Technical Report No. 22-01

Aquatic Biomonitoring at Red Dog Mine, 2021

A requirement under Alaska Pollution Discharge Elimination System Permit No. AK0038652 (Modification #1)

by

Chelsea M. Clawson

May 2022

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. 22-01

AQUATIC BIOMONITORING AT RED DOG MINE, 2021

A REQUIREMENT UNDER ALASKA POLLUTION DISCHARGE ELIMINATION SYSTEM PERMIT NO. AK0038652 (MODIFICATION #1)

By

Chelsea M. Clawson
Habitat Section, Fairbanks

Alaska Department of Fish and Game
Habitat Section
1300 College Rd, Fairbanks, Alaska, 99701

May, 2022

Cover: Fyke net set on North Fork Red Dog Creek, June 2, 2021. Photograph by Chelsea Clawson

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Chelsea M. Clawson
Alaska Department of Fish and Game, Habitat Section
1300 College Rd., Fairbanks, AK 99701-1599, USA

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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, Maria Wessel, and Audra Brase provided constructive reviews of this report.

Executive Summary

● In 2021, 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 and zinc increased in North Fork Red Dog Creek, although not as sharply as they did in 2020. Zinc, cadmium, nickel, aluminum, and lead decreased substantially in Mainstem Red Dog Creek from 2020 levels, although levels are still higher than those seen pre-mining. Total dissolved solids (TDS) in Mainstem Red Dog Creek were higher than pre-mining, but consistent with past years' data, and pH increased slightly in 2021.

●Zinc and cadmium steeply decreased in Mainstem Red Dog Creek, after a notable increase beginning in 2018. The source of the cadmium and zinc was traced to Kaviqsaaq Seep, which drains into Middle Fork Red Dog Creek above the clean water bypass system. Capture and diversion of the Kaviqsaaq Seep in 2021 likely contributed to the decrease in zinc and cadmium levels in Red Dog Creek.

●Periphyton standing crop, as estimated by chlorophyll-a concentration, is determined each year in drainages near the Red Dog Mine. In 2021, chlorophyll-a concentrations were highest in Bons Creek below the pond (Sta 220) and lowest in Middle Fork Red Dog Creek (Sta 20), Mainstem Red Dog Creek (Sta 10), lower Ikalukrok Creek (Sta 160) and upper Ikalukrok Creek (Sta 9). Chlorophyll-a concentration in Ikalukrok Creek at Station 9 continues to track closely 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 2021, ten sites were sampled, and the aquatic invertebrate density was highest, although variable, in North Fork Red Dog Creek (Sta 12). In 2021, similar to past years, the percentage of Chironomidae was higher than EPT at most sites. Overall taxa richness varied from 19 to 29 taxa per site.

●Juvenile Arctic grayling from Bons Pond have been analyzed for selected whole body elements in 2004, 2007, 2010, and 2014 – 2021. Average cadmium, lead, and zinc concentrations in Arctic grayling juveniles in 2022 were consistent with past years' levels. The average selenium concentration in juvenile Arctic grayling in 2021 was the highest since sampling began. Average mercury concentration decreased again in 2021, down from peak values seen in 2018 and 2019.

●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 2021. Juvenile Dolly Varden median whole body concentrations of cadmium, lead, and zinc are consistently highest in Mainstem Red Dog Creek. Element concentrations in juvenile Dolly Varden in 2021 were generally consistent with past years.

●In 2021 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 2021 a total of 87,361 Dolly Varden were counted in the Wulik River, although this should be considered a minimum estimate due to visibility issues due to turbidity.

●Only 117 chum salmon were observed in Ikalukrok Creek in 2021, although this is likely a considerable underestimate as visibility was severely impeded by turbidity in Ikalukrok Creek.

●In spring 2021, resident Dolly Varden (n = 13) were captured with fyke nets in North Fork Red Dog Creek, averaging 155 mm FL. Juvenile Dolly Varden sampling with minnow traps was conducted in late summer 2021. The total number of juvenile Dolly Varden captured at all sample sites in early August was 137 fish with an average size of 89 mm FL. The highest catch was in Anxiety Ridge Creek (90 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 spent females were never captured. The 2020 population of Arctic grayling in North Fork Red Dog Creek was estimated to be 206 fish $\geq$ 200 mm FL.

●The estimated Arctic grayling population in Bons Pond in 2020 was 716 fish $\geq$ 200 mm FL. In 2019 over 3,000 fish < 100 mm FL were captured, and this age cohort was strongly represented as age-3 fish in the 2021 length frequency.

●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 2021, with only two sculpin captured in Ikalukrok Creek and no sculpin 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 is presented in Appendix 1 and Ott et al. 2016. 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 also 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 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 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 1000 mg/L (prior to July 25th) or 500 mg/L (July 25th and later) threshold. 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.

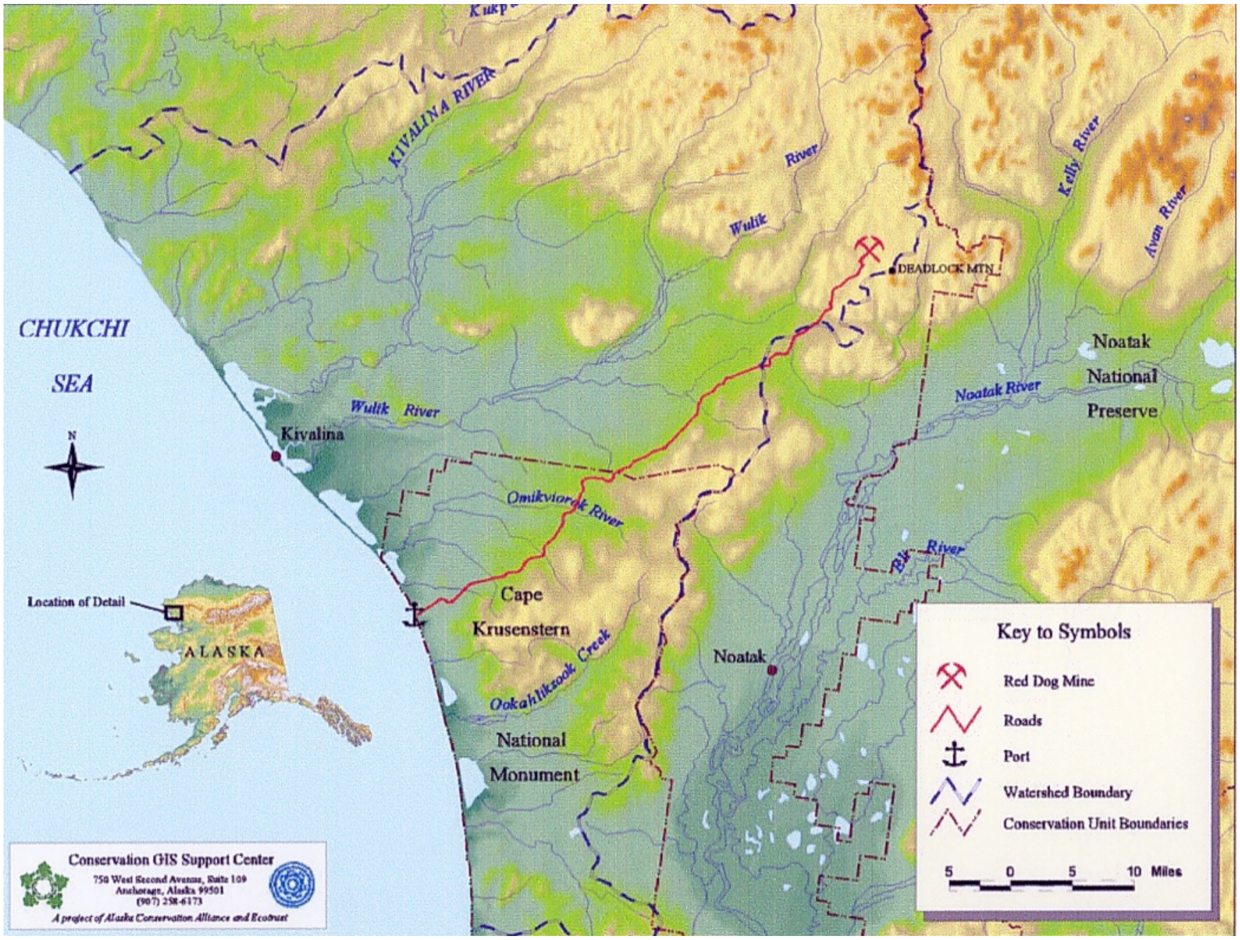


Figure 1. Location of the Red Dog Mine in northwestern Alaska.[1]

Table 1. Location of biological sample sites and factors measured at the Red Dog Mine, 2021.

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

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 metals 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 metals 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 metals in tissue
Evaingiknuk	WMP	Evaingiknuk Creek east of haul road	Fish presence and use
Bons Pond	WMP	Above reservoir spillway	Juvenile Arctic grayling metals in tissue Arctic grayling population estimate

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

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 2021 and where applicable, these data are compared with previous years.

Structure of Report

This report is presented in several sections as follows:

1) Water quality;
2) Periphyton standing crop;
3) Aquatic invertebrates;
4) 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;
5) Aerial survey estimates of overwintering Dolly Varden in the Wulik River and chum salmon (*Oncorhynchus keta*) spawners in Ikalukrok Creek; and
6) 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 2021) when compared to the pre-development baseline data.

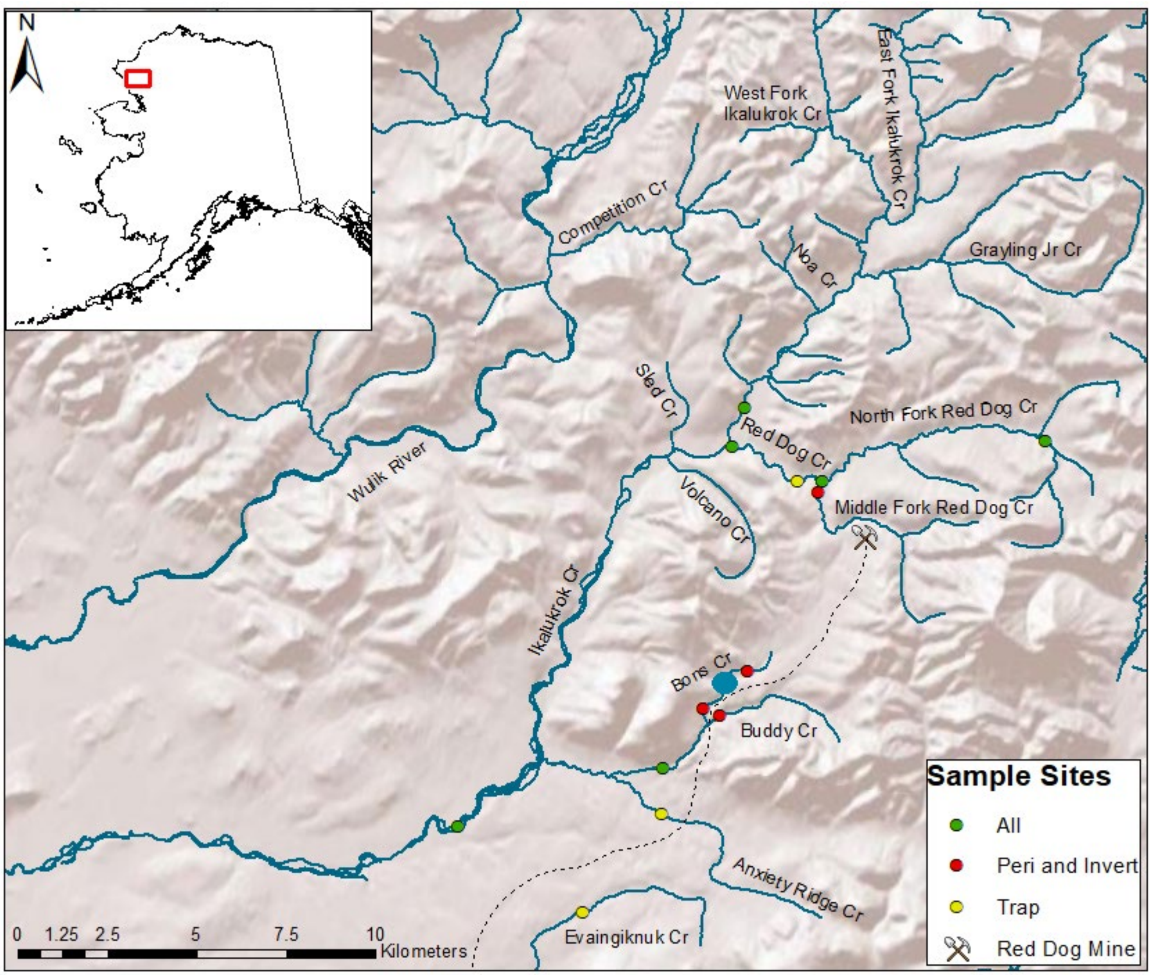


Figure 2. Location of sample sites in the Ikalukrok Creek drainage (tributary of the Wulik River) and Evaingiknuk Creek (a tributary of the Noatak River) drainage.

Methods

Five sampling events occurred in the Red Dog vicinity in 2021 including spring Arctic grayling and adult Dolly Varden sampling (May 27 – June 3), mid-summer aquatic invertebrates and periphyton (July 1 – 10), late-summer juvenile Dolly Varden sampling (August 5 – 12), early fall juvenile Dolly Varden sampling and gamete collection for chum salmon/Dolly Varden fertilization tests (August 23 – September 2), and fall aerial surveys of Dolly Varden in Wulik River and chum salmon in Ikalukrok Creek (October 6 – 9). The gamete collection in early fall was part of the additional studies commissioned to establish compliance with the TDS water quality based effluent limits of the permit. Owl Ridge Natural Resource Consultants is the project lead on these studies, with logistical support from ADF&G Habitat staff.

Methods used for the 2021 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 2021 invertebrate sampling was conducted at two sites using Hess samplers in addition to 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.

All 2021 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, but samples are collected twice each month with a sample size of 9 to 13 per year per site. Baseline water quality pre-mining data presented in the report were collected from 1979 to 1982.

In 2021, 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):

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

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

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

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 2021 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 2020 (Station 151).

In 2021, 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.

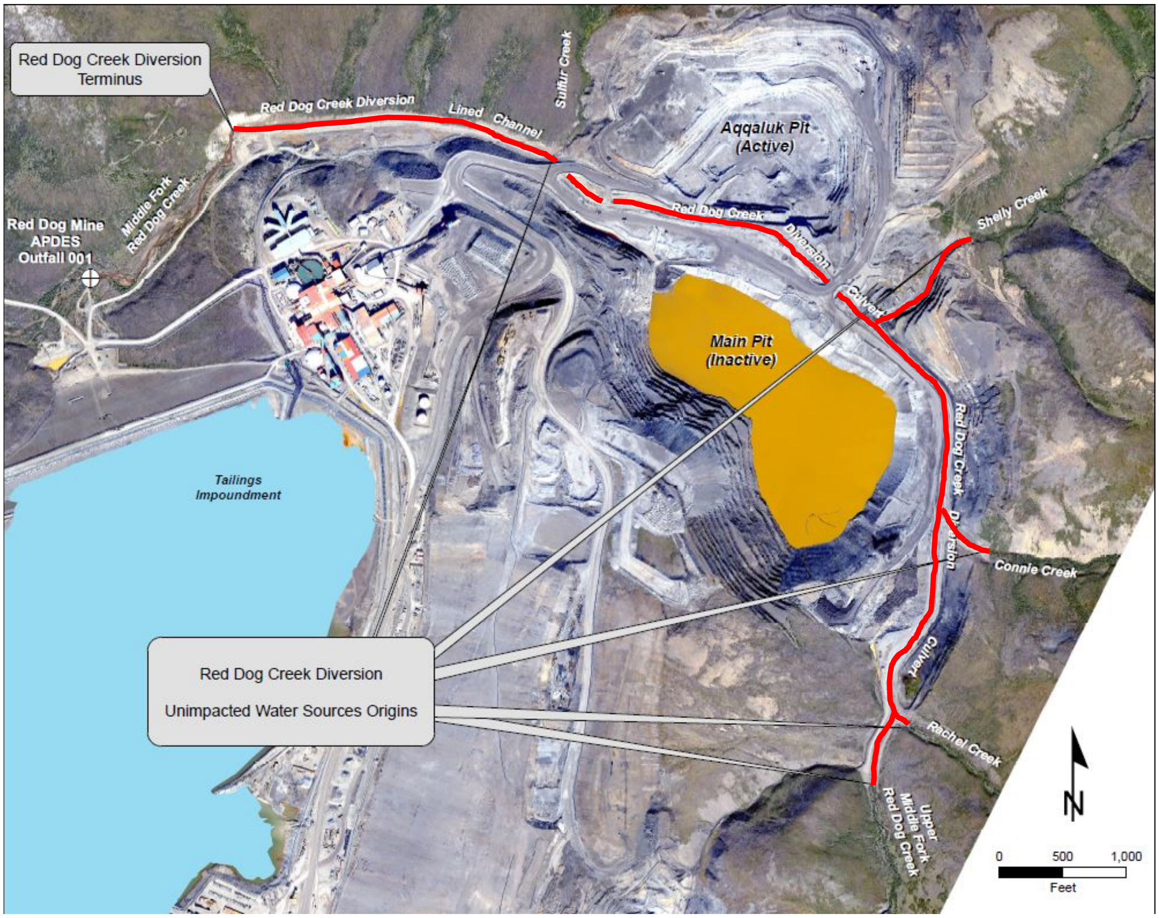


Figure 4. Clean water bypass system at the Red Dog Mine. The Red Dog Creek diversion structure (delineated by labels in the photograph and shown in red) picks up non-mining impacted waters from upstream tributaries and moves them between the Aqqaluk pit and the main pit back to the original Middle Fork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

In 2021, the median lead concentration in Mainstem Red Dog Creek (Station 151/10), downstream of the clean water bypass system, was lower than pre-mining (1979-83). However, in some years the maximum lead concentration has been higher than pre-mining (Figure 5). Median lead concentrations increased from 2017 to 2020 to a high of 18.0 µg/L in 2020, then declined somewhat in 2021 to 7.2 µg/L.

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

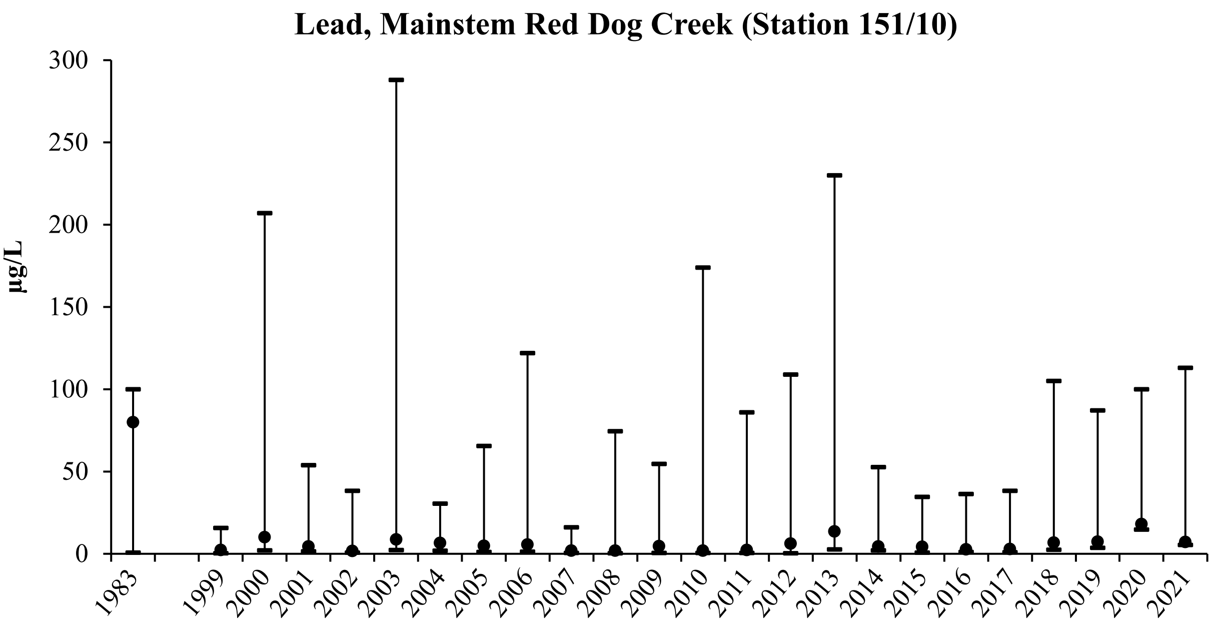


Figure 5. Median, maximum, and minimum lead concentrations at Station 151/10.

In 2021, the system with the highest concentration of lead was Station 145 on Middle Fork Red Dog Creek upstream of the clean water bypass with a median lead concentration of 108.5 µg/L (Figure 6). In 2020, lead concentrations at Station 145 more than doubled, from 94.2 µg/L in 2019 to 215.0 µg/L in 2020. Station 145 is affected by the Kaviqsaaq Seep, which could have been contributing to the increased lead concentrations. Kaviqsaaq Seep was captured and diverted in 2021, which could have contributed to the decrease in lead levels at Station 145. Sulfur Creek had the second highest median lead concentration with 86.3 µg/L, a substantial decrease from the 2020 median lead concentration of 1,550 µg/L. 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.

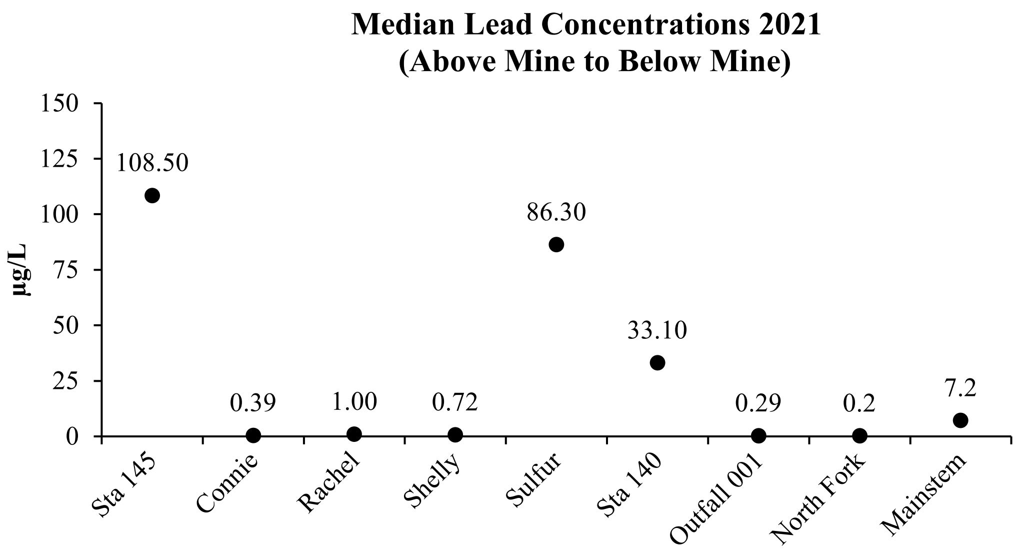


Figure 6. Median lead concentrations in 2021 from upstream (Station 145) of the clean water bypass, including tributaries to the clean water bypass (Connie, Rachel, Shelly, and Sulfur), and Station 140 (above the Outfall 001), Outfall 001, and North Fork Red Dog and Mainstem Red Dog creeks.

The median zinc concentration in Mainstem Red Dog Creek (Station 151/10) decreased in 2021, reversing the steep increase observed in 2020, although zinc levels are still higher than those observed from 1999 to 2017 (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. Zinc levels decreased in 2021 to levels similar to those observed in 2019, which are still higher than any median zinc concentration from 1999 to 2018 (Figure 8). The elevated zinc can be traced to upper Middle Fork Red Dog Creek (Station 145), above the clean water bypass. The other component creeks of the clean water bypass (Connie, Rachel, Shelly, and Sulfur) have low zinc concentrations (Figure 9). The Kaviqsaaq Seep on upper Middle Fork Red Dog Creek has been identified as a major source of metals to Red Dog Creek, likely influenced by the Qanaiyaq 1500 bench development and other localized changes in the surrounding area (SRK 2015, Golder 2020). Teck regraded the surface of the Qanaiyaq 1500 bench in September 2019 to direct surface-water drainage toward the Qanaiyaq pit and away from Red Dog Creek drainages, and in March/April 2020, placed cover material on the eastern side of the Qanaiyaq 1500 bench to reduce possible permafrost melt. Despite these remedial efforts, water quality did not improve in 2020, so Kaviqsaaq Seep was captured and diverted to the tailings pond in 2021.

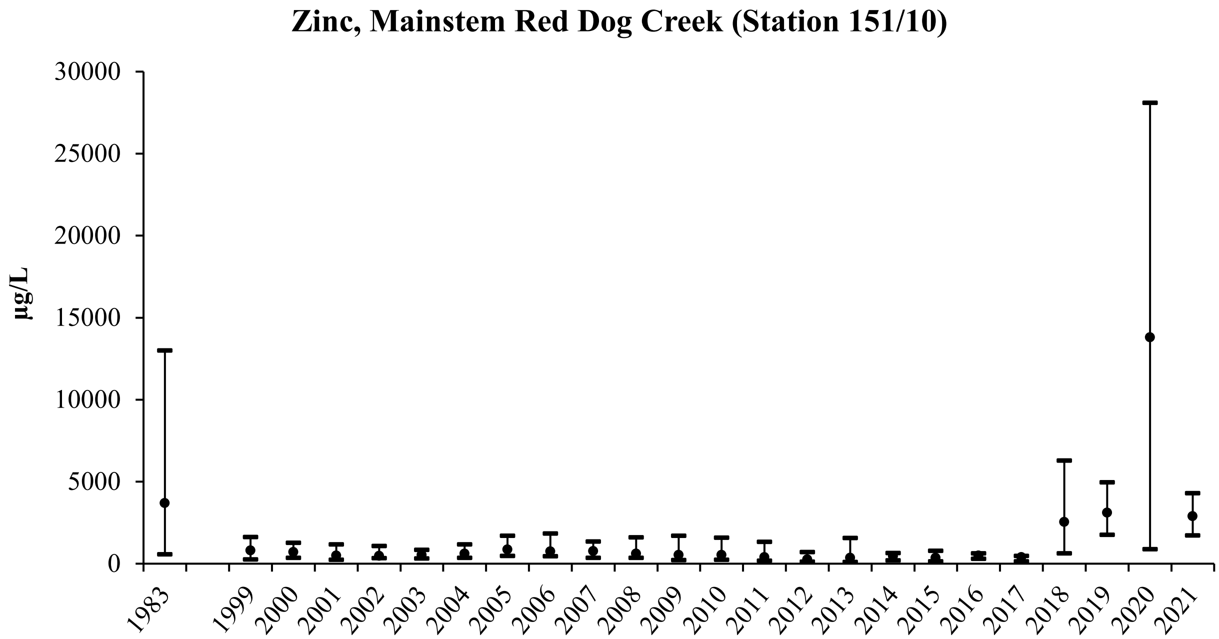


Figure 7. Median, maximum, and minimum zinc concentrations at Station 151/10.

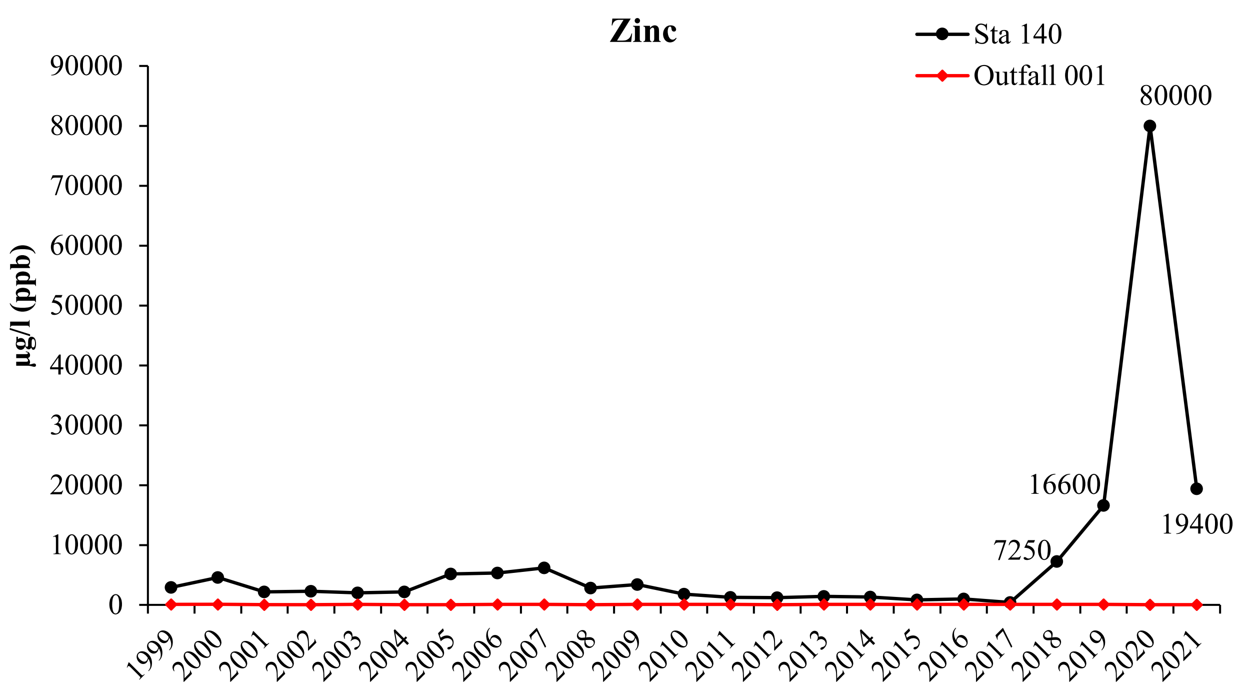


Figure 8. Median zinc levels in water samples from Station 140 and Outfall 001, 1999 - 2021.

