Technical Report No. 17-07

Aquatic Biomonitoring at Red Dog Mine, 2016

A requirement under Alaska Pollution Discharge Elimination System Permit No. AK00038652 (Modification #1)

by

Alvin G. Ott and Parker T. Bradley

May 2017

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

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AQUATIC BIOMONITORING AT RED DOG MINE, 2016

A REQUIREMENT UNDER ALASKA POLLUTION DISCHARGE ELIMINATION SYSTEM PERMIT NO. AK00038652 (MODIFICATION #1)

By

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May, 2017

Cover: Upper North Fork Red Dog Creek, August 4, 2016. Photograph by Parker T. Bradley

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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 reviews of this report.

Executive Summary

●In 2016, 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 2016 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 2016.

●Periphyton standing crop, as estimated by chlorophyll-a concentration, is determined each year in the drainages near the Red Dog Mine. In 2016 Chlorophyll-a concentrations were highest in Buddy Creek below the falls 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 elevated 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 2016, ten sites were sampled and the aquatic invertebrate density was highest in Upper North Fork Red Dog Creek. In 2016 all sites sampled contained a higher percentage of Chironomidae than Ephemeroptera, Plecoptera, and Trichoptera (EPT). In 2016, Buddy Creek had the highest taxa richness since sampling began in 2004. North Fork Red Dog creek also had higher than average taxa richness in 2016. Overall taxa richness is similar among these sites.

●Juvenile Arctic grayling from Bons Pond have been analyzed for selected whole body metals in 2004, 2007, 2010, and 2014–2016. Cadmium concentrations in Arctic grayling are similar among the sample years. The average lead and selenium concentrations in juvenile Arctic grayling from Bons Pond were similar from 2014 to 2016 and similar but slightly lower in 2004, 2007, and 2010. Average zinc concentrations have varied from a high of 104 mg/kg in 2016 to a low of 68 mg/kg in 2004. Average mercury concentrations in juvenile Arctic grayling has been variable, but all have been low or at the detection limit.

●In all years, juvenile Dolly Varden median whole body concentrations of cadmium, lead, and zinc are consistently higher in Mainstem Red Dog Creek than in Buddy and Anxiety Ridge creeks. Cadmium and zinc water quality data track with whole body concentrations, but lead does not. Median whole body selenium concentrations in juvenile Dolly Varden generally are lowest in fish from Anxiety Ridge Creek, but mercury concentrations are higher.

●Selenium concentrations in Arctic grayling ovaries were highest in fish from Bons Pond (2014–2016) and lowest in Fish Creek (1999 and 2015) at Ft. Knox Mine near Fairbanks. Selenium concentrations in fish ovaries from 1999, 2015, and 2016 from North Fork Red Dog and Fish creeks have not changed.

●In 2016 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 metals do concentrate in specific tissues: cadmium, zinc and mercury in kidney; copper in liver, selenium in kidney and ovary, and zinc in ovary.

Executive Summary (continued)

●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 63,000 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.

●Resident Dolly Varden (n = 4) were collected with fyke nets in North Fork Red Dog Creek in spring 2016. Juvenile Dolly Varden sampling was conducted in late summer 2016. The total number of juvenile Dolly Varden captured in early August was 238 fish, with the highest catches occurring in Anxiety Ridge and Buddy creeks.

●In spring 2016, the Arctic grayling spawning migration into North Fork Red Dog Creek was monitored and 175 Arctic grayling were captured in North Fork Red Dog Creek. It appears that spawning was substantially complete in Mainstem Red Dog Creek by May 20 – the earliest documented in 15 years. The population of Arctic grayling was estimated at 905 fish ≥ 200 mm FL (fork length).

●The estimated Arctic grayling population in Bons Pond in 2015 was 769 fish ≥ 200 mm FL. The population estimate shows the first increase since 2005. Sampling in recent years (2012 to 2016) has included catches of juvenile fish (< 200 mm FL) suggesting that the population likely will increase in the future. In spring 2016 Arctic grayling spawning was observed in Bons Creek and in the Bons Pond outlet channel. Arctic grayling fry were 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 fully described in 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 Weber Scannell et al. 2000.

Aquatic biomonitoring has occurred annually since 1995 and has included periphyton, aquatic invertebrate, and fish sampling, including tissue and whole body metals analyses for Dolly Varden (*Salvelinus malma*) and spawning season monitoring for Arctic grayling (*Thymallus arcticus*). The Alaska Department of Environmental Conservation (ADEC) Alaska Pollution Discharge Elimination System Permit No. AK00038652 (Modification #1 - APDES Permit) issued to Teck Alaska Incorporated (Teck) allows discharge of up to 2.418 billion gallons of treated effluent per year 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 (Table 1). The bioassessment program became fully effective and enforceable on March 31, 2010.

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

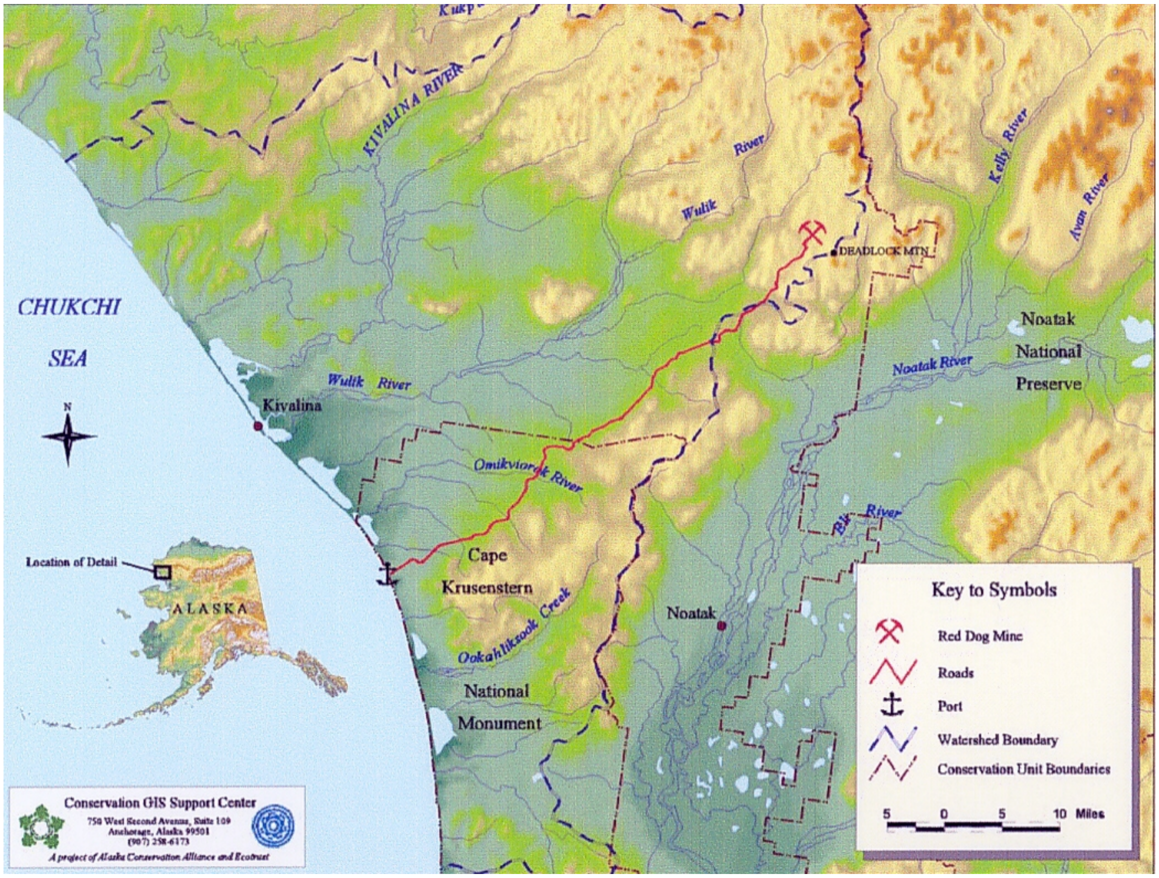


Figure 1. Location of the Red Dog Mine in northwestern Alaska.[1]

On December 2, 2009, the ADEC issued Waste Management Permit No. 0132-BA002 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 Alaska Department of Fish and Game (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, 2016.

Location	APDES/ADEC	Location Description	Sampling Frequency	Parameters
Wulik River	ADEC	Kivalina Lagoon upstream to about 10 km upstream of the mouth of Ikalukrok Creek (where the canyon starts)	1/year	Fall aerial surveys for overwintering Dolly Varden
Ikalukrok Creek	ADEC	Lower Ikalukrok Creek to mouth of Dudd Creek	1/year	Fall aerial surveys for adult chum salmon
Station 9	APDES/ADEC	Ikalukrok Creek upstream of confluence with 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
Station 160	ADEC	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	ADEC	Middle Fork Red Dog Creek upstream on confluence with	1/year	Periphyton (as chlorophyll-a concentrations)
			1/year	Aquatic invertebrates (monitored for taxonomic richness, abundance, and density)
Station 10	APDES/ADEC	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 metals in tissue (Zn, Pb, Se, Hg, and Cd)
Station 12	APDES/ADEC	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	ADEC	Below falls, about 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 metals in tissue (Zn, Pb, Se, Hg, and Cd)
Buddy 221	ADEC	Buddy Creek, above road	1/year	Periphyton (as chlorophyll-a concentrations)
			1/year	Aquatic invertebrates (monitored for taxonomic richness, abundance, and density)
Bons 220	ADEC	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	ADEC	Above pond	1/year	Periphyton (as chlorophyll-a concentrations)
			1/year	Aquatic invertebrates (monitored for taxonomic richness, abundance, and density)
Anxiety Ridge Creek	ADEC	below DMTS road	1/year	Fish presence and use
			1/year	Juvenile Dolly Varden metals in tissue (Zn, Pb, Se, Hg, and Cd)
Evaingiknuk Creek	ADEC	East of DMTS road	1/year	Fish presence and use
Bons Reservoir	ADEC	Above reservoir spillway	1/year	Juvenile Arctic grayling metals in tissue (Zn, Pb, Se, Hg, and Cd)
			1/year	Arctic grayling population estimate

Table 3. Location of sample sites for 2016 Red Dog aquatic biomonitoring study.

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

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 (F20099958) dated December 2, 2009. 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 2016 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 invertebrate data
4) Metals concentration data for juvenile Dolly Varden and juvenile and adult Arctic grayling collected from small 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.
6) Biological monitoring data for Dolly Varden juveniles, Arctic grayling, and slimy sculpin (*Cottus cognatus*).

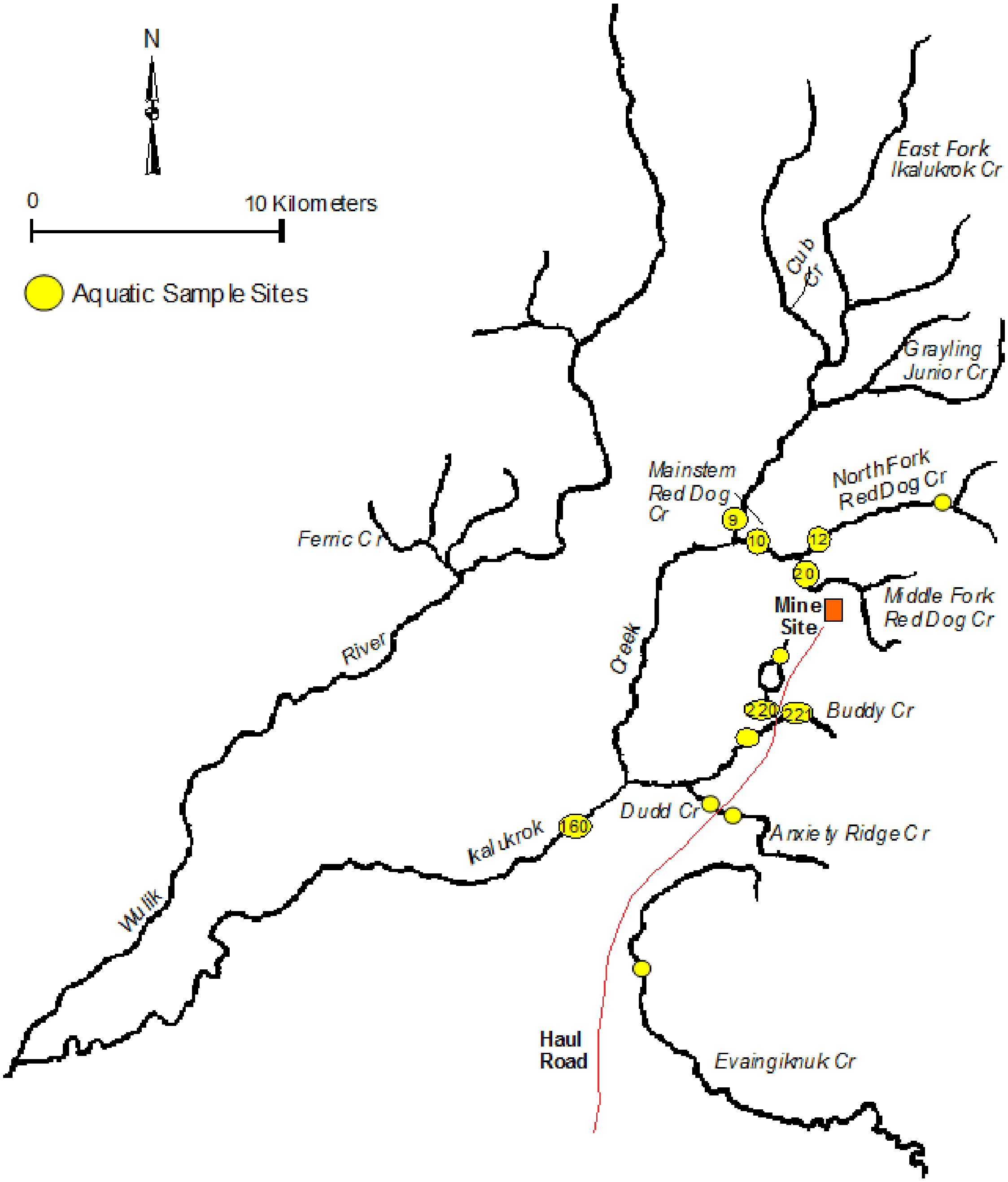


Figure 2. Location of sample sites (some have a Station #) in the Ikalukrok (tributary of the Wulik River) and Evaingiknuk Creek (a tributary of the Noatak River) drainages.

