Technical Report No. 18-06

Aquatic Biomonitoring at Red Dog Mine, 2017

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

by

Parker T. Bradley and Alvin G. Ott

May 2018

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

Symbols and Abbreviations

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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. 18-06

AQUATIC BIOMONITORING AT RED DOG MINE, 2017

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

By

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May, 2018

Cover: Minnow traps near the Wulik River, August 4, 2017. Photograph by Audra Brase

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Acknowledgements

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Nora Foster (NRF Taxonomic Services) was responsible for sorting and identification of aquatic invertebrates. Robert Napier and Audra Brase provided constructive review of this report.

Executive Summary

●In 2017, median metals concentrations (lead, zinc, aluminum, cadmium) in Mainstem Red Dog Creek were consistently lower when compared with pre-mining data. The pH and total dissolved solids (TDS) in Mainstem Red Dog Creek were higher than pre-mining. Median concentrations of cadmium, lead, and zinc were consistently higher in Mainstem Red Dog Creek as compared with Buddy and North Fork Red Dog creeks and Bons Pond. In 2017, Teck continued to maintain the clean water bypass system. Median lead concentrations in Mainstem Red Dog Creek, which had increased from 2011 to 2013, decreased and remained lower from 2014 to 2017.

●Periphyton standing crop, as estimated by chlorophyll-a concentration, is determined each year in drainages near the Red Dog Mine. In 2017, chlorophyll-a concentrations were highest in Upper North Fork Red Dog Creek and lowest in Middle Fork Red Dog Creek. Generally, chlorophyll concentrations are higher in Buddy Creek (below the falls) and/or Bons Creek (below Bons Pond). Chlorophyll-a concentration continues to track closely with zinc and cadmium in Ikalukrok Creek at Station 9. 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 2017, ten sites were sampled and the aquatic invertebrate density was highest in Buddy Creek below the falls. In 2017 all sites sampled contained a higher percentage of Chironomidae than Ephemeroptera, Plecoptera, and Trichoptera (EPT). Overall taxa richness was similar among the sites.

●Juvenile Arctic grayling from Bons Pond have been analyzed for selected whole body elements in 2004, 2007, 2010, and 2014–2017. Average cadmium, lead, and zinc concentrations in Arctic grayling juveniles were lowest in 2017. Average selenium concentrations in juvenile Arctic grayling have showed a decreasing trend since 2014. Average mercury concentrations have been variable, ranging from a high of 0.05 mg/kg in 2007, 2010, 2016 and 2017 to a low at detection limit of 0.02 mg/kg in 2004 and 2014.

●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 2017. In all years, juvenile Dolly Varden median whole body concentrations of cadmium, lead, and zinc are consistently highest in Mainstem Red Dog Creek; however, since 2009 zinc concentrations have been relatively stable and lower. Median selenium concentrations have been higher from 2014 to 2017 in Mainstem Red Dog Creek. Median mercury concentrations have consistently been highest in Anxiety Ridge Creek. Median cadmium and zinc concentrations seem to track with water quality - lead and selenium do not.

●Selenium concentrations were compared among Arctic grayling in Bons Pond (Red Dog), North Fork Red Dog Creek, and Fish Creek (Ft. Knox Mine). Selenium concentrations were highest in Arctic grayling ovaries from Bons Pond (2014-2017) and lowest in Fish Creek (1999, 2015, and 2017). Selenium concentrations if fish ovaries from North Fork Red Dog Creek were intermediate between Bons Pond and Fish Creeks. Selenium concentrations over time have not changed in these waterbodies.

Executive Summary (concluded)

●In 2017 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. None of the analytes measured appear to concentrate in muscle. Various elements concentrate in specific tissues.

●The number of overwintering Dolly Varden is estimated each fall in the Wulik River. The number of fish overwintering in the Wulik River has exhibited a decreasing trend since 2006 reaching a low of 21,084 fish in 2012, but since 2014 over 62,029 fish have been estimated annually. Aerial surveys prior to mine development found that over 90% of overwintering Dolly Varden in the Wulik River were located below the mouth of Ikalukrok Creek. Surveys performed since development of the mine show the same distribution.

●Annual aerial surveys assess the distribution of chum salmon in Ikalukrok Creek. The highest number of chum salmon estimated since mining began was 5,733 fish in 2015. Returns of adult chum salmon to Ikalukrok Creek have been above average since 2006.

●In spring 2017, resident Dolly Varden (n = 41) were collected with fyke nets in North Fork Red Dog Creek, these fish averaged 213 mm FL. Juvenile Dolly Varden sampling with minnow traps was conducted in late summer 2017. The total number of juvenile Dolly Varden captured in early August was 75 fish, the average size was 100 mm FL, and the highest catch occurred in Anxiety Ridge Creek.

●In spring 2017, the Arctic grayling spawning migration into North Fork Red Dog Creek was monitored. However, because North Fork Red Dog Creek was completely inundated with aufeis only 25 Arctic grayling were captured. Spawning time in Mainstem Red Dog Creek could not be determined as spent females were never captured. Fourteen larval Arctic grayling were captured in drift nets in Mainstem Red Dog Creek in early July. The 2016 population of Arctic grayling in North Fork Red Dog Creek was estimated at 1,230 fish ≥ 200 mm FL (fork length).

●The estimated Arctic grayling population in Bons Pond in 2016 was 981 fish ≥ 200 mm FL. The population estimates show a gradual increase since 2014. Sampling in recent years (2014, 2015, and 2017) has included catches of juvenile fish (< 200 mm FL) suggesting that the population likely will continue to increase. In spring 2017 Arctic grayling spawning was note observed in the Bons Pond outlet channel and Arctic grayling fry were not observed in Bons Pond outlet later in the summer.

●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 continue to be captured in Mainstem Red Dog Creek, but the highest catches consistently occur in Ikalukrok Creek downstream of the mouth of Dudd 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 performed annually. In 2010, the Alaska Department of Environmental Conservation (ADEC) issued Alaska Pollution Discharge Elimination System Permit No. AK0038652 (Modification #1 - APDES Permit) 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 effective March 1, 2010. The APDES Permit required a bioassessment program that included periphyton, aquatic invertebrates, and fish in selected streams near the Red Dog Mine (Tables 1 and 2). The bioassessment program became fully effective and enforceable on March 31, 2010. The APDES permit was updated and reissued in September 2017.

Table 1. Location of APDES Sample Sites and Factors Measured.

Sample Site	Factors Measured
North Fork Red Dog Creek	Periphyton (chlorophyll-a concentrations) Aquatic Invertebrates (taxonomic richness and abundance) Fish Presence and Use
Mainstem Red Dog Creek	Periphyton (chlorophyll-a concentrations) Aquatic Invertebrates (taxonomic richness and abundance) Fish Presence and Use
Ikalukrok Creek	Periphyton (chlorophyll-a concentrations) Aquatic Invertebrates (taxonomic richness and abundance) Fish Presence and Use

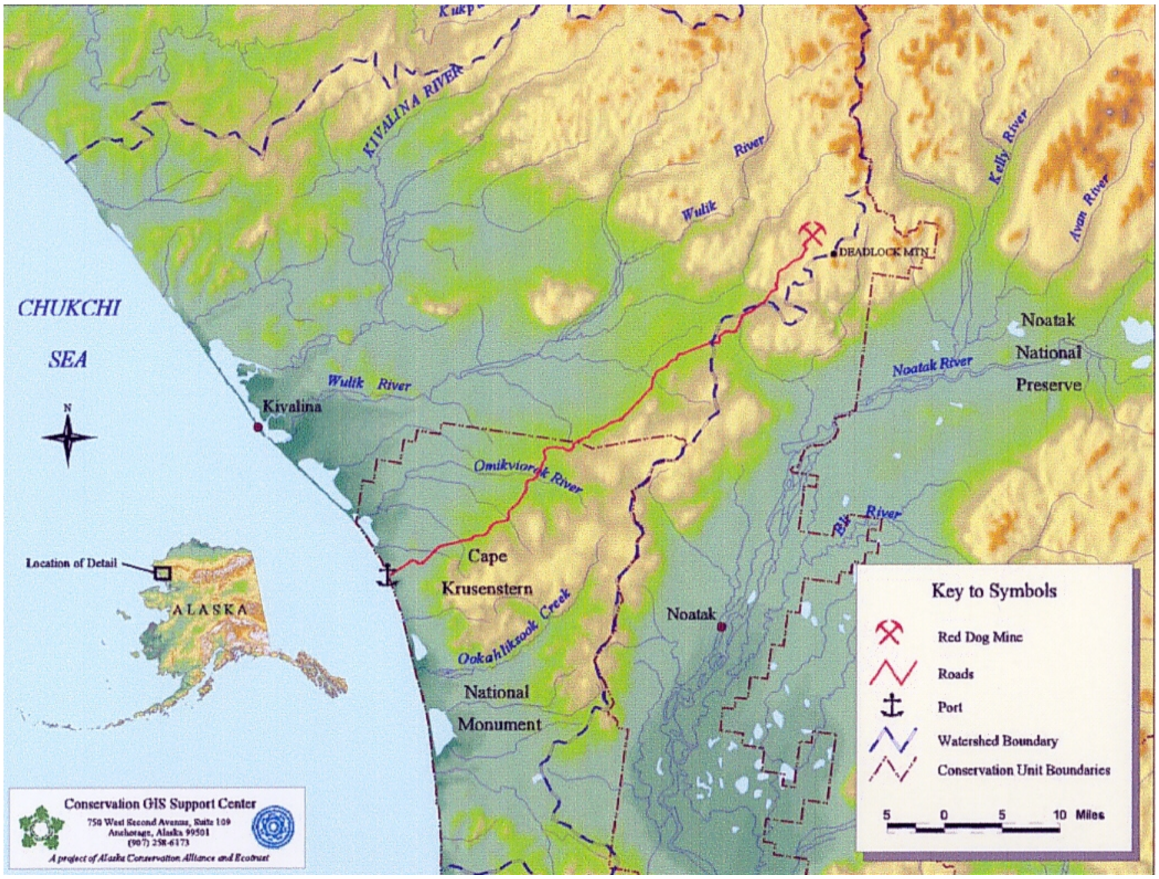


Figure 1. Location of the Red Dog Mine in northwestern Alaska.[1]

On September 23, 2016, the ADEC issued Waste Management Permit No. 2016DB002 for the Red Dog Mine that included a condition that Teck adhere to the requirements of the monitoring plan submitted by Teck in May 2009. Teck's May 2009 monitoring plan includes sample sites, sampling frequency, and parameters for all aquatic sites, including those required by the APDES Permit (Tables 2 and 3). In April 2010 to satisfy conditions in the US Environmental Protection Agency (EPA) and ADEC permits, the ADF&G submitted Technical Report #10-04 Methods for Aquatic Life Monitoring to Satisfy Requirements of 2010 NPDES Permit, Red Dog Mine Site (Revision #1).

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

Table 2. Location of Biological Sample Sites, Factors Measured and Sampling Frequency at the Red Dog Mine, 2017.

Location	APDES[1]/WMP[2]	Location Description	Sampling Frequency	Parameters
Wulik River	WMP	Kivalina Lagoon to about 10 km upstream of the mouth of Ikalukrok Creek	1/year	Fall aerial surveys for overwintering Dolly Varden
Ikalukrok Creek	WMP	Lower Ikalukrok Creek to mouth of Dudd Creek	1/year	Fall aerial surveys for adult chum salmon
Station 9	APDES/WMP	Ikalukrok Creek	1/year	Periphyton (as chlorophyll-a concentrations)
			1/year	Aquatic invertebrates (monitored for taxonomic richness, abundance, and density)
			1/year	Fish presence and use
Station 160	WMP	Lower Ikalukrok Creek	1/year	Periphyton (as chlorophyll-a concentrations)
			1/year	Aquatic invertebrates (monitored for taxonomic richness, abundance, and density)
			1/year	Fish presence and use
Station 20	WMP	Middle Fork Red Dog Creek	1/year	Periphyton (as chlorophyll-a concentrations)
			1/year	Aquatic invertebrates (monitored for taxonomic richness, abundance, and density)
Station 10	APDES/WMP	Mouth of Red Dog Creek	1/year	Periphyton (as chlorophyll-a concentrations)
			1/year	Aquatic invertebrates (monitored for taxonomic richness, abundance, and density)
			1/year	Fish presence and use
			1/year	Juvenile Dolly Varden elements in tissue (Zn, Pb, Se, Hg, and Cd)
Station 12	APDES/WMP	North Fork Red Dog Creek	1/year	Periphyton (as chlorophyll-a concentrations)
			1/year	Aquatic invertebrates (monitored for taxonomic richness, abundance, and density)
			1/year	Fish presence and use
			1/year	Record of spawning activity (Arctic grayling)
			Periodic	Capture/mark Arctic grayling
Buddy Creek	WMP	Below Falls, 1.5 km Downstream of Haul Road	1/year	Periphyton (as chlorophyll-a concentrations)
			1/year	Aquatic invertebrates (monitored for taxonomic richness, abundance, and density)
			1/year	Fish presence and use
			1/year	Juvenile Dolly Varden elements in tissue (Zn, Pb, Se, Hg, and Cd)
Buddy 221	WMP	Buddy Creek, Above Road	1/year	Periphyton (as chlorophyll-a concentrations)
			1/year	Aquatic invertebrates (monitored for taxonomic richness, abundance, and density)
Bons 220	WMP	Bons Creek, Below Pond	1/year	Periphyton (as chlorophyll-a concentrations)
			1/year	Aquatic invertebrates (monitored for taxonomic richness, abundance, and density)
Bons Above Pond	WMP	Above Pond	1/year	Periphyton (as chlorophyll-a concentrations)
			1/year	Aquatic invertebrates (monitored for taxonomic richness, abundance, and density)
			Periodic	Capture/mark Arctic grayling
Anxiety Ridge Creek	WMP	Haul Road Crossing	1/year	Fish presence and use
			1/year	Juvenile Dolly Varden metals in tissue (Zn, Pb, Se, Hg, and Cd)
Evaingiknuk Creek	WMP	East of Haul Road	1/year	Fish presence and use
Bons Reservoir	WMP	Above Reservoir Spillway	1/year	Juvenile Arctic grayling elements in tissue (Zn, Pb, Se, Hg, and Cd)
			1/year	Arctic grayling population estimate
[1]APDES - Alaska Permit Discharge Elimination System				
[2]WMP - Waste Management Plan				

Table 3. Location of sample sites for 2017 Red Dog aquatic biomonitoring study.

Site Type	Water Body	Site ID	Latitude	Longitude
Invert Sites	Bons Creek ds Bons Pond	Station 220	68.0183	-162.9395
Invert Sites	Bons Creek	Bons Creek us Bons Pond	68.0317	-162.9149
Invert Sites	Buddy Creek ds road	Buddy Creek	68.0062	-162.9628
Invert Sites	Buddy Creek us road	Station 221	68.0189	-162.9362
Invert Sites	Ikalukrok Creek	Station 160 (upstream)	67.9856	-163.0915
Invert Sites	Ikalukrok Creek	Station 9 (upstream)	68.0993	-162.9410
Invert Sites	Mainstem Red Dog Creek	Station 10	68.0889	-162.9433
Invert Sites	Middle Fork Red Dog Creek	Station 20	68.0820	-162.8837
Invert Sites	North Fork Red Dog Creek	Station 12	68.0835	-162.8852
Invert Sites	Upper North Fork Red Dog Creek	Above Aqqualuk	68.1009	-162.7397
Trap Sites	Anxiety Ridge Creek	Anxiety Ridge ds Trap	67.9940	-162.9589
Trap Sites	Anxiety Ridge Creek	Anxiety Ridge us Trap	67.9935	-162.9509
Trap Sites	Buddy Creek ds road	Buddy ds Trap	68.0062	-162.9629
Trap Sites	Buddy Creek ds road	Buddy us Trap	68.0074	-162.9548
Trap Sites	Evaingiknuk Creek	Evaingiknuk Creek ds Trap	67.9655	-163.0094
Trap Sites	Evaingiknuk Creek	Evaingiknuk Creek us Trap	67.9674	-163.0020
Trap Sites	Ikalukrok Creek	Station 160 ds Trap	67.9846	-163.0921
Trap Sites	Ikalukrok Creek	Station 160 us Trap	67.9871	-163.0895
Trap Sites	Ikalukrok Creek	Station 9 ds Trap	68.0971	-162.9430
Trap Sites	Ikalukrok Creek	Station 9 us Trap	68.1008	-162.9413
Trap Sites	Mainstem Red Dog Creek	Station 10 ds Trap	68.0890	-162.9458
Trap Sites	Mainstem Red Dog Creek	Station 10 us Trap	68.0900	-162.9343
Trap Sites	Mainstem Red Dog Creek	Station 151 ds Trap	68.0827	-162.8999
Trap Sites	Mainstem Red Dog Creek	Station 151 us Trap	68.0842	-162.8921
Trap Sites	North Fork Red Dog Creek	Station 12 ds Trap	68.0835	-162.8833
Trap Sites	North Fork Red Dog Creek	Station 12 us Trap	68.0839	-162.8774
Trap Sites	Upper North Fork Red Dog Creek	ds Trap	68.1019	-162.7422
Trap Sites	Upper North Fork Red Dog Creek	us Trap	68.1003	-162.7362

ds – the location of the most downstream minnow trap
us - the location of the most upstream minnow trap

The reinstated limits for total dissolved solids became effective on April 1, 2013, in the APDES Permit. Modification #1 of the APDES Permit which authorizes a mixing zone for selenium (Mixing Zone 2) and adjusts Outfall 001 effluent limits for selenium, came into effect on May 8, 2014.

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 2017 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*).

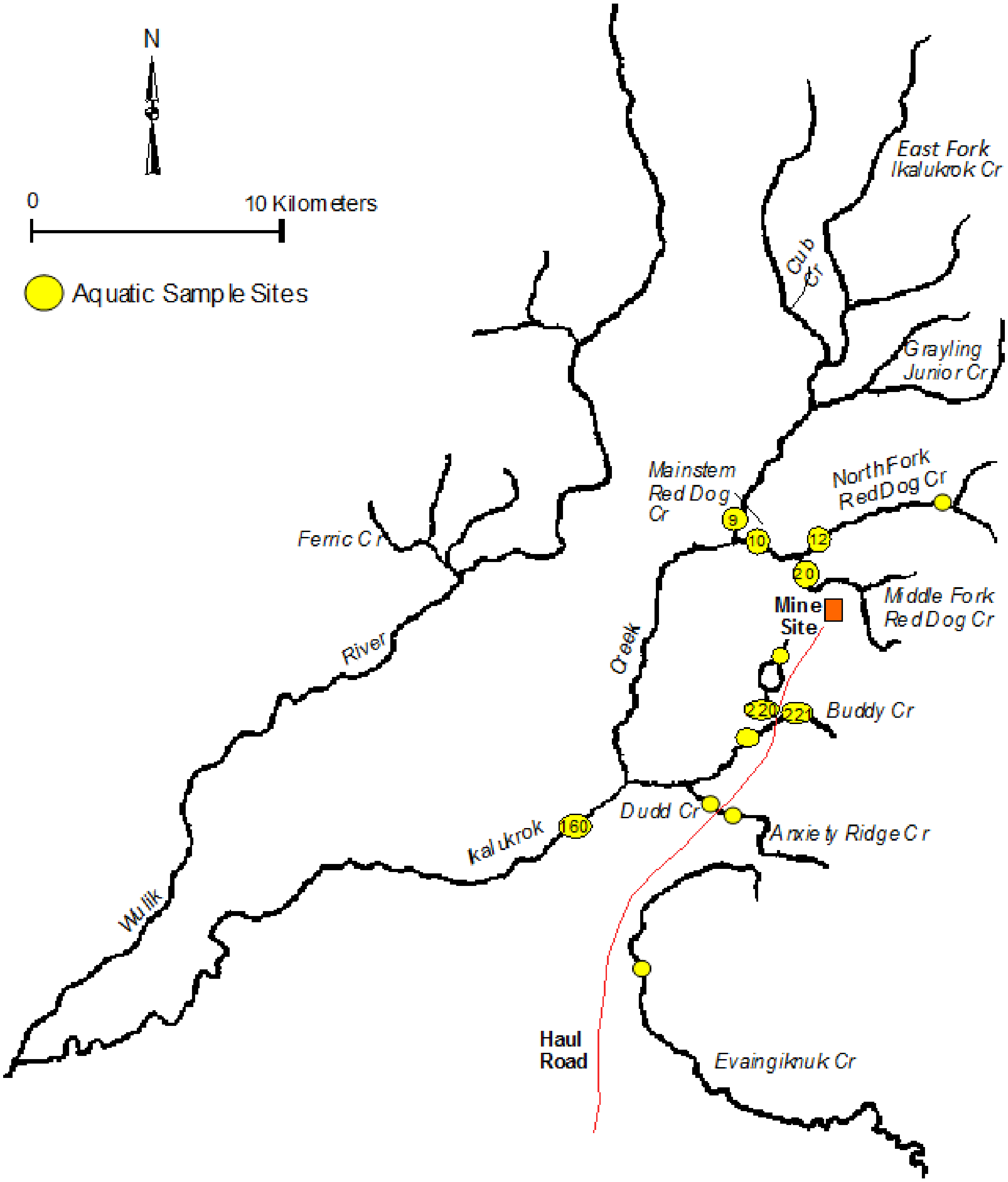


Figure 2. Location of sample sites (some have a Station #) in the Ikalukrok River drainage (tributary of the Wulik River) and Evaingiknuk Creek (a tributary of the Noatak River) drainage.

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 (Modification #1) (Tables 1 and 2 and Figures 2 and 3) 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 take into account that there is a much longer time series of data since mining began (1990 to 2017) when compared to the pre-development baseline data.

Methods

Four sampling events occurred in the Red Dog vicinity in 2017 including spring Arctic grayling and adult Dolly Varden sampling (May 28–June 4), mid-summer aquatic invertebrates and periphyton (July 2–5), late-summer juvenile Dolly Varden sampling (August 4–8), and fall aerial surveys of Dolly Varden in Wulik River and fall chum salmon in Ikalukrok Creek (September 23-25).

All methods used for the 2017 Red Dog Mine aquatic biomonitoring study are fully described by ADF&G (2010) in Technical Report No. 10-04 Methods for Aquatic Life Monitoring to Satisfy Requirements of 2010 NPDES Permit, Red Dog Mine Site (Revision #1).

All 2017 water quality sampling was performed by Red Dog Mine personnel following their standard methodology. Water quality analysis was performed by a laboratory and results provided to ADF&G for inclusion in this report. All water quality presented in this report are for “total recoverable.” 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 2017, the abundance of Arctic grayling was estimated using Chapman's modification of the Lincoln-Petersen two-sample mark-recapture model (Chapman 1951),

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

where $\hat{N}_c$ = 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):

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

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

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

Results and Discussion

Water Quality

Water quality data collected in Mainstem Red Dog Creek prior to 2010 are from Station 10, located near the mouth of the creek. Data from 2010 to 2017 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. Station 151 replaced Station 10 effective spring 2010. 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. Water quality data collected in Mainstem Red Dog Creek continues to be evaluated as part of the ongoing aquatic biomonitoring program.

Figure 3. Downstream end of mixing zone in Mainstem Red Dog Creek in early August 2015 (Station 151).

In 2017, 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 by the currently active Aqqaluk pit, to its original channel via a combination of culverts and lined open ditch. These bypass conveyance structures serve to isolate the non-contact water from areas disturbed by mining activities.

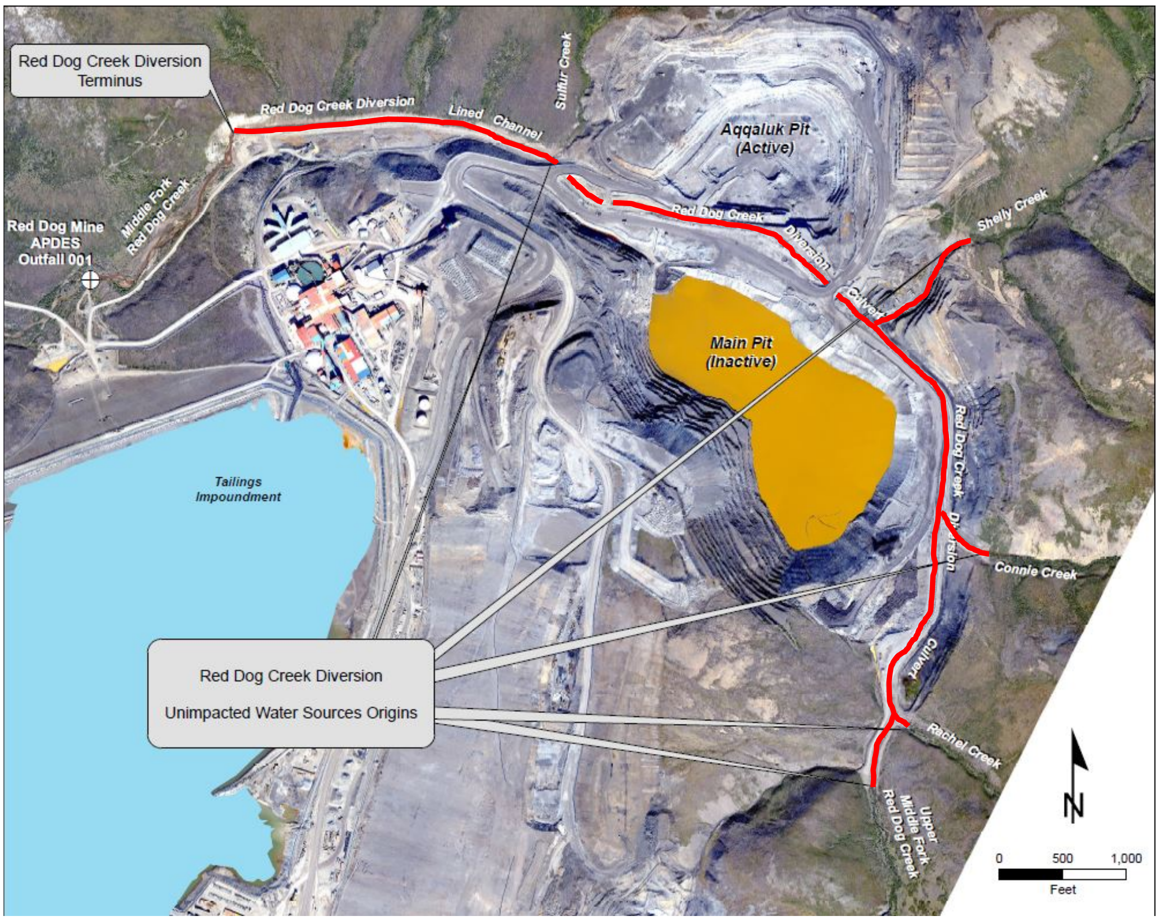


Figure 4. Clean water bypass system at the Red Dog Mine. The Red Dog Creek diversion structure (delineated by labels in the photograph and shown in red) picks up non-mining impacted waters from upstream tributaries and moves them between the Aqqaluk pit and the main pit back to the original Middle Fork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

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

In 2017, the median lead and zinc concentrations at Station 151/10, downstream of the clean water bypass system, were lower than pre-mining (1979-82). However, in some years the maximum lead concentration has been higher than pre-mining (Figure 5). Median lead concentrations, which had increased from 2011 to 2013, decreased from 2014 to 2017. Median zinc concentration in 2017 was 402 µg/L as compared with a baseline median concentration of 3,700 µg/L (Figure 6).

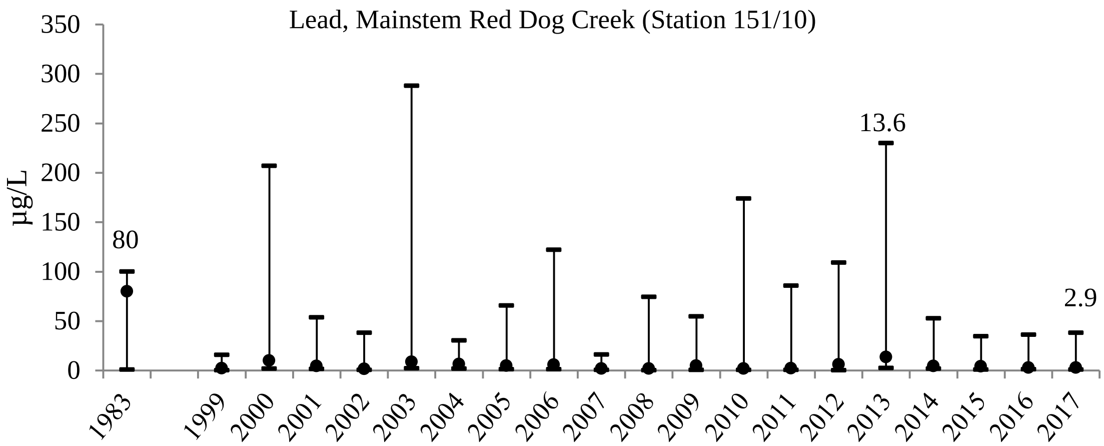


Figure 5. Median, maximum, and minimum lead concentrations at Station 151/10 (selected median values shown).

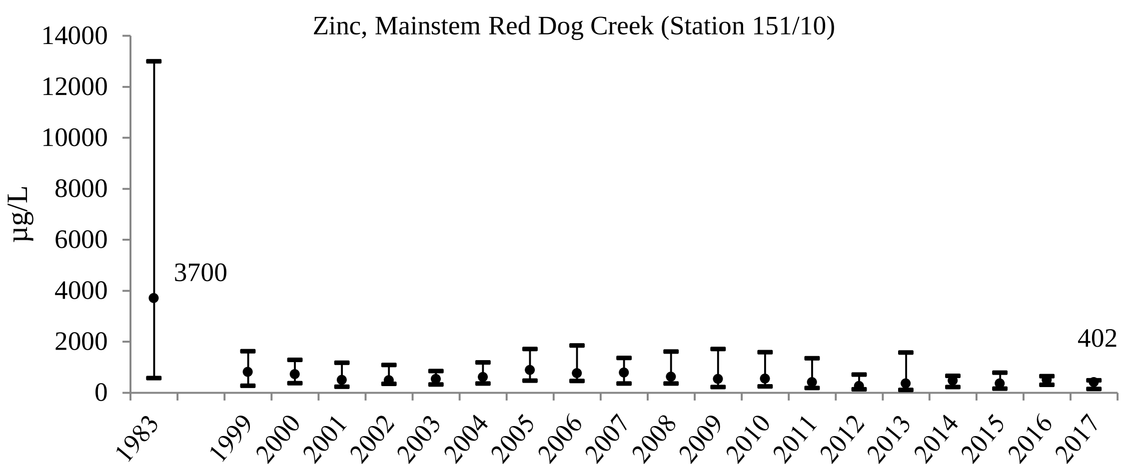


Figure 6. Median, maximum, and minimum zinc concentrations at Station 151/10 (selected median values shown).

In 2017, the systems with the highest concentrations of lead were Middle Fork Red Dog Creek (Station 145) upstream of the clean water bypass and Sulfur Creek (a tributary to the clean water bypass). Sulfur Creek had the highest median lead concentration (Figure 7). The median lead concentration in Sulfur Creek was 362 µg/L in 2013, 122.4 µg/L in 2014, 88.4 µg/L in 2015, 150.6 µg/L in 2016, and 127 µg/L in 2017. Sulfur Creek may eventually be incorporated into the Aqqaluk Pit. Overall, the median lead concentrations in 2017 at Station 140 (below the clean water bypass), but upstream from Outfall 001) were lower than those reported in 2014 and 2015.