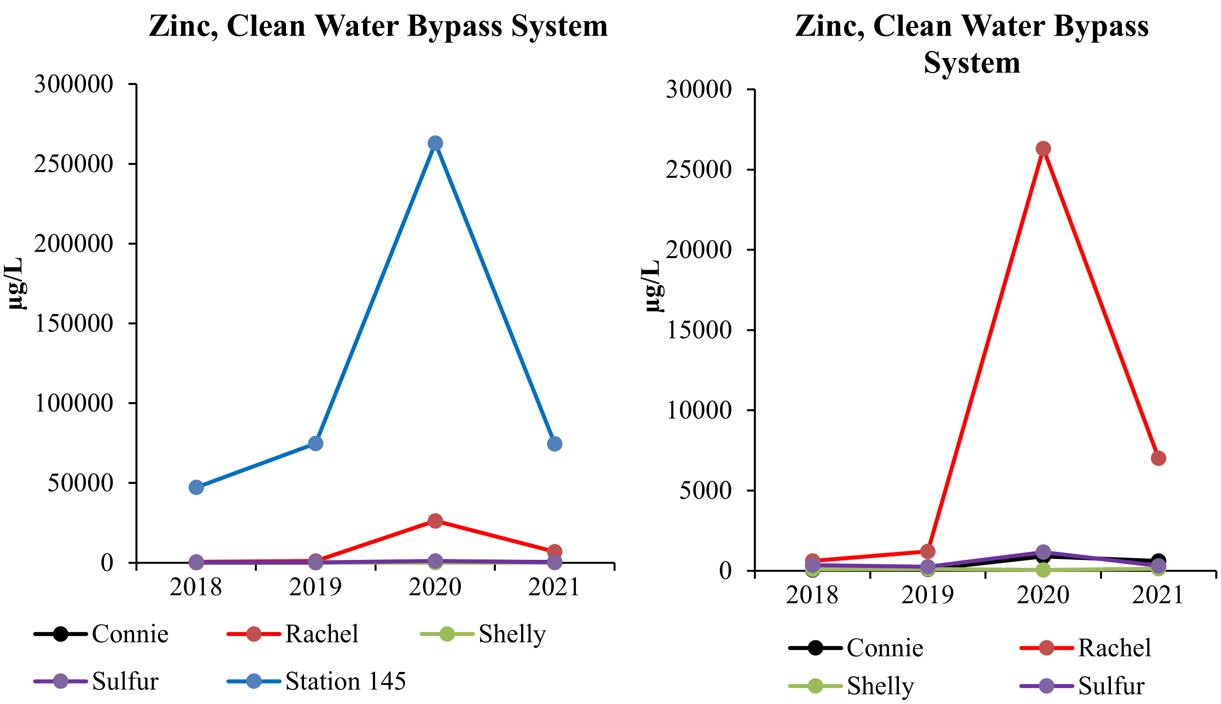


Figure 9. Median zinc concentrations in water samples from Sulfur, Shelly, Connie, and Rachel creeks, and Station 145, 2018 - 2021. Station 145 is on Middle Fork Red Dog Creek, downstream of the Kaviqsaaq Seep and before the clean water diversion system begins. The figure on the right uses a different scale as it does not include Station 145.

Median aluminum concentrations in Mainstem Red Dog Creek (Station 151/10) decreased in 2021 following a sharp increase in 2020, although levels are still higher than those observed pre-mining. Median aluminum concentration in 2021 was 643 µg/L (Figure 10). Cadmium concentrations also exhibited a similar trend, decreasing in 2021 following a steep increase in 2020. Median cadmium concentration in 2021 was 15.4 µg/L (Figure 11).

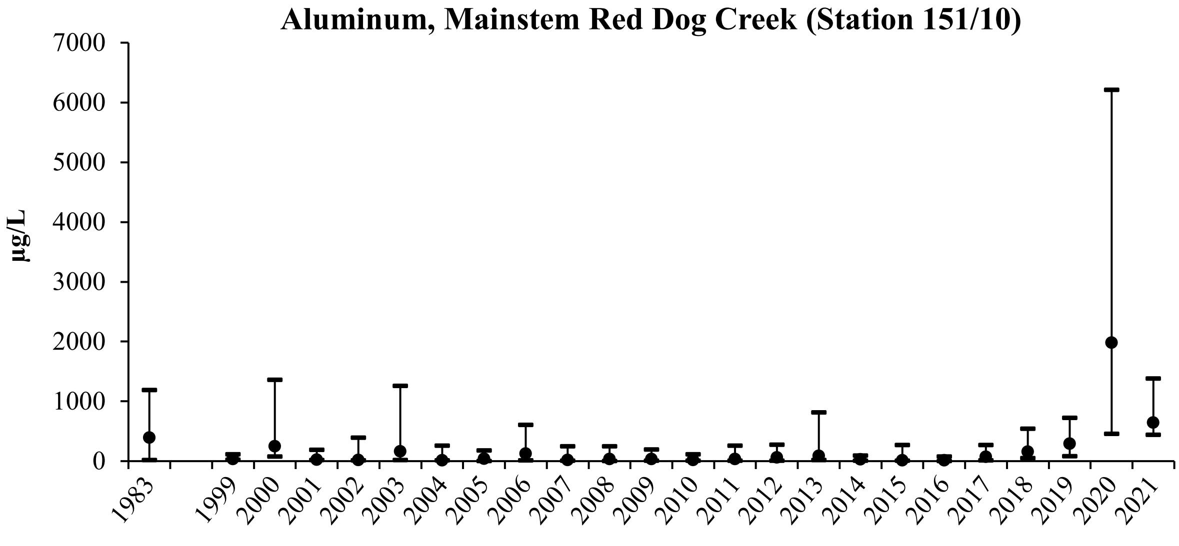


Figure 10. Median, maximum, and minimum aluminum concentrations at Station 151/10.

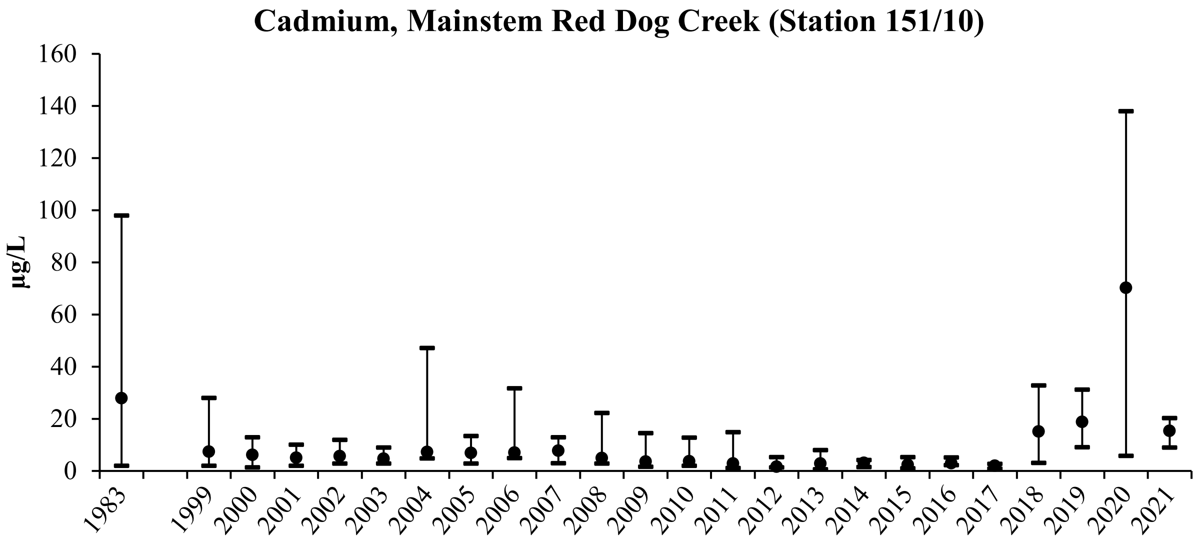


Figure 11. Median, maximum, and minimum cadmium concentrations at Station 151/10.

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 the 2012 open water period. 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).

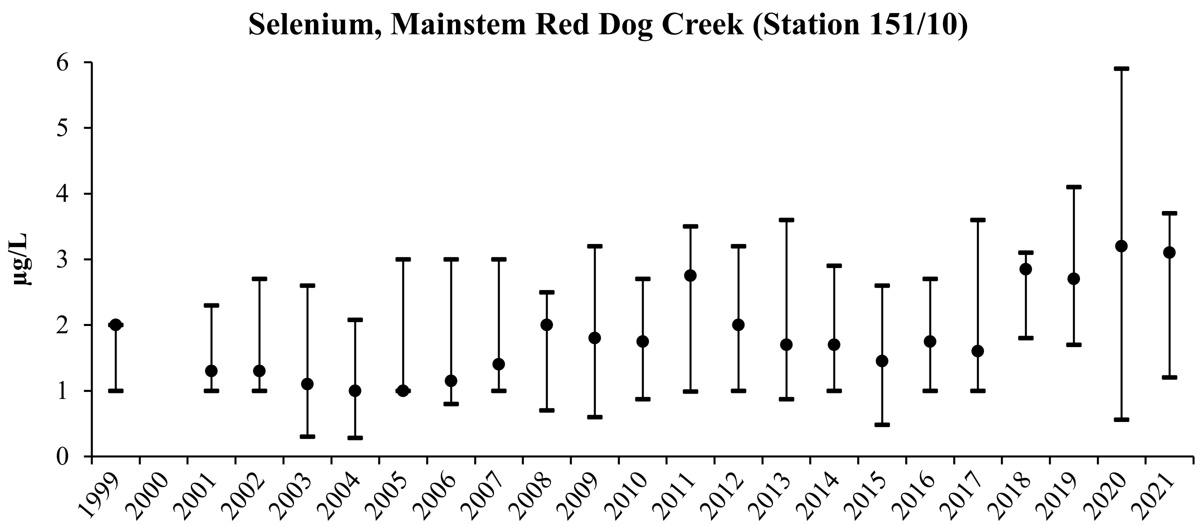


Figure 12. Median, maximum, and minimum selenium concentrations at Station 151/10.

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, which is still higher than any other year of data collection except 2020. The component creeks of the clean water bypass system were not analyzed for nickel in 2020 or 2021, so the source of the increased nickel concentration is unknown.

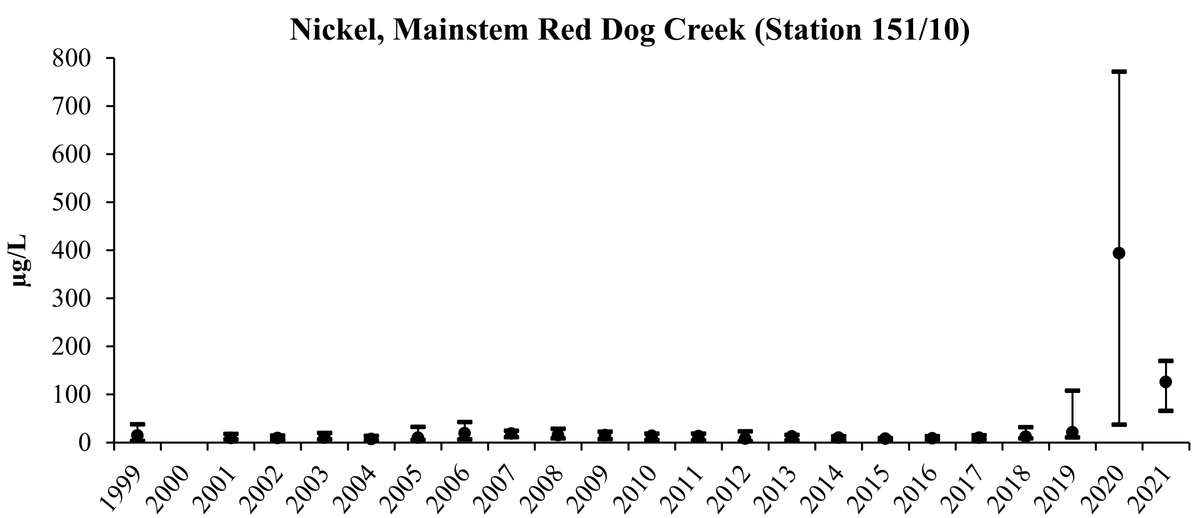


Figure 13. Median, maximum, and minimum nickel concentrations at Station 151/10.

In 2021, 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 in 2020 was the lowest since 1999. Median pH increased in 2021 to 7.53. 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 six once, in 2011. The 1990 data set is during mining, but prior to construction of the clean water bypass system.

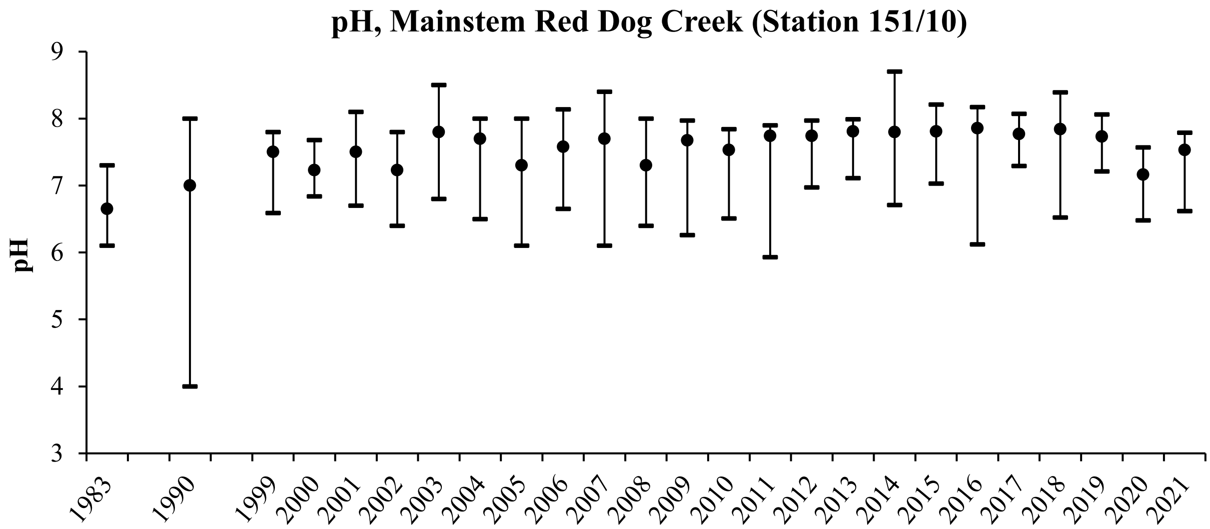


Figure 14. Median, maximum, and minimum pH values at Station 151/10.

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 hydroxide 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 the elevated TDS concentrations.

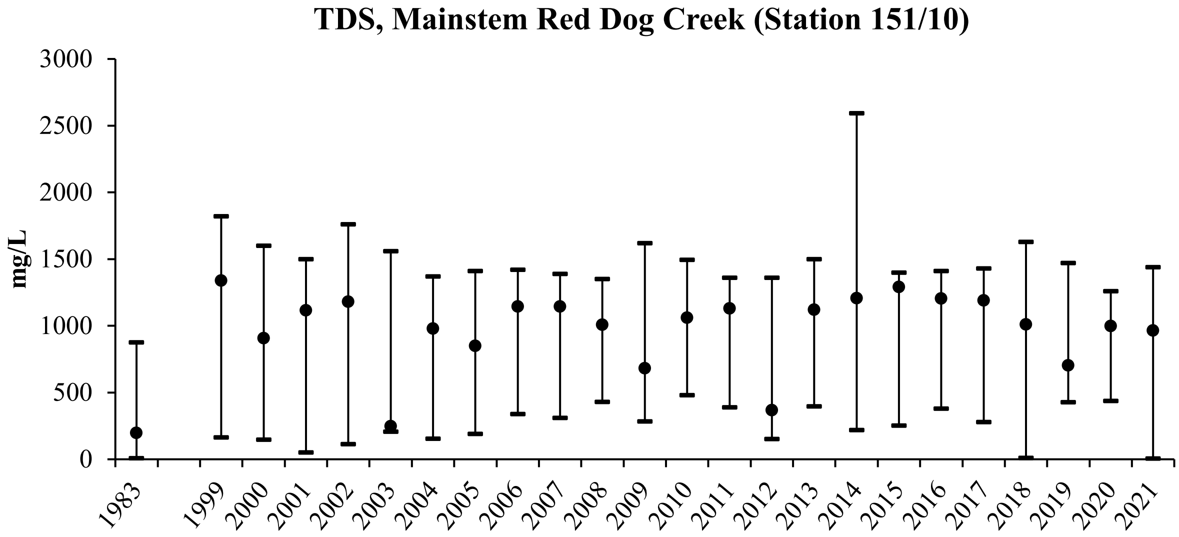


Figure 15. Median, maximum, and minimum TDS concentrations at Station 151/10.

Natural changes in water quality continued throughout the Ikalukrok Creek drainage in 2021, both upstream and downstream of the mine. 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 quality, 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), July 2020 (right).

Figure 17. Station 10 Mainstem Red Dog Creek - July 2016 (left), July 2020 (right).

Figure 18. Station 9 Ikalukrok Creek upstream of Red Dog Creek - July 2019 (left), July 2020 (right).

Figure 19. Station 160 Ikalukrok Creek downstream of Dudd Creek – July 2018 (left), July 2020 (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 with 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 were 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 has been low and stable in North Fork Red Dog Creek, Buddy Creek, and Bons Pond from 2001 to 2019. In 2020 and 2021, 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 in 2021 reversed the steep increase observed in 2020, dropping down to 15.4 µg/L 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 increased beginning in 2019 (Figure 22). Selenium concentrations among these sites are similar, and variable amoung 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 2021 were 3.1, 3.0, 2.7, and 2.5 µg/L, respectively.

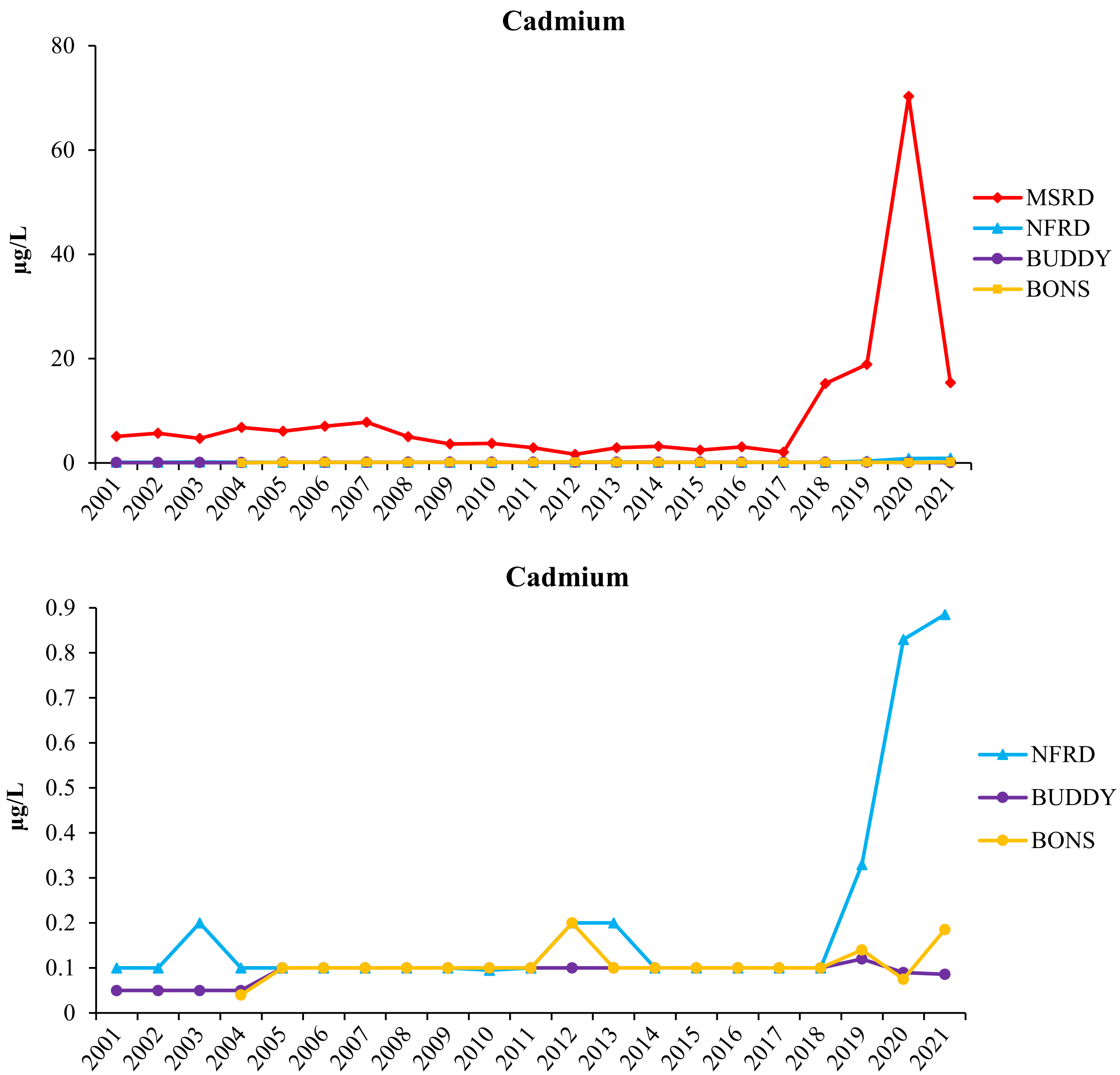
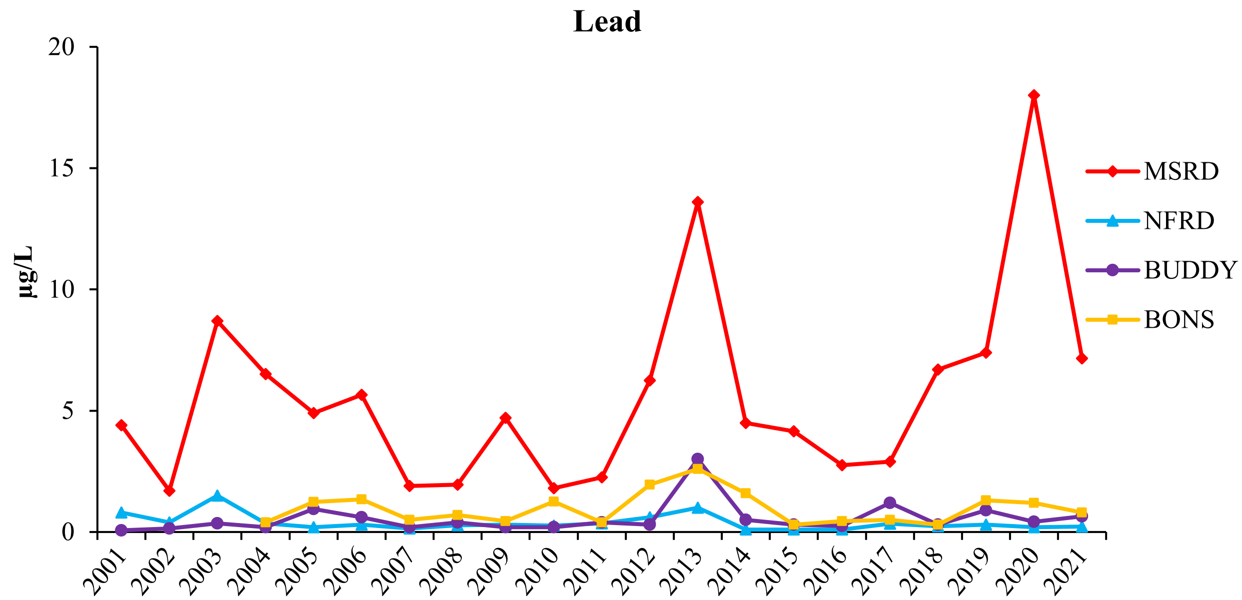


Figure 20. Median cadmium concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2021). Two graphs are presented, the bottom graph uses a different scale as it does not include Mainstem Red Dog Creek.



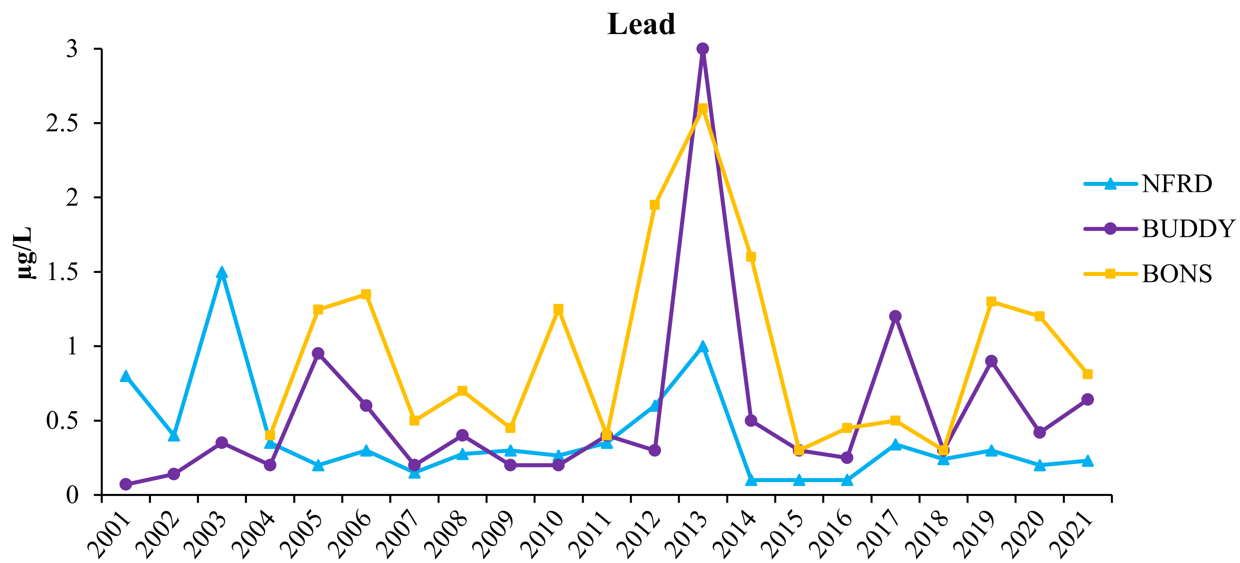


Figure 21. Median lead concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2021). Two graphs are presented, the bottom graph uses a different scale as it does not include Mainstem Red Dog Creek.

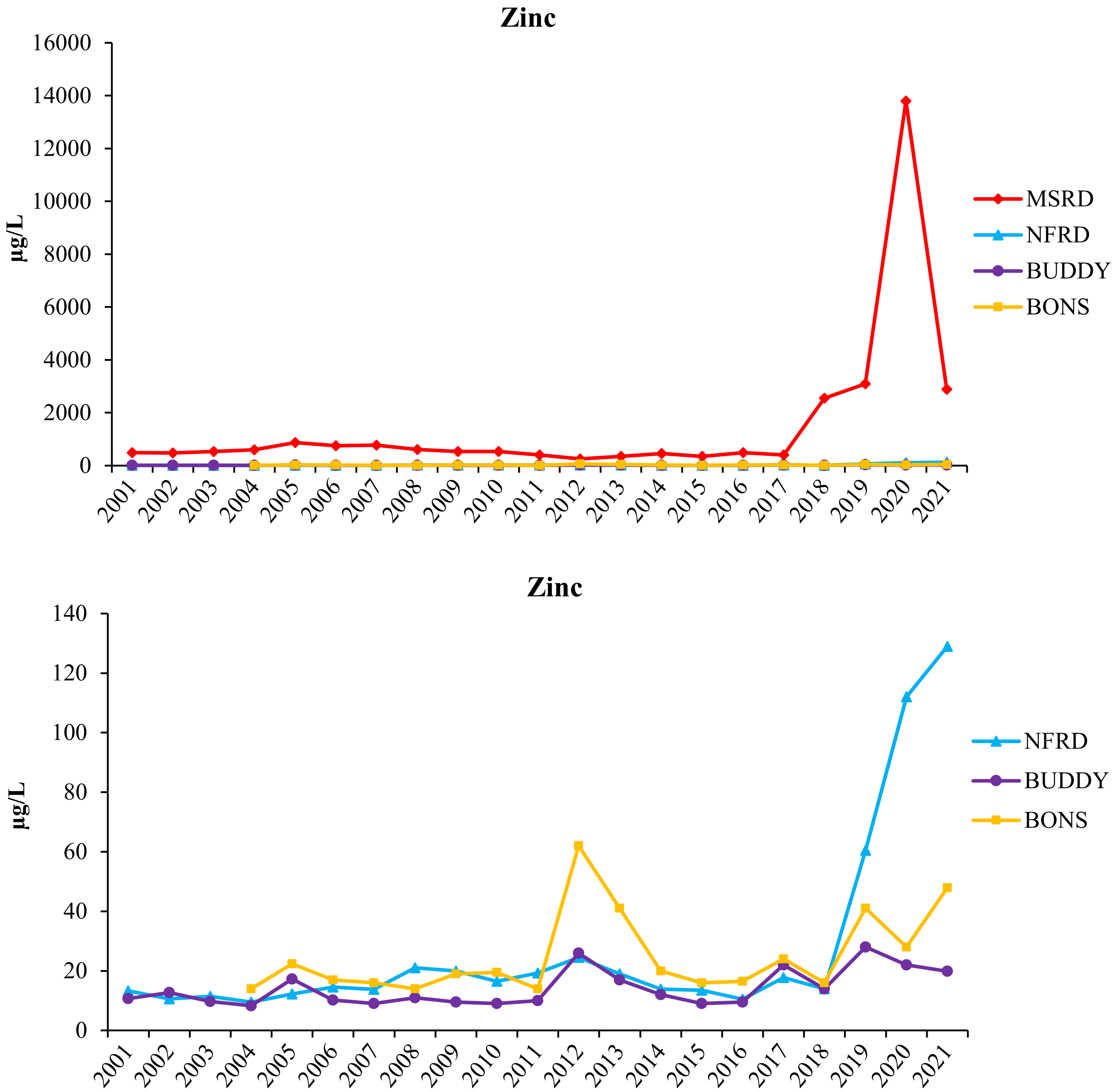


Figure 22. Median zinc concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2021). Two graphs are presented, the bottom graph uses a different scale as it does not include Mainstem Red Dog Creek.