Location and Description of Sample Sites

Biomonitoring is conducted in streams adjacent to and downstream from the Red Dog Mine as required under the APDES Permit No. AK00038652 (Tables 1 and 2 and Figures 2 and 3), and by condition in 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 baseline studies (1979 to 1982) represent pre-mining conditions. Comparisons of existing conditions relative to baseline data should take into account that there are many years of data during mining and only a short time frame of baseline data.

Methods

Three sampling events occurred in 2016 including spring Arctic grayling and adult Dolly Varden sampling (May 18–23), aquatic invertebrates and periphyton (July 2–6), and juvenile Dolly Varden sampling (August 3–7).

All methods used for the 2016 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).

The method detection limit (MDL) in 2000 for copper (Cu), lead (Pb), and selenium (Se) was 50, 20, and 50 µg/L, respectively, for a portion of the samples early in the ice-free season. MDL's were changed part way through summer 2000 for copper, lead, and selenium to 1, 2, and 1 µg/L respectively. Because of the high MDL's used in early 2000, water quality data for these samples are not presented. Water quality data presented in this report are for "total recoverable." All water quality data are provided by Teck. The number of water quality samples taken each year varies with the permit condition requirements, but for most analytes, 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.

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 2016 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 2016, Teck continued to maintain the mine's clean water bypass system which picks up non-mining impacted 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 clean water from contact with areas disturbed by mining activities.

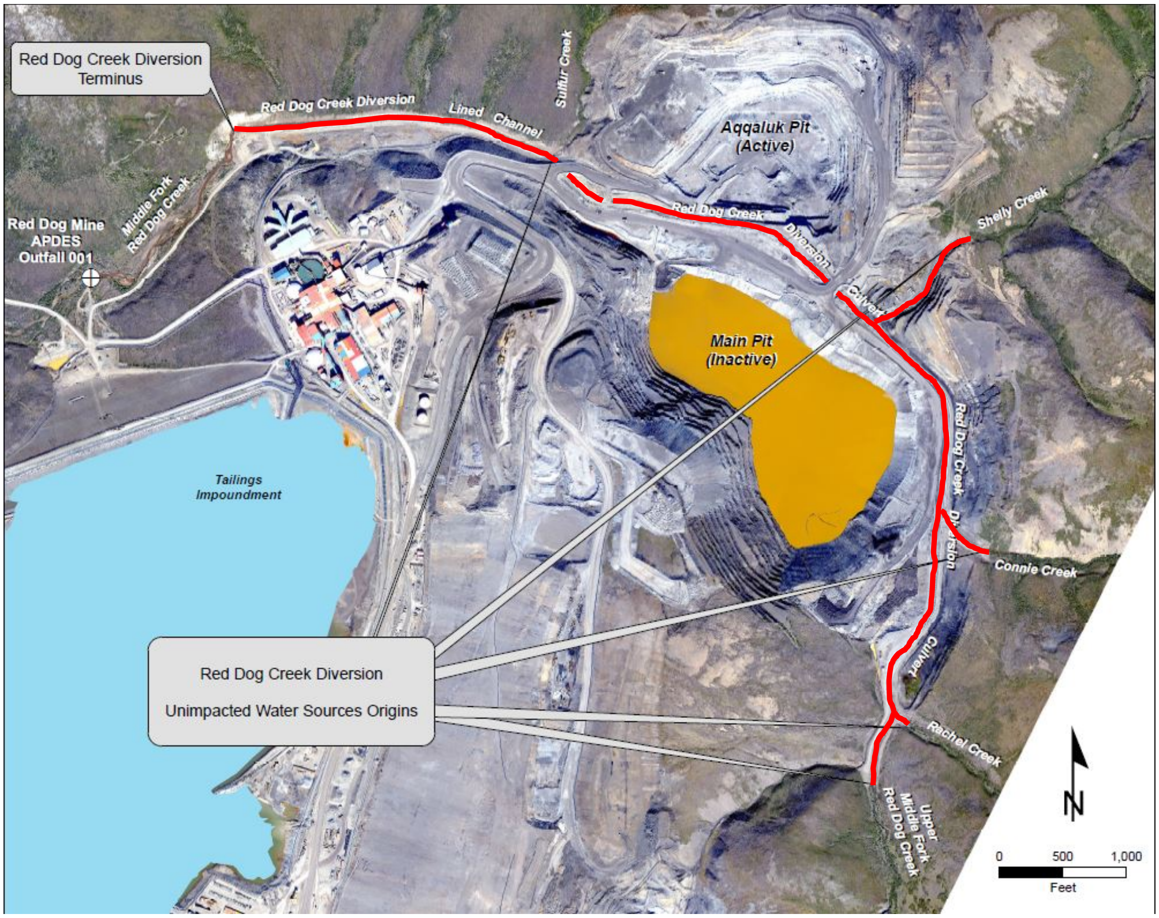


Figure 4. Clean water bypass system at the Red Dog Mine. The Red Dog Creek diversion structure (delineated by labels in the photograph and shown in red) picks up non-mining impacted waters from upstream tributaries and moves them between the Aqqaluk pit and the main pit back to the original Middle Fork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

In 2016, 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 2016. Median zinc concentration in 2016 was 495 µg/L as compared with a baseline median concentration of 3,700 µg/L (Figure 6).

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

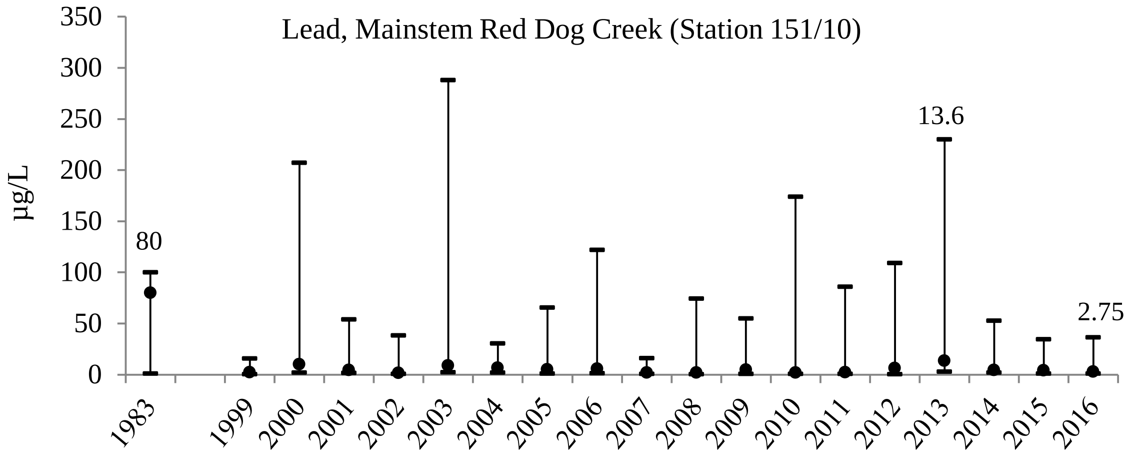


Figure 5. Median, maximum, and minimum lead concentrations at Station 151/10 (selected median values shown).

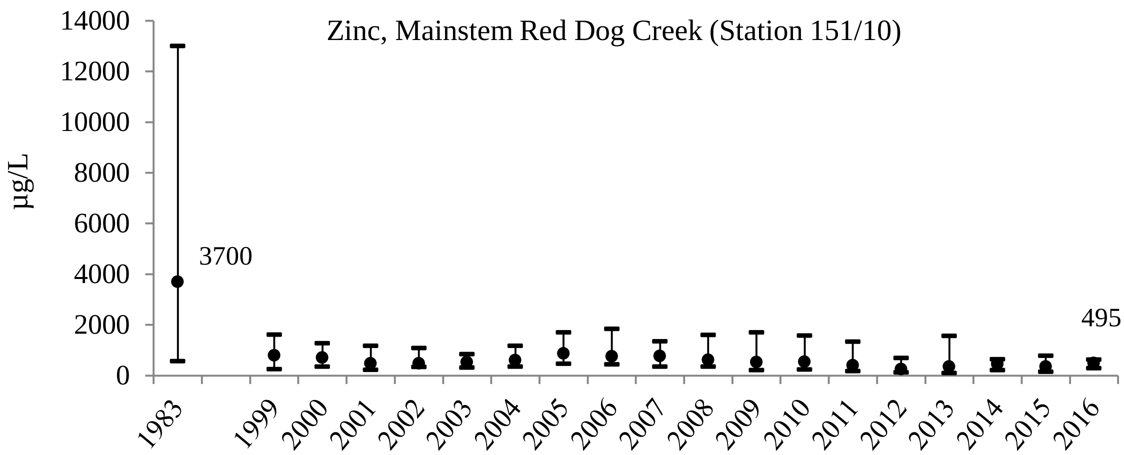


Figure 6. Median, maximum, and minimum zinc concentrations at Station 151/10 (selected median values shown).

In 2016, the major sources 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 in 2013, 122.4 in 2014, 88.4 µg/L in 2015, and 150.6 in 2016. Sulfur Creek may eventually be incorporated into the Aqqaluk Pit. Overall, the median lead concentrations in 2016 at Station 140 (below the clean water bypass), but upstream from Outfall 001) were lower than those reported in 2014 and 2015.

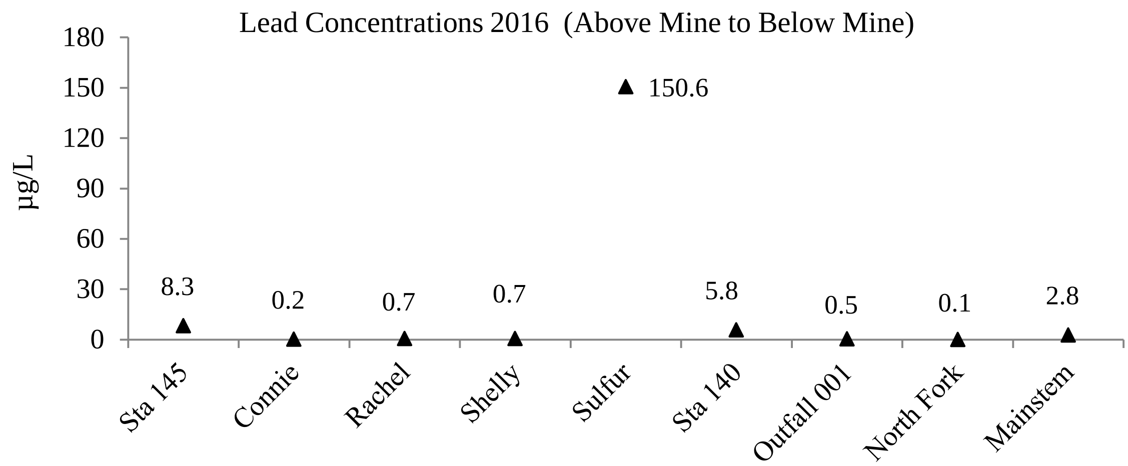


Figure 7. Median lead concentrations in 2016 from upstream (Station 145) of the clean water bypass, including tributaries to the clean water bypass (Connie, Rachel, Shelly, and Sulfur), and Station 140 (above the Outfall 001), Outfall 001, and North Fork Red Dog and Mainstem Red Dog Creeks.

Median aluminum concentrations at Station 10/151 continue to be lower than pre-mining (Figure 8). Cadmium concentrations are lower than pre-mining conditions (Figure 9). The median cadmium concentration in 1983 was 28 µg/L and in summer 2016 it was 2.3 µg/L. In most years (1999 to 2016), the maximum cadmium concentration is lower than the pre-mining (1983) median value.

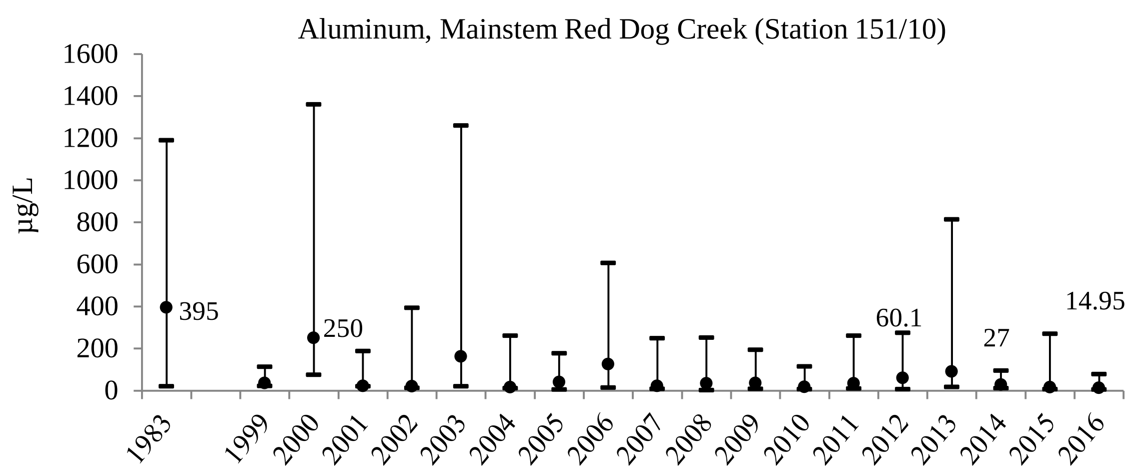


Figure 8. Median, maximum, and minimum aluminum concentrations at Station 151/10 (selected median values shown).

