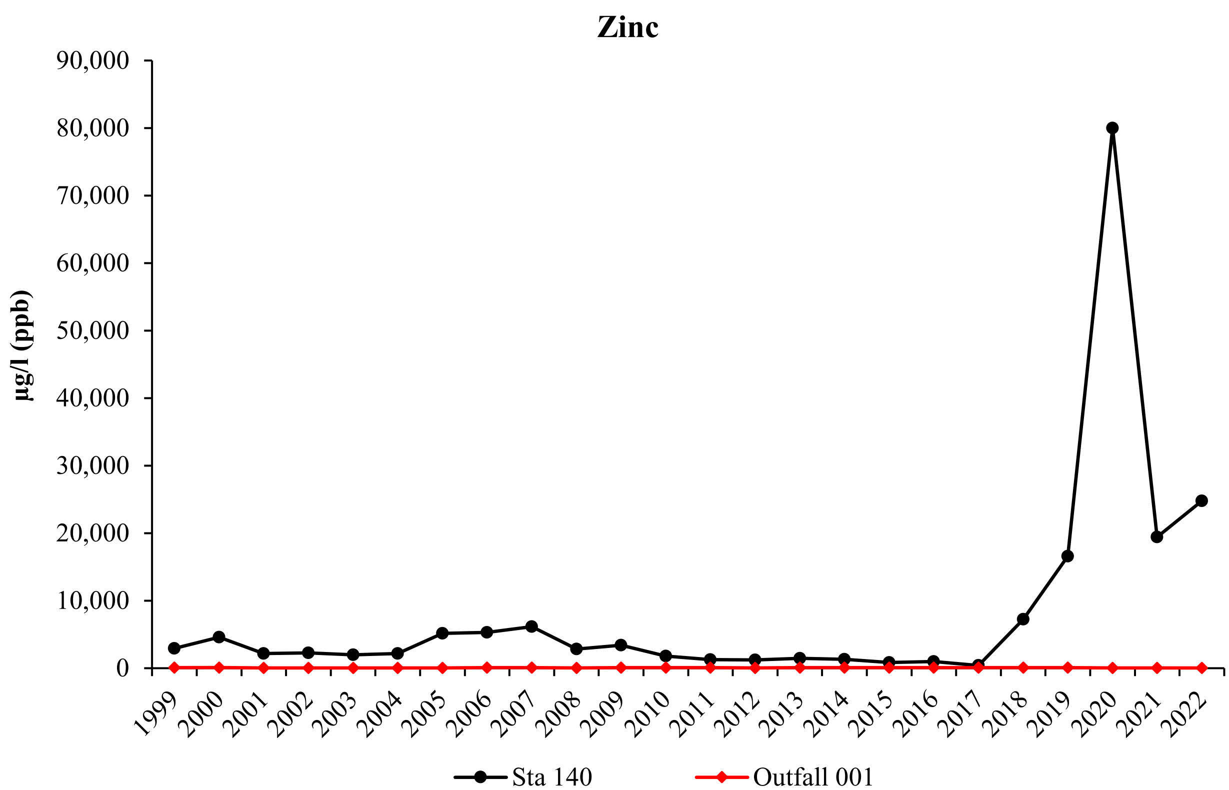
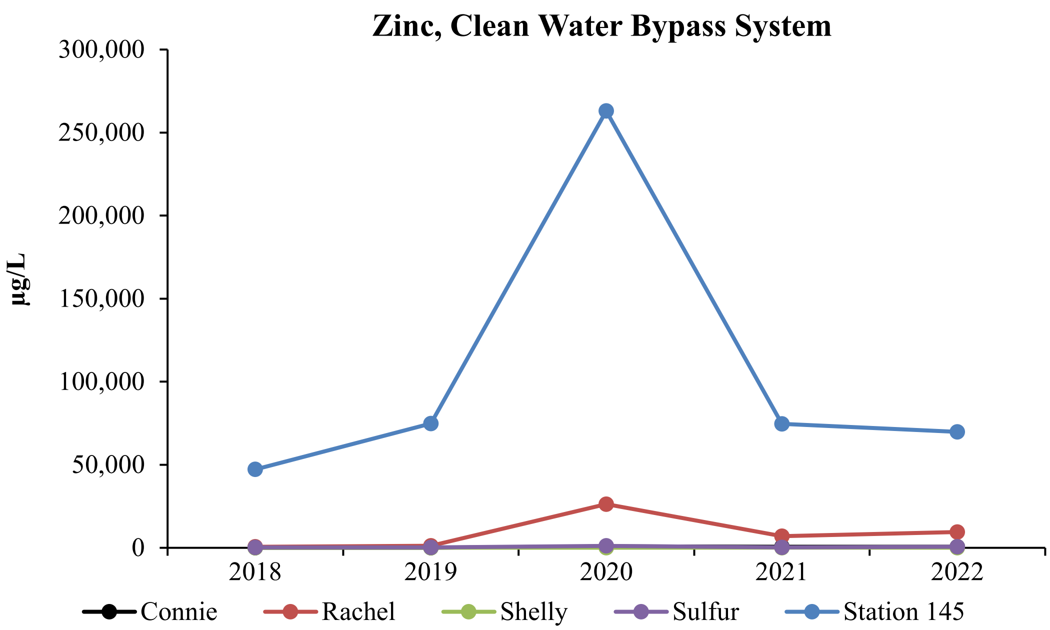


Figure 8. Median zinc levels in water samples from Station 140 and Outfall 001, 1999 - 2022.



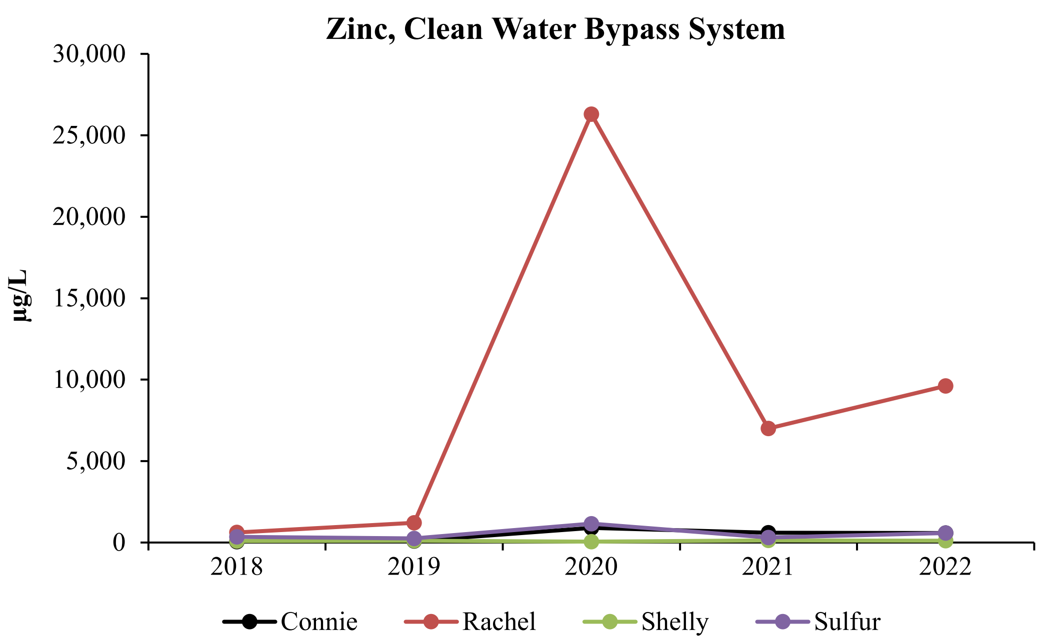


Figure 9. Median zinc concentrations in water samples from Sulfur, Shelly, Connie, and Rachel creeks, and Station 145, 2018 - 2022. Station 145 is on Middle Fork Red Dog Creek, downstream of the Kaviqsaaq Seep and before the clean water diversion system begins. The bottom figure presents the same data but uses a different scale as it does not include Station 145.

Median aluminum concentrations in Mainstem Red Dog Creek (Station 151/10) continued to decrease in 2022 following a sharp increase in 2020, although levels are still slightly higher than those observed pre-mining. Median aluminum concentration in 2022 was 550 µg/L (Figure 10).

Cadmium concentrations were similar to concentrations observed in 2018, 2019, and 2021 and were lower than the steep increase measured in 2020. Median cadmium concentration in 2022 was 16.6 µg/L (Figure 11).

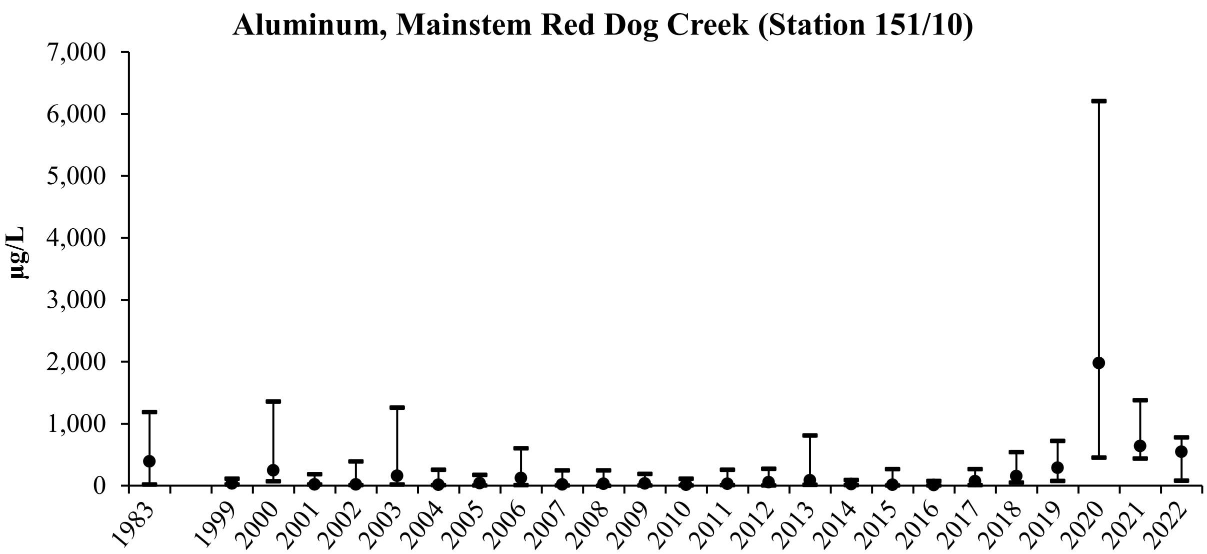


Figure 10. Median, maximum, and minimum aluminum concentrations at Station 151/10.

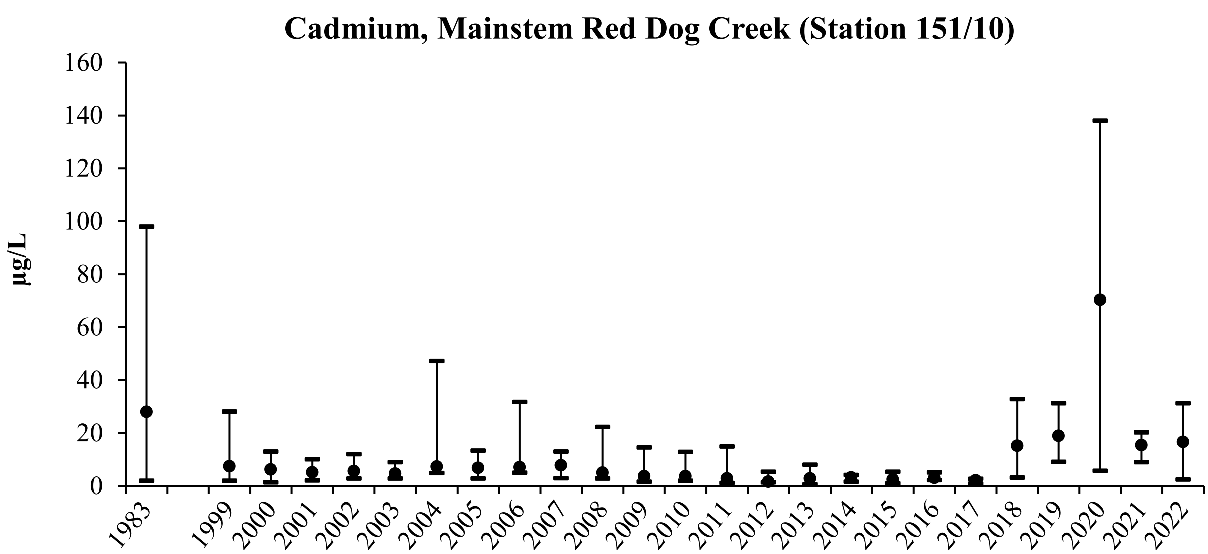


Figure 11. Median, maximum, and minimum cadmium concentrations at Station 151/10.

Pre-mining data for selenium are not available. Median selenium concentrations in Mainstem Red Dog Creek (Station 151/10) remained similar from 2001 to 2007, but then increased reaching a high of 2.75 µg/L in 2011. In 2012, discharge of treated water to Middle Fork Red Dog Creek was stopped on June 8 due to elevated selenium and was not resumed for the remainder of 2012. After selenium decreased in treated water and a mixing zone was authorized in Mainstem Red Dog Creek, discharge resumed in 2013. Selenium remained low from 2014 to 2017, then began to increase in 2018 to a median selenium concentration of 3.2 µg/L in 2020 and 3.1 µg/L in 2021 (Figure 12). Selenium decreased in 2022 to a median concentration of 2.5 µg/L.

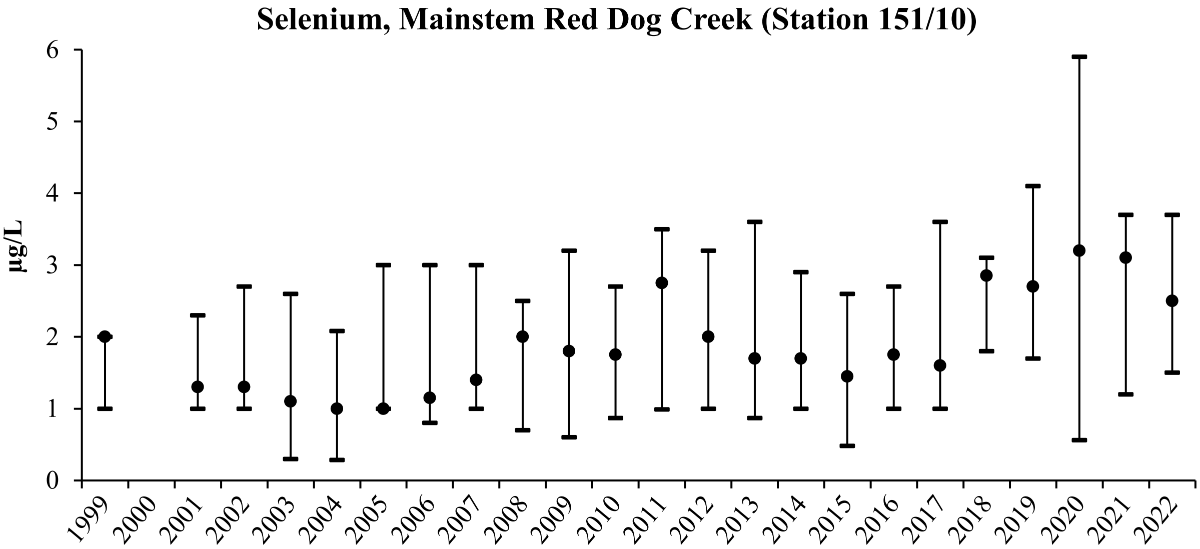


Figure 12. Median, maximum, and minimum selenium concentrations at Station 151/10.

Pre-mining data for nickel are not available. Median nickel concentration in Mainstem Red Dog Creek (Station 151/10) increased sharply in 2020 to 394 µg/L, the highest median concentration since 1999, and an order of magnitude greater than any previously recorded value (Figure 13). Median nickel concentration decreased in 2021 to 126 µg/L and remained almost the same in 2022 at 124 µg/L, which is still higher than pre-2020 levels. The component creeks of the clean water bypass system were not analyzed for nickel in recent years, so the source of the increased nickel concentration is unknown.

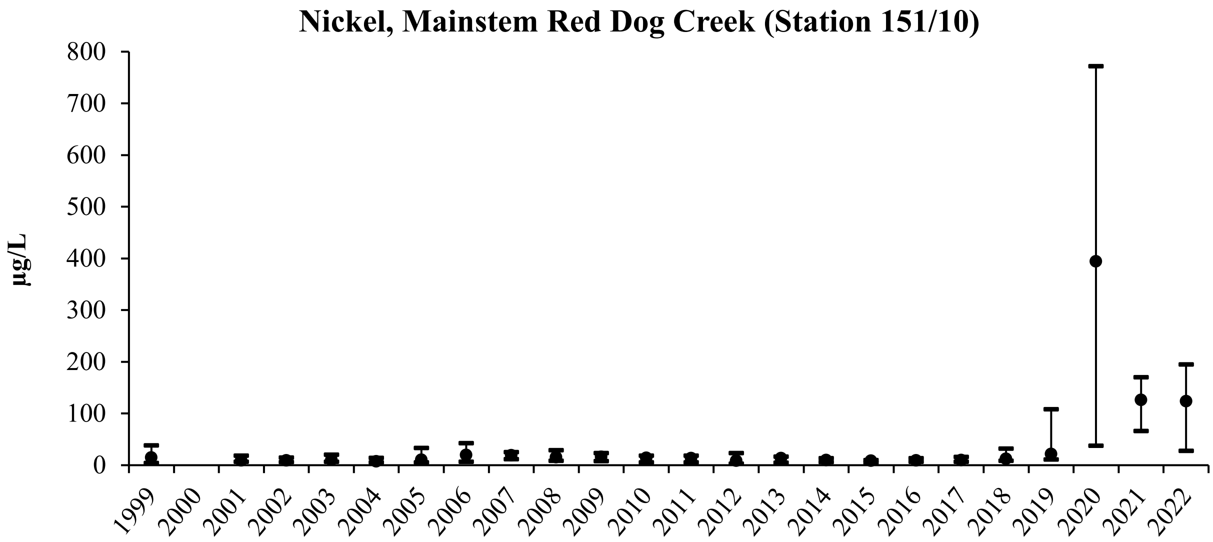


Figure 13. Median, maximum, and minimum nickel concentrations at Station 151/10.

In 2022, the pH in Mainstem Red Dog Creek (Station 151/10) was slightly higher (more basic) than pre-mining, which has been the case since 1999 (Figure 14). The median pH has increased since 2020 after a low of 7.165 and was 7.62 in 2022. The clean water bypass system was built and operational prior to spring breakup in 1991, and since then the minimum pH value has only dropped below 6.0 once, in 2011. The 1990 data set is during mining, but prior to construction of the clean water bypass system.

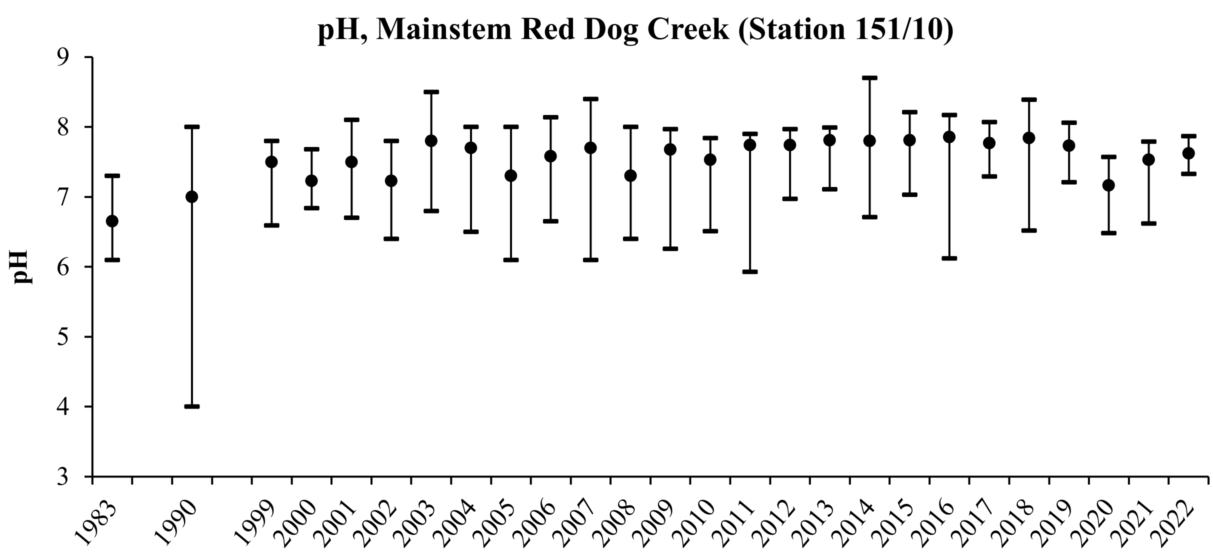


Figure 14. Median, maximum, and minimum pH values at Station 151/10. The optimal range for aquatic life is 6.5 to 8.5.

Total dissolved solids (TDS) in Mainstem Red Dog Creek (Station 151/10) are higher than pre-mining (Figure 15). TDS are directly related to high concentrations of calcium and sulfates in the treated wastewater discharge at Outfall 001. Calcium hydroxide is added to precipitate and collect metals from the tailings water as metal hydroxides prior to discharge. Sulfates released in this process along with the calcium result in elevated TDS concentrations, however natural changes in water quality attributed to permafrost thaw are also increasing TDS levels throughout the Ikalukrok Creek drainage. The increased median TDS value in 2022 is likely a result of increasing naturally occurring TDS, as the composition of the treated discharge water has not changed.

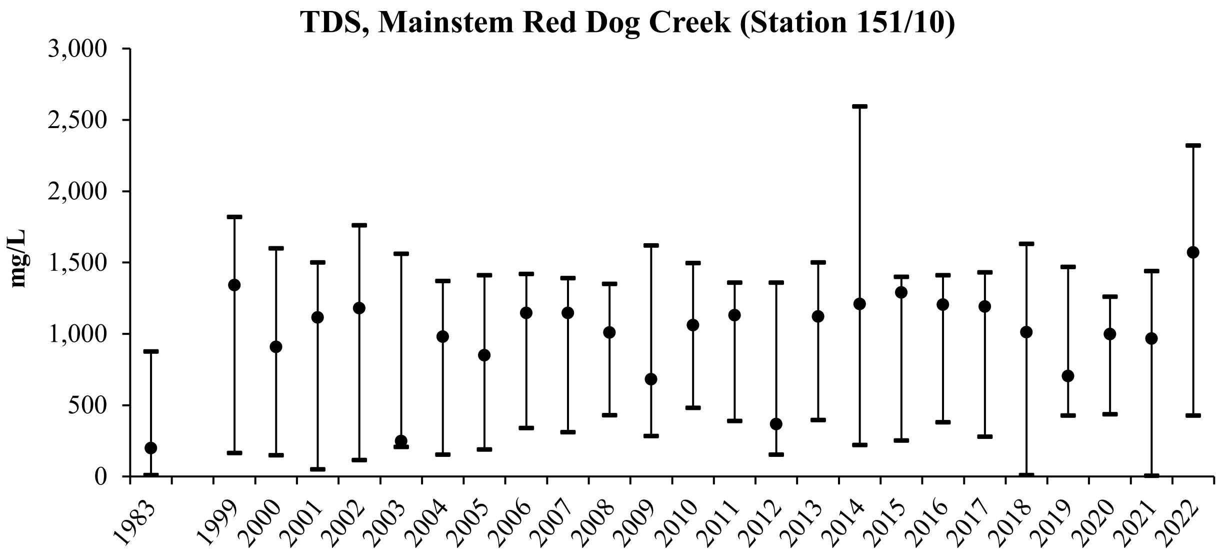


Figure 15. Median, maximum, and minimum TDS concentrations at Station 151/10.

As was initially observed in 2020, several streams that are typically clear during the summer were very turbid and either milky white or yellowish orange (Figures 16 – 19). Aerial surveys of the affected streams did not detect any obvious large scale permafrost slumps or other indicators as to the source of the water quality changes. Small scale permafrost thaw could be a contributor to these changes but wouldn't necessarily be visible from the air. Other streams and rivers throughout Alaska have exhibited similar changes in water clarity, such as tributaries to the Middle Fork Koyukuk (personal communication, Christy Gleason, ADF&G Commercial Fisheries Yukon Area Assistant Manager), tributaries to the Alatna River (personal communication, Nate Cathcart, ADF&G Sport Fisheries), and rivers on the North Slope, including the Ivishak, Kavik, and Canning rivers (personal communication, Brendan Scanlon, ADF&G Sport Fish).

Figure 16. Station 151 Mainstem Red Dog Creek - August 2018 (left), August 2022 (right).

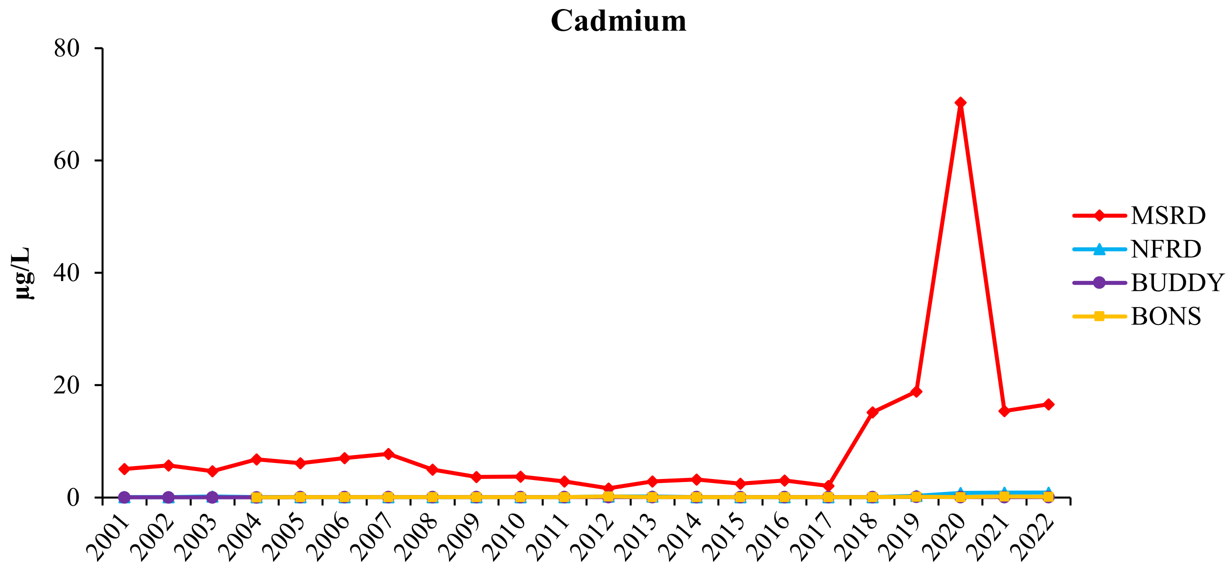
Figure 17. Station 10 Mainstem Red Dog Creek - July 2016 (left), August 2022 (right).

Figure 18. Station 9 Ikalukrok Creek upstream of Red Dog Creek - July 2019 (left), August 2022 (right).

Figure 19. Station 160 Ikalukrok Creek downstream of Dudd Creek – July 2018 (left), August 2022 (right).

Cadmium, lead, zinc, and selenium concentrations in Mainstem Red Dog Creek (Station 151/10) were compared with those found in North Fork Red Dog Creek, Buddy Creek (below the confluence of Bons and Buddy creeks), and Bons Pond (Figures 20-22). Sites in North Fork Red Dog and Buddy creeks and Bons Pond were selected because they are reference sites with no direct effects from the mine process or discharge. Mainstem Red Dog Creek (Station 151/10) is directly downstream of the mine clean water bypass and wastewater effluent discharge at Outfall 001. Buddy Creek and Bons Pond are reference sites but have the potential to be affected by the road, airport, overburden stockpile, and they are down gradient from the tailings backdam. Cadmium, lead, zinc, and selenium were selected for comparison because these elements are analyzed for whole body element concentrations in juvenile Arctic grayling from Bons Pond and juvenile Dolly Varden from Mainstem Red Dog, Anxiety Ridge, and Buddy creeks.

Cadmium, lead, and zinc median concentrations are highest in Mainstem Red Dog Creek. The mine discharge of treated water at Outfall 001 has very low concentrations of these elements, so the major sources of these elements are the clean water bypass and other locations in the Red Dog Creek drainage. Cadmium was low and stable in North Fork Red Dog Creek, Buddy Creek, and Bons Pond from 2001 to 2019. In 2020 – 2022, cadmium levels remained low in Buddy Creek and Bons Pond, but increased in North Fork Red Dog Creek. Cadmium in Mainstem Red Dog Creek is higher and much more variable and was 16.6 µg/L in 2022, down from the high of 70.3 µg/L observed in 2020 (Figure 20). Lead concentrations demonstrate more variability than cadmium, but are consistently highest in Mainstem Red Dog Creek (Figure 21). Zinc concentrations in North Fork Red Dog Creek, Buddy Creek, and Bons Pond have remained fairly stable, although zinc levels in North Fork Red Dog Creek have increased beginning in 2019 (Figure 22). Selenium concentrations among these sites are similar, and variable among years (Figure 23). Most of the selenium concentrations range from 1.0 µg/L (the detection limit) to 3.0 µg/L. The median selenium concentrations in Mainstem Red Dog, North Fork Red Dog, and Buddy creeks and Bons Pond in summer 2022 were 2.5, 2.0, 2.6, and 2.1 µg/L, respectively.



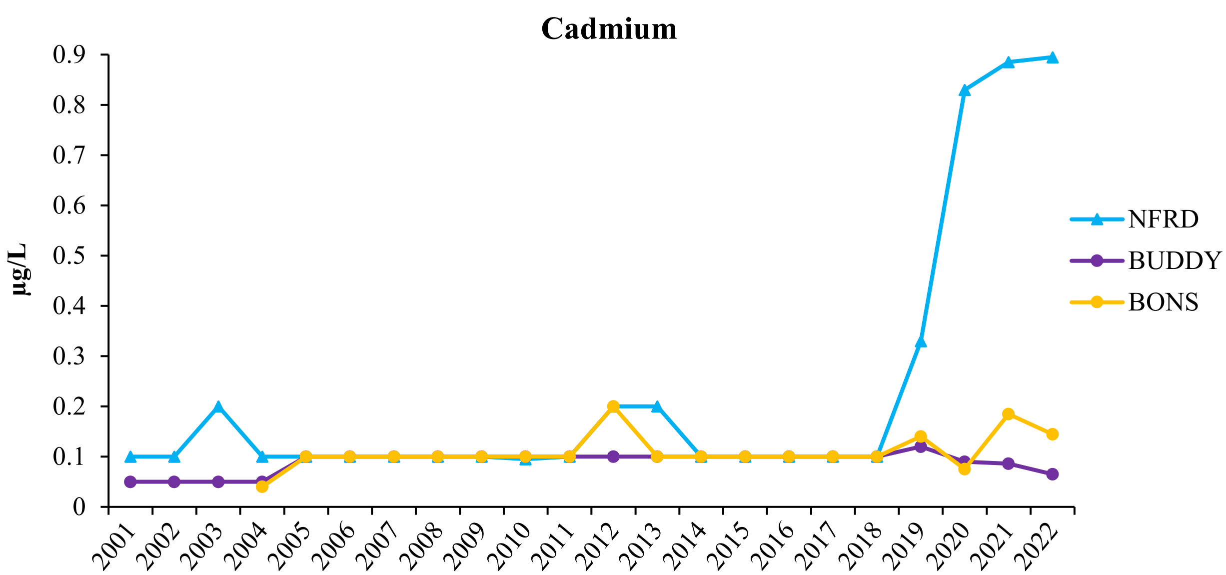
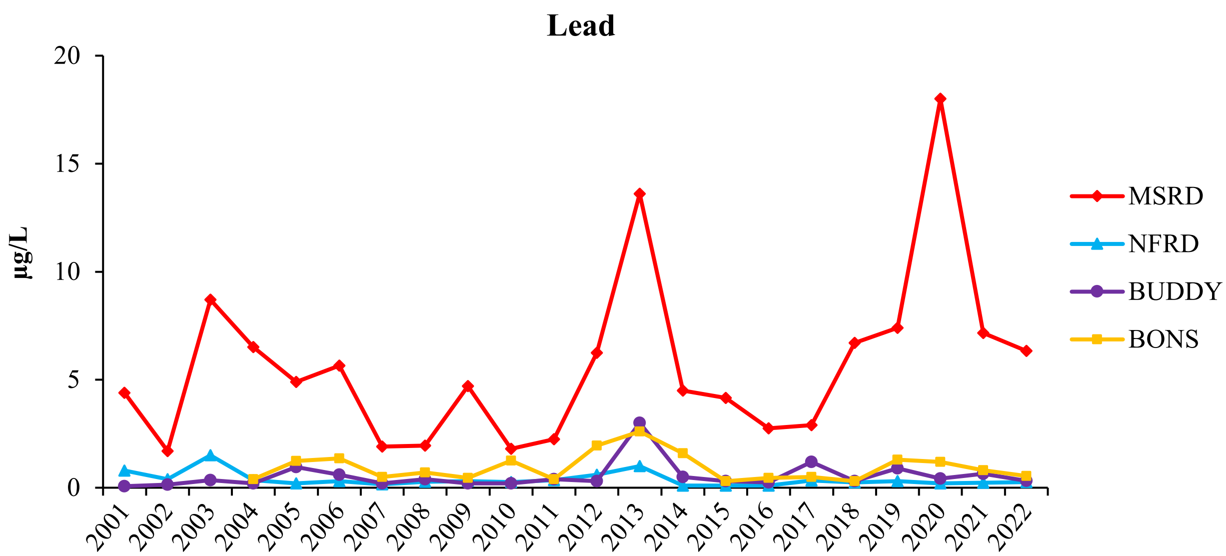


Figure 20. Median cadmium concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2022). Two graphs are presented, the bottom graph presents the same data but uses a different scale as it does not include Mainstem Red Dog Creek.