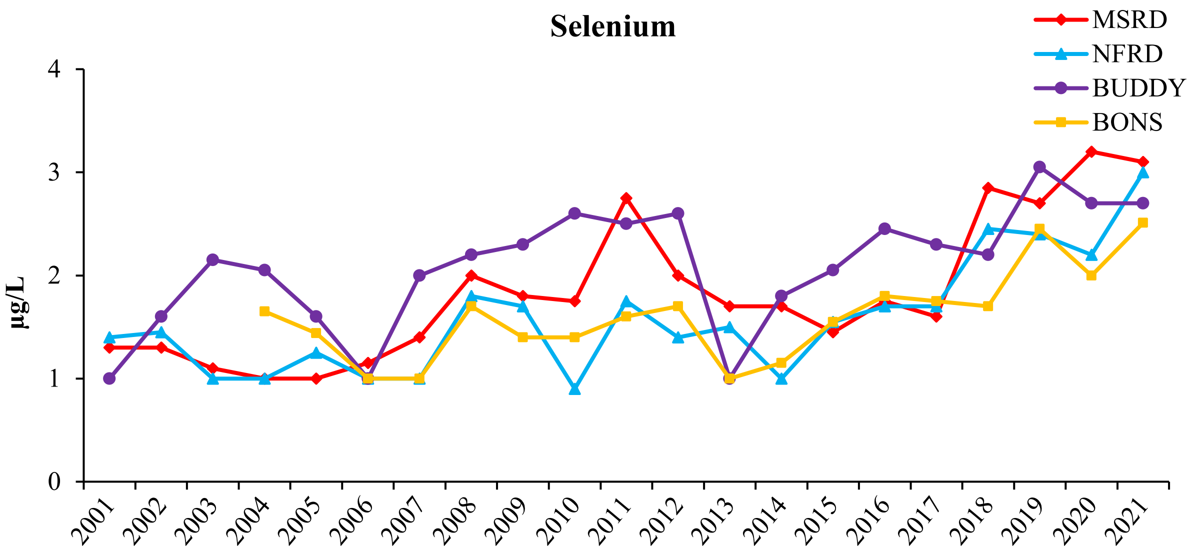


Figure 23. Median selenium concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2021).

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 2021, 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 determined as mg/m^2 chlorophyll-a.

Average chlorophyll-a concentration in 2021 was highest at Station 220 on Bons Creek (15.01 mg/m^2) and lowest at Station 20 on Middle Fork Red Dog Creek and Station 10 on Mainstem Red Dog Creek (0.05 mg/m^2) (Figure 24). Periphyton standing crop was also very low on Ikalukrok Creek at Station 9 (0.06 mg/m^2) and Station 160 (0.10 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).

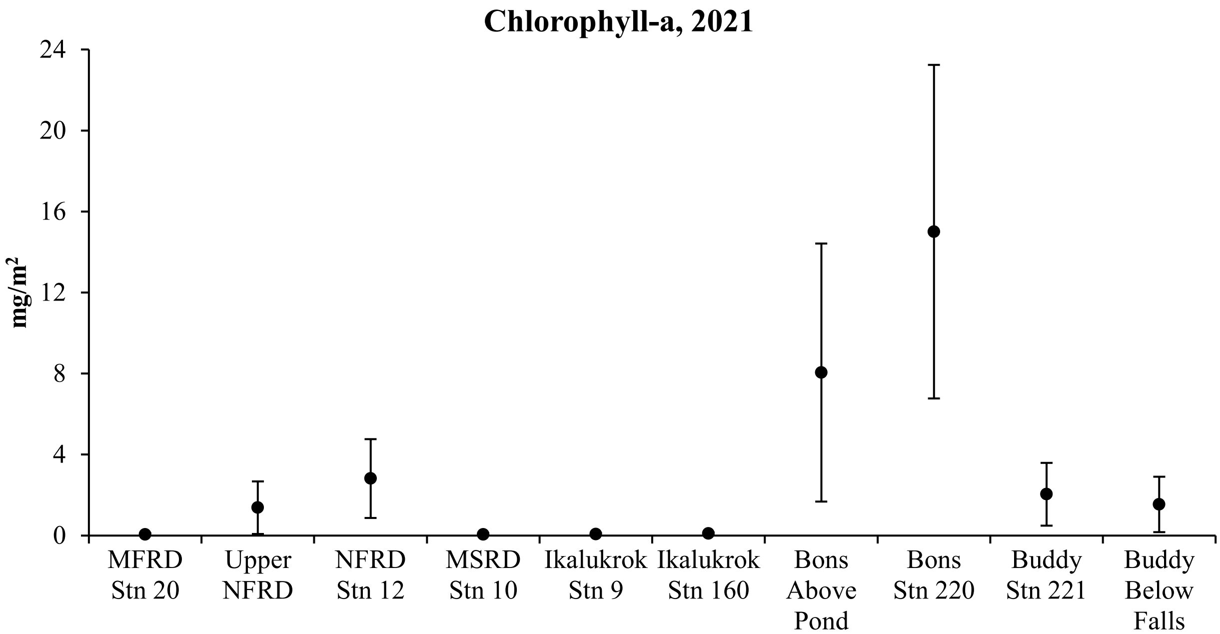


Figure 24. Average concentration of chlorophyll-a (± 1SD) at Red Dog Mine sample sites, 2021. Sites in the Red Dog Creek drainage include Middle Fork Red Dog (MFRD), Upper North Fork Red Dog (Upper NFRD), North Fork Red Dog (NFRD), and Mainstem Red Dog (MSRD).

Generally, average chlorophyll-a concentrations are higher in Mainstem Red Dog and North Fork Red Dog creeks as compared with Middle Fork Red Dog Creek, although in recent years chlorophyll-a concentrations in Mainstem Red Dog Creek have been very low (Figure 25). In 15 of 23 years, average chlorophyll-a concentration in North Fork Red Dog Creek was equal to or higher than Mainstem Red Dog Creek. Lower chlorophyll-a concentration in Middle Fork Red Dog Creek is probably 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 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 increased in 2020 and 2021.

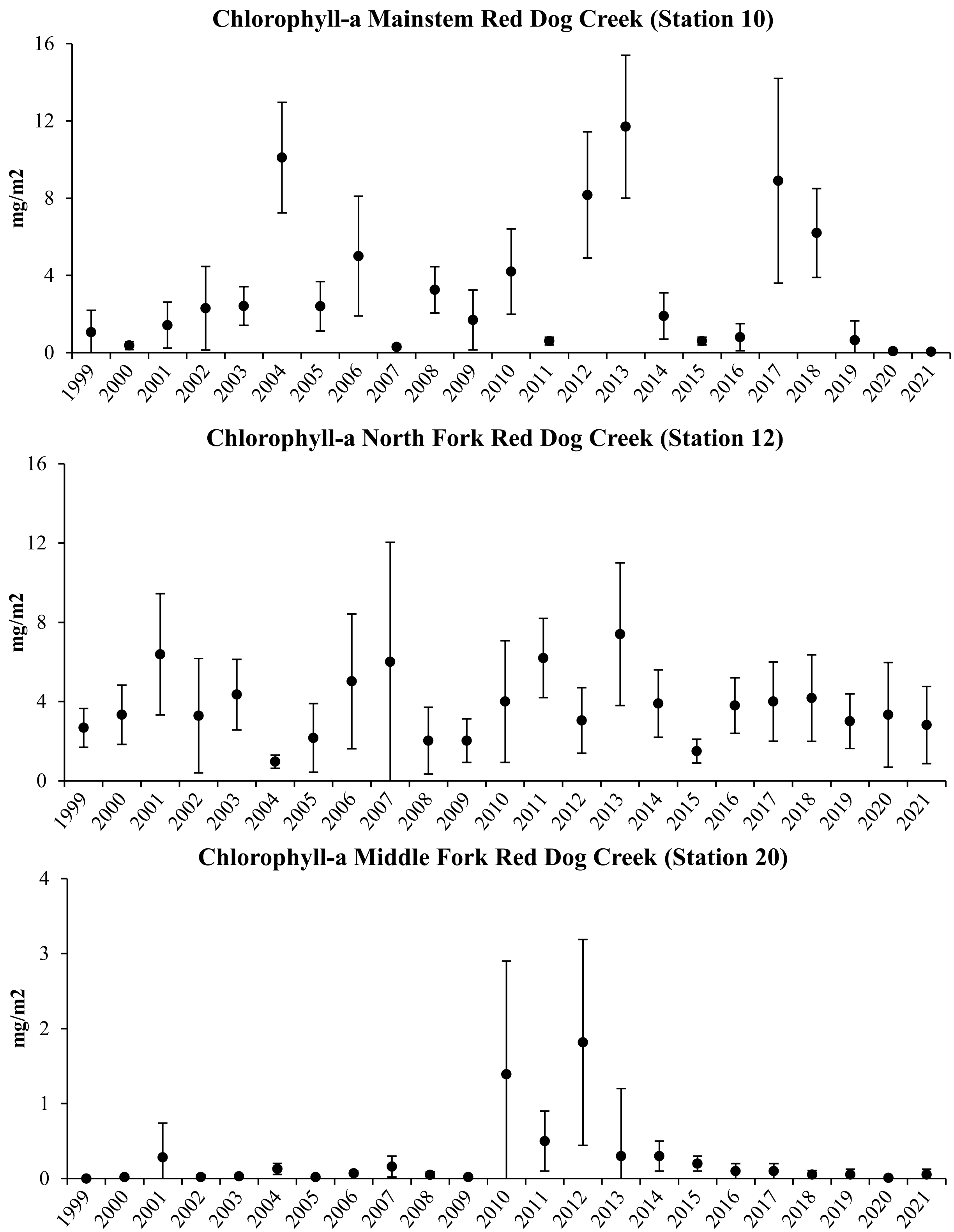


Figure 25. Average concentration (± 1SD) of chlorophyll-a in Mainstem Red Dog Creek (Station 10/151), North Fork Red Dog Creek (Station 12), and Middle Fork Red Dog Creek (Station 20), 1999-2021.

Periphyton standing crop tracks closely 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 from 2018 to 2021, 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 time frame. We believe 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).

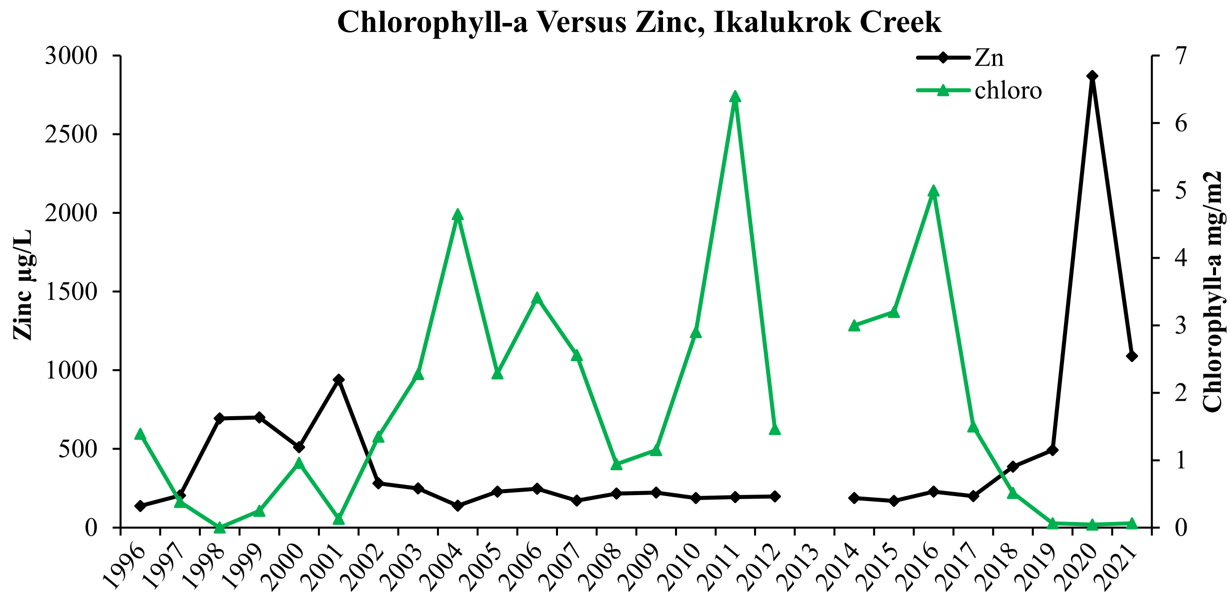


Figure 26. Average concentrations of chlorophyll-a and zinc in Ikalukrok Creek (Station 9), 1996–2021.

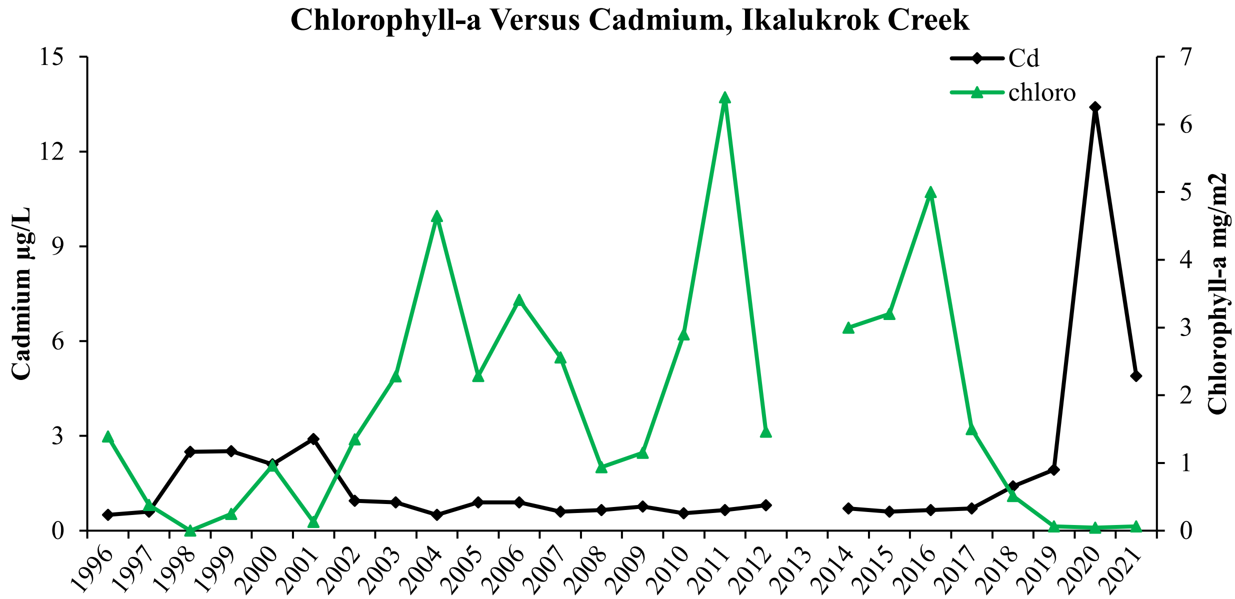


Figure 27. Average concentrations of chlorophyll-a and cadmium in Ikalukrok Creek (Station 9), 1996-2021.

Figure 28. Ikalukrok Creek at the Cub Creek seep about 10 km upstream of Station 9. Station 9 is just upstream of the mouth of Mainstem Red Dog Creek – note mineral staining in and along the edge of Cub Creek, July 2017.

Aquatic Invertebrates

Aquatic invertebrate samples are collected annually using drift nets (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 North Fork Red Dog Creek (Sta 12) with 39.7 invertebrates per m^3 (Figure 29).

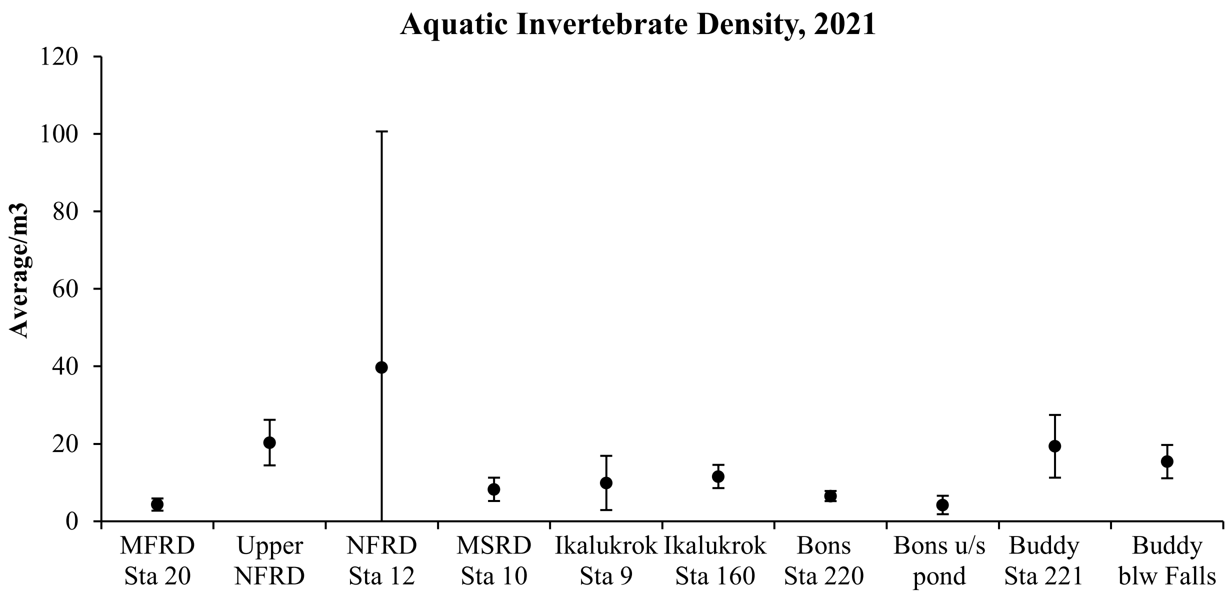


Figure 29. Average aquatic invertebrate densities (± 1SD) in all sample sites near the Red Dog Mine, July 2021.

Prior to 2017, Buddy Creek Station 221 (above the haul road) generally had higher aquatic invertebrate densities than the other sample sites. However, since 2017, Buddy Creek below the falls has had higher aquatic invertebrate densities than Station 221. The average aquatic invertebrate density at Buddy Creek Station 221 (above road) has varied from a low of 3.8 to a high of 164.5 invertebrates per m^3 (Figure 30). In 2021, average aquatic invertebrate density was 19.4 invertebrates per m^3.

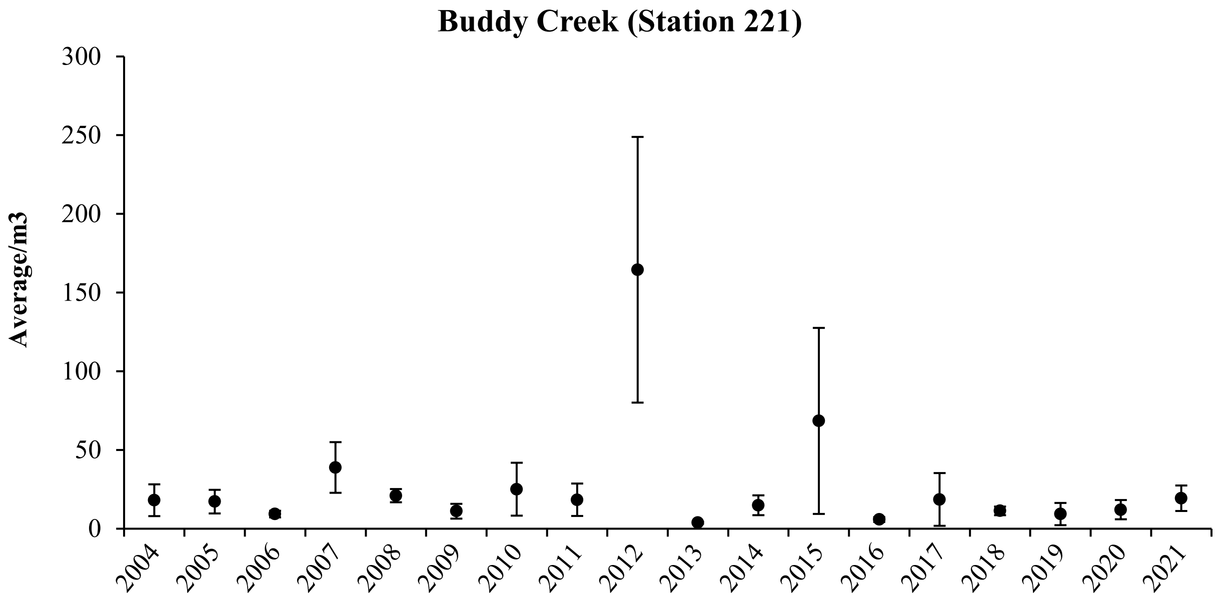


Figure 30. The average aquatic invertebrate density (± 1SD) in Buddy Creek (Station 221) upstream of the road 2004–2021.

Aquatic invertebrate densities are typically higher in North Fork Red Dog Creek than in Mainstem Red Dog Creek, and this was the case in 2021 (Figure 31). In 22 out of 23 years, the aquatic invertebrate density was higher in North Fork Red Dog Creek than in Mainstem Red Dog Creek.

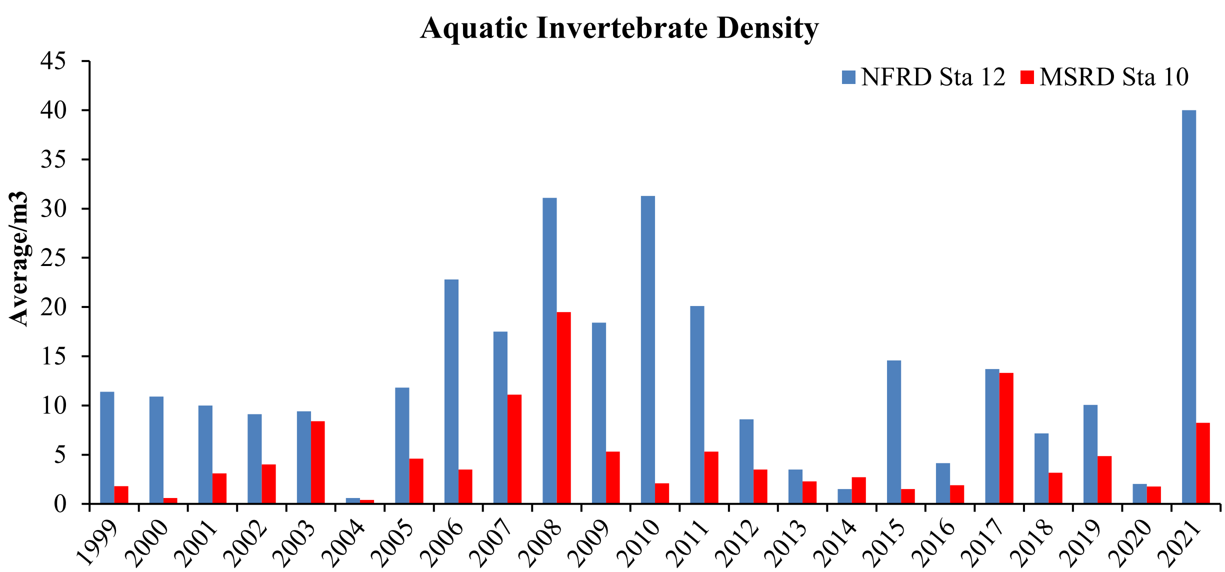


Figure 31. Average aquatic invertebrate densities in North Fork Red Dog and Mainstem Red Dog creeks 1999 – 2021.

The percent Ephemeroptera, Plecoptera, and Trichoptera (EPT) and the percent Chironomidae for sample sites in 2021 are presented in Figure 32. In most sample years the percentage of Chironomidae is higher than EPT at most sample sites, and this was the case in 2021. Trichoptera are not common in the samples and are not a substantial contributor to EPT. Generally, the aquatic systems in the Red Dog Mine area are dominated by Chironomidae which is one of the primary food items of the fish species (e.g. Arctic grayling and Dolly Varden) using these creeks.

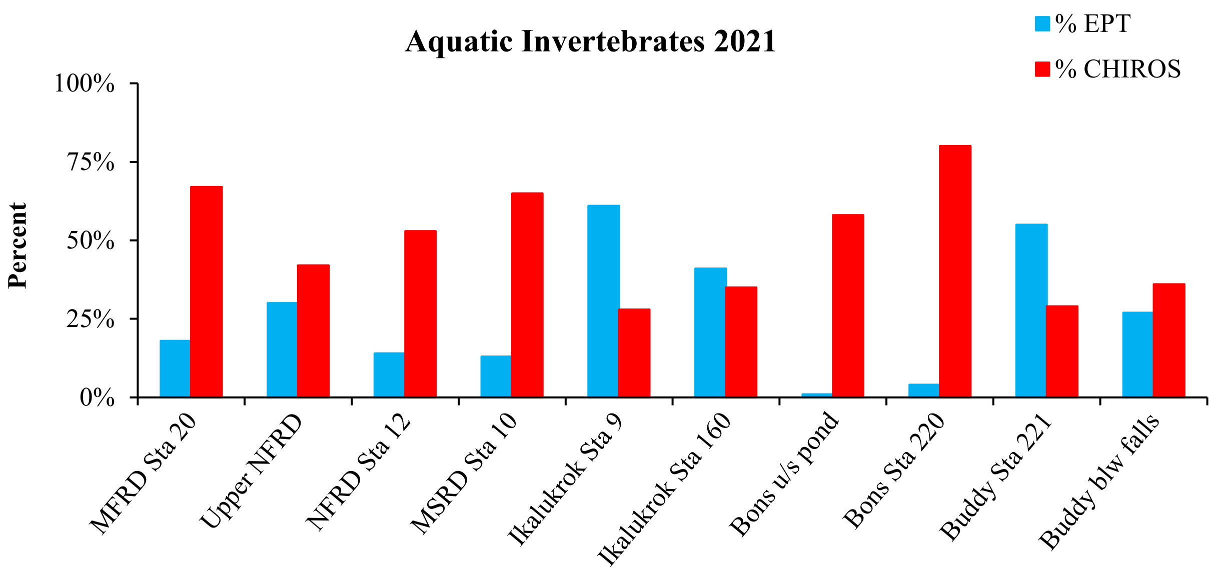


Figure 32. Percent EPT and Chironomidae in the aquatic invertebrate samples at all sample sites Red Dog Mine, July 2021.

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 33). In 18 out of the last 23 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 33). Like North Fork Red Dog Creek, percent Chironomidae has been higher than percent EPT in 17 out of the last 23 years. 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) (Figure 33). In Buddy Creek, percent Chironomidae has been higher than the percent EPT 11 out of 18 years.

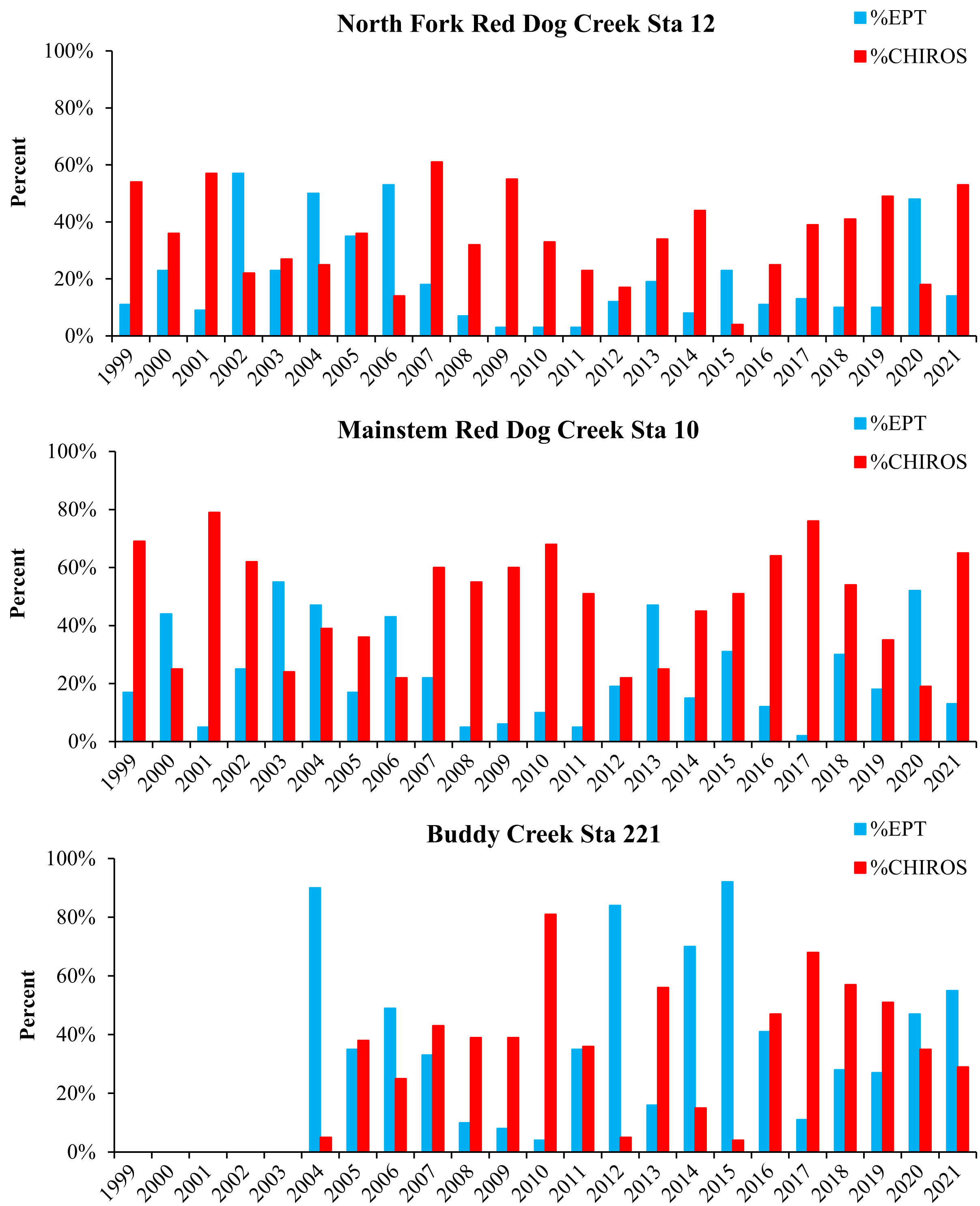


Figure 33. Percent EPT and Chironomidae in North Fork Red Dog Creek (top), Mainstem Red Dog Creek (middle), and Buddy Creek (bottom) 1999–2021. Aquatic invertebrate sampling in Buddy Creek drainage began in 2004.

Taxa richness was compared for the three sample sites in North Fork Red Dog, Mainstem Red Dog, and Buddy creeks (Figure 34). 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 2021, taxa richness was equal in Buddy and North Fork Red Dog creeks with 27 taxa identified. Mainstem Red Dog Creek was slightly lower, with 24 taxa identified. Peak taxa richness in Mainstem Red Dog Creek occurred in 2019, and the lowest was in 2000. In 2021, North Fork Red Dog Creek had the highest taxa richness since aquatic invertebrate sampling began in 1999. The lowest was in 1999 and 2000. Peak taxa richness in Buddy Creek occurred in 2019 and the lowest taxa richness was seen in 2009 and 2010.