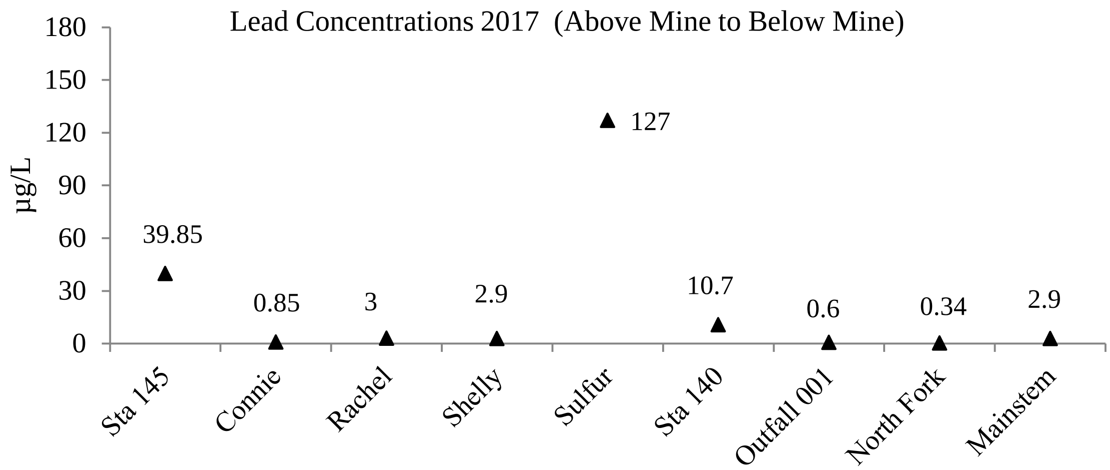


Figure 7. Median lead concentrations in 2017 from upstream (Station 145) of the clean water bypass, including tributaries to the clean water bypass (Connie, Rachel, Shelly, and Sulfur), and Station 140 (above the Outfall 001), Outfall 001, and North Fork Red Dog and Mainstem Red Dog Creeks.

Median aluminum concentrations at Station 10/151 continue to be lower than pre-mining (Figure 8). Cadmium concentrations were lower than pre-mining conditions (Figure 9). The median cadmium concentration in 1983 was 28 µg/L and in summer 2017 it was 2.1 µg/L. In most years (1999 to 2017), the maximum cadmium concentration is lower than the pre-mining median value.

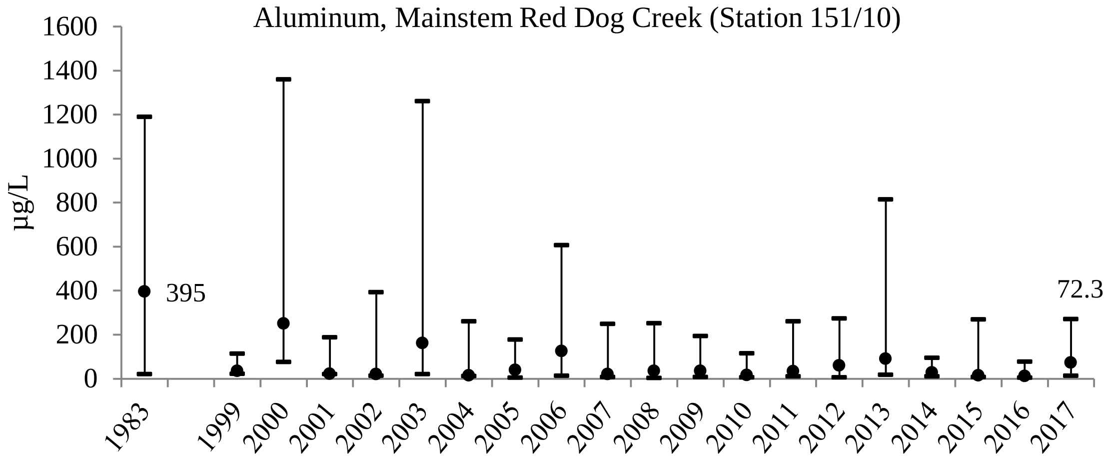


Figure 8. Median, maximum, and minimum aluminum concentrations at Station 151/10 (selected median values shown).

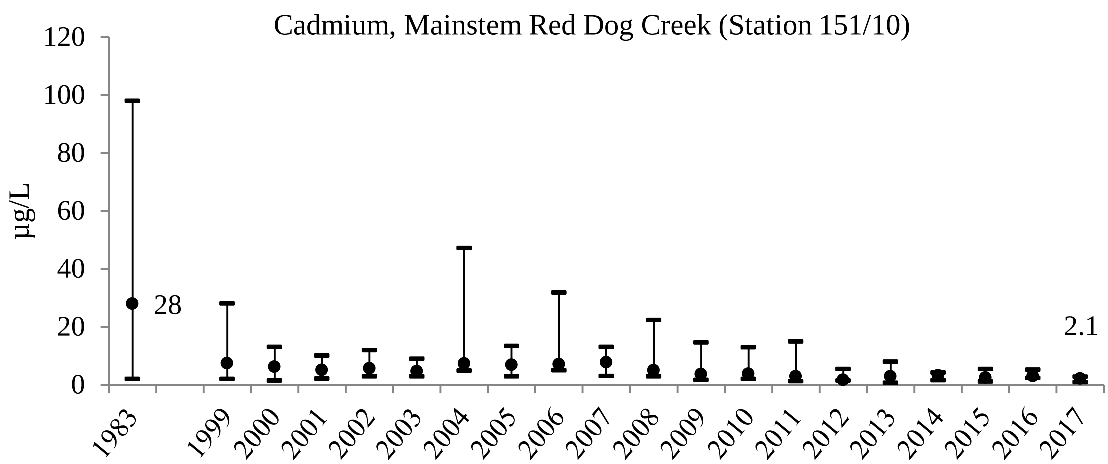


Figure 9. Median, maximum, and minimum cadmium concentrations at Station 151/10 (selected median values shown).

Pre-mining data for selenium are not available. Median selenium concentrations in Mainstem Red Dog Creek remained similar from 2001 to 2007, but then increased reaching a high of 2.75 µg/L in 2011 (Figure 10). In 2012, discharge of treated water to Middle Fork Red Dog Creek was stopped on June 8 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 and by summer 2014, the median selenium concentration in Mainstem Red Dog Creek was 1.7 µg/L. The median selenium concentration in Mainstem Red Dog Creek was 1.6 µg/L in 2017.

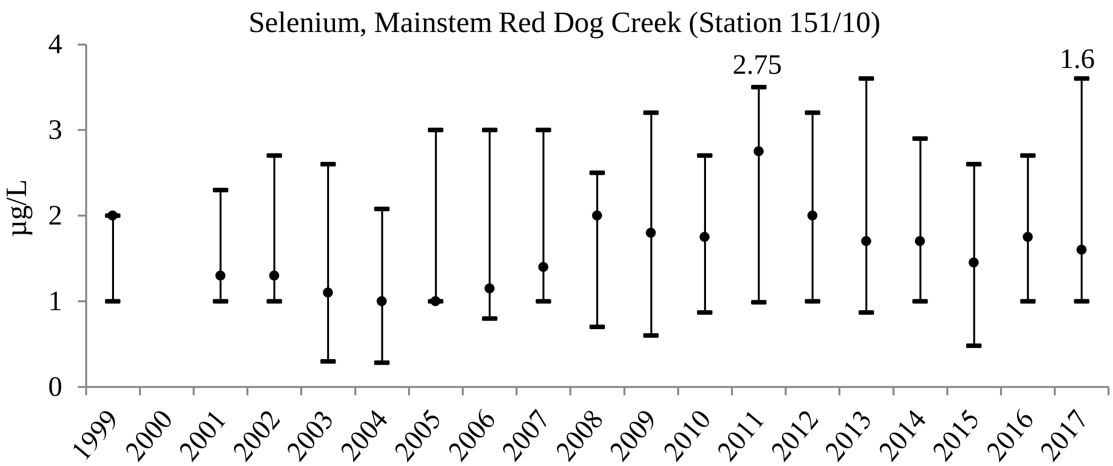


Figure 10. Median, maximum, and minimum selenium concentrations at Station 151/10 (selected median values shown).

Pre-mining data for nickel are not available. Median nickel concentrations at Station 151/10 were highest in 2006 and 2007 (Figure 11). The primary source of nickel to the clean water bypass system has been Rachael Creek (Ott and Morris 2010). Median nickel concentration in Mainstem Red Dog Creek was 10.1 µg/L in 2017.

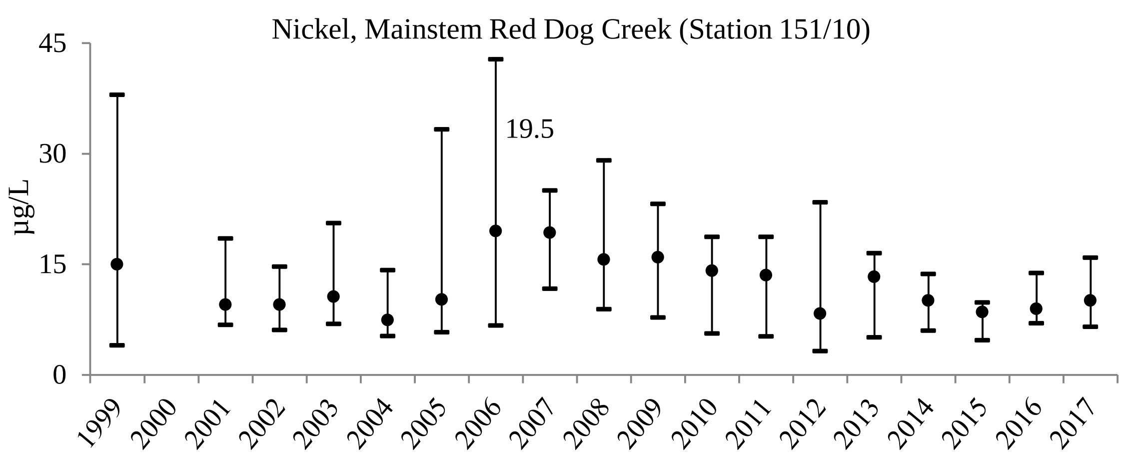


Figure 11. Median, maximum, and minimum nickel concentrations at Station 151/10 (selected median values shown).

In 2017, the pH at Station 151/10 was higher than pre-mining (Figure 12). The pH is slightly more basic and 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. The clean water bypass system was built and operational prior to spring breakup in 1991.

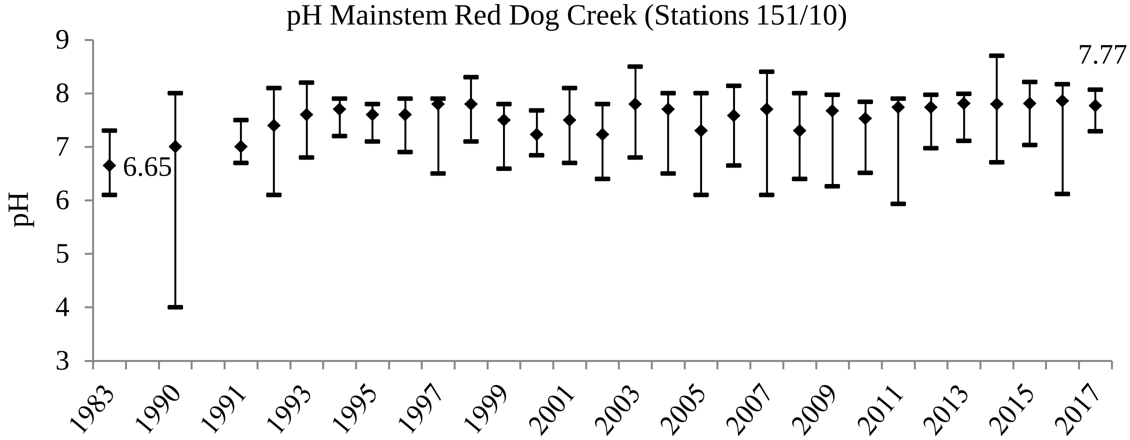


Figure 12. Median, maximum, and minimum pH values at Station 151/10 (selected median values shown).

Total dissolved solids (TDS) in Mainstem Red Dog Creek are higher than pre-mining (Figure 13). TDS is 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. TDS concentrations in Mainstem Red Dog Creek in summer 2017 never exceeded the 1,500 mg/L standard as specified in the APDES permit for Station 151.

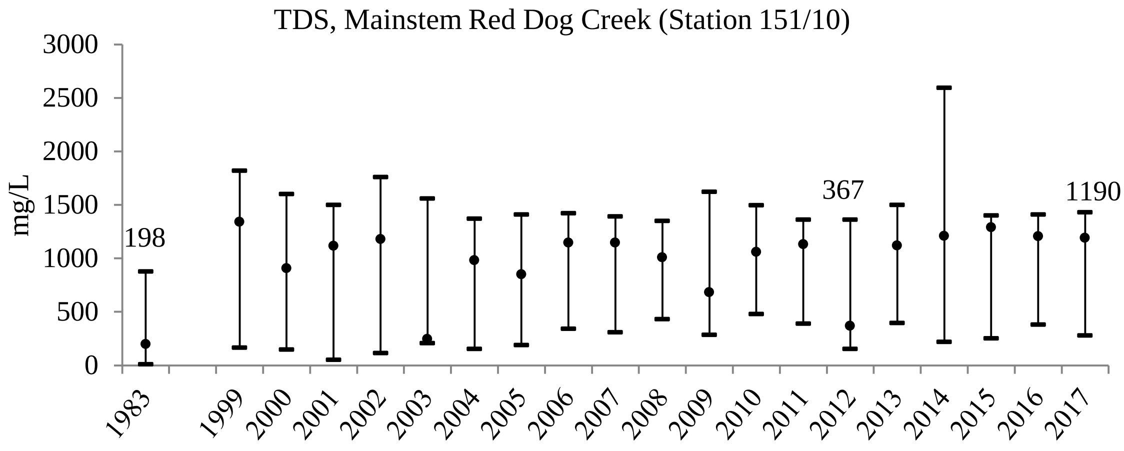


Figure 13. Median, maximum, and minimum TDS concentrations at Station 151/10 (selected median values shown).

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 14 to 17). 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 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 tailing 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 major source of these elements is from the clean water bypass and not from the mine discharge of treated water at Outfall 001. (Note: Two graphs are presented for cadmium, lead, and zinc so the differences in North Fork Red Dog and Buddy creeks and Bons Pond can be seen) (Figures 14, 15, and 16). In the three reference sites, cadmium and zinc concentrations are stable over the sampling period from 2001 to 2017. Lead concentrations demonstrate more variability, but are still consistently lower in North Fork Red Dog and Buddy creeks and Bons Pond. Lead concentrations have been decreasing in Mainstem Red Dog Creek since 2013.

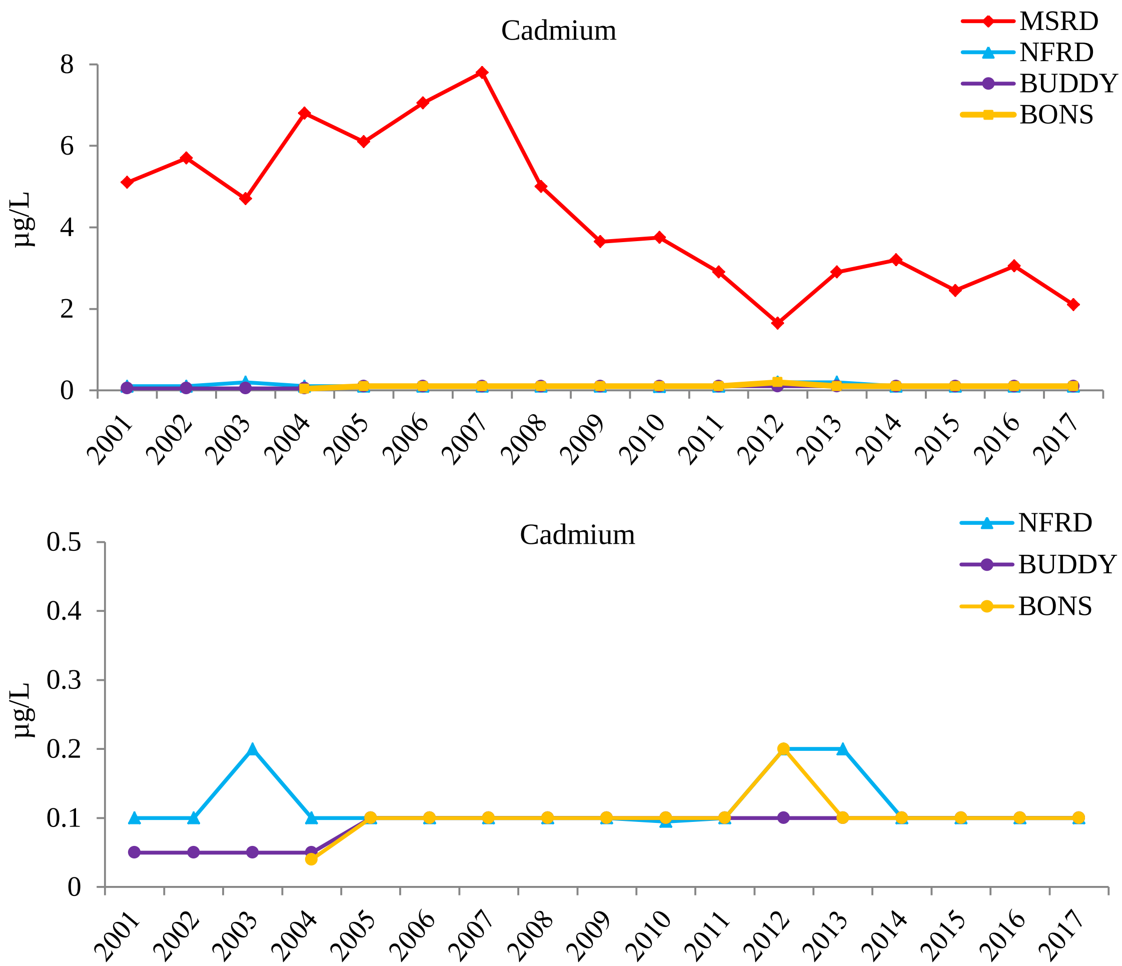
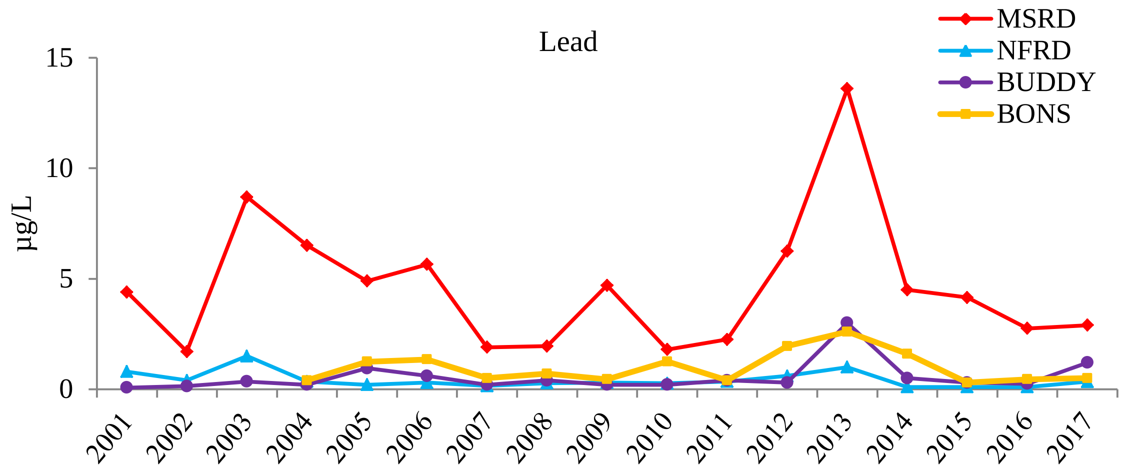


Figure 14. Median cadmium concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2017). Two graphs are presented, the bottom graph uses a different scale as it does not include Mainstem Red Dog Creek.



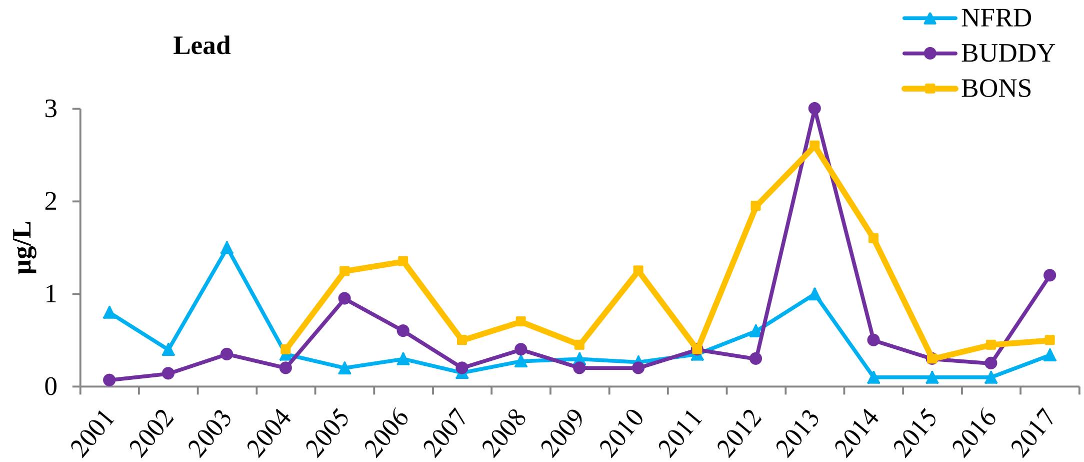
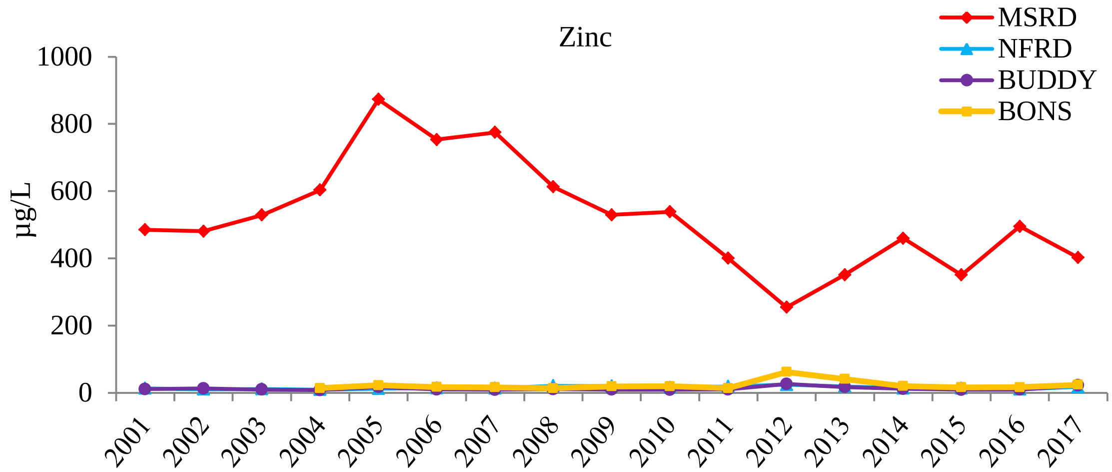


Figure 15. Median lead concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2017). Two graphs are presented, the bottom graph uses a different scale as it does not include Mainstem Red Dog Creek.



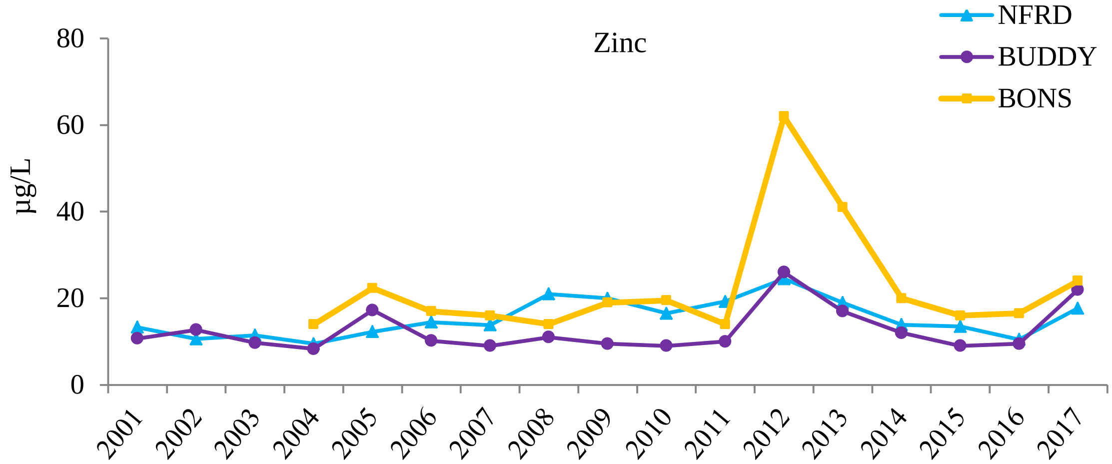


Figure 16. Median zinc concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2017). Two graphs are presented, the bottom graph uses a different scale as it does not include Mainstem Red Dog Creek.

Differences in selenium among these sites are not substantial (Figure 17). Most of the selenium concentrations range from 1 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 2017 were 1.6, 1.7, 2.3, and 1.75 µg/L.

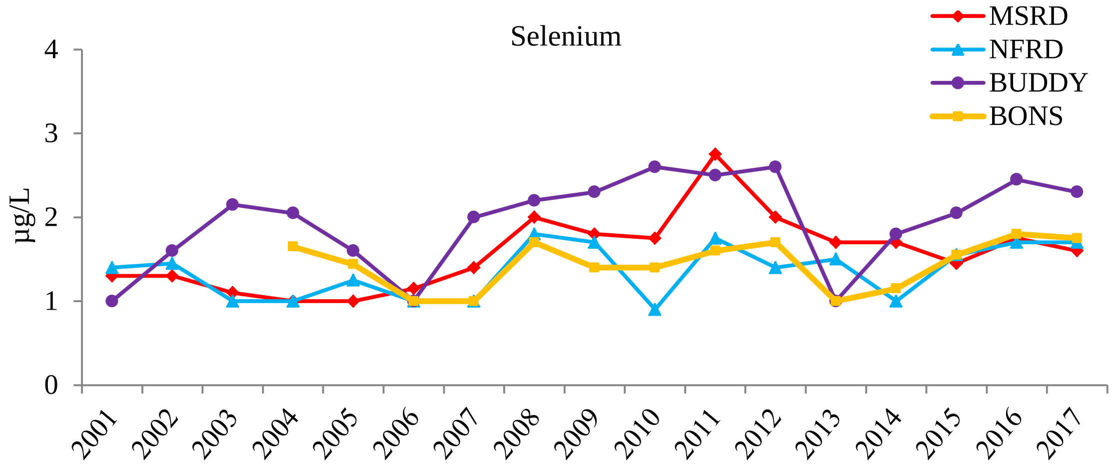


Figure 17. Median selenium concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2017).

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 2017, 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 2017 was highest in Upper North Fork Red Dog Creek (9.1 mg/m^2) and lowest in Middle Fork Red Dog Creek (0.1 mg/m^2) (Figure 18). Periphyton standing crops also were high (> 5 mg/m^2) in Mainstem Red Dog Creek and Bons Creek below Bons Pond. Generally, chlorophyll-a concentration is lowest in Middle Fork Red Dog Creek and highest in Bons Creek (below Bons Pond) and Buddy Creek (below falls).

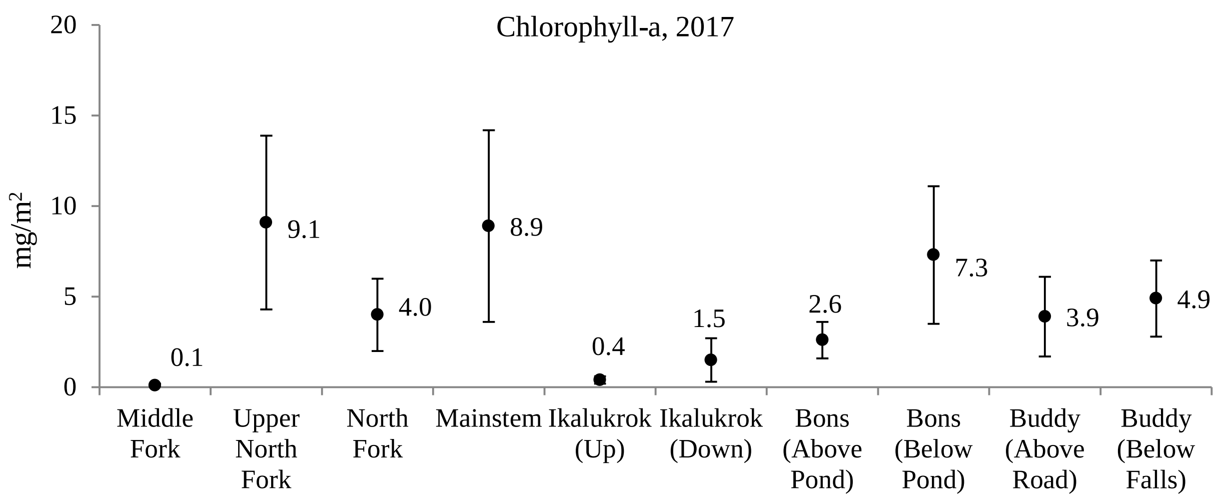


Figure 18. Average concentration of chlorophyll-a (± 1SD) at Red Dog Mine sample sites, 2017.

Average chlorophyll-a concentration in Middle Fork Red Dog, Mainstem Red Dog, and North Fork Red Dog creeks is presented in Figures 19, 20 and 21. Generally, average chlorophyll-a concentration are higher in Mainstem Red Dog and North Fork Red Dog creeks as compared with Middle Fork Red Dog Creek. In 12 of 19 years, average chlorophyll-a concentration in North Fork Red Dog Creek was equal to or higher than Mainstem Red Dog Creek. Low chlorophyll-a concentration in Middle Fork Red Dog Creek probably are 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 waste water discharge from Outfall 001 are low. Most of the TDS in Middle Fork Red Dog Creek is from the waste water discharge at Outfall 001.

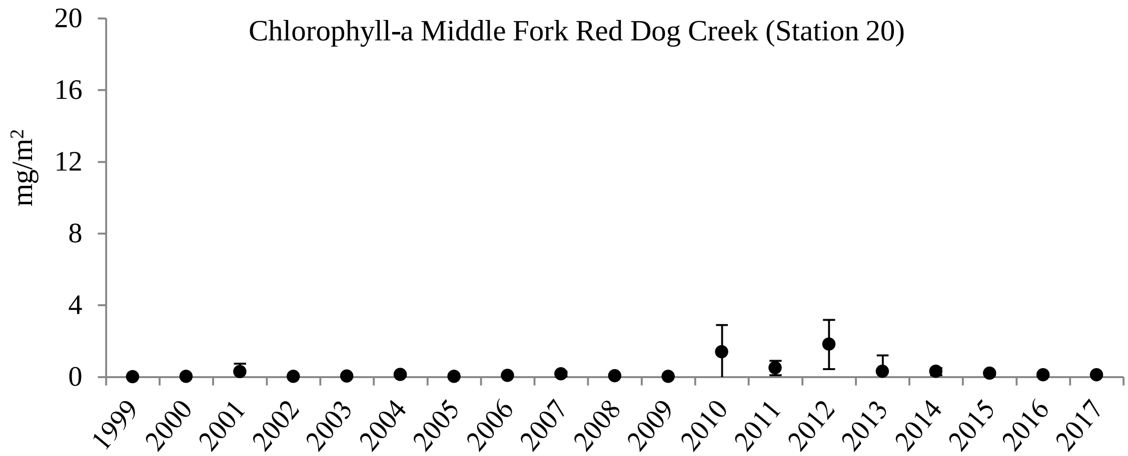


Figure 19. Average concentration (± 1SD) of chlorophyll-a in Middle Fork Red Dog Creek, Station 20, 1999-2017.