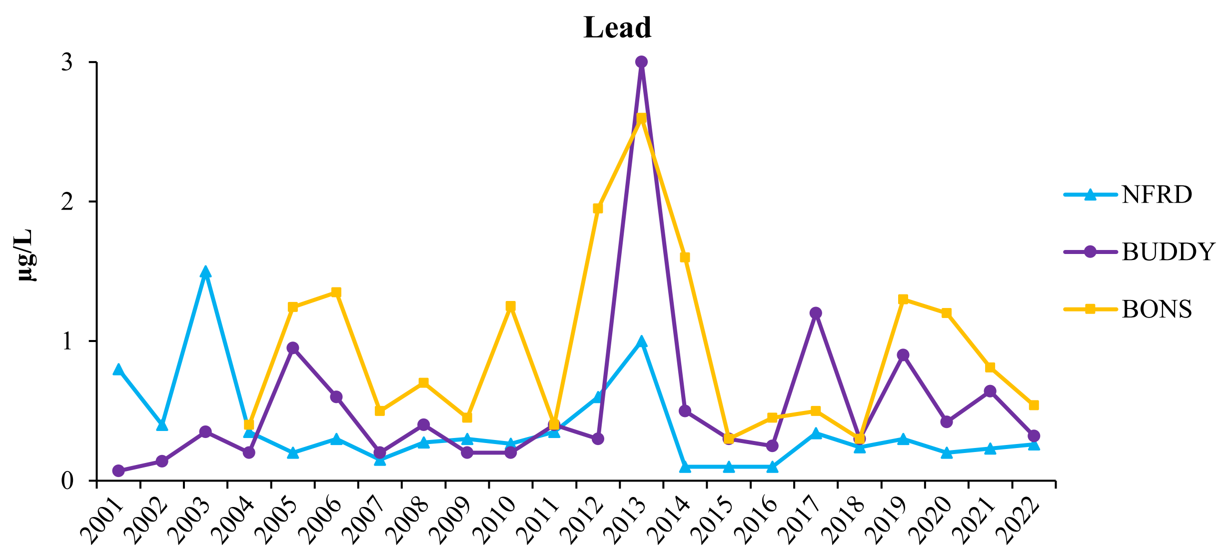
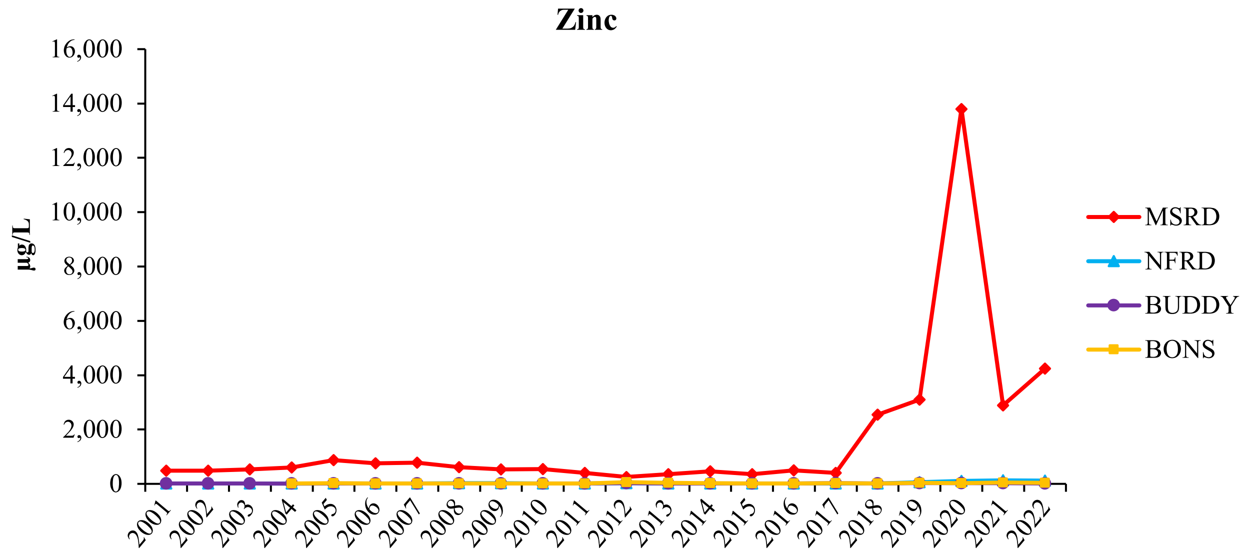


Figure 21. Median lead concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2022). Two graphs are presented, the bottom graph presents the same data but uses a different scale as it does not include Mainstem Red Dog Creek.



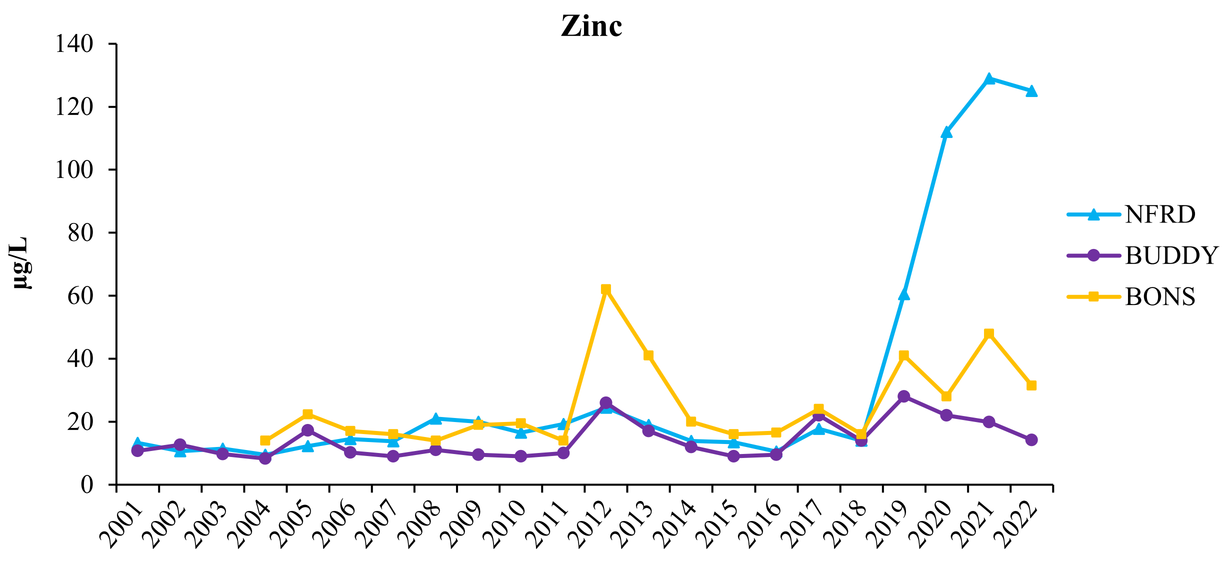


Figure 22. Median zinc concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2022). Two graphs are presented, the bottom graph presents the same data but uses a different scale as it does not include Mainstem Red Dog Creek.

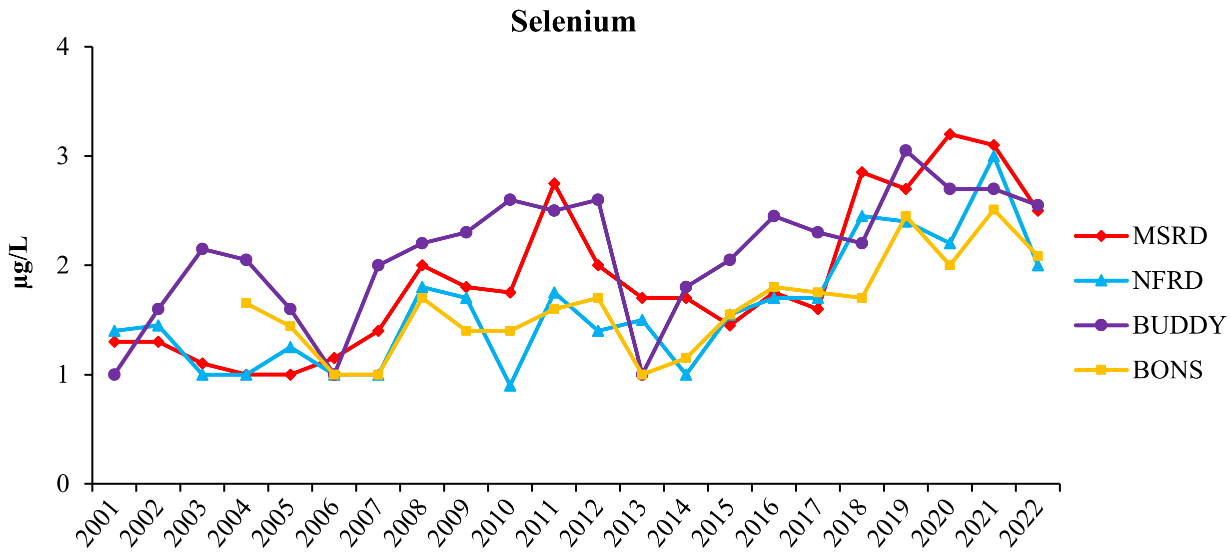


Figure 23. Median selenium concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2022).

Periphyton Standing Crop

Periphyton (attached microalgae) biomass samples have been collected annually since 1999. Under the program initiated in 2010, sampling occurred at a minimum of nine sites (Table 2). In 2022, samples were collected at all nine standard sites, with the addition of Upper North Fork Red Dog Creek (Appendix 2). Periphyton samples were processed in the laboratory and standing crop was determined as mg/m^2 chlorophyll-a.

Average chlorophyll-a concentration in 2022 was highest at Station 220 on Bons Creek (28.65 mg/m^2) and lowest at Station 9 on Ikalukrok Creek and Station 10 on Mainstem Red Dog Creek (0.06 mg/m^2) (Figure 24). Periphyton standing crop was also very low on Middle Fork Red Dog Creek at Station 20 (0.10 mg/m^2) and at Station 160 on Ikalukrok Creek (0.14 mg/m^2). Generally, chlorophyll-a concentration is lowest in Middle Fork Red Dog Creek and highest in Bons Creek (below Bons Pond/Station 220) and Buddy Creek (below falls).

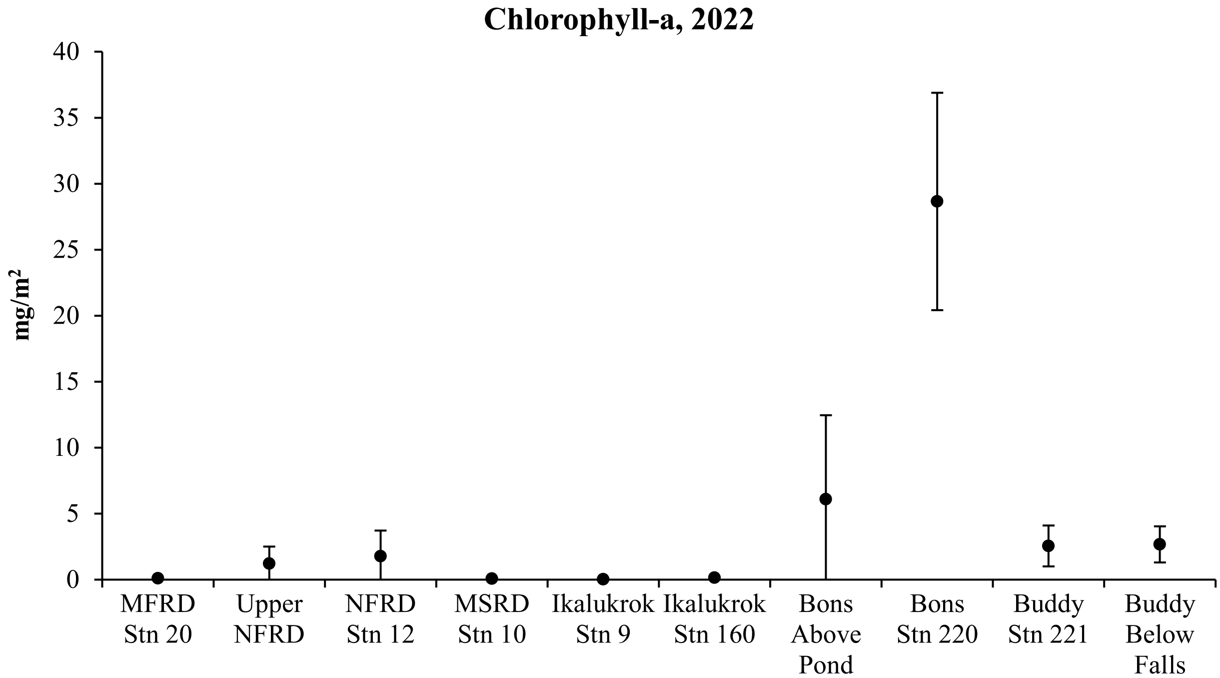


Figure 24. Average concentration of chlorophyll-a (± 1 SD) at Red Dog Mine sample sites, 2022. Sites in the Red Dog Creek drainage include Middle Fork Red Dog (MFRD), Upper North Fork Red Dog (Upper NFRD), North Fork Red Dog (NFRD), and Mainstem Red Dog (MSRD).

Historically, average chlorophyll-a concentrations were higher in Mainstem Red Dog and North Fork Red Dog creeks as compared with Middle Fork Red Dog Creek, but since 2020 chlorophyll-a concentrations in Mainstem Red Dog Creek have also been very low (Figure 25). In 16 of 24 years, average chlorophyll-a concentrations in North Fork Red Dog Creek were equal to or higher than Mainstem Red Dog Creek. Lower chlorophyll-a concentrations in Middle Fork Red Dog Creek are likely related to higher metals concentrations and higher TDS in the creek. Most of the metals in Middle Fork Red Dog Creek originate from the clean water bypass and its tributaries, as metals concentrations in the treated effluent discharge from Outfall 001 are very low. The treated effluent discharge at Outfall 001 on Middle Fork Red Dog Creek contributes TDS to the creek, but the naturally occurring background levels of TDS in Red Dog Creek and surrounding streams have increased beginning in 2020. Similar to Middle Fork Red Dog Creek, low chlorophyll-a concentrations in Mainstem Red Dog Creek from 2019 – 2022 are likely related to the increased metals concentrations from the clean water bypass. These levels have been high enough that the diluting influence of the low metals water from North Fork Red Dog Creek is no longer sufficient to mitigate impacts to periphyton growth in Mainstem Red Dog Creek.

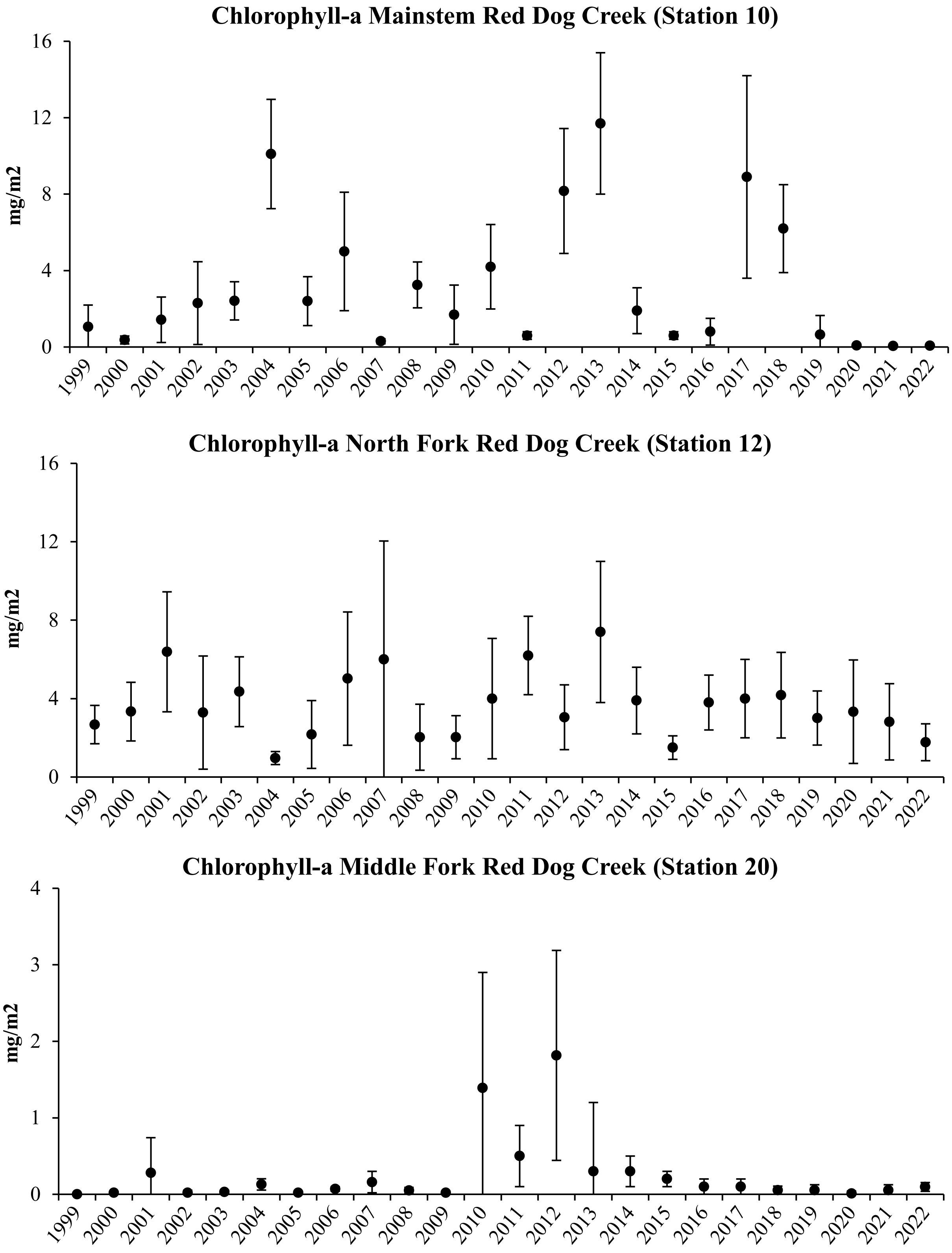


Figure 25. Average concentration (± 1 SD) of chlorophyll-a in Mainstem Red Dog Creek (Station 10/151), North Fork Red Dog Creek (Station 12), and Middle Fork Red Dog Creek (Station 20), 1999-2022. Note the different y-axis for Middle Fork Red Dog Creek.

Periphyton standing crop has an inverse relationship with zinc and cadmium in Ikalukrok Creek at Station 9, which is just upstream of the mouth of Mainstem Red Dog Creek. Water quality at this site is not affected by water from the Red Dog Mine facility, but is affected by natural mineral seeps located upstream and along Ikalukrok Creek (Ott and Morris 2007). The concentration of chlorophyll-a is higher when the zinc and cadmium concentrations are lower (Figures 26 and 27). Both zinc and cadmium increased dramatically between 2018 and 2022, and chlorophyll-a concentrations dropped to nearly zero. The variability in chlorophyll-a concentration from 2002 to 2017 may be natural as both cadmium and zinc concentrations remained low and consistent during this period. Based on water quality sampling conducted by Red Dog Mine, the major source of zinc and cadmium to Ikalukrok Creek is the Cub Creek seep, although there are other seeps along Ikalukrok Creek which are potential sources (Figure 28).

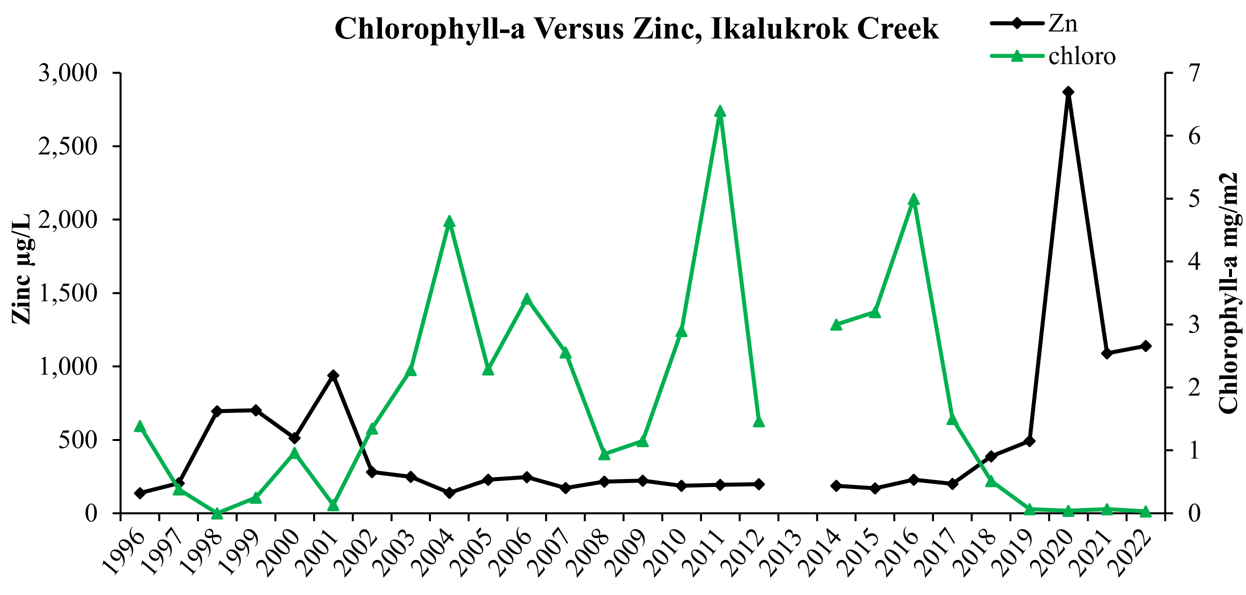


Figure 26. Average concentrations of chlorophyll-a and zinc in Ikalukrok Creek (Station 9), 1996 – 2022.

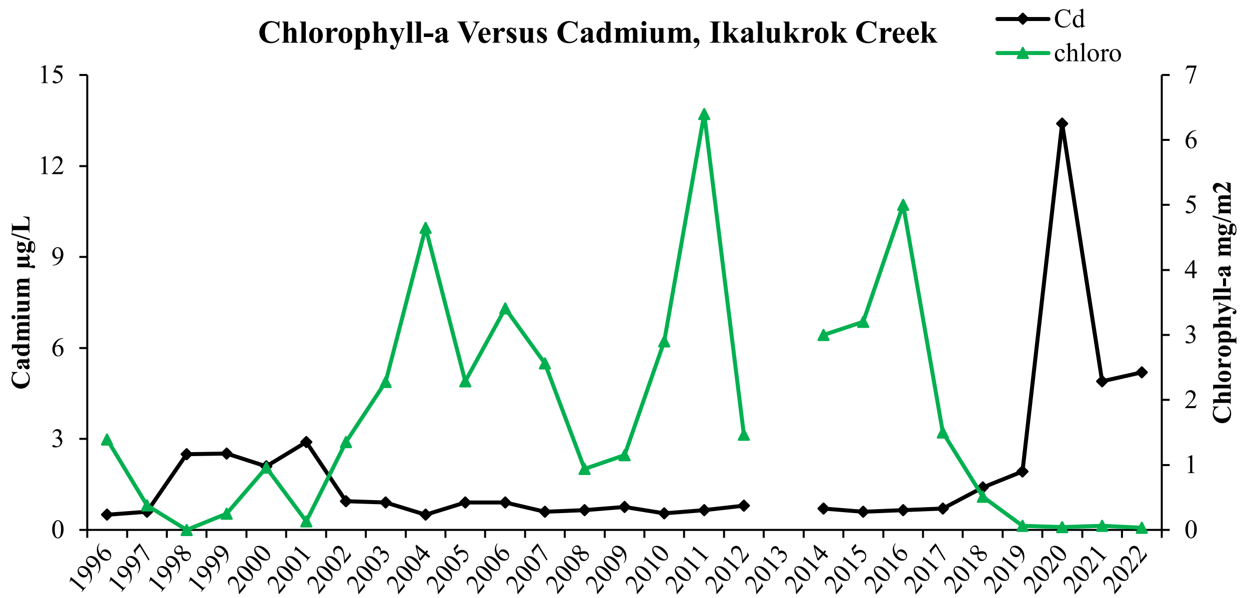


Figure 27. Average concentrations of chlorophyll-a and cadmium in Ikalukrok Creek (Station 9), 1996 – 2022.

Figure 28. Ikalukrok Creek at the Cub Creek seep about 10 km upstream of Station 9. Note the mineral staining in and along the edge of Cub Creek, July 2017.

Aquatic Invertebrates

Aquatic invertebrate samples are collected annually using Hess samplers (Appendix 3). The purpose of this effort is: (1) to determine if differences exist in the macroinvertebrate populations among the sample sites; and (2) to track changes over time.

Average aquatic invertebrate density was highest in Bons Pond at Sta 220, upstream of the confluence with Buddy Creek, with 17,205 aquatic invertebrates/m^2 (Figure 29). Buddy Creek below the falls also had very high aquatic invertebrate density with 15,491 aquatic invertebrates/m^2. In 2022, the sample method was changed from drift nets to Hess samplers, so any comparisons with past years' results should account for the change in collection method. In past years, the Buddy Creek and Bons Creek sample sites have often had the highest densities of aquatic invertebrates. Aquatic invertebrate densities are typically higher at the North Fork Red Dog Creek sample sites (Upper NFRD and Sta 12) than in Mainstem Red Dog Creek, and this was the case in 2022 (Figure 30).

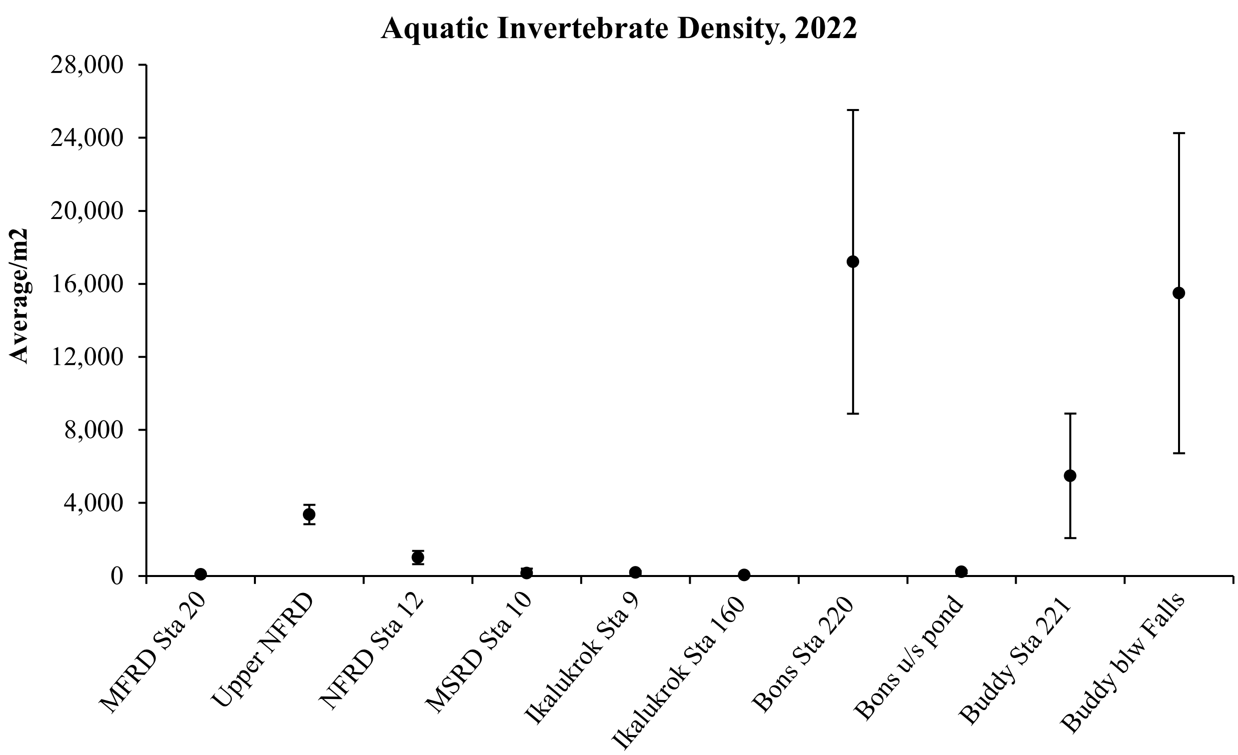


Figure 29. Average aquatic invertebrate densities (± 1 SD) in all sample sites near the Red Dog Mine, July 2022.

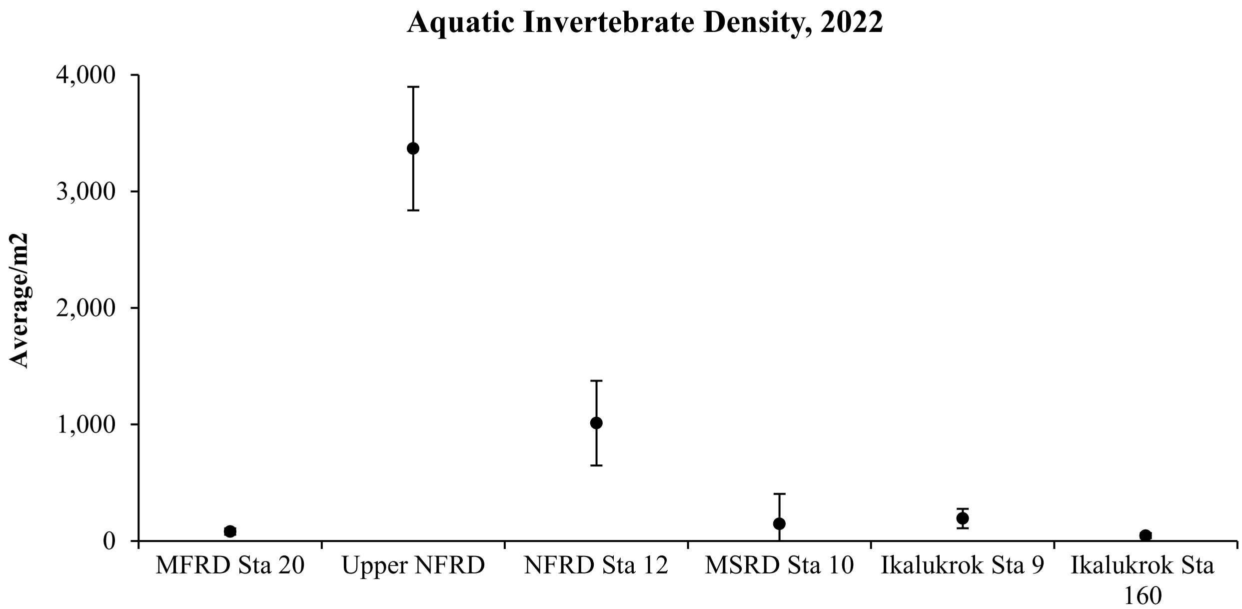


Figure 30. The average aquatic invertebrate density (± 1 SD) at sample sites in the Red Dog and Ikalukrok creek drainages in July 2022. This is the same data as Figure 29, but is presented at a different scale as it does not include the results from Bons or Buddy creeks.

The percent Ephemeroptera, Plecoptera, and Trichoptera (EPT) and the percent Chironomidae for sample sites in 2022 are presented in Figure 31. Trichoptera are not common in the samples and are not a substantial contributor to EPT. In past sample years the percentage of Chironomidae was higher than EPT at most sample sites, however this was not the case in 2022. This could be due to the change in sampling method.

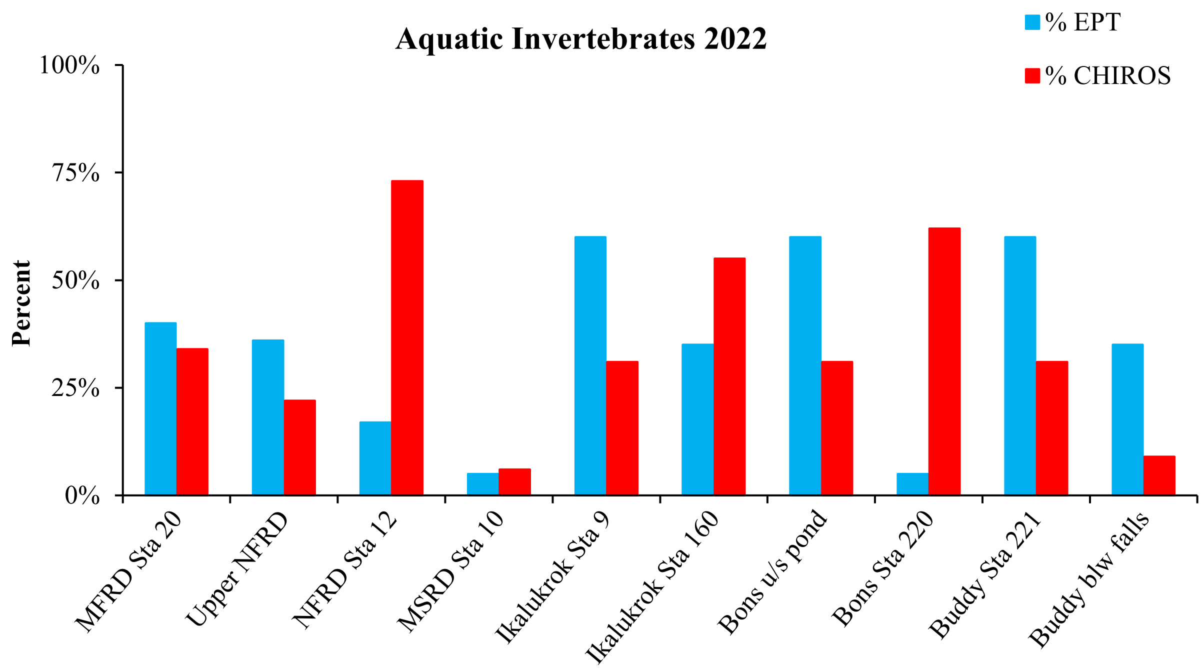


Figure 31. Percent EPT and Chironomidae in the aquatic invertebrate samples at all sample sites Red Dog Mine, July 2022.