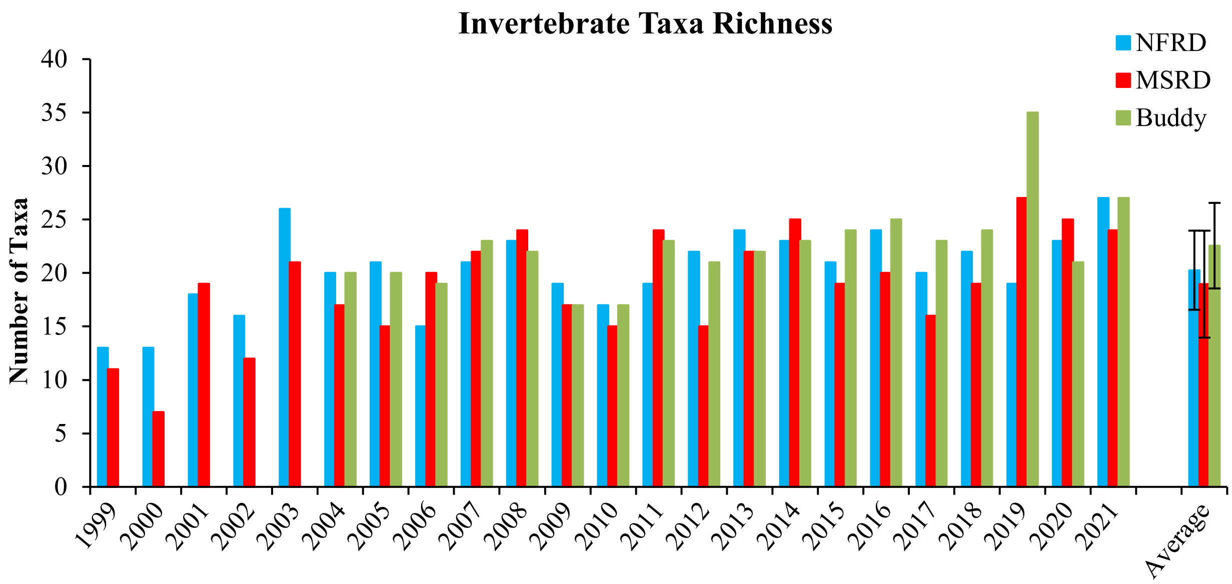


Figure 34. Aquatic invertebrate taxa richness in North Fork Red Dog (Sta 12) and Mainstem Red Dog Creek (Sta 10) 1999–2021 and Buddy Creek (Sta 221) 2004–2021. The running average (± 1 SD) is included for each site.

In addition to the drift net samples, aquatic invertebrates were collected with Hess samplers at Bons Creek (Sta 220) and at Buddy Creek below the falls. Both sample sites exhibited similar differences between the drift and Hess samples. The number of taxa decreased, as did the total number of invertebrates. Notably, the number of terrestrial invertebrates dropped precipitously in the Hess samples, which is to be expected given the sampling methodology. The percent composition of Chironomidae and EPT in the samples also changed substantially in the drift versus Hess. At Bons Creek Station 220, the drift nets had 4% EPT and 80% Chironomidae. In the Hess samples, EPT were 10% of the sample and Chironomidae were 48%. This change was even more pronounced at Buddy Creek below the falls. The drift nets contained 27% EPT and 36% Chironomidae, while the Hess samples contained 58% EPT and 9% Chironomidae.

Table 2. Aquatic invertebrate samples collected using drift nets versus Hess samplers. All results have been corrected for subsampling.

	Bons Cr Sta 220 drift	Bons Cr Sta 220 Hess		Buddy blw falls drift	Buddy blw falls Hess
Total aquatic taxa/site	23	20		29	17
Avg #/sample Ephemeroptera	58	38		691	238
Avg #/sample Plecoptera	21	19		77	16
Avg #/sample Trichop.	5	2		2	0
Avg #/sample Aq. Diptera	1741	292		1343	62
Avg #/sample Misc.Aq.sp	217	243		696	121
% other	11%	41%		25%	28%
% Ephemeroptera	3%	6%		25%	54%
% Plecoptera	1%	3%		3%	4%
% Trichoptera	0%	0%		0%	0%
% Aq. Diptera	85%	49%		48%	14%
% EPT	4%	10%		27%	58%
% Chironomidae	80%	48%		36%	9%
% Dominant Taxon	65%	45%		26%	41%
Total aquatic inverts	10235	2975		14145	2190
Total terrestrial inverts	1585	17		1879	7
Total invertebrates	11820	2992		16024	2197
% Sample aquatic	87%	99%		88%	100%
% Sample terrestrial	13%	1%		12%	0%

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 opportunistically from Anxiety Ridge, Buddy, and Mainstem Red Dog creeks during the minnow trap sample event in late summer. Minnow traps were set repeatedly in Mainstem Red Dog Creek in August 2020, but no fish were captured. These locations have been sampled annually since 2005, except for in 2012 and 2013 when water levels were too high to effectively sample.

Fifteen juvenile Arctic grayling were captured in Bons Pond in early June (Appendix 4). The average length of these fish was 169 mm FL ± 10.5 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 2021, the median cadmium concentration in Bons Pond juvenile Arctic grayling was 0.1 mg/kg (Figure 35). The highest median cadmium concentration was 0.3 mg/kg in 2004.

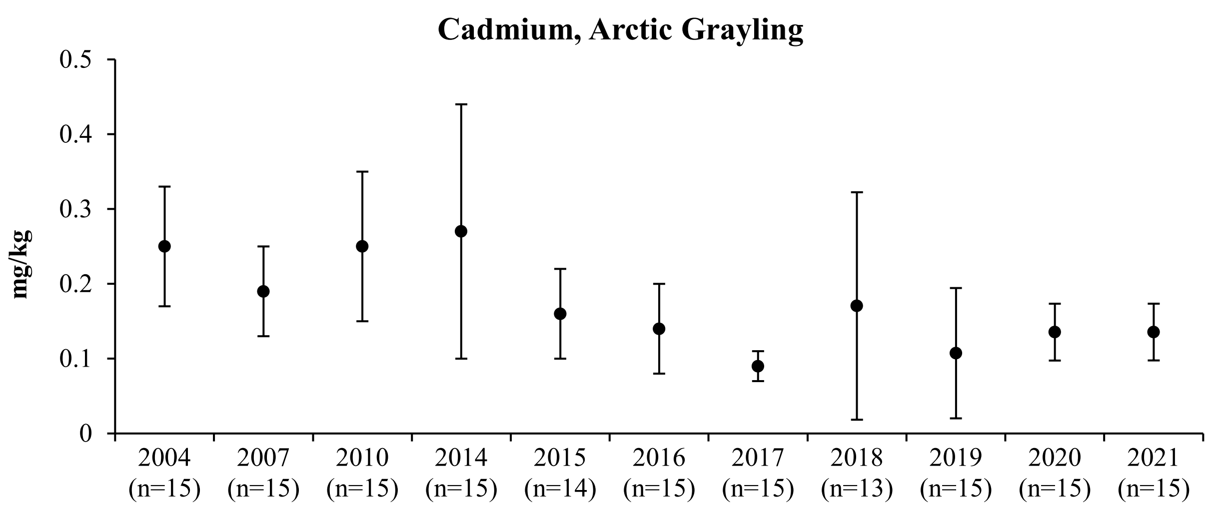


Figure 35. Median cadmium concentrations (± 1 SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

In 2021, the median lead concentration was 0.8 mg/kg in juvenile Arctic grayling from Bons Pond (Figure 36). This was slightly higher than the median concentration in recent years, but still within the range of variation seen since whole body element analysis began.

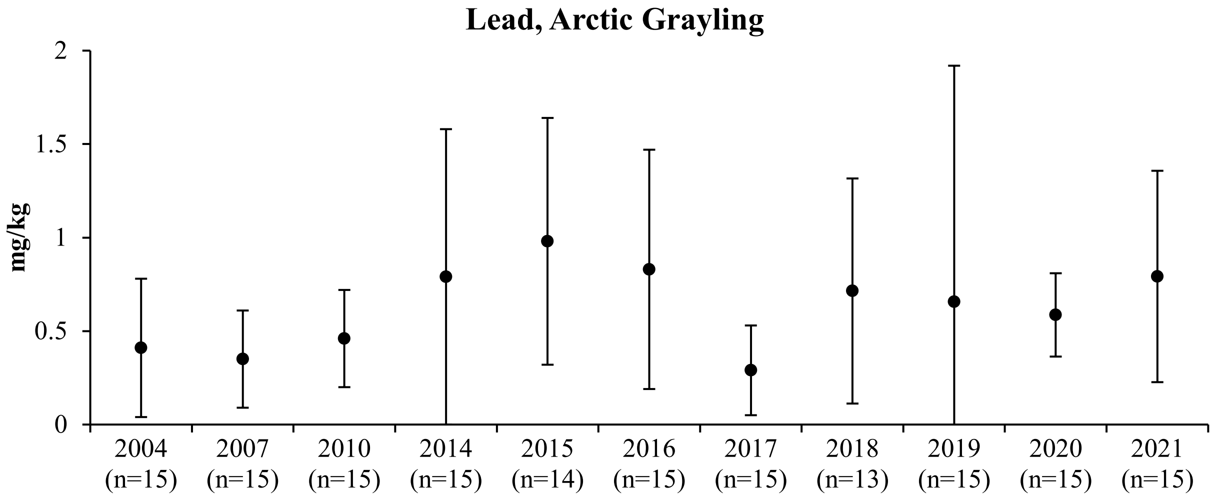


Figure 36. Median lead concentrations (± 1 SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

The median selenium concentration in juvenile Arctic grayling from Bons Pond decreased from 2014 to 2019, but increased in 2020 and 2021 (Figure 37). The median concentration in 2021 was 16.6 mg/kg, the highest median value since record keeping began in 2004.

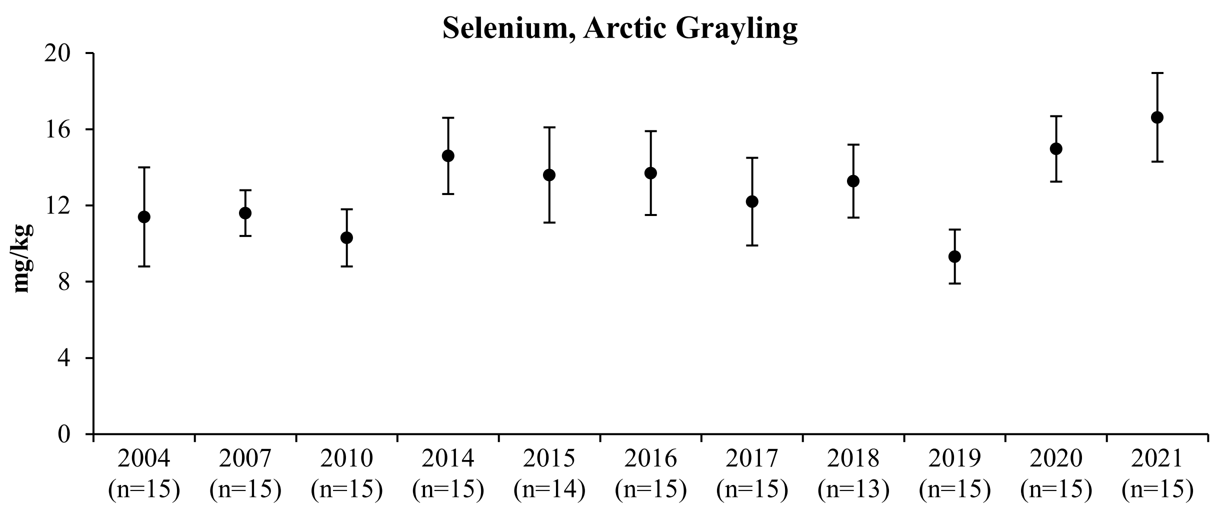


Figure 37. Median selenium concentrations (± 1 SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

Median zinc concentration in juvenile Arctic grayling from Bons Pond in 2021 was 84.4 mg/kg (Figure 38). Median zinc concentrations have varied from a high of 107.0 mg/kg in 2016 to a low of 55.5 mg/kg in 2017.

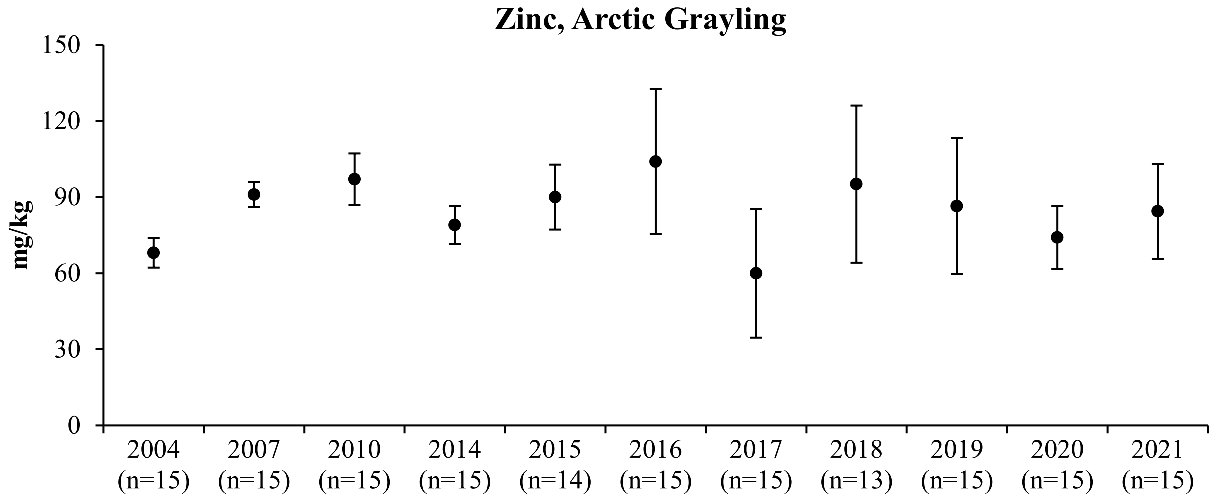


Figure 38. Median zinc concentrations (± 1 SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

Median 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 39). The median mercury concentration in 2021 was 0.04 mg/kg.

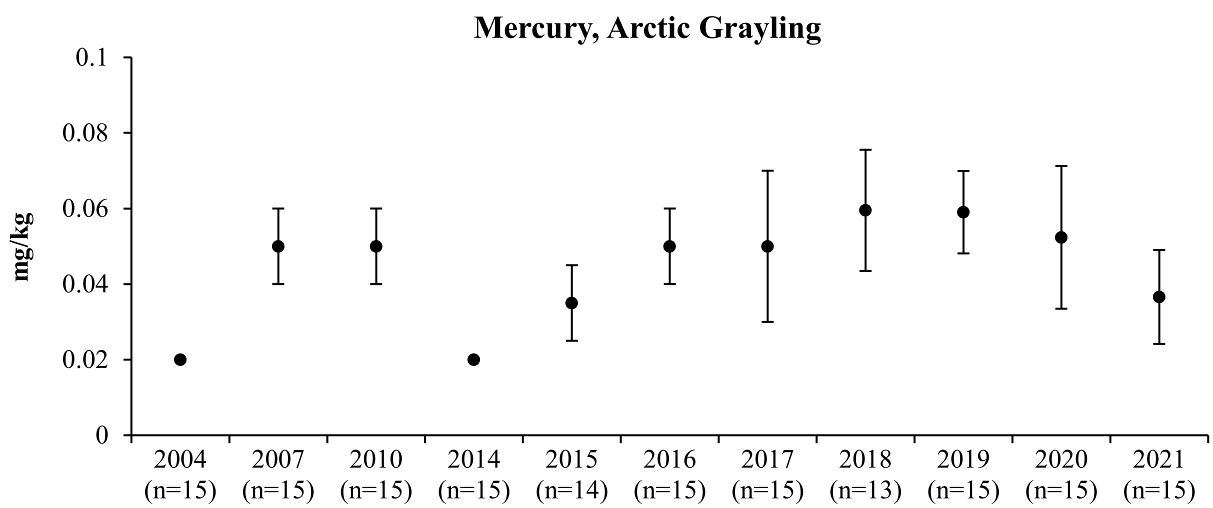


Figure 39. Median mercury concentrations (± 1 SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

In August 2021, juvenile Dolly Varden were collected from Buddy (n = 9), Anxiety Ridge (n = 15), and Mainstem Red Dog creeks (n = 14) for whole body element analysis (Appendix 5).

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 (median value) are typically highest in juvenile Dolly Varden collected from Mainstem Red Dog Creek and consistently lowest in Anxiety Ridge Creek (Figure 40). Peak median cadmium concentrations occurred at all three sites in 2006. Median cadmium concentrations have been at or below 1 mg/kg in fish from Buddy Creek since 2007 and Anxiety Ridge Creek 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 41).

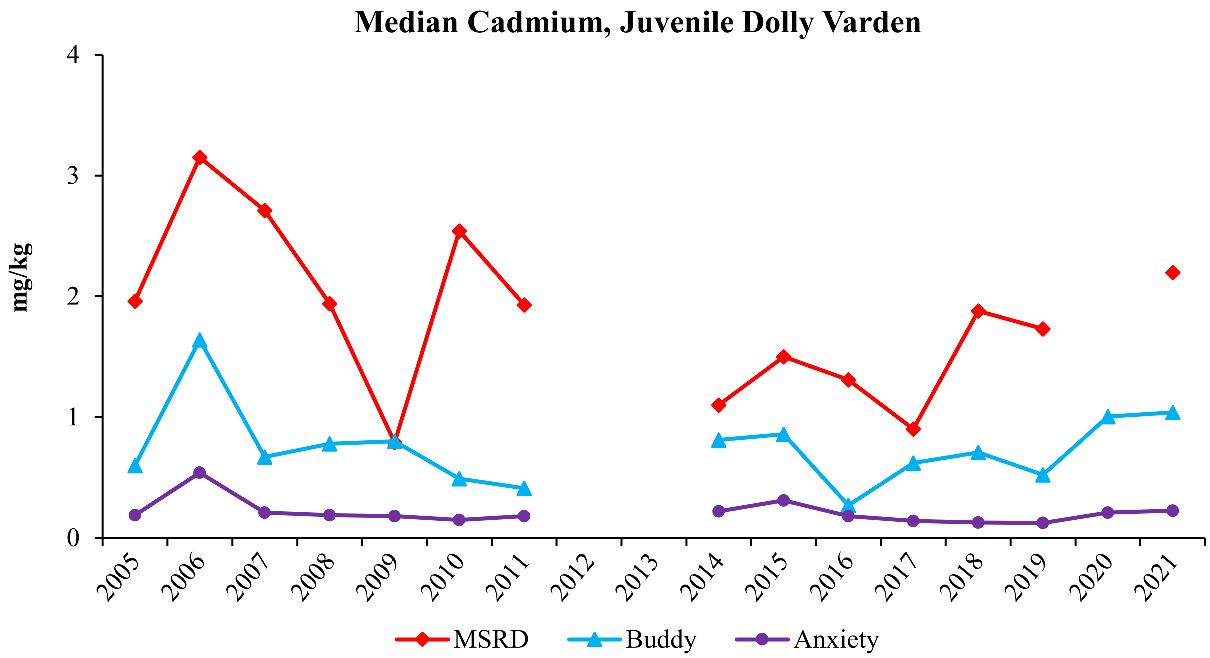


Figure 40. Median whole body cadmium concentrations in juvenile Dolly Varden from 2005 to 2021. No fish were captured in Mainstem Red Dog Creek in 2020.

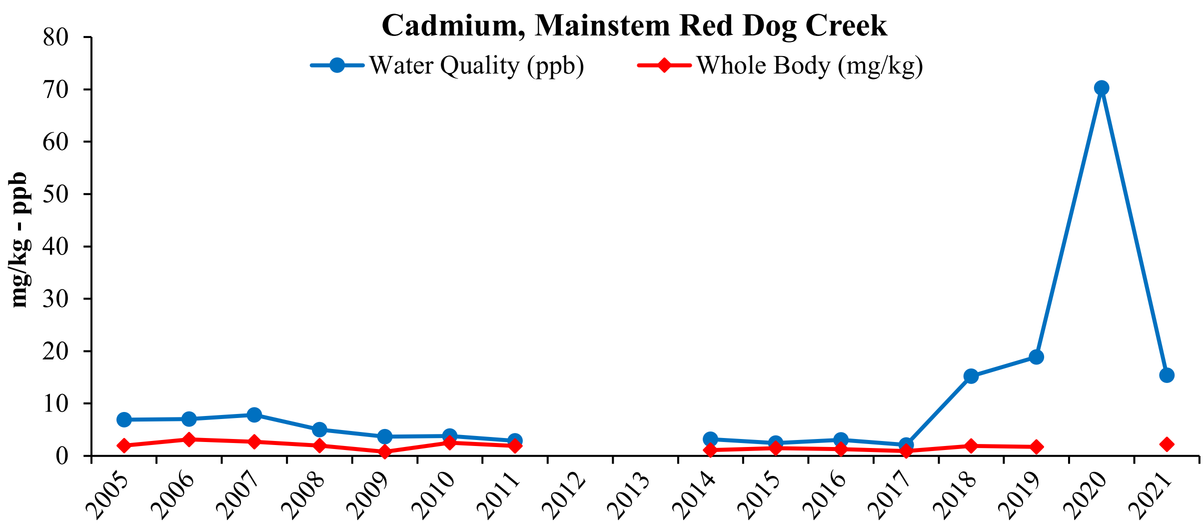


Figure 41. Median whole body cadmium concentrations in juvenile Dolly Varden and median cadmium water quality data for Mainstem Red Dog Creek. No fish were captured in Mainstem Red Dog Creek in 2020.

Median whole body lead concentrations in juvenile Dolly Varden are consistently higher in Mainstem Red Dog Creek than in Buddy and Anxiety Ridge creeks, which have similar lead concentrations (Figure 42). 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 43).

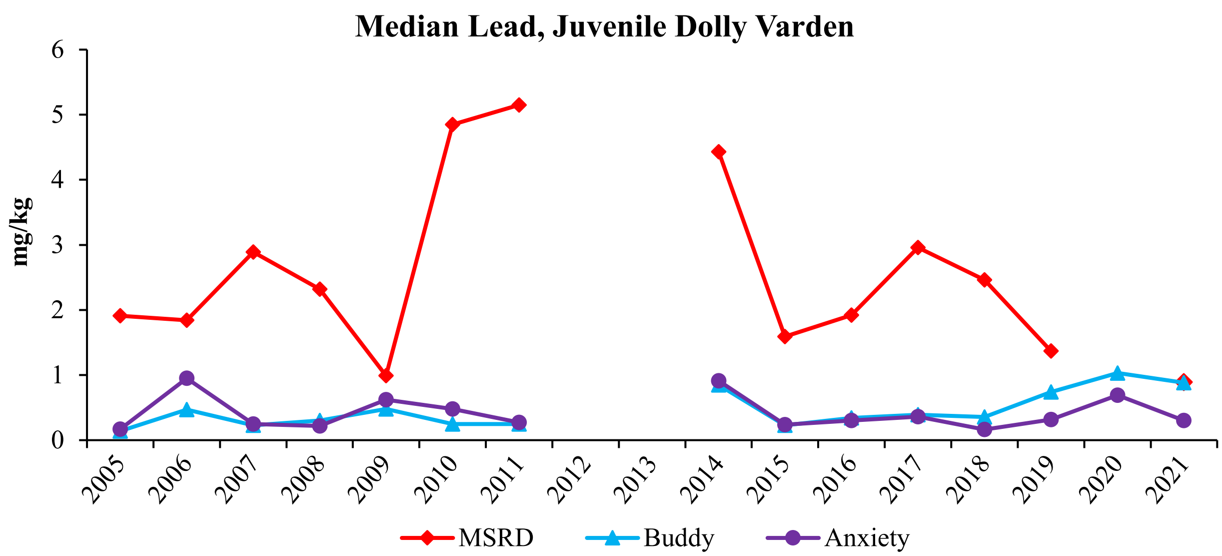


Figure 42. Median whole body lead concentrations in juvenile Dolly Varden from 2005 to 2021. No fish were captured in Mainstem Red Dog Creek in 2020.

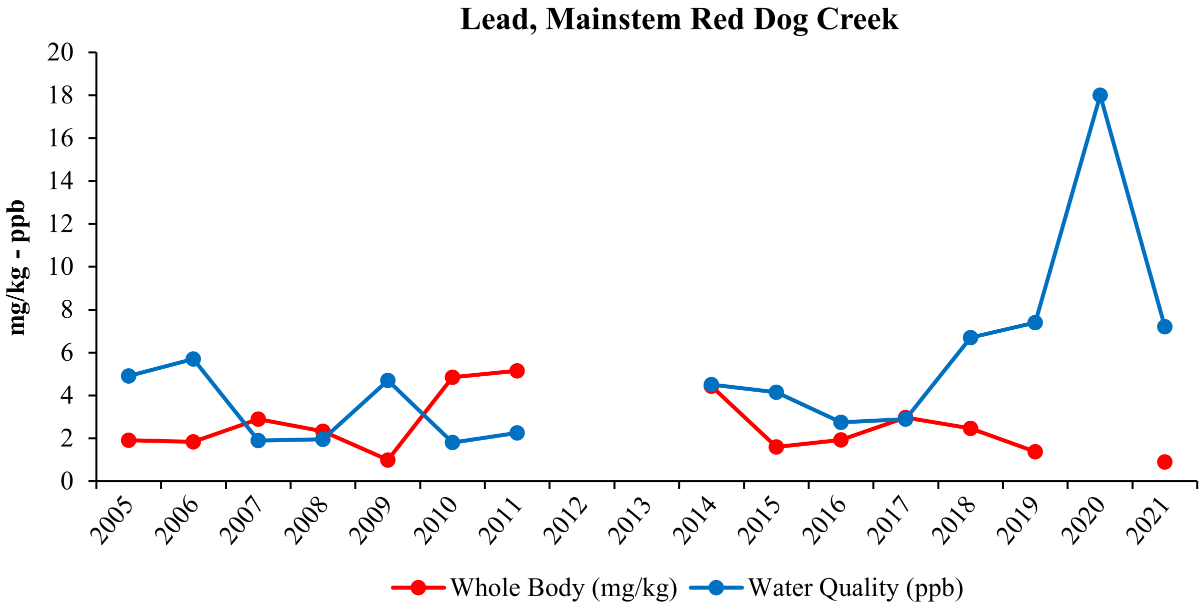


Figure 43. Median whole body lead concentrations in juvenile Dolly Varden and median lead water quality data for Mainstem Red Dog Creek. No fish were captured in Mainstem Red Dog Creek in 2020.

Median whole body selenium concentrations in juvenile Dolly Varden are generally lowest in fish from Anxiety Ridge Creek (Figure 44). 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 increased slightly in 2021. There is no clear relationship in Mainstem Red Dog Creek between selenium concentrations in the water and in whole body juvenile Dolly Varden (Figure 45).

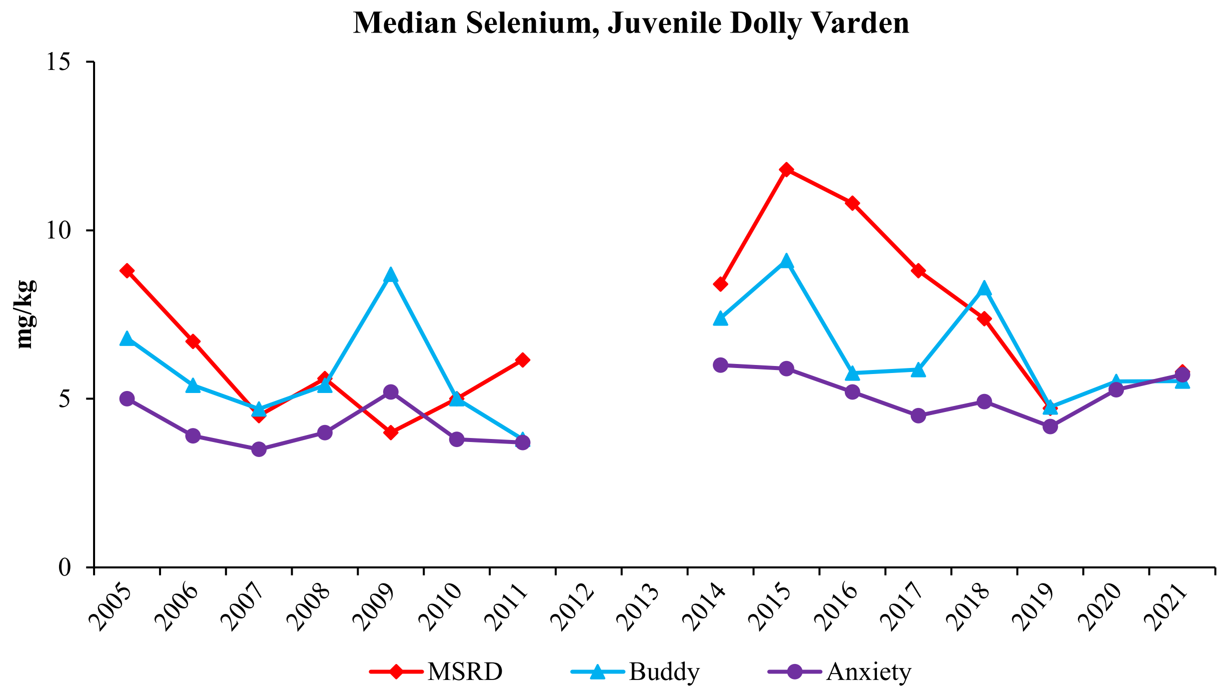


Figure 44. Median whole body selenium concentrations in juvenile Dolly Varden from 2005 to 2021. No fish were captured in Mainstem Red Dog Creek in 2020.