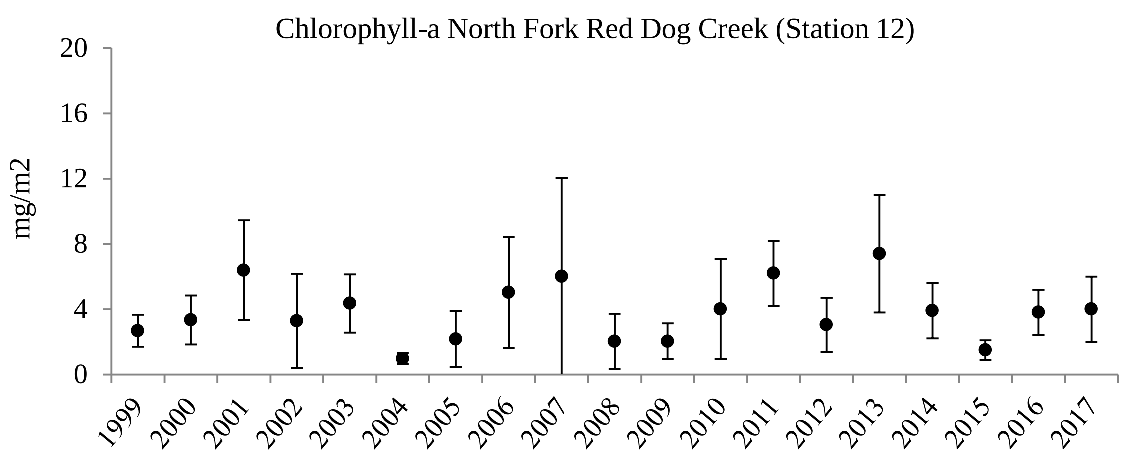


Figure 20. Average concentration (± 1SD) of chlorophyll-a in North Fork Red Dog Creek, Station 12, 1999-2017.

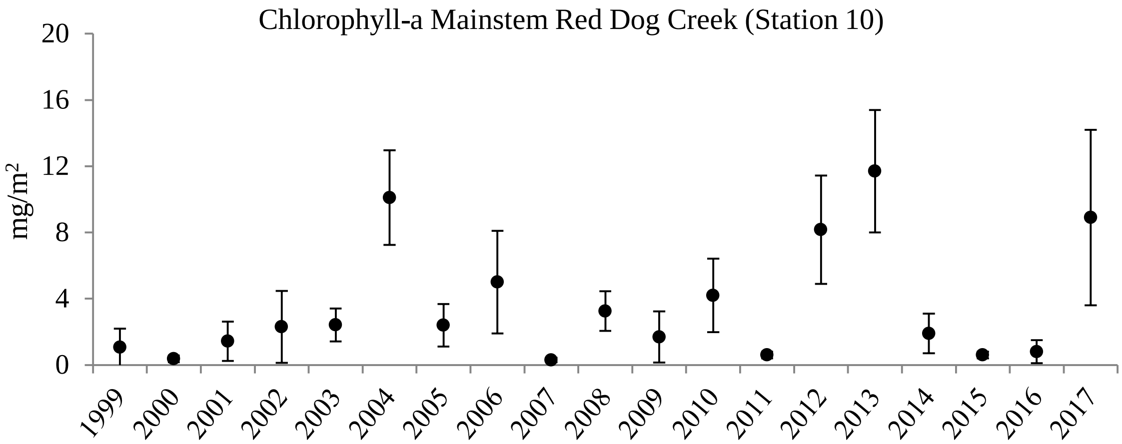


Figure 21. Average concentration (± 1 SD) of chlorophyll-a in Mainstem Fork Red Dog Creek, Station 10, 1999-2017.

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 22 and 23). The variability seen 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, but there are other seeps along Ikalukrok Creek (Figure 24).

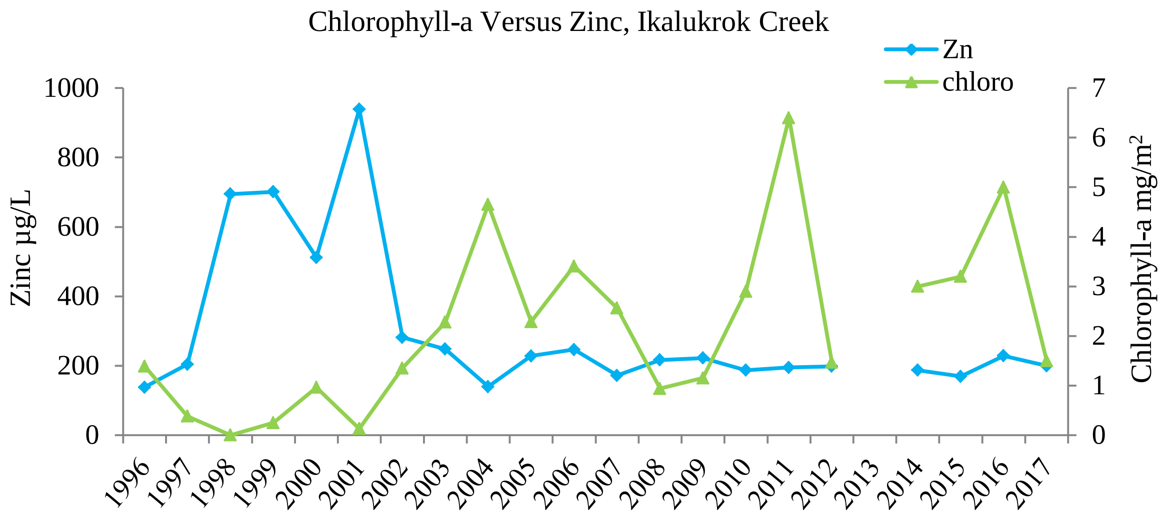


Figure 22. Average concentrations of chlorophyll-a and zinc in Ikalukrok Creek, 1996–2017.

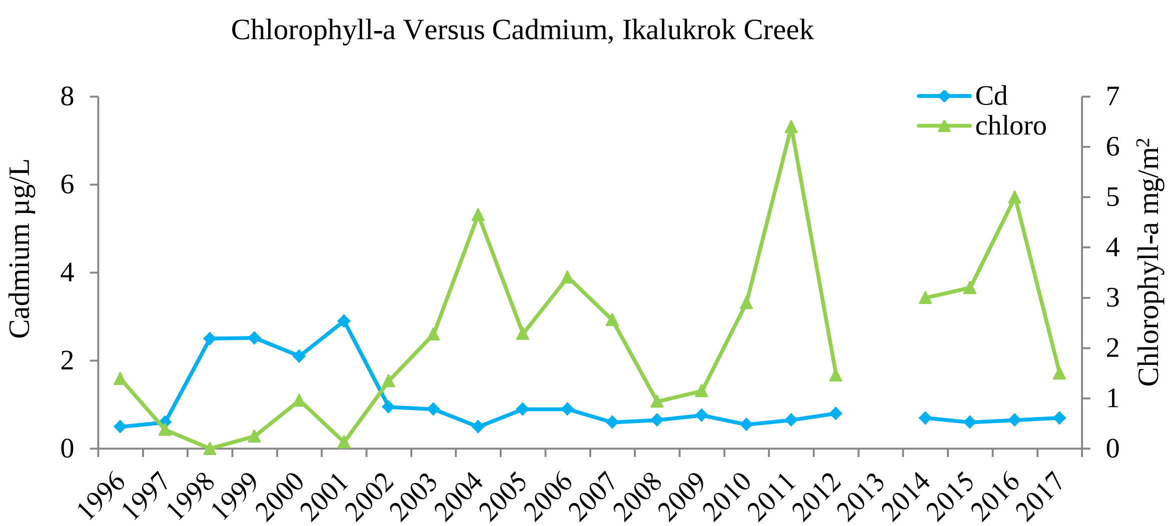


Figure 23. Average concentrations of chlorophyll-a and cadmium in Ikalukrok Creek. 1996-2017.

Figure 24. 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.

In 2017, flows were low at many of the sample sites. Aquatic invertebrate densities were highest in Buddy Creek below the falls with 33.68 per m^3 (Figure 25).

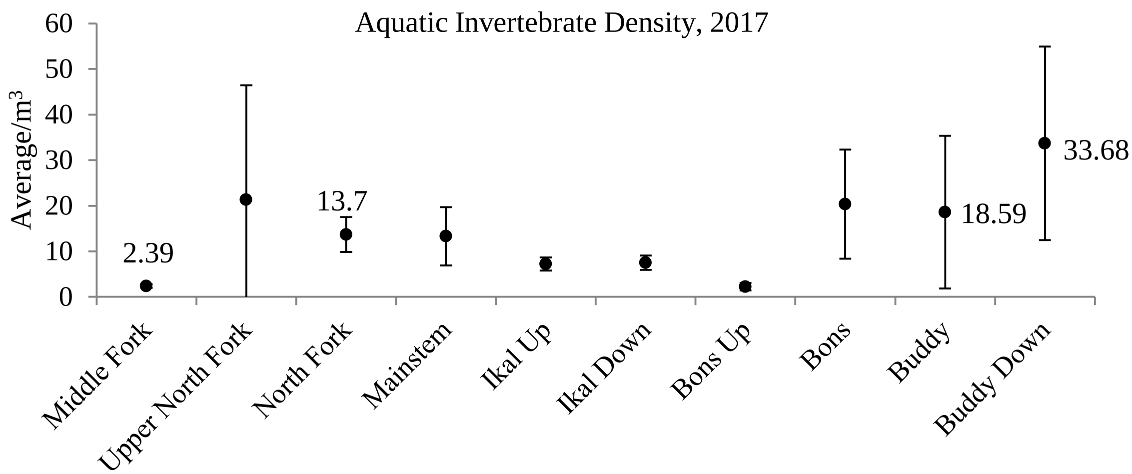


Figure 25. Average aquatic invertebrate densities (± 1SD) in all sample sites near the Red Dog Mine, July 2017. Selected average values shown.

Buddy Creek (above road) generally has higher aquatic invertebrate densities than other sample sites in most years; however, in 2017 the Upper North Fork Red Dog Creek and Buddy Creek sites (below the falls) had higher densities. The average aquatic invertebrate density in Buddy Creek (above road) has varied from a low of 3.8 to a high of 164.5 invertebrates per m^3 (Figure 26). In 2017, average aquatic invertebrate density was 18.59 invertebrates per m^3.

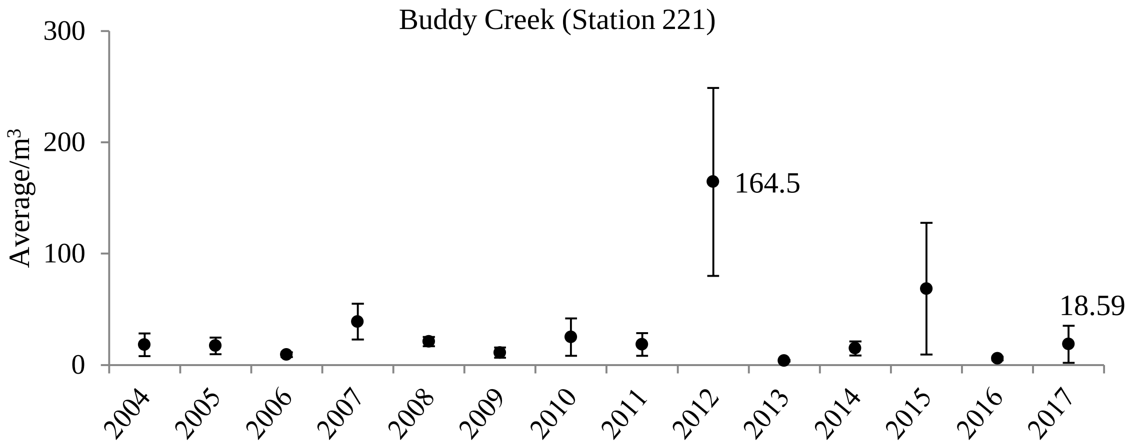


Figure 26. The average aquatic invertebrate density (± 1SD) in Buddy Creek (Station 221) upstream of the road 2004–2017. Selected averages shown.

Aquatic invertebrate densities in North Fork Red Dog Creek generally are higher than in Mainstem Red Dog Creek, but were very similar in 2017 (Figure 27). In 18 out of 19 years, the aquatic invertebrate density was higher in North Fork Red Dog Creek than in Mainstem Red Dog Creek.

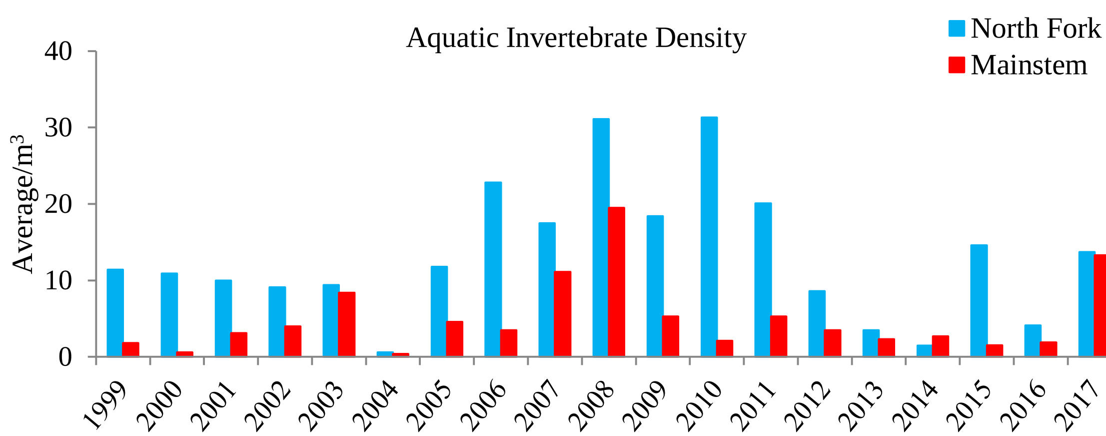


Figure 27. Average aquatic invertebrate densities in North Fork Red Dog and Mainstem Red Dog creeks 1999–2017.

The percent Ephemeroptera, Plecoptera, and Trichoptera (EPT) and the percent Chironomidae for sample sites in 2017 are presented in Figure 28. All sites contained a higher percentage of Chironomidae in 2017, which is a general pattern seen most years. 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.

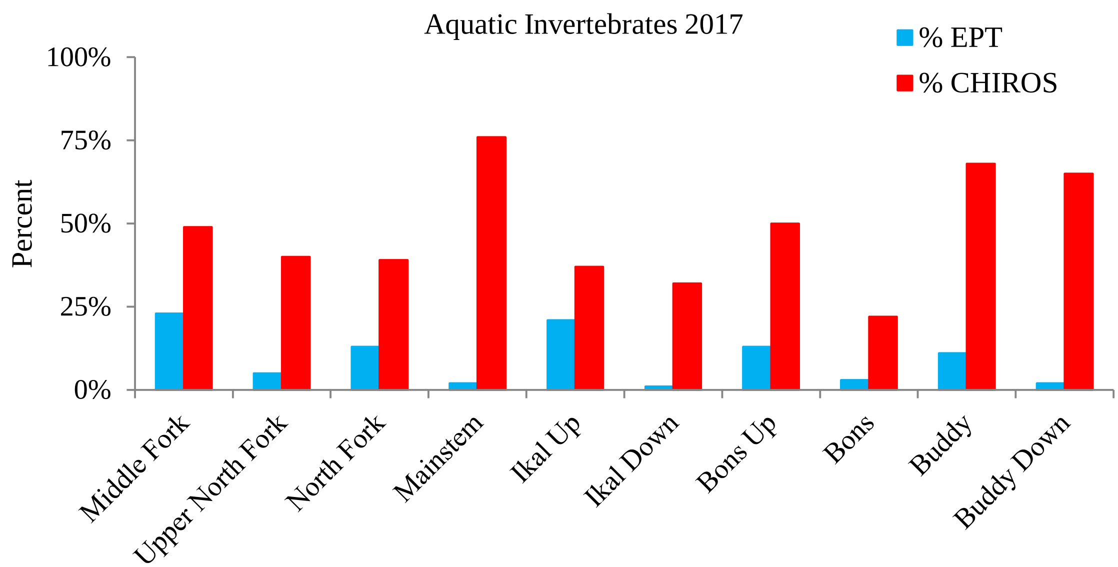


Figure 28. Percent EPT and Chironomidae in the aquatic invertebrate samples at all sample sites Red Dog Mine, July 2017.

The percent EPT in North Fork Red Dog and Mainstem Red Dog creeks was low in 2001 and from 2008 to 2011 (Figure 29). Buddy Creek in certain years (2004, 2011, 2012, 2014, 2015, and 2016) had a much higher percentage of EPT than either North Fork Red Dog or Mainstem Red Dog creeks (Figure 29). In most years since 1999, the percent Chironomidae in North Fork Red Dog and Mainstem Red Dog Creeks has been higher than the percent EPT. In Buddy Creek, percent Chironomidae has been higher than the percent EPT in nine out of 14 years.

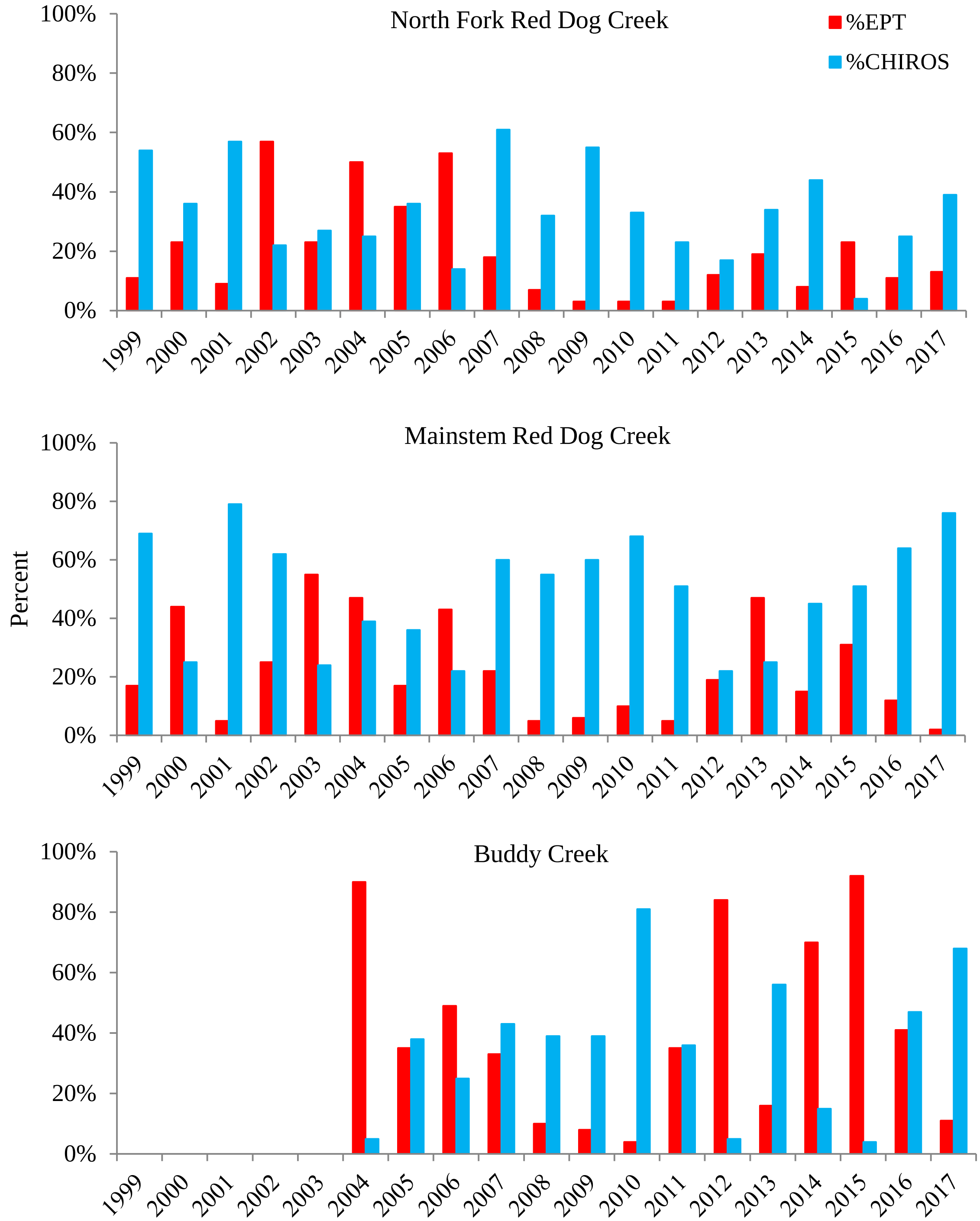


Figure 29. Percent EPT and Chironomidae in North Fork Red Dog Creek (top), Mainstem Red Dog Creek (middle), and Buddy Creek (bottom) 1999–2017. Aquatic invertebrate sampling in Buddy Creek drainage began in 2004.

Taxa richness was compared for the three sample sites in North Fork Red Dog, Mainstem Red Dog, and Buddy creeks (Figure 30). 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. Taxa richness was highest in the Mainstem Red Dog Creek in 2014 and lowest in 2000. In 2016, Buddy Creek had the highest taxa richness since aquatic invertebrate sampling began in 2004, and highest taxa richness among the three sites in 2017. The North Fork Red Dog creek also had average taxa richness in 2017. Overall taxa richness is similar among these sites.

Figure 30. Aquatic invertebrate taxa richness in North Fork Red Dog and Mainstem Red Dog Creek 1999–2017 and Buddy Creek 2004–2017. The running average is included for each site.

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 purpose of this effort is: (1) to determine if differences exist in element concentrations in fish among the sample sites that can be linked with background water quality; and (2) to 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 sample event when fish are moving from Bons Pond into Bons Creek. However, catches of juvenile Arctic grayling were low in spring 2017 so about half of the samples were collected in early July with a fyke net in Bons Pond.

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 were collected opportunistically from Mainstem Red Dog, Anxiety Ridge, and Buddy creeks during the minnow trap sample event in late summer. These locations have been sampled annually since 2005, except for in 2012 and 2013 when water levels were too high to effectively sample.

In May and June 2017, six juvenile Arctic grayling were captured in Bons Creek just upstream of Bons Pond and in early July, nine juvenile Arctic grayling were captured in Bons Pond (Appendix 4). The average length of these fish was 173.4 mm FL ± 8.6 mm (1SD). Cadmium, lead, selenium, zinc, and mercury concentrations have been analyzed in juvenile Arctic grayling from Bons Pond. All results are for whole body in mg/kg (dry weight).

In 2017, the average cadmium concentration in Bons Pond juvenile Arctic grayling was 0.09 mg/kg which was the lowest since measurements began in 2004 (Figure 31). The highest average cadmium concentration was 0.27 mg/kg in 2014.

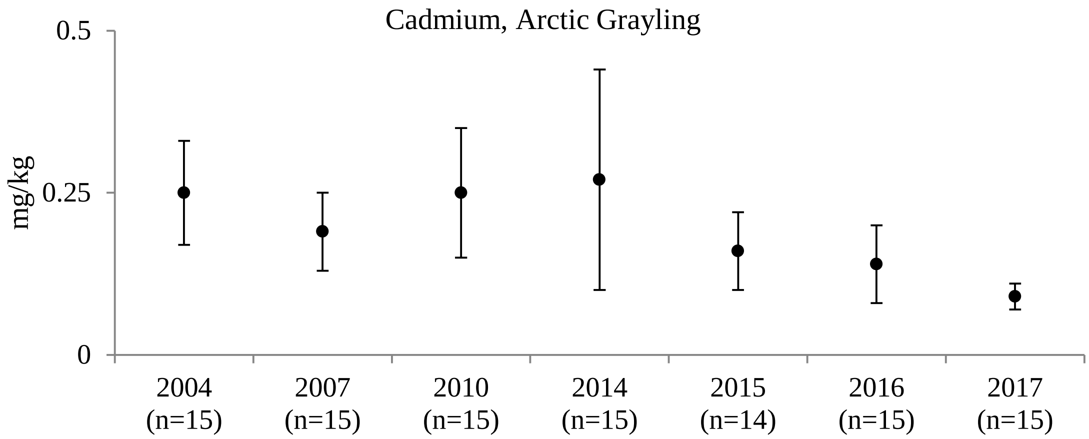


Figure 31. Average cadmium concentrations (± 1SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).[3]

In 2017, the average lead concentration was 0.29 mg/kg in juvenile Arctic grayling from Bons Pond (Figure 32). This was the lowest documented lead concentration to date, and similar to that found in 2007 (0.35 mg/kg). Average lead concentration was highest from 2014 to 2016.

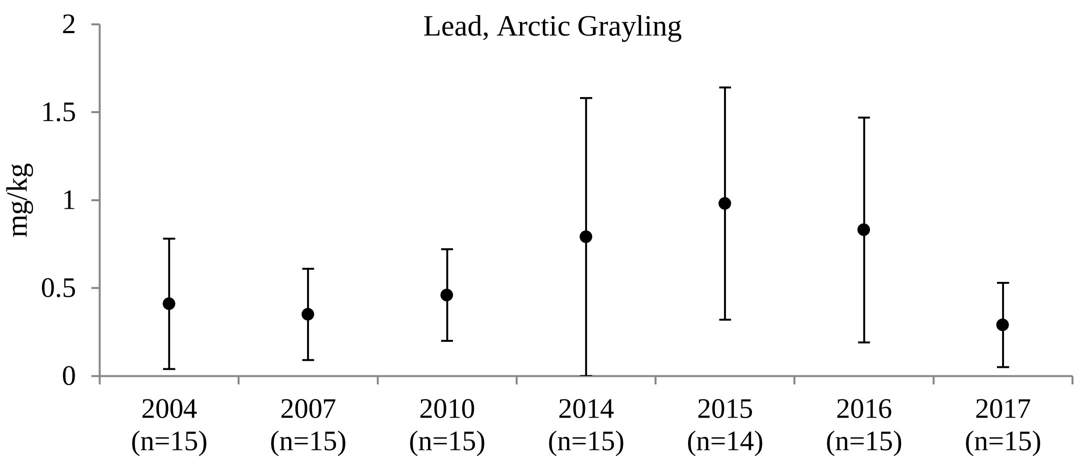


Figure 32. Average lead concentrations (± 1SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

Average selenium concentrations in juvenile Arctic grayling from Bons Pond have showed a decreasing trend since 2014 (Figure 33). Average values in 2017 were 12.2 mg/kg, which are higher than average values found prior to 2014.

[3] In 2015 only 14 juvenile Arctic grayling samples were analyzed; the lab was unable to analyze one fish.

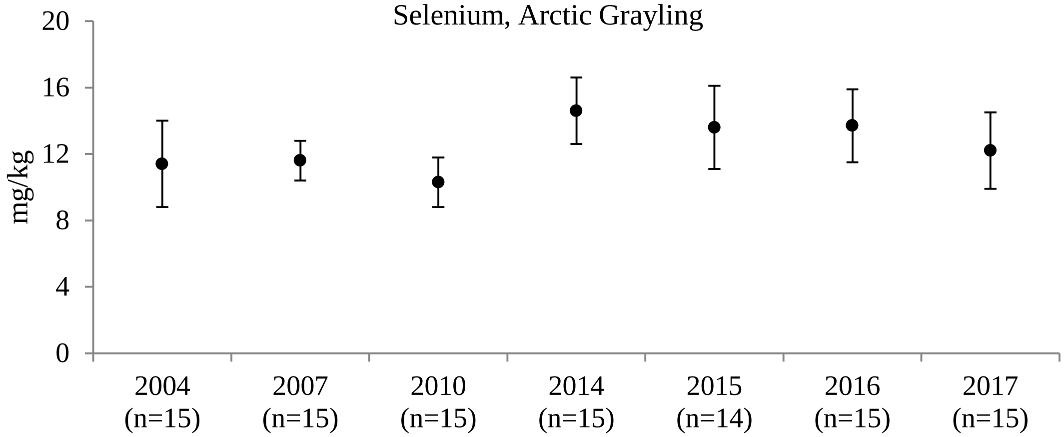


Figure 33. Average selenium concentrations (± 1SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

Similar to cadmium and lead, average zinc concentrations in juvenile Arctic grayling from Bons Pond in 2017 (60 mg/kg) were the lowest since 2004 (Figure 34). Average concentrations have varied from a high of 104 mg/kg in 2016 to a low of 60 mg/kg in 2017.

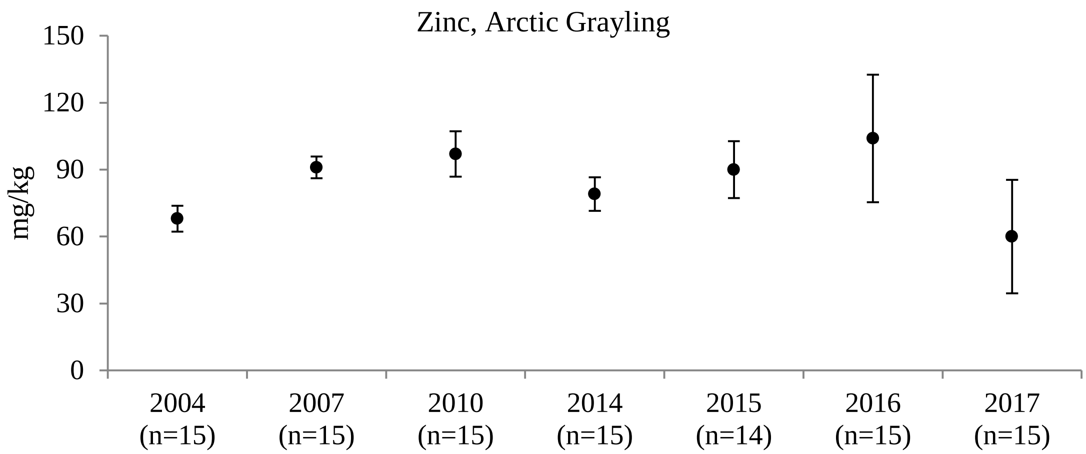


Figure 34. Average zinc concentrations (± 1SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

Average mercury concentrations in juvenile Arctic grayling from Bons Pond has been variable and ranged from a high of 0.05 mg/kg in 2007, 2010, 2016 and 2017 to a low at detection limit of 0.02 mg/kg in 2004 and 2014 (Figure 35).