The percent EPT in North Fork Red Dog Creek has been highly variable, ranging from 3% in 2010 and 2011 to 57% in 2002 (Figure 32). In 19 out of the last 24 years, percent Chironomidae has been higher than percent EPT in North Fork Red Dog Creek (Figure 33). Mainstem Red Dog Creek also has had highly variable percent EPT, ranging from 2% in 2017 to 55% in 2003 (Figure 32). Like North Fork Red Dog Creek, percent Chironomidae has been higher than percent EPT in 18 out of the last 24 years. The very low percentage of both EPT and Chironomidae in the Mainstem Red Dog Creek samples in 2022 (5% and 6%, respectively) is due to several factors related to the change in sampling method. The total number of aquatic invertebrates captured in 2022 was very low with 63 total individuals captured, compared to the 5,076 (corrected for subsampling) captured with drift nets in 2021. Of the 63 captured in 2022, 50 were Oligochaetes, which are small slender worms that live in sediment. These would be unlikely to be captured in drift nets but are easily captured with Hess samplers as the stream bed is disturbed as part of sampling. Buddy Creek at Station 221 has had a much higher percentage of EPT than either North Fork Red Dog or Mainstem Red Dog creeks in certain years (2004, 2011, 2012, 2014 - 2016, and 2021 - 2022) (Figure 32). In Buddy Creek, percent Chironomidae has been higher than the percent EPT 11 out of 19 years. However, since sampling method changed in 2022, comparisons to historical data at all sites should be evaluated with caution.

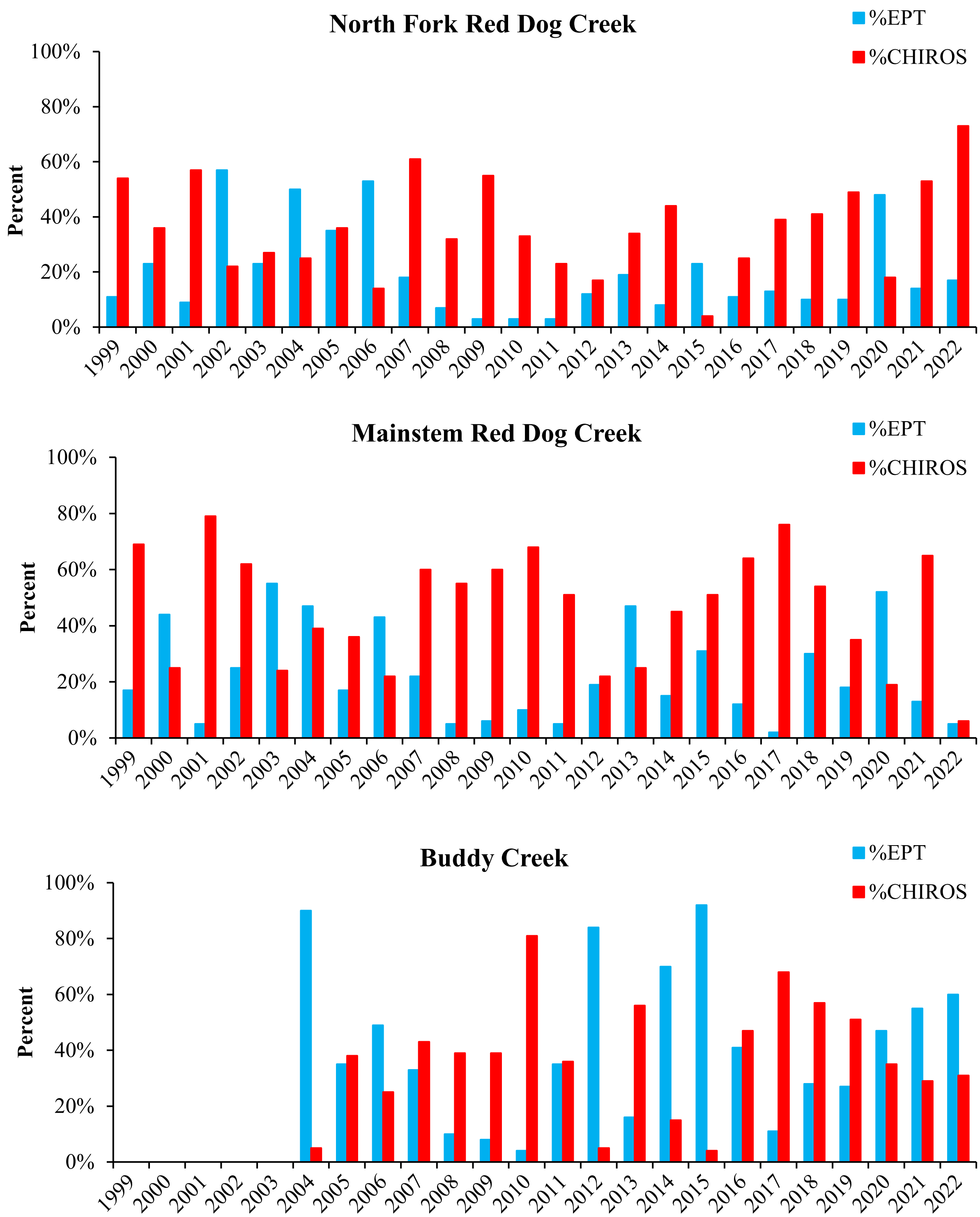


Figure 32. Percent EPT and Chironomidae in North Fork Red Dog Creek (top), Mainstem Red Dog Creek (middle), and Buddy Creek (bottom) 1999 – 2022. Aquatic invertebrate sampling in Buddy Creek drainage began in 2004. Sampling method was changed from drift nets to Hess samplers in 2022.

Taxa richness was compared for the three sample sites in North Fork Red Dog, Mainstem Red Dog, and Buddy creeks (Figure 33). Richness is the total number of taxa seen in the sample and includes mayflies, stoneflies, and caddisflies (to genus when possible), diptera (to family or genus), coleoptera (to family), hemiptera (to family), collembola (to family or genus), lepidoptera (to family), and other taxa to order. In 2022, taxa richness was highest in Buddy Creek with 21 taxa identified. North Fork Red Dog Creek had 13 identified taxa and Mainstem Red Dog Creek had 10. Taxa richness in North Fork Red Dog and Mainstem Red Dog creeks was lower than recent years, but within the range of historical values. Since sampling method changed in 2022, comparisons to historical data at all sites should be evaluated with caution.

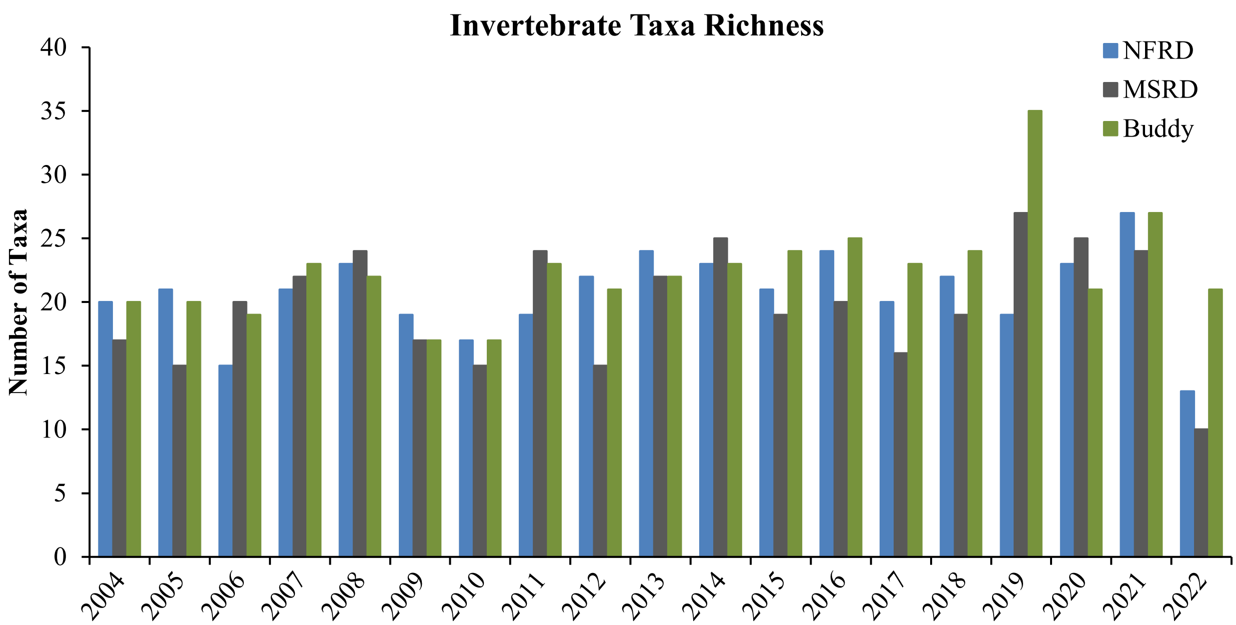


Figure 33. Aquatic invertebrate taxa richness in North Fork Red Dog (Sta 12) and Mainstem Red Dog Creek (Sta 10) and Buddy Creek (Sta 221) 2004 – 2022. Sampling method was changed from drift nets to Hess samplers in 2022.

Metal Concentrations in Juvenile Arctic Grayling and Dolly Varden

Juvenile Arctic grayling and Dolly Varden were sampled to determine whole body concentrations of selected elements. The purposes of this effort are to: (1) determine if differences exist in element concentrations in fish among the sample sites that can be linked with background water quality; and (2) track changes over time.

Juvenile Arctic grayling were selected for long-term monitoring after a self-sustaining population became established in Bons Pond. Arctic grayling captured in Bons Pond have been in the pond system, including upstream tributaries for their entire life cycle. Arctic grayling that leave Bons Pond go over a waterfall that prohibits upstream/return movement of fish. Therefore, these Arctic grayling serve as an indicator of change over time in Bons Pond. Fish samples are typically collected during the spring sampling event when fish are moving from Bons Pond into Bons Creek.

Juvenile Dolly Varden were selected as a target species because of their wide distribution in the Red Dog area streams, their residence in freshwater for two to four years before smolting, and their rearing in the selected sample sites only during the ice-free season. Juvenile Dolly Varden are collected from Anxiety Ridge, Buddy, and Mainstem Red Dog creeks during the minnow trap sampling event in late summer. These locations have been sampled annually since 2005, except for 2012 and 2013 when water levels were too high to effectively sample.

Eleven juvenile Arctic grayling were captured in Bons Pond in early June (Appendix 4). The average length of these fish was 165.6 mm FL ± 8.9 mm (1 SD). These fish were analyzed for cadmium, lead, selenium, zinc and mercury, and results are for whole body in mg/kg (dry weight).

In 2022, the mean cadmium concentration in Bons Pond juvenile Arctic grayling was 0.12 mg/kg (Figure 34). The highest mean cadmium concentration was 0.27 mg/kg in 2014.

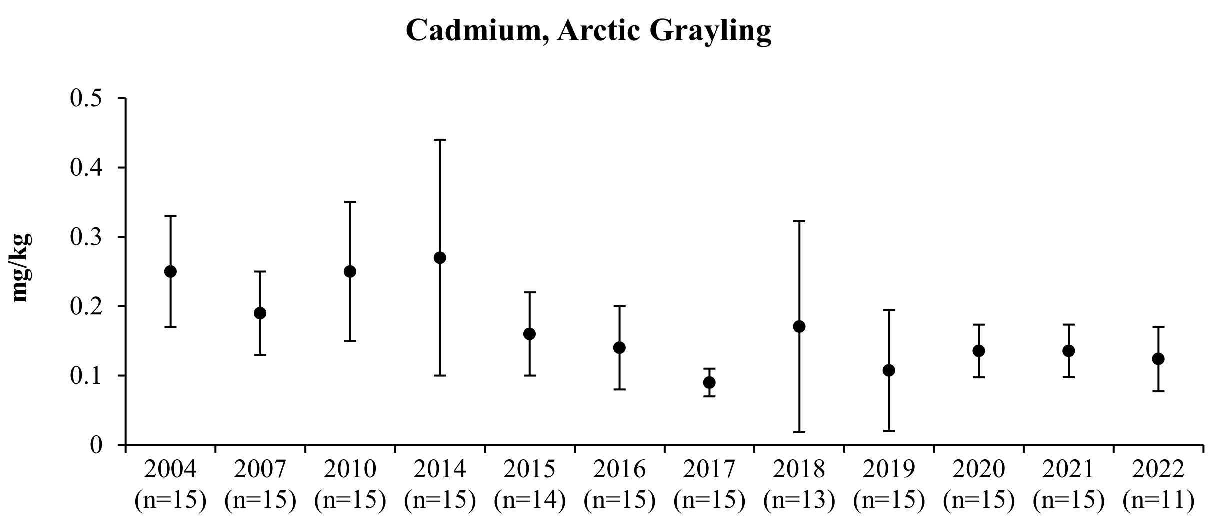


Figure 34. Mean cadmium concentrations (± 1 SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

In 2022, the mean lead concentration was 0.53 mg/kg in juvenile Arctic grayling from Bons Pond (Figure 35). This is a decrease from 2018 – 2021 mean concentrations.

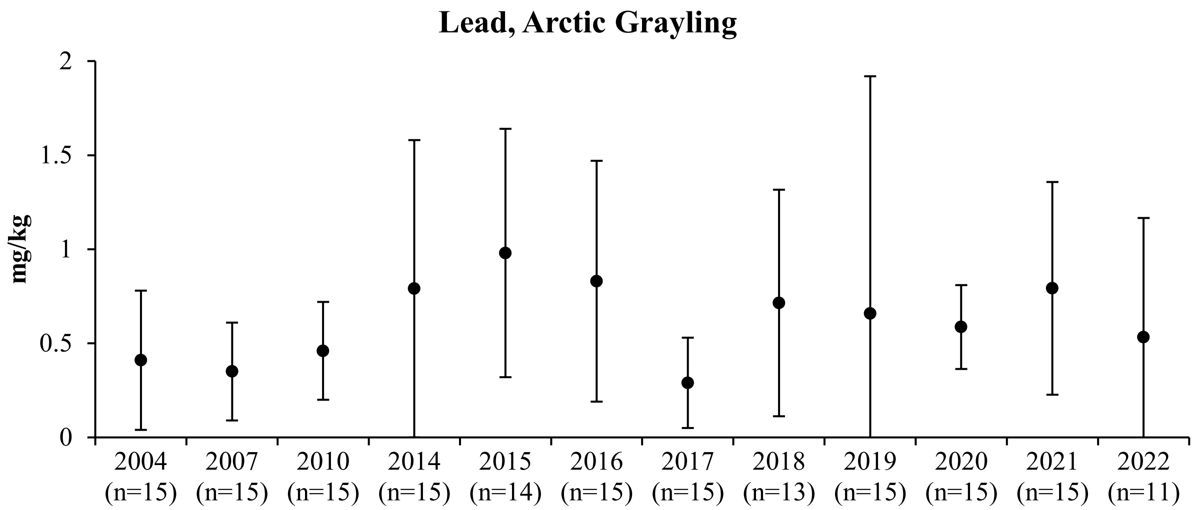


Figure 35. Mean lead concentrations (± 1 SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

The mean selenium concentration in juvenile Arctic grayling from Bons Pond decreased from 2014 to 2019, increased in 2020 and 2021, and decreased in 2022 (Figure 36). The mean concentration in 2022 was 13.3 mg/kg.

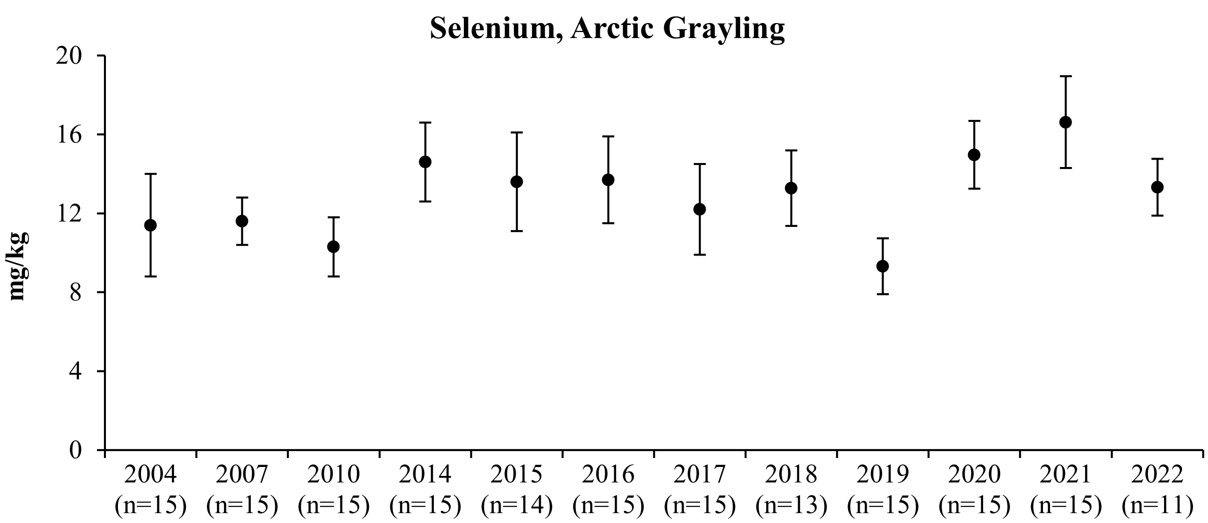


Figure 36. Mean selenium concentrations (± 1 SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

Mean zinc concentration in juvenile Arctic grayling from Bons Pond in 2022 was 106.3 mg/kg, the highest mean value since sampling began in 2004, however the range of observed values substantially overlap with previous years (Figure 37).

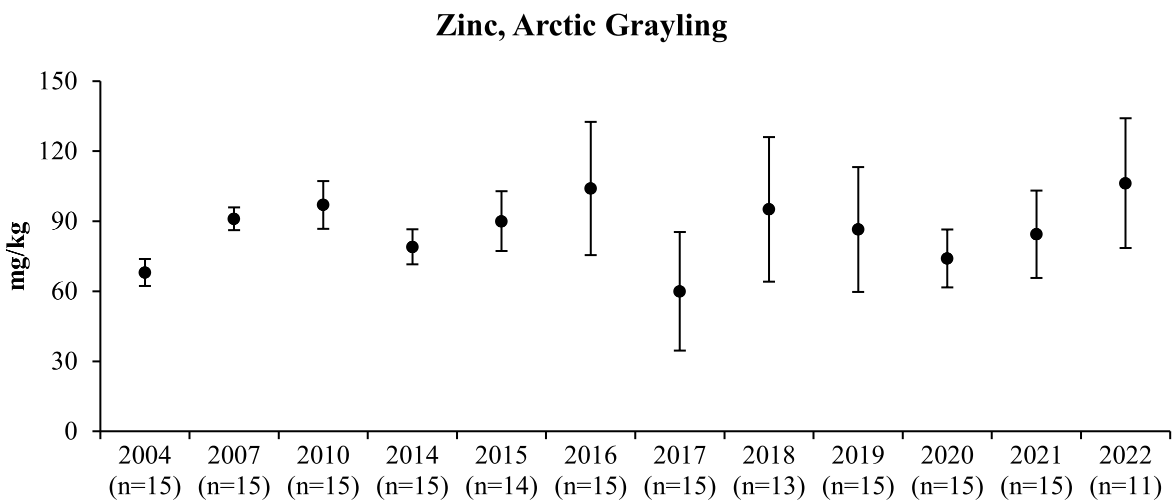


Figure 37. Mean zinc concentrations (± 1 SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

Mean mercury concentrations in juvenile Arctic grayling from Bons Pond have been variable and ranged from a high of 0.06 mg/kg in 2018 and 2019 to a low of the detection limit of 0.02 mg/kg in 2004 and 2014 (Figure 38). The mean mercury concentration in 2022 was 0.03 mg/kg.

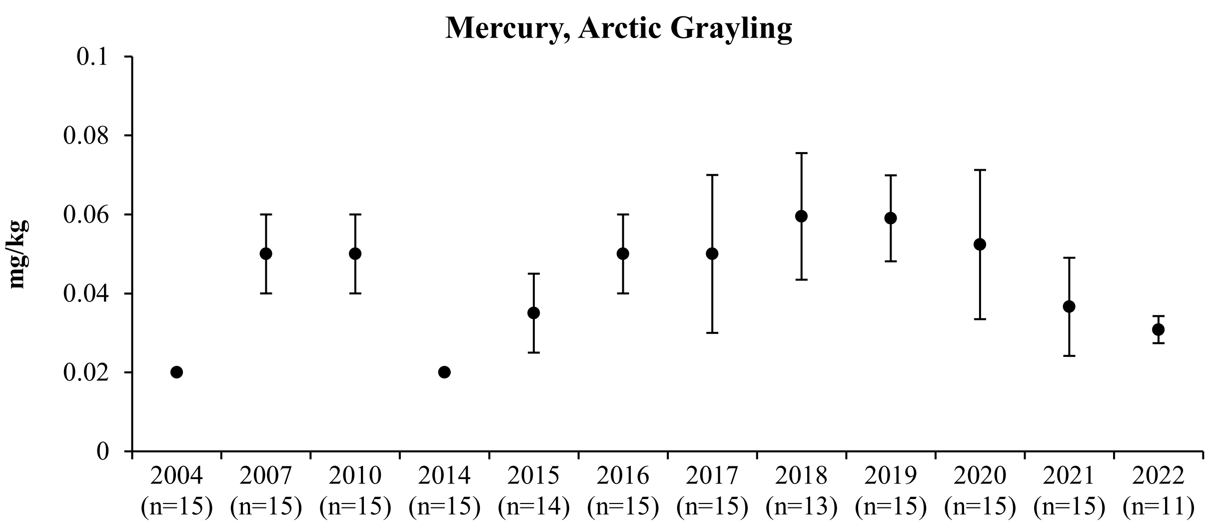


Figure 38. Mean mercury concentrations (± 1 SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

In August 2022, juvenile Dolly Varden were collected from Buddy (n = 15), Anxiety Ridge (n = 15), and Mainstem Red Dog creeks (n = 10) for whole body element analysis (Appendix 5). In 2022, four juvenile Dolly Varden captured in the minnow traps were dead or dying. These fish were smaller than the minimum weight (5 grams) for analysis, so two fish each were used to form composite samples.

Since water quality concentrations of cadmium, lead, and zinc are highest in Mainstem Red Dog Creek, higher concentrations of these metals in whole body samples of juvenile Dolly Varden are expected. The main sources of cadmium, lead, and zinc to Mainstem Red Dog creek are the waters from the clean water bypass (Figure 4).

Whole body cadmium concentrations (mean value) are typically highest in juvenile Dolly Varden collected from Mainstem Red Dog Creek and consistently lowest in Anxiety Ridge Creek (Figure 39). Peak mean cadmium concentration for Mainstem Red Dog Creek occurred in 2007 (3.41 mg/kg), in Buddy Creek the peak was in 2022 (1.85 mg/kg), and in Anxiety Ridge Creek the peak was in 2006 (0.49 mg/kg). Mean cadmium concentrations were at or below 1 mg/kg in fish from Buddy Creek from 2007 – 2020, but have increased in recent years. Anxiety Ridge Creek concentrations have remained low since 2005. Among data for Mainstem Red Dog Creek, changes in whole body cadmium concentrations generally track with the water quality data, although the sharp increase in cadmium in the 2018 – 2021 water quality data is not evident in the whole body cadmium concentration. The lack of fish captures in 2020 may be related to the extremely high cadmium concentrations in the water that year (Figure 40). No fish kills were observed in 2020, so the assumption is that fish avoided Red Dog Creek and moved to other areas in the Ikalukrok Creek drainage.

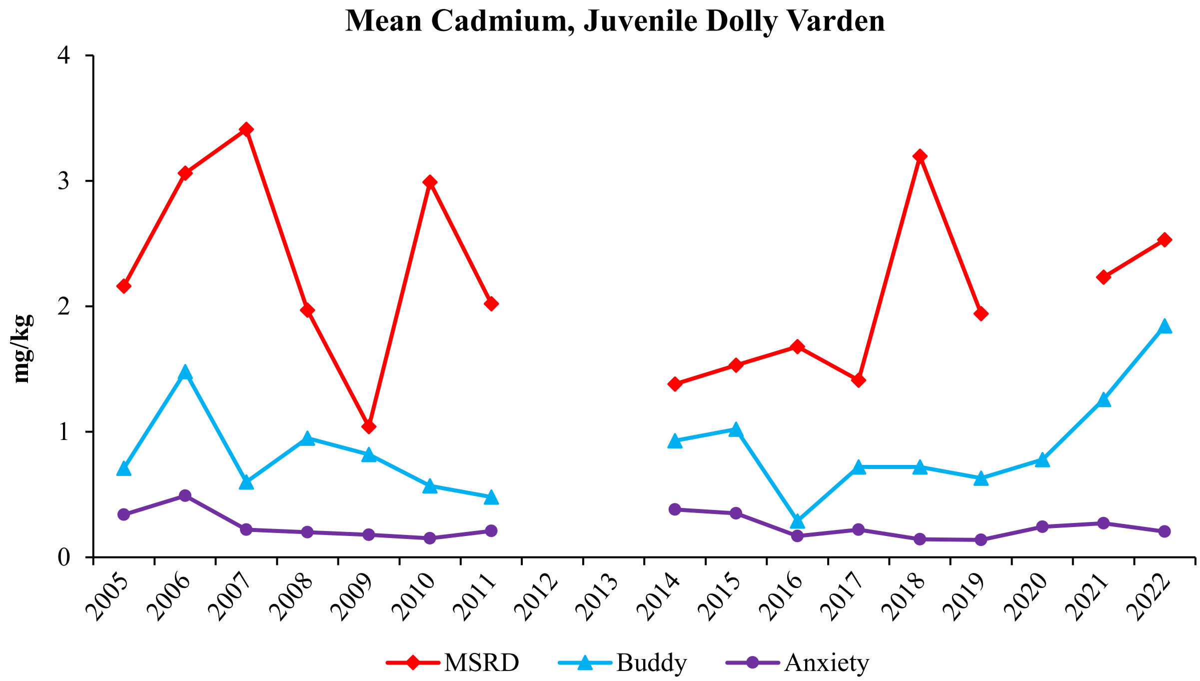


Figure 39. Mean whole body cadmium concentrations in juvenile Dolly Varden from 2005 to 2022. No fish were captured in Mainstem Red Dog Creek in 2020.

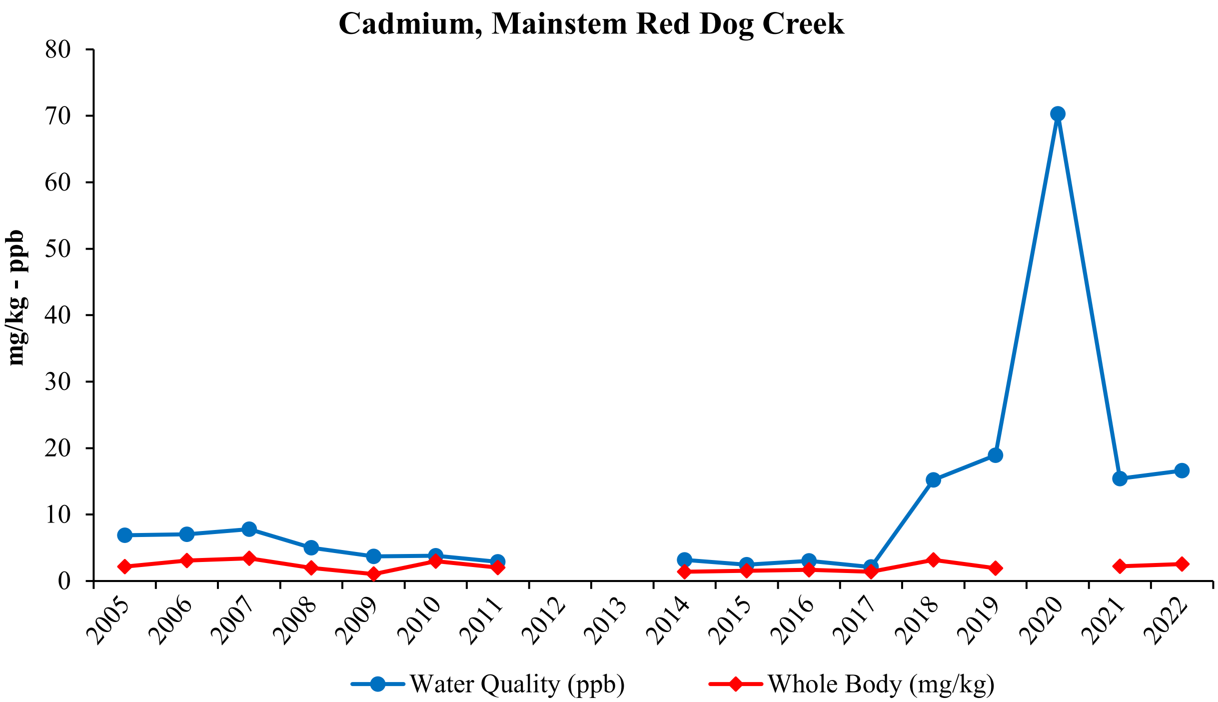


Figure 40. Mean whole body cadmium concentrations in juvenile Dolly Varden and median cadmium water quality data for Mainstem Red Dog Creek. No fish were captured in Mainstem Red Dog Creek in 2020.

Prior to 2019, mean whole body lead concentrations in juvenile Dolly Varden were consistently highest in Mainstem Red Dog Creek, and lower and similar in Buddy and Anxiety Ridge creeks, (Figure 41). From 2019 on, mean lead concentrations have decreased in Mainstem Red Dog Creek and increased in Buddy Creek, while Anxiety Ridge Creek levels have remained low. In 2022, one fish in Buddy Creek had an unusually high lead level of 14.67 mg/kg dry weight, while all other fish from this creek ranged from 0.22 mg/kg to 5.31 mg/kg. All fish captured in minnow traps in Buddy Creek appeared to be healthy. Similarly, one sample in Mainstem Red Dog Creek that was a composite sample of two small dying fish had a lead value of 8.28 mg/kg, while all other samples ranged from 0.19 to 2.40 mg/kg. The other composite sample from Mainstem Red Dog Creek of fish that were dying had a lead level of 0.41 mg/kg, so lead does not appear to be the cause of the fish distress. Lead concentrations in the water of Mainstem Red Dog Creek have been highly variable since 2005 and there does not seem to be a relationship between lead in the water and lead in whole body samples from Mainstem Red Dog Creek juvenile Dolly Varden (Figure 42).

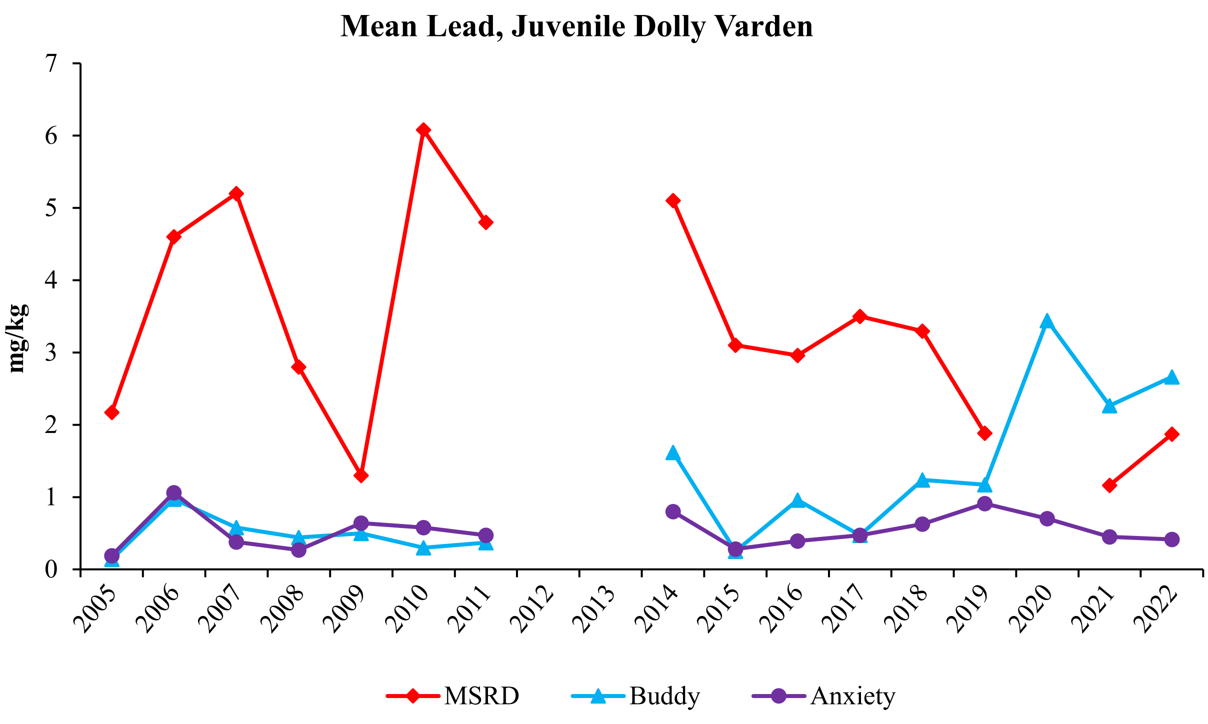


Figure 41. Mean whole body lead concentrations in juvenile Dolly Varden from 2005 – 2022. No fish were captured in Mainstem Red Dog Creek in 2020.