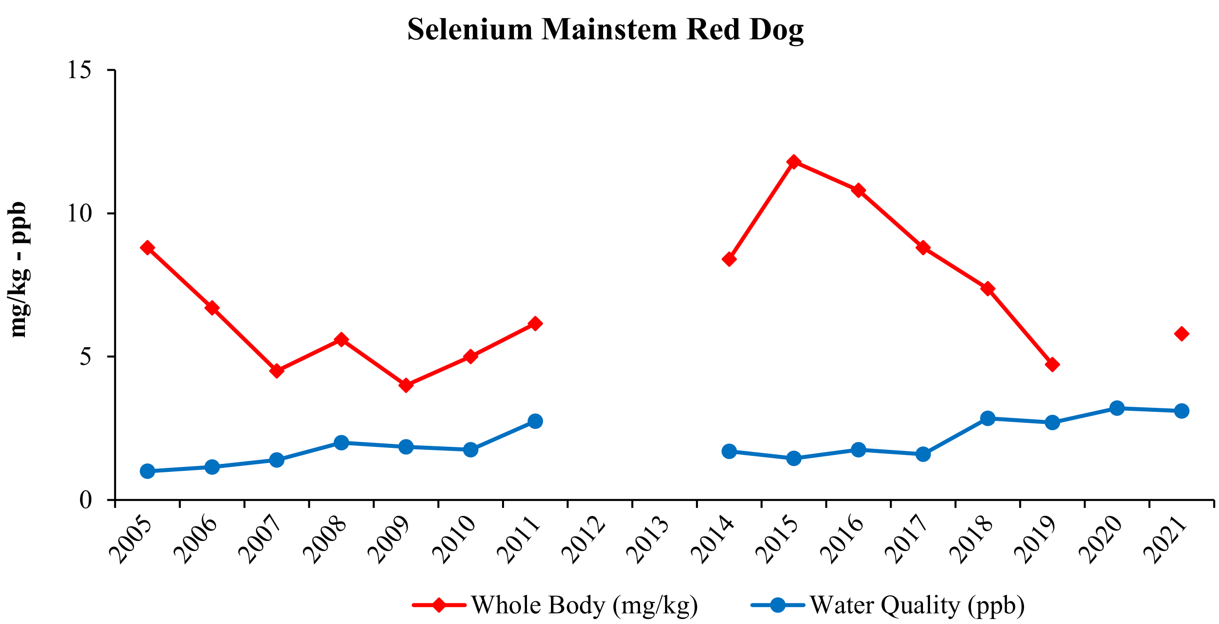


Figure 45. Median whole body selenium concentrations in juvenile Dolly Varden and median selenium water quality data for Mainstem Red Dog Creek. No fish were captured in Mainstem Red Dog Creek in 2020.

Median zinc whole body concentrations are generally highest in fish from Mainstem Red Dog Creek and lowest in fish from Anxiety Ridge Creek (Figure 46). Zinc whole body concentrations in Mainstem Red Dog Creek decreased from a high of 351 mg/kg in 2007 to a low of 154 mg/kg in 2017, but then increased in 2018, 2019, and 2021. 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 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 (Figure 47).

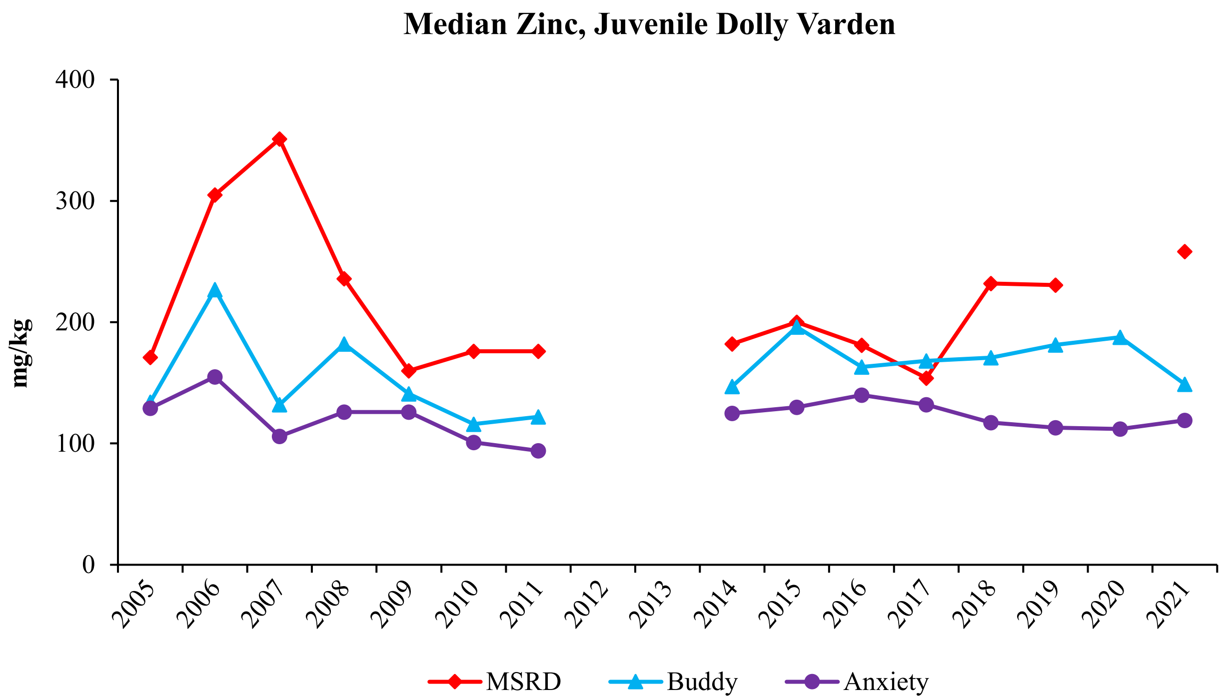
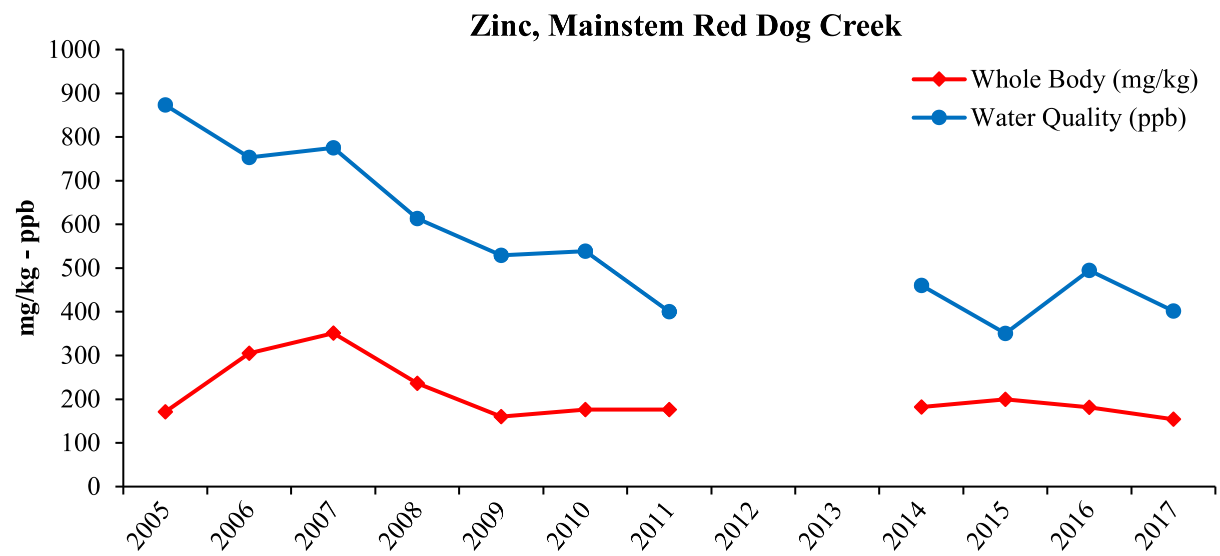


Figure 46. Median whole body zinc concentrations in juvenile Dolly Varden from 2005 to 2021.



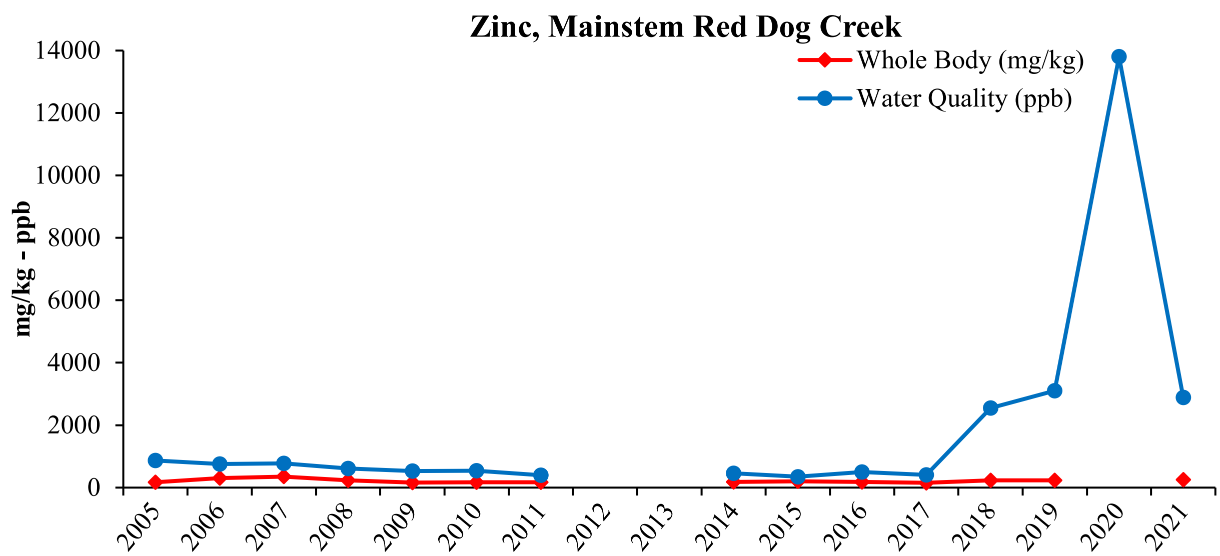


Figure 47. Median whole body zinc concentrations in juvenile Dolly Varden and median zinc water quality data for Mainstem Red Dog Creek. No fish were captured in Mainstem Red Dog Creek in 2020. The top graph presents data from 2005 to 2017, before zinc levels in the water sharply increased beginning in 2018. Please note the different y-axes in the two graphs.

Median mercury concentrations in juvenile Dolly Varden are consistently higher in Anxiety Ridge Creek and very similar between Buddy and Mainstem Red Dog creeks (Figure 48). The highest recorded median concentration of mercury was detected in 2020 in Anxiety Creek at 0.141 mg/kg.

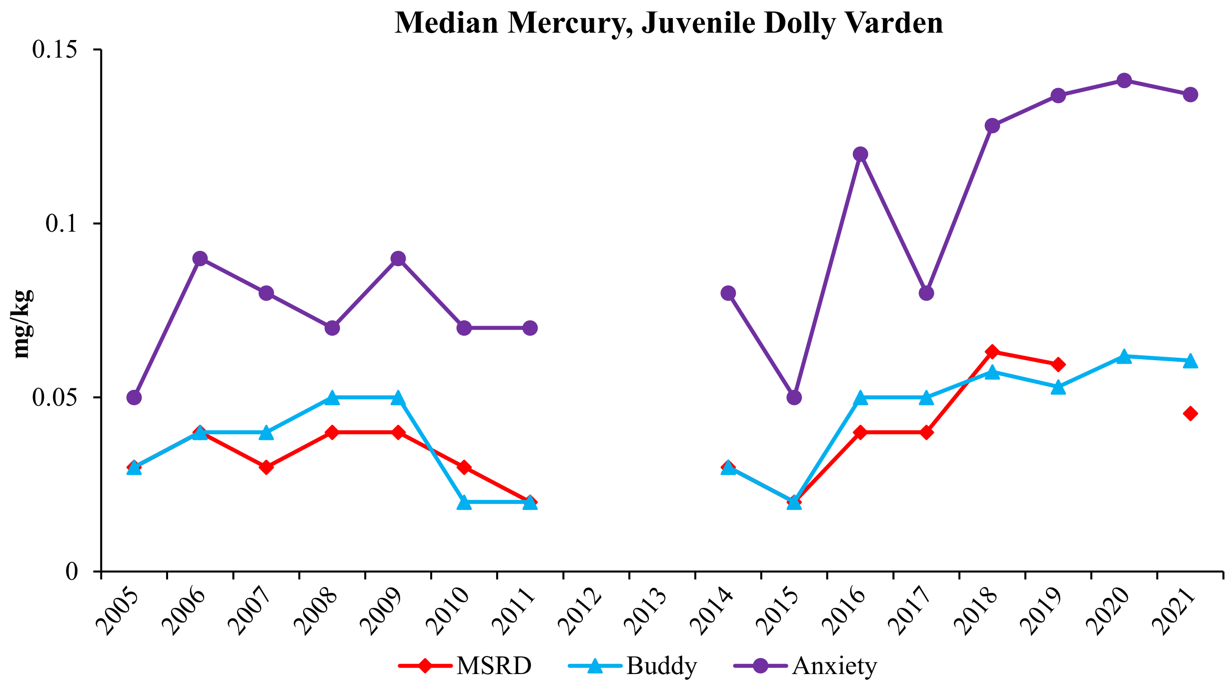


Figure 48. Median whole body mercury concentrations in juvenile Dolly Varden from 2005 to 2021. No fish were captured in Mainstem Red Dog Creek in 2020.

Metal Concentrations in Adult Dolly Varden

In 2021, 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. Thirteen fish were sampled in 2021, seven in the spring and six 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 the majority of Dolly Varden growth occurs in the marine environment. All laboratory work was done with Level III Quality Assurance. Data for 2021 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 2021, 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.

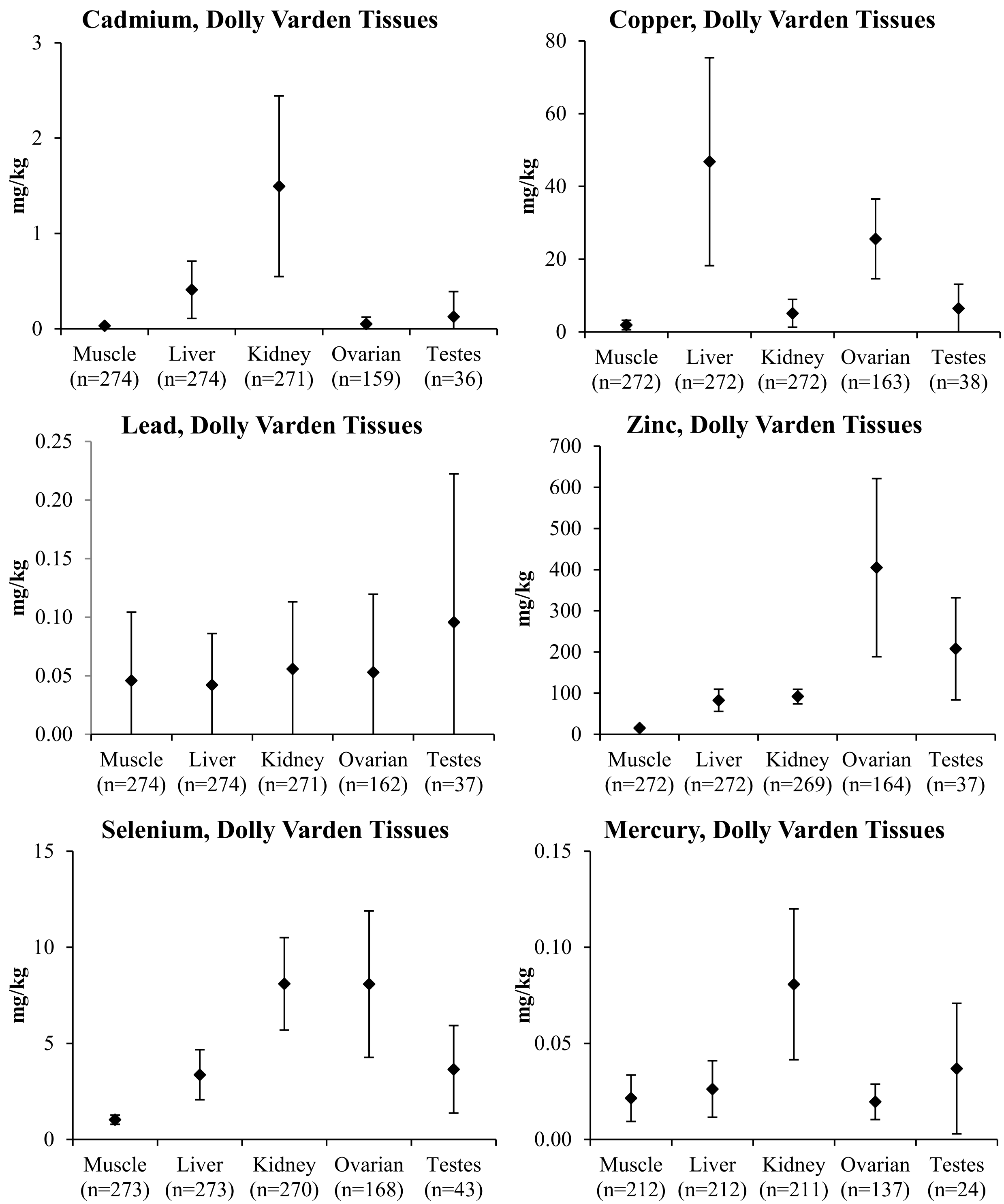


Figure 49. Average element concentration (dry weight) ±1 SD in adult Dolly Varden tissues, Wulik River (1999–2021[3]).

[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 remained low until increasing in 2020 and 2021.

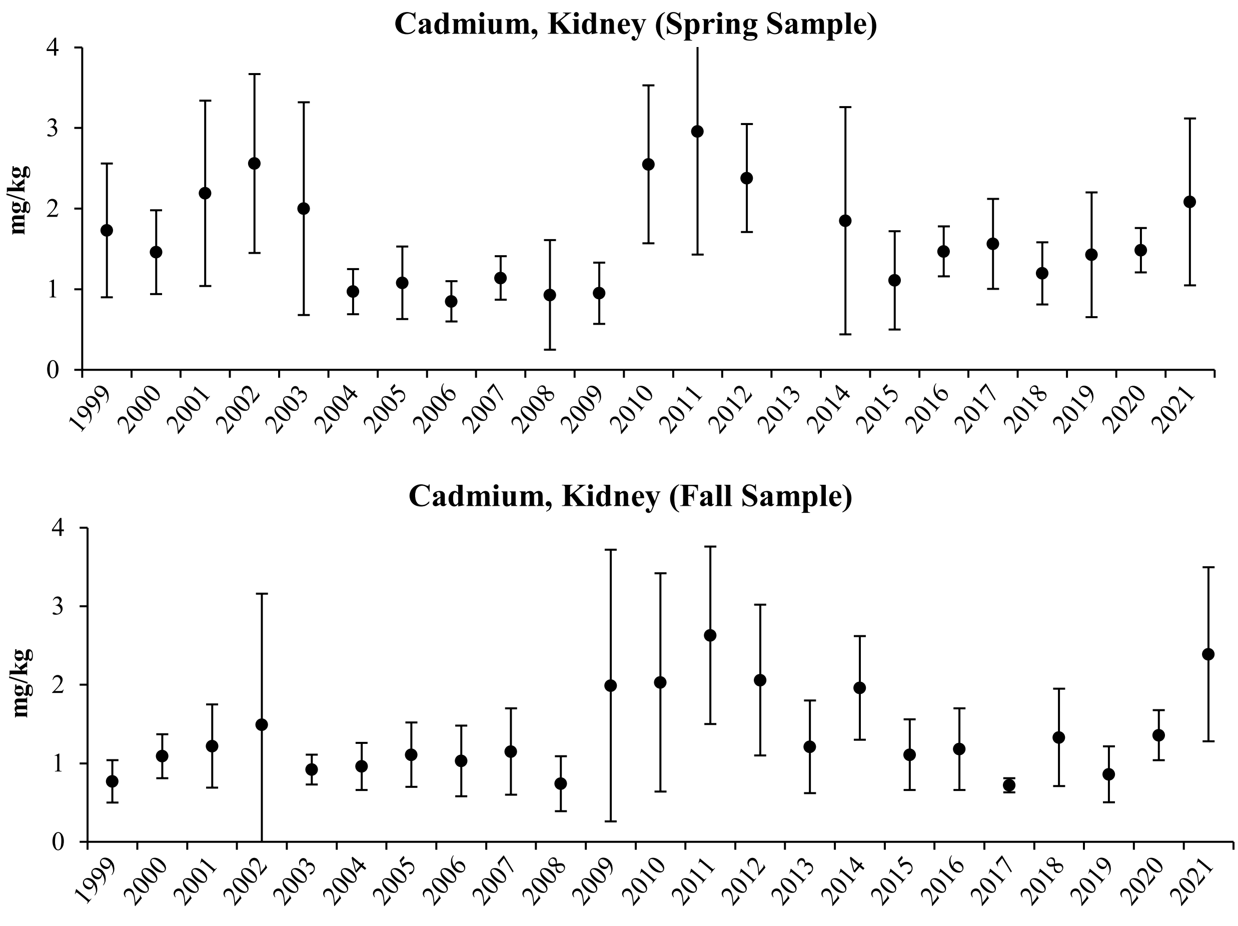


Figure 50. Average cadmium (± 1SD) concentrations (dry weight) in adult Dolly Varden kidney tissues from 1999 to 2021.

Average selenium concentrations in adult Dolly Varden ovaries are higher for fish sampled in the fall (9.85 mg/kg) than for fish sampled in the spring (5.72 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.

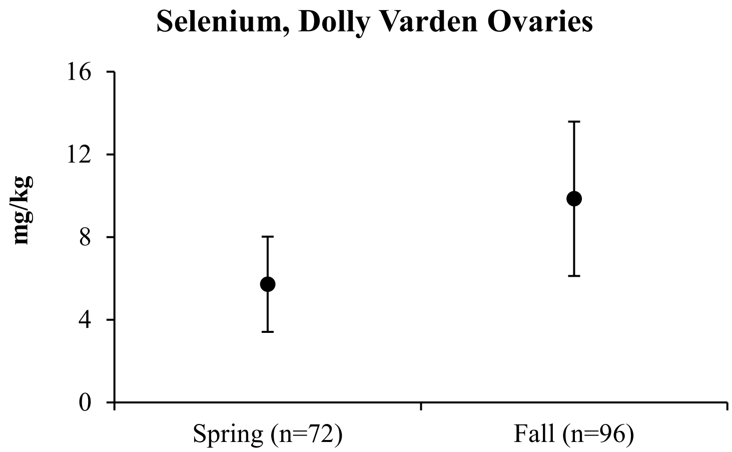


Figure 51. Average selenium (± 1SD) concentrations (dry weight) in Dolly Varden ovaries from 1999 to 2021.

Dolly Varden, Overwintering

An aerial survey was conducted using a helicopter on October 8, 2021, to estimate the number of overwintering Dolly Varden in the Wulik River (Figure 52). 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 and 2020 surveys. A total of 87,361 Dolly Varden were counted in the Wulik River, although this should be considered a minimum estimate due to reduced visibility.

In 2018, 1,590 fish were counted in the Wulik River upstream of the mouth of Ikalukrok Creek. In 2019, 17,308 fish were counted upstream of the mouth of Ikalukrok Creek. In 2020, 19,860 fish were counted above the mouth, and in 2021, 12,201 fish were counted upstream of the mouth. On average, 95% of Dolly Varden observed have been downstream of the mouth of Ikalukrok Creek (36 surveys 1979-2021, Table 2). In 2021, 86% of the fish observed were downstream of the confluence, although the number of fish counted downstream may be an underestimate due to reduced visibility.

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).

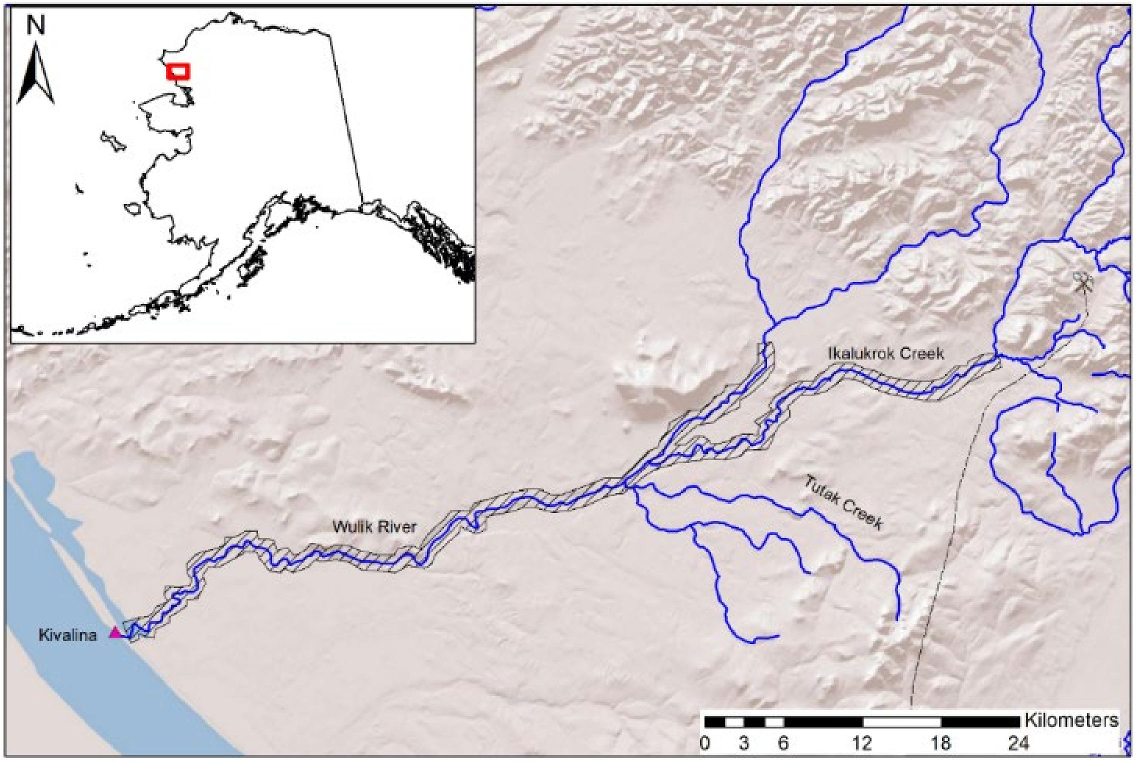


Figure 52. Dolly Varden and chum salmon aerial survey area. The striped polygon denotes the surveyed portion of the drainage.

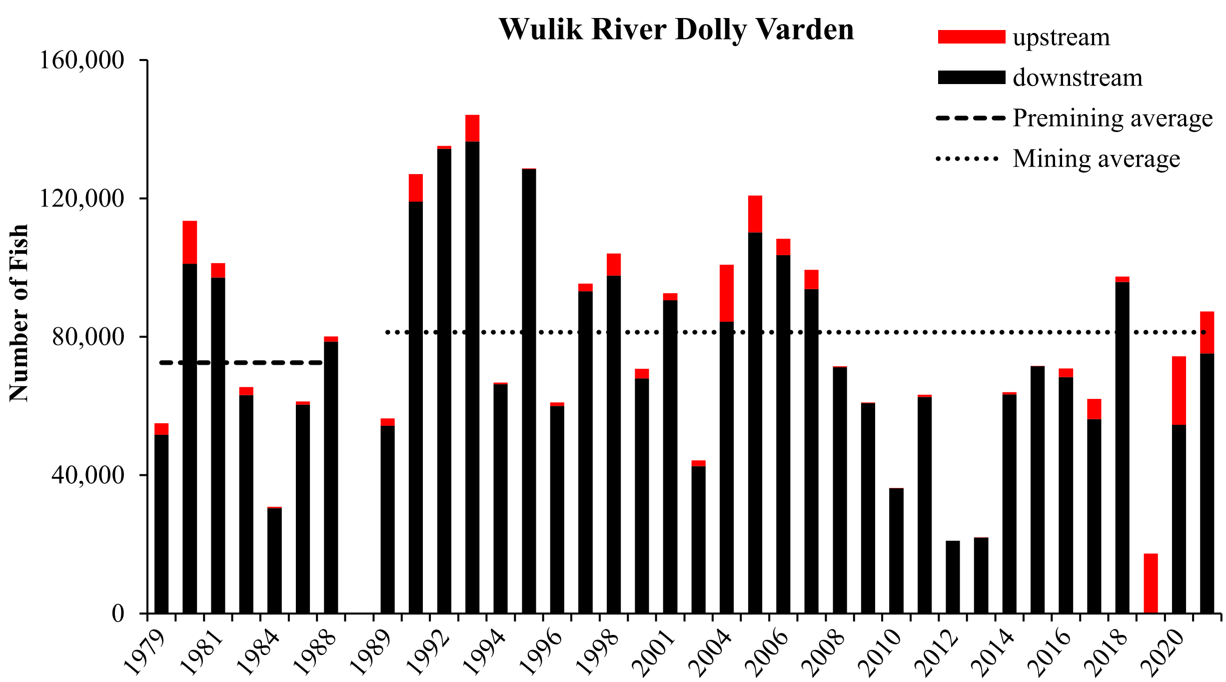


Figure 53. Aerial survey estimates of the number of Dolly Varden in the Wulik River just prior to freeze up, 1979-2021. In 2019, turbidity prevented a count of fish downstream of Ikalukrok Creek, and in 2020 - 2021, turbidity limited visibility in deep water areas downstream of Ikalukrok Creek.

Table 3. 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

[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 flown using a helicopter on September 10, 2021. Visibility was severely impeded by turbidity in Ikalukrok Creek and only side channels, sloughs and backwaters were clear enough for reliable observation, so although 117 chum salmon were counted, this is likely a considerable underestimate (Figure 54).

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.