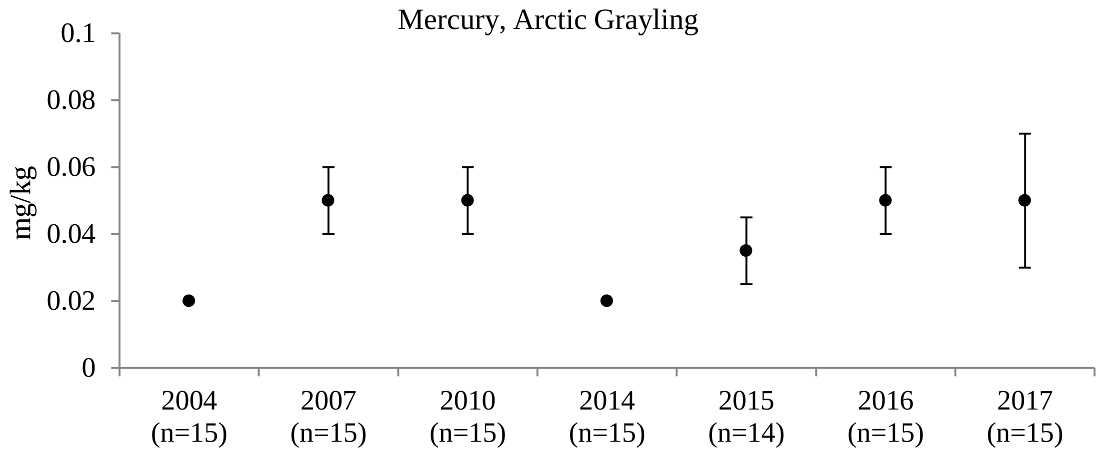


Figure 35. Average mercury concentrations (± 1SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

In August 2017, juvenile Dolly Varden were collected from Mainstem Red Dog (n=11), Buddy (n=9), and Anxiety Ridge creeks (n=15) for whole body element analysis (Appendix 5). Due to recent and ongoing rainfall, water levels at all sites were high and sampling was challenging. Over three times the typical number of minnow traps were set at the Mainstem Red Dog Creek site in an attempt to collect enough fish for element analysis.

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 were expected. However, as noted in the Water Quality section of this report, specific element concentrations are substantially higher in the clean water bypass than in the treated mine discharge water. The main source of cadmium, lead, and zinc to Mainstem Red Dog creek is the waters from the clean water bypass.

Whole body cadmium concentrations (median value) are higher in juvenile Dolly Varden collected from Mainstem Red Dog Creek and consistently lowest in Anxiety Ridge Creek (Figure 36). Highest median cadmium concentrations occurred at all three sites in 2006. Median cadmium concentrations have been below 1 mg/kg in fish from Buddy Creek since 2007 and Anxiety Ridge Creek since 2005. In 2016, Dolly Varden from Buddy Creek had the lowest median concentrations since sampling began. Among data for Mainstem Red Dog Creek, changes in whole body cadmium concentrations seem to track closely with the water quality data (Figure 37).

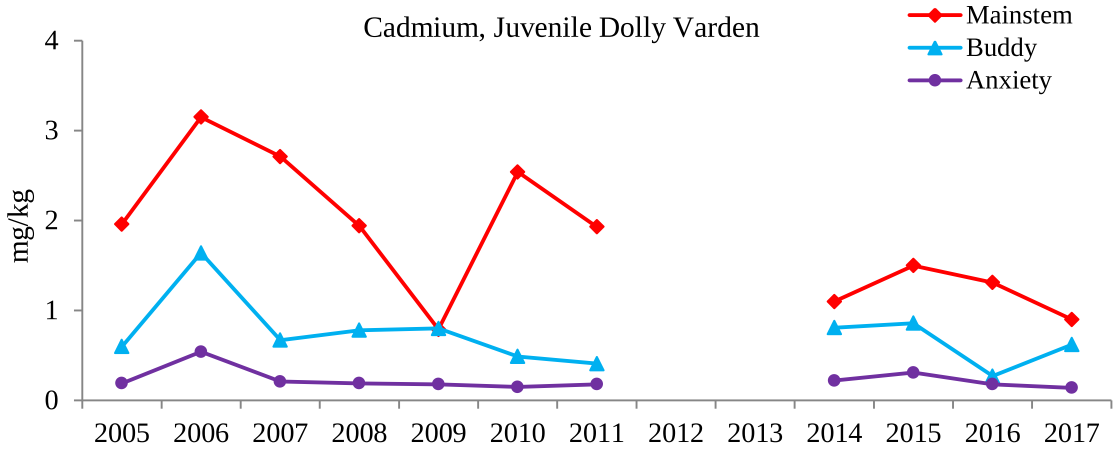


Figure 36. Median cadmium whole body concentrations in juvenile Dolly Varden from 2005 to 2017.

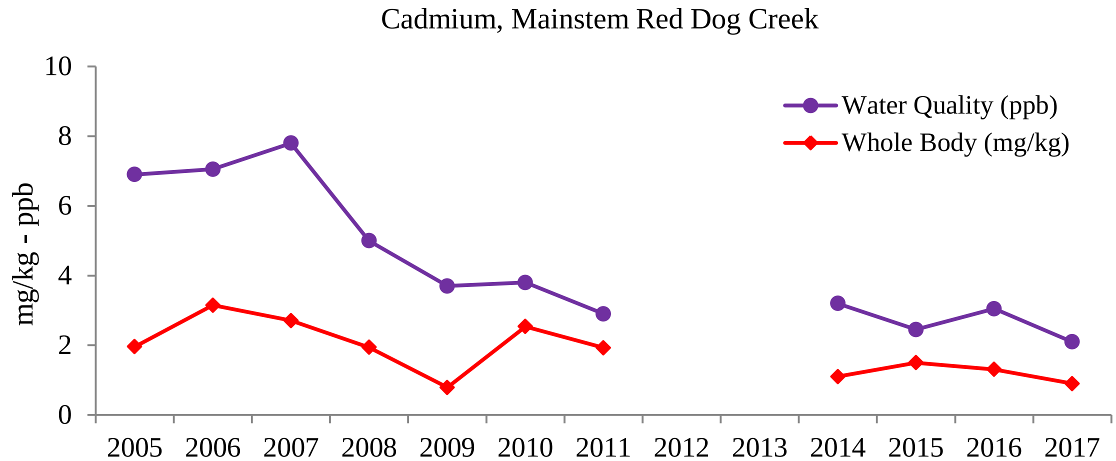


Figure 37. Median whole body cadmium concentrations in juvenile Dolly Varden and median cadmium water quality data for Mainstem Red Dog Creek.

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 38). Lead concentrations in the water of Mainstem Red Dog Creek have been highly variable since 2005 and there does not seem to be any relationship between lead in the water and lead in whole body samples from Mainstem Red Dog Creek juvenile Dolly Varden (Figure 39).

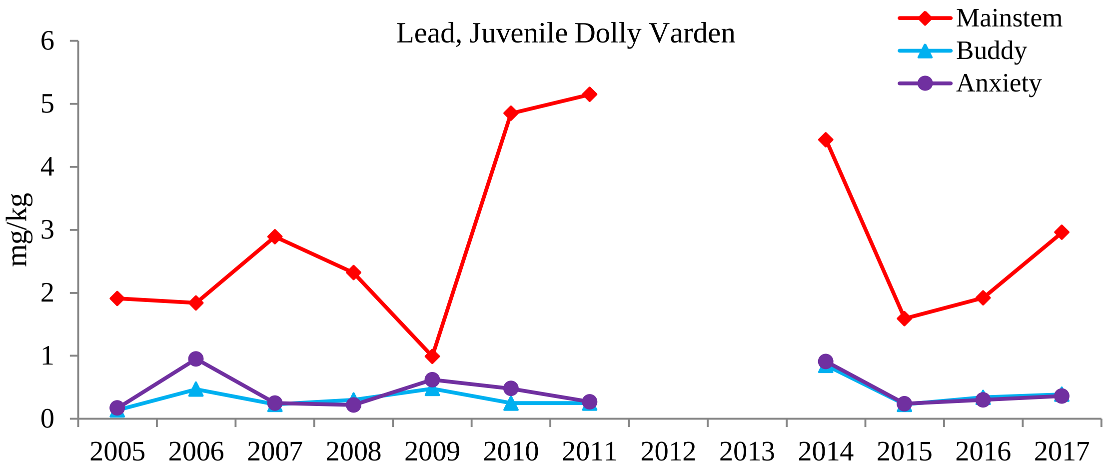


Figure 38. Median lead whole body concentrations in juvenile Dolly Varden from 2005 to 2017.

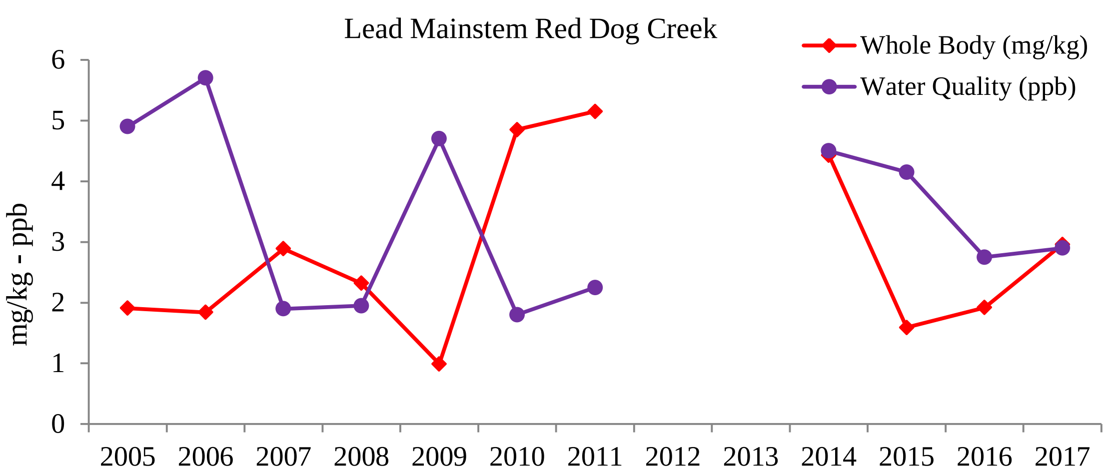


Figure 39. Median whole body lead concentrations in juvenile Dolly Varden and median lead water quality data for Mainstem Red Dog Creek.

Median whole body selenium concentrations in juvenile Dolly Varden generally are lowest in fish from Anxiety Ridge Creek (Figure 40). Whole body selenium concentrations in juvenile Dolly Varden from Mainstem Red Dog Creek have increased from 2009 to 2015, and slightly decreased in 2016 and 2017. Among data for Mainstem Red Dog Creek there doesn't seem to be any relationship between selenium concentrations in the water and in whole body juvenile Dolly Varden (Figure 41).

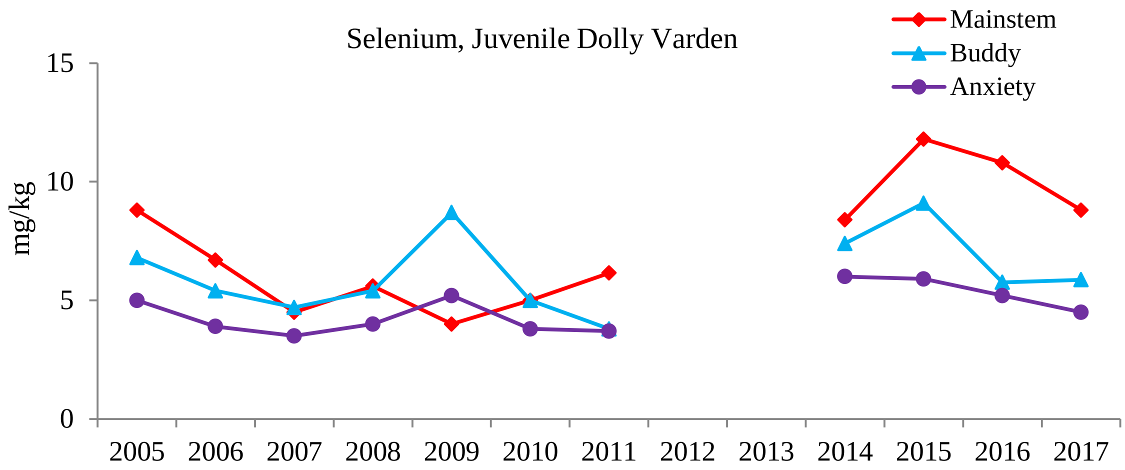


Figure 40. Median selenium whole body concentrations in juvenile Dolly Varden from 2005 to 2017.

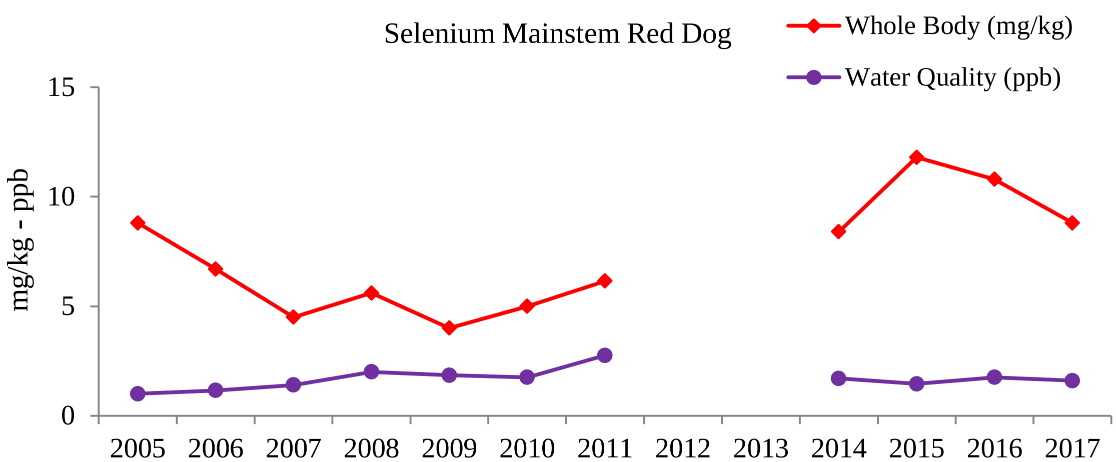


Figure 41. Median whole body selenium concentrations in juvenile Dolly Varden and median selenium water quality data for Mainstem Red Dog Creek.

Median zinc whole body concentrations are generally highest in fish from Mainstem Red Dog Creek and lowest in fish from Anxiety Ridge Creek (Figure 42). Zinc whole body concentrations have decreased from a high of 351 mg/kg in 2007 to a low of 154 mg/kg in 2017 in Mainstem Red Dog Creek, with values remaining relatively stable since 2009 among the three sites. This is the first year median zinc concentrations were lower in Mainstem Red Dog Creek than Buddy Creek. Generally among Mainstem Red Dog Creek data, as zinc concentrations in the water have decreased so have whole body zinc concentrations (Figure 43).

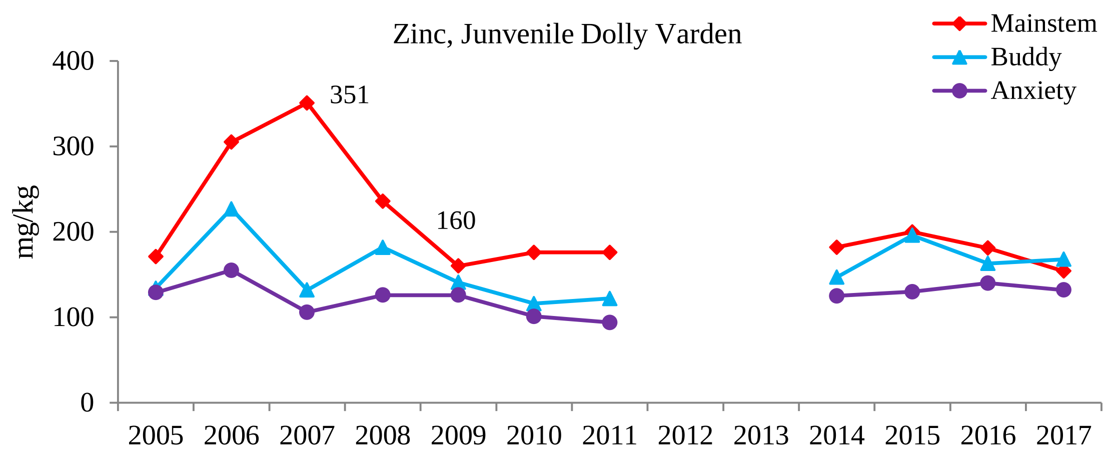


Figure 42. Median zinc whole body concentrations in juvenile Dolly Varden from 2005 to 2017.

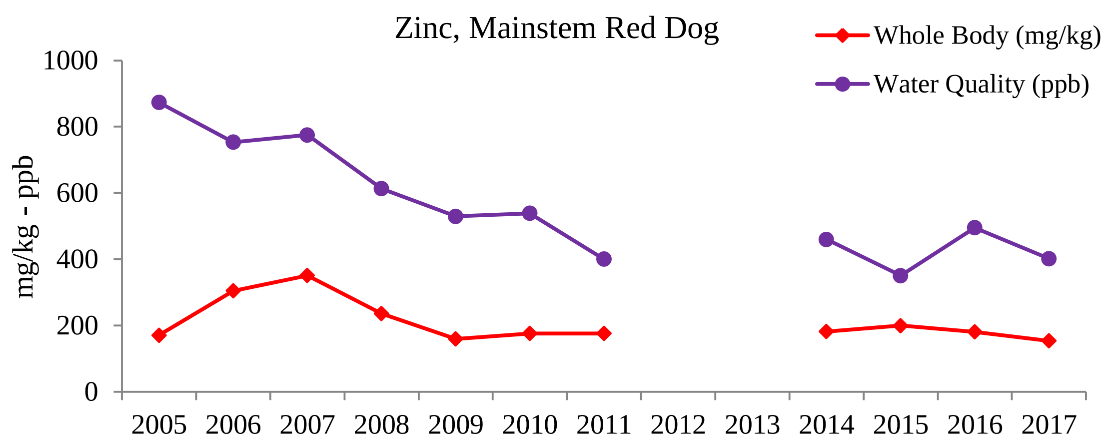


Figure 43. Median whole body zinc concentrations in juvenile Dolly Varden and median zinc water quality data for Mainstem Red Dog Creek.

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 44). The highest recorded median of mercury was detected in 2016 in Anxiety Creek at 0.12 mg/kg.

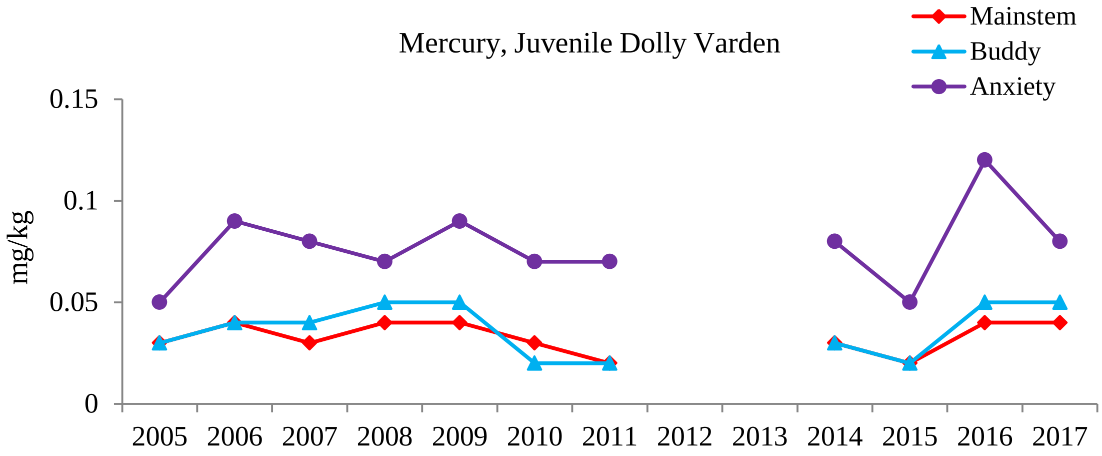


Figure 44. Median mercury whole body concentrations in juvenile Dolly Varden from 2005 to 2017.

Selenium Concentrations in Adult Arctic Grayling

In spring 1999, and 2014–2016, Arctic grayling females were collected at selected sites in northwestern Alaska near the Red Dog Mine and at sites located in Interior Alaska. Samples were collected from the Chena River (Fairbanks), the water supply reservoir (upper Fish Creek) at the Fort Knox Mine, and from Bons Pond and North Fork Red Dog Creek near the Red Dog Mine. In spring 2017, samples were collected upper Fish Creek and from the Red Dog Mine area. All selenium data collected to date are contained in Appendix 6.

The purpose of these collection efforts is to compare the selenium concentration in the ovaries of Arctic grayling among sites and over time. Literature suggests that selenium concentrates in the ovaries of fishes and can have adverse effects on reproductive success. Selenium accumulation in the eggs of fish has been shown to yield the most robust relationship with the occurrence of deformities and reduced survival of offspring.

Bons Pond and the Fort Knox water supply reservoir support Arctic grayling. Both populations occur upstream of an earthen fill dam that is a barrier to upstream movement of fish. At Fort Knox, the Arctic grayling overwinter in the water supply reservoir and spawn in tributaries, primarily in the developed wetland complex (Ott and Bradley, 2017). In Bons Pond, the Arctic grayling overwinter in the pond and spawn in Bons Creek and in the outlet of Bons Pond. The Arctic grayling ovary samples from these two sites are from fish that have spent their entire life history in these waterbodies.

Fort Knox mature Arctic grayling were the youngest while Bons Pond fish are the oldest. The Fort Knox Arctic grayling had an average age of 8 ± 1 year (1SD) while the Bons Pond fish averaged 11.8 ± 3.1 years (1SD). The five fish retained from Mainstem Red Dog Creek averaged 9.8 ± 4.6 years (1SD).

Selenium concentrations in Arctic grayling ovaries were highest in Bons Pond, while concentrations in Arctic grayling ovaries from the North Fork Red Dog Creek remain the second highest (Figure 45). Arctic grayling from Fish Creek at Fort Knox contained the lowest concentration of selenium in ovaries.

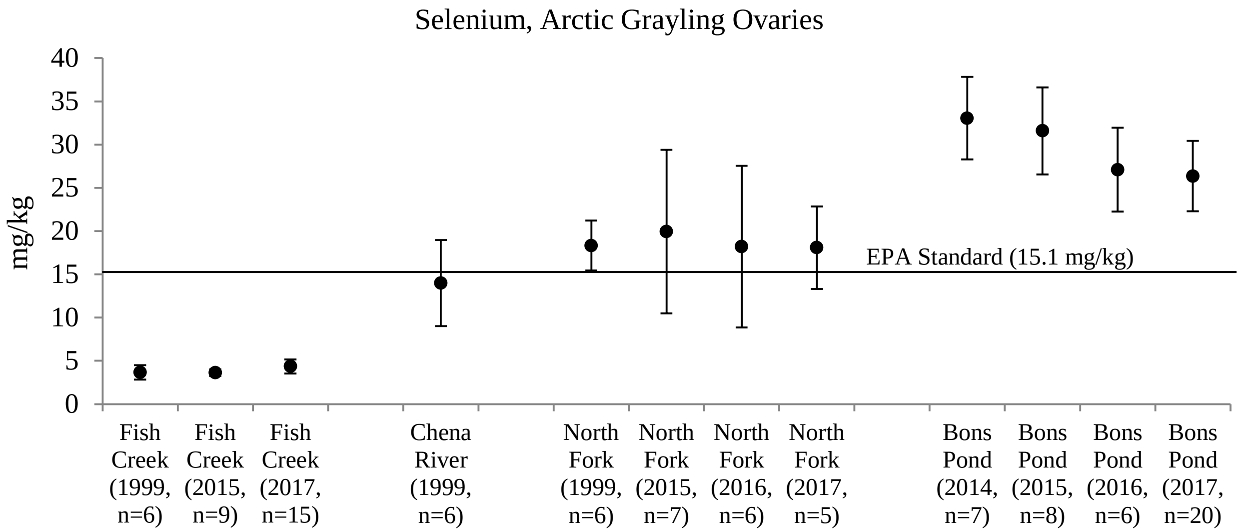


Figure 45. Average selenium (± 1SD) concentrations (dry weight) in Arctic grayling ovaries from Fish Creek, Chena River, North Fork Red Dog Creek, and Bons Pond.

Selenium concentrations found in the ovaries of Bons Pond Arctic grayling are higher than the EPA's final chronic aquatic life criterion for fresh water (15.1 mg/kg – dry weight)(EPA, 2016), while selenium concentrations in Fish Creek Arctic grayling are substantially lower. Selenium concentrations in ovaries of Arctic grayling from North Fork Red Dog Creek are equal to or slightly higher than the EPA criterion. Selenium concentrations over time in North Fork Red Dog Creek, Bons Pond, and Fish Creek have not changed; however, abundance estimates of Arctic grayling in Bons Pond has shown that the population has steadily decreased from 2007 to 2014, with a slight increase in 2015 and 2016. The decrease in the Bons Pond Arctic grayling population might be due to elevated selenium in the ovaries, but it also may be related to the fact that this introduced population expanded rapidly after their introduction in 1994 and 1995. The decrease in the number of Arctic grayling in Bons Pond may be related to predation of larger fish on age-0 recruits since there is no separation of age classes by habitat type. Recent sampling in Bons Pond indicates that there is an increasing number of smaller fish; therefore the population of adult fish (≥ 200 mm FL) may increase in the future.

The North Fork Red Dog Creek Arctic grayling population has been relatively stable over time and recruitment of new fish has been strong since 2007 with the exception of spring 2017 when the North Fork was inundated in aufeis. The Arctic grayling population in Fish Creek at Fort Knox has been variable over the sample years and population changes have been linked closely with access to spawning habitat and access from spawning and rearing habitat to overwintering which can be adversely affected by beaver activity (Ott and Bradley, 2016).

Metal Concentrations in Adult Dolly Varden

In 2017, 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. Fourteen fish were sampled in 2017, half in the spring and half in the fall.

The purposes 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 Dolly Varden attain the majority of their growth while in the marine environment. All laboratory work was done with Level III Quality Assurance. Data for 2017 are presented in Appendix 7 and 8.

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 metals vary with season, age, size, weight, and feeding habits of fish (Jenkins 1980) and in the case of anadromous Dolly Varden, the metals concentrations vary with exposure to freshwater and marine environments. None of the analytes measured appear to concentrate in muscle tissue.

Analyte concentration in various tissues is summarized below and in Figures 46 through 51: One figure is presented for each analyte and contains a summation of data for fish sampled from 1999 to 2017.

- cadmium concentrates in kidney tissue (Figure 46)
- copper concentrates in liver tissue and eggs (Figure 47);
- lead does not concentrate in any specific tissue (Figure 48);
- selenium concentrates in kidney and eggs (Figure 49);
- zinc concentrates in eggs (Figure 50); and
- mercury concentrates in kidney tissue (Figure 51).

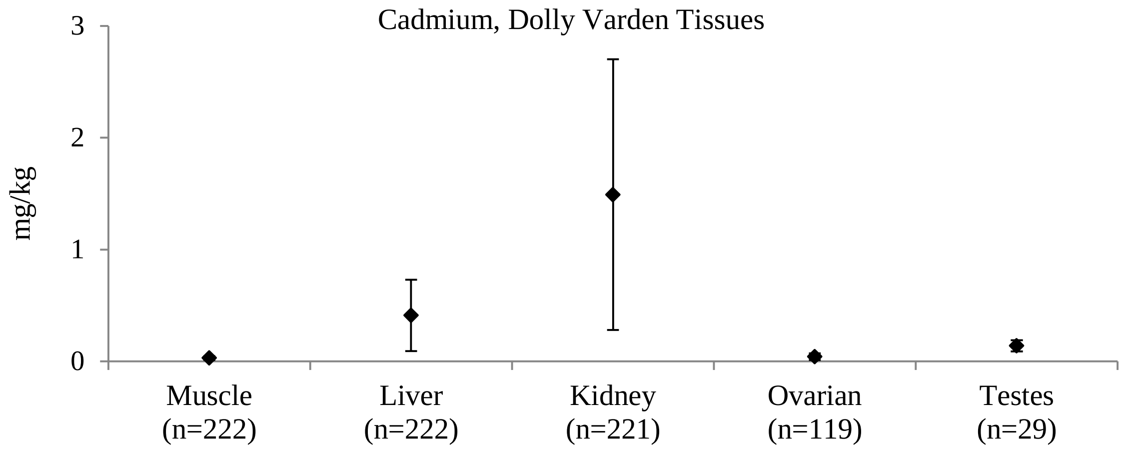


Figure 46. Average cadmium (± 1SD) concentration (dry weight) in adult Dolly Varden tissues, Wulik River (1999–2017).

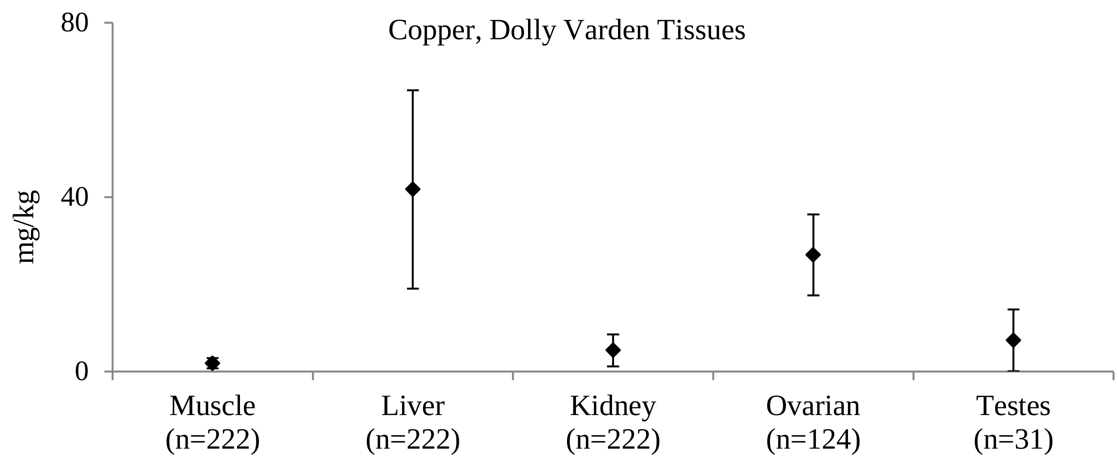


Figure 47. Average copper (± 1SD) concentration (dry weight) in adult Dolly Varden tissues, Wulik River (1999–2017).

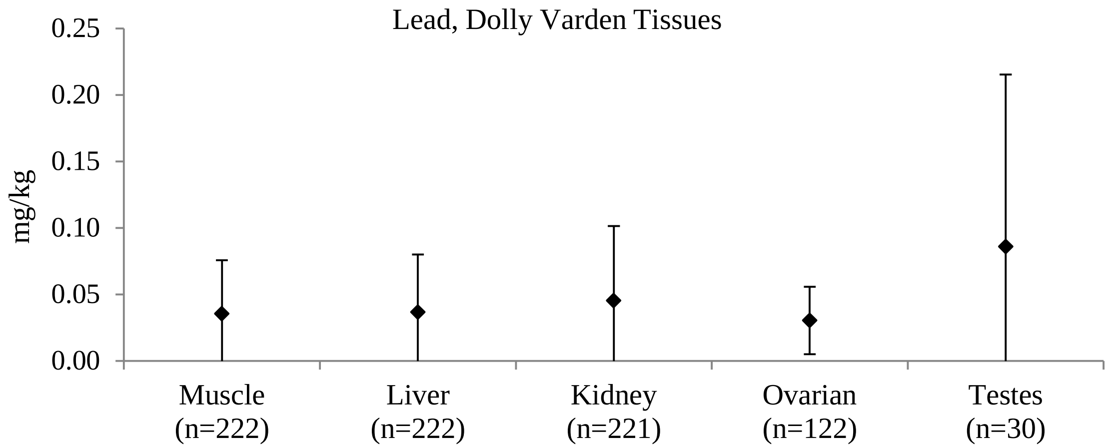


Figure 48. Average lead (± 1SD) concentration (dry weight) in adult Dolly Varden tissues, Wulik River (1999–2017).