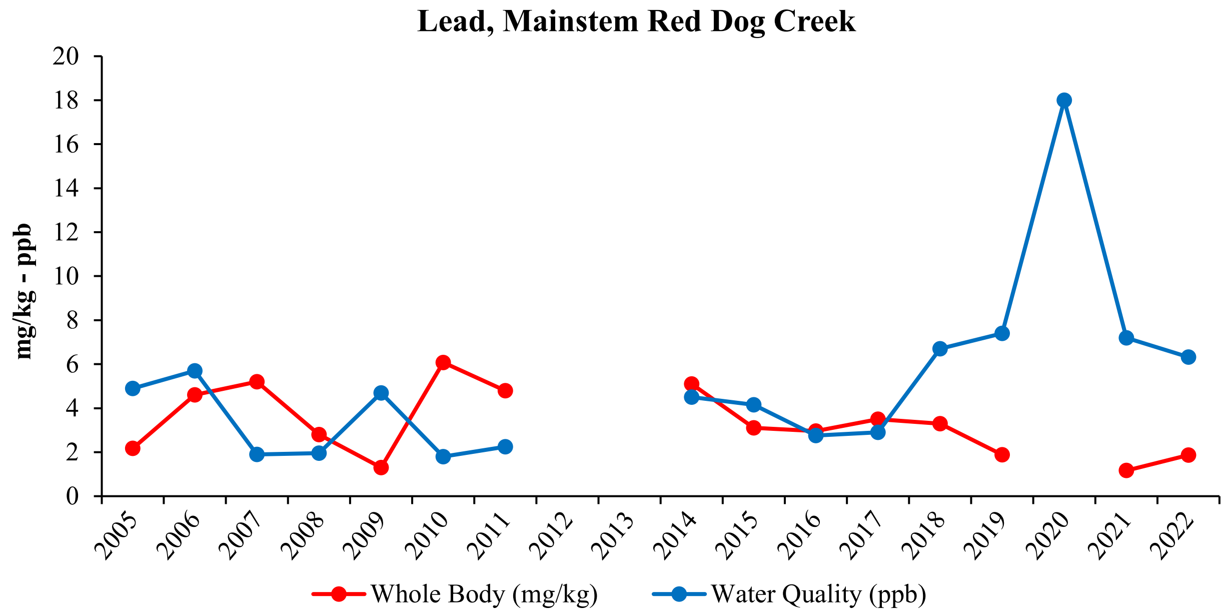


Figure 42. Mean whole body lead concentrations in juvenile Dolly Varden and median lead water quality data for Mainstem Red Dog Creek. No fish were captured in Mainstem Red Dog Creek in 2020.

Mean whole body selenium concentrations in juvenile Dolly Varden are generally lowest in fish from Anxiety Ridge Creek (Figure 43). Whole body selenium concentrations in juvenile Dolly Varden from Mainstem Red Dog Creek increased from 2009 to 2015, then decreased each year from 2016 to 2019. Selenium concentrations in all three sample sites have been very similar from 2020 to present. There is no clear relationship in Mainstem Red Dog Creek between selenium concentrations in the water and in whole body juvenile Dolly Varden (Figure 44).

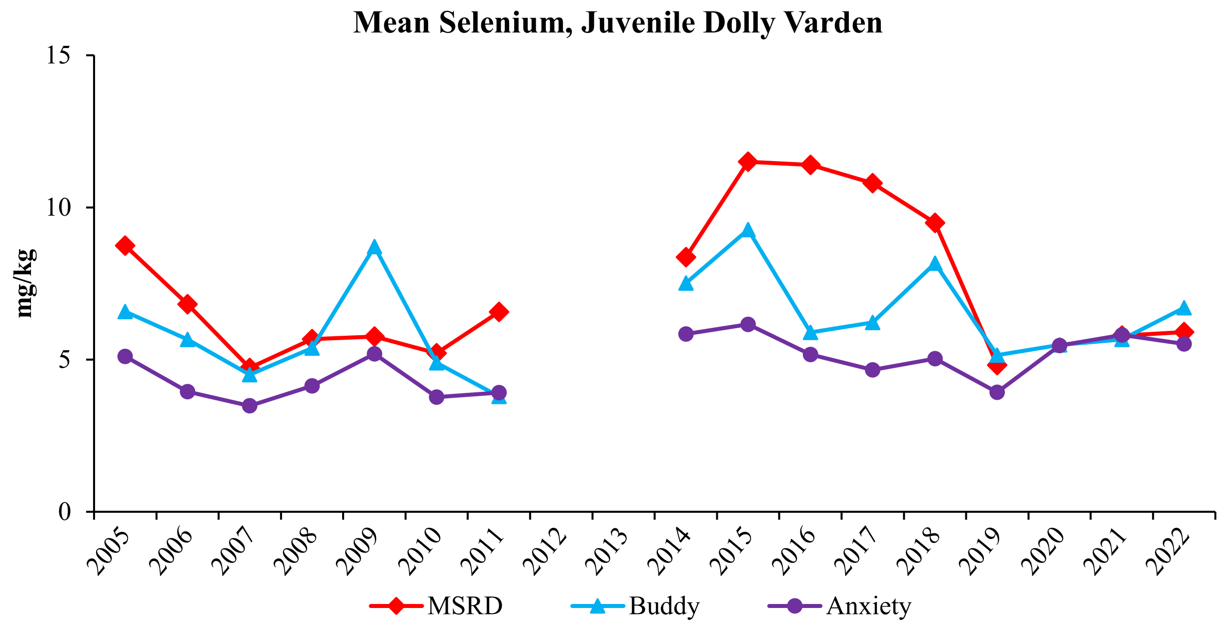


Figure 43. Mean whole body selenium concentrations in juvenile Dolly Varden from 2005 – 2022. No fish were captured in Mainstem Red Dog Creek in 2020.

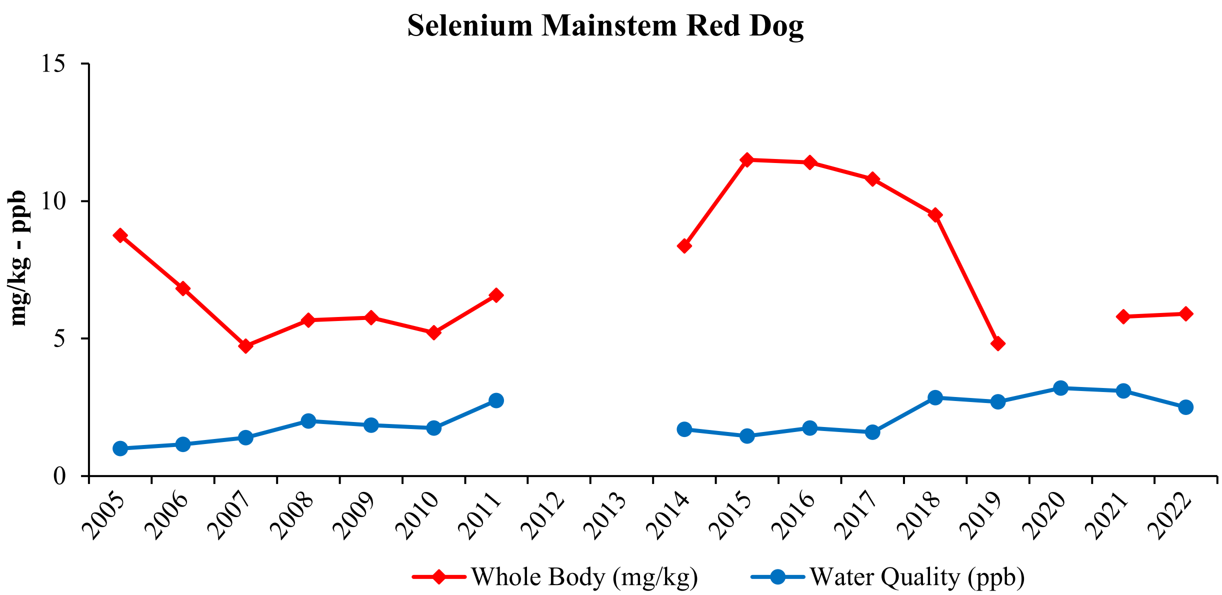


Figure 44. Mean whole body selenium concentrations in juvenile Dolly Varden and median selenium water quality data for Mainstem Red Dog Creek. No fish were captured in Mainstem Red Dog Creek in 2020.

Mean zinc whole body concentrations are generally highest in fish from Mainstem Red Dog Creek and lowest in fish from Anxiety Ridge Creek (Figure 45). Zinc whole body concentrations in Mainstem Red Dog Creek decreased from 358 mg/kg in 2006 to a low of 158 mg/kg in 2009, remained low until 2017, then increased to a high of 400 mg/kg in 2022. Whole body zinc concentrations in fish from Mainstem Red Dog Creek generally mirrored the trends in water concentration from 2005 to 2017, but the sharp increase in water zinc levels that began in 2018 was not reflected in the whole body concentration, although it may be related to the lack of fish captures in 2020 (Figures 46 and 47).

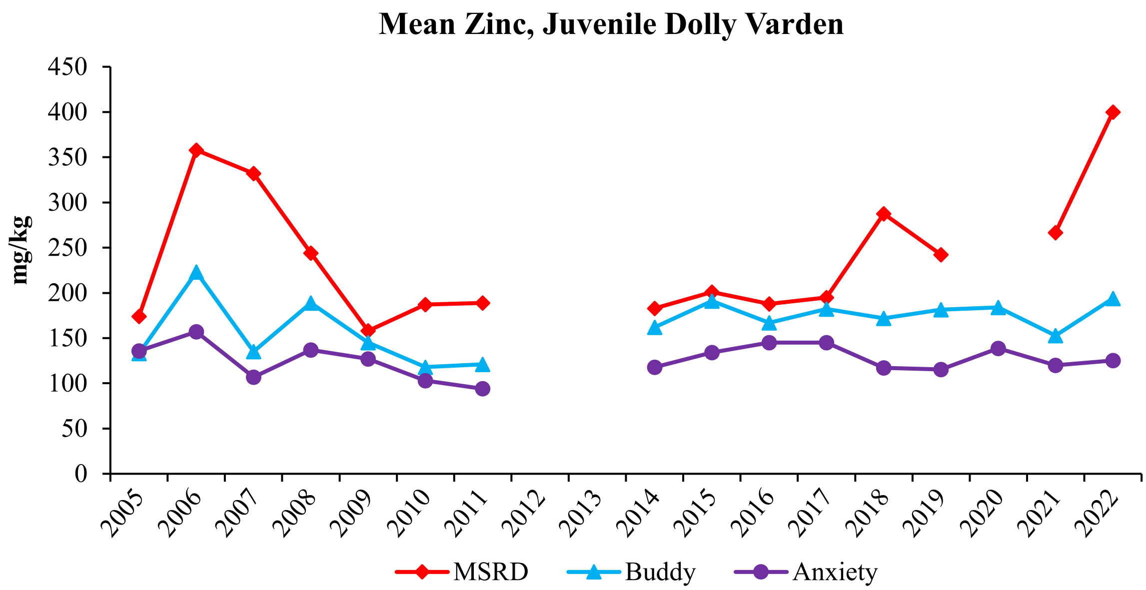


Figure 45. Mean whole body zinc concentrations in juvenile Dolly Varden from 2005 – 2022.

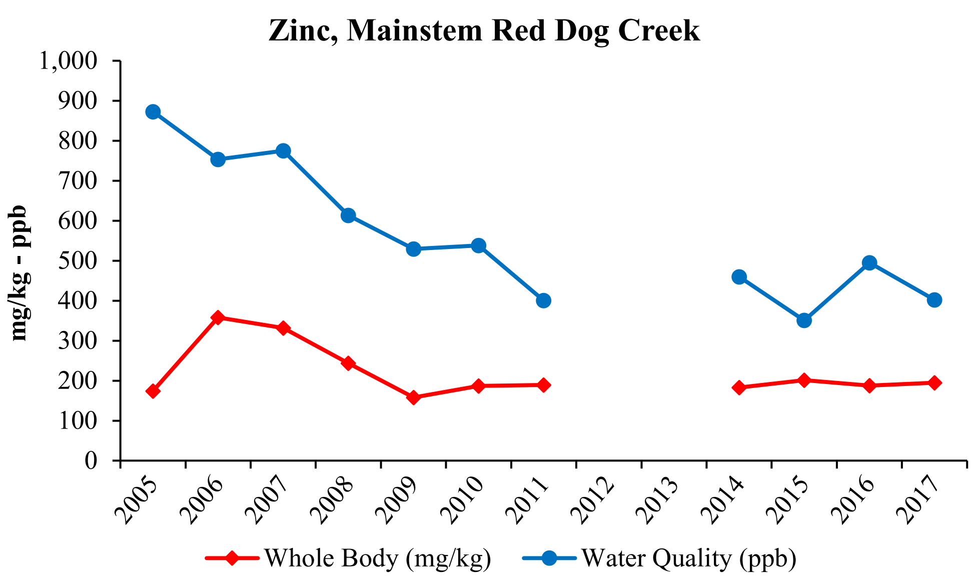


Figure 46. Mean whole body zinc concentrations in juvenile Dolly Varden and median zinc water quality data for Mainstem Red Dog Creek from 2005 – 2017.

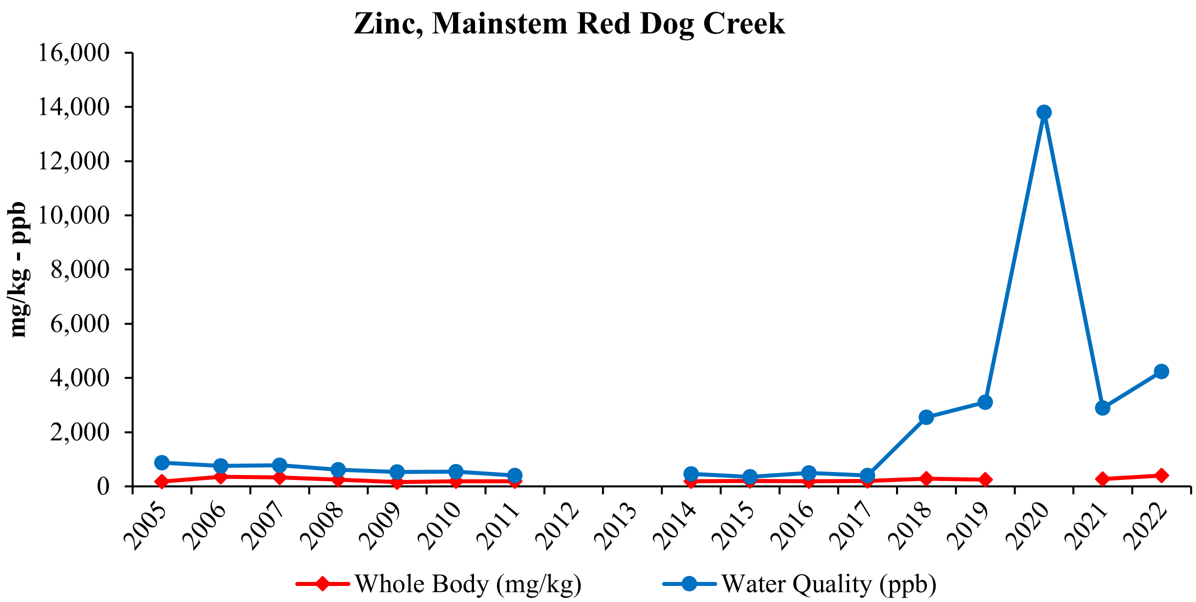


Figure 47. Mean whole body zinc concentrations in juvenile Dolly Varden and median zinc water quality data for Mainstem Red Dog Creek from 2005 – 2022. No fish were captured in Mainstem Red Dog Creek in 2020. Please note the different y-axis from Figure 46.

Mean mercury concentrations in juvenile Dolly Varden are consistently highest in Anxiety Ridge Creek and very similar between Buddy and Mainstem Red Dog creeks (Figure 48). The highest recorded mean concentration of mercury was 0.14 mg/kg in Anxiety Ridge Creek in 2016 and 2019.

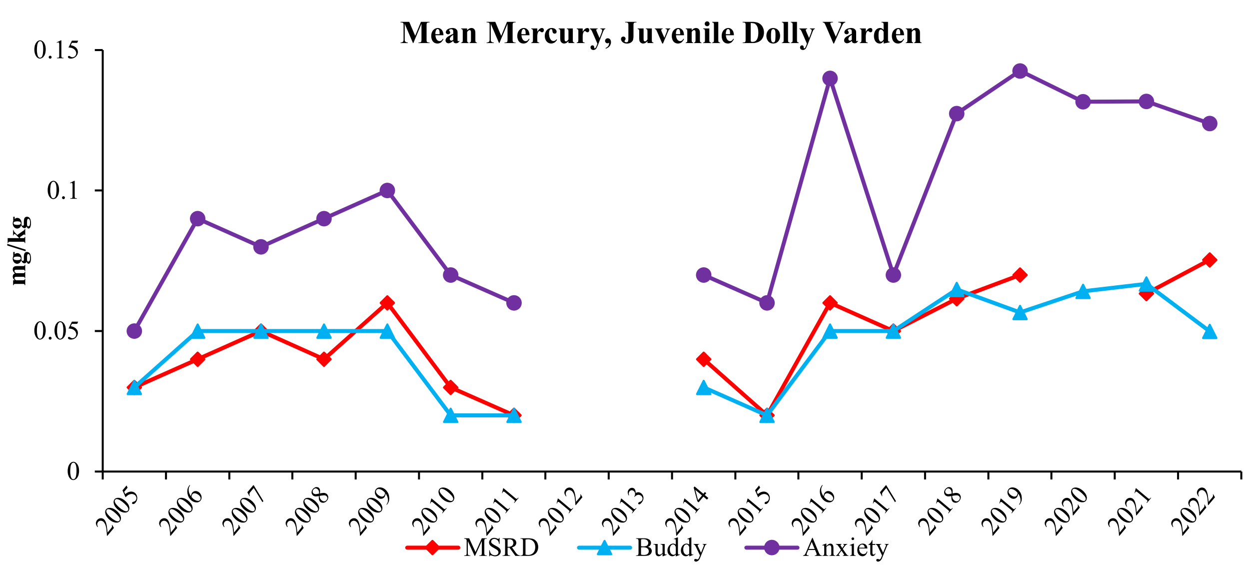


Figure 48. Mean whole body mercury concentrations in juvenile Dolly Varden from 2005 – 2022. No fish were captured in Mainstem Red Dog Creek in 2020.

Metal Concentrations in Adult Dolly Varden

In 2022, adult Dolly Varden were collected from the Wulik River (Station 2) about 2 km downstream from the mouth of Ikalukrok Creek, near Tutak Creek, to be sampled for selected element concentrations in kidney, liver, muscle, and reproductive tissue. Fifteen fish were sampled in 2022, eight in the spring and seven in the fall.

The purpose of sampling adult Dolly Varden for element concentration is to monitor tissue concentrations over time and to provide a database for use by other professionals. It is unlikely that tissue element concentrations in adult fish could be related to events at the Red Dog Mine, since most Dolly Varden growth occurs in the marine environment. All laboratory work was done with Level III Quality Assurance. Data for 2022 are presented in Appendices 6 and 7.

Certain elements are known to concentrate preferentially in certain organs; however, the relationship of organ concentration to ambient environmental concentrations is unknown. Concentrations of selected elements vary with season, age, size, weight, and feeding habits of fish (Jenkins 1980) and in the case of anadromous Dolly Varden, the element concentrations vary with exposure to freshwater and marine environments. None of the analytes measured appear to concentrate in muscle tissue (Figure 49). In Wulik River Dolly Varden sampled from 1999 to 2022, cadmium was highest in kidney samples, copper was highest in liver samples, lead was highest in testes tissue, zinc was highest in reproductive tissues, selenium was highest in ovaries and kidneys, and mercury was highest in kidneys.

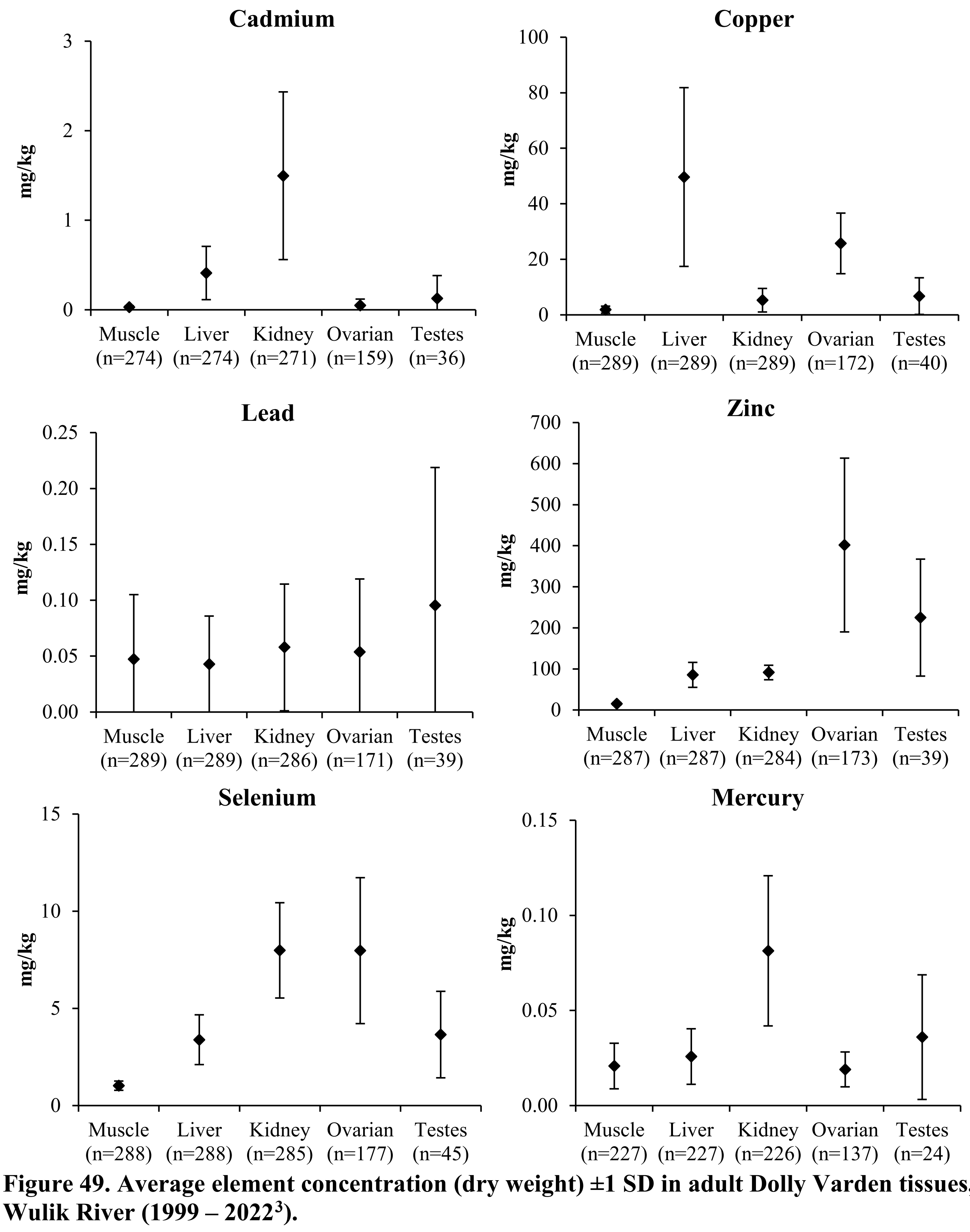


Figure 49. Average element concentration (dry weight) ±1 SD in adult Dolly Varden tissues, Wulik River (1999 – 2022[3]).

[3] Mercury results from 2018 samples are not included in the running average. Lab equipment was being repaired and samples were analyzed past holding time, producing unreliable results.

Cadmium concentrations in adult Dolly Varden kidney tissue have been variable since 1999 (Figure 50). Concentrations of cadmium slightly increased from 1999 to 2002, then abruptly decreased and remained around 1 mg/kg through spring of 2009. Average cadmium concentrations doubled in fall of 2009 to 1.99 mg/kg, reached a high of 2.96 mg/kg in spring 2011, then have remained intermediate and variable from 2013 - 2022.

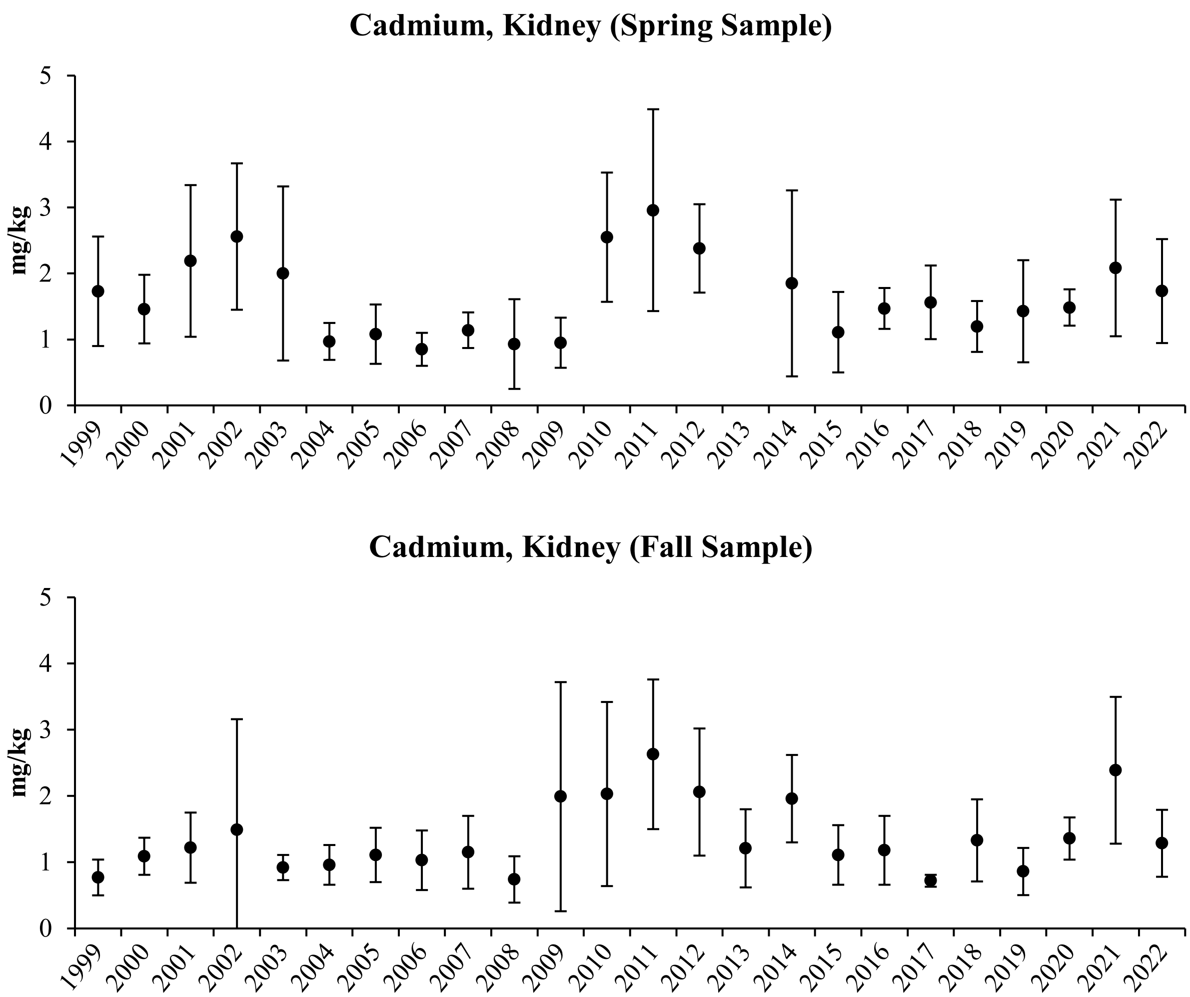


Figure 50. Average cadmium (± 1 SD) concentrations (dry weight) in adult Dolly Varden kidney tissues from 1999 – 2022.

Average selenium concentrations in adult Dolly Varden ovaries are higher for fish sampled in the fall (9.72 mg/kg) than for fish sampled in the spring (5.70 mg/kg) (Figure 51). The Dolly Varden sampled in the fall would have recently returned from the marine environment, which may be where they acquired the selenium.

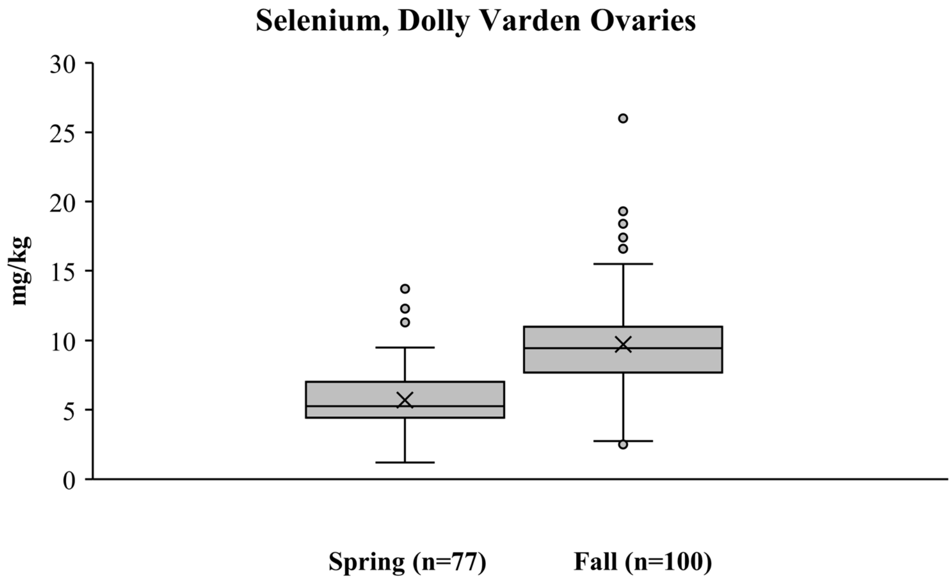


Figure 51. Selenium concentrations (dry weight) in Dolly Varden ovaries from 1999 – 2022.

Dolly Varden, Overwintering

An aerial survey was conducted using a helicopter on October 2, 2022, to estimate the number of overwintering Dolly Varden in the Wulik River (Figure 52). Lower Ikalukrok Creek also was surveyed, but Dolly Varden observed here are considered fall spawning fish and are not included in the count of overwintering fish. Turbidity from Ikalukrok Creek impeded visibility in the deep water areas between Tutak Creek and the mouth of Ikalukrok Creek, but was less severe than during the 2019 – 2021 surveys. A total of 74,482 Dolly Varden were counted in the Wulik River, although this should be considered a minimum estimate due to reduced visibility.

On average, 95% of Dolly Varden observed have been downstream of the mouth of Ikalukrok Creek (37 surveys 1979-2022, Table 2). However, in 2019 – 2021 much higher numbers of fish were counted upstream of the mouth of Ikalukrok Creek. In 2019, 17,308 fish were counted upstream of the mouth, in 2020, 19,860 fish (27%) were counted above the mouth, and in 2021, 12,201 fish (14%) were counted upstream of the mouth. In 2022, the proportion of fish counted upstream of the mouth returned to the historical average of 5% (Figure 53).

Fall estimates of Dolly Varden have varied annually and reached their lowest (21,084 fish) number in 2012, but then increased in fall 2014 (63,951 fish) and have been relatively stable since then (Figure 53 and Table 2).