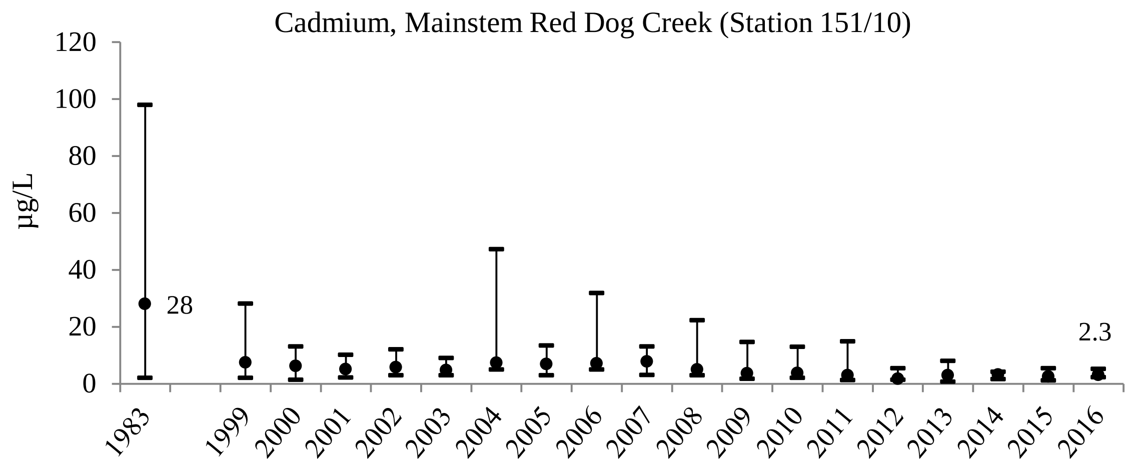


Figure 9. Median, maximum, and minimum cadmium concentrations at Station 151/10 (selected median values shown).

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. Median selenium concentration in Mainstem Red Dog Creek was 1.75 µg/L in 2016.

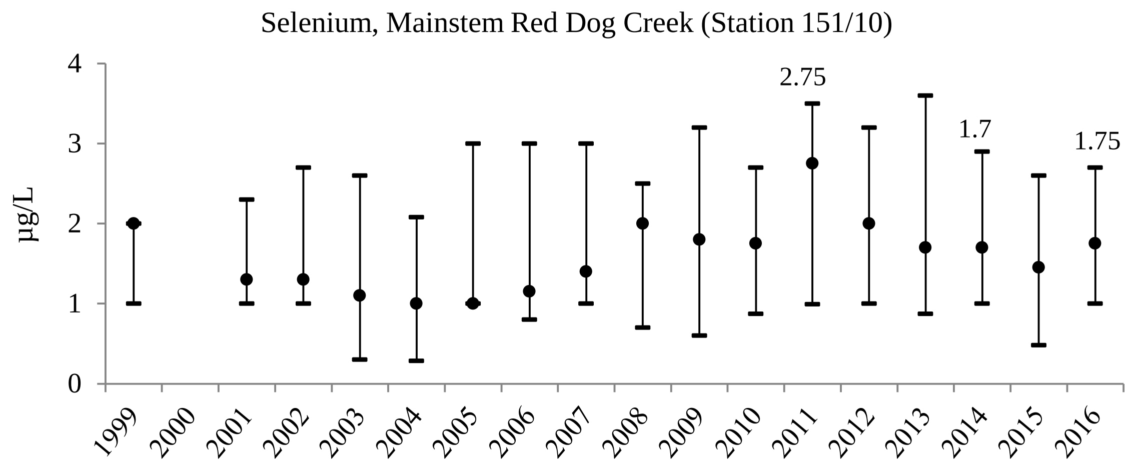


Figure 10. Median, maximum, and minimum selenium concentrations at Station 151/10 (selected median values shown).

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 8.95 µg/L in 2016.

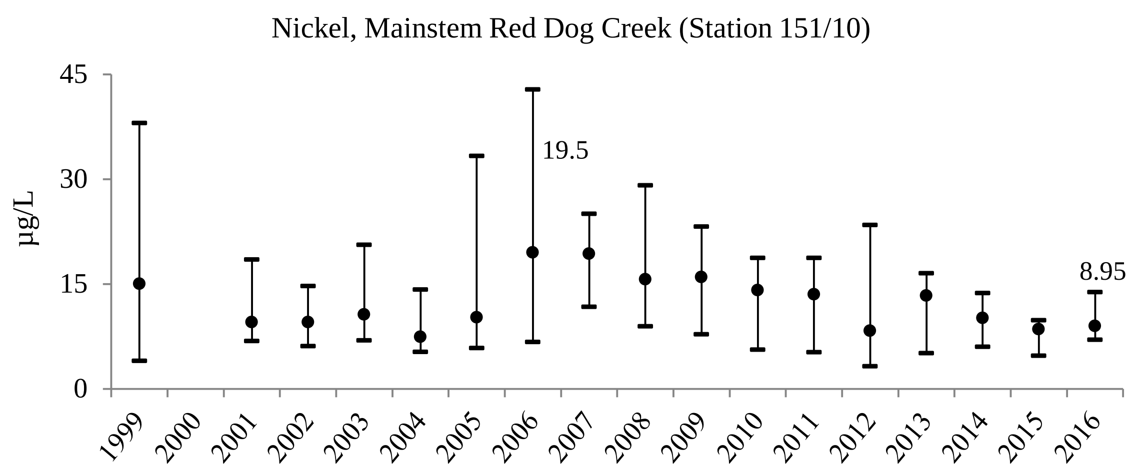


Figure 11. Median, maximum, and minimum nickel concentrations at Station 151/10 (selected median values shown).

The pH at Station 151/10 is higher than pre-mining (Figure 12). The pH is slightly more basic and has only dropped below 6 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.

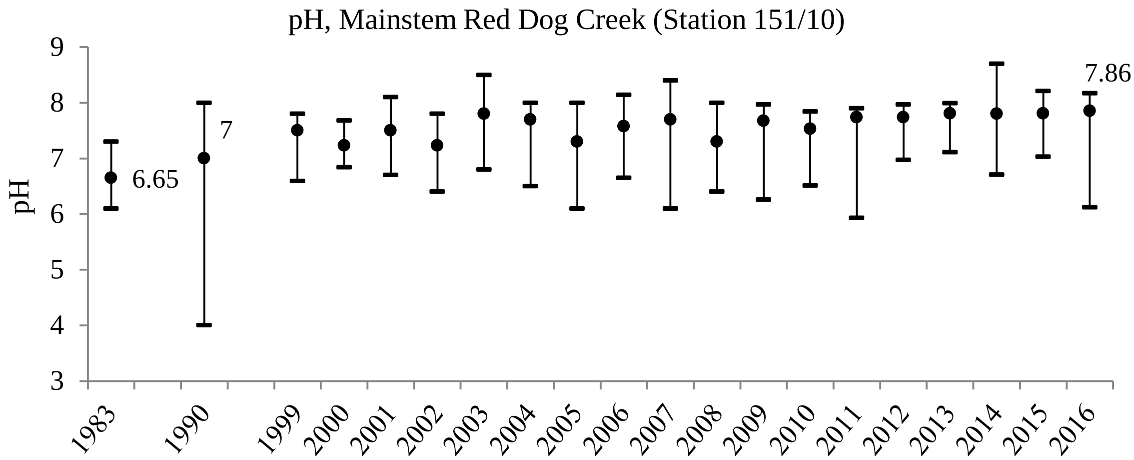


Figure 12. Median, maximum, and minimum pH values at Station 151/10 (selected median values shown).

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 2016 never exceeded the 1,500 mg/L standard applied at Station 151.

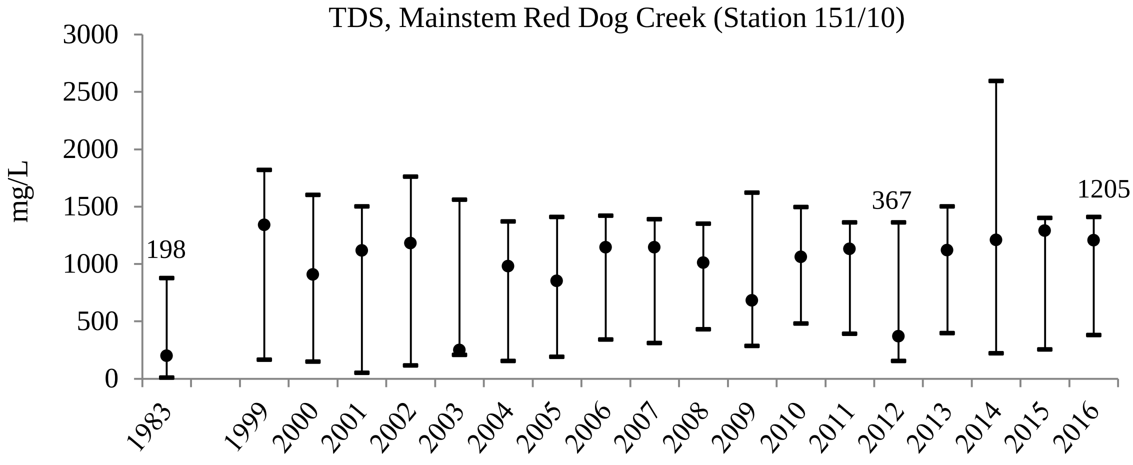
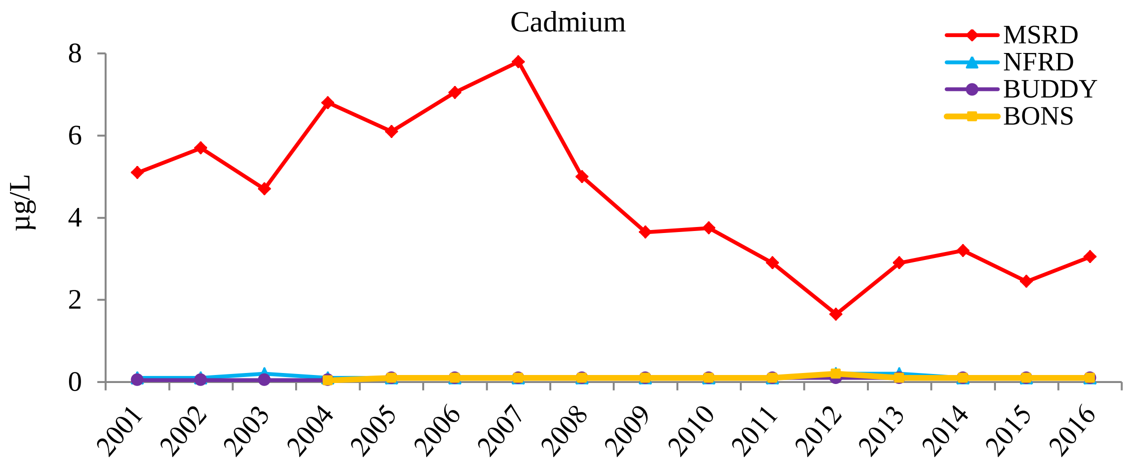


Figure 13. Median, maximum, and minimum TDS concentrations at Station 151/10 (selected median values shown).

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 metals concentrations in juvenile Arctic grayling from Bons Pond and juvenile Dolly Varden from Mainstem Red Dog, Anxiety Ridge, and Buddy creeks.

Cadmium, lead, and zinc median concentrations are highest in Mainstem Red Dog Creek. The 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 2016. 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.