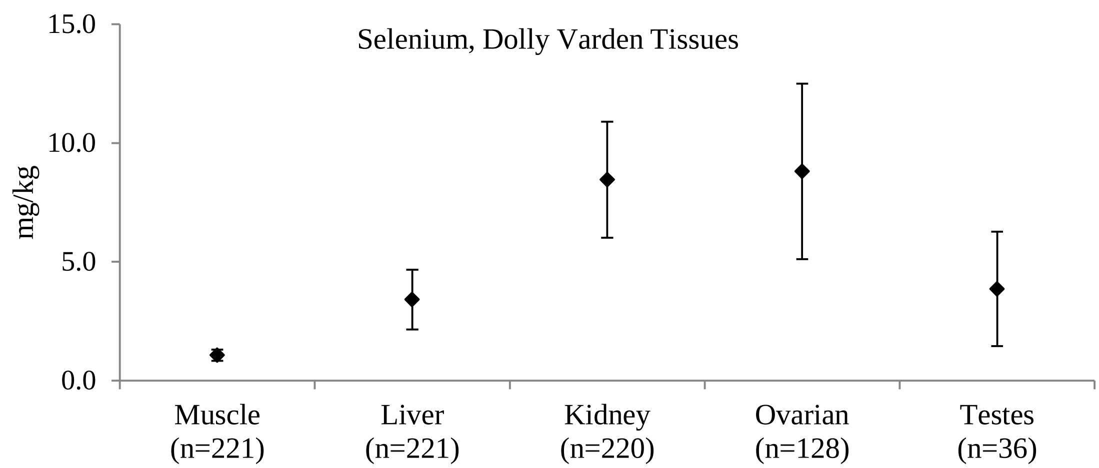


Figure 49. Average selenium (± 1SD) concentration (dry weight) in adult Dolly Varden tissues, Wulik River (1999–2017).

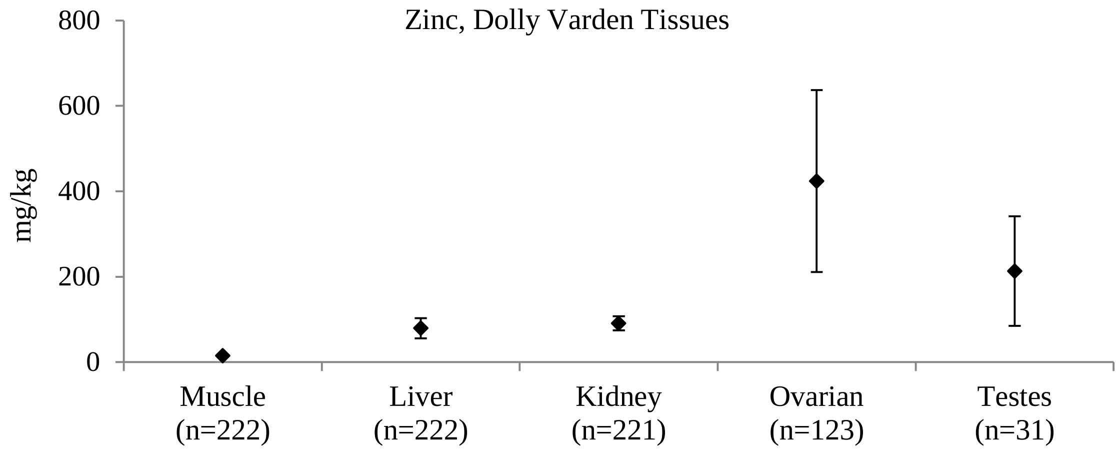


Figure 50. Average zinc (± 1SD) concentration (dry weight) in adult Dolly Varden tissues, Wulik River (1999–2017).

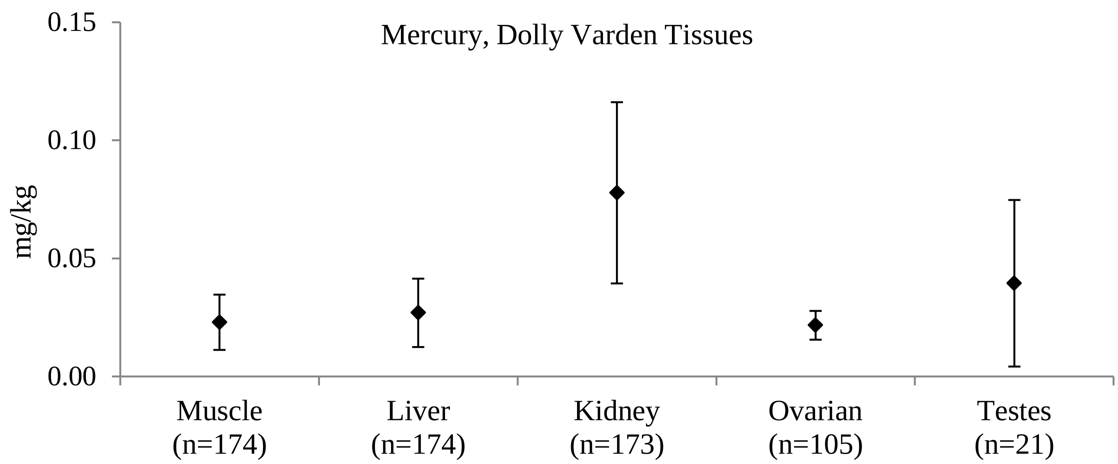


Figure 51. Average mercury (± 1SD) concentration (dry weight) in adult Dolly Varden tissues, Wulik River(2003–2017).

Average cadmium concentrations in adult Dolly Varden kidney tissue have been variable since 1999 (Figure 52). 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, and has since been slowly decreasing.

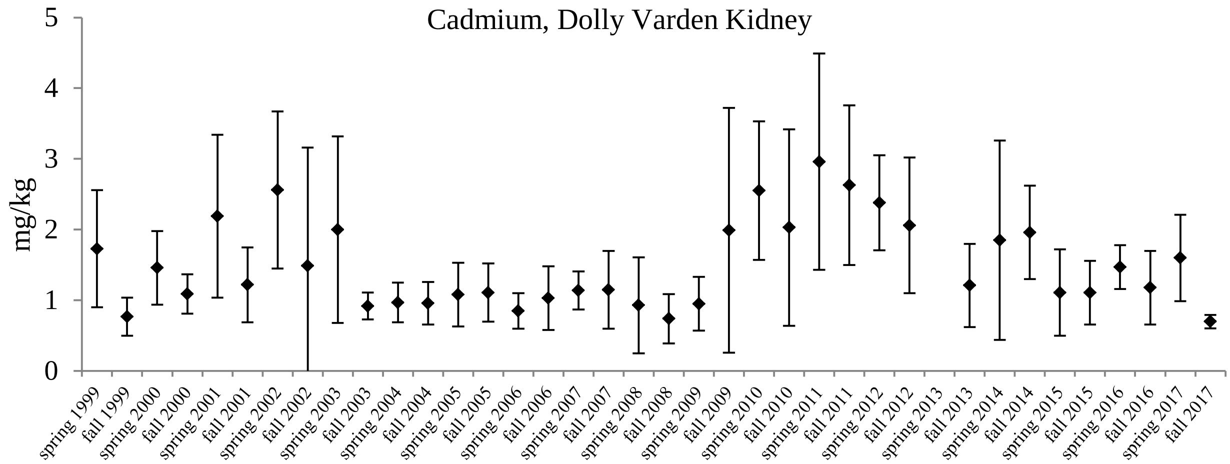


Figure 52. Average cadmium (± 1SD) concentrations (dry weight) in adult Dolly Varden kidney tissues from 1999 to 2017.

Average selenium concentrations in Dolly Varden ovaries are higher for fish sampled in the fall (10.5 mg/kg) than for fish sampled in the spring (6.3 mg/kg) (Figure 53). The Dolly Varden sampled in the fall would have recently returned from the marine environment and thus one may that is where they acquired the selenium.

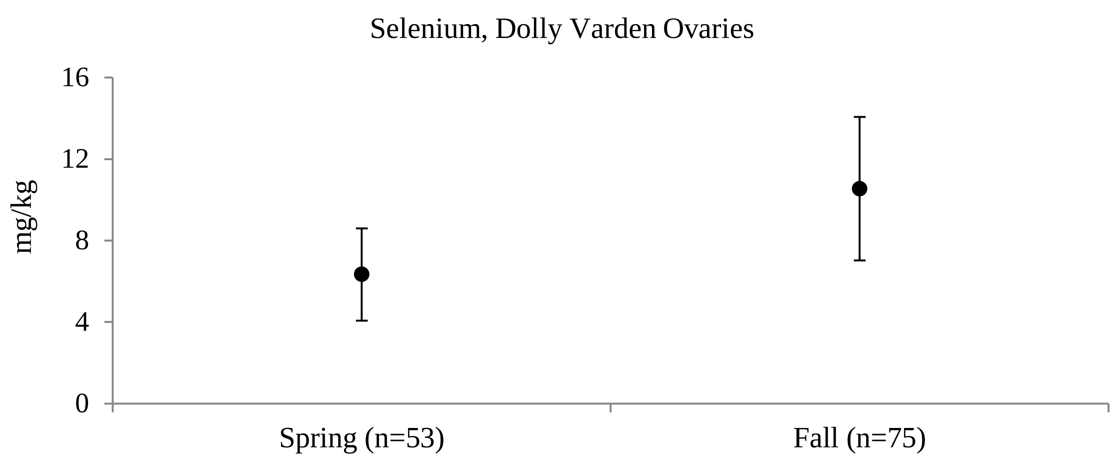


Figure 53. Average selenium (± 1SD) concentrations (dry weight) in Dolly Varden ovaries from 1999 to 2017.

Dolly Varden, Overwintering

Two aerial surveys were performed in 2017 to estimate the number of overwintering Dolly Varden in the Wulik River. Surveys were conducted on September 23 and 25 from an AStar helicopter provided by Teck (Appendix 9). Weather conditions were good for both flights, with clear skies, and windy conditions on September 23. Winds were much calmer on September 25, resulting in better overall observations and more reliable counts. Fish were present near the lower boundary of the survey area suggesting they were still moving into the river, so it is likely that the overwintering population is higher than reported here. Estimated stream flow in the Wulik River was 1,300 cfs on September 23 and 1,100 cfs on September 25.

Late September estimates of Dolly Varden have decreased annually since 2005, reached their lowest (21,084 fish) number in 2012, but then increased in fall 2014 (63,951 fish), and have been relatively stable with a 2017 estimate of 62,029 fish (Figure 54 and Table 4). Dolly Varden may be delaying their migration until later in the fall; therefore, aerial surveys may need to be conducted later in the season.

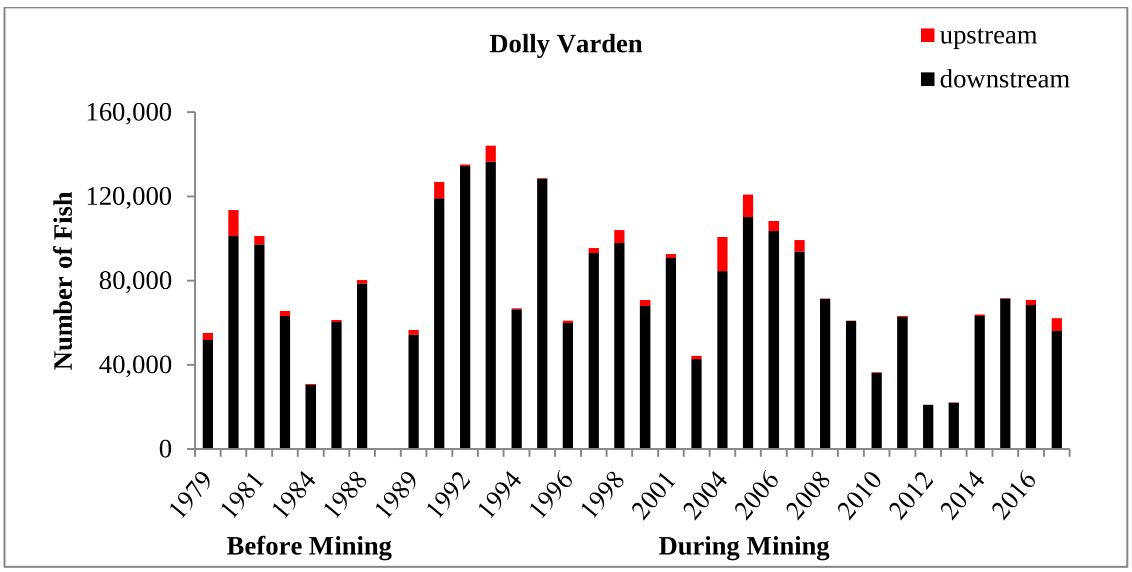


Figure 54. Aerial survey estimates of the number of Dolly Varden in the Wulik River just prior to freezeup, 1979-2017.

The number of Dolly Varden estimated in the fall in the Wulik River varies annually. Survey results in 2017 found that 91% of the fish observed were downstream of the mouth of Ikalukrok Creek (Table 4). Continued use of this section of the Wulik River by the majority of overwintering Dolly Varden suggests that conditions have not changed to alter their distribution.

Table 4. Estimated number of Dolly Varden in the Wulik River.

Year	Wulik River upstream of Ikalukrok Creek	Wulik River downstream of Ikalukrok Creek	Total Fish	Percent 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	1,500	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	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
2001	2,020	90,594	92,614	98
2002	1,675	42,582	44,257	96
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
The population estimate (mark/recapture) for winter 1988/1989 for fish				
>400 mm was 76,892 (DeCicco 1990)				
The population estimate (mark/recapture) for winter 1994/1995 for fish				
>400 mm was 361,599 (DeCicco 1996)				
Fall 2000 and 2003 aerial surveys were not made 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 (Figure 55, and Appendix 9). In fall 2017, an aerial survey was flown using an AStar helicopter. On September 25, an estimated 1,423 live and dead chum salmon were observed in Ikalukrok Creek. Weather conditions were excellent with mostly clear skies and light winds. All chum salmon were located below Station 160 on Ikalukrok Creek, the furthest downstream location at which the instream TDS limits apply (500 mg/L TDS from July 25 through the end of the discharge season).

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.

Annual aerial surveys, post-mining, were initiated in 1990. Based on the number of chum salmon counted in the Ikalukrok Creek drainage during 1981 and 1982 and recognizing that the 1981 estimate was an extrapolation, data collected suggest that the chum salmon population has recovered to its pre-mining level.

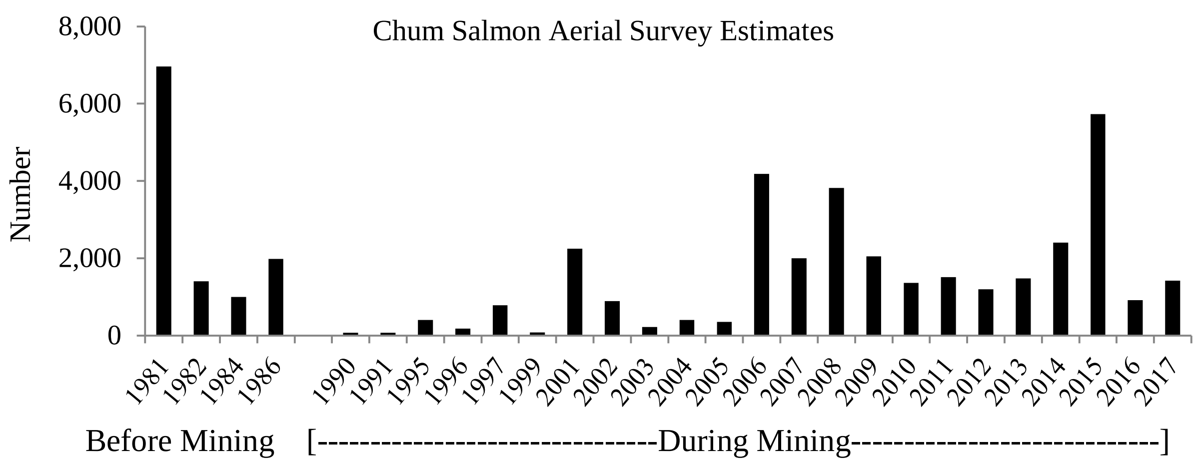


Figure 55. Peak estimates of chum salmon escapement in Ikalukrok Creek. Note, the 1981 count was an estimate based on extrapolation from aerial photographs. The chum salmon spawning reaches are concentrated in select areas along this reach of the creek.

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 (EVS Consultants Ltd and Ott Water Engineers 1983, Ward and Olson 1980).

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 were increased to ten per sample reach. Under the modified program that began in 2010, nine sites are now sampled with 10 minnow traps per sample reach with about 24 hrs of effort in early-to-mid August (Table 5, Appendix 10). 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 5. Location of juvenile Dolly Varden sample sites.[4]

Site Name	Station No.	Year Sampling Started
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

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

During the August 2017 juvenile Dolly Varden sampling event, there were several rainfall events resulting in water levels at all sites becoming unusually high. Water levels in North Fork and Mainstem Red Dog creeks and Ikalukrok Creek were up to 126 percent of the most recent five year average stage (Appendix 11).

Dolly Varden Catches and Metrics

The relative abundance of juvenile Dolly Varden varies considerably among sample years (Appendix 12); however, the catches among the sample sites follow similar patterns. Generally, the CPUE (total number of fish for ten traps fished for 24 hr) in Anxiety and Buddy creeks is higher than at the other sample reaches. In 2017, the CPUE was highest in Anxiety Ridge (55 fish/24 hours) and Buddy creeks (10.5 fish/24 hours) and lowest in North Fork Red Dog Creek and upper Ikalukrok Creek where no fish were caught (Figure 56).

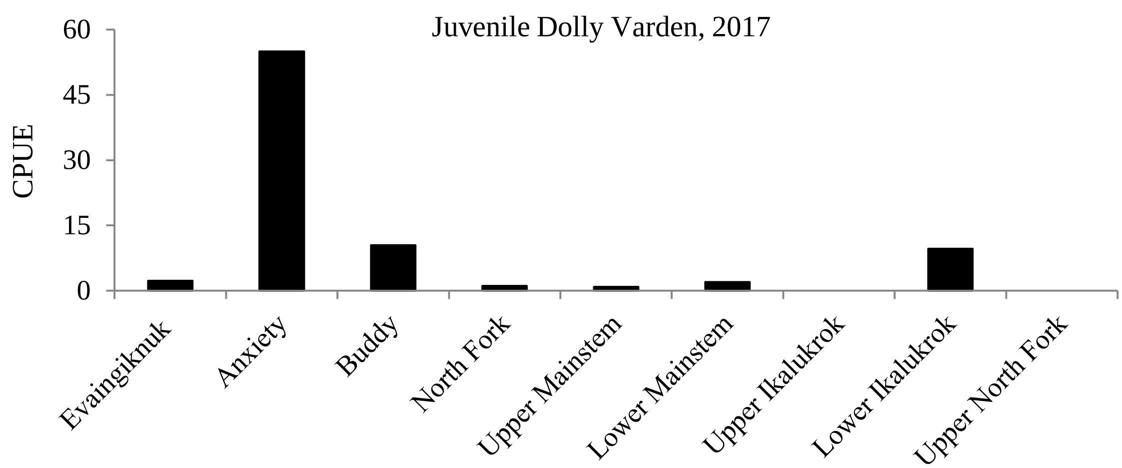


Figure 56. CPUE for juvenile Dolly Varden in the Red Dog sample reaches in 2017.

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. Probably the most important factor is 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 2017 reflects the high degree of variability among sample years (Figures 57 and 58). The CPUE follows a similar pattern between Anxiety Ridge and Buddy creeks.

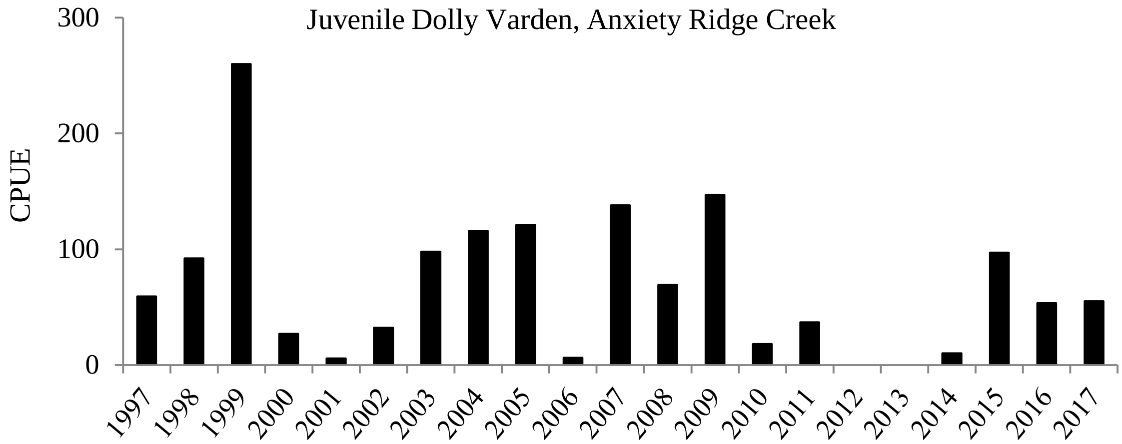


Figure 57. CPUE of juvenile Dolly Varden in Anxiety Ridge Creek, 1997–2017.

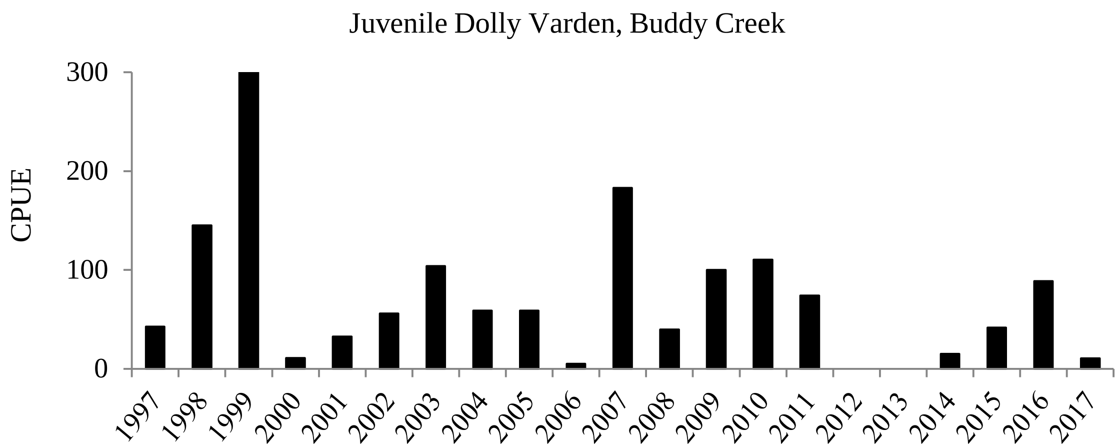


Figure 58. CPUE of juvenile Dolly Varden in Buddy Creek, 1997–2017.

The CPUE for lower Mainstem Red Dog Creek from 1997 to 2017 is presented in Figure 59. The CPUE ranged from a low of 0.0 in 2004 to a high of 73.3 in 1999. A similar pattern was found for Anxiety Ridge and Buddy creeks. Catches since 2000 in lower Mainstem Red Dog Creek have remained low, but relatively consistent. Use of lower Mainstem Red Dog Creek by juvenile Dolly Varden is substantially greater than what was found by Houghton and Hilgert (1983) during baseline studies before mine development.

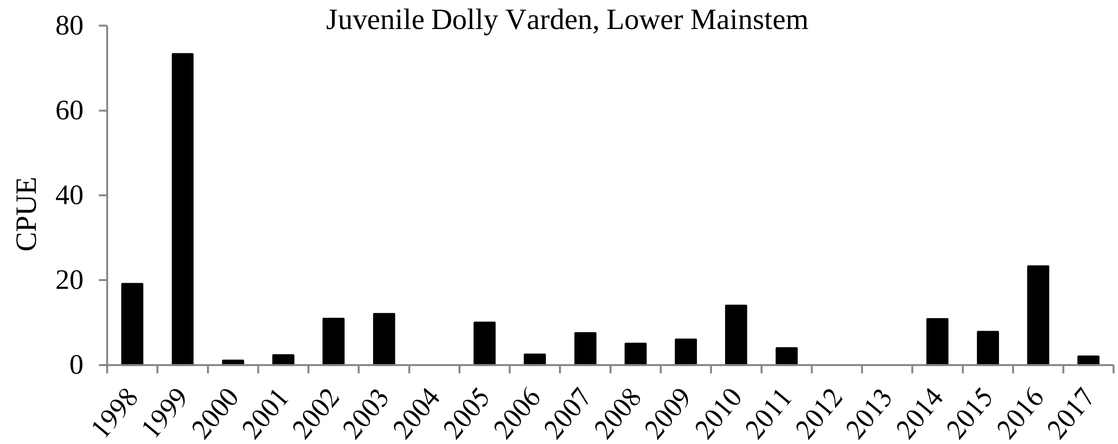


Figure 59. CPUE of juvenile Dolly Varden in Lower Mainstem Red Dog Creek.

Anadromous Dolly Varden spend at least one year in freshwater before their migration to the marine environment (DeCicco 1990). Adult Dolly Varden collected from the Wulik River (1999 to 2017) had an average freshwater residency of 2.9 ± 0.6 years (1 SD, n = 154). Based on length frequency distributions for juvenile Dolly Varden captured in 2017, 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 2017 only two captured fish were < 70 mm FL (Figure 60).

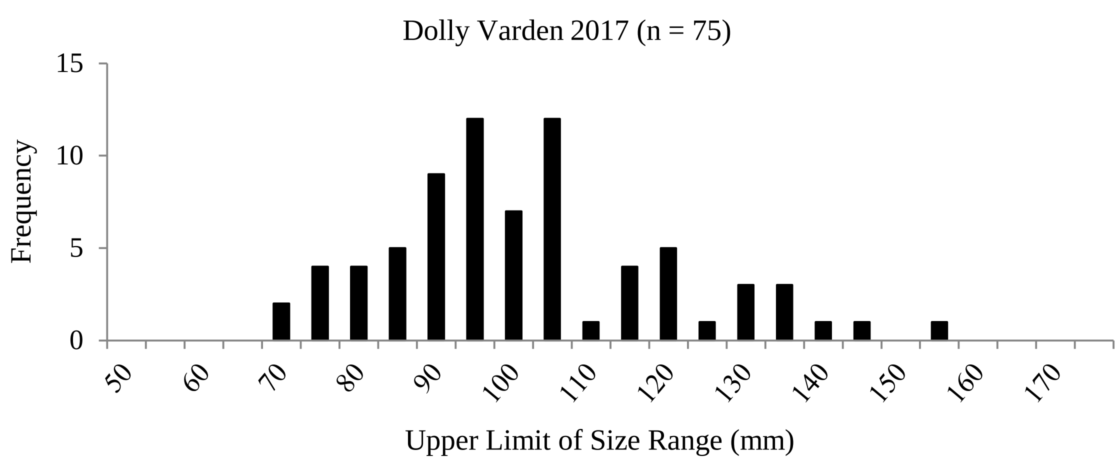


Figure 60. Length frequency distribution of Dolly Varden in the Ikalukrok Creek drainage in fall 2017.

In the catches of Dolly Varden in the Ikalukrok Creek drainage, some fish are occasionally captured that are > 145 mm FL and sexually mature. The majority 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 reach lengths over 600 mm FL and have 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 also are caught in the fyke nets and generally these fish are larger than those caught later in the summer in minnow traps, this is likely due to the inability of the larger fish to enter the minnow traps. In spring 2017, 41 Dolly Varden were caught in the fyke nets and those fish averaged 213 mm FL (Figure 61). This was the most Dolly Varden captured in the spring fyke net since 2001 when 43 fish were captured. Many of the Dolly Varden caught in North Fork Red Dog Creek are the resident form.

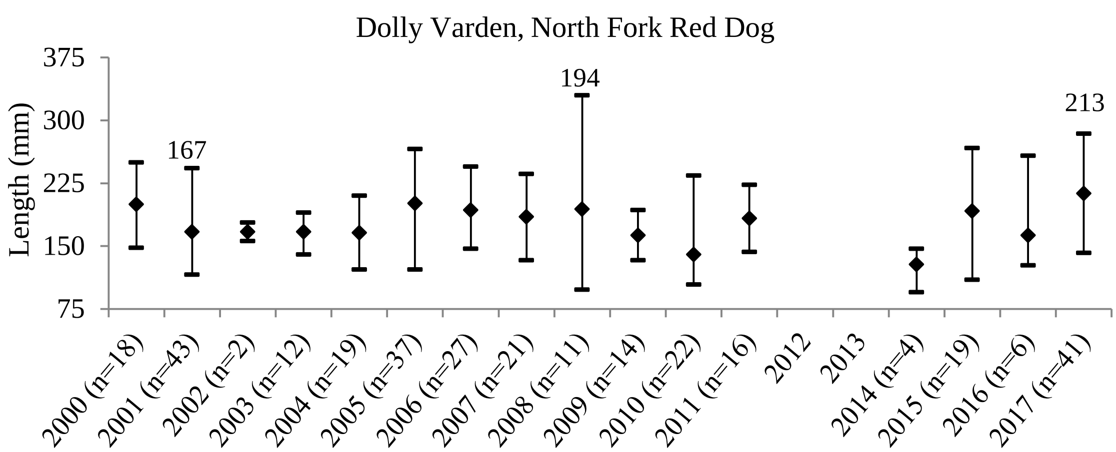


Figure 61. Dolly Varden caught in fyke nets fished in North Fork Red Dog Creek in spring during the Arctic grayling spawning run. Average, maximum, and minimum lengths are shown for each sample year. Selected average lengths are shown.

Arctic Grayling, Red Dog Creek Drainage

Before mine development, Arctic grayling adults migrated through Mainstem Red Dog Creek in spring when flows were high and metals concentrations were low (Ward and Olsen 1980, EVS and Ott Water Engineers 1983, and Houghton and Hilgert 1983). Arctic grayling moved through Mainstem Red Dog Creek to spawn in North Fork Red Dog Creek. None of these 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 EVS Consultants and Ott Water Engineers (1983) and Ward and Olsen (1980). Since 1994 Arctic grayling have been documented using Mainstem Red Dog Creek and no fish mortality events have been observed.

Since 2001, Arctic grayling spawning has been monitored during the spring in North Fork Red Dog and Mainstem Red Dog creeks. The purposes of this sampling effort are to document when spawning has been substantially completed in Mainstem Red Dog Creek and to assess the return of Arctic grayling 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, 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). Teck regulates the wastewater discharge to ensure that TDS concentrations do not exceed the ADEC approved TDS limit of 1,500 mg/L at Station 151.

In 2017, one fyke net was set to capture Arctic grayling in Mainstem Red Dog Creek from May 30 to June 4. Substantial aufeis had formed in North Fork Red Dog Creek during winter (2016-2017) preventing a net to be set in its usual location in North Fork. Flows were low, but with the additional flow from the Middle Fork Red Dog Creek at the fyke net location and ice chunks from the North Fork Red Dog Creek flowing downstream, keeping the set effective for capturing fish was difficult (Figure 62). Peak daily water temperatures ranged from about 3 to 4°C.

Figure 62. Fyke nets in Mainstem Red Dog Creek, June 2017.

Limited spawning in Mainstem Red Dog Creek could have started on May 31 when the water temperature reached 3.0°C (Figure 63). Females captured in the fyke net were judged to be green or ripe and none were determined to be spent (Table 6). Water temperatures were consistently higher in Mainstem Red Dog Creek than in North Fork Red Dog Creek. 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. In spring 2017, aufeis completely covered the creek and the adjacent riparian habitat. Lack of aufeis in

Middle Fork Red Dog Creek is due to the fact that baseline ground water flow has been reduced by the tailing impoundment and the excavated mine cuts which are dewatered.