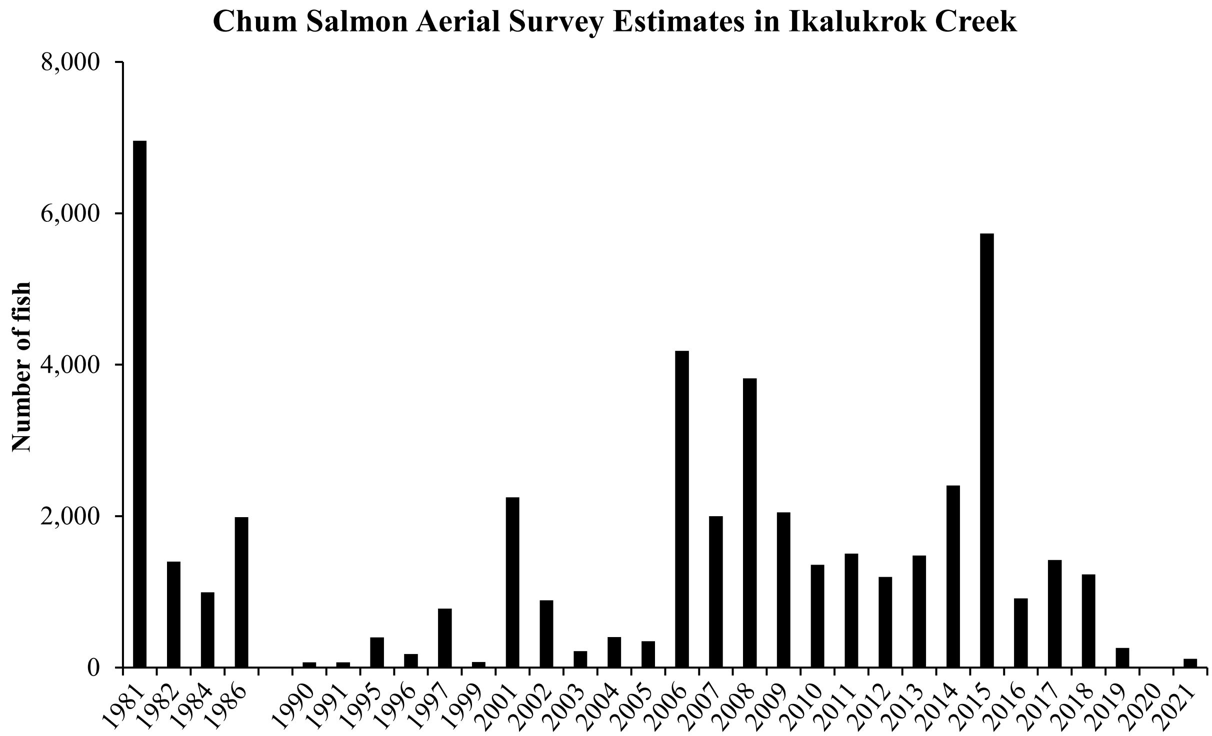


Figure 55. Peak estimates of chum salmon escapement in Ikalukrok Creek. The chum salmon spawning reaches are concentrated in select areas along this reach of the creek. The 1981 count was an estimate based on extrapolation from aerial photographs. The 2019 – 2021 counts were impacted by limited visibility in Ikalukrok Creek due to unusually high turbidity.

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 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 the new Station 160 corresponds to Station 7 – instead of being immediately downstream of Dudd Creek, it is now located about 7 km downstream.

Table 4. 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 2021, the CPUE was highest in Anxiety Ridge Creek (81.0 fish/24 hours), Buddy Creek (24.7 fish/24 hours) and Evaingiknuk Creek (13.1 fish/24 hours) (Figure 56). In 2020, no fish were caught in the Red Dog Creek drainage. In 2021, juvenile Dolly Varden were caught at both sample sites in Mainstem Red Dog Creek.

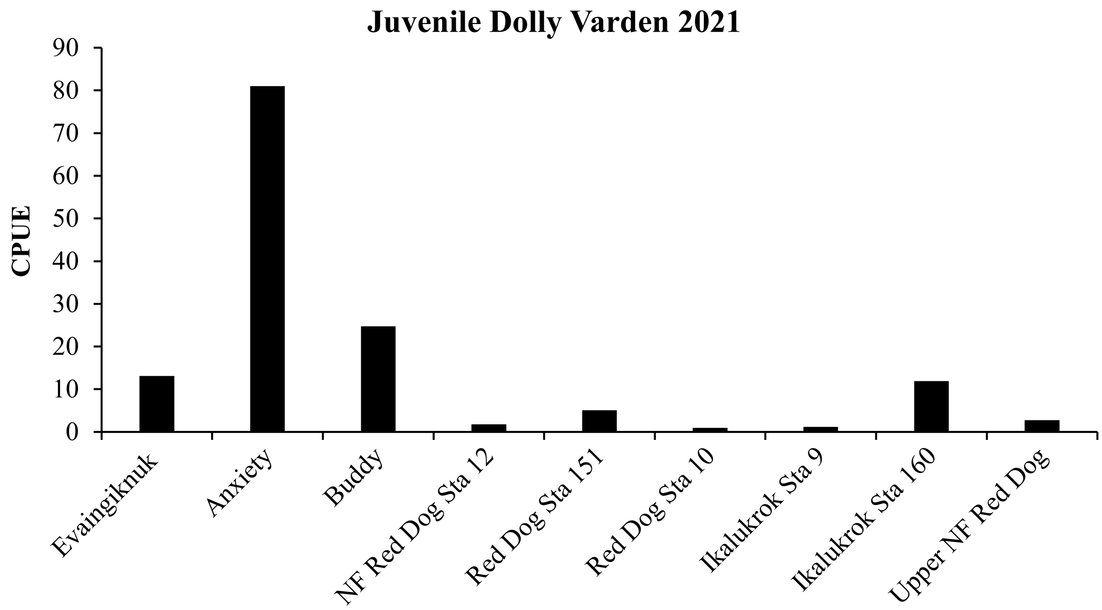


Figure 56. CPUE for juvenile Dolly Varden in the Red Dog sample reaches in 2021.

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 2021 reflects the high degree of variability among sample years (Figure 57).

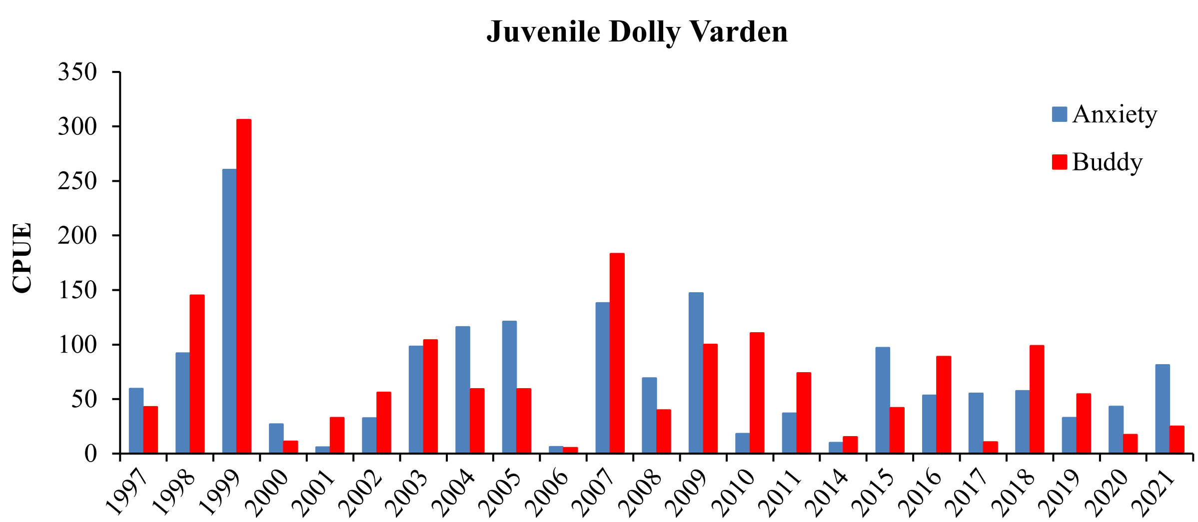


Figure 57. CPUE of juvenile Dolly Varden in Anxiety Ridge and Buddy creeks, 1997–2021. No sampling was performed in 2012 or 2013 due to high water.

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.

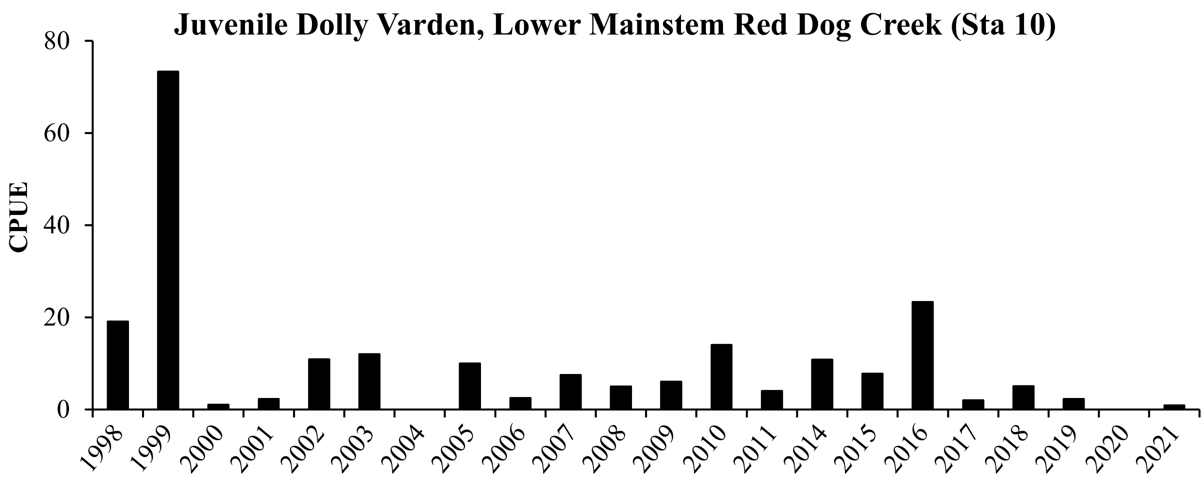


Figure 58. CPUE of juvenile Dolly Varden in Lower Mainstem Red Dog Creek, 1998 - 2021. No sampling was performed in 2012 or 2013 due to high water.

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 2021, 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 2021, 11 out of 137 captured fish were ≤ 70 mm FL (Figure 59).

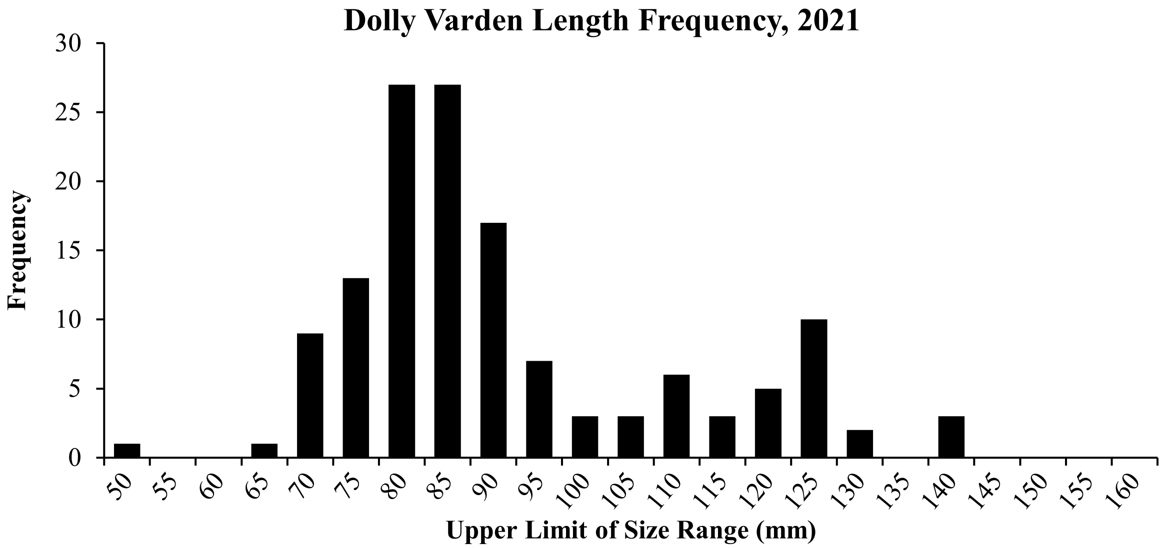


Figure 59. Length frequency distribution of Dolly Varden in the Ikalukrok Creek drainage in August 2021.

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 to the inability of larger fish to enter the minnow traps. In spring 2021, 13 Dolly Varden were caught in the fyke nets ranging from 96 mm FL to 260 mm FL, with an average size of 155 mm FL (Figure 60). Many of the Dolly Varden caught in North Fork Red Dog Creek in the spring are likely the resident form.

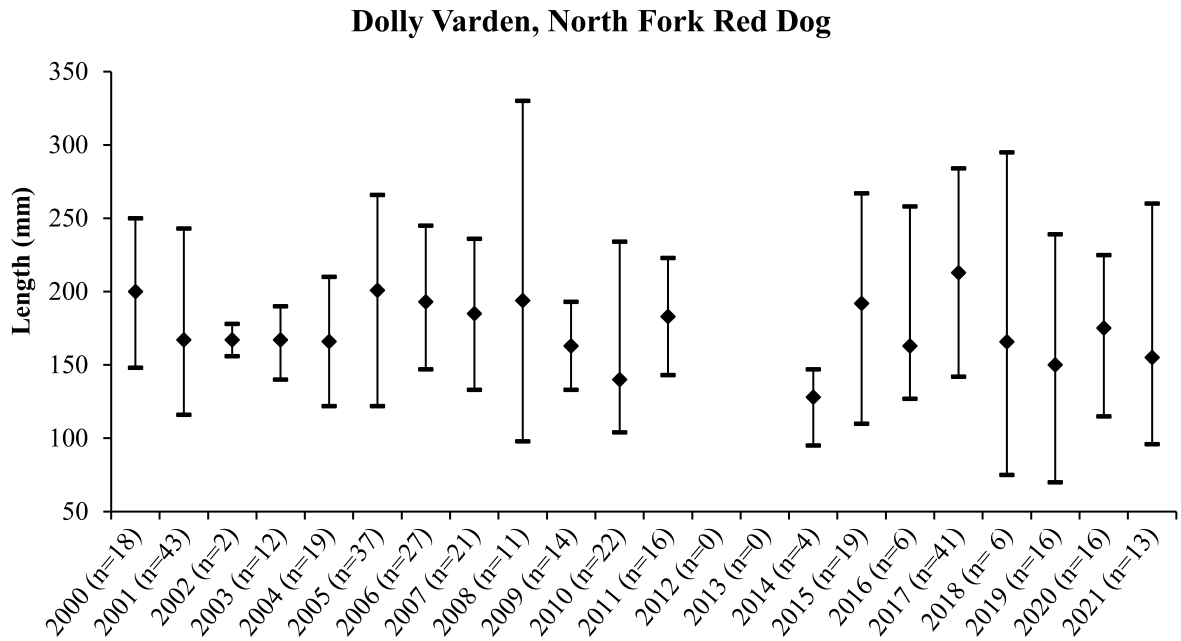


Figure 60. Dolly Varden caught in fyke nets fished in North Fork Red Dog Creek in spring. Average, maximum, and minimum lengths are shown for each sample year.

Juvenile Coho Salmon

In recent years, juvenile coho salmon have been captured during the juvenile Dolly Varden sampling event, however no salmon were captured in 2021. In 2020, a total of four juvenile coho were captured, two at Buddy Creek below the falls and two in Anxiety Ridge Creek. In 2019, juvenile coho were captured at Mainstem Red Dog Creek Station 10, Ikalukrok Creek Station 160, Buddy Creek below the falls, Anxiety Ridge Creek, and Dudd Creek (Table 4). Fifteen of the captured juvenile salmon were retained for visual and DNA species identification. All 15 were confirmed as coho salmon. Red Dog, Anxiety Ridge, Buddy, Dudd, and Ikalukrok creeks were added to the Anadromous Waters Catalog as rearing habitat for juvenile coho salmon. Prior to 2019, the only species of juvenile salmon captured in minnow traps in the Ikalukrok Creek drainage was Chinook salmon. In 2004, five juvenile Chinook were captured in Anxiety Ridge Creek and one in Ikalukrok Creek.

Table 5. Juvenile coho salmon captured in minnow traps in August 2019 and August 2020.

Sample Site	Station #	2019	2020
Mainstem Red Dog Creek	10	1	
Ikalukrok Creek	160	13	
Buddy Creek below falls		5	2
Anxiety Ridge Creek		10	2
Dudd Creek		18	

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. Dolly Varden and Arctic grayling fry mortality was 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.

Arctic grayling spawning 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 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 2021, one fyke net was set to capture Arctic grayling in North Fork Red Dog Creek from May 28 to June 3. Water flows were low throughout the fishing period, which allowed the fyke net to effectively capture fish for the duration of the sampling event. Peak daily water temperatures ranged from 5.3 to 8.0°C.

Limited spawning in Mainstem Red Dog Creek could have started on May 23, when the peak daily water temperature reached 3°C (Figure 61, Table 4). Six females were captured in the fyke net during the sampling period. Two were green and four were ripe, and none were determined to be spent. Spawning completion date is determined based on catch of spent females in the North Fork Red Dog Creek fyke net and water temperature data, and could not be determined in 2021 as no spent females were captured.

Water temperatures are typically higher in Mainstem Red Dog Creek than in North Fork Red Dog Creek, although this was not observed in 2021 (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.

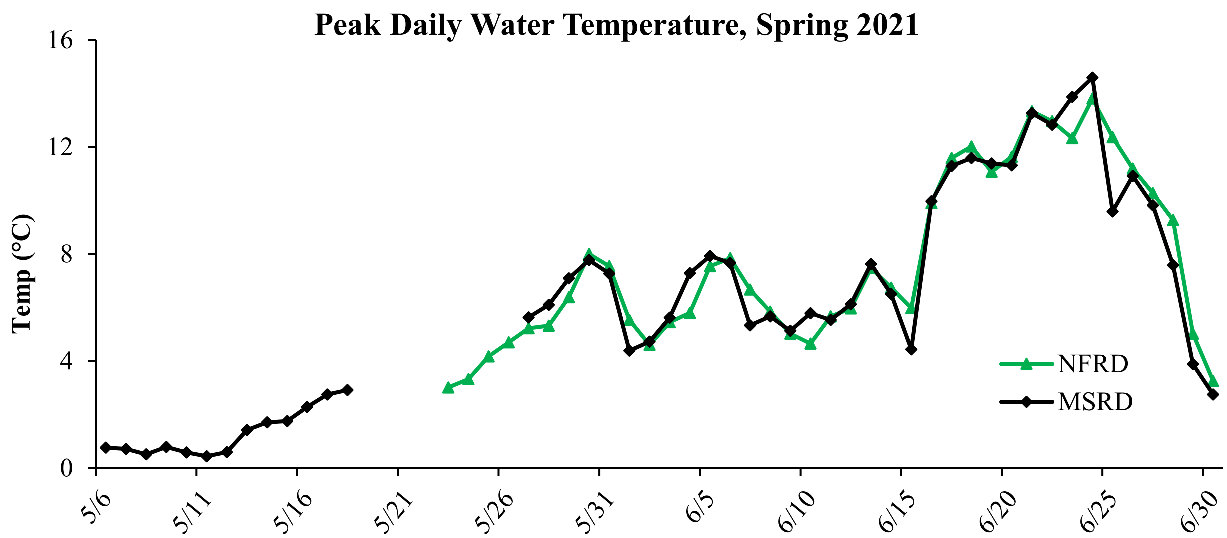


Figure 61. Peak daily water temperatures in North Fork Red Dog (Station 12) and Mainstem Red Dog (Station 151) creeks, May and June 2021.

Table 6. Summary of Arctic grayling spawning in Mainstem Red Dog Creek.

Year	Date When Limited Spawning Began (3°C)	Date When Spawning Complete	# of Days Peak Temp > 4°C
2001	6-Jun	15-Jun	6
2002	29-May	8-Jun	8
2003	7-Jun	14-Jun	6
2004	25-May	31-May	4
2005	27-May	6-Jun	9
2006	30-May	15-Jun	10
2007	26-May	3-Jun	8
2008	1-Jun	9-Jun	9
2009	8-Jun	13-Jun	4
2010	21-May	29-May	6
2011	6-Jun	9-Jun	4
2012	27-May	4-Jun	7
2013[1]			
2014	5-Jun	11-Jun	4
2015	28-May	1-Jun	4
2016	12-May	20-May	8
2017[2]	31-May		
2018[2]	2-Jun		
2019[2]	31-May		
2020[2]	29-May		
2021[2]	23-May		

[1] Sampling was not conducted in spring 2013 due to extremely high water during the sampling period.
[2]The end of spawning could not be judged as spent females were not captured in the fyke net.

In spring 2021, the catches of Arctic grayling were low throughout the sampling period (Figure 62). The fyke net in North Fork Red Dog Creek captured 27 Arctic grayling, one of which was immature.

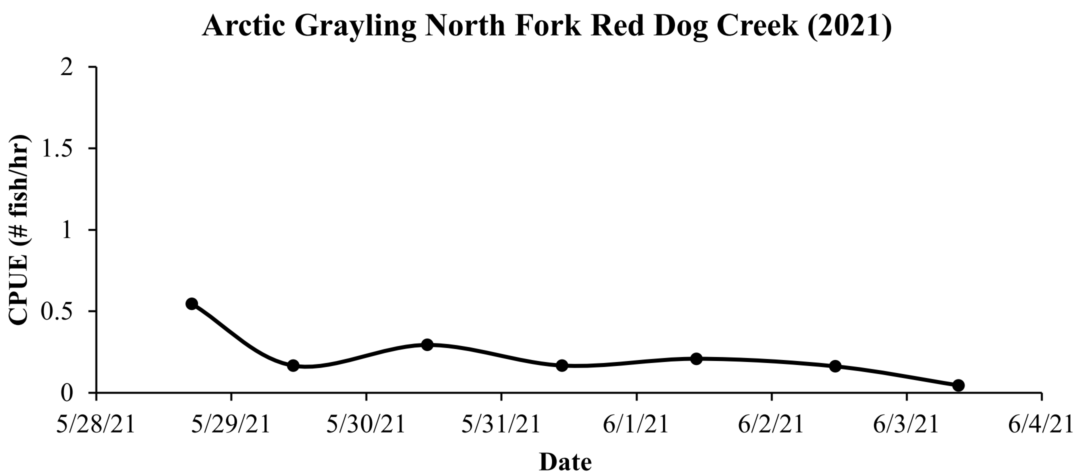


Figure 62. The CPUE of Arctic grayling in North Fork Red Dog Creek in spring 2021.

Recruitment of immature fish to North Fork Red Dog Creek was strong from 2007 to 2016, but low from 2017 to 2021 (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, and 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 in 2020 and 2021 is unknown, but may have to do with the altered water quality in Mainstem Red Dog Creek.

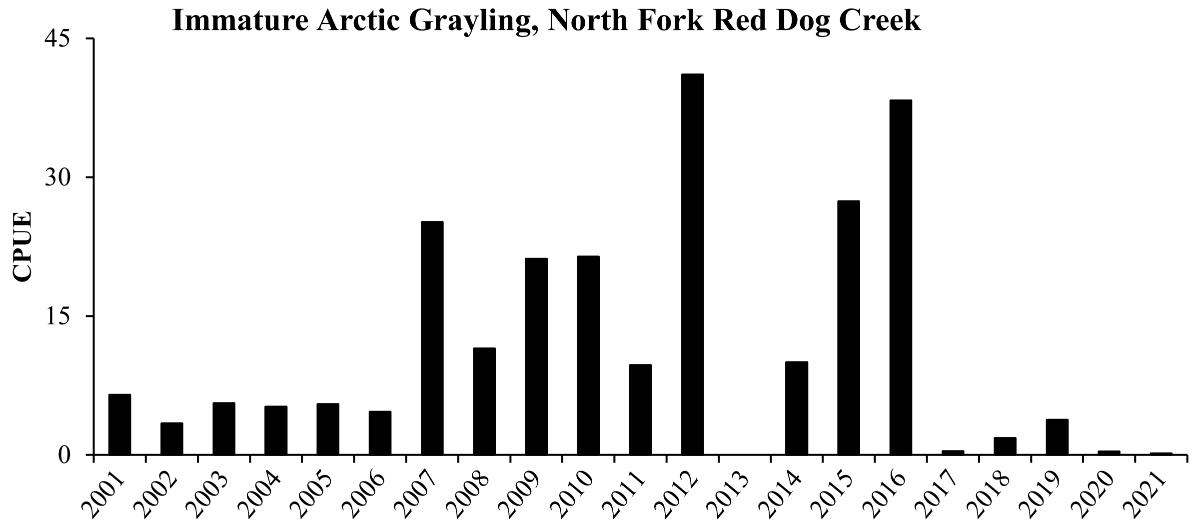


Figure 63. CPUE of immature Arctic grayling in North Fork Red Dog Creek fyke net during spring sampling. Sampling was not conducted in 2013 due to high water.

Catches of mature Arctic grayling in North Fork Red Dog Creek have been relatively stable since 2001, with a few exceptions (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 (≤ 100 cfs) when fyke nets can be set, maintained, and fished effectively.

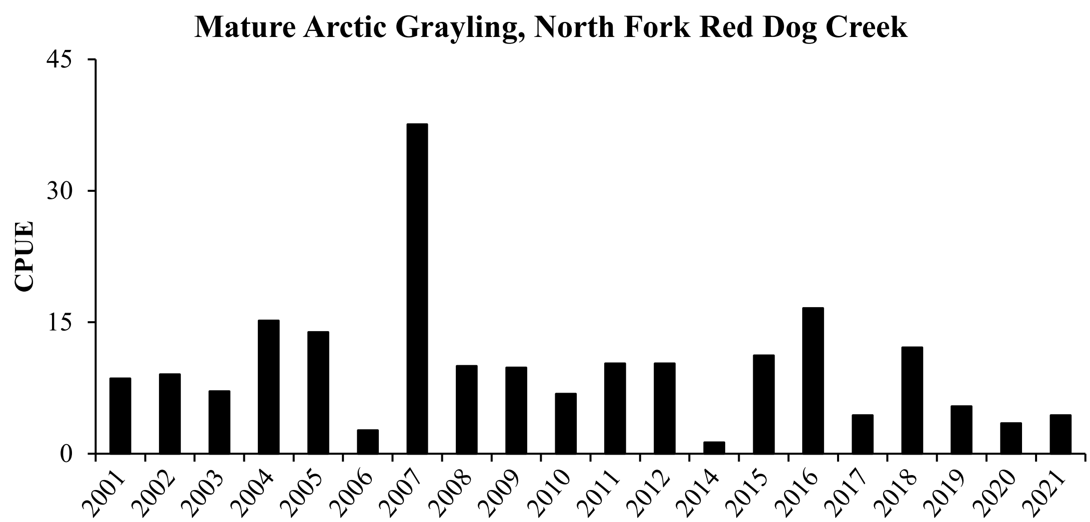


Figure 64. Average CPUE (fish/day) of mature ("ripe" or "spent") Arctic grayling in North Fork Red Dog Creek from spring 2001 to spring 2021. Sampling was not conducted in 2013 due to high water.

Some of the Arctic grayling caught in the North Fork Red Dog Creek are fish that were originally tagged in Bons Pond. In 2021, none of the marked fish captured in North Fork Red Dog Creek were Bons Pond tagged fish (Figure 65).

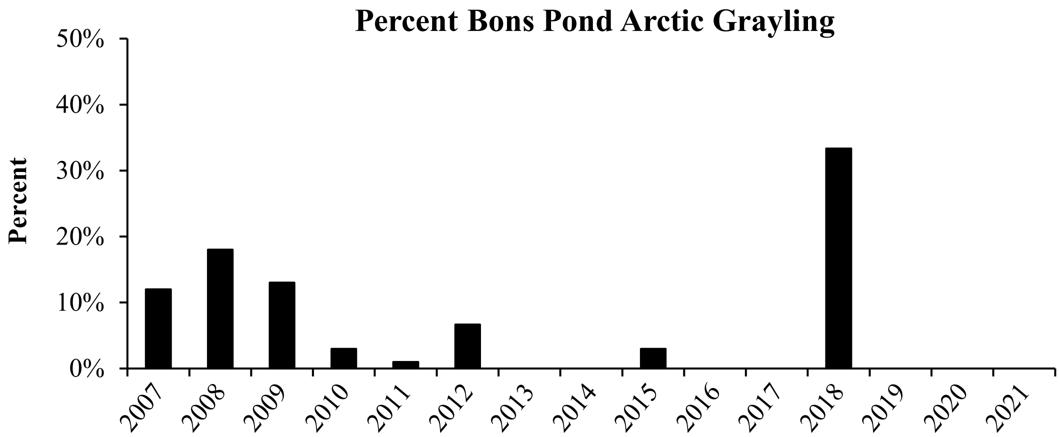


Figure 65. Percent of Bons Pond marked fish caught in North Fork Red Dog Creek.

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 two fish were recaptured in 2021. The growth rate for the two fish recaptured in 2021 was zero mm. Both of these fish were large, sexually mature fish when they were initially tagged in 2020 (402 and 394 mm FL), so it is expected that their growth rate would be very low.

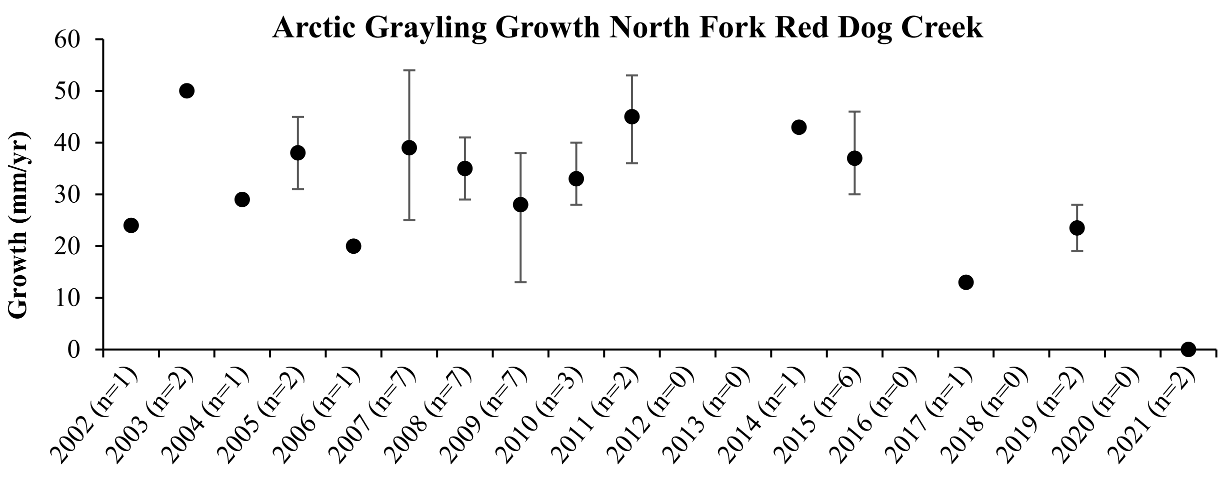


Figure 66. Average, maximum, and minimum annual growth of Arctic grayling in North Fork Red Dog Creek for fish at least 250 mm FL when marked.

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). The confidence limits overlap for all of the population estimates suggesting that there are no substantial differences among years. There were two recaptures in 2021, so we were able to perform a population estimate, although the 95% confidence interval is large.