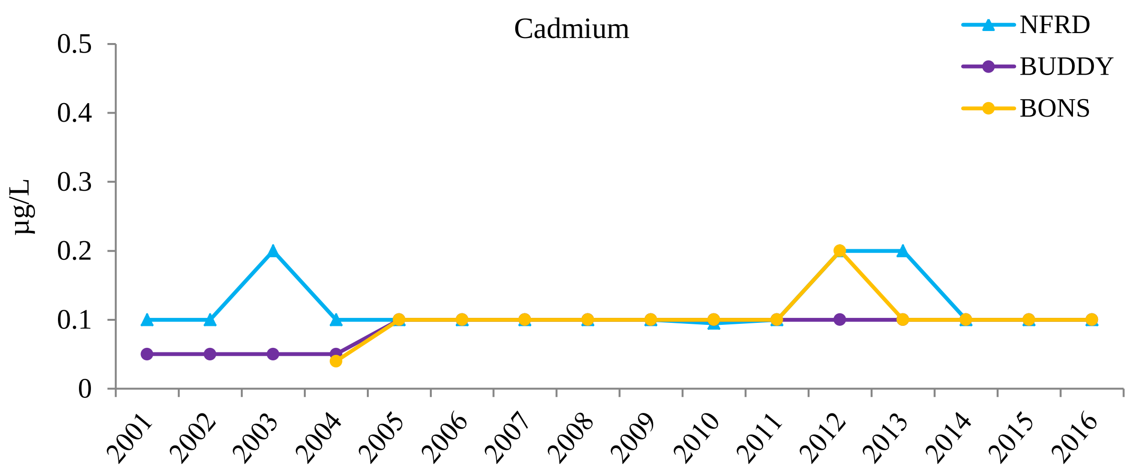
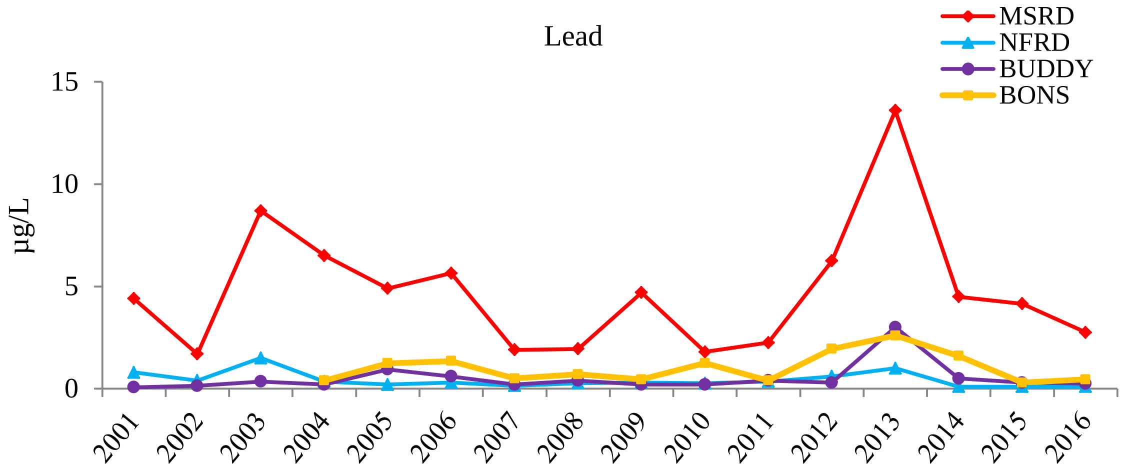


Figure 14. Median cadmium concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2016). Two graphs are presented, the bottom graph contains only the reference sites and not Mainstem Red Dog Creek.



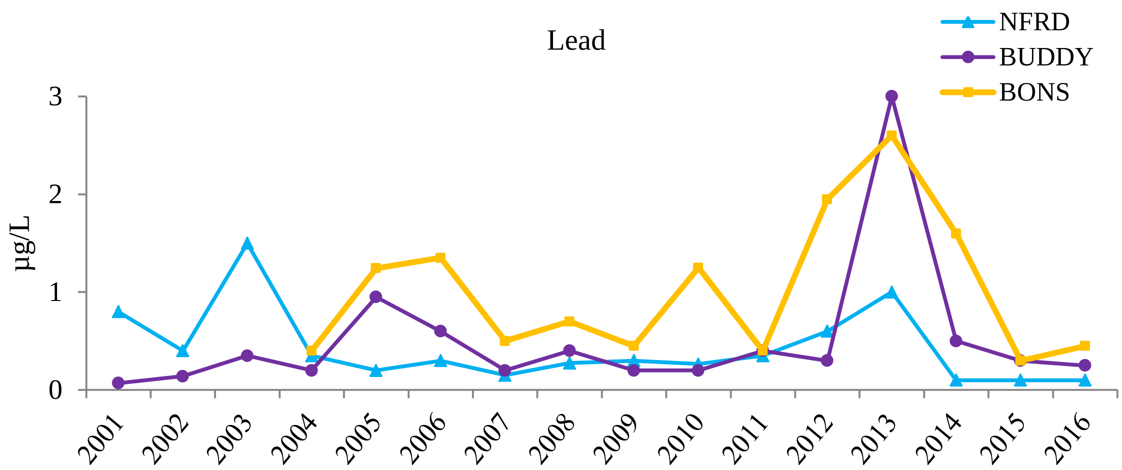
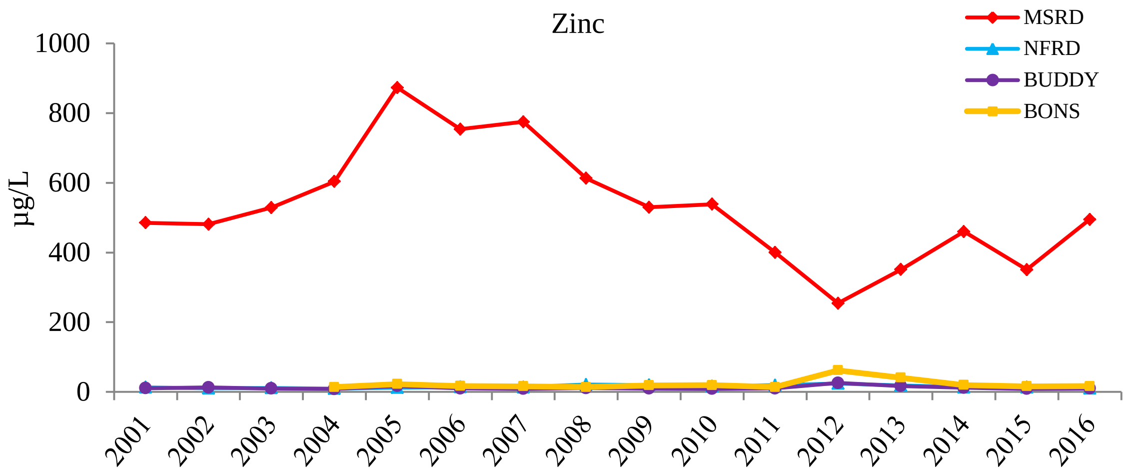


Figure 15. Median lead concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2016). Two graphs are presented, the bottom graph contains only the reference sites and not Mainstem Red Dog Creek.



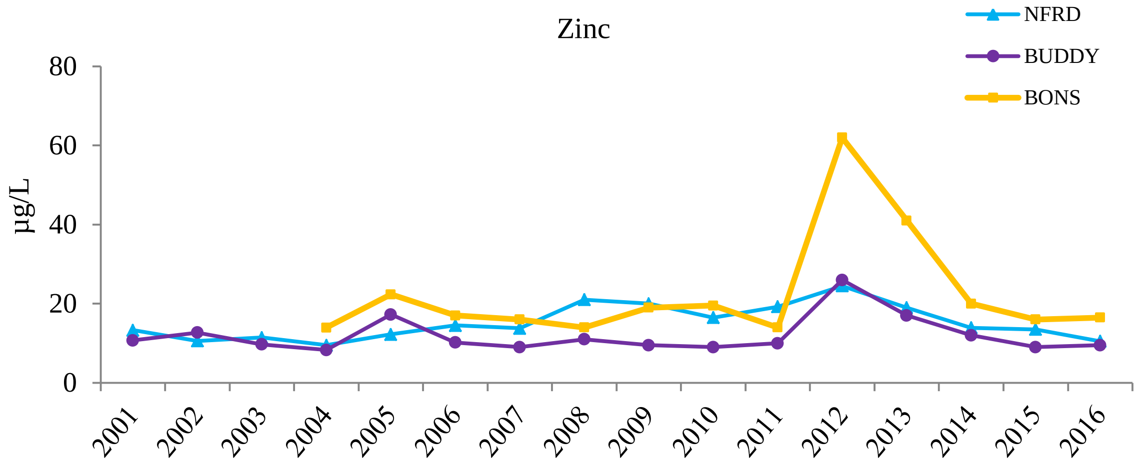


Figure 16. Median zinc concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2016). Two graphs are presented, the bottom graph contains only the reference sites and not Mainstem Red Dog Creek.

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 2016 were 1.75, 1.7, 2.45, and 1.8 µg/L.

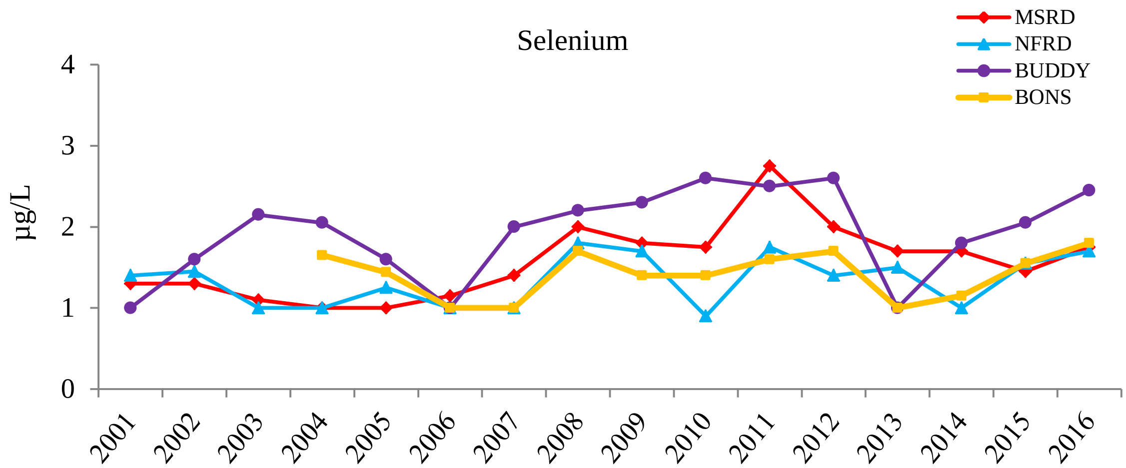


Figure 17. Median selenium concentrations in Mainstem Red Dog (MSRD), North Fork Red Dog (NFRD), and Buddy creeks and Bons Pond (2001 to 2016).

Periphyton Standing Crop

Periphyton (attached microalgae) biomass samples have been collected annually since 1999 (2016 data, Appendix 2). Under the program initiated in 2010, sampling occurred at a minimum of nine sites (Table 2). In 2016, samples were collected at all nine standard sites, with the addition of Upper North Fork Red Dog Creek. Periphyton samples were processed in the laboratory and standing crop determined as mg/m^2 chlorophyll-a.

Average chlorophyll-a concentrations in 2016 were highest in Buddy Creek (below the falls) (12.6 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 Ikalukrok and Bons creeks. Generally, chlorophyll-a concentrations are lowest in Middle Fork Red Dog Creek and highest in Bons Creek (below Bons Pond) and Buddy Creek (below falls).

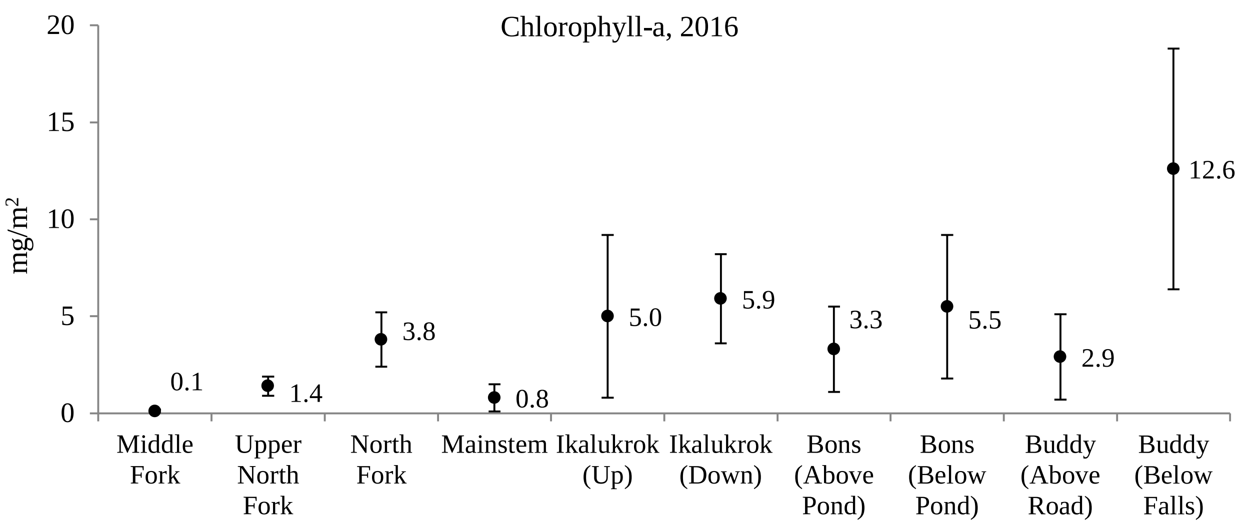


Figure 18. Average concentration of chlorophyll-a (± 1SD) at Red Dog Mine sample sites, 2016.

Average chlorophyll-a concentrations in Middle Fork Red Dog, Mainstem Red Dog, and North Fork Red Dog creeks are presented in Figures 19, 20 and 21. Generally, average chlorophyll-a concentrations are higher in Mainstem Red Dog and North Fork Red Dog creeks as compared with Middle Fork Red Dog Creek. In 14 of 18 years, average chlorophyll-a concentrations in North Fork Red Dog Creek were equal to or higher than in Mainstem Red Dog Creek. Low chlorophyll-a concentrations 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 very low. Most of the TDS in Middle Fork Red Dog Creek is from the waste water discharge at Outfall 001.