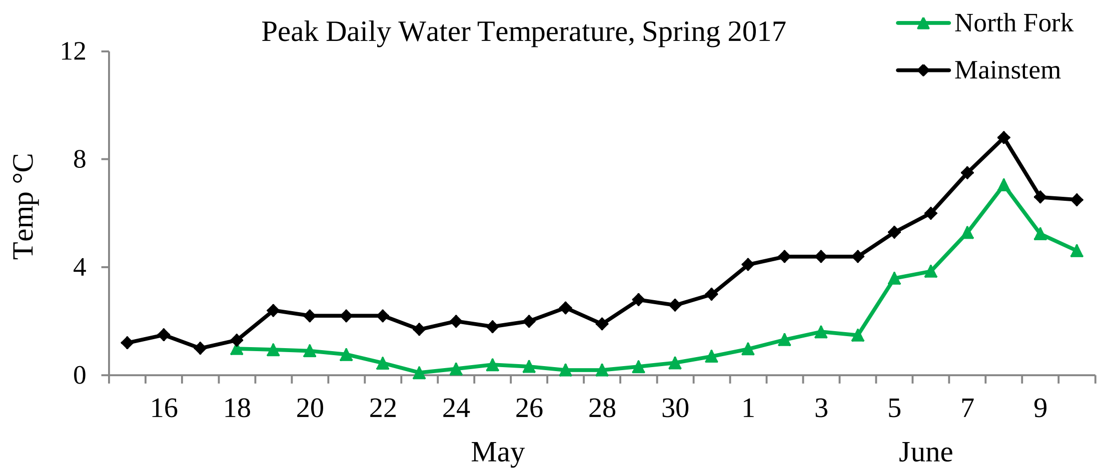


Figure 63. Peak daily water temperatures in North Fork Red Dog (Station 12) and Mainstem Red Dog (Station 151) creeks, May and June 2017.

In spring 2017, the catches of Arctic grayling were overall very low, with catches peaking June 2, then decreasing to nearly zero (Figure 64). The fyke net in Mainstem Red Dog Creek captured 25 Arctic grayling, two of which were immature (Figure 65). Arctic grayling probably did not spawn in North Fork Red Dog Creek due to massive aufeis which kept water temperatures cold (Table 6). Water temperatures did not exceed 3.0°C until June 5.

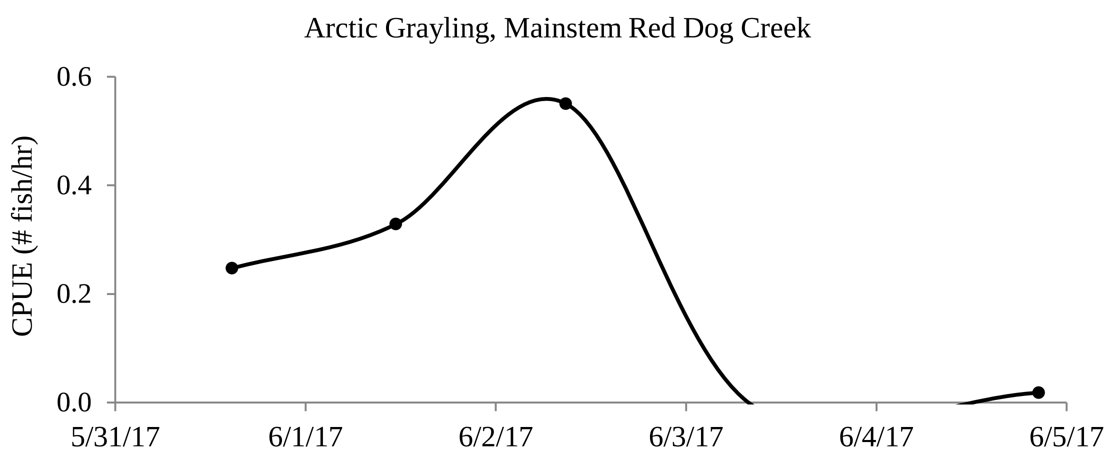


Figure 64. The CPUE of Arctic grayling in Mainstem Red Dog Creek in spring 2017.

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

Year	Date When Limited Spawning Started (3°C)	Date When Spawning Complete (Condition of Females)	Number of Days Peak Temperatures Exceeded 4°C[1]
2001	June 6	June 15	6
2002	May 29	June 8	8
2003	June 7	June 14	6
2004	May 25	May 31	4
2005	May 27	June 6	9
2006	May 30	June 15	10
2007	May 26	June 3	8
2008	June 1	June 9	9
2009	June 8	June 13	4
2010[2]	May 21	May 29	6
2011	June 6	June 9	4
2012	May 27	June 4	7
2013[3]			
2014	June 5	June 11	4
2015	May 28	June 1	4
2016	May 12	May 20	8
2017[4]	May 31		

[1]Does not include the day spawning was judged to be complete, since the fyke net is worked in the early morning prior to peak temperatures on that day.

[2]The date spawning was judged to be substantially complete was based solely on the water temperature data collected in spring 2010.

[3]Arctic grayling sampling was not conducted in spring 2013 due to extremely high water throughout the spring sampling period.

[4]The end of spawning could not be judged in spring 2017, spent females were not captured in the fyke net. Water temperatures remained cool due to massive aufeis in North Fork Red Dog Creek.

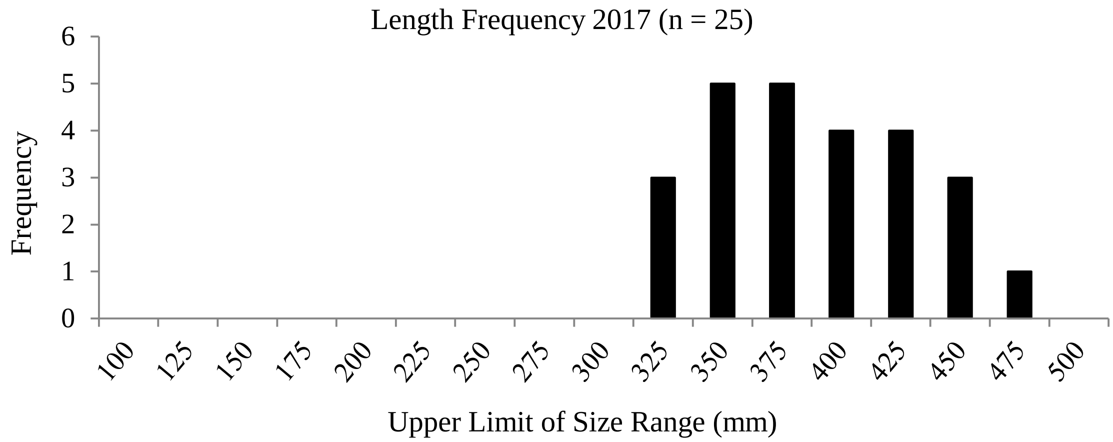


Figure 65. Length frequency distribution of Arctic grayling (n=25) in spring 2017.

Drift net sampling in early July in Mainstem and North Fork Red Dog creeks resulted in the capture of 16 larval Arctic grayling in Mainstem Red Dog Creek and zero larval Arctic grayling in North Fork Red Dog Creek. These data confirm successful spawning by Arctic grayling in Mainstem Red Dog Creek in spring 2017.

Recruitment of immature fish to North Fork Red Dog Creek has been strong since 2007, except for spring 2017 (Figure 66). 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.

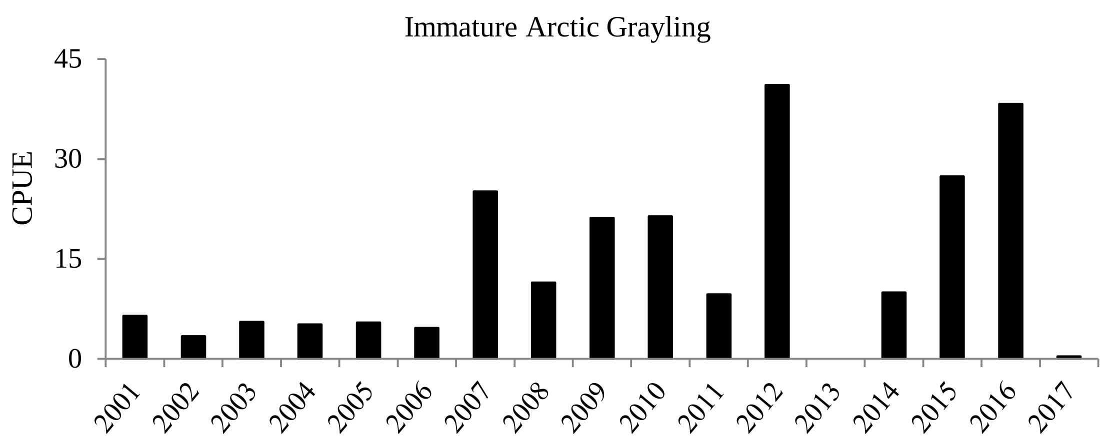


Figure 66. Average CPUE (fish/day) of immature Arctic grayling in North Fork Red Dog Creek from spring 2001 to spring 2017. No sampling was done due to high water in spring 2013.

Catches of mature Arctic grayling in North Fork Red Dog Creek have remained stable since 2001 (Figure 67). 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.

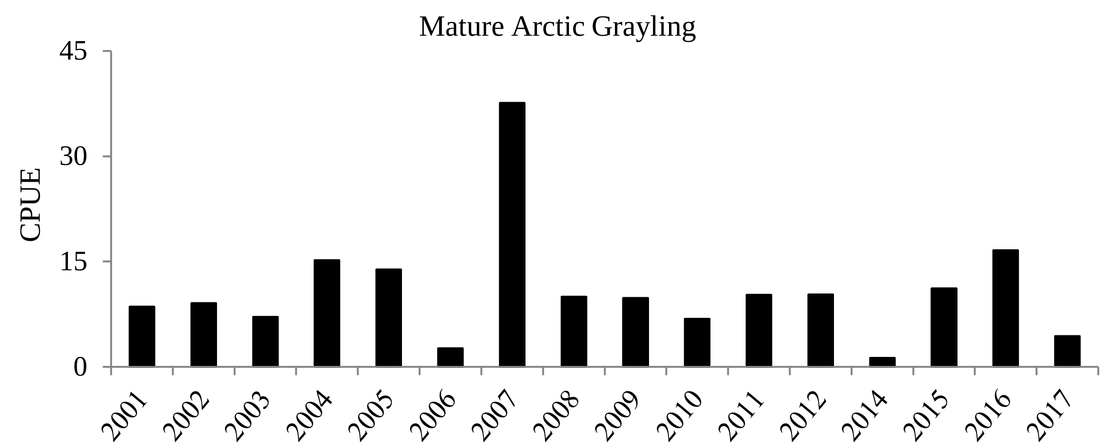


Figure 67. Average CPUE (fish/day) of mature ("ripe" or "spent") Arctic grayling in North Fork Red Dog Creek from spring 2001 to spring 2017.

Some of the Arctic grayling caught in the North Fork Red Dog Creek are fish that were originally tagged in Bons Pond. In 2017, no Bons Pond tagged fish were captured in North Fork Red Dog Creek (Figure 68).

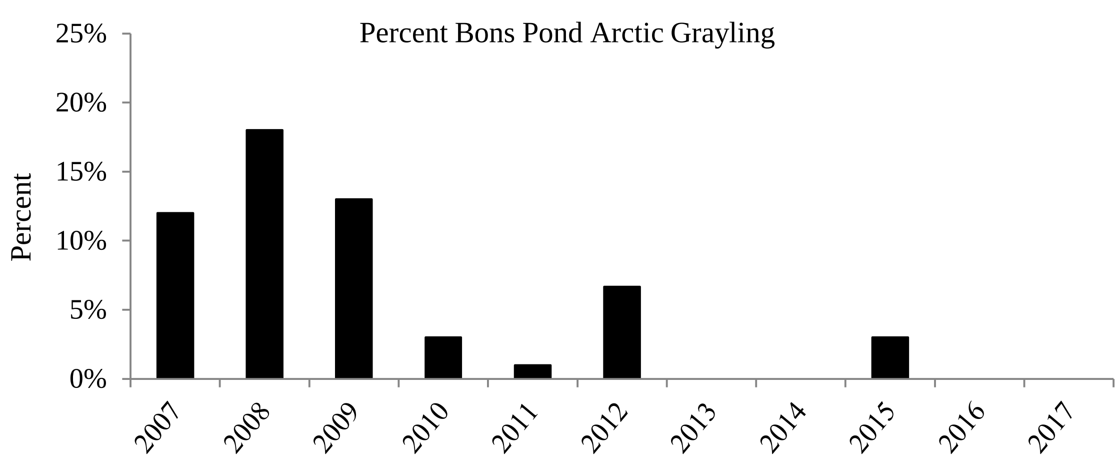


Figure 68. Percent of Bons Pond marked fish caught in North Fork Red Dog Creek.

The average growth rate (mm/year) for Arctic grayling between 250 and 300 mm FL when marked and at large for about one year is presented in Figure 69. 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).

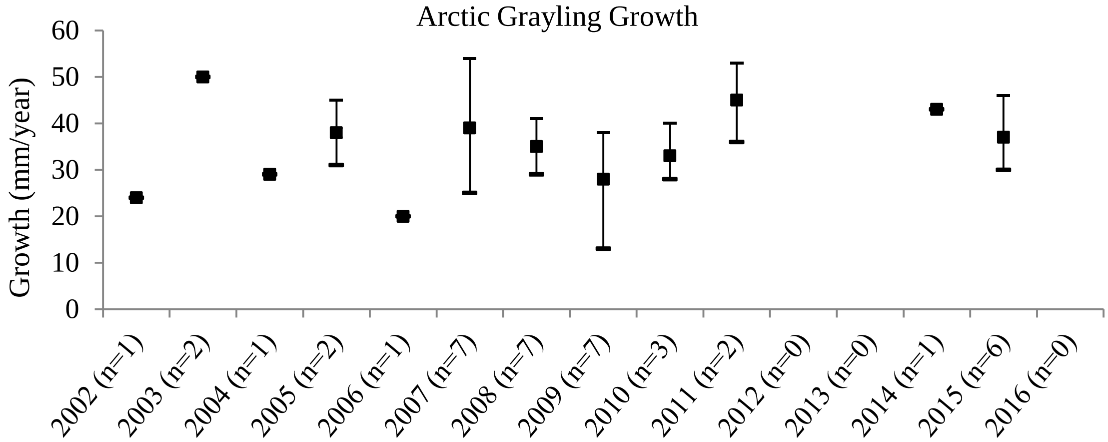


Figure 69. Average, maximum, and minimum annual growth of Arctic grayling in North Fork Red Dog Creek for fish between 250 and 300 mm FL when marked.

The population of Arctic grayling in North Fork Red Dog Creek, pre-mining, is not known. The highest estimate was 1,422 ≥ 200 mm FL in 2010 and the lowest estimate was 905 fish ≥ 200 mm FL in 2015 (Figure 70). The confidence limits overlap for all of the population estimates suggesting that there are no substantial differences among years.

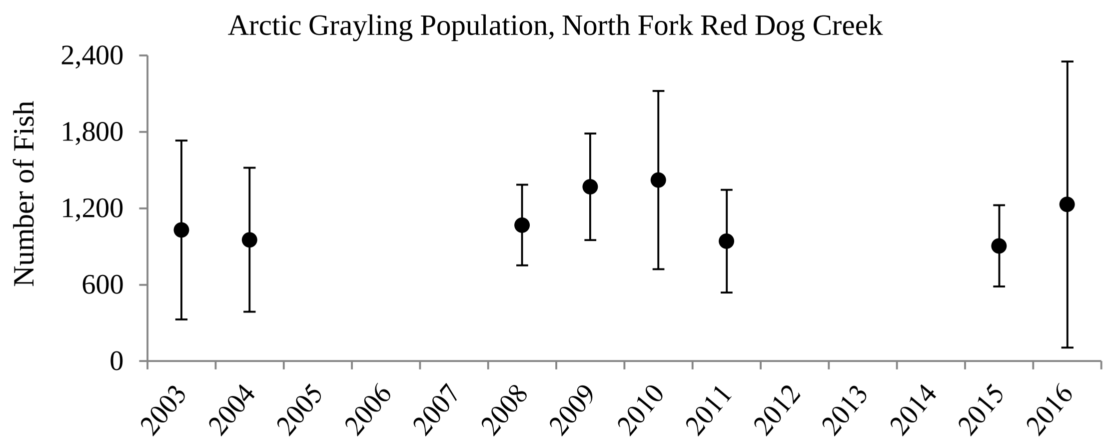


Figure 70. The estimated Arctic grayling population (95% CI) in North Fork Red Dog Creek for fish ≥ 200 mm FL.

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 71). Bons Creek flows into Buddy Creek and eventually into Ikalukrok Creek.

Figure 71. 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. However, in 2001 and 2002 Arctic grayling juveniles were observed in Bons Creek immediately downstream of the blast road. 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. 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 also is used to sample larval fish (Figure 72). In Bons Creek, upstream of Bons Pond, catches of Arctic grayling fry have been zero in seven of the 14 years of sampling. The highest number of Arctic grayling fry caught in the drift nets was 78 in 2007 (Figure 73).

In most years, Arctic grayling are seen spawning in the outlet of Bons Pond and typically fry are observed in July and August. However, no fry were observed in the outlet of Bons Pond in early July, 2017.

Figure 72. Looking upstream at drift nets in Bons Creek upstream of Bons Pond on July 2, 2016.

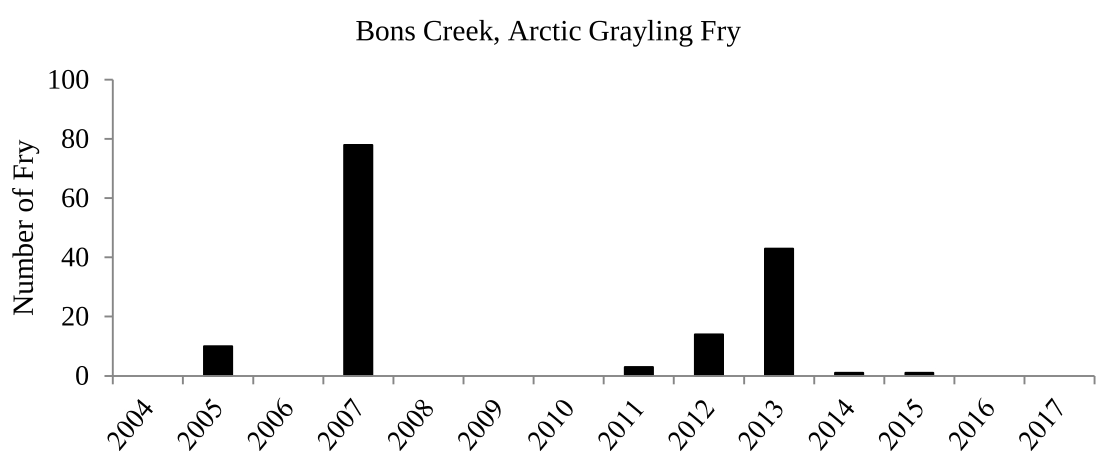


Figure 73. Number of Arctic grayling fry caught in drift nets 2004–2017.

A fyke net fished in Bons Creek from May 30 to June 4, 2017 caught 310 Arctic grayling; 140 of those fish were ≥ 200 mm FL and were not previously tagged. A fyke net set in Bons Pond and angling activities in the pond resulted in catches of an additional 54 Arctic grayling. The mean CPUE (#fish/day) for the fyke net in 2017 was 65 (Figure 74). The CPUE for Arctic grayling <

200 mm FL has ranged from 1 to 38 since 2006 and catch rates in 2006, 2012, and 2014 were the highest (Figure 75).

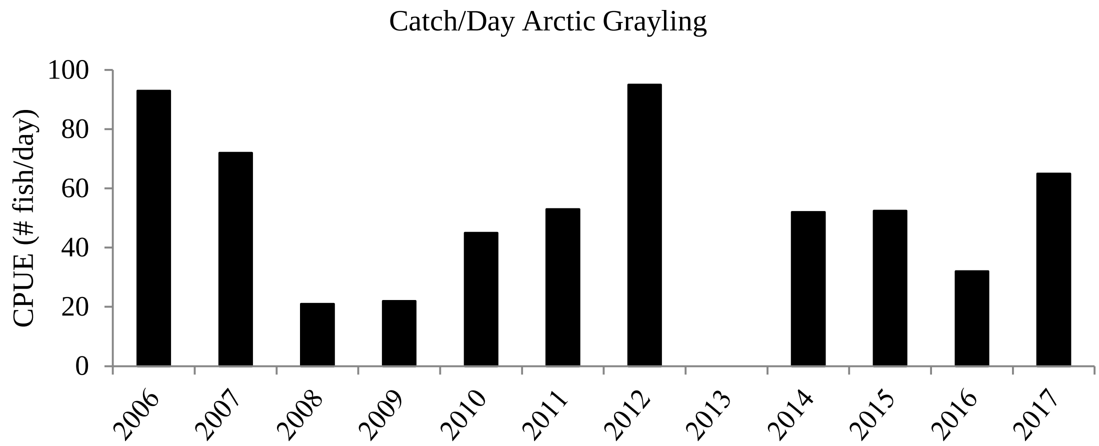


Figure 74. CPUE for all Arctic grayling in Bons Creek 2006–2017. Sampling was not done in 2013 due to high water.

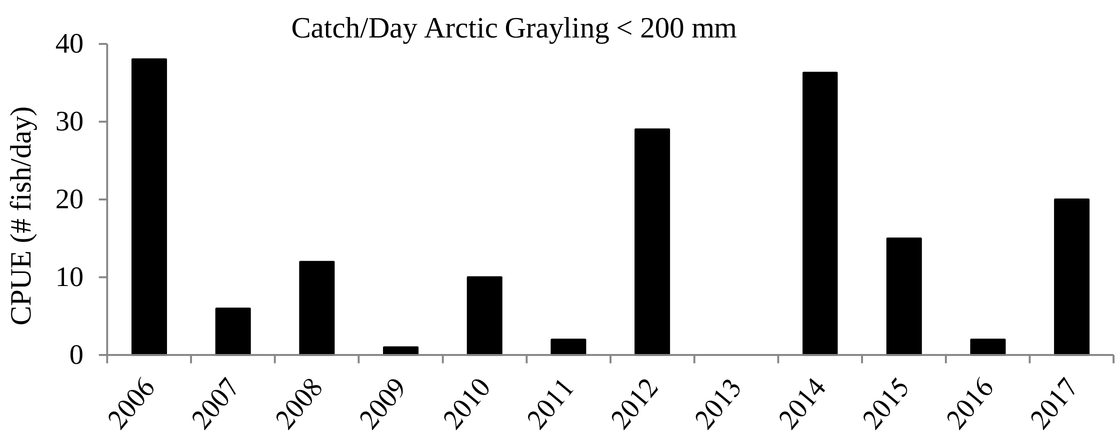


Figure 75. CPUE for Arctic grayling < 200 mm FL in Bons Creek 2006–2017. Sampling was not done in 2013 due to high water.

The length frequency distribution for Arctic grayling caught in fyke nets and by angling in spring 2017 is presented in Figure 76. The current population in Bons Pond has had a relatively consistent length frequency the past few years with a stable population of mature fish 300–390 mm. In 2017, a relatively large number of fish 80–100 mm (n = 45) were captured, which are likely age-1 fish.

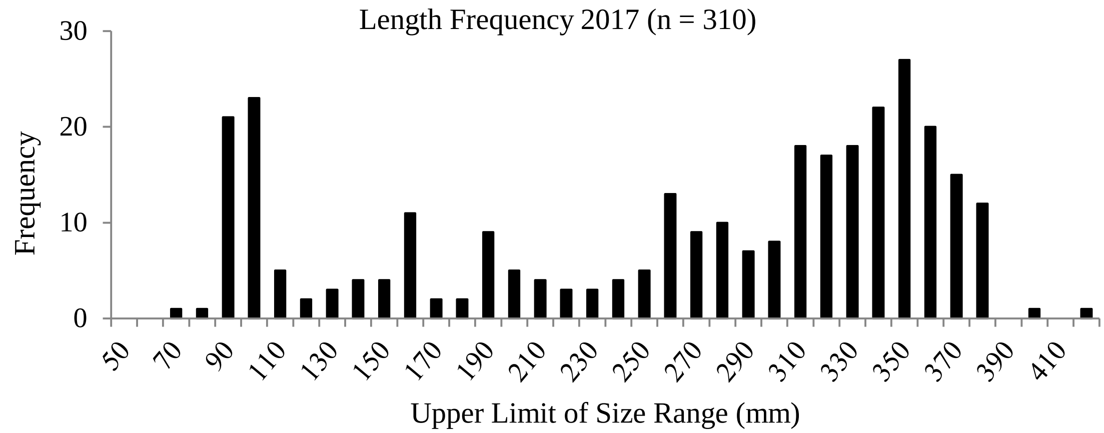


Figure 76. Length frequency distribution of Arctic grayling in Bons Pond in spring 2017.

Growth rates for Arctic grayling from Bons Pond are much less 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. Average annual growth of fish ≥ 250 mm FL at marking is presented in Figure 77. Average annual growth rates since 2014 has ranged from 14 to 21 mm. Higher growth rates since 2011 likely are related to the population decline which resulted in the availability of more food for individual fish.

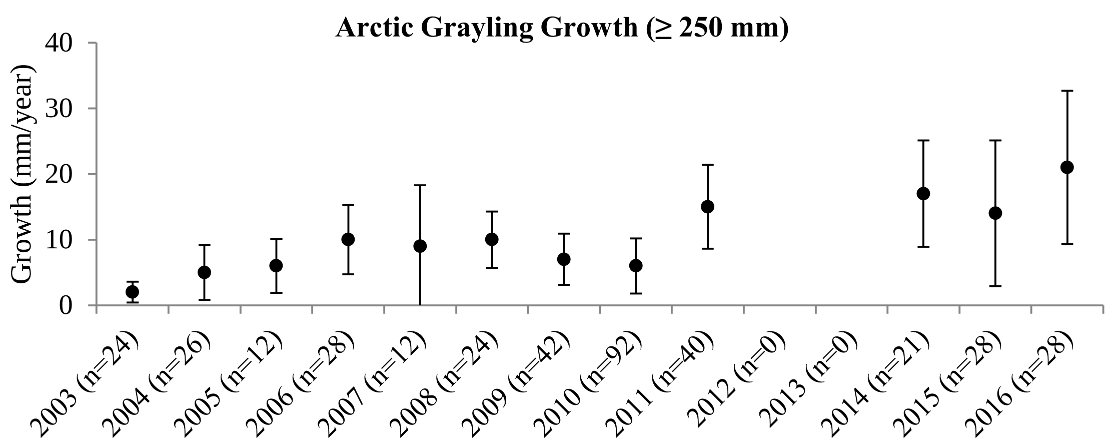


Figure 77. Average annual growth (± 1SD) of Arctic grayling ≥ 250 mm FL at time of marking.

The 2016 Arctic grayling population in Bons Pond was estimated by using 2016 as the mark event (n = 154) and spring 2017 as the recapture event. In spring 2017, there were 189 fish that were either recaptures or new marks. In spring 2017, 29 of the fish were recaptures from the spring 2016 mark event. Based on these values, the estimated Arctic grayling population for 2016 was 981 fish (95% CI, 696 to 1,265 fish) $\geq$ 200 mm FL. The population estimates show a gradual increase in the population beginning in 2014 (Figure 78). However, catches of small Arctic grayling (< 200 mm FL) have been relatively high the last two years, indicating that the population of large fish may increase in future years.

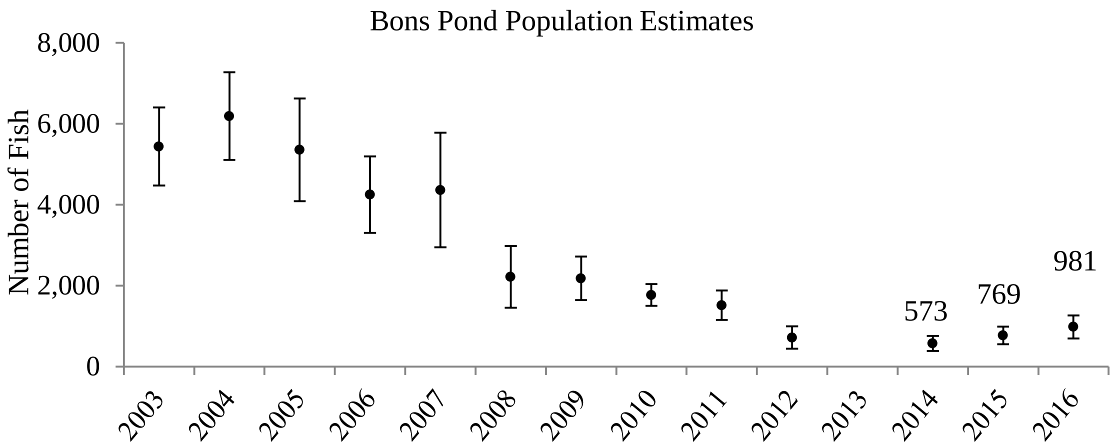


Figure 78. Estimated Arctic grayling population (95% CI) in Bons Pond for fish $\geq$ 200 mm FL.

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). Large (> 120 mm total length (TL)) slimy sculpin were caught in North Fork Red Dog Creek in some years during the spring Arctic grayling sampling event with fyke nets. In spring 2017, two slimy sculpin (132 and 113 mm TL) were caught. These large sculpin are likely following the Arctic grayling to feed on their eggs and they may spawn in North Fork Red Dog Creek.

Minnow trap data (CPUE is for 10 minnow traps fished for 24 hr) since 1997 for lower Mainstem Red Dog Creek is presented in Figure 79. There is no apparent trend with CPUE which ranges from zero to a high of five in fall, 2009. Catches have been fairly consistent from 2014 to 2017.

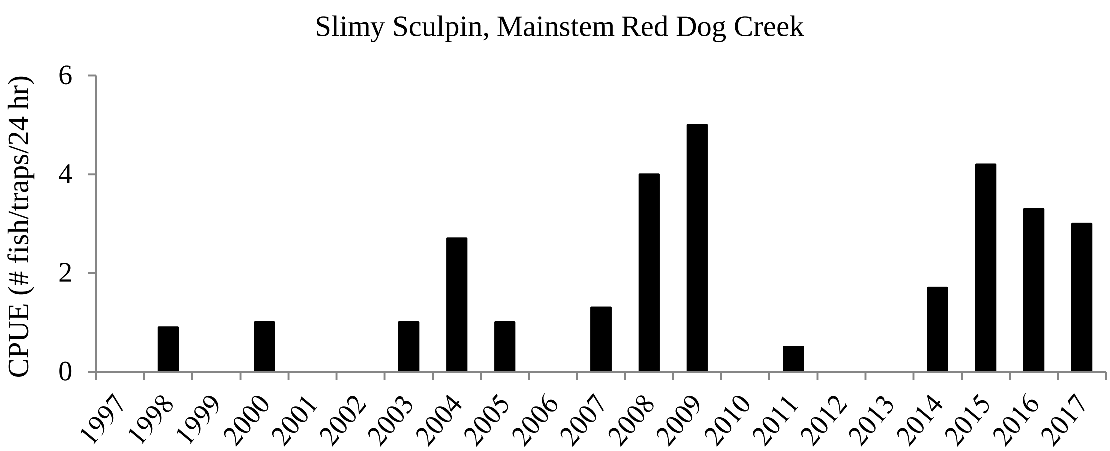


Figure 79. CPUE of slimy sculpin caught in Mainstem Red Dog Creek at the sample reach in the vicinity of Station 10 near the mouth of the creek. No sampling in 2012 and 2013 due to high water.