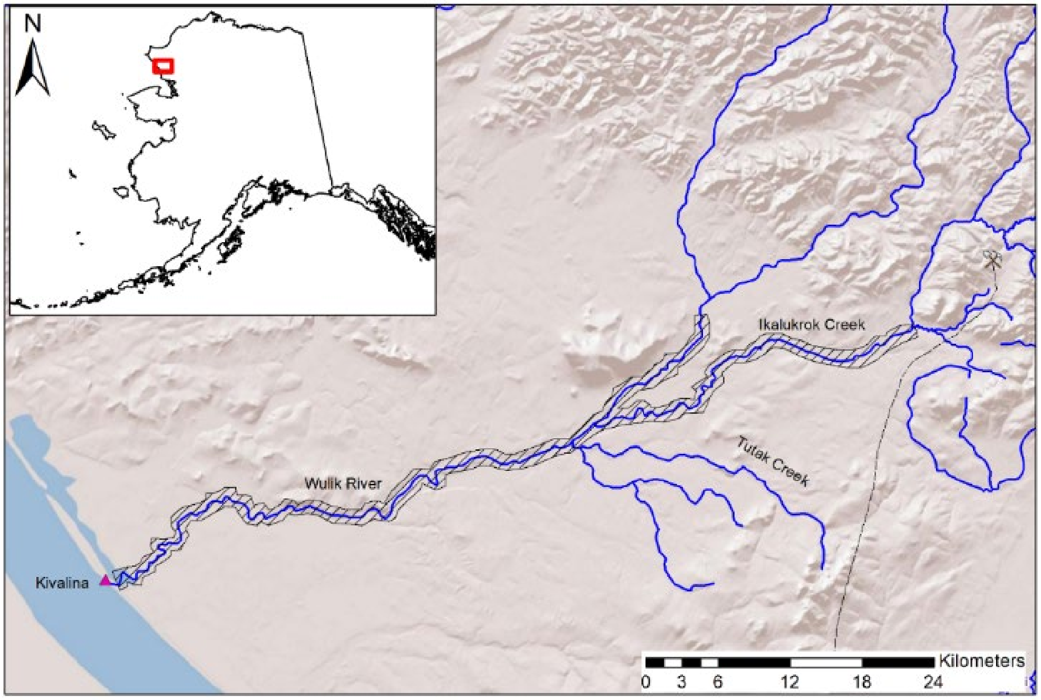


Figure 52. Dolly Varden and chum salmon aerial survey area. The striped polygon denotes the surveyed portion of the drainage.

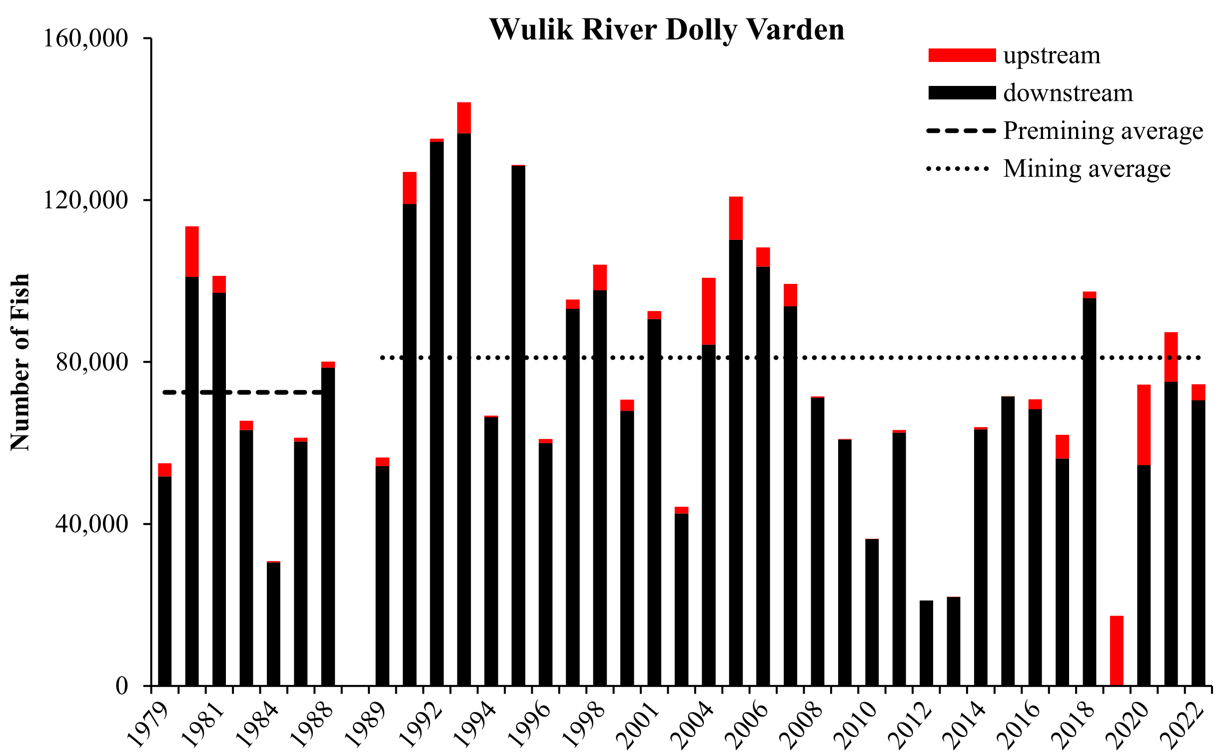


Figure 53. Aerial survey estimates of the number of Dolly Varden in the Wulik River just prior to freeze up, 1979 – 2022. "Upstream" fish are those counted upstream of the mouth of Ikalukrok Creek on the Wulik River.

Table 2. Estimated number of Dolly Varden in the Wulik River.

Year	Wulik River upstream of Ikalukrok Creek	Wulik River downstream of Ikalukrok Creek	Total Fish	% of fish downstream of Ikalukrok Creek
Before Mining 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[1]	1,500	78,644	80,144	98
During Mining 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
1994[2]	415	66,337	66,752	99
1995	240	128,465	128,705	99
1996	1,010	59,995	61,005	98
1997	2,295	93,117	95,412	98
1998	6,350	97,693	104,043	94
1999	2,750	67,954	70,704	96
2000[3]				
2001	2,020	90,594	92,614	98
2002	1,675	42,582	44,257	96
2003[3]				
2004	16,486	84,320	100,806	84
2005	10,645	110,203	120,848	91
2006	4,758	103,594	108,352	96
2007	5,503	93,808	99,311	94
2008	271	71,222	71,493	99
2009	122	60,876	60,998	99
2010	70	36,248	36,318	99
2011	637	62,612	63,249	99
2012	0	21,084	21,084	100
2013	114	21,945	22,059	99
2014	610	63,341	63,951	99
2015	10	71,474	71,484	100
2016	2,490	68,312	70,802	96
2017	5,856	56,173	62,029	91
2018	1,590	95,795	97,385	98
2019	17,308	too turbid	incomplete	unknown
2020	19,860	54,546	74,406	73
2021	12,201	75,160	87,361	86
2022	3,887	70,595	74,482	95

[1]The population estimate (mark/recapture) for winter 1988/1989 for fish > 400 mm was 76,892 (DeCicco 1990).
[2]The population estimate (mark/recapture) for winter 1994/1995 for fish > 400 mm was 361,599 (DeCicco 1996).
[3]Fall 2000 and 2003 aerial surveys did not occur due to weather.

Chum Salmon, Spawning

Annual chum salmon escapement is estimated in Ikalukrok Creek from its confluence with the Wulik River upstream to Dudd Creek (Figures 52 and 55). An aerial survey was planned in September 2022 but was postponed due to storms in the region. Chum salmon in Ikalukrok Creek were counted during the Dolly Varden survey on October 2, 2022. Similar to 2019 – 2021, turbidity was very high in Ikalukrok Creek, making it nearly impossible to count fish in the mainstem of Ikalukrok Creek (Figure 54). A total of 208 live and dead chum salmon were counted in clear water side channels or on the banks of the mainstem, but this should be considered a minimum estimate due to severely impeded visibility (Figure 55).

Figure 54. Turbid water in Ikalukrok Creek looking upstream towards Station 160, September 10, 2021 (photo provided by Owl Ridge Natural Resource Consultants).

Annual post-mining aerial surveys were initiated in 1990. Counts of chum salmon in Ikalukrok Creek in 1990 and 1991 (mine discharge began in 1989) were lower than reported in baseline studies in 1981 and 1982. It should be noted that the reported number of chum salmon in 1981 was an extrapolation based on aerial photographs, and therefore, is not comparable to the aerial survey dataset.

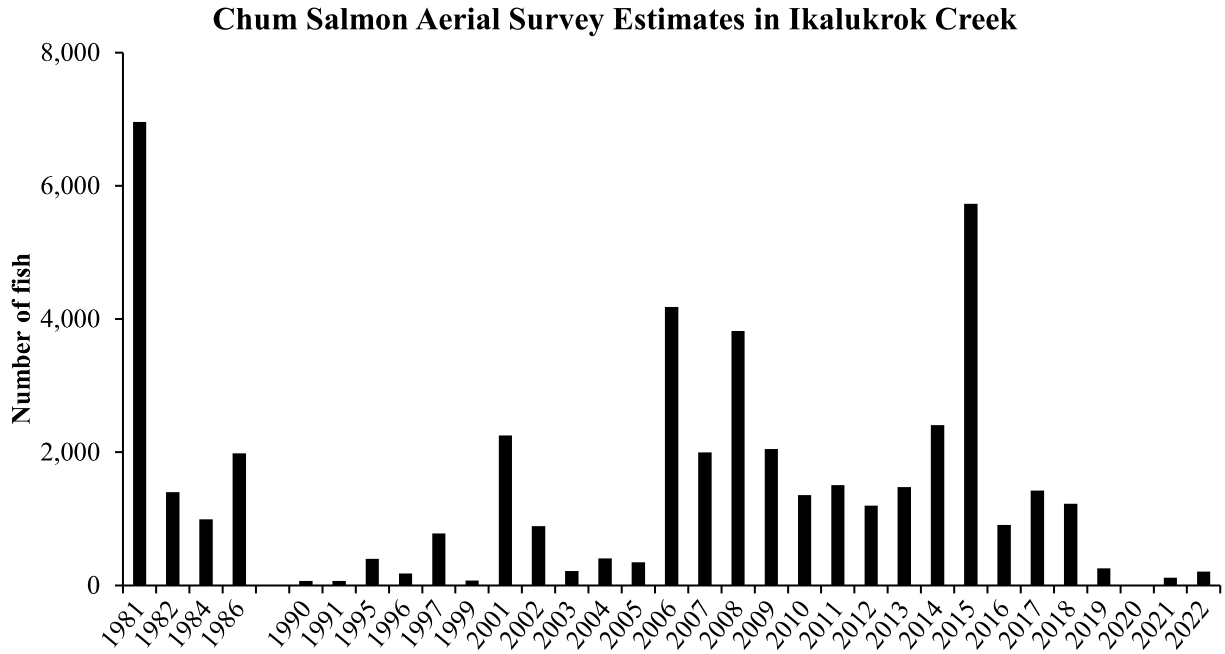


Figure 55. Peak estimates of chum salmon escapement in Ikalukrok Creek. The 2019 – 2022 counts were impacted by limited visibility in Ikalukrok Creek due to unusually high turbidity and should be considered minimum estimates.

Dolly Varden, Juveniles

Limited pre-mining juvenile Dolly Varden distribution data are available for streams in the Red Dog Mine area. Houghton and Hilgert (1983) identified Anxiety Ridge Creek as the most productive system in the project area. They also reported finding only one juvenile Dolly Varden in the North Fork Red Dog Creek drainage and presumed it was a resident fish. Surveys along Mainstem Red Dog Creek reported either few fish or no fish, and in some cases mortalities of small juvenile Dolly Varden and Arctic grayling fry (Ward and Olson 1980, EVS Consultants Ltd and Ott Water Engineers 1983).

Juvenile Dolly Varden have been sampled in streams within the Red Dog Mine area since 1990. In 1992, new sample sites were added, and the number of minnow traps was increased to 10 per sample reach. Under the modified program that began in 2010, nine sites are now sampled with 10 minnow traps per sample reach, typically with around 24 hours of effort in early-to-mid August (Table 3, Appendix 8). Seven of these sites are unchanged in location and Station 7 was replaced with Station 160 – instead of being immediately downstream of Dudd Creek, it is now located about 7 km downstream.

Table 3. Location of juvenile Dolly Varden sample sites.[1]

Site Name	Station #	Year Sampling Began
Evaingiknuk Creek		1990
Anxiety Ridge Creek		1990
Buddy Creek		1996
North Fork Red Dog Creek	12	1993
Mainstem Red Dog Creek	151	1995
Mainstem Red Dog Creek	10	1996
Ikalukrok Creek above Mainstem	9	1996
Ikalukrok Creek below Dudd	7/160	1990
Upper North Fork Red Dog Creek		2014

[1]Sampling has been performed annually at each of these sites except in 2012 and 2013, when water levels were too high to effectively sample.

Dolly Varden Catches and Metrics

The relative abundance of juvenile Dolly Varden varies considerably among sample years (Appendix 8); however, the catches among the sample sites follow similar patterns. Generally, the CPUE (number of fish caught in 10 traps per 24 hour period) in Anxiety and Buddy creeks is higher than at the other sample reaches. In 2022, the CPUE was highest in Buddy Creek (193.9 fish/24 hours) and Anxiety Ridge Creek (111.7 fish/24 hours) (Figure 56). In 2020, no fish were caught in the Red Dog Creek drainage. In 2021, seven juvenile Dolly Varden were caught in Mainstem Red Dog Creek. In 2022, 94 juvenile Dolly Varden were caught in Mainstem Red Dog Creek, with 67 caught at Station 151 and 27 caught at Station 10. As discussed earlier in the element analysis section, four of the Dolly Varden captured at Station 151 were dead or dying in the minnow traps for unknown reasons.

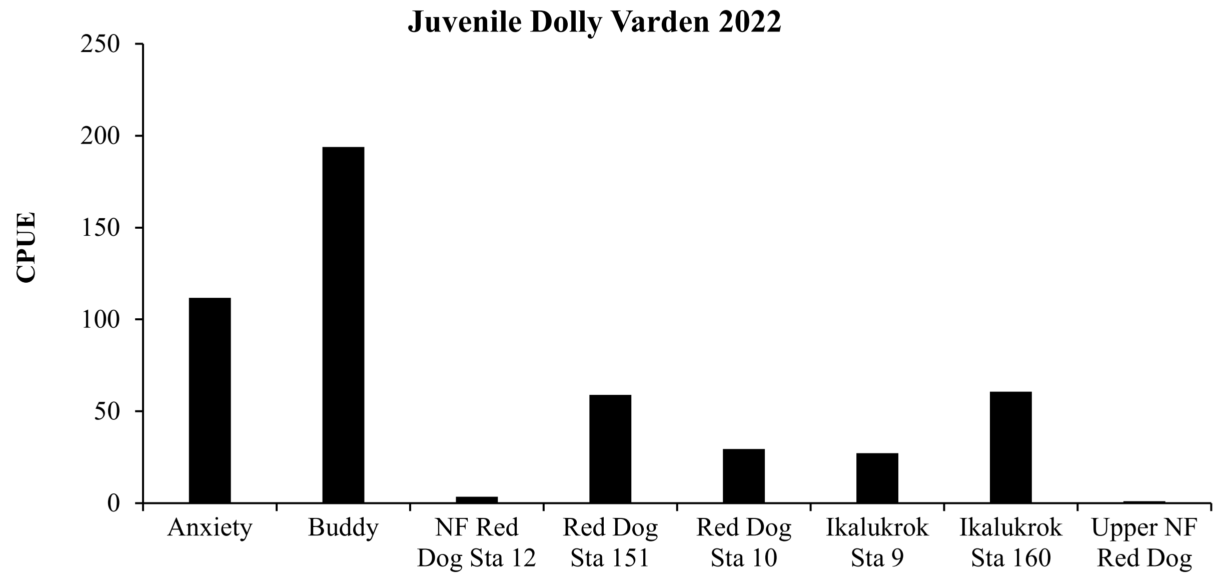


Figure 56. CPUE for juvenile Dolly Varden in the Red Dog sample reaches in 2022.

Natural environmental variability such as duration of breakup, patterns and magnitude of rainfall, ambient air temperatures, and the strength of the age-1 cohort affect distribution of juveniles and relative abundance. The most important factor is probably the strength of the age-1 cohort, which is directly related to number of spawners, spawning success, and survival the previous winter. The CPUE for juvenile Dolly Varden in Anxiety Ridge and Buddy creeks from 1997 to 2022 reflects the high degree of variability among sample years (Figure 57).

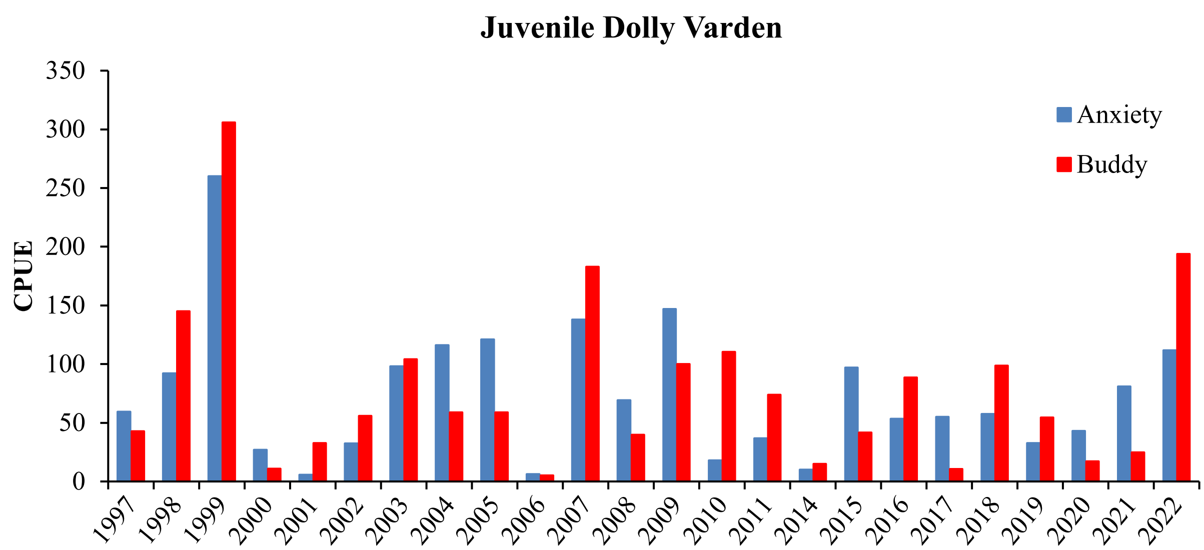


Figure 57. CPUE of juvenile Dolly Varden in Anxiety Ridge and Buddy creeks, 1997 – 2022. No sampling was performed in 2012 or 2013 due to high water.

CPUE in lower Mainstem Red Dog Creek has ranged from a low of 0 in 2004 and 2020 to a high of 73.3 in 1999 (Figure 58). The highest catches in Anxiety Ridge and Buddy creeks also occurred in 1999. Catches since 2000 in lower Mainstem Red Dog Creek have remained low, but relatively consistent prior to 2020. Use of lower Mainstem Red Dog Creek by juvenile Dolly Varden has generally been greater than what was found by Houghton and Hilgert (1983) during baseline studies before mine development.

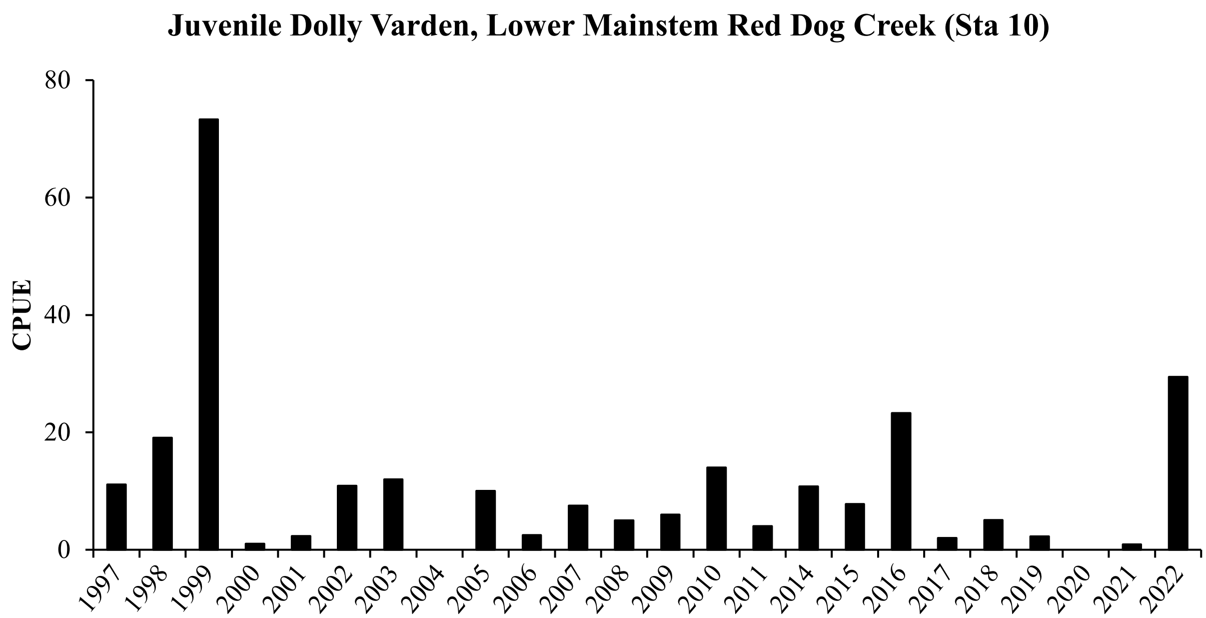


Figure 58. CPUE of juvenile Dolly Varden in Lower Mainstem Red Dog Creek, 1998 – 2022. No sampling was performed in 2012 or 2013 due to high water.

Anadromous Dolly Varden spend at least one year in freshwater before their migration to the marine environment (DeCicco 1990). Microchemical analyses of different Dolly Varden populations in Alaska indicate that most fish first migrate to sea at ages 2 or 3 (Hart et. al 2015, Bond et al. 2015). Based on length frequency distributions for juvenile Dolly Varden captured in 2022, it is likely most fish were age 1+. Small Dolly Varden (≤ 70 mm FL) captured in late July and August are likely age 0 fish. In 2022, 71 out of 491 captured fish were ≤ 70 mm FL (Figure 59).

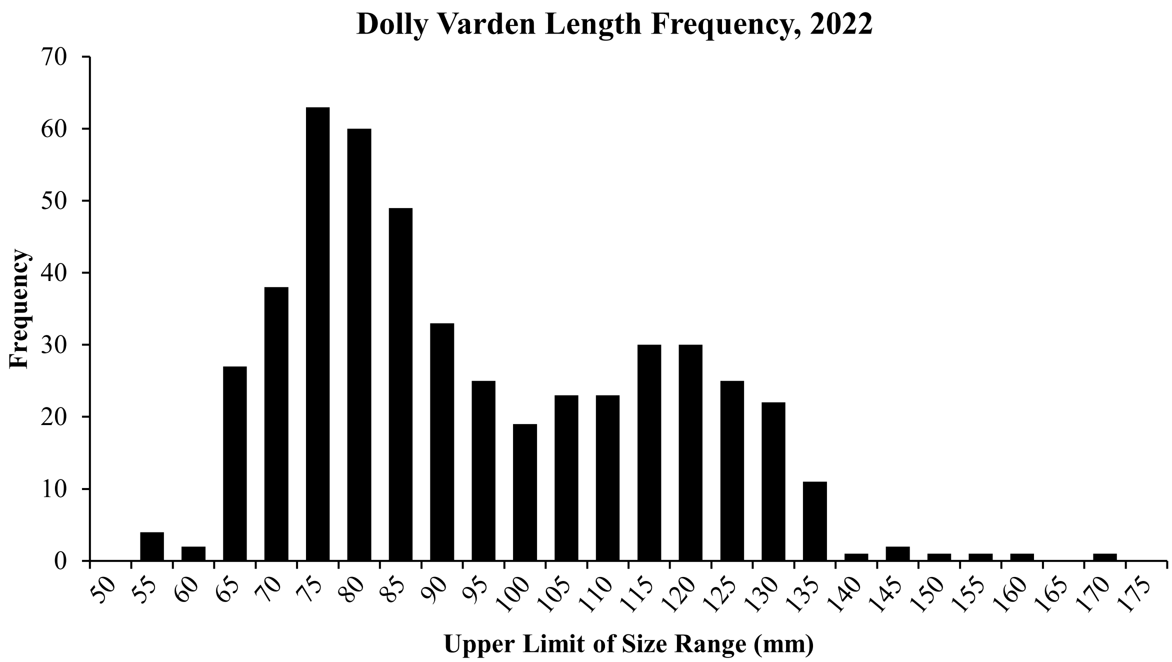


Figure 59. Length frequency distribution of Dolly Varden in the Ikalukrok Creek drainage in August 2022.

In the Ikalukrok Creek drainage, some Dolly Varden are occasionally captured that are > 145 mm FL and sexually mature. Most of these fish are residents that will not out-migrate to the marine environment. These resident fish are identified by their coloration (orange spots and white edges on the pelvic fins) and sexual condition (milt observed). These sexually mature resident Dolly Varden can be contrasted to the anadromous form, which can attain over 600 mm FL and has very distinctive coloration in the fall, prior to spawning.

During spring each year, fyke net(s) are fished in North Fork Red Dog Creek for the primary purpose of catching Arctic grayling. However, Dolly Varden are also caught in the fyke nets and these fish are generally larger than those caught later in the summer in minnow traps, likely due in part to the inability of larger fish to enter the minnow traps. In spring 2022, six Dolly Varden were caught in the fyke nets ranging from 140 mm FL to 186 mm FL, with an average size of 159 mm FL (Figure 60). Many of the Dolly Varden caught in North Fork Red Dog Creek in the spring are likely the resident form.

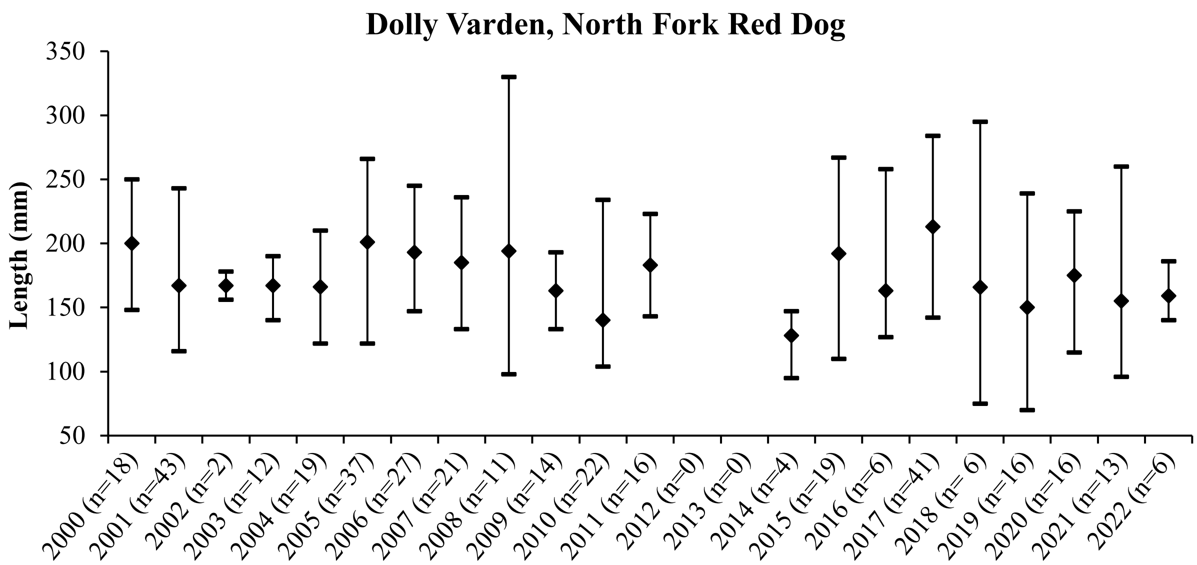


Figure 60. Dolly Varden caught in fyke nets fished in North Fork Red Dog Creek in spring. Average, maximum, and minimum lengths are shown for each sample year.

Arctic Grayling, Red Dog Creek Drainage

Before mine development, Arctic grayling adults migrated through Mainstem Red Dog Creek in the spring when flows were high and naturally occurring metals concentrations were low (Ward and Olsen 1980, EVS and Ott Water Engineers 1983, and Houghton and Hilgert 1983). Arctic grayling moved upstream through Mainstem Red Dog Creek to spawn in North Fork Red Dog Creek. None of the historical reports indicated that Arctic grayling spawned in Mainstem Red Dog Creek. Arctic grayling fry reared in North Fork Red Dog Creek and were displaced downstream by high-water events or outmigrated as water temperatures cooled in the fall. Only a few juvenile Arctic grayling were collected in North Fork Red Dog Creek prior to mine development. Incidental observations of Dolly Varden and Arctic grayling fry mortality were reported in Mainstem Red Dog Creek before mine development by Ward and Olsen (1980) and EVS Consultants and Ott Water Engineers (1983). Since 1994 Arctic grayling have been documented using Mainstem Red Dog Creek and no fish mortality events have been observed.

Presently, spawning occurs in Mainstem Red Dog and North Fork Red Dog creeks and has been monitored during the spring in North Fork Red Dog and Mainstem Red Dog creeks since 2001. The goal of this sampling effort is to document when spawning has been substantially completed in Mainstem Red Dog Creek and post-spawn Arctic grayling return to North Fork Red Dog Creek.

Spring water temperatures and timing of warming appear to be the key variables in determining spawning success, spawning time, fry emergence, first year growth, and likely survival. High flows during or immediately following spawning can have a negative effect on fry survival (Clark 1992).

Discharge volume and quality from the wastewater treatment facility at the Red Dog Mine are regulated to meet APDES permit conditions. From 2001 to 2007, TDS concentrations were regulated to be less than 500 mg/L at Station 151 (Station 10) during Arctic grayling spawning. During that time frame, monitoring of Arctic grayling spawning was performed to determine when spawning was substantially completed in Mainstem Red Dog Creek, thus allowing Teck to regulate the discharge rate to comply with the post-spawning TDS limit of 1,500 mg/L at Station 151 for the rest of the ice-free season.

A TDS site-specific criterion (SSC) of 1,500 mg/L during Arctic grayling spawning was issued by ADEC and became effective on February 15, 2006. The EPA approved the 1,500 mg/L TDS SSC on April 21, 2006. The SSC developed by ADEC was based on field and laboratory studies conducted with Arctic grayling at the Red Dog Mine site (Brix and Grosell 2005).

In 2022, one fyke net was set to capture Arctic grayling in North Fork Red Dog Creek from June 3 to June 9. Water flows dropped throughout the fishing period, which allowed the fyke net to effectively capture fish for the duration of the sampling event. The Red Dog water temperature sensor was not operational during this time frame, but measurements taken with handheld thermometers during sampling ranged from 1.3°C to 2.9°C.

Limited spawning in Mainstem Red Dog Creek could have started on May 26, when the peak daily water temperature reached 3.3°C (Figure 61, Table 4). A total of 13 females were captured in the fyke net during the sampling period. Four were in pre-spawning condition (green), three were in spawning condition (ripe), two were in post-spawning condition (spent), and the reproductive condition of four was not recorded. Spawning completion date is determined based on catch of spent females in the North Fork Red Dog Creek fyke net and water temperature data. Although two spent females were captured in the fyke net on June 6 and 7, green and ripe females were captured on June 8 and 9, indicating that spawning had not yet concluded.

Water temperatures are typically higher in Mainstem Red Dog Creek than in North Fork Red Dog Creek, as was the case in 2022 although early spring data are missing from North Fork Red Dog Creek (Figure 61). This pattern has been observed for multiple years and may be due to a lack of aufeis in Middle Fork Red Dog Creek while massive aufeis exists each spring in North Fork Red Dog Creek. Lack of aufeis in Middle Fork Red Dog Creek is due to reduced ground water flow caused by the tailing impoundment.

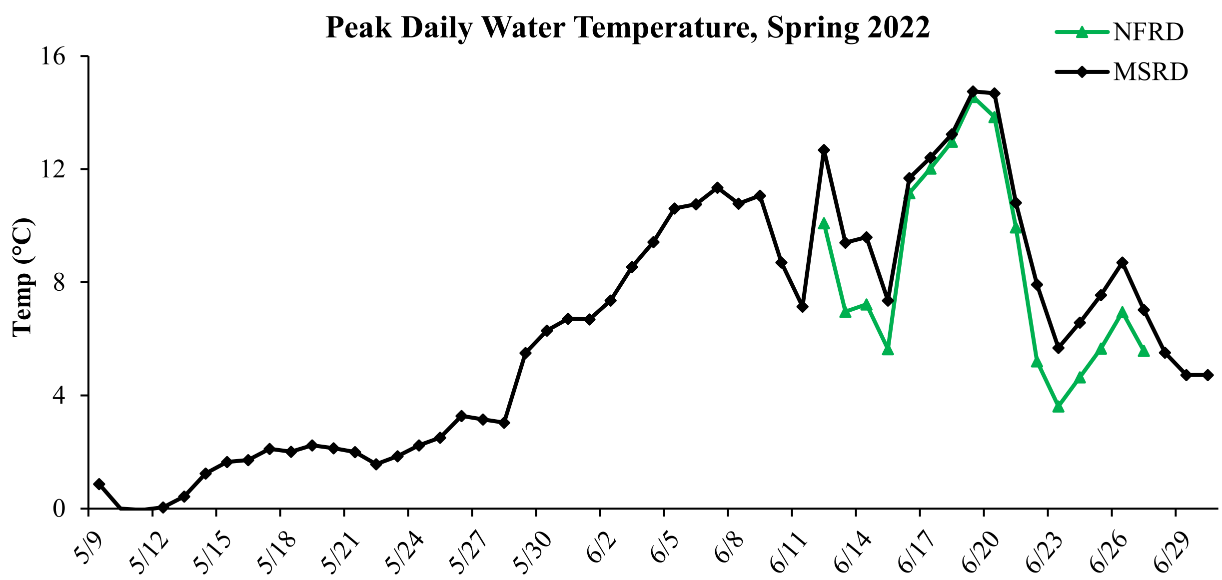


Figure 61. Peak daily water temperatures in North Fork Red Dog (Station 12) and Mainstem Red Dog (Station 151) creeks, May and June 2022.