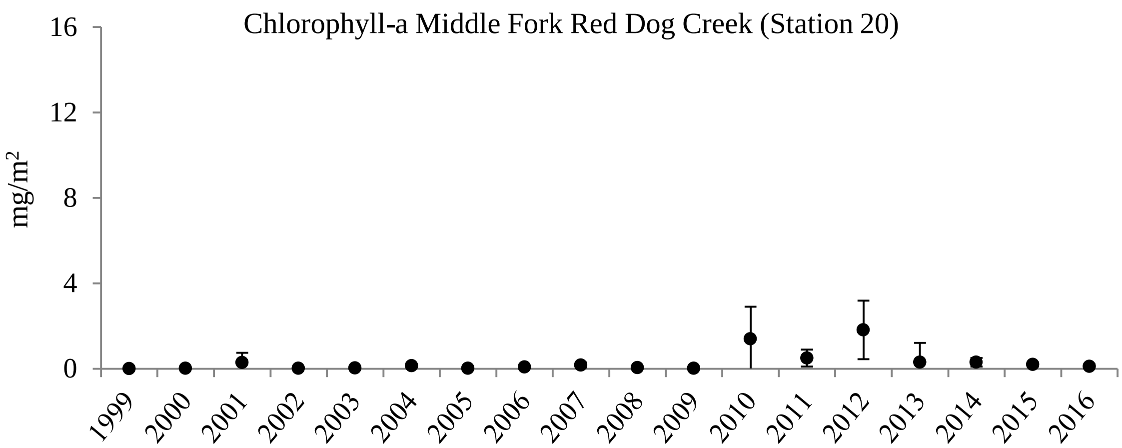


Figure 19. Average concentration (± 1SD) of chlorophyll-a in Middle Fork Red Dog Creek, 1999-2016.

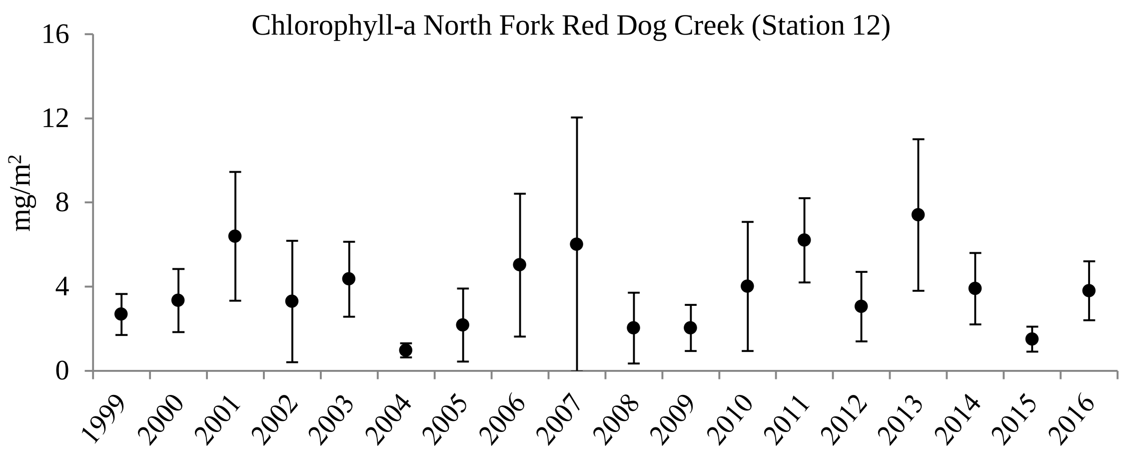


Figure 20. Average concentration (± 1SD) of chlorophyll-a in North Fork Red Dog Creek, 1999-2016.

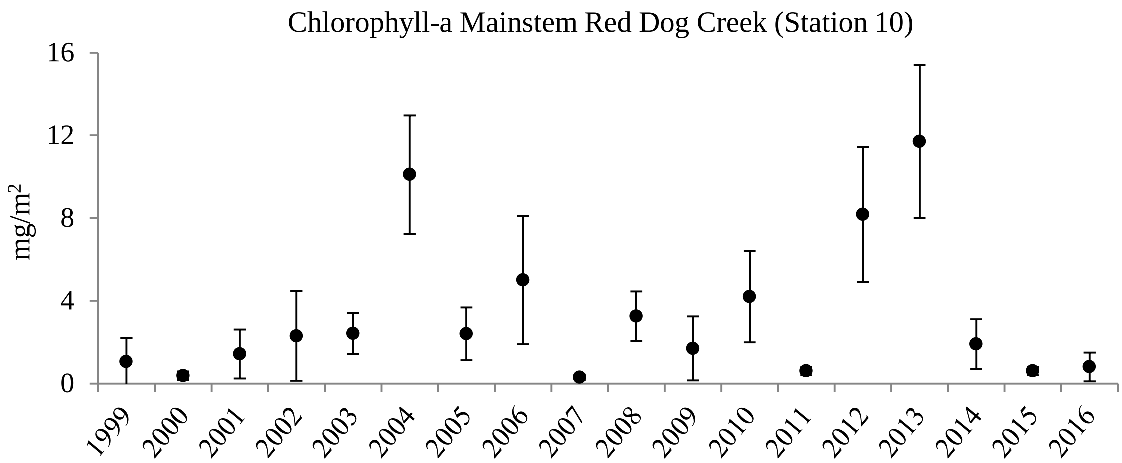


Figure 21. Average concentration (± 1 SD) of chlorophyll-a in Mainstem Fork Red Dog Creek, 1999-2016.

Periphyton standing crop tracks closely with elevated 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). Chlorophyll-a concentrations are higher when the zinc and cadmium concentrations are lower (Figures 22 and 23). The variability seen from 2002 to 2016 may be natural as both cadmium and zinc concentrations remained low and consistent during this time frame. The major source of zinc and cadmium to Ikalukrok Creek is the Cub Creek seep (Figure 24).

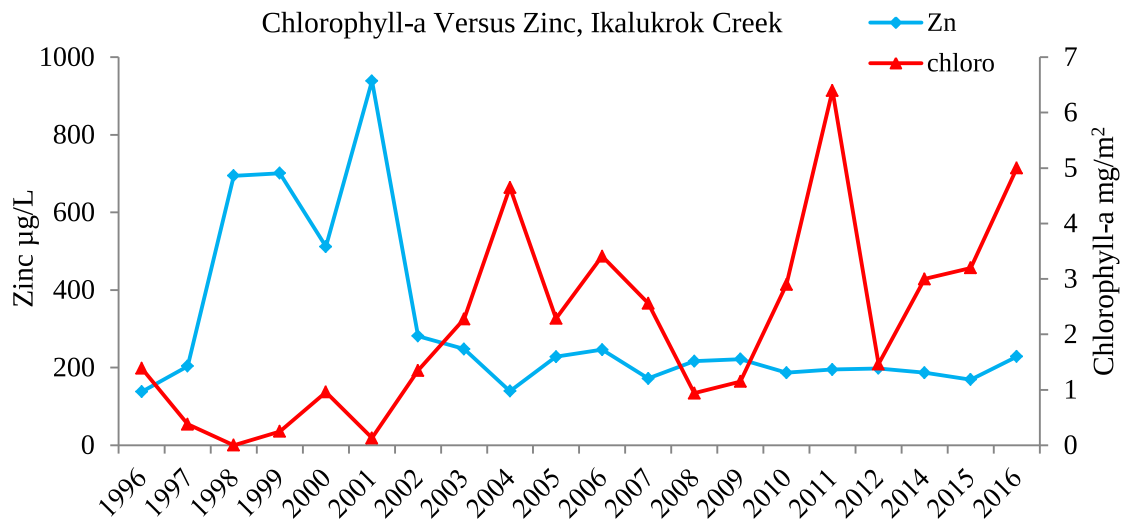


Figure 22. Average chlorophyll-a concentrations versus zinc in Ikalukrok Creek, 1996–2016.

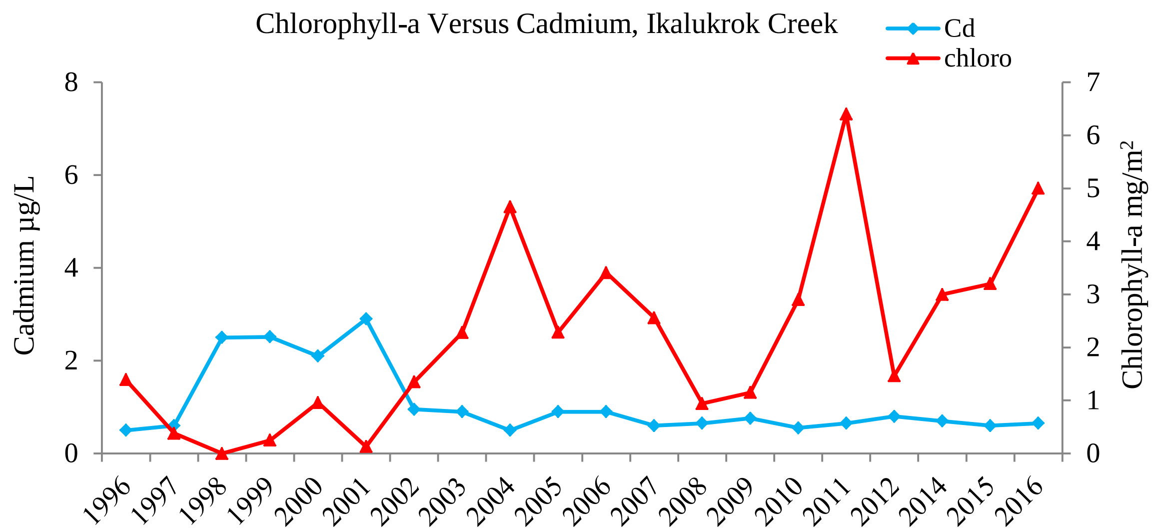


Figure 23. Average chlorophyll-a concentrations versus cadmium in Ikalukrok Creek. 1996-2016.

Figure 24. Ikalukrok Creek at the Cub Creek seep about 10 km upstream of the mouth of Mainstem Red Dog Creek – note iron staining in and along the edge of Cub Creek, July 2016.

Aquatic Invertebrates

Aquatic invertebrate samples are collected annually using drift nets (Appendix 3). In 2016, flows were very low at many of the sample sites. Aquatic invertebrate densities were highest in the upper North Fork Red Dog Creek (17.0 per m^3) (Figure 25).

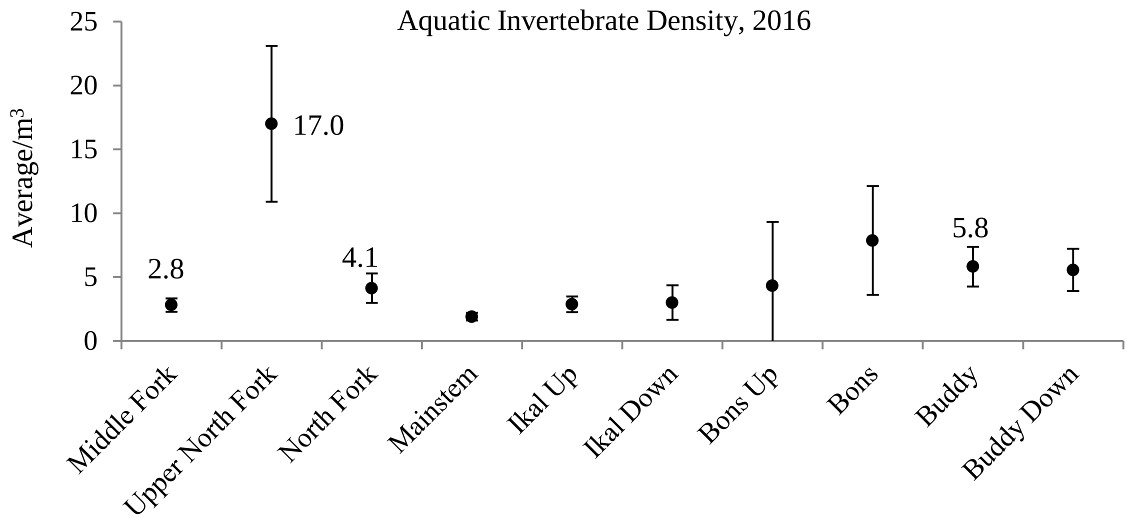


Figure 25. Average aquatic invertebrate densities (± 1SD) in all sample sites near the Red Dog Mine, July 2016. Selected average values shown.

Buddy Creek (above road) generally has higher aquatic invertebrate densities than other sample sites in most years, however in 2016 the upper North Fork Red Dog Creek had the highest 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 per m^3 (Figure 26). In 2016, average aquatic invertebrate densities were the second lowest on record at 5.82 per m^3.

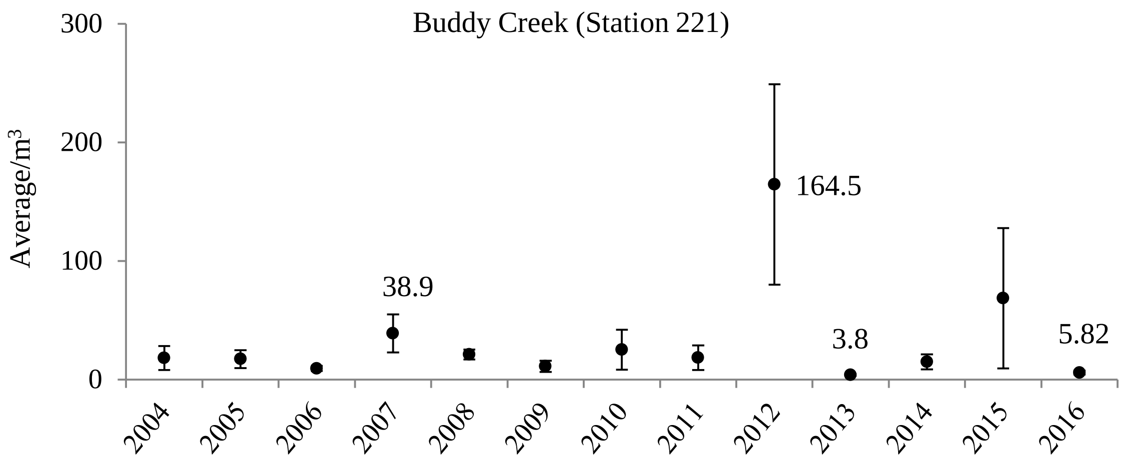


Figure 26. The average aquatic invertebrate density (± 1SD) in Buddy Creek upstream of the road. Selected averages shown.