The mean size of captured Arctic grayling in North Fork Red Dog Creek in 2021 was 376 mm FL. Sizes ranged from 235 mm FL to 450 mm FL (Figure 68). Only fish over 200 mm FL were tagged.

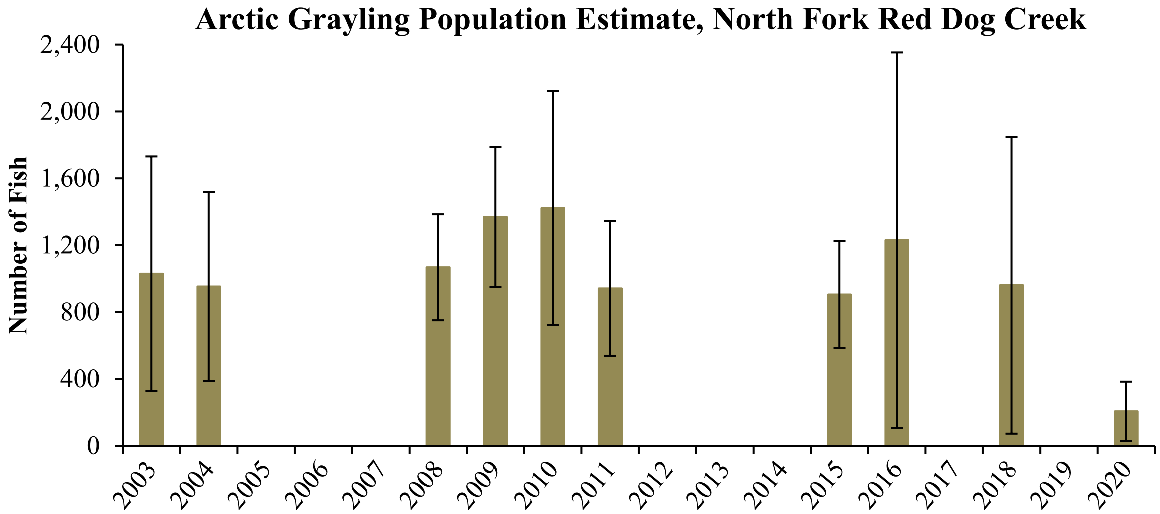


Figure 67. The estimated Arctic grayling population (95% CI) in North Fork Red Dog Creek for fish ≥ 200 mm FL.

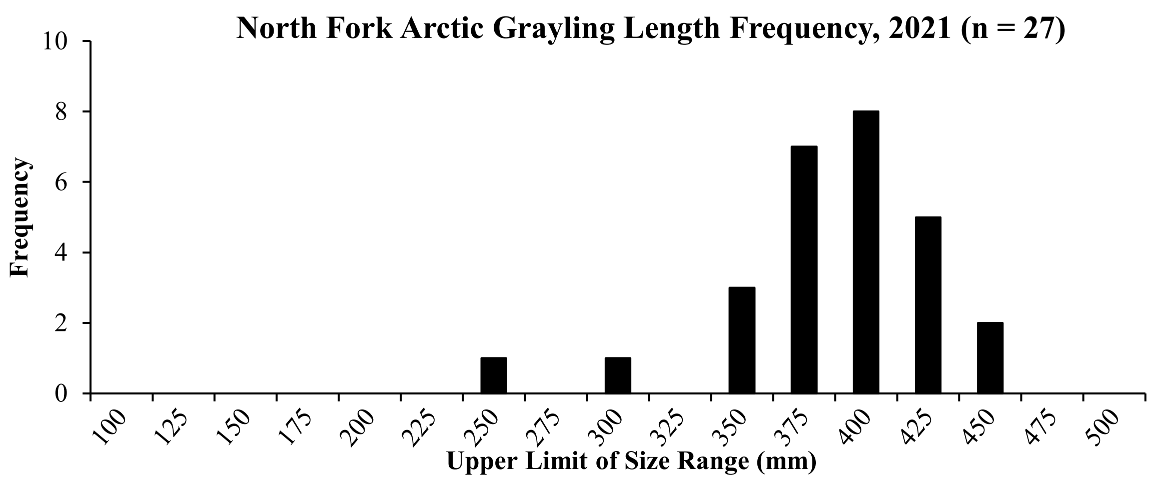


Figure 68. Length frequency distribution of Arctic grayling (n = 27) in North Fork Red Dog Creek, spring 2021.

Arctic Grayling, Bons Pond

Bons Pond is an impoundment created by construction of an earthen dam placed on Bons Creek. The dam was built in 1987/1988 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 69). Bons Creek flows into Buddy Creek and eventually into Ikalukrok Creek.

Figure 69. 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 $\geq$ 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 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.

The aquatic invertebrate sampling methodology that was described earlier in this report is also simultaneously used to sample larval fish. In Bons Creek, upstream of Bons Pond, catches of Arctic grayling fry have ranged from zero to 132 in 17 years of sampling. The highest number of Arctic grayling fry caught in the drift nets was 132 in 2019 (Figure 70).

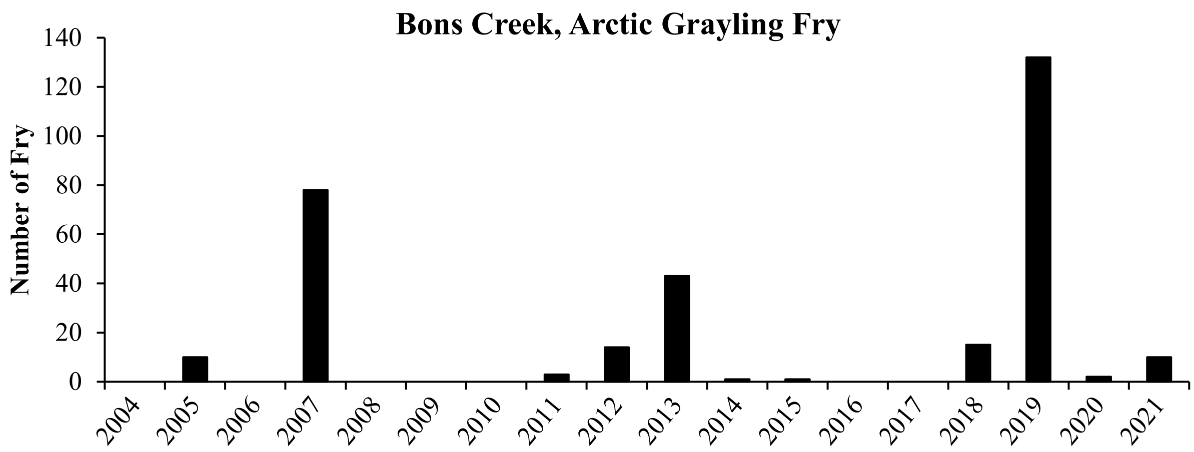


Figure 70. Number of Arctic grayling fry caught in drift nets 2004 – 2021.

A fyke net fished in Bons Creek from May 28 – June 2, 2021 caught 208 unique Arctic grayling of taggable size, plus 349 fish too small to tag (< 200 mm FL). A fyke net set in the outlet of Bons Pond captured an additional 149 Arctic grayling of taggable size and 18 juvenile Arctic grayling <200 mm FL. Unlike 2019, when 3,873 juvenile Arctic grayling <100 mm FL were captured, in 2021 only 17 of the Arctic grayling captured in both nets were <100 mm FL. Of the 357 fish that were ≥ 200 mm FL, 105 were recaptures, and 252 were tagged.

The mean CPUE (#fish/day) for all fish in the Bons Creek fyke net in 2021 was 111 (Figure 71). The CPUE for Arctic grayling < 200 mm FL was 69 in 2021, the highest seen since sampling began in 2006 (Figure 72).

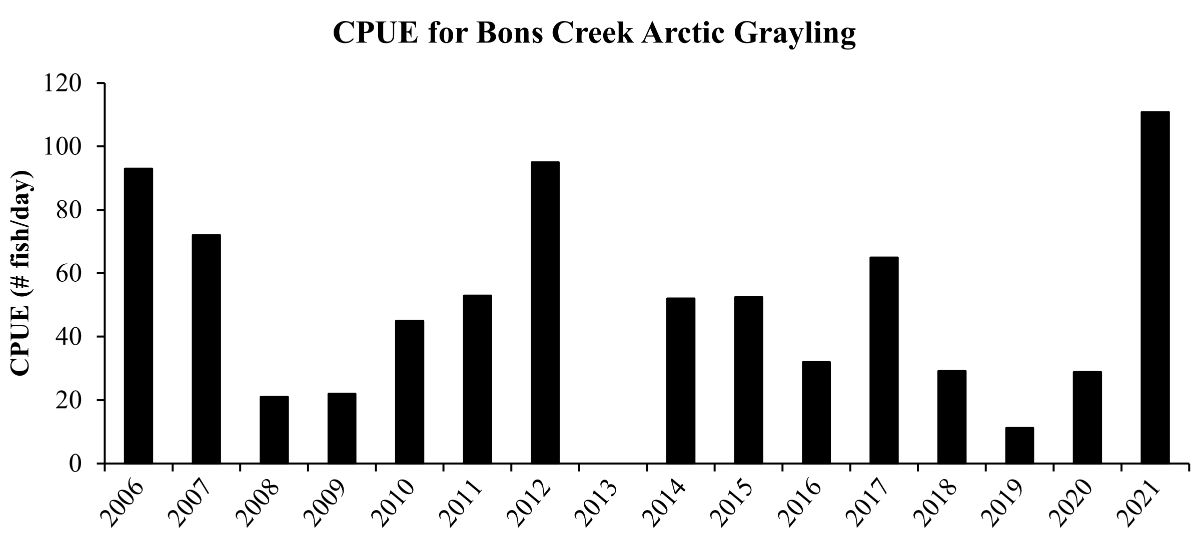


Figure 71. CPUE for all Arctic grayling in Bons Creek 2006–2021. Sampling was not done in 2013 due to high water.

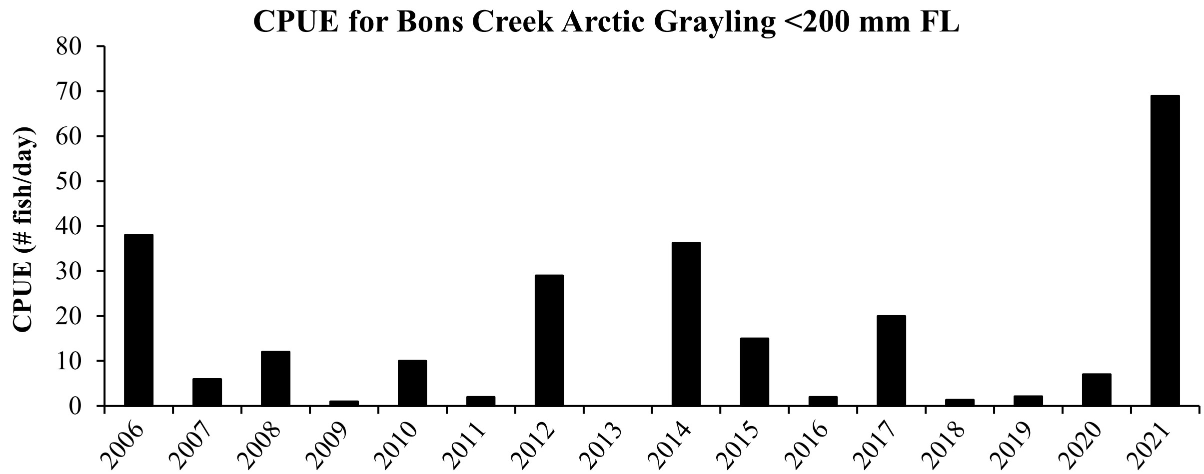


Figure 72. CPUE for Arctic grayling < 200 mm FL in Bons Creek 2006–2021. Sampling was not done in 2013 due to high water.

The length frequency distribution for Arctic grayling caught in fyke nets in spring 2021 is presented in Figure 73. The length frequency distribution in Bons Pond fish had been relatively consistent over the past several years, with a stable population of mature fish 300 – 390 mm. In 2019, a large number of fish 50 – 100 mm (n = 3,873) were captured, which were likely age-1 fish. Only 17 fish under 100 mm were captured in 2021, but quite a few age-2 and age-3 fish were captured, indicating good survival of this age cohort.

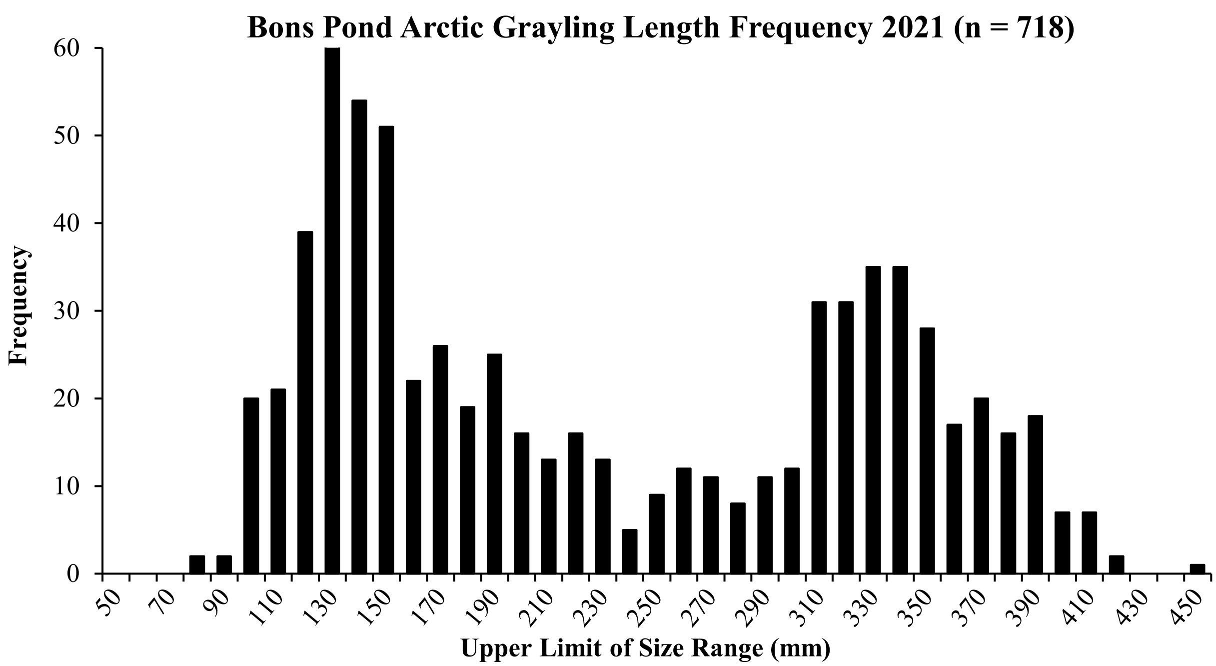


Figure 73. Length frequency distribution of Arctic grayling in Bons Pond in spring 2021. This includes fish captured in Bons Creek and the outlet of Bons Pond.

Growth rates for Arctic grayling from Bons Pond are lower than for comparable sized fish from North Fork Red Dog Creek. 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 74). The average annual growth rate was 32 mm in 2020, nearly triple the rate observed in 2018, and has ranged from a high of 32 mm in 2020 to a low of 2 mm in 2003. Higher growth rates in most years since 2011 could be related to the population decline which has resulted in increased food availability.

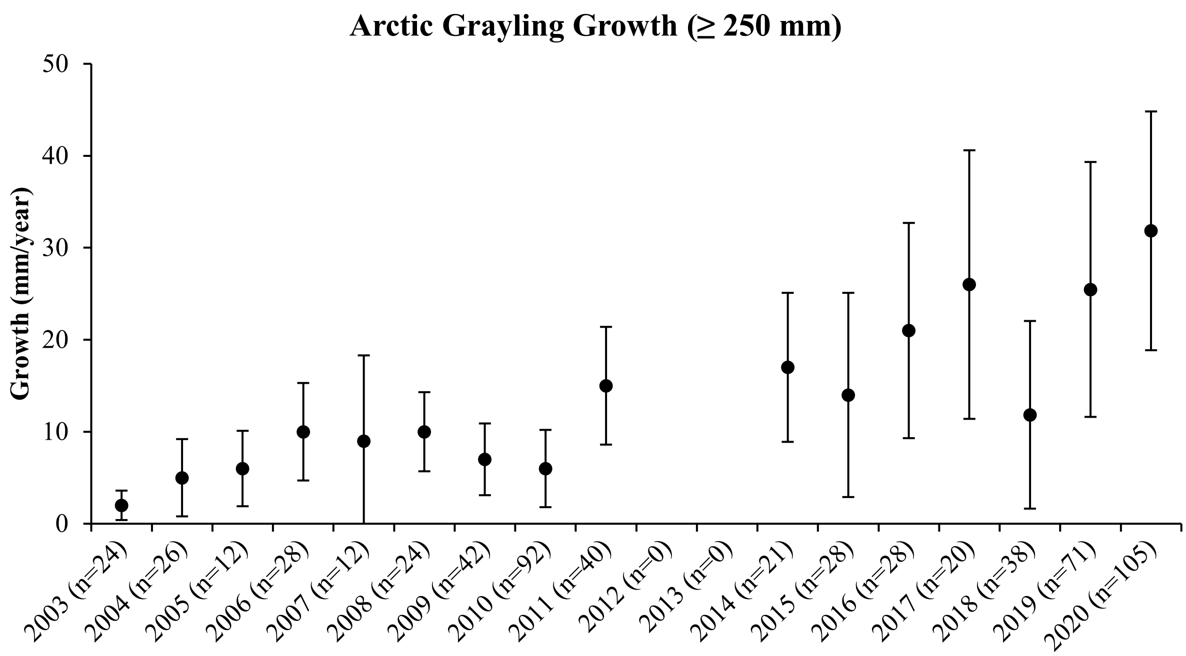


Figure 74. Average annual growth (± 1 SD) of Arctic grayling ≥ 250 mm FL at time of marking.

The 2020 Arctic grayling population in Bons Pond was estimated by using 2020 as the mark event (n = 248) and spring 2021 as the recapture event (n = 304). The recapture number does not include fish less than 250 mm FL, as they were likely too small to tag in 2020. In spring 2021, 105 of the fish were recaptures from the spring 2020 mark event. Based on these values, the estimated Arctic grayling population for 2020 was 716 fish (95% CI, 632 to 799 fish) ≥ 200 mm FL, nearly identical to the 2019 estimate of 701 fish (Figure 75).

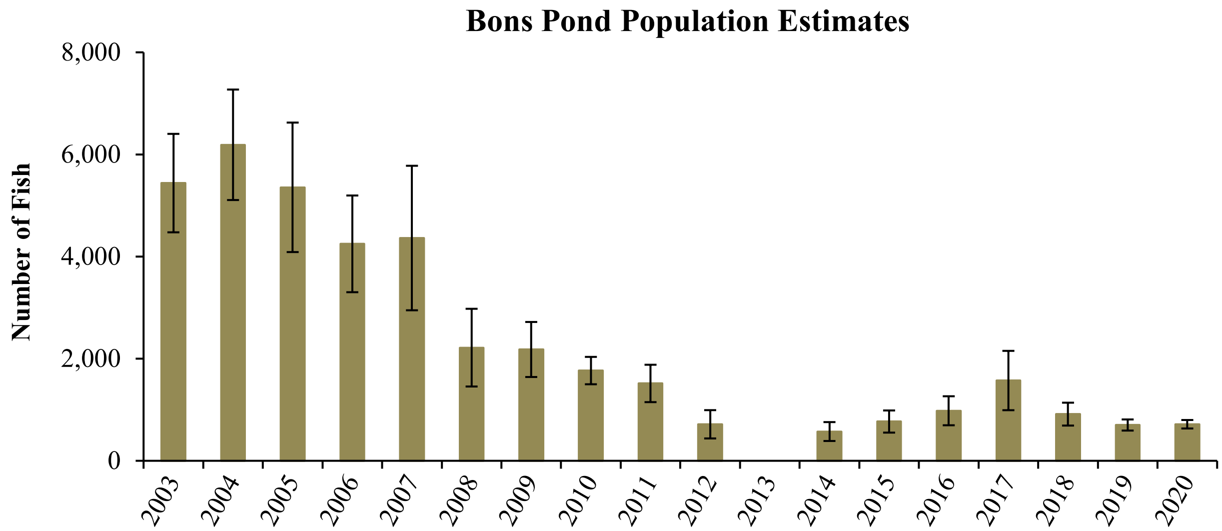


Figure 75. Estimated Arctic grayling population (95% CI) in Bons Pond for fish ≥ 200 mm FL.

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 spring 2020 or in spring 2021.

The number of slimy sculpin caught in minnow traps during the August sampling event in lower Mainstem Red Dog Creek is presented in Figure 76. There is no apparent trend with CPUE (number of fish caught in 10 traps per 24 hour period) which ranges from zero to a high of 8 in 2018.

In 2010, the minnow trap sample reach from Station 7 on Ikalukrok Creek was moved to a new site on the same system, upstream of Station 160. The water quality monitoring station was moved downstream in 2010 to ensure waters from Dudd and Ikalukrok creeks were completely mixed.

Slimy sculpin CPUE in Ikalukrok Creek has varied from a low of 0 to a high of 24 in 2004 (Figure 76). 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 2021. Four slimy sculpin was captured, a slight increase from the single sculpin captured in 2020 (Figure 77).

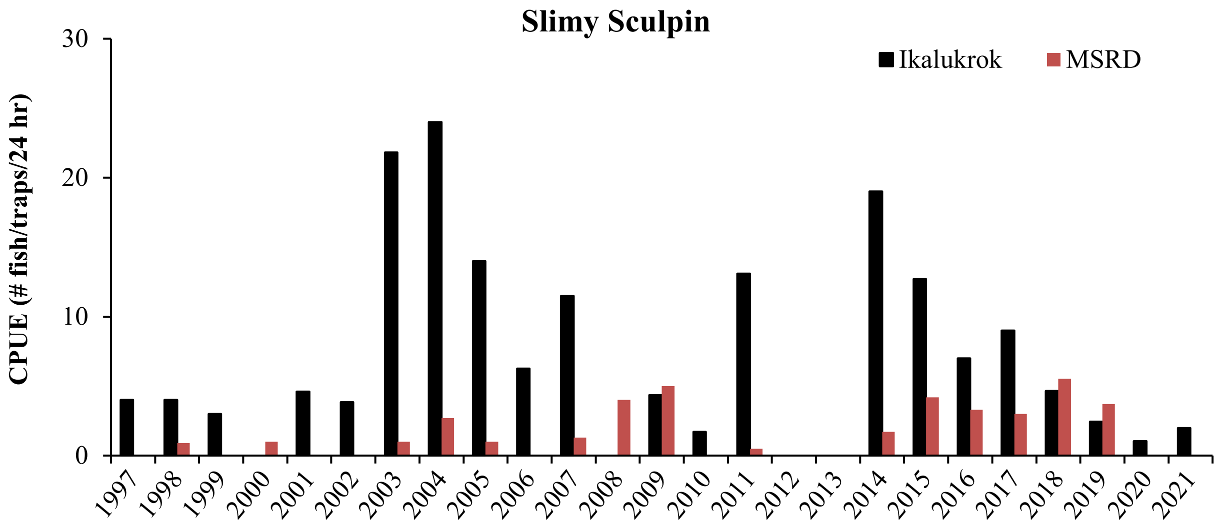


Figure 76. CPUE of slimy sculpin caught in Ikalukrok Creek and Mainstem Red Dog Creek. No sampling was performed in 2012 or 2013 due to high water.

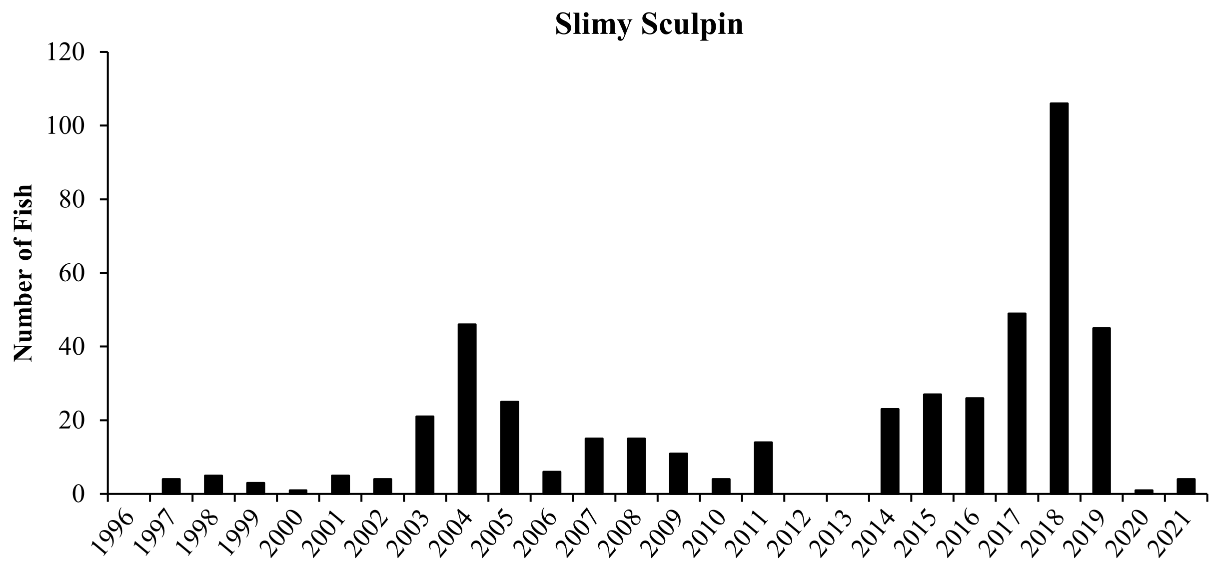


Figure 77. Number of slimy sculpin captured at all seven sample sites in the Ikalukrok Creek drainage, including Red Dog, Buddy, and Anxiety Ridge creeks.

Literature Cited

Bond M.H., J.A. Miller, and T.P. Quinn. 2015. Beyond dichotomous life histories in partially migrating populations: cessation of anadromy in a long-lived fish. Ecology 96:1899–1910

Bradley, P.T. 2017. Methods for aquatic life monitoring at the Red Dog mine site, a requirement of the 2017 APDES Permit AK0038652. Alaska Department of Fish and Game Technical Report 17-09. Division of Habitat. Juneau.

Brix, K.V. and M. Grosell. 2005. Report on the effects of total dissolved solids on Arctic grayling and Dolly Varden fertilization success. Prepared for Teck Cominco. 23 pp.

Dames and Moore. 1983. Environmental baseline studies Red Dog project.

Chapman, D.G. 1951. Some practices of the hypergeometric distribution with applications to zoological censuses. University of California Publications in Statistics. 1:131-60.

Clark, R.A. 1992. Influence of stream flows and stock size on recruitment of Arctic grayling (*Thymallus arcticus*) in the Chena River, Alaska. Can. J. Fish Aquat. Sci. 49:1027-1034.

DeCicco, A.L. 1990. Northwest Alaska Dolly Varden study 1989. Federal Aid in Sport Fish Restoration Act. Alaska Department of Fish and Game Fishery Data Series No. 90-8. Fairbanks.

DeCicco, A.L. 1996b. Abundance of Dolly Varden overwintering in the Wulik River, Northwestern Alaska during 1994/1995. Alaska Department of Fish and Game Sport Fish Fishery Data Series No. 96-3. Anchorage.

Environmental Protection Agency. 2016. Aquatic life ambient water quality criterion for selenium – freshwater 2016. EPA-822-R-16-006.

EVS Consultants Ltd and Ott Water Engineers. 1983. Toxicological, biophysical and chemical assessment of Red Dog, Delong Mountains, Alaska, 1982. Prepared for the Alaska Department of Environmental Conservation, Juneau, by G. Vigers, J. Barrett, R. Hoffman, J. Humphrey, D. Kathman, D. Konasewich, R. Olmsted, and B. Reid. 245 pp.

Golder Associates Inc. 2020. Summary Report of Zinc Concentrations: Red Dog Creek and Tributaries. Prepared for Teck Alaska Incorporated, January 2, 2020.

Hart, L. M., M. H. Bond, S. L. May-McNally, J. A. Miller, and T. P. Quinn. 2015. Use of otolith microchemistry and stable isotopes to investigate the ecology and anadromous migrations of Northern Dolly Varden from the Egegik River, Bristol Bay, Alaska. Environ. Biol. Fish 98(6).

Houghton, J.F. and P.J. Hilgert. 1983. In environmental baseline studies Red Dog project. Dames and Moore. 82 pp.

Jenkins, D.W. 1980. Biological monitoring of toxic trace metals. Vol. 1. Biological Monitoring and Surveillance. J EPA-600/3-80-089. 215 pp.

Ott, A.G. and P.T. Bradley. 2017. Fish and Water Quality Monitoring at the Fort Knox Mine, 2017. Alaska Department of Fish and Game Technical Report 17-10. Division of Habitat. Juneau.

Ott, A.G. and P.T. Bradley. 2016. Arctic Grayling and Burbot Studies at the Fort Knox Mine, 2016. Alaska Department of Fish and Game Technical Report No. 16-09. Division of Habitat. Juneau.

Ott, A.G. and W.A. Morris. 2010. Aquatic biomonitoring at Red Dog Mine, 2009. Alaska Department of Fish and Game Technical Report No. 10-02. Division of Habitat. Juneau.

Ott, A.G. and W.A. Morris. 2007. Aquatic biomonitoring in Bons Pond, and Bons and Buddy Creeks, 2004 to 2006, at Red Dog Mine. Alaska Department of Natural Resources Technical Report No. 07-04. Office of Habitat Management and Permitting. Juneau.

Ott, A.G. and W.A. Morris. 2004. Juvenile Dolly Varden whole body metals analyses, Red Dog Mine (2002). Alaska Department of Natural Resources Technical Report No. 04-01. Office of Habitat Management and Permitting. Juneau.

Ott, A.G., H.L. Scannell, and P.T. Bradley. 2016. Aquatic biomonitoring at Red Dog Mine, 2015. Alaska Department of Fish and Game Technical Report No. 16-01. Division of Habitat. Juneau.

Ott, A.G. and A.H. Townsend. 2003. A transplant of Arctic grayling to Bons Pond at the Red Dog Mine. Alaska Department of Natural Resources Technical Report No. 03-06. Office of Habitat Management and Permitting. Juneau.

Seber, G.A.F. 1982. The estimation of abundance. Charles Griffin & Company LTD.

SRK. 2015. Red Dog Qanaiyaq Static and Kinetic Results Report – FINAL.