In spring 2022, the catches of Arctic grayling were low throughout the sampling period (Figure 62). The fyke net in North Fork Red Dog Creek captured 34 Arctic grayling, four of which were immature.

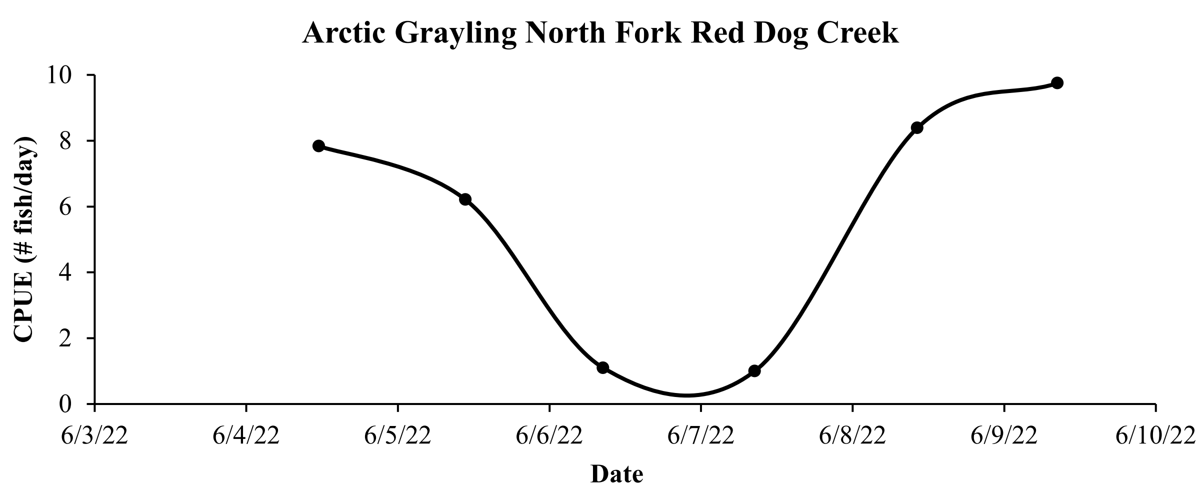


Figure 62. The CPUE of Arctic grayling in North Fork Red Dog Creek in spring 2022.

Recruitment of immature fish to North Fork Red Dog Creek was strong from 2007 to 2016, but low from 2017 to 2022 (Figure 63). Recruitment may be due in part to juvenile fish leaving Bons Pond and returning to North Fork Red Dog Creek. The low catches in 2017 were likely a result of very cold water from the substantial aufeis in the North Fork Red Dog Creek. Low recruitment in 2018 and 2019 could be due in part to less successful spawning in 2017 due to the aufeis. The reason for low recruitment from 2020 to 2022 is unknown but may have to do with the altered background water quality in Mainstem Red Dog Creek.

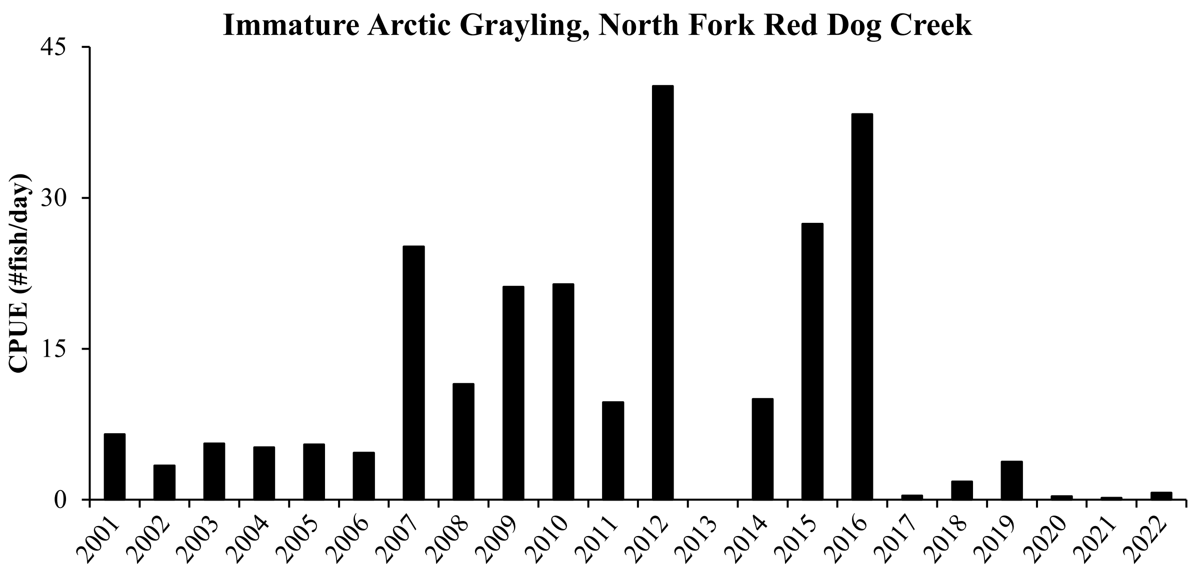


Figure 63. CPUE of immature Arctic grayling in North Fork Red Dog Creek fyke net during spring sampling. Sampling was not conducted in 2013 due to high water.

Catches of mature Arctic grayling in North Fork Red Dog Creek have been more stable than catches of immature fish since 2001, although catches from 2019 – 2022 were generally lower than previous years (Figure 64). The highest CPUE of mature fish was 37.6 fish/day in 2007 and the lowest was 1.3 fish/day in 2014. Most of the variability in the catches is related to temporal variability in spring breakup, warming water temperatures, and sampling efficiency. Sampling events are limited to times of lower discharge ($\leq$ 100 cfs) when fyke nets can be safely set, maintained, and fished effectively.

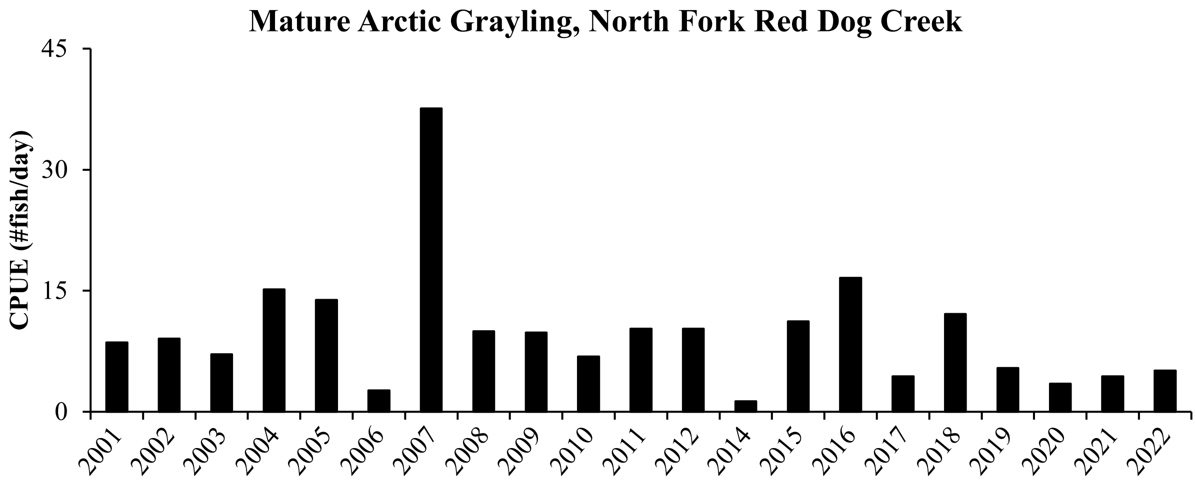


Figure 64. Average CPUE (fish/day) of mature ("ripe" or "spent") Arctic grayling in North Fork Red Dog Creek from spring 2001 – spring 2022. Sampling was not conducted in 2013 due to high water.

The mean size of captured Arctic grayling in North Fork Red Dog Creek in 2022 was 376 mm FL. Sizes ranged from 235 mm FL to 450 mm FL (Figure 65). Only fish over 200 mm FL were tagged.

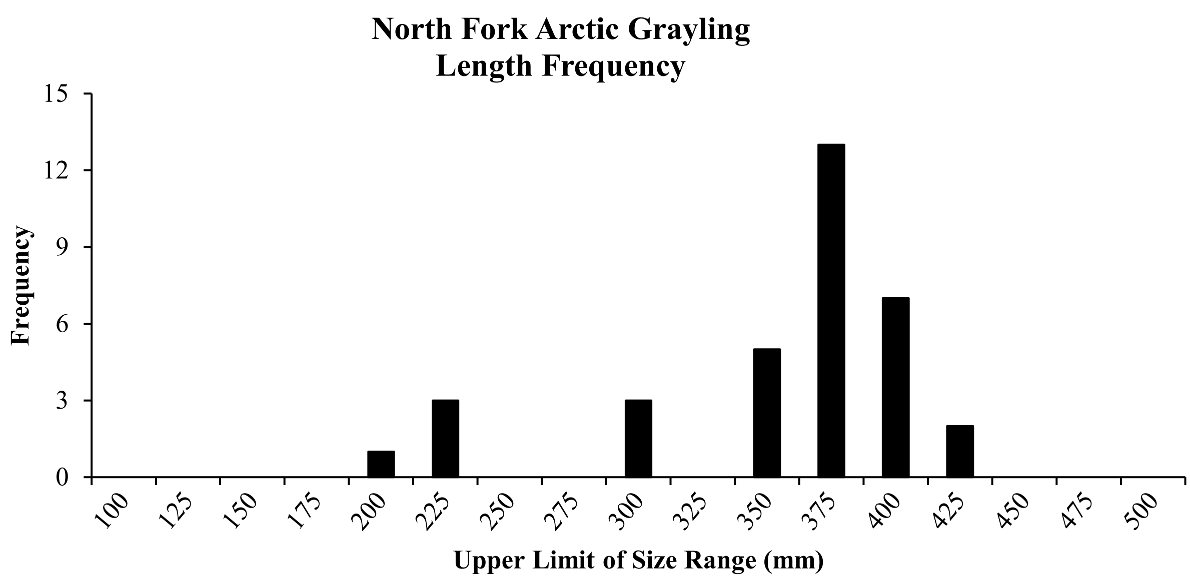


Figure 65. Length frequency distribution of Arctic grayling (n = 34) in North Fork Red Dog Creek, spring 2022.

The average growth rate (mm/year) for Arctic grayling at least 250 mm FL when marked and at large for about one year is presented in Figure 66. Fish growth data includes only those fish captured the previous year and recaptured the following spring. Recapture numbers in any given year are low (0 to 7 fish per year), and no fish from the 2021 season were recaptured in 2022.

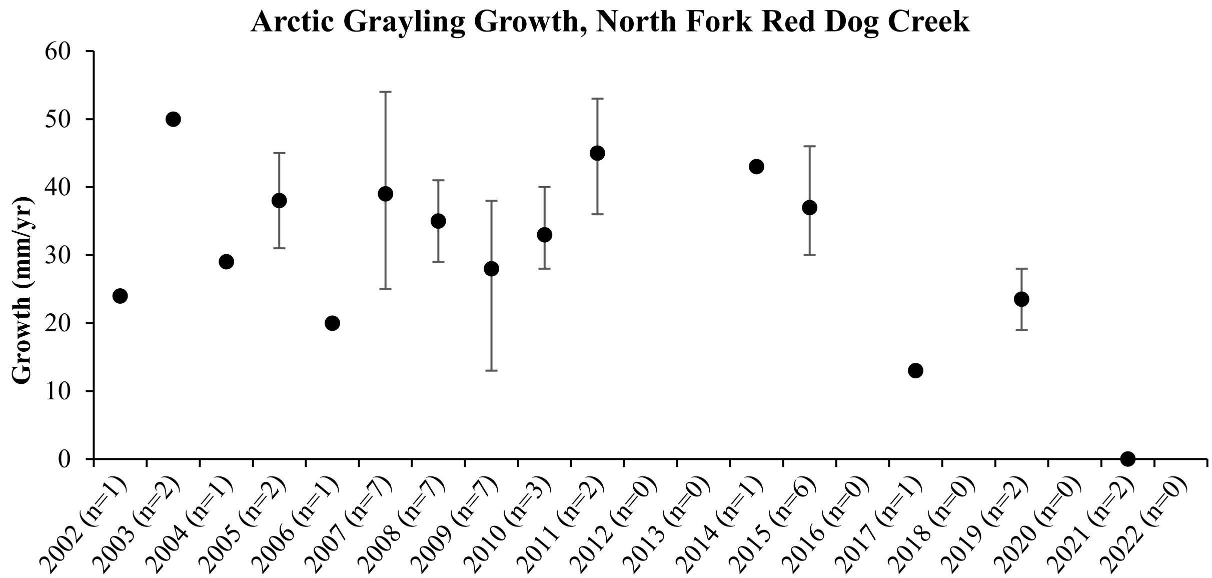


Figure 66. Average, maximum, and minimum annual growth of Arctic grayling in North Fork Red Dog Creek for fish at least 250 mm FL when marked.

Sometimes Arctic grayling are caught in the North Fork Red Dog Creek that were originally tagged in Bons Pond. These fish leave Bons Pond over a waterfall, make their way downstream to Ikalukrok Creek and upstream to Red Dog Creek. Bons Pond tagged fish were caught every year from 2007 to 2012, but only intermittently since then. No Bons Pond tagged fish have been captured in North Fork Red Dog Creek since 2018 when two were captured.

The population of Arctic grayling in North Fork Red Dog Creek, pre-mining, is not known. The highest population estimate post-mining was 1,422 fish ≥ 200 mm FL in 2010 and the lowest estimate was 905 fish ≥ 200 mm FL in 2015 (Figure 67). Confidence limits overlap for the population estimates suggesting that there are no substantial differences among years. There were no recaptures in 2022, so we were unable to perform a population estimate.

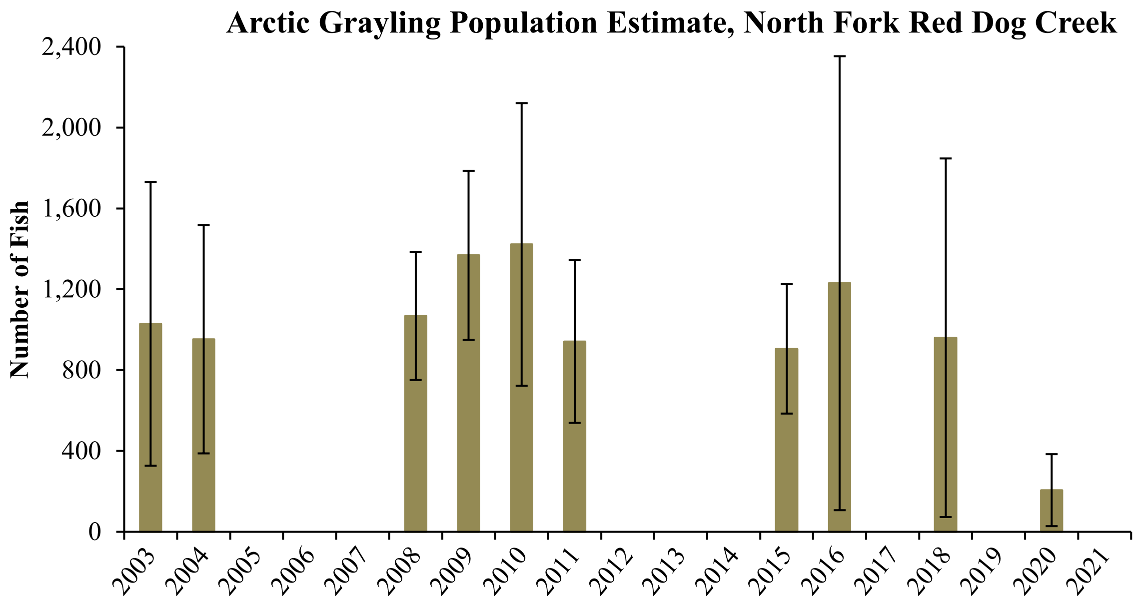


Figure 67. The estimated Arctic grayling population (95% CI) in North Fork Red Dog Creek for fish $\geq$ 200 mm FL.

Arctic Grayling, Bons Pond

Bons Pond is an impoundment created by construction of an earthen dam placed on Bons Creek. Dam construction was completed in 1988 to provide potable and make-up water for operational activities. Prior to construction of the dam, there were no fish present in Bons Creek due to a series of impassable waterfalls and chutes in bedrock about 1 km downstream of the dam (Figure 68). Bons Creek flows into Buddy Creek and eventually into Ikalukrok Creek.

Figure 68. Outlet of Bons Pond – Arctic grayling leaving Bons Pond go over the falls and into Bons Creek.

The Arctic grayling population in Bons Pond is the result of a fish transplant conducted in 1994 and 1995 (Ott and Townsend 2003). In 1994, 102 Arctic grayling from North Fork Red Dog Creek that ranged in size from 158 to 325 mm FL and five Arctic grayling from Ikalukrok Creek (350 to 425 mm FL) were transplanted to Bons Pond. In 1995, about 200 Arctic grayling fry were caught in North Fork Red Dog Creek and moved to Bons Pond.

In 1996 and 1997 visual observations and fyke net sampling in Bons Pond were conducted and no fish were caught or observed. From 1995 to 1997, 12 of the marked Arctic grayling transplanted to Bons Pond were recaptured in North Fork Red Dog Creek. Initially, it was believed that the fish transplant was unsuccessful since no fish were observed in Bons Pond. However, in 2001 and 2002 Arctic grayling juveniles were observed in Bons Creek immediately downstream of the blast road (upstream from Bons Pond). In summer 2003, fish sampling was conducted in Bons Pond to determine fish use and the estimated Arctic grayling population was 6,773 fish ≥ 200 mm FL (Ott and Townsend 2003).

Since 2003, Bons Pond and Bons Creek have been sampled in the spring with additional sampling later in the ice-free season to increase the number of marked fish and catch juveniles for element analysis, as needed. Spawning has been observed in Bons Creek and in the outlet of Bons Pond. The current program in Bons Pond includes a mark/recapture study to estimate the population size and the collection of 15 juvenile Arctic grayling for whole body element analysis.

Bons Creek, upstream of Bons Pond, is incised with streambanks vegetated with willows and sedges, and measures 1 to 2 m wide with depths from 0.3 to 1 m. In the sample reach, located about 200 m upstream of Bons Pond, the substrate consists of gravel in riffles, with fine sediments and organics in the pools.

A diversion ditch was constructed in 1997 to carry surface water around the overburden stockpile. Thermal and hydraulic erosion in the diversion ditch contributes seasonally to the sediment and organic load in Bons Creek. Most of the Bons Creek drainage area is in ice-rich permafrost with thermal erosion and sediment/organic input that varies with seasonal conditions. Generally, there is a high input of sediments and organics to Bons Creek, particularly during rainfall events.

A fyke net fished in Bons Creek from June 3 – June 9, 2022 caught 40 unique Arctic grayling of taggable size, plus 20 fish too small to tag (< 200 mm FL). A fyke net set in the outlet of Bons Pond captured an additional 53 Arctic grayling of taggable size and 20 juvenile Arctic grayling < 200 mm FL, and a third net set in Bons Pond by the pumphouse caught seven Arctic grayling of taggable size and 154 juvenile Arctic grayling < 200 mm FL. Of the 100 fish total that were ≥ 200 mm FL, 53 were recaptures and 47 were tagged.

The mean CPUE (#fish/day) for all fish in the Bons Creek fyke net in 2022 was 11 (Figure 69). The CPUE for Arctic grayling < 200 mm FL in the Bons Creek fyke net in 2022 was 3 (Figure 70). The CPUE for small grayling has been variable over the sample years, ranging from 1 fish/day in 2009 and 2018 to a high of 69 fish/day in 2021.

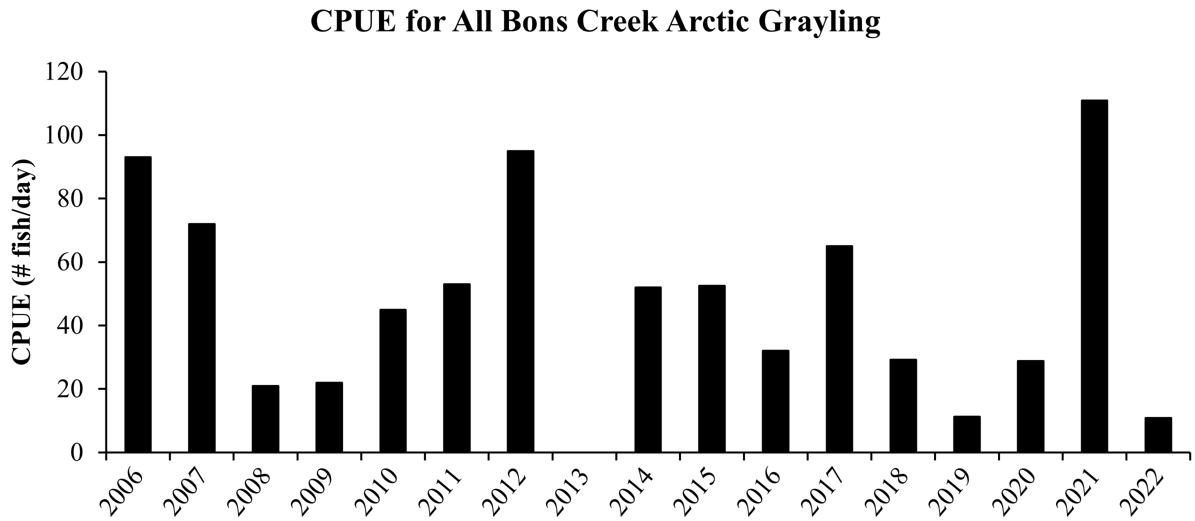


Figure 69. CPUE for all Arctic grayling in Bons Creek 2006 – 2022. Sampling was not done in 2013 due to high water.

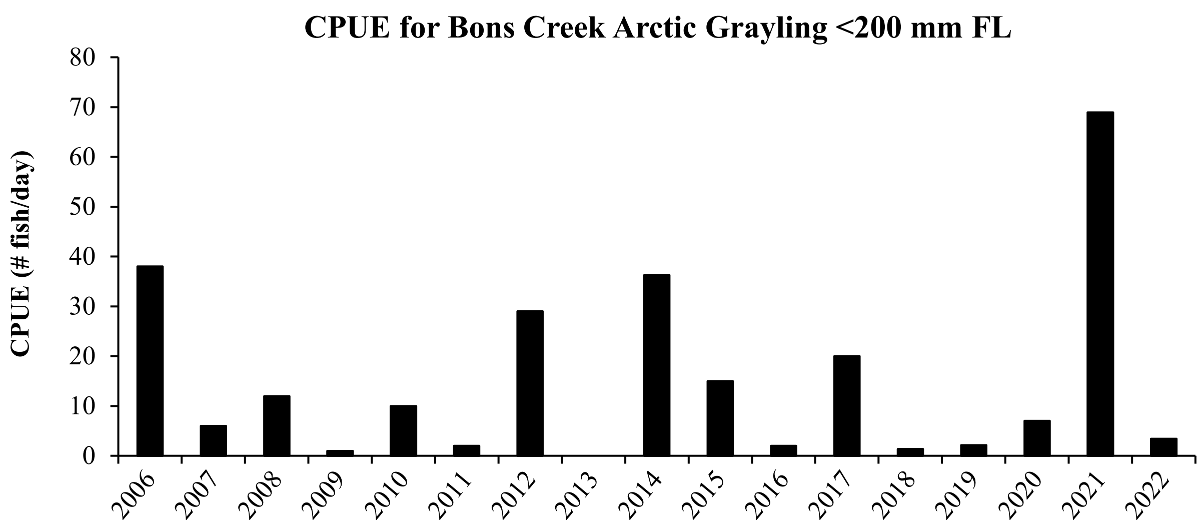


Figure 70. CPUE for Arctic grayling < 200 mm FL in Bons Creek 2006 – 2022. Sampling was not done in 2013 due to high water.

The length frequency distribution for Arctic grayling caught in all three fyke nets in spring 2022 is presented in Figure 71. The length frequency distribution in Bons Pond fish has been relatively consistent over the past several years, with a stable population of mature fish 300 – 390 mm. In 2019, many fish 50 – 100 mm (n = 3,873) were captured, which were likely age-1 fish. This strong age cohort was seen in subsequent sampling in 2020 and 2021, but was virtually absent in the 2022 sampling. Since size selective mortality for fish 200 – 250 mm FL is unlikely, these fish were either not captured or left Bons Pond over the waterfall. Numerous Arctic grayling in this approximate size range were observed in Bons Creek downstream of the waterfall during July periphyton and aquatic invertebrate sampling.

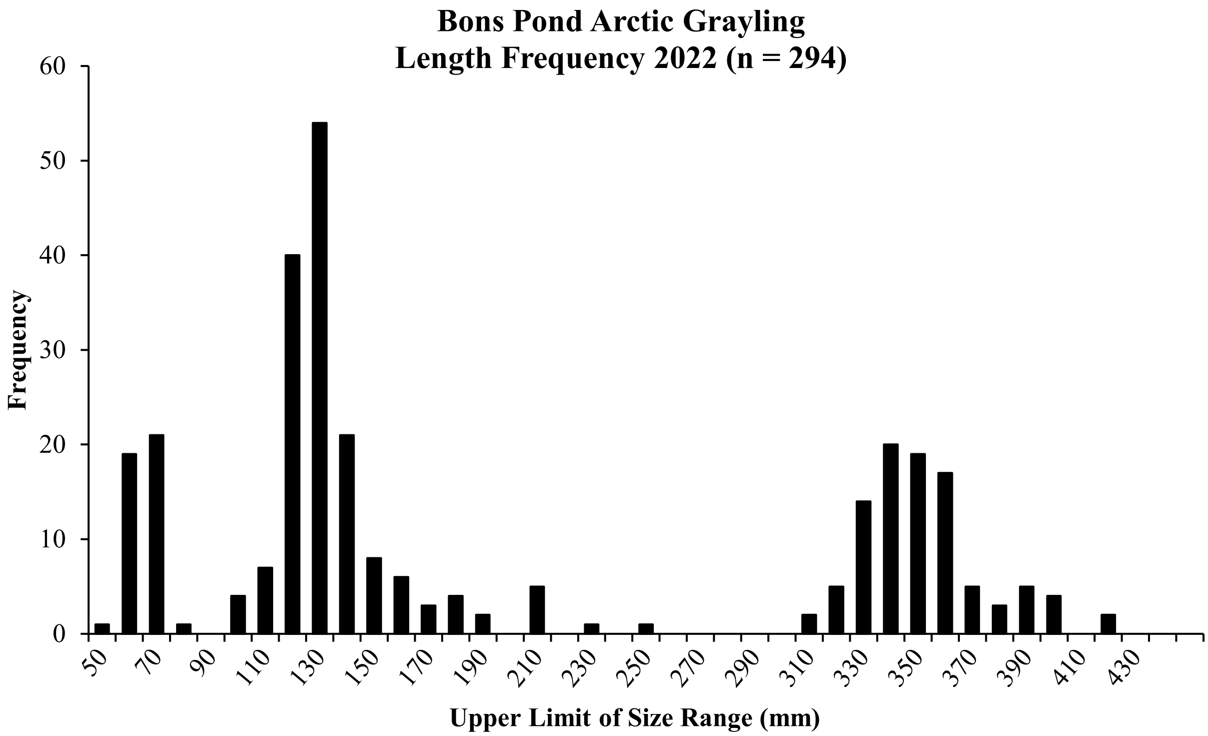


Figure 71. Length frequency distribution of Arctic grayling from Bons Pond and Bons Creek in spring 2022.

Growth rates for Arctic grayling from Bons Pond were lower historically than for comparable sized fish from North Fork Red Dog Creek, however growth rates in Bons Pond fish have been higher from 2013 to present. Only growth data for fish ≥ 250 mm FL (at the time of marking) are presented as there are very few recaptures of marked fish from 200 to 249 mm FL (Figure 72). The average annual growth rate was 35 mm in 2021, the highest rate observed since sampling began in 2003. Higher growth rates in most years since 2011 could be related to the population decline which has resulted in decreased competition and increased food availability (Figure 73).

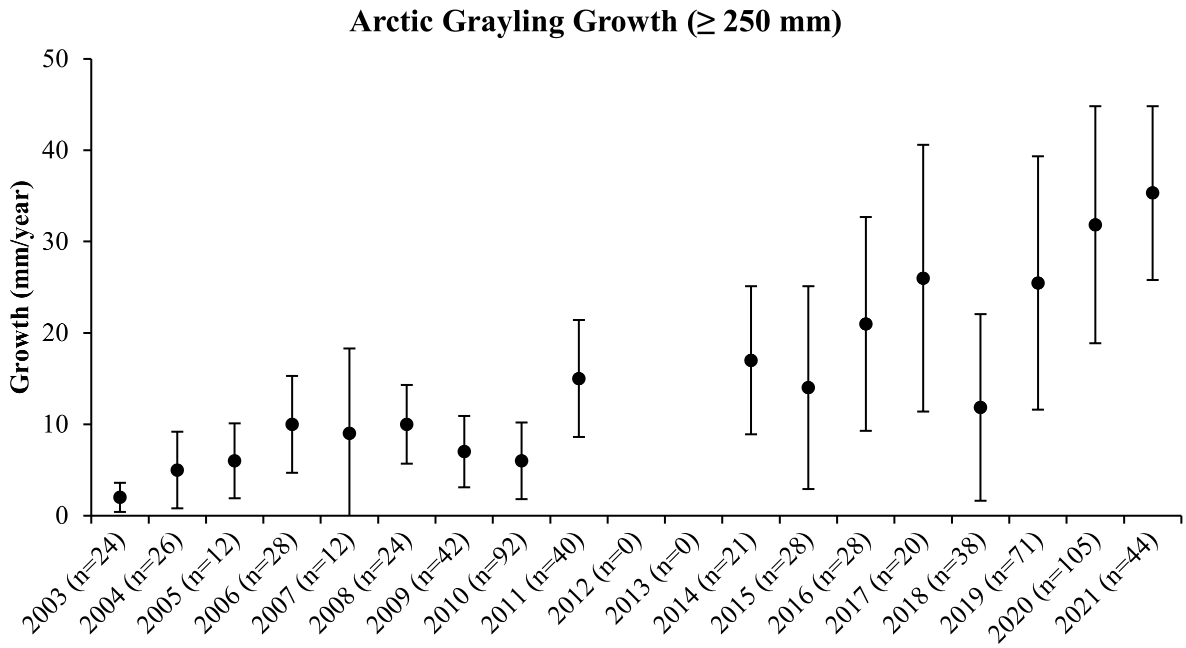


Figure 72. Average annual growth (+ 1 SD) of Arctic grayling ≥ 250 mm FL at time of marking.

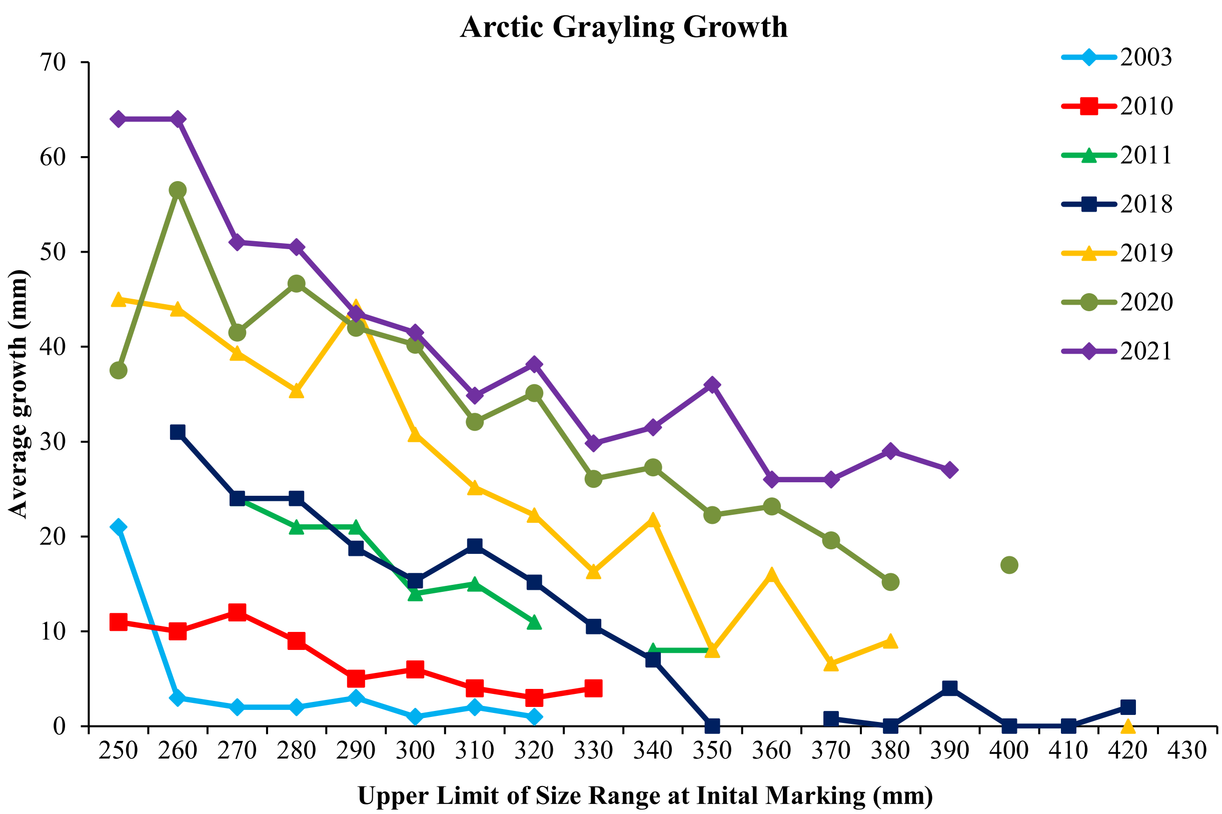


Figure 73. Bons Pond Arctic grayling annual growth rates by size class for select years from 2003 – 2022.