Aquatic invertebrate densities in North Fork Red Dog Creek generally are higher than in Mainstem Red Dog Creek (Figure 27). In 17 out of 18 years, the aquatic invertebrate density was higher in North Fork Red Dog Creek than in Mainstem Red Dog Creek.

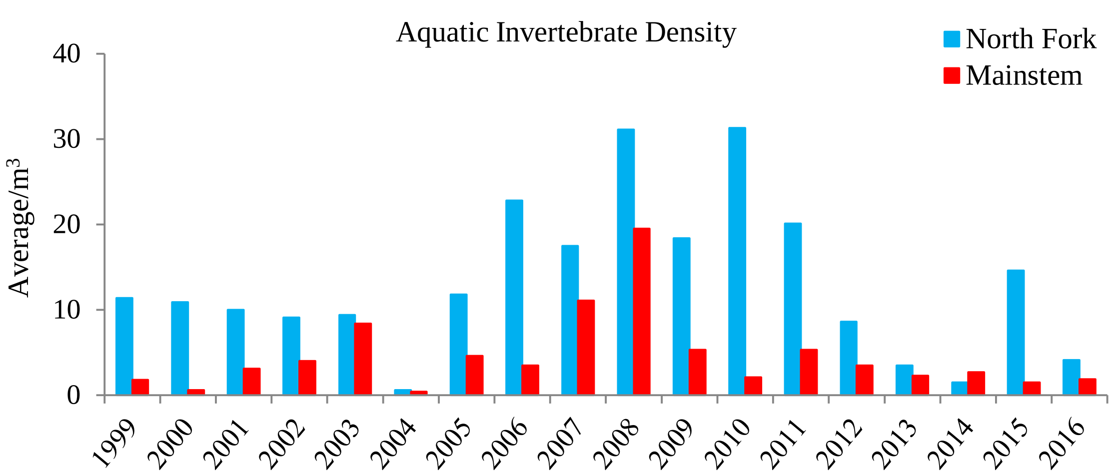


Figure 27. Average aquatic invertebrate densities in North Fork Red Dog and Mainstem Red Dog creeks 1999–2016.

The percent Ephemeroptera, Plecoptera, and Trichoptera (EPT) and the percent Chironomidae for sample sites in 2016 are presented in Figure 28. All sites contained a higher percentage of Chironomidae in 2016. 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.

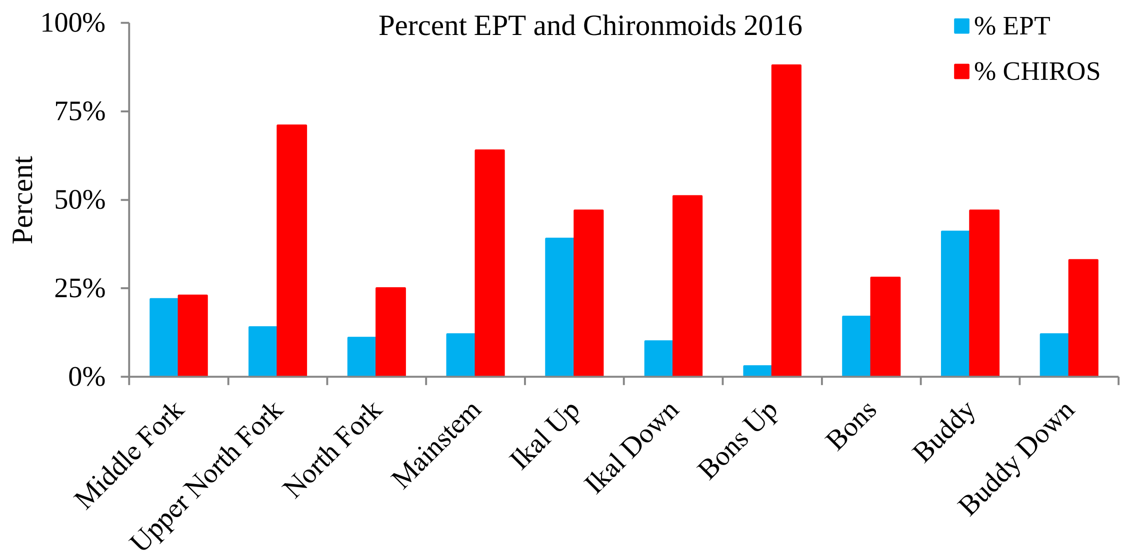


Figure 28. Percent EPT and Chironomidae in the aquatic invertebrate samples at all sample sites Red Dog Mine, July 2016.

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 eight out of 13 years.

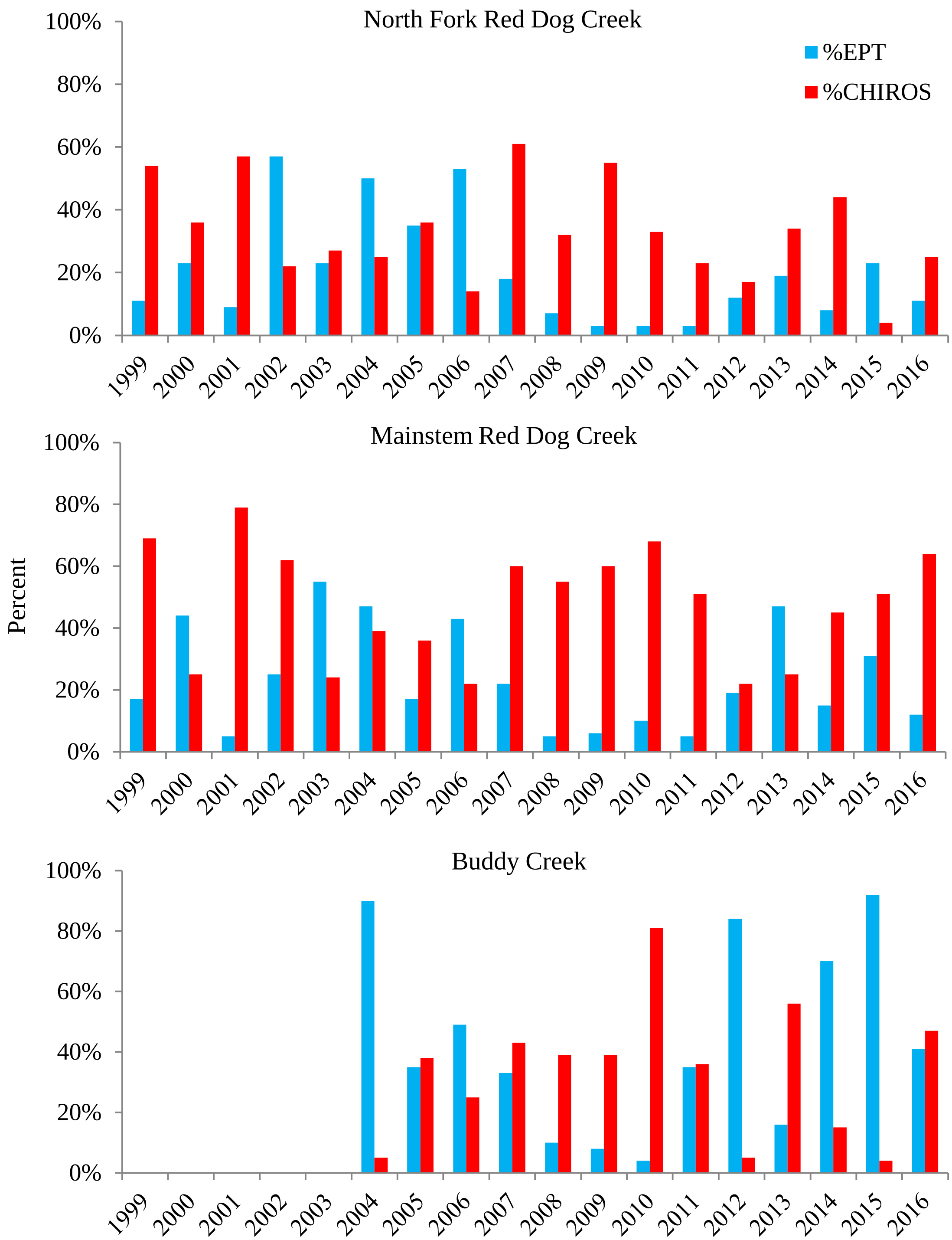


Figure 29. Percent EPT and Chironomidae in North Fork Red Dog Creek (top), Mainstem Red Dog Creek (middle), and Buddy Creek (bottom) 1999–2016. Aquatic invertebrate sampling in Buddy Creek drainage began in 2004.

Taxa richness was compared for the three sample sites in North Fork Red Dog, Mainstem Red Dog, and Buddy creeks (Figure 30). 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. The North Fork Red Dog creek also had higher than average taxa richness in 2016. Overall taxa richness is similar among these sites.

Figure 30. Aquatic invertebrate taxa richness in North Fork Red Dog and Mainstem Red Dog Creek 1999–2016 and Buddy Creek 2004–2016. 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 annual 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 had become established in Bons Pond. Arctic grayling captured in Bons Pond have been in the pond system, including tributaries for their entire life. Arctic grayling that leave Bons Pond must 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. Juvenile Arctic grayling that were between 140 and 220 mm FL were selected to minimize variability due to age. In 2010, the sample effort was refined to include only Arctic grayling between 150 and 200 mm FL. 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 2016 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 are collected opportunistically from Mainstem Red Dog, Anxiety Ridge, and Buddy creeks during the minnow trap sample event in late summer. Ott and Morris (2004) found no relationship between fish length and whole body concentrations of selected elements for pre-smolt sized Dolly Varden. To minimize age-related variability, juvenile Dolly Varden from 90 to 140 mm FL (likely 2 and 3 year old fish) were targeted, and all samples were collected in August after fish had likely spent most of the summer in the sample reach. Fish larger than 140 mm FL were excluded because they could be resident fish and may be much older than the fish from 90 to 140 mm FL. The preferred sample size for both juvenile Arctic grayling and Dolly Varden is 15 fish each year, recognizing that in some years this goal is not achieved.

In May 2016, seven Arctic grayling were captured in Bons Creek just upstream of Bons Pond and in early July, eight Arctic grayling were captured in Bons Pond (Appendix 4). The average length of these fish was 164.5 mm FL ± 15.8 mm (1SD). Cadmium, lead, selenium, zinc, and mercury concentrations have been analyzed in juvenile Arctic Grayling from Bons Pond for six years beginning in 2004.

Cadmium concentrations in Bons Pond juvenile Arctic grayling in 2016 (0.14 mg/kg) were similar to concentrations in 2015 (0.16 mg/kg) (Figure 31). The highest average cadmium was 0.27 mg/kg in 2014.

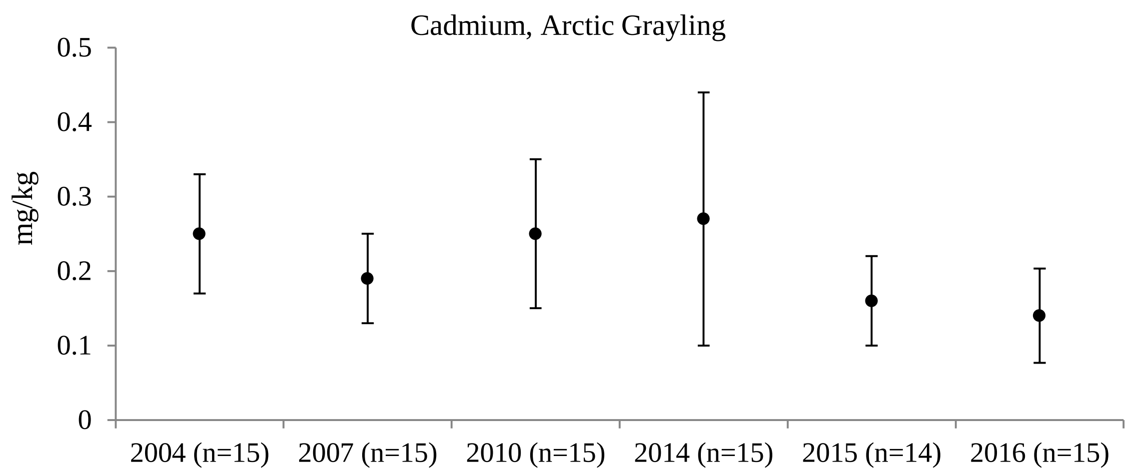


Figure 31. Average cadmium concentrations (± 1SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).[3]

The average lead concentrations in juvenile Arctic grayling from Bons Pond in 2016 (0.83 mg/kg) were similar to those found in 2014 (0.79 mg/kg) and 2015 (0.98 mg/kg) (Figure 32). Average lead concentrations were lower in 2004, 2007, and 2010.