Ward, D.L. and T.J. Olson. 1980. Baseline aquatic investigations of fishes and heavy metal concentrations in the Kivalina and Wulik Rivers, 1978-79. LGL Ecological Research Associates, Inc. Prepared for GCO Minerals Company. 89 pp.

Weber Scannell P., A.G. Ott, and W.A. Morris. 2000. Fish and aquatic taxa report at Red Dog Mine, 1998-1999. Alaska Department of Fish and Game Technical Report No. 00-03. Habitat and Restoration Division. Juneau.

Weber Scannell P. and A.G. Ott. 1998. Fisheries resources and water quality, Red Dog Mine. Alaska Department of Fish and Game Technical Report No. 98-02. Habitat and Restoration Division. Juneau.

Appendix 1. Summary of Red Dog Mine Development and Operations, 2014-2021.[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 Modification #1 to the APDES Permit (AK0038652) which authorized a mixing zone for selenium and adjusts 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 Compliance Schedule. 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 in 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.

Appendix 2. Periphyton Standing Crop, Red Dog Mine Monitoring Sites, 2021. Results below the detection limit are shaded in gray.

2021 Chloro Results - Red Dog								
IDL = 0.12 mg/m2			Linear Check Max = 67.43 mg/m2					
EDL = 0.56 mg/m2					**Phaeo Corrected**			
Daily Vial #	Site	Date Analyzed	Vial Chl a	Chl a mg/m^2	**Chl a mg/m^2**	**664/665 Ratio**	Chl b mg/m^2	Chl c mg/m^2
12	Mainstem Red Dog Station 10	11/22/21	0.01	0.04	0.11		0.05	0.06
13	Mainstem Red Dog Station 10	11/22/21	0.02	0.09	0.21		0.03	0.05
14	Mainstem Red Dog Station 10	11/22/21	0.00	0.00	0.00		0.00	0.00
15	Mainstem Red Dog Station 10	11/22/21	0.02	0.09	0.00		0.03	0.05
16	Mainstem Red Dog Station 10	11/22/21	0.00	0.00	0.00		0.00	0.00
17	Mainstem Red Dog Station 10	11/22/21	0.00	0.00	0.00		0.00	0.00
18	Mainstem Red Dog Station 10	11/22/21	0.01	0.04	0.11		0.05	0.06
19	Mainstem Red Dog Station 10	11/22/21	0.00	0.00	0.00		0.15	0.14
20	Mainstem Red Dog Station 10	11/22/21	0.01	0.04	0.11		0.05	0.06
21	Mainstem Red Dog Station 10	11/22/21	0.01	0.05	0.00		0.00	0.09
2	Upper North Fork Red Dog	12/01/21	0.12	0.50	0.21	1.22	0.06	0.20
3	Upper North Fork Red Dog	12/01/21	1.29	5.15	5.02	1.68	1.82	0.20
4	Upper North Fork Red Dog	12/01/21	0.54	2.16	1.92	1.58	0.98	0.16
5	Upper North Fork Red Dog	12/01/21	0.25	0.99	0.96	1.69	0.13	0.20
6	Upper North Fork Red Dog	12/01/21	0.34	1.36	1.28	1.67	0.03	0.21
7	Upper North Fork Red Dog	12/01/21	0.28	1.13	0.96	1.56	0.15	0.15
8	Upper North Fork Red Dog	12/01/21	0.22	0.86	0.75	1.58	0.04	0.18
9	Upper North Fork Red Dog	12/01/21	0.39	1.54	1.39	1.62	0.10	0.22
10	Upper North Fork Red Dog	12/01/21	0.22	0.86	0.85	1.73	0.04	0.18
11	Upper North Fork Red Dog	12/01/21	0.09	0.34	0.43	2.00	0.27	0.35
22	Ikalukrok u/s Red Dog Station 9	11/30/21	0.02	0.09	0.21		0.02	0.15
23	Ikalukrok u/s Red Dog Station 9	11/30/21	0.02	0.09	0.11	2.00	0.02	0.15
24	Ikalukrok u/s Red Dog Station 9	11/30/21	0.01	0.04	0.00	1.00	0.04	0.16
25	Ikalukrok u/s Red Dog Station 9	11/30/21	0.01	0.04	0.11		0.05	0.06
26	Ikalukrok u/s Red Dog Station 9	11/30/21	0.02	0.08	0.11	2.00	0.10	0.12
27	Ikalukrok u/s Red Dog Station 9	11/30/21	0.01	0.04	0.00	1.00	0.05	0.06
28	Ikalukrok u/s Red Dog Station 9	11/30/21	0.01	0.04	0.00	1.00	0.05	0.06
29	Ikalukrok u/s Red Dog Station 9	11/30/21	0.01	0.04	0.00	1.00	0.05	0.06
30	Ikalukrok u/s Red Dog Station 9	11/30/21	0.01	0.04	0.00	1.00	0.05	0.06
31	Ikalukrok u/s Red Dog Station 9	11/30/21	0.02	0.09	0.11	2.00	0.02	0.15

					Phaeo Corrected			
Daily		Date	Vial	Chl a	**Chl a**	**664/665**	Chl b	Chl c
Vial #	Site	Analyzed	Chl a	mg/m^2	**mg/m^2**	**Ratio**	mg/m^2	mg/m^2
52	Bons u/s pond	11/24/21	0.63	2.51	2.35	1.67	0.04	0.13
53	Bons u/s pond	11/24/21	2.24	8.94	8.12	1.63	0.00	0.55
54	Bons u/s pond	11/24/21	0.65	2.60	2.46	1.68	0.00	0.31
55	Bons u/s pond	11/24/21	4.35	17.40	16.23	1.65	3.30	0.54
56	Bons u/s pond	11/24/21	0.20	0.81	16.98	1.67	3.58	0.79
57	Bons u/s pond	11/24/21	1.53	6.10	5.45	1.61	0.10	0.37
58	Bons u/s pond	11/24/21	1.40	5.59	5.34	1.68	0.19	0.41
59	Bons u/s pond	11/24/21	0.20	0.78	0.75	1.70	0.00	0.00
60	Bons u/s pond	11/24/21	3.28	13.12	12.50	1.68	0.19	0.46
61	Bons u/s pond	11/24/21	4.69	18.75	17.73	1.67	0.55	0.60
12	North Fork Red Dog Station 12	11/30/21	0.23	0.90	0.85	1.67	0.10	0.14
13	North Fork Red Dog Station 12	11/30/21	0.40	1.60	1.50	1.64	0.47	0.16
14	North Fork Red Dog Station 12	11/30/21	0.27	1.08	1.07	1.71	0.17	0.15
15	North Fork Red Dog Station 12	11/30/21	0.11	0.45	0.43	1.67	0.08	0.20
16	North Fork Red Dog Station 12	11/30/21	0.60	2.40	2.24	1.66	0.16	0.21
17	North Fork Red Dog Station 12	11/30/21	0.44	1.77	1.71	1.70	0.08	0.16
18	North Fork Red Dog Station 12	11/30/21	1.37	5.50	5.02	1.63	0.81	0.86
19	North Fork Red Dog Station 12	11/30/21	0.81	3.25	3.10	1.67	0.47	0.10
20	North Fork Red Dog Station 12	11/30/21	1.45	5.79	5.13	1.60	0.55	0.49
21	North Fork Red Dog Station 12	11/30/21	1.91	7.64	6.73	1.59	0.93	0.41
12	Middle Fork Red Dog Station 20	11/24/21	0.02	0.09	0.11	2.00	0.03	0.05
13	Middle Fork Red Dog Station 20	11/24/21	0.02	0.09	0.21		0.03	0.05
14	Middle Fork Red Dog Station 20	11/24/21	0.01	0.04	0.00	1.00	0.05	0.06
15	Middle Fork Red Dog Station 20	11/24/21	0.00	0.00	0.00		0.00	0.00
16	Middle Fork Red Dog Station 20	11/24/21	0.00	0.00	0.00		0.00	0.00
17	Middle Fork Red Dog Station 20	11/24/21	0.00	0.00	0.00		0.00	0.00
18	Middle Fork Red Dog Station 20	11/24/21	0.00	0.00	0.00		0.00	0.00
19	Middle Fork Red Dog Station 20	11/24/21	0.00	0.00	0.11	0.00	0.00	0.00
20	Middle Fork Red Dog Station 20	11/24/21	0.00	0.00	0.00		0.00	0.00
21	Middle Fork Red Dog Station 20	11/24/21	0.01	0.04	0.11		0.05	0.06
12	Buddy blw falls	11/23/21	0.37	1.49	1.39	1.65	0.13	0.13
13	Buddy blw falls	11/23/21	0.12	0.50	0.43	1.57	0.06	0.20
14	Buddy blw falls	11/23/21	0.09	0.36	0.32	1.60	0.06	0.05
15	Buddy blw falls	11/23/21	1.32	5.28	5.13	1.69	1.37	0.24
16	Buddy blw falls	11/23/21	0.65	2.60	2.56	1.73	0.00	0.31
17	Buddy blw falls	11/23/21	0.16	0.63	0.53	1.56	0.07	0.15
18	Buddy blw falls	11/23/21	0.37	1.50	1.50	1.74	0.03	0.36
19	Buddy blw falls	11/23/21	0.23	0.94	0.96	1.75	0.25	0.08
20	Buddy blw falls	11/23/21	0.54	2.17	1.82	1.57	0.00	0.00
21	Buddy blw falls	11/23/21	0.23	0.91	0.75	1.54	0.02	0.17

					Phaeo Corrected			
Daily		Date	Vial	Chl a	**Chl a**	**664/665**	Chl b	Chl c
Vial #	Site	Analyzed	Chl a	mg/m^2	**mg/m^2**	**Ratio**	mg/m^2	mg/m^2
2	Ik d/s Dudd Station 160	11/30/21	0.01	0.04	0.11		0.05	0.06
3	Ik d/s Dudd Station 160	11/30/21	0.01	0.03	0.00	1.00	0.13	0.13
4	Ik d/s Dudd Station 160	11/30/21	0.01	0.04	0.00	1.00	0.05	0.06
5	Ik d/s Dudd Station 160	11/30/21	0.03	0.12	0.11	1.50	0.16	0.18
6	Ik d/s Dudd Station 160	11/30/21	0.02	0.08	0.11	2.00	0.09	0.22
7	Ik d/s Dudd Station 160	11/30/21	0.03	0.13	0.11	1.50	0.07	0.21
8	Ik d/s Dudd Station 160	11/30/21	0.02	0.08	0.11	2.00	0.10	0.12
9	Ik d/s Dudd Station 160	11/30/21	0.02	0.08	0.11	2.00	0.10	0.12
10	Ik d/s Dudd Station 160	11/30/21	0.02	0.08	0.11	2.00	0.09	0.22
11	Ik d/s Dudd Station 160	11/30/21	0.02	0.08	0.21		0.10	0.12
42	Buddy u/s Haul Rd Station 221	11/24/21	0.25	0.99	0.96	1.69	0.14	0.10
43	Buddy u/s Haul Rd Station 221	11/24/21	0.50	2.01	1.92	1.69	0.00	0.22
44	Buddy u/s Haul Rd Station 221	11/24/21	1.37	5.49	5.34	1.68	1.58	0.18
45	Buddy u/s Haul Rd Station 221	11/24/21	0.11	0.45	0.43	1.67	0.01	0.04
46	Buddy u/s Haul Rd Station 221	11/24/21	0.48	1.90	1.82	1.68	0.17	0.18
47	Buddy u/s Haul Rd Station 221	11/24/21	0.86	3.42	3.20	1.67	0.00	0.14
48	Buddy u/s Haul Rd Station 221	11/24/21	0.31	1.23	1.28	1.80	0.02	0.16
49	Buddy u/s Haul Rd Station 221	11/24/21	0.34	1.36	1.17	1.58	0.13	0.08
50	Buddy u/s Haul Rd Station 221	11/24/21	1.06	4.24	3.95	1.66	0.06	0.32
51	Buddy u/s Haul Rd Station 221	11/24/21	0.08	0.32	0.32	1.75	0.01	0.00
2	Bons us Buddy Station 220	11/24/21	6.98	27.93	26.17	1.66	3.33	1.60
3	Bons us Buddy Station 220	11/24/21	3.02	12.09	11.64	1.69	1.77	0.46
4	Bons us Buddy Station 220	11/24/21	0.52	2.07	1.92	1.64	0.32	0.16
5	Bons us Buddy Station 220	11/24/21	6.75	27.00	25.74	1.67	5.37	1.20
6	Bons us Buddy Station 220	11/24/21	2.60	10.40	9.51	1.63	1.18	0.38
7	Bons us Buddy Station 220	11/24/21	3.60	14.38	13.46	1.65	2.80	0.37
8	Bons us Buddy Station 220	11/24/21	5.78	23.12	21.36	1.62	8.95	0.96
9	Bons us Buddy Station 220	11/24/21	1.19	4.76	4.38	1.64	0.33	0.52
10	Bons us Buddy Station 220	11/24/21	3.50	14.01	12.82	1.64	0.41	1.03
11	Bons us Buddy Station 220	11/24/21	6.16	24.65	23.07	1.65	3.28	1.34

Appendix 3. Aquatic Invertebrate Drift Samples, 2021.

Station	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	Bons u/s Bons Pond	Bons u/s Buddy Sta 220	Buddy u/s Haul Road Sta 221	Buddy below falls
Total aquatic invert taxa/site	25	27	22	24	19	26	21	23	27	29
Tot. Ephemeroptera	78	261	225	74	517	571	12	58	1305	691
Tot. Plecoptera	25	248	293	60	35	13	3	21	653	77
Tot. Trichop.	0	2	0	1	0	0	0	5	4	2
Total Aq. Diptera	419	2152	908	711	336	632	930	1741	1419	1343
Misc.Aq.sp	53	954	290	168	11	196	603	217	178	696
% other	9%	26%	17%	17%	1%	14%	39%	11%	5%	25%
% Ephemeroptera	13%	7%	13%	7%	58%	40%	1%	3%	37%	25%
% Plecoptera	4%	7%	17%	6%	4%	1%	0%	1%	18%	3%
% Trichoptera	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
% Aq. Diptera	73%	59%	53%	70%	37%	45%	60%	85%	40%	48%
% EPT	18%	14%	30%	13%	61%	41%	1%	4%	55%	27%
% Chironomidae	67%	53%	42%	65%	28%	35%	58%	80%	29%	36%
% Dominant Taxon	64%	47%	25%	60%	38%	32%	32%	65%	26%	26%
Volume of water (m3)	662	1332	422	665	644	644	1124	1627	981	907
Average vol.water/net	132	266	84	133	129	129	225	325	196	181
StDev of Water Volume/Net	22	167	57	71	68	68	126	119.81	57	69
Estimated total inverts/m3 water	11.46	17.17	27.88	12.30	7.37	12.59	8.59	7.27	19.72	17.66
Estimated aquatic inverts/m3 water	4.35	13.58	20.32	7.63	6.97	10.96	6.90	6.29	18.15	15.59
Average invertebrates/m3 water	11.60	52.23	30.23	13.05	10.49	13.06	5.28	7.57	21.06	17.23
Average aq. invertebrates/m3 water	4.32	39.67	20.32	8.25	9.90	11.57	4.21	6.52	19.36	15.41
StDev of Aq. Invert Density	1.58	60.99	5.88	3.01	7.00	3.00	2.38	1.31	8.10	4.30
Total aquatic invertebrates	2876	18085	8580	5076	4492	7058	7760	10235	17806	14145
Total. terrestrial invertebrates	4711	4780	3193	3100	252	1052	1895	1585	1534	1879
Total invertebrates	7586	22865	11773	8176	4744	8109	9655	11820	19341	16024
% Sample aquatic	38%	79%	73%	62%	95%	87%	80%	87%	92%	88%
% Sample terrestrial	62%	21%	27%	38%	5%	13%	20%	13%	8%	12%
Average # aquatic inverts / net	575	3617	1716	1015	898	1412	1552	2047	3561	2829
StDev of Aq. Inv./Net	254	1974	1330	408	271	696	207	655	1523	1591
Average # terr. inverts / net	942	956	639	620	50	210	379	317	307	376
Average # inverts / net	1517	4573	2355	1635	949	1622	1931	2364	3868	3205
StDev of Inv./Net	529	2488	1630	723	293	847	245	733.39	1632.049	1977.9
Total Larval Arctic Grayling/site	0	0	0	0	0	0	10	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, 2021.

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
052821BPAGJ01	5/28/2021	178	56.8	0.16	2.12	0.05	18.62	116.6	24.7
053021BPAGJ02	5/30/2021	160	39.4	0.14	0.71	0.04	18.09	99.2	24.6
053021BPAGJ03	5/30/2021	160	40.8	0.21	0.90	0.05	13.16	70.3	26.3
053121BPAGJ04	5/31/2021	161	40.8	0.09	0.60	0.05	21.40	121.3	22.1
053121BPAGJ05	5/31/2021	151	31.3	0.11	0.54	0.05	16.89	109.8	25.4
053121BPAGJ06	5/31/2021	166	36.7	0.15	2.09	0.02	16.44	87.2	25
053121BPAGJ07	5/31/2021	176	58.0	0.20	0.70	0.02	18.19	84.7	24.9
053121BPAGJ08	5/31/2021	179	62.6	0.15	0.50	0.06	13.99	83.6	23.8
053121BPAGJ09	5/31/2021	185	68.8	0.11	0.38	0.03	17.23	80.5	25.6
053121BPAGJ10	5/31/2021	159	39.4	0.17	1.13	0.02	17.23	55.3	25.3
053121BPAGJ11	5/31/2021	182	62.2	0.14	0.58	0.03	13.22	77.3	26.4
053121BPAGJ12	5/31/2021	159	37.8	0.09	0.31	0.04	15.74	63.7	25.1
060121BPAGJ13	6/1/2021	180	57.9	0.08	0.22	0.02	17.92	72.1	26.5
060121BPAGJ14	6/1/2021	179	63.0	0.14	0.80	0.03	18.26	73.3	25.8
060121BPAGJ15	6/1/2021	164	44.0	0.09	0.29	0.03	12.99	71.3	26.8

Appendix 5. Juvenile Dolly Varden from Buddy and Anxiety Ridge creeks Whole Body Element Concentrations, 2021.

Sample Number	Date Collected	Length (mm)	Weight (g)	Cadmium (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Selenium (mg/kg)	Zinc (mg/kg)	% Solids
080921BCDVJ01	8/6/2021	120	17.2	0.33	1.91	0.08	3.85	101.62	24.7
080921BCDVJ02	8/6/2021	123	16.7	1.03	0.33	0.04	4.47	148.78	24.6
080921BCDVJ03	8/6/2021	92	8.4	1.04	3.35	0.04	6.94	164.71	25.5
080921BCDVJ04	8/6/2021	122	18.9	1.62	10.38	0.06	5.53	200.48	20.8
080921BCDVJ05	8/6/2021	98	9.2	1.18	0.70	0.05	5.81	134.93	22.9
080921BCDVJ06	8/6/2021	122	19.1	2.90	1.72	0.06	6.26	210.43	21.1
080921BCDVJ07	8/6/2021	136	25.9	0.56	0.30	0.16	7.77	98.58	21.1
080921BCDVJ08	8/6/2021	94	8.3	0.84	0.80	0.07	4.93	173.93	21.1
080921BCDVJ09	8/6/2021	108	11.6	1.82	0.88	0.04	5.44	140.55	21.7
081021AXDVJ01	8/10/2021	106	11.5	0.61	1.06	0.16	5.87	117.43	21.8
081021AXDVJ02	8/10/2021	120	15.2	0.23	0.216	0.12	5.71	104.76	23.1
081021AXDVJ03	8/10/2021	122	17.6	0.19	0.14	0.12	6.34	95.154	22.7
081021AXDVJ04	8/10/2021	101	9.2	0.28	0.74	0.15	5.15	118.30	23.5
081021AXDVJ05	8/10/2021	113	14.1	0.25	0.76	0.15	5.62	152.19	25.1
081021AXDVJ06	8/10/2021	122	18.2	0.22	0.85	0.15	5.43	121.43	21
081021AXDVJ07	8/10/2021	90	6.6	0.21	0.27	0.10	4.86	130.19	21.2
081021AXDVJ08	8/10/2021	90	7.6	0.38	0.78	0.09	6.25	120.69	23.2
081021AXDVJ09	8/10/2021	123	18.8	0.43	0.24	0.12	5.73	116.86	25.5
081021AXDVJ10	8/10/2021	106	11.7	0.29	0.30	0.14	7.19	137.19	24.2
081021AXDVJ11	8/10/2021	136	24.7	0.21	0.32	0.16	5.36	98.07	20.7
081021AXDVJ12	8/10/2021	105	11.1	0.09	0.29	0.14	5.43	121.72	22.1
081021AXDVJ13	8/10/2021	95	7.7	0.19	0.18	0.09	6.65	119.07	23.6
081021AXDVJ14	8/10/2021	124	17.8	0.20	0.25	0.16	5.54	132.43	22.2
081021AXDVJ15	8/10/2021	111	13.7	0.31	0.35	0.12	6.08	111.21	23.2
080921RDDVJ01	8/9/2021	95	8.9	2.69	2.71	0.04	4.55	370.98	22.4
081021RDDVJ02	8/10/2021	120	12.0	1.94	1.72	0.10	4.29	278.74	20.7
081021RDDVJ03	8/10/2021	110	11.9	1.56	0.89	0.03	4.84	256.50	22.3
081021RDDVJ04	8/10/2021	115	14.1	3.28	1.82	0.05	5.74	340.43	23.0
081021RDDVJ05	8/10/2021	109	12.4	2.51	1.10	0.05	5.86	210.13	22.7
081021RDDVJ06	8/10/2021	119	15.2	2.48	0.74	0.04	6.14	252.90	25.9
081021RDDVJ07	8/10/2021	122	16.0	1.89	0.53	0.02	6.23	274.58	23.6
082521RDDVJ08	8/25/2021	114	14.2	2.07	3.01	0.03	5.54	217.75	23.1
082721RDDVJ09	8/27/2021	133	22.4	1.63	0.89	0.08	5.86	340.95	23.2
082721RDDVJ10	8/27/2021	106	9.8	2.43	0.25	0.04	5.40	225.66	22.6
082721RDDVJ11	8/27/2021	128	17.8	1.71	0.27	0.04	6.11	188.65	22.9
082721RDDVJ12	8/27/2021	127	18.2	2.69	1.33	0.05	5.90	292.17	21.7
082721RDDVJ13	8/27/2021	131	21.0	2.13	0.66	0.10	8.90	259.82	21.9
082721RDDVJ14	8/27/2021	131	21.2	2.26	0.37	0.22	5.69	225.43	23.2

Appendix 6. Dolly Varden Element Data, Wulik River, May 2021.

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.

Tissue	Sample Identification	Sex	Length (mm)	Weight (g)	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Se (mg/kg)	Zn (mg/kg)	Hg (mg/kg)	% Solids
Kidney	053021WUDVA01K	F	488	1580	0.61	2.49	0.08	3.66	55.40	0.09	28.70
Kidney	053021WUDVA02K	F	555	1850	1.09	3.16	0.09	6.26	55.61	0.15	21.40
Kidney	053021WUDVA03K	F	500	1520	2.75	7.39	0.06	6.96	128.50	0.07	20.70
Kidney	053021WUDVA04K	F	417	820	1.62	3.27	0.11	7.36	95.83	0.05	21.60
Kidney	053021WUDVA05K	F	508	1560	2.45	7.36	0.12	7.12	112.98	0.13	20.80
Kidney	053021WUDVA06K	F	497.0	1360	2.11	4.69	0.08	6.81	71.24	0.03	22.60
Kidney	053021WUDVA07K	F	535	1660	3.96	6.49	0.10	6.38	111.17	0.14	18.80
Kidney	duplicate of fish #7	F	535	1660	1.84	4.42	0.11	6.44	111.17	0.15	18.80
Liver	053021WUDVA01L	F	488	1580	0.36	82.39	0.14	2.82	106.69	0.01	28.40
Liver	053021WUDVA02L	F	555	1850	0.74	121.90	0.06	4.30	129.34	0.05	24.20
Liver	053021WUDVA03L	F	500.0	1520	0.43	98.08	0.07	2.63	122.7	0.02	31.30
Liver	053021WUDVA04L	F	417	820	0.43	79.85	0.07	4.03	133.70	0.02	27.30
Liver	053021WUDVA05L	F	508	1560	0.28	66.88	0.04	1.61	60.90	0.01	46.80
Liver	053021WUDVA06L	F	497	1360	0.51	166.28	0.07	4.10	126.44	0.02	26.10
Liver	053021WUDVA07L	F	535	1660	2.46	162.63	0.25	4.45	178.28	0.07	19.80
Liver	duplicate of fish #7	F	535	1660	2.51	141.71	0.10	4.30	162.3	0.06	19.90
Muscle	053021WUDVA01M	F	488	1580	0.03	1.07	0.07	0.92	11.88	0.01	28.20
Muscle	053021WUDVA02M	F	555	1850	0.04	2.39	0.07	0.76	16.24	0.01	29.00
Muscle	053021WUDVA03M	F	500	1520	0.04	1.67	0.08	1.03	16.12	0.01	25.50
Muscle	053021WUDVA04M	F	417	820	0.03	2.47	0.05	0.98	24.03	0.01	28.30
Muscle	053021WUDVA05M	F	508	1560	0.03	3.35	0.06	0.89	22.53	0.01	27.70
Muscle	053021WUDVA06M	F	497	1360	0.03	2.13	0.06	0.68	18.33	0.01	32.40
Muscle	053021WUDVA07M	F	535	1660	0.03	3.61	0.07	0.88	29.56	0.03	22.80
Muscle	duplicate of fish #7	F	535	1660	0.04	2.26	0.07	0.82	30.00	0.02	23.80
Reproductive	053021WUDVA01R	F	488	1580	0.03	29.07	0.05	5.34	271.72	0.01	29.00
Reproductive	053021WUDVA02R	F	555	1850	0.04	23.81	0.07	7.21	248.67	0.01	22.60
Reproductive	053021WUDVA03R	F	500	1520	0.03	24.49	0.06	6.21	407.02	0.01	28.50
Reproductive	053021WUDVA04R	F	417	820	0.13	2.97	0.27	3.46	260.23	0.01	17.60
Reproductive	053021WUDVA05R	F	508	1560	0.13	2.08	0.26	2.35	131.44	0.01	19.40
Reproductive	053021WUDVA06R	F	497	1360	0.05	8.12	0.08	4.48	1035.87	0.01	22.30
Reproductive	053021WUDVA07R	F	535	1660	0.17	29.89	0.12	4.75	328.49	0.02	17.90
Reproductive	duplicate of fish #7	F	535	1660	0.39	36.65	0.09	4.79	338.73	0.02	17.30

Appendix 7. Dolly Varden Element Data, Wulik River, September 2021.

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.

Tissue	Sample Identification	Sex	Length (mm)	Weight (g)	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Se (mg/kg)	Zn (mg/kg)	Hg (mg/kg)	% Solids
Kidney	090121WUDVA01K	F	452	1160	3.09	4.54	0.10	9.53	89.53	0.11	19.1
Kidney	090121WUDVA02K	F	472	1180	3.21	25.72	0.08	6.92	110.69	0.19	15.9
Kidney	090121WUDVA03K	F	495	1460	3.34	4.37	0.07	7.20	88.32	0.07	21.4
Kidney	090121WUDVA04K	F	434	1120	0.85	5.00	0.08	6.31	65.77	0.05	22.2
Kidney	090221WUDVA05K	F	448	1160	3.03	10.05	0.09	8.85	102.76	0.07	21.7
Kidney	duplicate of fish #5	F	448	1160	1.00	4.84	0.09	8.07	83.41	0.06	22.3
Kidney	090221WUDVA06K	F	442	1020	0.81	3.26	0.09	7.28	67.14	0.07	21.3
Liver	090121WUDVA01L	F	452	1160	0.99	147.52	0.07	8.51	154.26	0.02	28.2
Liver	090121WUDVA02L	F	472	1180	1.53	157.99	0.07	3.39	188.58	0.08	21.9
Liver	090121WUDVA03L	F	495	1460	0.98	76.23	0.06	7.74	131.70	0.03	26.5
Liver	090121WUDVA04L	F	434	1120	0.28	62.99	0.07	4.96	122.05	0.01	25.4
Liver	090221WUDVA05L	F	448	1160	0.46	102.18	0.05	4.52	104.90	0.02	36.7
Liver	duplicate of fish #5	F	448	1160	0.44	81.59	0.04	4.59	100.27	0.02	36.4
Liver	090221WUDVA06L	F	442	1020	0.34	40.48	0.06	4.86	108.76	0.02	33.1
Muscle	090121WUDVA01M	F	452	1160	0.03	1.07	0.07	1.25	14.39	0.01	24.6
Muscle	090121WUDVA02M	F	472	1180	0.05	2.54	0.09	0.98	19.28	0.03	20.8
Muscle	090121WUDVA03M	F	495	1460	0.03	1.06	0.07	1.18	15.02	0.01	24.9
Muscle	090121WUDVA04M	F	434	1120	0.04	1.33	0.08	1.11	13.04	0.01	23.7
Muscle	090221WUDVA05M	F	448	1160	0.03	1.40	0.06	1.05	16.03	0.01	26.7
Muscle	duplicate of fish #5	F	448	1160	0.03	1.60	0.05	0.99	17.44	0.01	29.3
Muscle	090221WUDVA06M	F	442	1020	0.04	1.76	0.08	1.31	16.09	0.01	25.8
Reproductive	090121WUDVA01R	F	452	1160	0.08	43.37	0.09	14.25	922.65	0.01	18.1
Reproductive	090121WUDVA02R	F	472	1180	0.07	11.48	0.12	2.91	509.88	0.02	16.2
Reproductive	090121WUDVA03R	F	495	1460	0.05	36.38	0.08	8.65	408.21	0.0	20.7
Reproductive	090121WUDVA04R	F	434	1120	0.02	9.14	0.04	4.46	62.05	0.01	36.1
Reproductive	090221WUDVA05R	F	448	1160	0.06	43.79	0.12	12.31	512.82	0.01	19.5
Reproductive	duplicate of fish #5	F	448	1160	0.06	52.78	0.10	13.09	613.58	0.01	16.2
Reproductive	090221WUDVA06R	F	442	1020	0.06	38.96	0.13	10.88	526.37	0.01	18.2

Appendix 8. Total Catch of Juvenile Dolly Varden at Red Dog Mine Sampling Sites, 1997-2021.

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.

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