The 2021 Arctic grayling population in Bons Pond was estimated by using 2021 as the mark event (n = 360) and spring 2022 as the recapture event (n = 94). The 2022 recapture number does not include fish less than 250 mm FL, as they were likely too small to tag in 2021. In spring 2022, 45 of the fish were recaptures from the spring 2021 mark event. Based on these values, the estimated Arctic grayling population for 2021 was 747 fish (95% CI, 603 to 890 fish) ≥ 200 mm FL, very similar to the estimated 2020 population of 716 fish (Figure 74).

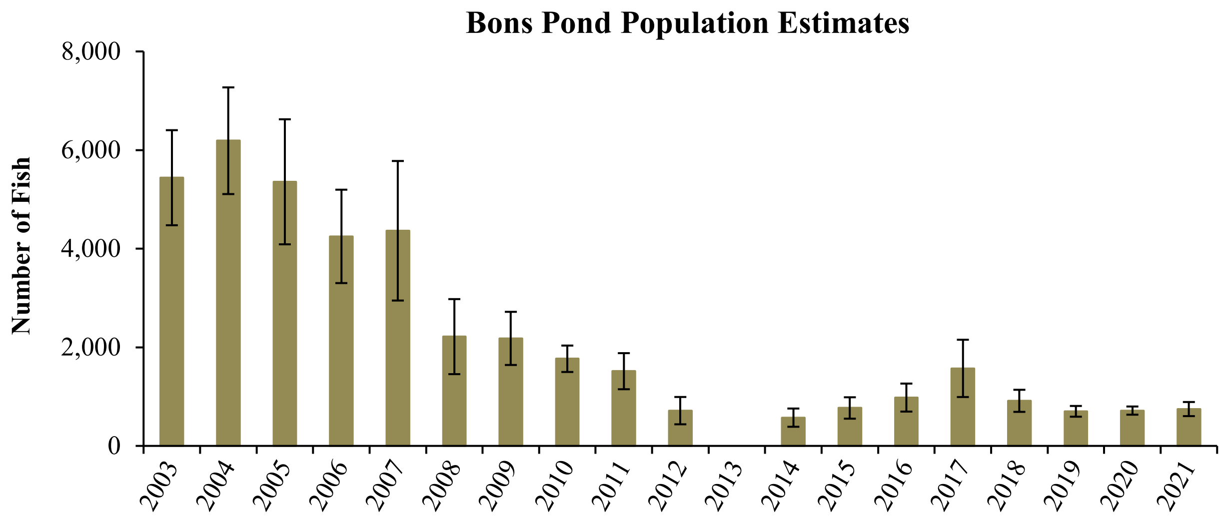


Figure 74. Estimated Arctic grayling population (95% CI) in Bons Pond for fish ≥ 200 mm FL.

Slimy Sculpin

Prior to development of the Red Dog Mine, Houghton and Hilgert (1983) found slimy sculpin in Ikalukrok and Dudd creeks, but none were observed or caught in the Red Dog Creek drainage. However, in 1995, slimy sculpin were captured in both Mainstem Red Dog and North Fork Red Dog creeks (Weber Scannell and Ott 1998). In some years slimy sculpin are caught in North Fork Red Dog Creek during the spring Arctic grayling sampling event with fyke nets and are likely following the Arctic grayling to feed on their eggs. No slimy sculpin were caught in the fyke nets in 2020 - 2022.

The number of slimy sculpin caught in minnow traps during the August sampling event in lower Mainstem Red Dog Creek is presented in Figure 75. There is no apparent trend with CPUE (number of fish caught in 10 traps per 24 hour period) which ranges from zero in multiple years to a high of 8 in 2018 (Figure 75).

Slimy sculpin CPUE in Ikalukrok Creek has varied from a low of 0 in multiple years to a high of 24 in 2004 (Figure 75). Catches of slimy sculpin are generally higher in Ikalukrok Creek than in the other sample reaches located in North Fork Red Dog, Mainstem Red Dog, upper Ikalukrok (Station 9), Buddy, Anxiety, and Evaingiknuk creeks. These data are consistent with findings by Houghton and Hilgert (1983) in the early 1980s prior to development of the Red Dog Mine when they reported slimy sculpin to be numerous in Ikalukrok Creek. The main difference is that slimy sculpin are now also captured in the Red Dog Creek drainage. Catches of slimy sculpin were low at all sample sites in 2022. Eight slimy sculpin were captured, an increase from the four sculpin captured in 2021 (Figure 76).

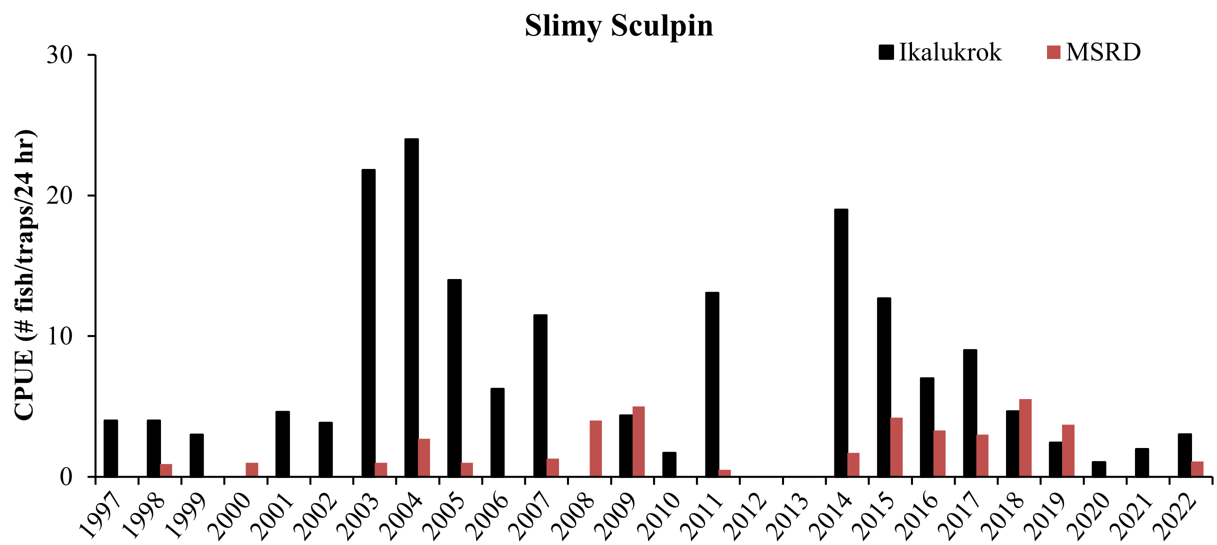


Figure 75. CPUE of slimy sculpin caught in Ikalukrok Creek (Sta 160) and Mainstem Red Dog Creek (Sta 10). No sampling was performed in 2012 or 2013 due to high water.

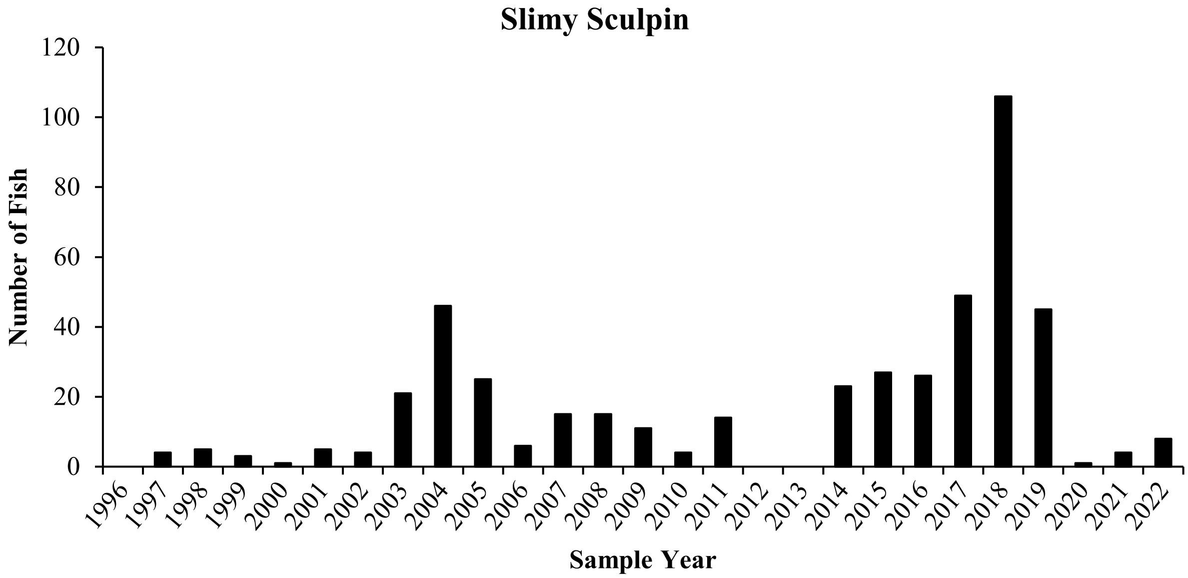


Figure 76. Number of slimy sculpin captured at all seven sample sites in the Ikalukrok Creek drainage, including Red Dog, Buddy, and Anxiety Ridge creeks.

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Appendix 1. Summary of Red Dog Mine Development and Operations, 2014-2022.[a]

2014

- Technical Report No. 14-02 titled "Aquatic biomonitoring at Red Dog Mine, 2013 National Pollution Discharge Elimination System Permit (NPDES) No. AK-003865-2" was submitted to EPA and ADEC on February 28, 2014.
- April 8, ADEC issued a modification to the APDES Permit (AK0038652) which authorized a mixing zone for selenium and adjusted Outfall 001 effluent limits for selenium. The modification became effective on May 8, 2014.
- Discharge through Outfall 001 to Middle Fork Red Dog Creek began on May 1, 2014 and ended on September 20, 2014.
- May 5, TDS concentrations at Station 151 as measured with a conductance probe exceeded the TDS limit of 1,500 mg/L – measures will be implemented (during episodic freezing conditions conductance probes will be removed and washed and checks will be made with calibrated, hand-held instruments).
- May 28, ice buildup in the clean water bypass culvert caused water to overflow. The water was collected and pumped back into the creek for about 24 hr until it was determined that it may have mixed with mine contact water. Pumping was then diverted to the mine water drainage containment system. Water quality changes downstream during this 24 hr period were undetectable at monitoring stations.
- A DIDSON® side-scanning sonar was operated in the lower Wulik River from May 30 to June 6 – over this time period 229 fish moved downstream and 52 moved upstream – water remained high and turbid during the entire sample period.
- June 5, Teck filed a court report stating that it was exercising their option not to build a pipeline to the coast.
- The spring spawning migration of Arctic grayling in Bons Pond/Bons Creek and North Fork Red Dog Creek was sampled from June 7 to 16. Adult Dolly Varden were collected for metals analyses in tissues and adult Arctic grayling were retained from Bons Creek for selenium analysis of ovaries.
- July 26 to August 2, periphyton, aquatic invertebrate, and juvenile fish sampling was done at all nine sites in accordance with permit requirements. In addition, aquatic biomonitoring was conducted in Volcano, Competition, Sourdock, and Upper North Fork Red Dog creeks.
- Two aerial surveys of Dolly Varden in the Wulik River were flown (September 21 and October 7, 2014). The chum salmon survey in Ikalukrok Creek also was done on September 21. Radio-tags were placed in 15 adult Dolly Varden in the Wulik River – these fish will be monitored next year during the spring outmigration.
- December 1, DNR administratively extended the Final Reclamation Plan approval (F20099958) to July 2, 2015.

[a] The summary of previous years of mine development and operations (1982 to 2013) can be found in Ott and Morris 2014.

2015

- January 6, ADF&G by email indicated that we would be willing to assume regulatory oversight over Teck's maintenance of the fish weir on Middle Fork Red Dog Creek.
- January 22, ADF&G by letter reported a summary of selenium data (ovaries and livers) collected on Arctic grayling females at the Red Dog Mine, Fort Knox Mine, and from the Chena River near Fairbanks.
- February 10, Habitat (Parker Bradley) gave a presentation at the Alaska Center for the Environment Forum in Anchorage on biomonitoring at Red Dog, Fort Knox, and Greens Creek.
- Technical Report No. 15-01 titled "Aquatic biomonitoring at Red Dog Mine, 2014 Alaska Pollution Discharge Elimination System Permit (APDES) No. AK00038652" was submitted to EPA and ADEC.
- Discharge through Outfall 001 to Middle Fork Red Dog Creek began on May 12 and ended on September 19.
- April 21, ADF&G by letter proposed to collect Arctic grayling females in Fish Creek (Fort Knox Mine) and at several sites (North Fork Red Dog, Bons, and Tutak creeks) near the Red Dog Mine and have the ovaries analyzed for selenium.
- A DIDSON® side-scanning sonar was operated in the lower Wulik River from May 30 to June 13 – over this time period 26,613 fish moved downstream and 26,577 moved upstream, with much milling behavior observed.
- The spring spawning migration of Arctic grayling in Bons Pond/Bons Creek and North Fork Red Dog Creek was sampled from May 28 to June 3. Adult Dolly Varden were collected for metals analyses in tissues and adult Arctic grayling were retained from Bons, North Fork Red Dog, and Tutak creeks for selenium analysis of ovaries.
- June 30, the fish protection barrier on Middle Fork Red Dog Creek was inspected by Teck
- July 9 - 12, periphyton and aquatic invertebrate sampling was done at all nine sites in accordance with permit requirements. In addition, aquatic biomonitoring was conducted at seven sites near the Anarraaq Prospect and at one site in Upper North Fork Red Dog creek.
- July 29 - August 3, juvenile fish sampling was done at all nine sites in accordance with permit requirements. In addition, juvenile fish sampling was conducted at seven sites near the Anarraaq Prospect.
- September 13 and 15, two aerial surveys were conducted: one on the Wulik River and the second on Ikalukrok Creek. The estimated number of Dolly Varden in the Wulik River was 71,484. The estimated number of chum salmon in Ikalukrok Creek was 5,733.
- September 30, DNR by letter extended the approval of the Red Dog Mine Reclamation Plan.
- October 22, ADF&G by letter provided a summary of Wulik River and Ikalukrok Creek aerial surveys for Dolly Varden and chum salmon.
- November 18, ADF&G by letter provided a copy of the report titled "Red Dog Mine June 2015 Wulik River Dolly Varden Enumeration Report" that summarized work done by Sport Fish Division in spring 2014 and 2015.

2016

- Technical Report No. 16-01 titled "Aquatic biomonitoring at Red Dog Mine, 2015 Alaska Pollution Discharge Elimination System Permit (APDES) No. AK00038652" was submitted to EPA and ADEC on February 27.
- April 15, ADF&G, by letter, submitted the work plan for fish and aquatic taxa studies to be conducted from July 1, 2016 to June 30, 2017.
- Discharge through Outfall 001 to Middle Fork Red Dog Creek began on May 1 and ended on September 24.
- The spring spawning migration of Arctic grayling in Bons Pond/Bons Creek and North Fork Red Dog Creek was sampled from May 18 to 23. Adult Dolly Varden were collected for element analyses in tissues and adult Arctic grayling were retained from Bons and North Fork Red Dog creeks for selenium analysis of ovaries.
- July 2 to 5, periphyton and aquatic invertebrate sampling were done at all nine sites in accordance with permit requirements. In addition, aquatic biomonitoring (periphyton and aquatic invertebrates) was conducted at several sites near the Anarraaq Prospect and at one site in Upper North Fork Red Dog creek.
- August 4 to 7, juvenile fish sampling using minnow traps was conducted at all the APDES sample sites and at sites located in the vicinity of the Anarraaq Prospect.
- September 28, DNR issued the reclamation plan approval.
- September 28, Teck, by letter, submitted their field inspection of the Fish Protection Barrier on Middle Fork Red Dog Creek.
- Aerial surveys for Dolly Varden and chum salmon were conducted in September and October. Chum salmon numbers (live and dead) in Ikalukrok Creek were estimated at 913 fish on September 15. The total count of Dolly Varden in the Wulik River was 56,818 in September and 70,802 in October.

2017

- February 8, ADEC notified Teck that the aquatic biomonitoring report for 2016 data deadline was extended to May 15.
- March 17, ADF&G by email provided comments regarding operation of a new water treatment plant for the construction camp.
- March 21, ADF&G by email asked questions about an ore spill in the vicinity of Buddy Creek.
- May 7, discharge through Outfall 001 to Middle Fork Red Dog Creek began, ended on September 23.
- May 15, ADF&G emailed Technical Report No. 17-07 “Aquatic Biomonitoring at Red Dog Mine, 2016” to DEC.
- May 23, ADF&G by email provided input to Teck regarding the expansion of the waste rock dump to the south – recommendation was to stay north of Bons Creek making sure a buffer remained.
- May 28 - June 4, the spring spawning migration of Arctic grayling in Bons Pond/Bons Creek and North Fork Red Dog Creek was sampled. Adult Dolly Varden were collected for element analyses in tissues and adult Arctic grayling were retained from Bons and North Fork Red Dog creeks for selenium analysis of ovaries.
- The spring sampling effort for Arctic grayling also included Little Creek, a Tutak River tributary). Little Creek was added as a sample site for female Arctic grayling as North Fork Red Dog Creek was completely inundated with aufeis.
- June 8, DNR by email notified the COE that changes to state permits (DNR and DEC) would be required for expansion of the waste rock storage facility.
- July 10, Teck notified ADF&G by letter of snow/ice work at bridges and culverts conducted during spring.
- July 2 - 5, periphyton and aquatic invertebrate sampling were done at all nine sites in accordance with permit requirements. In addition, aquatic biomonitoring (periphyton and aquatic invertebrates) was conducted at several sites near the Anarraaq Prospect and at one site in Upper North Fork Red Dog creek.
- July 12, ADF&G by email provided input to Teck regarding access, exploratory road, to the Anarraaq and Aktigiruq prospects which involves multiple stream crossings of Ikalukrok Creek and one crossing of North Fork Red Dog Creek.
- July 27, a drill cuttings spill was reported near Barb Creek.
- July 28, ADEC issued the new APDES permit (AK0038652) for discharge of water at Outfall 001 to Middle Fork Red Dog Creek, effective September 1, 2017.
- August 2 - 9, juvenile Dolly Varden sampling performed at all the APDES sample sites and sites located in the vicinity of the Anarraaq/Aktigiruq prospect. Water levels at all sites were unusually high.
- October 2, DeCicco provided a summary of aerial surveys for Dolly Varden in Wulik River and chum salmon in Ikalukrok Creek and he collected seven adult Dolly Varden for tissue analyses.
- October 30, ADF&G by email to DEC distributed Technical Report 17-09 titled “Methods for Aquatic Life Monitoring at the Red Dog Mine Site” to satisfy a condition in the new APDES permit issued by ADEC.

2018

- January 9, ADF&G by email provided comments to ADNR regarding material extractions at Red Dog MS-9 and Red Dog DD-2.
- April 25, ADF&G by email provided information to Teck on mercury in fish tissues in regard to human consumption.
- May 7, ADF&G by email transmitted Technical Report No. 18-06 "Aquatic Biomonitoring at Red Dog Mine, 2017" to DEC.
- May 15, Teck received approval from DNR-Dam Safety Unit to increase nominal crest elevation of the Tailings Back Dam by 10 feet from 986 feet to 996.5 feet.
- June 12-18, the spring spawning migration of Arctic grayling in Bons Pond/Bons Creek and North Fork Red Dog Creek was sampled. Adult Dolly Varden were collected for element analyses in tissues and adult Arctic grayling were retained from Bons and North Fork Red Dog creeks for selenium analysis of ovaries.
- June 25, ADNR DMLW issued Red Dog Mine Reclamation Plan Amendment Approval F20169958.01 (RPA) to expand the Tailings Storage Facility and Main Waste Dump.
- July 13, ADNR DMLW issued a Certificate of Approval to Modify a Dam to Teck for the Stage XI raise on the Red Dog Tailings Main Dam (NID ID# AK00201).
- July 9 - 16, periphyton and aquatic invertebrate sampling were done at all nine sites in accordance with permit requirements. In addition, aquatic biomonitoring (periphyton and aquatic invertebrates) was conducted at sites near the Anarraaq Prospect and at one site in Upper North Fork Red Dog creek.
- August 1, Teck issued a memo regarding orange precipitate in Red Dog Creek caused by two natural metal seeps above the diversion system.
- August 13, Teck issued a 5-day notification letter to ADEC explaining the cause of the exceedance of allowed TDS values at Station 151.
- August 2 - 9, juvenile Dolly Varden sampling performed at all the APDES sample sites and sites located in the vicinity of the Anarraaq/Aktigiruq prospect.
- October 4 - 5, ADF&G and DeCicco conducted aerial surveys for Dolly Varden in Wulik River and chum salmon in Ikalukrok Creek and collected seven adult Dolly Varden for tissue analyses.

2019

- January 25, ADF&G issued a memo about the elevated zinc concentrations observed in Red Dog Creek during open water, 2018.
- April 16, ADF&G issued a memo regarding inconsistent mercury results in 2018 adult Dolly Varden tissues from ACZ labs.
- May 7, ADF&G by email transmitted Technical Report No. 19-08 “Aquatic Biomonitoring at Red Dog Mine, 2018” to DEC.
- May 3, Golder Associates Inc. issued technical memorandum “Assessment of Increasing Zinc Concentration in Red Dog Creek and Tributaries.”
- May 13, discharge through Outfall 001 to Red Dog Creek was initiated under APDES Permit #AK0038652.
- June 6 - 15, the spring spawning migration of Arctic grayling in Bons Pond/Bons Creek and North Fork Red Dog Creek was sampled. Adult Dolly Varden were collected for tissue element analyses and adult Arctic grayling were retained from Bons and North Fork Red Dog creeks for selenium analysis of ovaries.
- July 1 - 8, periphyton and aquatic invertebrate sampling was done at all ten sites in accordance with permit requirements. In addition, aquatic biomonitoring (periphyton and aquatic invertebrates) was conducted at 12 sites near the Anarraaq Prospect.
- July 9 – 11, DNR, DEC, and ADF&G personnel conducted a multi-agency site visit to review current Red Dog operations and future expansion plans of the mine site and exploration for Anarraaq and Aktigiruq deposits.
- August 2, DEC sent a letter to Teck pertaining to Tundra Restoration in response to oil and hazardous materials spills.
- August 3 – 10, juvenile Dolly Varden sampling performed at all the APDES sample sites and sites located in the vicinity of the Anarraaq/Aktigiruq prospect.
- August 21, DNR Dam Safety issued a letter regarding survey control at Red Dog Mine. The maximum allowed operating pond was revised to nominal 980 feet pending additional detailed survey and modification for the Stage XI dam raise.
- August 23, DEC issued a temporary waiver of the Secondary Containment Requirement for the Teck Alaska Inc. Red Dog Operations Oil Discharge Prevention and Contingency Plan (ADEC Plan #17-CP-3050).
- September 10, discharge from Outfall 001 was halted for the year due to elevated TDS at Station 160. Discharge was also limited in August due to elevated TDS.
- September 20, DeCicco conducted aerial surveys for Dolly Varden in the Wulik River and chum salmon in Ikalukrok Creek, but could not complete the surveys due to high turbidity in Ikalukrok Creek and the Wulik River. Seven adult Dolly Varden were collected from the Wulik River for tissue analyses.
- October 13 – 14, ADF&G conducted aerial surveys for Dolly Varden in Wulik River, but could only obtain an incomplete count due to high turbidity in Ikalukrok Creek and the Wulik River.
- November 1, Teck ceased backfilling of the exhausted Main Pit to prevent 50-60 million gallons of water from being pumped into the Tailings Storage Facility (TSF).
- November 4, ADF&G submitted a nomination to add coho rearing in Red Dog, Anxiety Ridge, Buddy, Dudd, and Ikalukrok creeks to the Anadromous Waters Catalog.

- November 23, Teck commenced construction and installation of a reverse flow pumping system to direct reclaimed and seepage water to the Aqqaluk Pit. Aqqaluk Pit will store between 150-300 million gallons of water.
- December 12, DNR issued Temporary Water Use Authorization F2019-134 for Teck to pump 70 million gallons of water from the TSF and impound and freeze the water into ice cells/ice fields upgradient of the TSF. Once weather warms in the summer season this ice will melt and will flow or be pumped back into the TSF.

2020

- January 8, Golder Associates Inc. issued "Summary Report of Zinc Concentrations, Red Dog Creek and Tributaries."
- February 14, DNR Amendment 3 to Reclamation Plan F20169958 to amend the closure design of the Main Waste Stockpile from an engineered compacted soil cover to a geosynthetic liner and cover design.
- February 19, DEC-Water issued addendum 2 to APDES Permit AK0038652 after determining that commissioning of a Reverse Osmosis Water Treatment Facility would have no or de minimis impacts to wastewater discharge.
- February 28, Teck submitted the Stage XIA Interim Dam Raise Design Report to DNR-Dam Safety.
- April 27, insulating cover rock placed over the regraded Qanaiyaq 1500' level to help address Kaviqsaaq Seep drainage.
- May 8, DNR issued Entry Authorization ADL 725670, authorizing tailings placement in the Millsite Lease Area.
- May 10, discharge through Outfall 001 to Red Dog Creek initiated under APDES Permit Number AK0038652.
- May 19, DNR-Dam Safety issued Certificate of Approval to Modify a Dam FY2020-23-AK00201 authorizing Teck to raise the nominal crest elevation of the Tailings Main Dam to 991 feet.
- May 19, Reverse Flow Pumping System shut down. Between December 2019 and May 19, 2020, 397 million gallons of reclaim water were removed from the Tailings Storage Facility with the Reverse Flow Pumping System and temporary winter water storage (TWUA F2019-134).
- May 28, DNR DMLW signed and executed Millsite Lease ADL 233521 for tailings placement.
- May 28, DNR-Mining issued Plan of Operations Approval F20209958POOA.
- June 1 - 9, the spring spawning migration of Arctic grayling in Bons Pond/Bons Creek and North Fork Red Dog Creek was sampled. Adult Dolly Varden were collected for tissue element analyses and juvenile Arctic grayling were retained from Bons Pond for whole body element analysis.
- June 21 - 28, treated water discharge temporarily halted due to increased background total dissolved solids (TDS) and decreased stream flow.
- July 6 - 11, periphyton and aquatic invertebrate sampling was done at all ten sites in accordance with permit requirements. In addition, aquatic biomonitoring (periphyton and aquatic invertebrates) was conducted at 9 sites near the Anarraaq Prospect.

- July 6, treated water discharge halted due to increased background total dissolved solids (TDS) and decreased stream flow.
- July 10, DEC-Water issued minor modification to APDES Permit No. AK0038652, adding end of pipe TDS limits to Outfall 001 when naturally occurring in-stream TDS encroaches on the permitted in-stream TDS limit at Stations 150 and 160.
- August 1 – 6, juvenile Dolly Varden sampling performed at all the APDES sample sites and sites located in the vicinity of the Anarraaq/Aktigiruq prospect.
- August 7, DEC-Water issued Installation Approval for the Reverse Osmosis wastewater treatment plant.
- August 26, discharge initialized from the Reverse Osmosis water treatment system.
- September 13, DeCicco and ADF&G conducted aerial surveys for Dolly Varden in the Wulik River and chum salmon in Ikalukrok Creek. Seven adult Dolly Varden were collected from the Wulik River for tissue analyses.
- September 22, DNR-Dam Safety issued Temporary Certificate of Approval to Operate a Dam FY2021-3-AK00201 for the Tailings Main Dam, and Temporary Certificate of Approval to Operate a Dam FY2020-4-AK00303 for the Tailings Back Dam.
- September 26, discharge halted for the season. Approximately 870 million gallons were discharged into Red Dog Creek from Outfall 001 under APDES Permit No. AK0038652.
- October 5 – 8, ADF&G conducted aerial surveys for Dolly Varden in Wulik and Kivalina rivers.

2021

- February 26, ADEC issued minor amendment to Red Dog Operations Oil Discharge Prevention and Contingency Plan #17-CP-3050.
- April 4, ADF&G Habitat issued Fish Habitat Permit #FH21-III-0078 for the low water vehicle and equipment crossing on the spillway of Bons Pond.
- April 9, ADNR Water issued Temporary Water Use Authorization F2020-090, authorizing the capture and diversion of the Kaviqsaaq Seep.
- April 30, DNR-Dam Safety issued Certificate of Approval to Operate a Dam FY2021-27-AK00200 for the Water Supply Dam on Bons Creek.
- May 19, discharge through Outfall 001 to Red Dog Creek initiated under APDES Permit Number AK0038652.
- May 19, ADEC issued minor modification to APDES Permit No. AK0038652, adding a TDS Compliance Schedule and Action Items. Specifically, when water in the TSF approaches within 15 feet of the freeboard limit, discharge of high quality treated wastewater is allowed as in the past even though the natural TDS concentration of the receiving water is increasing.
- May 27 – June 3, the spring spawning migration of Arctic grayling in Bons Pond/Bons Creek and North Fork Red Dog Creek was sampled. Adult Dolly Varden were collected for tissue element analyses and juvenile Arctic grayling were retained from Bons Pond for whole body element analysis.
- June 10, diversion of the Kaviqsaaq Seep to the TSF was completed.
- June 22, ADNR issued a 5 year Land Use Permit (LAS 33736) for installation of a radio tower on top of Volcano Mountain.

- July 1 – 10, periphyton and aquatic invertebrate sampling was done at all eleven sites in accordance with permit requirements. In addition, aquatic biomonitoring (periphyton and aquatic invertebrates) was conducted at 13 sites near the Anarraaq Prospect.
- August 5 – 12, juvenile Dolly Varden sampling performed at all the APDES sample sites and sites located in the vicinity of the Anarraaq/Aktigiruq prospect.
- August 23 – September 2, additional juvenile fish sampling and gamete collection for chum salmon and Dolly Varden fertilization tests. Adult Dolly Varden were collected for tissue element analyses.
- September 5 – 6 and 10, Owl Ridge Natural Resource Consultants conducted aerial surveys for chum salmon and Dolly Varden in the Wulik and Kivalina rivers and Ikalukrok Creek.
- September 23, ADNR issued Reclamation Plan Approval No. F20219958RPA, Plan of Operations Approval No. F20219958POOA, and Waste Management Permit No. 2021DB0001.
- September 25, discharge into Red Dog Creek from Outfall 001 was halted for the season. Approximately 1.719 billion gallons were discharged under APDES Permit No. AK0038652**.** 173 million gallons of the discharge was from the RO plant.
- October 6 – 9, ADF&G conducted aerial surveys for Dolly Varden in Wulik and Kivalina rivers.
- November 18, ADNR issued an amendment to Reclamation Plan Approval No. F20219958.01RPA to delay covering a small section of the Main Waste Dump.
- November 29, DNR-Dam Safety issued Certificate of Approval to Operate a Dam FY2022-12-AK00201 for the Tailings Main Dam, and Certificate of Approval to Operate a Dam FY2021-13AK00200 for the Tailings Back Dam.

2022

- January 25, Red Dog Mine 2021 Environmental Audit finalized and published.
- April 1, ADEC approved the routine update for the Red Dog Operations Contingency Plan #17-CP-3050.
- May 9, discharge through Outfall 001 to Red Dog Creek initiated under APDES Permit Number AK0038652.
- May 16, ADNR Dam Safety issued a Certificate of Approval to Modify a Sam for Stage XII of the Red Dog Tailings Main Dam. This approved the construction of the Main Dam to the final elevation of 1,007.4 feet.
- May 17, ADNR Dam Safety issued a Certificate of Approval to Modify a Dam for the Red Dog Tailings Back Dam Stage V Raise.
- June 2 – 9, ADF&G sampled the spring spawning migration of Arctic grayling in Bons Pond/Bons Creek and North Fork Red Dog Creek. Adult Dolly Varden were collected for tissue element analyses and juvenile Arctic grayling were retained from Bons Pond for whole body element analysis. ADF&G assisted Owl Ridge Natural Resource Consultants with Arctic grayling gamete collection for fertilization studies.
- July 7 – 14, ADF&G conducted periphyton and aquatic invertebrate sampling at all 10 sites in accordance with permit requirements. In addition, aquatic biomonitoring (periphyton and aquatic invertebrates) was conducted at 17 sites near the Anarraaq Prospect.
- August 1 – 6, ADF&G performed juvenile Dolly Varden sampling at all the APDES sample sites and sites located in the vicinity of the Anarraaq/Aktigiruq prospect.