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

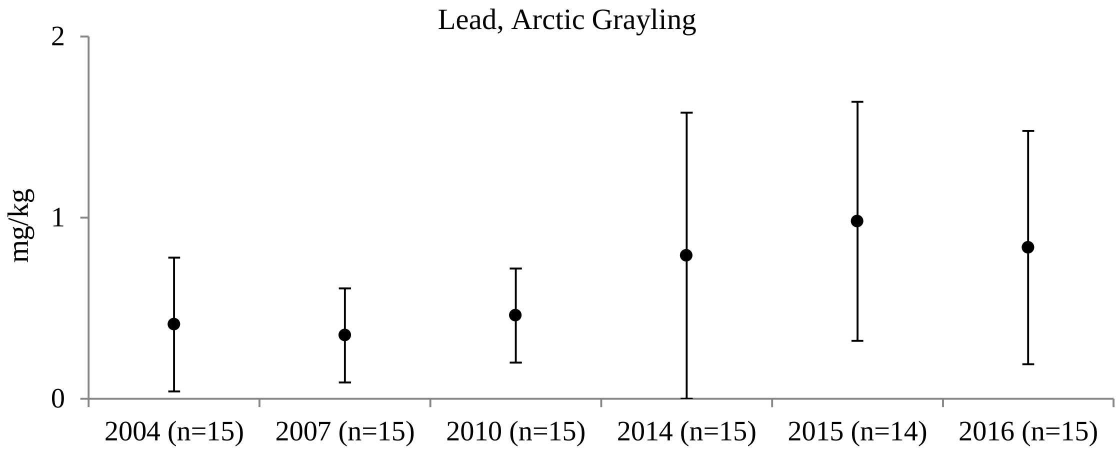


Figure 32. Average lead concentrations (± 1SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

A similar patterns was seen with selenium concentrations in juvenile Arctic grayling from Bons Pond, with average values in 2016 (13.7 mg/kg) being similar to 2014 (14.6 mg/kg) and 2015 (13.6 mg/kg) (Figure 33). Average selenium values were lower in 2004, 2007, and 2010.

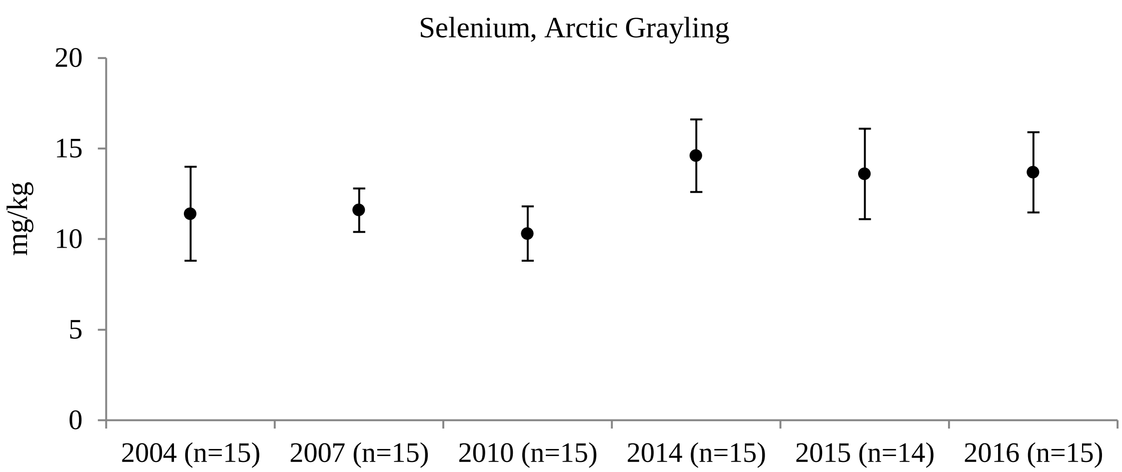


Figure 33. Average selenium concentrations (± 1SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

Average zinc concentrations in juvenile Arctic grayling from Bons Pond has varied from a high of 104 mg/kg in 2016 to a low of 68 mg/kg in 2004 (Figure 34).

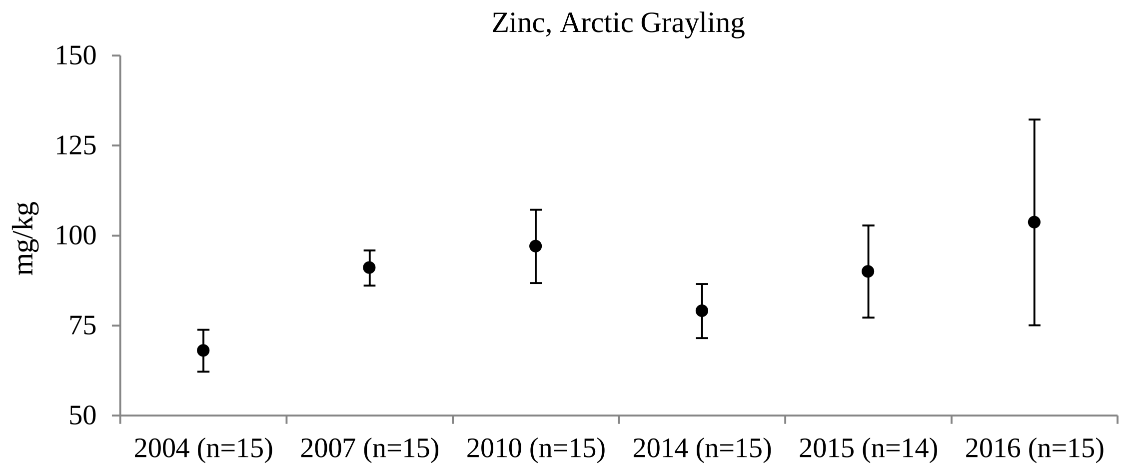


Figure 34. Average zinc concentrations (± 1SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

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 and 2010 to a low at detection limit of 0.02 mg/kg in 2004 and 2014 (Figure 35).

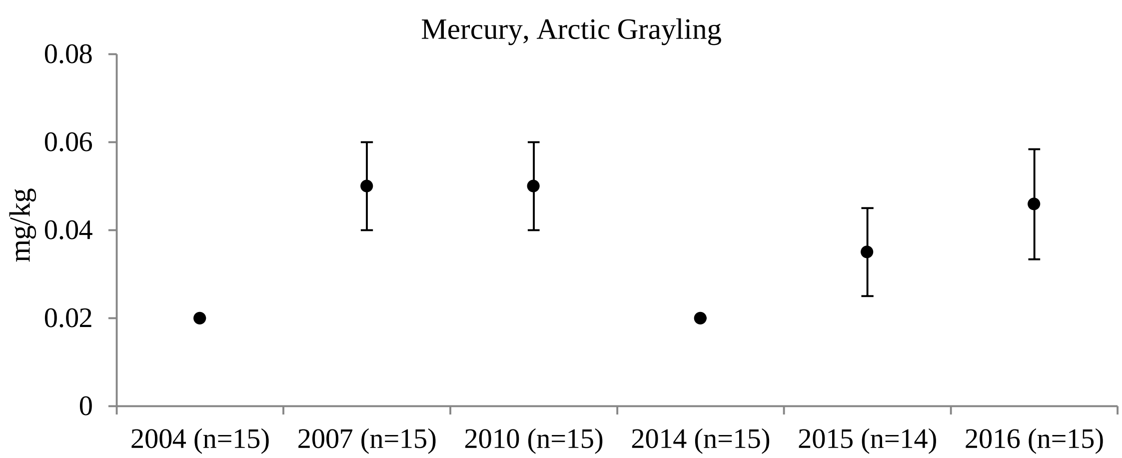


Figure 35. Average mercury concentrations (± 1SD) in juvenile Arctic grayling collected from Bons Pond drainage (whole body dry weight).

In late summer 2016, juvenile Dolly Varden were collected from Mainstem Red Dog (n=15), Buddy (n=15), and Anxiety Ridge creeks (n=15) for whole body metals analysis (Appendix 5). Since water quality concentrations of cadmium, lead, and zinc are highest in Mainstem Red Dog

Creek, higher concentrations of these metals in whole body samples of juvenile Dolly Varden were expected. However, as noted in the Water Quality section of this report, specific metal 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).

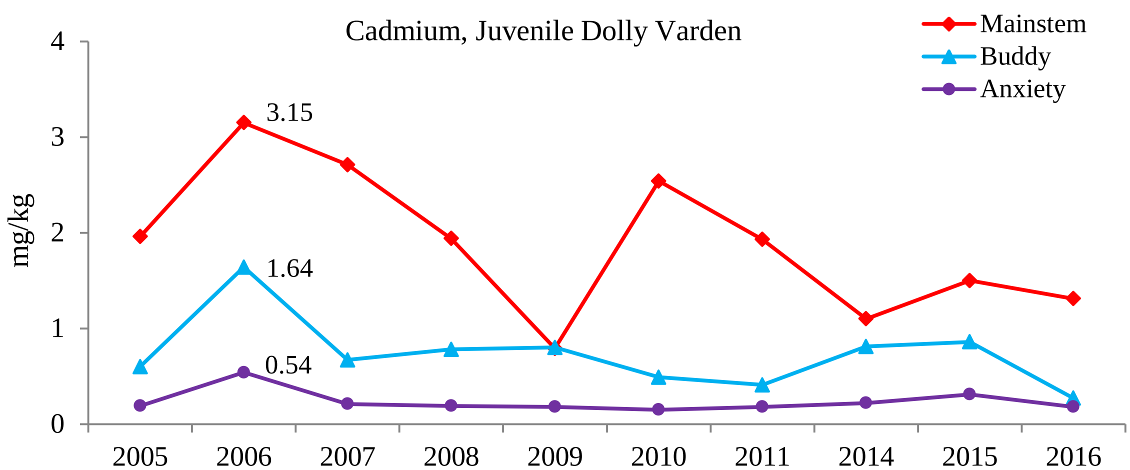


Figure 36. Median cadmium whole body concentrations in juvenile Dolly Varden from 2005 to 2016.

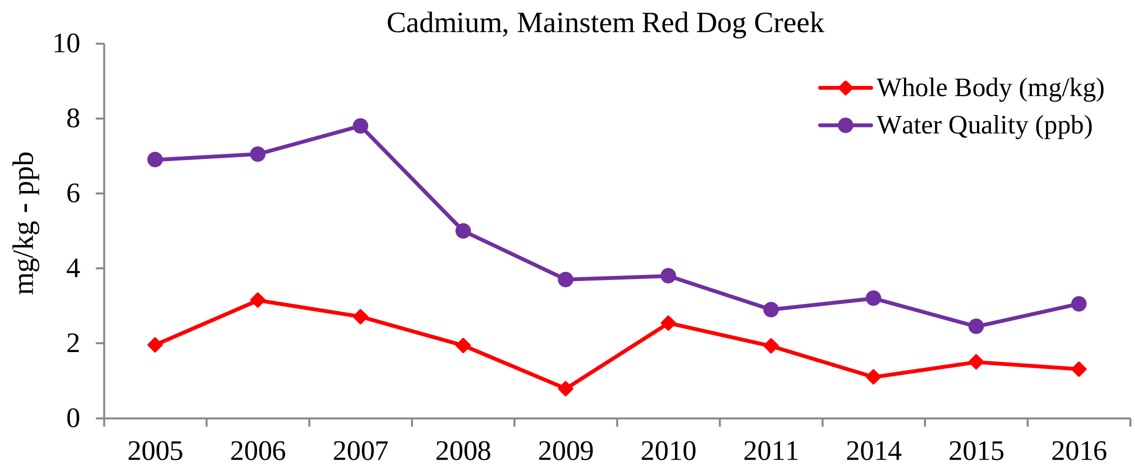


Figure 37. Median whole body cadmium concentrations and median cadmium water quality data for Mainstem Red Dog Creek.

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).

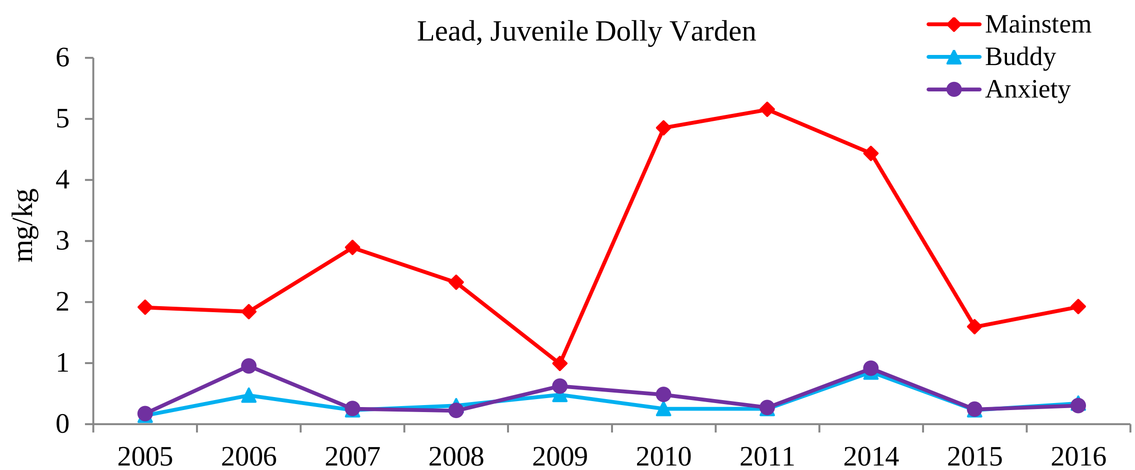


Figure 38. Median lead whole body concentrations in juvenile Dolly Varden from 2005 to 2016.