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 new sample reach in Ikalukrok Creek is similar to Station 7 in that there are multiple channels. The water quality monitoring station was moved downstream in 2010 to ensure waters from Dudd and Ikalukrok creeks were completely mixed.

Slimy sculpin CPUE has varied from a low of 0 to a high of 24 in 2004 (Figure 80). Catches of slimy sculpin generally are 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 captured in the Red Dog Creek drainage.

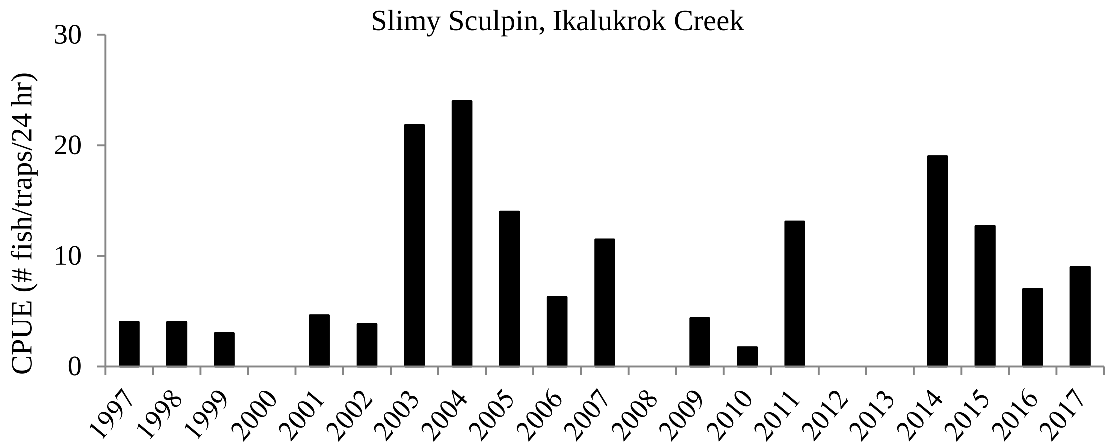


Figure 80. CPUE of slimy sculpin caught in Ikalukrok Creek at Station 7 (1997 to 2009) and Station 160 (2010, 2011, and 2014–2017). No sampling occurred in 2012 and 2013 due to high water.

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Appendix 1. Summary of Red Dog Mine Development and Operations, 2014-2017.[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]A summary of previous years of mine development and operations (1982 to 2013) can be found in Ott and Morris 2014

Appendix 1 (continued).

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
●Between July 9 and 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 Anaarraq Prospect and at one site in Upper North Fork Red Dog creek.
●Between July 29 and 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 Anaarraq 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.

Appendix 1 (continued).

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 Anaarraq 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 Anaarraq 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.

Appendix 1 (concluded).

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.
●Discharge through Outfall 001 to Middle Fork Red Dog Creek began on May 7 and ended on September 23.
●May 15, ADF&G by email transmitted 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 Anaarraq 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.
●August 2-9, juvenile Dolly Varden sampling performed at all the APDES sample sites and a sites located in the vicinity of the Anaarraq/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.

Appendix 2. Periphyton Standing Crop, Red Dog Mine Monitoring Sites, 2017.

2017 Chloro Results - Red Dog		IDL = 0.09 mg/m^2	Linear Check Maximum = 13.39mg/m^2				Phaeo			
		EDL = 0.07 mg/m^2					Corrected			
Daily			Date	Date	Vial	**Chl a**	**Chl a**	**664/665**	Chl b	Chl c
Vial #	Site	Station Number	Collected	Analyzed	Chl a	**mg/m^2**	**mg/m^2**	**Ratio**	mg/m^2	mg/m^2
Blank 33	Blank[a]			12/04/17	0.00	0.00	0.00		0.00	0.00
54	Ikalukrok D/S Dudd Cr.	Station 160	7/4/17	12/04/17	0.56	2.23	2.03	1.63	0.01	0.23
56	Ikalukrok D/S Dudd Cr.	Station 160	7/4/17	12/04/17	0.19	0.77	0.75	1.70	0.01	0.13
58	Ikalukrok D/S Dudd Cr.	Station 160	7/4/17	12/04/17	0.21	0.82	0.85	1.80	0.00	0.12
60	Ikalukrok D/S Dudd Cr.	Station 160	7/4/17	12/04/17	0.29	1.14	1.07	1.67	0.00	0.11
62	Ikalukrok D/S Dudd Cr.	Station 160	7/4/17	12/04/17	0.39	1.55	1.28	1.55	0.00	0.19
64	Ikalukrok D/S Dudd Cr.	Station 160	7/4/17	12/04/17	0.24	0.96	0.85	1.62	0.00	0.10
66	Ikalukrok D/S Dudd Cr.	Station 160	7/4/17	12/04/17	0.34	1.37	1.17	1.58	0.00	0.05
68	Ikalukrok D/S Dudd Cr.	Station 160	7/4/17	12/04/17	0.34	1.37	1.28	1.67	0.00	0.14
70	Ikalukrok D/S Dudd Cr.	Station 160	7/4/17	12/04/17	0.29	1.15	1.17	1.79	0.00	0.14
72	Ikalukrok D/S Dudd Cr.	Station 160	7/4/17	12/04/17	1.36	5.43	4.81	1.60	0.50	0.34
74	North Fork RD Sta 12	Station 12	7/4/17	12/04/17	1.18	4.73	3.84	1.52	0.76	0.37
76	North Fork RD Sta 12	Station 12	7/4/17	12/04/17	1.17	4.66	4.06	1.58	0.49	0.21
78	North Fork RD Sta 12	Station 12	7/4/17	12/04/17	1.15	4.60	3.74	1.52	0.68	0.16
80	North Fork RD Sta 12	Station 12	7/4/17	12/04/17	1.12	4.46	3.42	1.48	0.67	0.21
82	North Fork RD Sta 12	Station 12	7/4/17	12/04/17	1.39	5.55	4.81	1.58	0.86	0.16
84	North Fork RD Sta 12	Station 12	7/4/17	12/04/17	0.71	2.82	2.46	1.59	0.04	0.22
86	North Fork RD Sta 12	Station 12	7/4/17	12/04/17	0.34	1.36	1.17	1.58	0.04	0.11
88	North Fork RD Sta 12	Station 12	7/4/17	12/04/17	2.60	10.38	9.08	1.59	0.25	0.46
92	North Fork RD Sta 12	Station 12	7/4/17	12/04/17	1.32	5.27	4.17	1.50	0.77	0.76
94	North Fork RD Sta 12	Station 12	7/4/17	12/04/17	1.02	4.08	3.52	1.58	0.29	0.28
88 Double	Duplicate North Fork RD	Station 12	7/4/17	12/04/17	2.62	10.47	9.18	1.60	0.29	0.42
116	Blank[a]			12/04/17	0.00	0.00	0.00		0.00	0.00
3	Blank[a]			12/05/17	0.00	0.00	0.00		0.00	0.00
4	Mainstem Red Dog	Station 10	7/4/17	12/05/17	1.61	6.43	5.55	1.58	0.49	1.15
6	Mainstem Red Dog	Station 10	7/4/17	12/05/17	2.29	9.15	8.22	1.62	0.68	1.16
8	Mainstem Red Dog	Station 10	7/4/17	12/05/17	4.86	19.43	14.63	1.46	5.16	9.50
10	Mainstem Red Dog	Station 10	7/4/17	12/05/17	1.46	5.84	5.34	1.64	0.00	0.70
12	Mainstem Red Dog	Station 10	7/4/17	12/05/17	4.13	16.50	14.74	1.61	0.49	2.37
14	Mainstem Red Dog	Station 10	7/4/17	12/05/17	4.59	18.37	16.02	1.59	1.14	2.56
16	Mainstem Red Dog	Station 10	7/4/17	12/05/17	4.04	16.14	13.14	1.51	3.97	6.22
18	Mainstem Red Dog	Station 10	7/4/17	12/05/17	1.89	7.58	7.05	1.66	0.00	0.53
20	Mainstem Red Dog	Station 10	7/4/17	12/05/17	0.46	1.83	1.71	1.67	0.00	0.18
22	Mainstem Red Dog	Station 10	7/4/17	12/05/17	0.82	3.29	2.99	1.64	0.00	0.41
44	Ik U/S mouth Red Dog	Station 9	7/3/17	12/05/17	0.06	0.23	0.21	1.67	0.00	0.03
46	Ik U/S mouth Red Dog	Station 9	7/3/17	12/05/17	0.08	0.32	0.32	1.75	0.01	0.00
48	Ik U/S mouth Red Dog	Station 9	7/3/17	12/05/17	0.16	0.64	0.53	1.56	0.00	0.08
50	Ik U/S mouth Red Dog	Station 9	7/3/17	12/05/17	0.06	0.22	0.21	1.67	0.04	0.10
52	Ik U/S mouth Red Dog	Station 9	7/3/17	12/05/17	0.11	0.45	0.43	1.67	0.00	0.14
54	Ik U/S mouth Red Dog	Station 9	7/3/17	12/05/17	0.07	0.27	0.21	1.50	0.02	0.10
56	Ik U/S mouth Red Dog	Station 9	7/3/17	12/05/17	0.10	0.41	0.32	1.50	0.04	0.04
58	Ik U/S mouth Red Dog	Station 9	7/3/17	12/05/17	0.17	0.69	0.53	1.50	0.00	0.07
60	Ik U/S mouth Red Dog	Station 9	7/3/17	12/05/17	0.09	0.36	0.32	1.60	0.05	0.15
62	Ik U/S mouth Red Dog	Station 9	7/3/17	12/05/17	0.22	0.87	0.85	1.73	0.00	0.21
86	Buddy Creek Below Falls		7/4/17	12/05/17	1.20	4.81	4.49	1.65	0.97	0.17
88	Buddy Creek Below Falls		7/4/17	12/05/17	0.92	3.66	3.31	1.62	0.43	0.18
90	Buddy Creek Below Falls		7/4/17	12/05/17	2.02	8.08	7.48	1.65	0.48	0.44
92	Buddy Creek Below Falls		7/4/17	12/05/17	2.17	8.67	7.58	1.58	1.68	0.45
94	Buddy Creek Below Falls		7/4/17	12/05/17	0.69	2.76	2.56	1.65	0.31	0.13
96	Buddy Creek Below Falls		7/4/17	12/05/17	1.17	4.66	4.38	1.66	0.49	0.21
98	Buddy Creek Below Falls		7/4/17	12/05/17	0.52	2.09	1.92	1.64	0.07	0.25
100	Buddy Creek Below Falls		7/4/17	12/05/17	2.36	9.44	7.69	1.53	1.25	0.38
102	Buddy Creek Below Falls		7/4/17	12/05/17	1.58	6.32	5.66	1.60	1.42	0.17
104	Buddy Creek Below Falls		7/4/17	12/05/17	0.93	3.71	3.52	1.67	0.39	0.27
122	Blank			12/05/17	0.01	0.05	0.11		0.00	0.09

[a] Value below detection limit

Appendix 2 (concluded).

2	Blank[a]			12/06/17	0.00	0.00	0.00		0.00	0.10
18	Upper N.F. Red Dog C.		7/3/17	12/06/17	1.43	5.71	5.45	1.68	0.45	0.36
20	Upper N.F. Red Dog C.		7/3/17	12/06/17	0.93	3.72	3.42	1.64	0.31	0.30
22	Upper N.F. Red Dog C.		7/3/17	12/06/17	1.34	5.35	4.91	1.64	0.48	0.18
24	Upper N.F. Red Dog C.		7/3/17	12/06/17	2.63	10.52	9.83	1.65	1.35	0.46
26	Upper N.F. Red Dog C.		7/3/17	12/06/17	5.36	21.43	20.40	1.67	4.88	0.62
28	Upper N.F. Red Dog C.		7/3/17	12/06/17	2.76	11.02	10.04	1.62	1.98	0.34
30	Upper N.F. Red Dog C.		7/3/17	12/06/17	2.97	11.86	11.00	1.64	2.36	0.40
32	Upper N.F. Red Dog C.		7/3/17	12/06/17	1.48	5.92	5.55	1.66	0.75	0.28
34	Upper N.F. Red Dog C.		7/3/17	12/06/17	2.62	10.47	9.72	1.65	0.84	0.30
36	Upper N.F. Red Dog C.		7/3/17	12/06/17	2.79	11.15	10.68	1.69	0.00	0.48
78	Bons U/S Buddy C	Station 220	7/5/17	12/06/17	1.37	5.49	4.91	1.61	1.04	0.21
80	Bons U/S Buddy C	Station 220	7/5/17	12/06/17	3.39	13.55	12.39	1.64	0.54	1.13
82	Bons U/S Buddy C	Station 220	7/5/17	12/06/17	2.85	11.42	9.93	1.58	2.17	0.42
84	Bons U/S Buddy C	Station 220	7/5/17	12/06/17	1.00	4.00	3.52	1.60	0.19	0.16
86	Bons U/S Buddy C	Station 220	7/5/17	12/06/17	3.47	13.86	12.18	1.58	3.69	0.19
88	Bons U/S Buddy C	Station 220	7/5/17	12/06/17	3.38	13.50	11.53	1.55	4.16	0.31
90	Bons U/S Buddy C	Station 220	7/5/17	12/06/17	1.70	6.79	5.66	1.54	1.28	0.17
92	Bons U/S Buddy C	Station 220	7/5/17	12/06/17	1.77	7.08	6.41	1.60	2.85	0.23
94	Bons U/S Buddy C	Station 220	7/5/17	12/06/17	0.55	2.22	2.03	1.63	0.27	0.04
96	Bons U/S Buddy C	Station 220	7/5/17	12/06/17	1.37	5.47	4.59	1.54	1.21	0.15
108	Blank[a]			12/06/17	0.00	0.00	0.00		0.00	0.00
2	Blank[a]			12/07/17	0.00	0.00	0.00		0.00	0.00
33	Middle Fork Red Dog Creek	Station 20	7/4/17	12/07/17	0.02	0.09	0.21		0.03	0.05
34	Middle Fork Red Dog Creek[a]	Station 20	7/4/17	12/07/17	0.00	0.00	0.00		0.00	0.00
35	Middle Fork Red Dog Creek	Station 20	7/4/17	12/07/17	0.06	0.23	0.21	1.67	0.00	0.03
37	Middle Fork Red Dog Creek	Station 20	7/4/17	12/07/17	0.01	0.04	0.11		0.05	0.06
38	Middle Fork Red Dog Creek	Station 20	7/4/17	12/07/17	0.01	0.05	0.11		0.00	0.00
39	Middle Fork Red Dog Creek	Station 20	7/4/17	12/07/17	0.01	0.05	0.11		0.00	0.00
40	Middle Fork Red Dog Creek	Station 20	7/4/17	12/07/17	0.01	0.04	0.11		0.05	0.06
41	Middle Fork Red Dog Creek	Station 20	7/4/17	12/07/17	0.01	0.04	0.11		0.05	0.06
42	Middle Fork Red Dog Creek	Station 20	7/4/17	12/07/17	0.01	0.05	0.11		0.00	0.00
43	Middle Fork Red Dog Creek	Station 20	7/4/17	12/07/17	0.05	0.18	0.21	2.00	0.00	0.04
45	Bons Creek u/s Bons Pond		7/2/17	12/07/17	0.73	2.92	2.67	1.63	0.55	0.08
47	Bons Creek u/s Bons Pond		7/2/17	12/07/17	1.08	4.30	3.63	1.56	0.44	0.16
49	Bons Creek u/s Bons Pond		7/2/17	12/07/17	0.47	1.86	1.60	1.58	0.12	0.12
51	Bons Creek u/s Bons Pond		7/2/17	12/07/17	1.25	5.02	4.59	1.64	0.01	0.28
53	Bons Creek u/s Bons Pond		7/2/17	12/07/17	0.44	1.78	1.71	1.70	0.00	0.09
57	Bons Creek u/s Bons Pond		7/2/17	12/07/17	0.45	1.79	1.71	1.67	0.39	0.03
59	Bons Creek u/s Bons Pond		7/2/17	12/07/17	0.77	3.10	2.88	1.66	0.08	0.11
61	Bons Creek u/s Bons Pond		7/2/17	12/07/17	0.58	2.32	2.14	1.65	0.06	0.09
63	Bons Creek u/s Bons Pond		7/2/17	12/07/17	0.67	2.68	2.35	1.59	0.20	0.11
65	Bons Creek u/s Bons Pond		7/2/17	12/07/17	0.87	3.47	3.10	1.62	0.00	0.13
68	Buddy C u/s Haul Road	Station 221	7/5/17	12/07/17	0.40	1.60	1.50	1.67	0.01	0.15
70	Buddy C u/s Haul Road	Station 221	7/5/17	12/07/17	0.83	3.32	2.88	1.59	0.12	0.22
72	Buddy C u/s Haul Road	Station 221	7/5/17	12/07/17	1.05	4.20	3.84	1.64	0.00	0.49
74	Buddy C u/s Haul Road	Station 221	7/5/17	12/07/17	1.54	6.15	5.55	1.62	0.71	0.31
76	Buddy C u/s Haul Road	Station 221	7/5/17	12/07/17	0.48	1.92	1.92	1.72	0.50	0.61
78	Buddy C u/s Haul Road	Station 221	7/5/17	12/07/17	0.51	2.05	1.92	1.67	0.02	0.19
80	Buddy C u/s Haul Road	Station 221	7/5/17	12/07/17	0.93	3.73	3.52	1.67	0.06	0.39
82	Buddy C u/s Haul Road	Station 221	7/5/17	12/07/17	1.71	6.84	6.30	1.65	0.00	0.57
84	Buddy C u/s Haul Road	Station 221	7/5/17	12/07/17	2.26	9.04	8.22	1.64	0.00	0.76
86	Buddy C u/s Haul Road	Station 221	7/5/17	12/07/17	0.81	3.24	2.99	1.65	0.00	0.29
107	Blank[a]			12/07/17	0.00	0.00	0.00		0.00	0.00
53 Double	Bons Creek u/s Bons Pond		7/2/17	12/07/17	0.43	1.74	1.60	1.65	0.00	0.13

[a] Value below detection limit

Appendix 3. Aquatic Invertebrate Drift Samples, 2017.

	Middle Fork Red Dog	North Fork Red Dog	Upper North Fork Red Dog	Mainstem Red Dog	Ikalukrok	Ikalukrok below Dudd	Bons u/s Bons Pond	Bons u/s Buddy	Buddy u/s Haul Road	Buddy below falls
Station	20	12		10	9	160		220	221	
Total aquatic taxa	21	20	21	16	19	16	16	24	23	19
Total Ephemeroptera	44	57	145	7	206	9	12	13	121	66
Total Plecoptera	13	57	67	12	33	2	1	1	50	13
Total Trichoptera	0	3	0	0	1	0	0	0	0	0
Total aquatic Diptera	145	2137	857	868	500	765	76	124	1240	2487
Misc. aquatic species	53	279	504	53	380	29	12	309	107	841
% Ephemeroptera	17%	2%	9%	1%	18%	1%	12%	3%	8%	2%
% Plecoptera	5%	2%	4%	1%	3%	0%	1%	0%	3%	0%
% Trichoptera	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
% Aquatic Diptera	57%	84%	54%	92%	45%	95%	75%	28%	82%	73%
% other	21%	11%	32%	6%	34%	4%	12%	69%	7%	25%
% EPT	23%	5%	13%	2%	21%	1%	13%	3%	11%	2%
% Chironomidae	49%	40%	39%	76%	37%	32%	50%	22%	68%	65%
% Dominant Aquatic Taxon	29%	44%	34%	73%	32%	63%	29%	21%	59%	61%
Volume of water (m^3)	559	929	672	402	830	584	227	144	593	676
Average water (m^3)/net	112	186	134	80	166	117	45	29	119	135
StDev of water volume	40	72	89	45	100	79	15	15	67	79
Estimated total inverts/m^3 water	4.4	14.2	14.5	12.9	9	7.5	2.7	16.8	13.9	29.2
Estimated aquatic inverts/m^3 water	2.3	13.6	11.7	11.7	6.7	6.9	2.2	15.6	12.8	25.2
Average inverts/m^3 water	4.5	14.3	25.8	14.7	9.7	8.1	2.7	22.5	19.8	39.6
Average aquatic inverts/m^3 water	2.39	13.70	21.36	13.28	7.24	7.5	2.25	20.36	18.59	33.68
StDev of aquatic invert density	0.37	3.84	25.08	6.41	1.42	1.56	0.83	11.96	16.76	21.21
Total aquatic inverts	1283	12664	7863	4697	5595	4038	506	2240	7594	17046
Total terrestrial inverts	1158	511	1856	512	1838	336	105	164	662	2709
Total inverts	2441	13174	9719	5209	7433	4374	611	2404	8256	19755
% Sample aquatic	53%	96%	81%	90%	75%	92%	83%	93%	92%	86%
% Sample terrestrial	47%	4%	19%	10%	25%	8%	17%	7%	8%	14%
Average # aquatic inverts/net	257	2533	1573	939	1119	808	101	448	1519	3409
Stdev aquatic inverts/net	67	1043	510	464	570	382	45	96	1436	1360
Average # terrestrial inverts/net	232	102	371	102	368	67	21	33	132	542
Average # inverts/net	488	2635	1944	1042	1487	875	122	481	1651	3951
StDev inverts/net	173	1078	603	520	754	422	53	87	1588	1699
Total Larval Arctic Grayling/site	0	0	0	16	0	4	0	0	0	0
Total Larval Slimy Sculpin/site	0	0	0	0	0	0	0	0	0	0
Total Larval Dolly Varden/site	0	0	0	0	0	0	0	0	0	0

Appendix 4. Juvenile Arctic Grayling from Bons Creek, Whole Body Element Concentrations, 2017.

Shaded cells indicate value was at or below method detection limit (MDL), so detection limit is reported

Sample Number	Date Collected	Length (mm)	Weight (g)	Units dry weight	MDL	Cadmium 0.07[a]	Lead 0.07[a]	Mercury 0.01[a]	Selenium 0.07[a]	Zinc 1.49[a]	% Solids
060117BPAGJ01	6/1/2017	156	39.1	mg/Kg		0.11	0.18	0.03	13.57	63.90	27.7
060117BPAGJ02	6/1/2017	185	61.4	mg/Kg		0.13	0.46	0.10	9.54	62.76	23.9
060117BPAGJ03	6/1/2017	161	41.9	mg/Kg		0.07	0.14	0.06	5.91	57.25	27.6
060117BPAGJ04	6/1/2017	177	59	mg/Kg		0.11	0.85	0.05	12.54	55.51	27.2
060117BPAGJ05	6/1/2017	184	63.6	mg/Kg		0.12	0.69	0.02	12.90	76.61	24.8
060117BPAGJ06	6/1/2017	181	62	mg/Kg		0.08	0.42	0.03	11.52	45.25	26.3
070517BPAGJ07	7/5/2017	171	46.8	mg/Kg		0.08	0.16	0.03	12.79	52.33	25.8
070517BPAGJ08	7/5/2017	176	53.2	mg/Kg		0.08	0.16	0.04	12.54	38.71	24.8
070517BPAGJ09	7/5/2017	174	53	mg/Kg		0.08	0.20	0.03	12.94	40.00	25.5
070517BPAGJ10	7/5/2017	173	53.7	mg/Kg		0.08	0.08	0.05	11.10	22.36	24.6
070517BPAGJ11	7/5/2017	182	56.5	mg/Kg		0.08	0.08	0.04	15.21	40.34	23.8
070517BPAGJ12	7/5/2017	176	54.5	mg/Kg		0.08	0.15	0.06	13.50	47.74	26.6
070517BPAGJ13	7/5/2017	165	47.6	mg/Kg		0.08	0.15	0.05	12.49	124.52	26.1
070517BPAGJ14	7/5/2017	176	52.1	mg/Kg		0.08	0.16	0.05	11.10	73.73	25.5
070517BPAGJ15	7/5/2017	164	42.5	mg/Kg		0.08	0.51	0.03	15.43	96.09	25.6

[a] Detection limits for identified metals were based on % solids which varied for each fish, so MDL's presented are the mean MDL values

Appendix 5. Juvenile Dolly Varden from Buddy, Anxiety, and Mainstem Red Dog Creeks, Whole Body Element Concentrations, 2017.

Shaded cells indicate value was at or below method detection limit (MDL), so MDL is reported

Sample Number	Location	Date Collected	Length (mm)	Weight (g)	MDL	Cadmium 0.09[a]	Lead 0.09[a]		Mercury 0.01[a]	Selenium 0.09[a]	Zinc 1.92[a]	% Solids
17AXDVJ01	Anxiety Creek	8/5/2017	115	14.6		0.09	0.22		0.08	4.19	113.10	22.9
17AXDVJ02	Anxiety Creek	8/5/2017	88	6.4		0.41	0.91		0.05	3.47	130.14	21.9
17AXDVJ03	Anxiety Creek	8/5/2017	94	7.6		0.13	0.26		0.08	4.61	131.74	23
17AXDVJ04	Anxiety Creek	8/5/2017	100	9.2		0.13	0.36		0.05	4.11	99.11	22.4
17AXDVJ05	Anxiety Creek	8/5/2017	120	16.5		0.49	1.12		0.13	5.97	262.14	20.6
17AXDVJ06	Anxiety Creek	8/5/2017	103	10.4		0.24	0.96		0.05	5.94	134.94	24.9
17AXDVJ07	Anxiety Creek	8/5/2017	105	9.9		0.44	0.39		0.06	5.11	165.07	22.9
17AXDVJ08	Anxiety Creek	8/5/2017	115	13.5		0.09	0.24		0.08	4.06	134.91	21.2
17AXDVJ09	Anxiety Creek	8/5/2017	93	7.5		0.14	0.93		0.08	4.11	192.52	21.4
17AXDVJ10	Anxiety Creek	8/5/2017	97	8.3		0.09	0.18		0.04	3.96	114.67	22.5
17AXDVJ11	Anxiety Creek	8/5/2017	94	7.9		0.10	0.14		0.04	4.47	126.92	20.8
17AXDVJ12	Anxiety Creek	8/5/2017	100	8.7		0.28	0.37		0.05	5.02	221.20	21.7
17AXDVJ13	Anxiety Creek	8/5/2017	120	15		0.23	0.32		0.09	3.74	139.19	22.2
17AXDVJ14	Anxiety Creek	8/5/2017	119	16.1		0.34	0.45		0.09	6.54	107.82	17.9
17AXDVJ15	Anxiety Creek	8/5/2017	95	7.5		0.14	0.14		0.13	4.65	106.10	21.3
17BCDVJ01	Buddy Creek	8/8/2017	126	19.2		0.34	0.30		0.05	5.85	123.08	23.4
17BCDVJ02	Buddy Creek	8/8/2017	120	15.3		0.38	0.77		0.05	4.64	162.55	23.5
17BCDVJ03	Buddy Creek	8/8/2017	100	10.1		1.06	1.06		0.05	11.94	260.19	21.6
17BCDVJ04	Buddy Creek	8/8/2017	126	18.2		0.85	0.47		0.07	6.93	168.40	21.2
17BCDVJ05	Buddy Creek	8/8/2017	101	8.5		1.23	0.45		0.07	5.87	298.32	17.9
17BCDVJ06	Buddy Creek	8/8/2017	93	7.4		0.55	0.13		0.04	2.94	78.30	23.5
17BCDVJ07	Buddy Creek	8/8/2017	91	6.9		1.00	0.32		0.04	5.64	126.82	22
17BCDVJ08	Buddy Creek	8/8/2017	86	5.7		0.62	0.39		0.05	6.18	197.19	17.8
17BCDVJ09	Buddy Creek	8/8/2017	92	7.5		0.47	0.37		0.05	6.03	219.63	21.4
17MSRDDVJ01	Mainstem Red Dog	8/5/2017	102	9.1		0.79	0.56		0.04	8.79	230.37	21.4
17MSRDDVJ02	Mainstem Red Dog	8/5/2017	137	22.8		2.37	6.03		0.07	12.63	521.55	23.2
17MSRDDVJ03	Mainstem Red Dog	8/5/2017	90	7.2		1.24	1.42		0.04	13.13	187.98	23.3
17MSRDDVJ04	Mainstem Red Dog	8/8/2017	115	15.6		0.48	1.08		0.03	14.54	128.11	24.9
17MSRDDVJ05	Mainstem Red Dog	8/8/2017	125	17		0.88	5.23		0.06	7.45	119.91	21.6
17MSRDDVJ06	Mainstem Red Dog	8/8/2017	115	14		2.01	6.17		0.03	13.49	162.20	20.9
17MSRDDVJ07	Mainstem Red Dog	8/8/2017	94	8.1		3.40	9.25		0.05	18.73	253.30	21.2
17MSRDDVJ08	Mainstem Red Dog	8/8/2017	106	12		2.49	3.02		0.06	7.38	112.89	22.5
17MSRDDVJ09	Mainstem Red Dog	8/8/2017	103	10.2		0.62	2.04		0.04	6.93	127.11	22.5
17MSRDDVJ10	Mainstem Red Dog	8/8/2017	105	11.3		0.50	0.50		0.06	8.56	144.78	20.1
17MSRDDVJ11	Mainstem Red Dog	8/8/2017	107	10.8		0.80	2.96		0.04	7.39	153.98	22.6

[a] Detection limits for identified metals were based on % solids which varied for each fish, so MDL's presented are the mean MDL values

Appendix 6. Arctic Grayling Ovaries Tested for Selenium at locations near the Red Dog and Fort Knox mines; 1999, 2014-2017.

In 2017, some fish from Bons Pond and Bons Creek were not retained, but eggs were collected on site, so age and weight data are not available.