- September 23, discharge into Red Dog Creek from Outfall 001 was halted for the season. Approximately 1.725 billion gallons were discharged under APDES Permit No. AK0038652**.**
- September 28, ADF&G issued Fish Habitat Permit FH22-III-0209 for water withdrawal from Bons Reservoir and Bons Creek under Water Right LAS 1453.
- October 1 – 3, ADF&G conducted aerial surveys for Dolly Varden in Wulik and Kivalina rivers.
- December 29, ADNR Water issued water rights for five gravel pit ponds, Middle Fork Red Dog Creek, the Tailings Back Dam, South Fork Red Dog Creek Tailings Storage Facility, Middle Fork Red Dog Creek Bypass, and South Fork Red Dog Creek Bypass.

Appendix 2. Periphyton Standing Crop, Red Dog Mine Monitoring Sites, 2022. Results below the detection limit are shaded in gray.

2022 Chloro Results - Red Dog								
IDL = 0.12 mg/m^2					Linear Check Maximum = 73.12 mg/m^2			
EDL = 0.60 mg/m^2					**Phaeo Corrected**			
Daily Vial #	Site	Date Analyzed	Vial Chl a	Chl a mg/m2	**Chl a mg/m2**	**664/665 Ratio**	Chl b mg/m2	Chl c mg/m2
29	Upper NFRD	12/1/2022	0.18	0.72	0.75	1.78	0.11	0.10
31	Upper NFRD	12/1/2022	0.13	0.54	0.43	1.50	0.13	0.06
33	Upper NFRD	12/1/2022	0.52	2.07	1.82	1.59	0.41	0.13
35	Upper NFRD	12/1/2022	0.40	1.61	1.50	1.64	0.38	0.19
37	Upper NFRD	12/1/2022	0.82	3.29	2.88	1.59	0.54	0.06
39	Upper NFRD	12/1/2022	0.12	0.49	0.43	1.57	0.15	0.07
41	Upper NFRD	12/1/2022	0.39	1.56	1.39	1.59	0.42	0.09
43	Upper NFRD	12/1/2022	0.19	0.76	0.75	1.70	0.18	0.07
45	Upper NFRD	12/1/2022	0.34	1.35	1.17	1.58	0.21	0.05
47	Upper NFRD	12/1/2022	0.25	0.99	0.96	1.69	0.14	0.10
90	Ikalukrok d/s Dudd Sta 160	12/1/2022	0.01	0.05	0.11		0.00	0.09
91	Ikalukrok d/s Dudd Sta 160	12/1/2022	0.01	0.05	0.11		0.00	0.00
92	Ikalukrok d/s Dudd Sta 160	12/1/2022	0.03	0.14	0.21	3.00	0.01	0.05
94	Ikalukrok d/s Dudd Sta 160	12/1/2022	0.00	0.01	0.00		0.00	0.00
95	Ikalukrok d/s Dudd Sta 160	12/1/2022	0.01	0.05	0.11		0.00	0.00
96	Ikalukrok d/s Dudd Sta 160	12/1/2022	0.01	0.04	0.11		0.05	0.06
97	Ikalukrok d/s Dudd Sta 160	12/1/2022	0.01	0.04	0.11		0.05	0.06
98	Ikalukrok d/s Dudd Sta 160	12/1/2022	0.01	0.04	0.11		0.05	0.06
99	Ikalukrok d/s Dudd Sta 160	12/1/2022	0.12	0.46	0.43	1.67	0.00	0.07
101	Ikalukrok d/s Dudd Sta 160	12/1/2022	0.01	0.04	0.11		0.05	0.06
30	Middle Fork Red Dog Sta 20	12/2/2022	0.01	0.04	0.11		0.05	0.06
31	Middle Fork Red Dog Sta 20	12/2/2022	0.02	0.09	0.11	2.00	0.03	0.05
33	Middle Fork Red Dog Sta 20	12/2/2022	0.01	0.04	0.11		0.05	0.06
34	Middle Fork Red Dog Sta 20	12/2/2022	0.02	0.08	0.21		0.10	0.12
35	Middle Fork Red Dog Sta 20	12/2/2022	0.01	0.04	0.11		0.05	0.06
36	Middle Fork Red Dog Sta 20	12/2/2022	0.00	0.00	0.00		0.00	0.00
37	Middle Fork Red Dog Sta 20	12/2/2022	0.00	0.00	0.00		0.00	0.00
38	Middle Fork Red Dog Sta 20	12/2/2022	0.01	0.04	0.11		0.05	0.06
39	Middle Fork Red Dog Sta 20	12/2/2022	0.01	0.04	0.11		0.05	0.06
40	Middle Fork Red Dog Sta 20	12/2/2022	0.01	0.04	0.11		0.05	0.06

					Phaeo Corrected			
Daily Vial #	Site	Date Analyzed	Vial Chl a	Chl a mg/m2	**Chl a mg/m2**	**664/665 Ratio**	Chl b mg/m2	Chl c mg/m2
50	Bons us Buddy Sta 220	12/2/2022	11.07	44.29	37.81	1.56	7.00	2.50
52	Bons us Buddy Sta 220	12/2/2022	10.64	42.57	39.30	1.63	9.29	1.89
56	Bons us Buddy Sta 220	12/2/2022	1.88	7.51	6.19	1.54	0.84	0.39
58	Bons us Buddy Sta 220	12/2/2022	6.09	24.36	18.80	1.49	0.94	2.62
60	Bons us Buddy Sta 220	12/2/2022	9.17	36.67	30.65	1.55	4.17	1.60
62	Bons us Buddy Sta 220	12/2/2022	10.84	43.35	36.53	1.55	5.74	1.79
64	Bons us Buddy Sta 220	12/2/2022	5.73	22.92	17.73	1.49	3.10	1.96
67	Bons us Buddy Sta 220	12/2/2022	9.30	37.20	30.97	1.53	13.84	1.28
69	Bons us Buddy Sta 220	12/2/2022	6.44	25.75	21.89	1.55	6.20	1.18
71	Bons us Buddy Sta 220	12/2/2022	11.25	44.99	35.67	1.50	9.67	2.85
57	Buddy u/s road Sta 221	12/5/2022	1.18	4.73	4.59	1.68	1.31	0.25
59	Buddy u/s road Sta 221	12/5/2022	0.62	2.47	2.35	1.69	0.00	0.29
61	Buddy u/s road Sta 221	12/5/2022	1.13	4.54	4.06	1.61	0.30	0.42
63	Buddy u/s road Sta 221	12/5/2022	0.75	3.01	2.78	1.65	0.00	0.39
65	Buddy u/s road Sta 221	12/5/2022	0.57	2.28	2.14	1.67	0.00	0.22
67	Buddy u/s road Sta 221	12/5/2022	0.65	2.59	2.24	1.58	0.07	0.18
69	Buddy u/s road Sta 221	12/5/2022	0.29	1.14	1.07	1.67	0.00	0.11
71	Buddy u/s road Sta 221	12/5/2022	0.73	2.92	2.67	1.64	0.00	0.30
73	Buddy u/s road Sta 221	12/5/2022	0.62	2.48	2.24	1.62	0.36	0.20
75	Buddy u/s road Sta 221	12/5/2022	0.36	1.45	1.39	1.68	0.07	0.17
97	Bons u/s pond	12/5/2022	0.48	1.91	1.82	1.68	0.10	0.11
99	Bons u/s pond	12/5/2022	0.75	3.01	2.67	1.61	0.04	0.16
101	Bons u/s pond	12/5/2022	0.73	2.92	2.78	1.68	0.00	0.20
103	Bons u/s pond	12/5/2022	0.74	2.95	2.78	1.67	0.13	0.23
105	Bons u/s pond	12/5/2022	0.98	3.92	3.52	1.62	0.00	0.17
107	Bons u/s pond	12/5/2022	0.71	2.82	2.56	1.63	0.05	0.12
109	Bons u/s pond	12/5/2022	1.72	6.89	6.09	1.61	0.00	0.17
111	Bons u/s pond	12/5/2022	2.86	11.45	10.15	1.61	0.48	0.78
113	Bons u/s pond	12/5/2022	1.19	4.77	4.17	1.59	0.28	0.26
115	Bons u/s pond	12/5/2022	6.77	27.08	24.35	1.62	0.00	0.95
3	North Fork Red Dog Sta 12	12/6/2022	0.76	3.05	2.78	1.63	0.10	0.12
5	North Fork Red Dog Sta 12	12/6/2022	0.88	3.50	3.20	1.64	0.11	0.16
7	North Fork Red Dog Sta 12	12/6/2022	0.69	2.76	2.56	1.65	0.23	0.16
9	North Fork Red Dog Sta 12	12/6/2022	0.61	2.46	2.35	1.69	0.07	0.13
11	North Fork Red Dog Sta 12	12/6/2022	0.22	0.87	0.75	1.58	0.00	0.11
13	North Fork Red Dog Sta 12	12/6/2022	0.59	2.36	2.24	1.68	0.19	0.12
15	North Fork Red Dog Sta 12	12/6/2022	0.16	0.64	0.53	1.56	0.00	0.08
17	North Fork Red Dog Sta 12	12/6/2022	0.41	1.64	1.50	1.64	0.00	0.14
19	North Fork Red Dog Sta 12	12/6/2022	0.13	0.50	0.43	1.57	0.00	0.03
21	North Fork Red Dog Sta 12	12/6/2022	0.40	1.60	1.39	1.59	0.02	0.05

					Phaeo Corrected			
Daily Vial #	Site	Date Analyzed	Vial Chl a	Chl a mg/m2	**Chl a mg/m2**	**664/665 Ratio**	Chl b mg/m2	Chl c mg/m2
23	Buddy blw falls	12/6/2022	1.14	4.57	4.06	1.61	0.00	0.28
25	Buddy blw falls	12/6/2022	0.24	0.96	0.85	1.62	0.01	0.07
27	Buddy blw falls	12/6/2022	0.73	2.91	2.56	1.60	0.16	0.14
29	Buddy blw falls	12/6/2022	1.89	7.56	7.05	1.66	0.07	0.77
31	Buddy blw falls	12/6/2022	0.77	3.08	2.78	1.62	0.31	0.22
33	Buddy blw falls	12/6/2022	0.66	2.65	2.46	1.66	0.00	0.24
35	Buddy blw falls	12/6/2022	0.46	1.85	1.71	1.64	0.20	0.09
37	Buddy blw falls	12/6/2022	0.41	1.64	1.50	1.64	0.06	0.21
39	Buddy blw falls	12/6/2022	0.77	3.10	2.88	1.66	0.07	0.21
41	Buddy blw falls	12/6/2022	0.24	0.96	0.85	1.62	0.00	0.17
63	Mainstem Red Dog Sta 10	12/6/2022	0.00	0.00	0.00		0.00	0.00
64	Mainstem Red Dog Sta 10	12/6/2022	0.00	0.00	0.00		0.00	0.00
65	Mainstem Red Dog Sta 10	12/6/2022	0.00	0.00	0.00		0.00	0.10
66	Mainstem Red Dog Sta 10	12/6/2022	0.01	0.05	0.11		0.00	0.09
67	Mainstem Red Dog Sta 10	12/6/2022	0.01	0.04	0.11		0.04	0.16
68	Mainstem Red Dog Sta 10	12/6/2022	0.01	0.05	0.11		0.00	0.09
69	Mainstem Red Dog Sta 10	12/6/2022	0.01	0.04	0.11		0.05	0.06
70	Mainstem Red Dog Sta 10	12/6/2022	0.01	0.05	0.11		0.00	0.09
71	Mainstem Red Dog Sta 10	12/6/2022	0.01	0.04	0.11		0.05	0.06
72	Mainstem Red Dog Sta 10	12/6/2022	0.00	0.00	0.00		0.00	0.00
12	Ikalukrok u/s Red Dog Sta 9	12/7/2022	0.01	0.04	0.11		0.05	0.06
13	Ikalukrok u/s Red Dog Sta 9	12/7/2022	0.00	0.00	0.00		0.00	0.10
14	Ikalukrok u/s Red Dog Sta 9	12/7/2022	0.00	0.00	0.00		0.00	0.00
15	Ikalukrok u/s Red Dog Sta 9	12/7/2022	0.00	0.00	0.00		0.00	0.00
16	Ikalukrok u/s Red Dog Sta 9	12/7/2022	0.01	0.05	0.11		0.00	0.09
17	Ikalukrok u/s Red Dog Sta 9	12/7/2022	0.00	0.00	0.00		0.00	0.00
18	Ikalukrok u/s Red Dog Sta 9	12/7/2022	0.00	0.00	0.00		0.00	0.00
19	Ikalukrok u/s Red Dog Sta 9	12/7/2022	0.00	0.00	0.00		0.00	0.00
20	Ikalukrok u/s Red Dog Sta 9	12/7/2022	0.01	0.05	0.11		0.00	0.09
21	Ikalukrok u/s Red Dog Sta 9	12/7/2022	0.00	0.00	0.00		0.00	0.00

Appendix 3. Aquatic Invertebrate Samples, 2022.

	Middle Fork Red Dog Sta	North Fork Red Dog Sta 12	Upper North Fork Red Dog	Mainstem Red Dog Sta 10	Ikalukrok Upstream Sta 9	Ikalukrok below Dudd Sta 160	Bons u/s Bons	Bons u/s Buddy Sta 220	Buddy u/s Haul Road Sta 221	Buddy below falls
Total aquatic invert taxa/site	10	13	17	10	9	5	9	22	21	21
Tot. Ephemeroptera	8	1	180	2	48	1	48	179	1146	2160
Tot. Plecoptera	6	73	338	0	2	6	2	130	266	147
Tot. Trichop.	0	0	1	1	0	0	0	83	1	0
Total Aq. Diptera	14	329	343	7	30	13	30	4628	766	3738
Misc.Aq.sp	7	32	586	53	3	0	3	2358	180	616
% other	20%	7%	40%	84%	4%	0%	4%	32%	8%	9%
% Ephemeroptera	23%	0%	12%	3%	58%	5%	58%	2%	49%	32%
% Plecoptera	17%	17%	23%	0%	2%	30%	2%	2%	11%	2%
% Trichoptera	0%	0%	0%	2%	0%	0%	0%	1%	0%	0%
% Aq. Diptera	40%	76%	24%	11%	36%	65%	36%	63%	32%	56%
% EPT	40%	17%	36%	5%	60%	35%	60%	5%	60%	35%
% Chironomidae	34%	73%	22%	6%	31%	55%	31%	62%	31%	9%
% Dominant Taxon	31%	71%	19%	10%	47%	55%	40%	59%	29%	57%
Total Area Sampled (m2)	0.430	0.430	0.430	0.430	0.430	0.430	0.430	0.430	0.430	0.430
Estimated total inverts/m2	93	1014	3367	153	205	47	240	17212	5493	15498
Estimated aquatic inverts/m2	81	1012	3367	147	193	47	228	17205	5486	15491
StDev of Aq. Invert Density	27	363	530	258	83	22	74	8317	3410	8767
Total aquatic invertebrates	35	435	1448	63	83	20	98	7398	2359	6661
Total. terrestrial invertebrates	5	1	0	3	5	0	5	3	3	3
Total invertebrates	40	436	1448	66	88	20	103	7401	2362	6664
% Sample aquatic	88%	100%	100%	95%	94%	100%	95%	100%	100%	100%
% Sample terrestrial	13%	0%	0%	5%	6%	0%	5%	0%	0%	0%
Average # aquatic inverts/sample	7	87	290	13	17	4	20	1480	472	1332
StDev of Aq. Inv./sample	2	31	46	22	7	2	6	715	293	754
Average # terr. Inverts/sample	1	0	0	1	1	0	1	1	1	1
Average # inverts /sample	8	87	290	13	18	4	21	1480	472	1333
StDev of Inv./sample	3	32	46	22	7	2	7	716	294	754
Total Larval Arctic Grayling/site	0	0	0	0	0	0	0	0	0	0
Total Larval Slimy Sculpin/site	0	0	0	0	0	0	0	0	0	0
Total Larval Dolly Varden/site	0	0	0	0	0	0	0	0	0	0

Appendix 4. Juvenile Arctic Grayling from Bons Creek, Whole Body Element Concentrations, 2022.

Shaded cells indicate value was at or below method detection limit (MDL), so detection limit for that sample is reported. Detection limits for identified metals were based on % solids which varied for each fish.

Sample Number	Date Collected	Length (mm)	Weight (g)		Cadmium (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Selenium (mg/kg)	Zinc (mg/kg)	% Solids
060722BPAGJ01	6/7/2022	180	60.6		0.11	0.24	0.03	14.63	84.33	26.8
060722BPAGJ02	6/7/2022	179	54.8		0.09	0.20	0.04	13.62	108.12	27.1
060722BPAGJ03	6/7/2022	164	42.7		0.14	0.25	0.04	12.17	136.65	28.1
060822BPAGJ04	6/8/2022	155	35		0.12	0.35	0.03	10.98	111.58	28.5
060822BPAGJ05	6/8/2022	162	39.4		0.10	0.17	0.03	16.32	96.28	26.9
060822BPAGJ06	6/8/2022	161	38.5		0.22	0.70	0.03	12.87	160.00	27.5
060822BPAGJ07	6/8/2022	174	56.9		0.17	0.47	0.03	13.73	108.70	27.6
060822BPAGJ08	6/8/2022	174	49		0.12	2.47	0.03	11.48	60.27	29.7
060822BPAGJ09	6/8/2022	156	36.1		0.04	0.19	0.03	12.67	100.00	27.3
060822BPAGJ10	6/8/2022	157	37.9		0.10	0.28	0.03	13.97	70.99	26.2
060822BPAGJ11	6/8/2022	160	39.6		0.16	0.55	0.03	14.11	132.22	27.0

Appendix 5. Juvenile Dolly Varden from Buddy and Anxiety Ridge creeks Whole Body Element Concentrations, 2022.

Sample Number	Date Collected	Length (mm)	Weight (g)	Cadmium (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Selenium (mg/kg)	Zinc (mg/kg)	% Solids
080322BCDVJ01	8/3/2022	118	15.9	1.61	14.67	0.04	6.30	221.59	22.7
080322BCDVJ02	8/3/2022	118	14.8	1.20	0.58	0.05	6.28	181.40	21.5
080322BCDVJ03	8/3/2022	128	17.8	1.81	5.31	0.04	5.98	148.12	23.9
080322BCDVJ04	8/3/2022	130	19.8	1.38	1.48	0.05	6.14	165.68	23.6
080322BCDVJ05	8/3/2022	133	19.9	1.46	1.24	0.05	5.73	226.15	21.8
080322BCDVJ06	8/3/2022	97	9.5	2.00	3.60	0.03	5.42	217.13	21.6
080322BCDVJ07	8/3/2022	93	6.9	1.86	4.56	0.06	5.76	182.76	20.3
080322BCDVJ08	8/3/2022	96	6.4	1.87	0.22	0.06	6.59	173.46	21.1
080322BCDVJ09	8/3/2022	121	15.2	0.63	1.29	0.04	7.65	207.37	21.7
080322BCDVJ10	8/3/2022	94	7.6	2.63	0.64	0.07	8.65	178.03	22.3
080322BCDVJ11	8/3/2022	129	18.2	1.57	1.56	0.04	6.96	220.87	23
080322BCDVJ12	8/3/2022	127	16.6	1.29	3.50	0.07	7.59	197.69	21.6
080322BCDVJ13	8/3/2022	113	12.8	1.34	0.34	0.05	7.25	166.97	21.8
080322BCDVJ14	8/3/2022	98	8.8	2.90	0.44	0.05	6.67	192.13	21.6
080322BCDVJ15	8/3/2022	122	14.9	4.12	0.54	0.06	7.51	227.19	21.7
080322AXDVJ01	8/3/2022	95	9.2	0.16	0.20	0.13	6.68	152.53	21.7
080322AXDVJ02	8/3/2022	103	10.0	0.33	0.45	0.12	5.99	148.90	18.2
080322AXDVJ03	8/3/2022	106	13.2	0.24	0.38	0.12	4.66	109.42	22.3
080322AXDVJ04	8/3/2022	109	12.4	0.18	0.13	0.15	5.50	121.33	21.1
080322AXDVJ05	8/3/2022	116	14.7	0.09	0.20	0.15	4.48	155.81	21.5
080322AXDVJ06	8/3/2022	117	13.6	0.21	0.19	0.13	8.37	125.55	22.7
080322AXDVJ07	8/3/2022	99	9.1	0.46	0.34	0.09	5.79	120.77	18.3
080322AXDVJ08	8/3/2022	110	12.6	0.14	0.34	0.14	4.18	116.98	21.2
080322AXDVJ09	8/3/2022	121	17.3	0.11	0.11	0.15	5.79	124.07	21.6
080322AXDVJ10	8/3/2022	101	10	0.29	0.43	0.10	4.19	95.20	22.9
080322AXDVJ11	8/3/2022	114	13.7	0.15	0.18	0.11	5.26	115.64	21.1
080322AXDVJ12	8/3/2022	109	12.5	0.18	1.08	0.12	5.60	139.56	22.5
080322AXDVJ13	8/3/2022	109	12.9	0.25	1.21	0.10	5.85	123.67	20.7
080322AXDVJ14	8/3/2022	112	14.5	0.18	0.39	0.12	5.95	125.00	20.0
080322AXDVJ15	8/3/2022	121	15.6	0.09	0.59	0.14	4.49	106.93	20.2
080322RDDVJ01	8/3/2022	101	9.2	1.50	0.96	0.07	5.47	342.36	20.3
080322RDDVJ02	8/3/2022	117	13.3	2.09	0.19	0.04	6.53	262.87	20.2
080322RDDVJ03	8/3/2022	106	12.5	2.07	0.23	0.07	7.38	349.40	16.8
080322RDDVJ04	8/3/2022	104	9.2	2.48	1.96	0.08	5.96	536.52	17.8
080322RDDVJ05	8/3/2022	127	21.5	1.20	2.40	0.09	5.72	234.33	20.1
080322RDDVJ06	8/3/2022	104	11.2	6.32	1.56	0.10	5.58	484.74	19.0
080322RDDVJ07	8/3/2022	88	6.8	3.53	0.59	0.07	5.08	227.75	19.1
080322RDDVJ13	8/3/2022	-	6.6	2.58	2.12	0.07	6.01	584.27	17.8
080322RDDVJ14	8/3/2022	-	6.1	1.77	0.41	0.08	5.43	497.81	18.3
080322RDDVJ15	8/3/2022	-	8.6	1.77	8.28	0.09	5.86	478.74	17.4

Appendix 6. Dolly Varden Element Data, Wulik River, June 2022.

Red numbers indicate value was at or below method detection limit (MDL), so detection limit for that sample is reported. Detection limits for identified metals were based on % solids which varied for each fish.

Tissue	Sample Identification	Fish Species	Sex	Length (mm)	Weight (grams)	Cadmium mg/kg	Copper mg/kg	Lead mg/kg	Selenium mg/kg	Zinc mg/kg	Mercury mg/kg	% Solids
Kidney	060322WUDVA01K	DV	F	484	1610	1.00	5.38	0.11	4.35	77.83	0.13	21.2
Kidney	060322WUDVA02K	DV	F	488	1720	1.85	3.72	0.10	4.63	70.62	0.08	19.4
Kidney	060822WUDVA03K	DV	U	410	860	2.83	16.24	0.13	5.52	114.12	0.07	17.0
Kidney	060822WUDVA04K	DV	U	400	820	0.92	5.19	0.09	2.73	91.14	0.07	23.7
Kidney	060822WUDVA05K	DV	F	434	840	1.22	5.46	0.11	4.76	89.19	0.09	18.5
Kidney	060822WUDVA06K	DV	F	415	920	1.39	37.40	0.08	7.46	86.44	0.11	17.7
Kidney	060822WUDVA07K	DV	U	408	780	1.49	8.43	0.09	6.04	75.13	0.06	19.7
Kidney	060822WUDVA08K	DV	F	590	2340	3.18	6.51	0.07	13.02	85.12	0.23	21.5
Kidney	duplicate of fish #8	DV	F	590	2340	2.39	5.88	0.07	13.00	97.06	0.37	17.0
Liver	060322WUDVA01L	DV	F	484	1610	0.27	77.39	0.06	3.82	164.66	0.02	28.3
Liver	060322WUDVA02L	DV	F	488	1720	0.47	65.57	0.06	4.00	143.44	0.04	24.4
Liver	060822WUDVA03L	DV	U	410	860	0.85	109.96	0.05	4.22	194.42	0.02	25.1
Liver	060822WUDVA04L	DV	U	400	820	0.51	82.47	0.05	3.25	133.47	0.02	25.1
Liver	060822WUDVA05L	DV	F	434	840	0.33	80.85	0.05	3.72	195.39	0.02	28.2
Liver	060822WUDVA06L	DV	F	415	920	0.36	216.49	0.06	3.78	123.02	0.02	29.1
Liver	060822WUDVA07L	DV	U	408	780	0.68	141.12	0.11	5.14	208.88	0.02	21.4
Liver	060822WUDVA08L	DV	F	590	2340	1.01	149.47	0.06	4.18	150.18	0.04	28.5
Liver	duplicate of fish #8	DV	F	590	2340	1.04	146.62	0.06	4.16	125.62	0.04	28.1
Muscle	060322WUDVA01M	DV	F	484	1610	0.04	1.40	0.08	0.96	13.55	0.01	24.5
Muscle	060322WUDVA02M	DV	F	488	1720	0.03	1.24	0.06	0.83	12.06	0.01	27.7
Muscle	060822WUDVA03M	DV	U	410	860	0.04	1.18	0.08	0.94	13.24	0.01	22.5
Muscle	060822WUDVA04M	DV	U	400	820	0.03	1.30	0.06	0.94	12.79	0.01	24.7
Muscle	060822WUDVA05M	DV	F	434	840	0.04	1.25	0.07	1.03	12.44	0.01	24.2
Muscle	060822WUDVA06M	DV	F	415	920	0.03	1.39	0.05	0.89	14.41	0.01	23.8
Muscle	060822WUDVA07M	DV	U	408	780	0.03	1.44	0.06	1.18	16.37	0.01	22.6
Muscle	060822WUDVA08M	DV	F	590	2340	0.03	1.25	0.05	1.03	13.71	0.03	25.9
Muscle	duplicate of fish #8	DV	F	590	2340	0.03	1.33	0.05	1.07	13.83	0.02	25.3
Reproductive	060322WUDVA01R	DV	F	484	1610	0.02	18.59	0.05	3.76	313.18	0.01	31.1
Reproductive	060322WUDVA02R	DV	F	488	1720	0.03	19.66	0.05	5.38	289.10	0.01	26.6
Reproductive	060822WUDVA05R	DV	F	434	840	0.03	21.24	0.06	4.79	270.27	0.01	25.9
Reproductive	060822WUDVA06R	DV	F	415	920	0.04	36.61	0.08	8.47	360.66	0.02	18.3
Reproductive	060822WUDVA08R	DV	F	590	2340	0.04	15.17	0.04	5.20	218.03	0.01	29.4
Reproductive	duplicate of fish #8	DV	F	590	2340	0.07	24.05	0.05	6.56	245.70	0.01	29.1

Appendix 7. Dolly Varden Element Data, Wulik River, September 2022.

Red numbers indicate value was at or below method detection limit (MDL), so detection limit for that sample is reported. Detection limits for identified metals were based on % solids which varied for each fish.

Tissue	Sample Identification	Fish Species	Sex	Length (mm)	Weight (grams)	Cadmium mg/kg	Copper mg/kg	Lead mg/kg	Selenium mg/kg	Zinc mg/kg	Mercury mg/kg	% Solids
Kidney	100322WUDVA01K	DV	M	500	1600	1.37	4.06	0.12	6.09	89.86	0.07	20.7
Kidney	100322WUDVA02K	DV	F	485	1440	2.14	7.03	0.07	6.39	106.93	0.08	20.2
Kidney	100322WUDVA03K	DV	F	475	1540	0.95	4.75	0.10	4.63	66.12	0.05	24.2
Kidney	100322WUDVA04K	DV	F	495	1660	0.74	4.16	0.09	5.42	74.06	0.09	21.2
Kidney	100322WUDVA05K	DV	M	485	1400	1.02	4.70	0.10	5.49	75.35	0.09	21.5
Kidney	100322WUDVA06K	DV	M	580	2820	0.87	3.17	0.07	3.94	57.87	0.05	23.5
Kidney	100322WUDVA07K	DV	M	595	3120	1.91	6.57	0.12	8.79	105.31	0.10	20.7
Kidney	duplicate of fish #7	DV	M	595	3120	1.24	5.76	0.08	7.32	101.46	0.11	20.5
Liver	100322WUDVA01L	DV	M	500	1600	0.27	24.67	0.03	2.86	84.78	0.01	38.1
Liver	100322WUDVA02L	DV	F	485	1440	0.30	137.54	0.06	3.36	143.52	0.01	30.1
Liver	100322WUDVA03L	DV	F	475	1540	0.23	104.06	0.06	2.94	101.52	0.01	39.4
Liver	100322WUDVA04L	DV	F	495	1660	0.28	80.06	0.05	4.35	109.37	0.01	33.1
Liver	100322WUDVA05L	DV	M	485	1400	0.19	40.75	0.05	2.41	72.37	0.01	42.7
Liver	100322WUDVA06L	DV	M	580	2820	0.43	133.17	0.05	3.39	92.63	0.02	40.7
Liver	100322WUDVA07L	DV	M	595	3120	0.36	82.93	0.05	4.82	150.90	0.01	33.4
Liver	duplicate of fish #7	DV	M	595	3120	0.35	75.08	0.06	4.77	126.13	0.01	33.3
Muscle	100322WUDVA01M	DV	M	500	1600	0.02	0.79	0.05	0.75	10.10	0.01	28.7
Muscle	100322WUDVA02M	DV	F	485	1440	0.03	0.95	0.06	0.86	12.18	0.01	26.6
Muscle	100322WUDVA03M	DV	F	475	1540	0.04	1.04	0.07	0.87	12.44	0.01	27.9
Muscle	100322WUDVA04M	DV	F	495	1660	0.05	1.22	0.19	0.89	13.39	0.01	28.9
Muscle	100322WUDVA05M	DV	M	485	1400	0.04	0.83	0.08	0.84	12.10	0.01	27.6
Muscle	100322WUDVA06M	DV	M	580	2820	0.05	1.00	0.09	0.92	13.00	0.01	26.3
Muscle	100322WUDVA07M	DV	M	595	3120	0.03	1.17	0.05	0.97	13.75	0.01	28.5
Muscle	duplicate of fish #7	DV	M	595	3120	0.02	1.12	0.05	0.99	14.24	0.01	27.1
Reproductive	100322WUDVA01R	DV	M	500	1600	0.06	40.96	0.12	6.45	413.20	0.01	19.7
Reproductive	100322WUDVA03R	DV	F	475	1540	0.05	28.26	0.10	5.41	411.47	0.01	21.8
Reproductive	100322WUDVA04R	DV	F	495	1660	0.04	35.19	0.06	8.04	429.79	0.01	23.5
Reproductive	100322WUDVA05R	DV	M	485	1400	0.03	40.22	0.07	6.09	398.52	0.01	27.1
Reproductive	100322WUDVA06R	DV	M	580	2820	0.10	15.27	0.11	3.42	559.09	0.02	22.0
Reproductive	100322WUDVA07R	DV	M	595	3120	0.11	8.60	0.07	3.94	531.40	0.01	20.7

Appendix 8. Total Catch of Juvenile Dolly Varden at Red Dog Mine Sampling Sites, 1997 – 2022.

Year	Evaingiknuk (Noatak Tributary)	Anxiety Ridge Creek	Buddy Creek	North Fork Red Dog Creek (Sta 12)	Upper North Fork Red Dog Creek	Upper Red Dog Creek (Sta 151)	Lower Red Dog Creek (Sta 10)	Lower Ikalukrok Creek (Sta 7/160)	Upper Ikalukrok Creek (Sta 9)	Total Catch
1997	54	68	48	0		14	10	13	3	210
1998	27	94	154	12		70	21	51	44	473
1999	38	271	306	17	26	86	66	55	41	880
2000	2	27	11	1		13	1	31	5	91
2001	7	6	34	1		9	3	6	2	68
2002	20	33	57	1		12	12	17	18	170
2003	64	98	104	0		2	12	17	3	300
2004	71	116	59	1		2	0	27	12	288
2005	29	121	59	8		6	10	36	0	269
2006	4	8	5	0		8	3	2	5	35
2007	67	115	183	1		2	6	25	7	406
2008	21	75	43	0		13	5	7	3	167
2009	16	147	100	3		7	6	30	11	320
2010	48	18	115	6		13	14	10	37	261
2011	36	43	77	2		7	8	32	12	217
2012										
2013										
2014	17	7	18	0	2	1	13	7	2	65
2015	13	93	47	4	32	3	15	10	11	196
2016	8	61	88	0	0	19	21	24	17	238
2017	2	47	12	1	0	1	2	12	0	77
2018	16	57	109	0	2	9	5	8	2	206
2019	30	28	57	0	7	1	3	22	2	143
2020	7	50	15	0	0	0	0	9	4	85
2021	16	90	25	2	3	6	1	12	1	153
2022	21	114	202	4	1	67	27	60	25	520

No sampling occurred in 2012 and 2013 due to high water.
Total catch does not include Upper North Fork Red Dog Creek.
In 2016, a bear destroyed three traps at Station 151 and one trap at Station 12.
In 2020, a bear destroyed two traps at Station 151.