Units mg/kg dry weight									
Sample Identification	Collector	Location	Date	Length (mm)	Weight (g)	Age	Tissue	Selenium (mg/kg)	Percent Solids
1999RDAGA01R	ADF&G	North Fork (Red Dog)	5/30/1999	315	449	9	Ovary	20	27.5
1999RDAGA02R	ADF&G	North Fork (Red Dog)	5/30/1999	324	443	7	Ovary	16	27.5
1999RDAGA03R	ADF&G	North Fork (Red Dog)	5/30/1999	327	408	6	Ovary	18	30
1999RDAGA04R	ADF&G	North Fork (Red Dog)	5/30/1999	366	562	26	Ovary	15	27.4
1999RDAGA05R	ADF&G	North Fork (Red Dog)	5/30/1999	343	489	8	Ovary	18	26.7
1999RDAGA06R	ADF&G	North Fork (Red Dog)	5/30/1999	358	590	7	Ovary	23	31.3
1999FCAGA01R	ADF&G	Fish Creek (Fort Knox)	5/18/1999	266	279	5	Ovary	5	27
1999FCAGA02R	ADF&G	Fish Creek (Fort Knox)	5/18/1999	231	210	4	Ovary	3	31.1
1999FCAGA03R	ADF&G	Fish Creek (Fort Knox)	5/18/1999	264	279	4	Ovary	3	28.5
1999FCAGA04R	ADF&G	Fish Creek (Fort Knox)	5/18/1999	262	247	4	Ovary	4	29.1
1999FCAGA05R	ADF&G	Fish Creek (Fort Knox)	5/18/1999	234	188	5	Ovary	4	30.6
1999FCAGA06R	ADF&G	Fish Creek (Fort Knox)	5/18/1999	242	222	4	Ovary	3	27.7
1999CHAGA01R	ADF&G	Chena River (Fairbanks)	5/1/1999	305	395	10	Ovary	14	29
1999CHAGA02R	ADF&G	Chena River (Fairbanks)	5/1/1999	321	468	11	Ovary	23	31.1
1999CHAGA03R	ADF&G	Chena River (Fairbanks)	5/1/1999	332	527	9	Ovary	13	31.5
1999CHAGA04R	ADF&G	Chena River (Fairbanks)	5/1/1999	318	414	9	Ovary	10	25.2
1999CHAGA05R	ADF&G	Chena River (Fairbanks)	5/1/1999	304	397	10	Ovary	9	23.9
1999CHAGA06R	ADF&G	Chena River (Fairbanks)	5/1/1999	320	497	11	Ovary	15	30.1
061014BPAGA01	ADF&G	Bons Pond (Red Dog)	6/10/2014	321	284	21/22	Ovary	36.2	24.6
061014BPAGA02	ADF&G	Bons Pond (Red Dog)	6/10/2014	319	340	19+	Ovary	28.7	23.0
061014BPAGA03	ADF&G	Bons Pond (Red Dog)	6/10/2014	312	332	19+	Ovary	33.6	25.8
061014BPAGA04	ADF&G	Bons Pond (Red Dog)	6/10/2014	314	308	20+	Ovary	29.9	19.7
061014BPAGA05	ADF&G	Bons Pond (Red Dog)	6/10/2014	320	314	16/17	Ovary	35.6	26.0
061014BPAGA06	ADF&G	Bons Pond (Red Dog)	6/10/2014	322	332	16+	Ovary	27.0	24.3
061014BPAGA07	ADF&G	Bons Pond (Red Dog)	6/10/2014	321	303	16	Ovary	40.4	25.9
052915BPAGA01	ADF&G	Bons Pond (Red Dog)	5/29/2015	320	372.25	7	Ovary	32.6	26.6
052915BPAGA02	ADF&G	Bons Pond (Red Dog)	5/29/2015	330	393.15	13	Ovary	27.2	29.3
052915BPAGA03	ADF&G	Bons Pond (Red Dog)	5/29/2015	340	421.96	16	Ovary	25.7	28.3
052915BPAGA04	ADF&G	Bons Pond (Red Dog)	5/29/2015	336	414.06	7/8	Ovary	30.2	19.9
052915BPAGA05	ADF&G	Bons Pond (Red Dog)	5/29/2015	327	406.97	11	Ovary	29.7	21.5
052915BPAGA06	ADF&G	Bons Pond (Red Dog)	5/29/2015	327	416.68	16	Ovary	38.3	26.4
052915BPAGA07	ADF&G	Bons Pond (Red Dog)	5/29/2015	335	417.13	16	Ovary	39.7	26.7
052915BPAGA08	ADF&G	Bons Pond (Red Dog)	5/29/2015	322	392.22	no age	Ovary	29.3	17.4

Appendix 6. (continued)

Units mg/kg dry weight									
Sample Identification	Collector	Location	Date	Length (mm)	Weight (g)	Age	Tissue	Selenium (mg/kg)	Percent Solids
050515FTKAGA01	ADF&G	Fish Creek (Fort Knox)	5/5/2015	293	305.65	4	Ovary	3.4	31.7
050515FTKAGA02	ADF&G	Fish Creek (Fort Knox)	5/5/2015	250	178.41	5	Ovary	3.9	31.4
050515FTKAGA03	ADF&G	Fish Creek (Fort Knox)	5/5/2015	255	185.87	no age	Ovary	4.2	31.4
050515FTKAGA04	ADF&G	Fish Creek (Fort Knox)	5/5/2015	252	187.49	3	Ovary	3.9	31.5
050515FTKAGA05	ADF&G	Fish Creek (Fort Knox)	5/5/2015	261	205.86	5	Ovary	3.1	30.9
050515FTKAGA06	ADF&G	Fish Creek (Fort Knox)	5/5/2015	266	234.08	4	Ovary	3.5	30.4
050515FTKAGA07	ADF&G	Fish Creek (Fort Knox)	5/5/2015	256	193.48	3	Ovary	3.5	31.1
050515FTKAGA08	ADF&G	Fish Creek (Fort Knox)	5/5/2015	255	181.77	3/4	Ovary	4.0	32.4
050515FTKAGA09	ADF&G	Fish Creek (Fort Knox)	5/5/2015	245	151.83	4	Ovary	3.2	32.4
053015NFAGA01	ADF&G	North Fork (Red Dog)	5/30/2015	387	576.95	17	Ovary	28.3	24.0
053015NFAGA02	ADF&G	North Fork (Red Dog)	5/30/2015	342	405.56	7	Ovary	12.7	24.2
053015NFAGA03	ADF&G	North Fork (Red Dog)	5/30/2015	358	478	8	Ovary	31.8	26.3
053015NFAGA04	ADF&G	North Fork (Red Dog)	5/30/2015	379	605.85	18	Ovary	28.3	27.0
053015NFAGA05	ADF&G	North Fork (Red Dog)	5/30/2015	380	551.05	21	Ovary	15.2	25.6
053015NFAGA06	ADF&G	North Fork (Red Dog)	5/30/2015	388	605.3	20	Ovary	16.4	26.0
053015NFAGA07	ADF&G	North Fork (Red Dog)	5/30/2015	365	556.8	12	Ovary	6.9	27.9
053115NFAGA08	ADF&G	North Fork (Red Dog)	5/31/2015	366	436.95	14	Ovary		
053115TUAGA01	ADF&G	Tutak Creek (Red Dog)	5/31/2015	337	348.64	11	Ovary		
051916BPAGA01	ADF&G	Bons Pond (Red Dog)	5/19/2016	340	478.8	10	Ovary	33.4	29.1
051916BPAGA02	ADF&G	Bons Pond (Red Dog)	5/19/2016	314	361.9	no age	Ovary	29.2	21.7
051916BPAGA03	ADF&G	Bons Pond (Red Dog)	5/19/2016	337	408.9	12	Ovary	28.1	25.1
051916BPAGA04	ADF&G	Bons Pond (Red Dog)	5/19/2016	350	574.9	17	Ovary	18.6	13.4
051916BPAGA05	ADF&G	Bons Pond (Red Dog)	5/19/2016	330	405.8	11	Ovary	26.3	26.5
051916BPAGA06	ADF&G	Bons Pond (Red Dog)	5/19/2016	337	408.4	10	Ovary	27	23.4
051916NFAGA01	ADF&G	North Fork (Red Dog)	5/19/2016	352	513.4	9	Ovary	12.5	24.8
052016NFAGA02	ADF&G	North Fork (Red Dog)	5/20/2016	386	627.2	14	Ovary	16.1	25.7
052016NFAGA03	ADF&G	North Fork (Red Dog)	5/20/2016	346	440	14	Ovary	12.2	26.8
052016NFAGA04	ADF&G	North Fork (Red Dog)	5/20/2016	408	722.3	18	Ovary	8.88	27.7
052016NFAGA05	ADF&G	North Fork (Red Dog)	5/20/2016	332	457.6	10	Ovary	31.9	27.5
052016NFAGA06	ADF&G	North Fork (Red Dog)	5/20/2016	382	582.2	10	Ovary	27.6	28.5

Appendix 6. (concluded)

Units mg/kg dry weight									
Sample Identification	Collector	Location	Date	Length (mm)	Weight (g)	Age	Tissue	Selenium (mg/kg)	Percent Solids
F-01	Owl Ridge	Fish Creek	2017	317	289.6	10	Ovary	6.02	
F-02	Owl Ridge	Fish Creek	2017	271	185	7	Ovary	3.25	
F-03	Owl Ridge	Fish Creek	2017	291	241.9	8	Ovary	4.21	
F-04	Owl Ridge	Fish Creek	2017	292	246	7	Ovary	3.92	
F-05	Owl Ridge	Fish Creek	2017	290	248.7	8	Ovary	3.57	
F-06	Owl Ridge	Fish Creek	2017	314	307	8	Ovary	4.62	
F-07	Owl Ridge	Fish Creek	2017	298	262.4	7	Ovary	5.15	
F-08	Owl Ridge	Fish Creek	2017	328	369	9	Ovary	3.04	
F-09	Owl Ridge	Fish Creek	2017	304			Ovary	4.63	
F-10	Owl Ridge	Fish Creek	2017	312			Ovary	4.94	
F-11	Owl Ridge	Fish Creek	2017	304			Ovary	4.77	
F-12	Owl Ridge	Fish Creek	2017	303			Ovary	5.14	
F-13	Owl Ridge	Fish Creek	2017	270			Ovary	3.99	
F-14	Owl Ridge	Fish Creek	2017	268			Ovary	3.71	
F-15	Owl Ridge	Fish Creek	2017	300			Ovary	4.4	
TC-60	Owl Ridge	Little Creek	2017	405	701.7	10	Ovary	22.4	
TC-61	Owl Ridge	Little Creek	2017	390	639.5	8	Ovary	13.9	
TC-62	Owl Ridge	Little Creek	2017	370	512.5	11	Ovary	19	
TC-63	Owl Ridge	Little Creek	2017	351	465.6	7	Ovary	13.1	
TC-64	Owl Ridge	Little Creek	2017	326	340.8	10	Ovary	11.4	
TC-65	Owl Ridge	Little Creek	2017	360	415.9	11	Ovary	12.4	
TC-66	Owl Ridge	Little Creek	2017	392	570.2	26	Ovary	18.6	
TC-67	Owl Ridge	Little Creek	2017	333	343.8	8	Ovary	14.9	
TC-68	Owl Ridge	Little Creek	2017	288			Ovary	10.7	
TC-69	Owl Ridge	Little Creek	2017	347			Ovary	15.2	
BP-40	Owl Ridge	Bons Pond	2017	351	411	15	Ovary	28.8	
BP-41	Owl Ridge	Bons Pond	2017	324	325	7	Ovary	23.7	
BP-42	Owl Ridge	Bons Pond	2017	345	377.9	10	Ovary	25.5	
BP-43	Owl Ridge	Bons Pond	2017	343	406.6	15	Ovary	29.7	
BP-44	Owl Ridge	Bons Pond	2017	356	430.3	9	Ovary	26.7	
BP-45	Owl Ridge	Bons Pond	2017	345	349.2	14	Ovary	28.1	
BP-46	Owl Ridge	Bons Pond	2017	351	413.5	16	Ovary	28.3	
BP-47	Owl Ridge	Bons Pond	2017	340	374.2	15	Ovary	21.2	
BP-48	Owl Ridge	Bons Pond	2017	346	402.4	14	Ovary	26	
BP-49	Owl Ridge	Bons Pond	2017	339	376.5	11	Ovary	33.9	
BP-50	Owl Ridge	Bons Pond	2017	340			Ovary	32.3	
BP-51	Owl Ridge	Bons Pond	2017	307	270.4	7	Ovary	21.7	
BP-52	Owl Ridge	Bons Creek	2017	344	385.2	12	Ovary	20.6	
BP-53	Owl Ridge	Bons Creek	2017	340	382.1	14	Ovary	21.5	
BP-54	Owl Ridge	Bons Creek	2017	340	391.7	8	Ovary	27.4	
BP-55	Owl Ridge	Bons Creek	2017	349	413.5	10	Ovary	28.4	
BP-56	Owl Ridge	Bons Creek	2017	336			Ovary	28.8	
BP-57	Owl Ridge	Bons Creek	2017	331			Ovary	23.2	
BP-58	Owl Ridge	Bons Creek	2017	360			Ovary	26.8	
BP-59	Owl Ridge	Bons Creek	2017	342			Ovary	26.1	
NFRDC- 20	Owl Ridge	Mainstem RedDog	2017	396	638.6	17	Ovary	17.8	
NFRDC- 21	Owl Ridge	Mainstem RedDog	2017	342	424.9	9	Ovary	13.7	
NFRDC- 22	Owl Ridge	Mainstem RedDog	2017	326	332.1	5	Ovary	23	
NFRDC- 23	Owl Ridge	Mainstem RedDog	2017	351	416.4	7	Ovary	13.1	
NFRDC- 24	Owl Ridge	Mainstem RedDog	2017	368	514.2	11	Ovary	22.8	

Appendix 7. Dolly Varden Element Data, Wulik River, June 2017.

Shaded cells indicate value was at or below method detection limit (MDL), so MDL is reported. All values reported in dry weight.

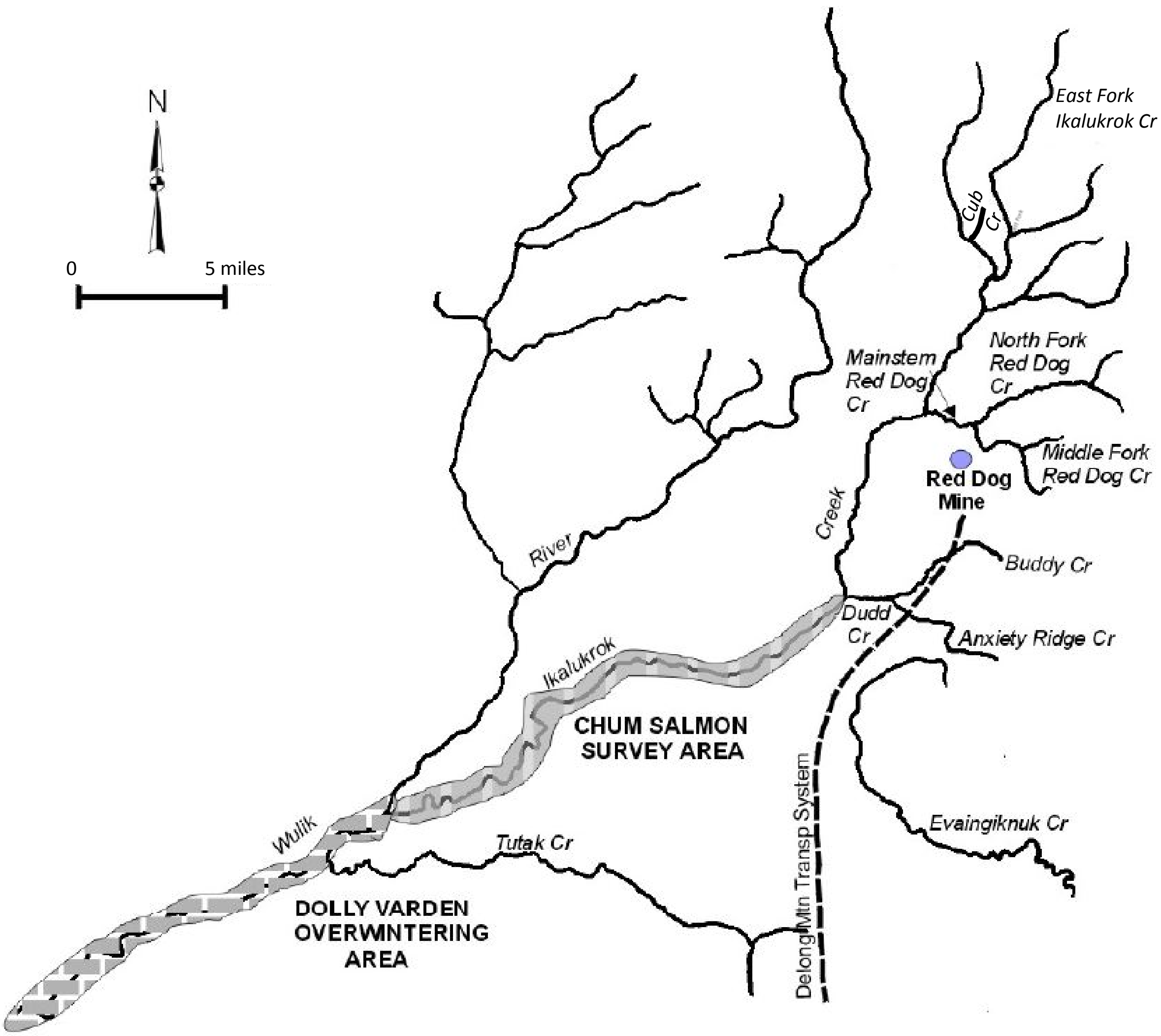
Tissue	Sample Identification	Fish Species	Sex	Weight (grams)	Length (mm)	Cadmium mg/kg	Copper mg/kg	Lead mg/kg	Selenium mg/kg	Zinc mg/kg	Mercury mg/kg	Percent Solids
Kidney	060217WUDVA01	Dolly	Female	844	420	0.6	3.5	0.09	9.4	65.4	0.05	23.4
Kidney	060217WUDVA02	Dolly	Male	1790	553	1.3	4.2	0.09	8.8	92.0	0.10	21.3
Kidney	060217WUDVA03	Dolly	Female	3020	604	2.5	3.7	0.14	9.7	60.6	0.12	21.6
Kidney	060217WUDVA04	Dolly	Female	2145	550	1.4	4.7	0.09	10.7	83.7	0.08	21.5
Kidney	060217WUDVA05	Dolly	Male	1467	526	1.6	4.4	0.09	5.8	89.4	0.06	21.6
Kidney	060217WUDVA06	Dolly	Female	661	400	2.0	4.5	0.10	11.2	115.1	0.05	20.5
Kidney	duplicate of Fish #3					1.2	3.0	0.09	12.0	80.5	0.10	22
Liver	060217WUDVA01	Dolly	Female	844	420	0.6	45.8	0.07	4.1	95.7	0.03	30.1
Liver	060217WUDVA02	Dolly	Male	1790	553	0.3	76.4	0.05	3.2	65.2	0.03	36.8
Liver	060217WUDVA03	Dolly	Female	3020	604	0.3	17.9	0.05	2.3	50.0	0.02	39.6
Liver	060217WUDVA04	Dolly	Female	2145	550	0.2	20.2	0.05	2.3	48.1	0.02	37.8
Liver	060217WUDVA05	Dolly	Male	1467	526	0.3	19.5	0.05	1.9	53.2	0.02	39.3
Liver	060217WUDVA06	Dolly	Female	661	400	0.4	30.2	0.06	5.2	104.8	0.04	31.5
Liver	duplicate of Fish #3					0.3	19.7	0.03	2.5	60.0	0.02	39.5
Muscle	060217WUDVA01	Dolly	Female	844	420	0.08	1.5	0.08	1.2	16.1	0.04	25.5
Muscle	060217WUDVA02	Dolly	Male	1790	553	0.06	2.6	0.06	1.1	13.5	0.02	31.9
Muscle	060217WUDVA03	Dolly	Female	3020	604	0.07	1.3	0.07	0.9	13.3	0.05	27
Muscle	060217WUDVA04	Dolly	Female	2145	550	0.07	1.4	0.07	0.9	11.4	0.04	28.1
Muscle	060217WUDVA05	Dolly	Male	1467	526	0.08	1.6	0.08	1.2	13.1	0.02	26
Muscle	060217WUDVA06	Dolly	Female	661	400	0.08	2.1	0.08	1.3	24.8	0.02	25.8
Muscle	duplicate of Fish #3					0.06	2.6	0.06	0.7	15.1	0.03	35.8
Reproductive	060217WUDVA01	Dolly	Female	844	420	0.12	24.3	0.12	8.2	634.1	0.02	16.4
Reproductive	060217WUDVA02	Dolly	Male	1790	553	0.12	4.8	0.12	4.1	155.7	0.02	16.7
Reproductive	060217WUDVA03	Dolly	Female	3020	604	0.07	16.9	0.07	4.7	153.2	0.01	30.1
Reproductive	060217WUDVA04	Dolly	Female	2145	550	0.07	17.9	0.07	6.9	246.9	0.02	28.6
Reproductive	060217WUDVA05	Dolly	Male	1467	526	0.15	2.0	0.15	2.4	130.5	0.02	19.7
Reproductive	060217WUDVA06	Dolly	Female	661	400	0.09	22.3	0.09	11.3	580.4	0.02	22.4
Reproductive	duplicate of Fish #3					0.10	17.9	0.10	5.0	174.4	0.01	30.1

Appendix 8. Dolly Varden Element Data, Wulik River, September 2017.

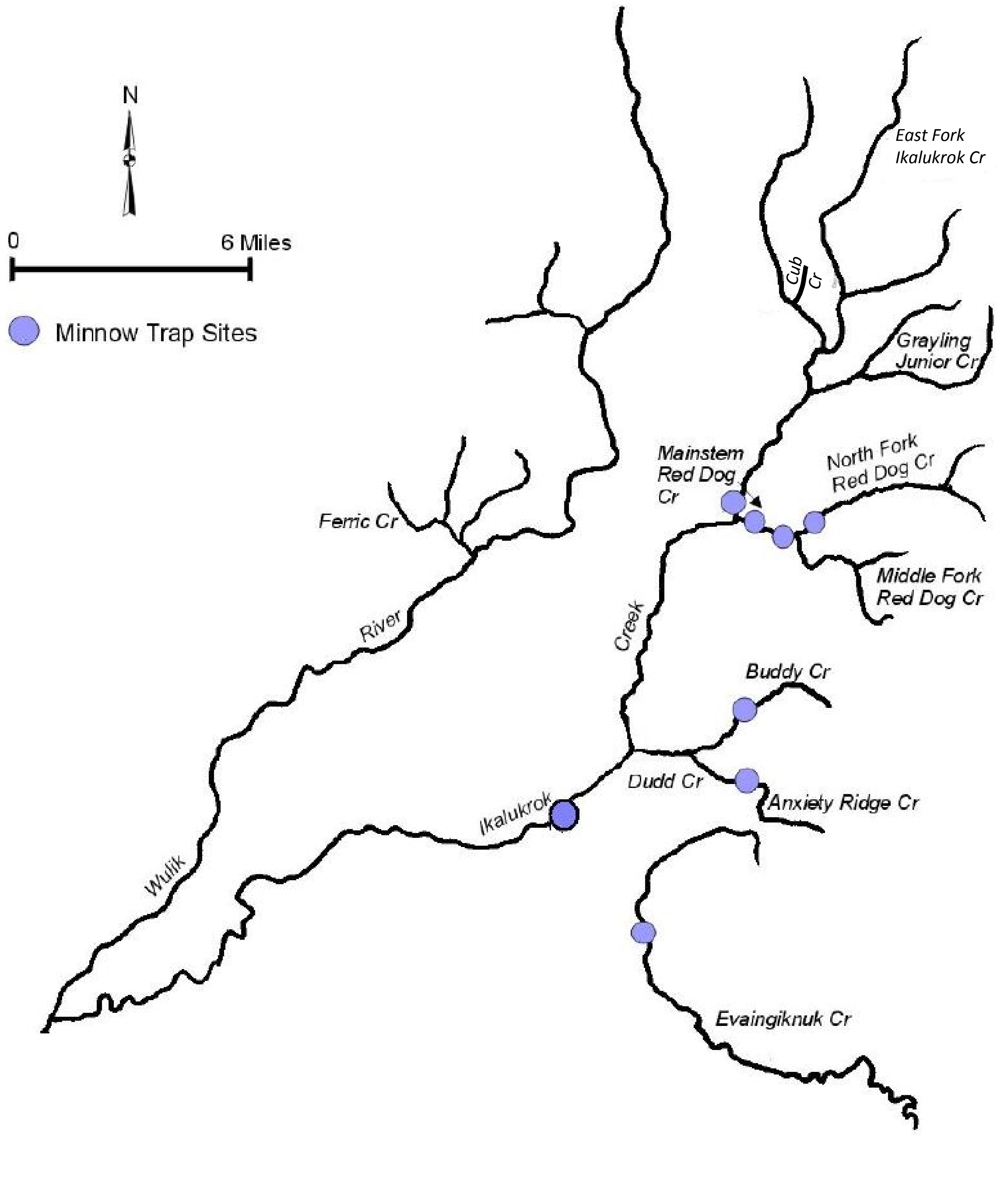
Shaded cells indicate value was at or below method detection limit (MDL), so MDL is reported. All values reported in dry weight.

Tissue	Sample Identification	Fish Species	Sex	Weight (grams)	Length (mm)	Cadmium mg/kg	Copper mg/kg	Lead mg/kg	Selenium mg/kg	Zinc mg/kg	Mercury mg/kg	Percent Solids
Kidney	092417WUDVA01	Dolly	Female	1585	492	0.9	4.3	0.05	9.5	110.9	0.04	20.2
Kidney	092417WUDVA02	Dolly	Immature	1715	518	0.7	3.7	0.10	7.2	106.7	0.06	19.5
Kidney	092417WUDVA03	Dolly	Female	2057	540	0.7	3.9	0.09	7.4	85.1	0.07	22.2
Kidney	092417WUDVA04	Dolly	Female	1994	534	0.8	4.3	0.10	7.3	104.3	0.06	21
Kidney	092417WUDVA05	Dolly	Male	1919	541	0.7	4.1	0.09	7.7	123.0	0.05	21.7
Kidney	092417WUDVA06	Dolly	Male	1628	516	0.6	5.1	0.05	8.1	122.7	0.07	20.7
Kidney	duplicate of Fish #3					1.4	5.4	0.09	9.4	114.1	0.06	22
Liver	092417WUDVA01	Dolly	Female	1585	492	0.2	32.7	0.05	4.0	79.0	0.02	39.5
Liver	092417WUDVA02	Dolly	Immature	1715	518	0.2	40.4	0.05	2.5	64.4	0.03	44.1
Liver	092417WUDVA03	Dolly	Female	2057	540	0.3	35.2	0.05	3.4	79.0	0.03	38.6
Liver	092417WUDVA04	Dolly	Female	1994	534	0.1	31.0	0.04	2.2	42.1	0.03	51.6
Liver	092417WUDVA05	Dolly	Male	1919	541	0.2	20.3	0.05	3.5	70.0	0.02	37.7
Liver	092417WUDVA06	Dolly	Male	1628	516	0.2	13.8	0.05	3.0	58.1	0.02	40.8
Liver	duplicate of Fish #3					0.2	27.1	0.05	2.6	63.8	0.02	41.7
Muscle	092417WUDVA01	Dolly	Female	1585	492	0.05	1.0	0.05	0.8	10.9	0.01	37.6
Muscle	092417WUDVA02	Dolly	Immature	1715	518	0.06	1.6	0.06	0.9	12.9	0.01	34
Muscle	092417WUDVA03	Dolly	Female	2057	540	0.06	1.0	0.06	0.9	12.3	0.02	32.6
Muscle	092417WUDVA04	Dolly	Female	1994	534	0.05	1.4	0.05	0.7	14.1	0.03	41.1
Muscle	092417WUDVA05	Dolly	Male	1919	541	0.06	1.2	0.06	1.0	14.9	0.02	32.9
Muscle	092417WUDVA06	Dolly	Male	1628	516	0.05	1.2	0.05	0.7	11.3	0.02	38
Muscle	duplicate of Fish #3					0.05	0.9	0.05	0.7	12.0	0.02	37.6
Reproductive	092417WUDVA01	Dolly	Female	1585	492	0.11	30.8	0.11	9.1	586.6	0.01	17.9
Reproductive	092417WUDVA02	Dolly	Immature	1715	518	0.44	3.4	0.44	3.4	117.1	0.02	20.5
Reproductive	092417WUDVA03	Dolly	Female	2057	540	0.10	33.1	0.10	10.5	817.3	0.02	19.7
Reproductive	092417WUDVA04	Dolly	Female	1994	534	0.10	51.4	0.10	13.1	447.9	0.02	19.2
Reproductive	092417WUDVA05	Dolly	Male	1919	541	0.45	4.5	0.45	3.9	133.7	0.02	20.2
Reproductive	092417WUDVA06	Dolly	Male	1628	516	0.56	3.9	0.56	5.0	307.3	0.02	17.9
Reproductive	duplicate of Fish #3					0.10	30.2	0.10	9.1	843.8	0.02	19.2

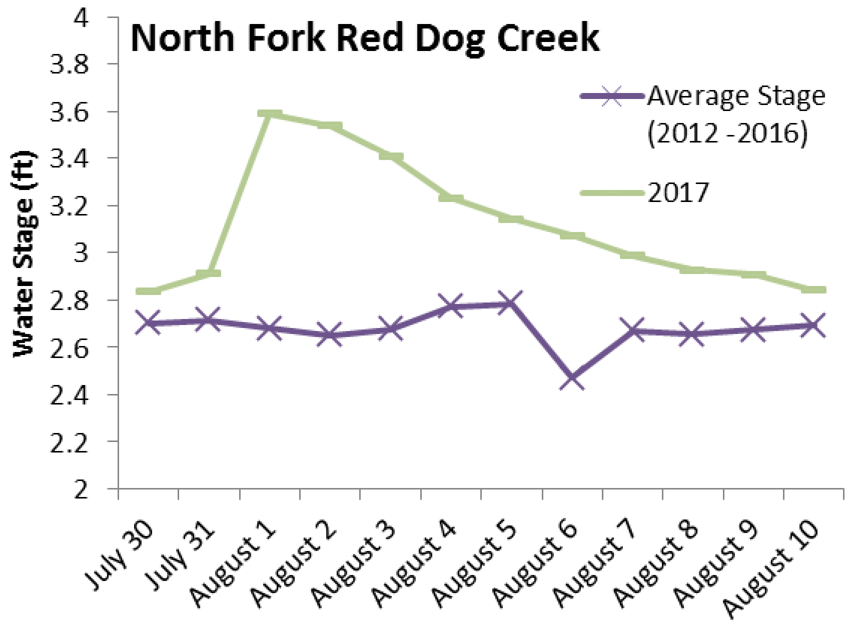
Appendix 9. Dolly Varden and Chum Salmon Aerial Survey Index Areas, Red Dog Mine, 2017.

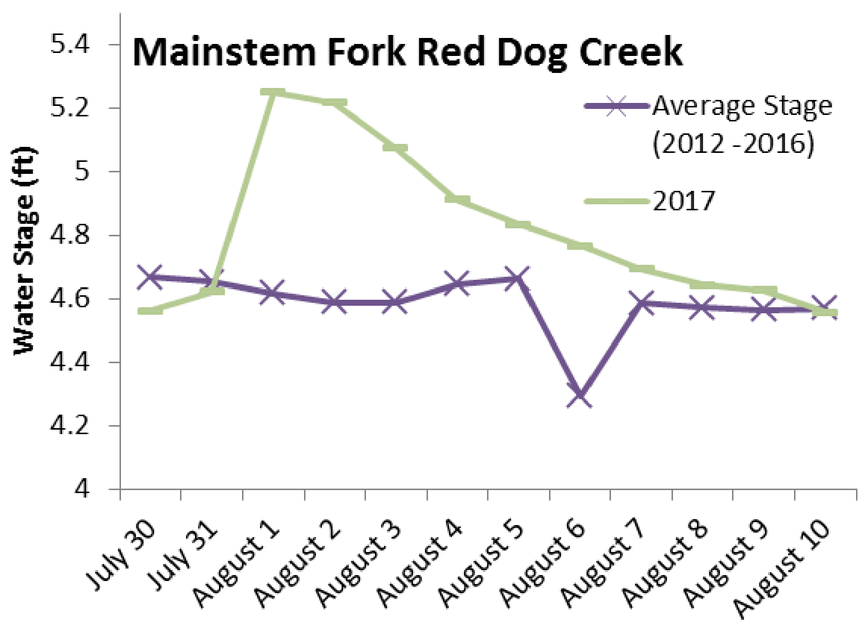


Appendix 10. Juvenile Dolly Varden Sampling Sites, Red Dog Mine, 2017.



Appendix 11. Five year average (2012-2016) stream stage (ft) of selected stations within the Red Dog Mine biomonitoring area and 2017 stage before, during, and after the August sampling event.[5]





[5] Data from Red Dog Mine stream gauges.

Appendix 12. Juvenile Dolly Varden Sampling Sites, Red Dog Mine, 1997-2017.

Number of Dolly Varden Caught in Late-July/Early August with ten minnow traps per sample site

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

2012 and 2013 no minnow traps fished due to multiple high water events

total catch does not include Upper North Fork Red Dog Creek

In 2016, a bear destroyed three deployed traps at station 151 and one trap at station 12