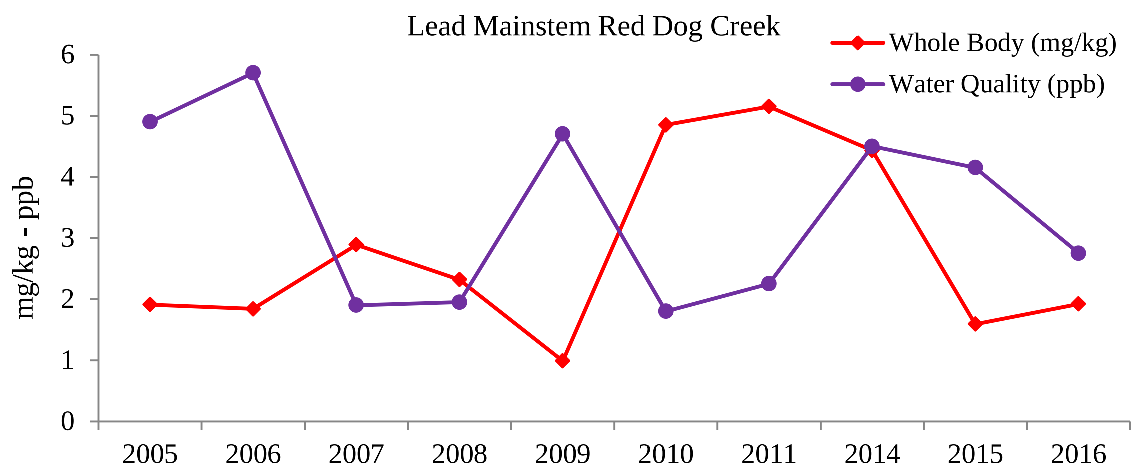


Figure 39. Median whole body lead concentrations and median lead water quality data for Mainstem Red Dog Creek.

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. 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).

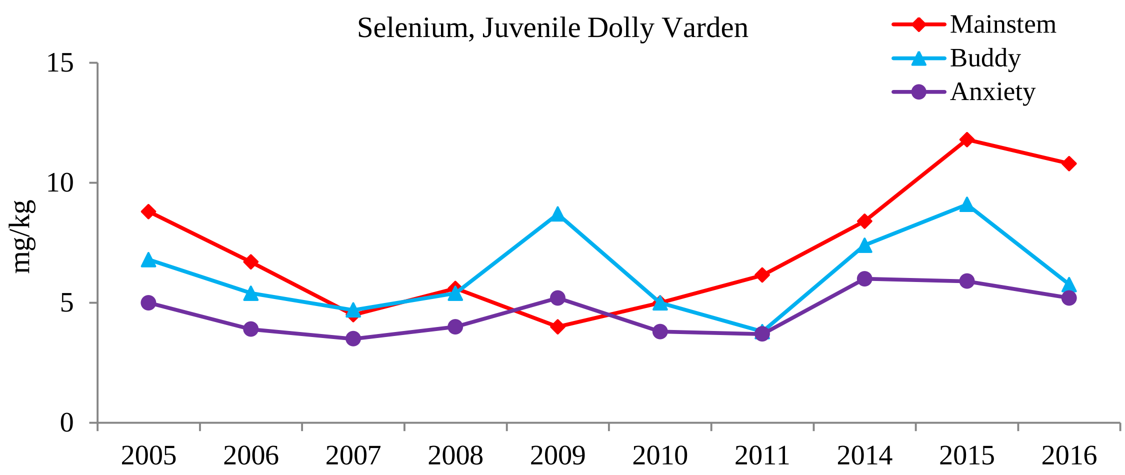


Figure 40. Median selenium whole body concentrations in juvenile Dolly Varden from 2005 to 2016.

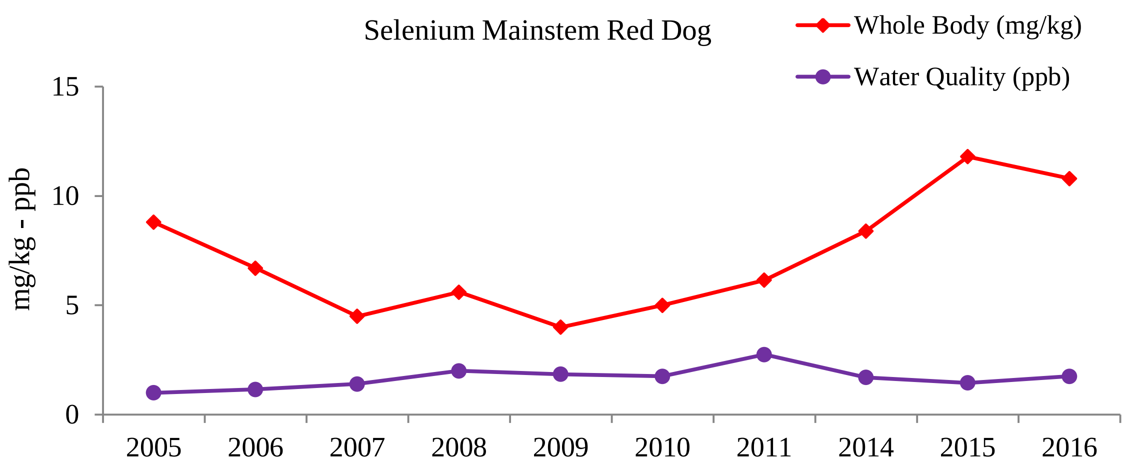


Figure 41. Median whole body selenium concentrations and median selenium water quality data for Mainstem Red Dog Creek.

Median zinc whole body concentrations are 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 160 mg/kg in 2009 in Mainstem Red Dog Creek. Median zinc whole body concentrations have remained relatively stable since 2009. Generally among Mainstem Red Dog Creek data, as zinc concentrations in the water have decreased so have whole body zinc concentrations (Figure 43).

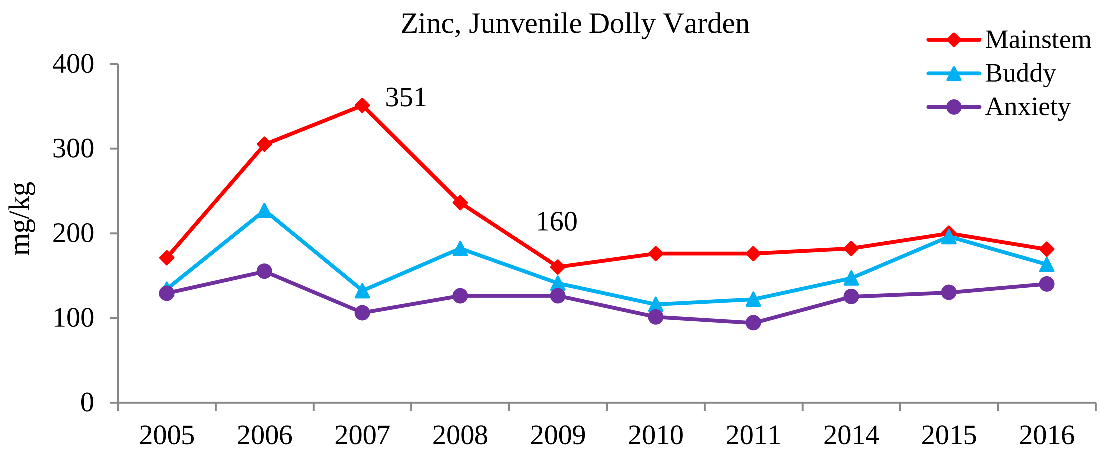


Figure 42. Median zinc whole body concentrations in juvenile Dolly Varden from 2005 to 2016.

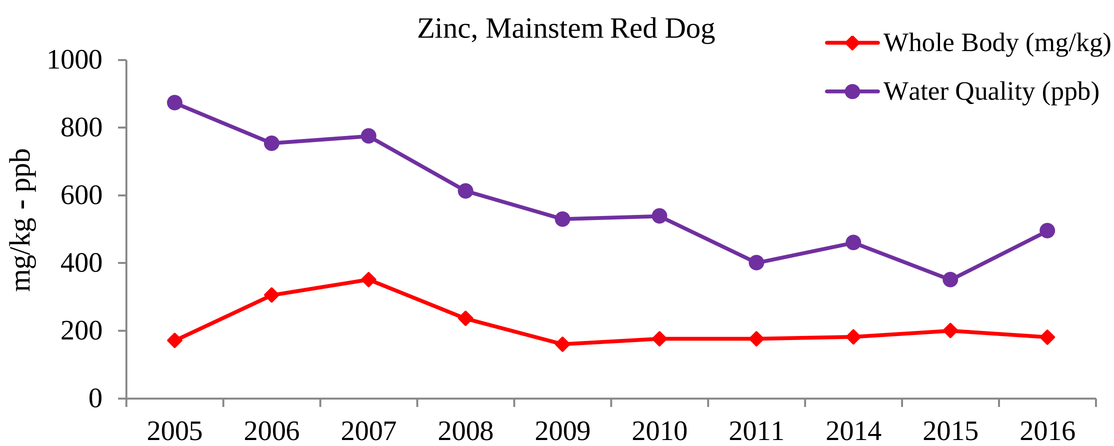


Figure 43. Median whole body zinc concentrations and median zinc water quality data for Mainstem Red Dog Creek.

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.

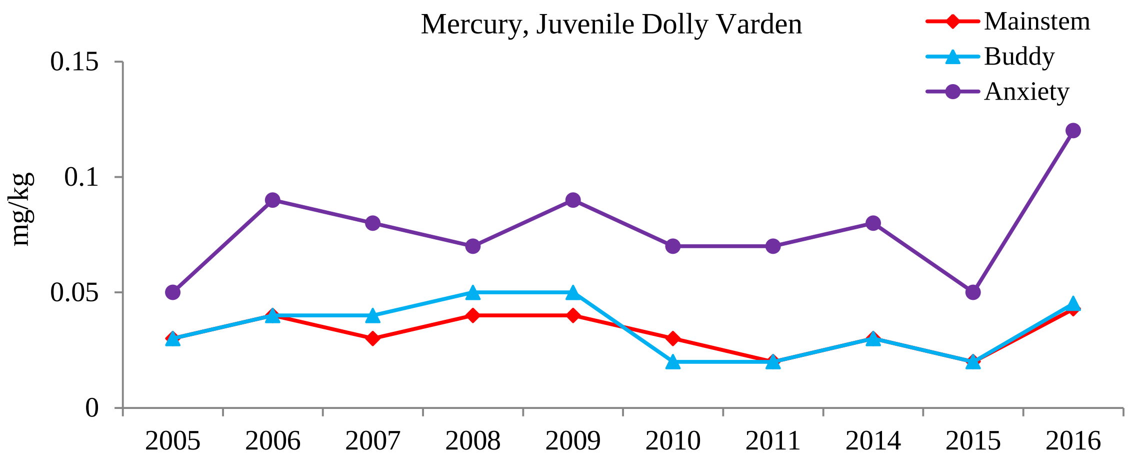


Figure 44. Median mercury whole body concentrations in juvenile Dolly Varden from 2005 to 2016.

Selenium Concentrations in Adult Arctic Grayling

In spring 1999, 2014, and 2015 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 2016, samples were collected only from the Red Dog Mine area. The purpose of this collection effort was 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. 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.

Selenium concentration in the ovaries of Arctic grayling, along with size, weight, and age of each fish are contained in Appendix 6. Fort Knox Arctic grayling were the youngest while Bons

Pond fish are the oldest. The Fort Knox Arctic grayling had an average age of 4.1±0.7 years (1SD) while the Bons Pond fish averaged 14.4±4.3 years (1SD). The highest degree of variability in the age of females occurs in North Fork Red Dog Creek where one female was aged at 26 (average = 12.7±5.8 (1SD)).

Selenium concentrations in Arctic grayling ovaries are 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 Ft. Knox contained the lowest concentration of selenium in ovaries.

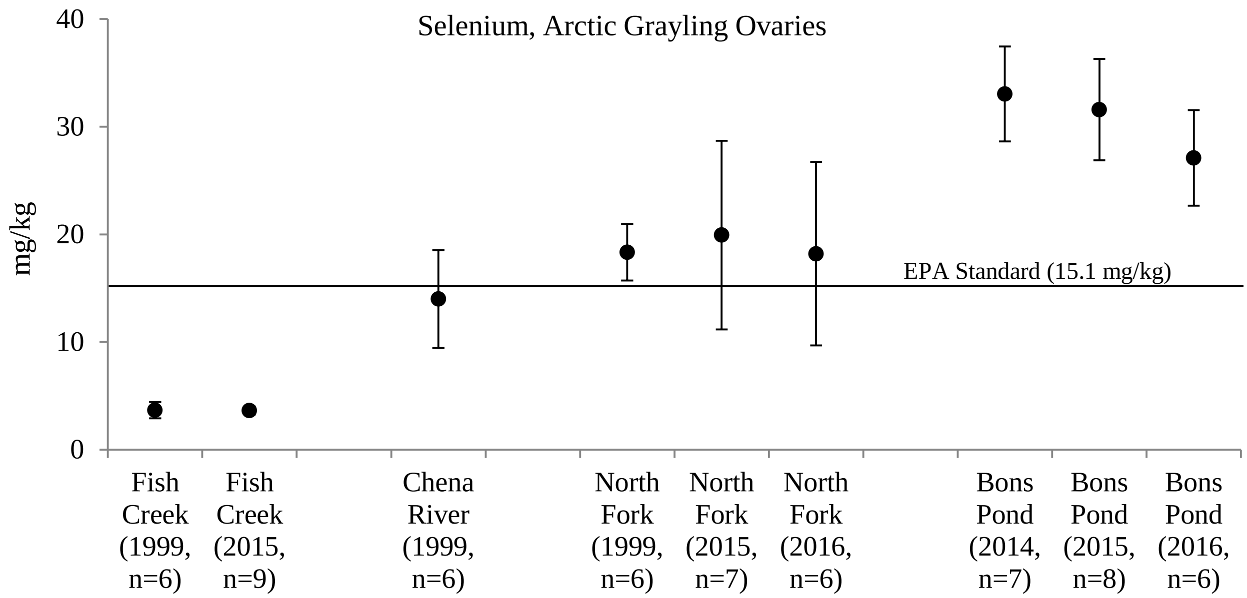


Figure 45. Average selenium (± 1SD) concentrations (dry weight) in Arctic grayling ovaries from Fish Creek, Chena River, North Fork Red Dog Creek, and Bons Pond.

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), 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. 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 very strong for the last seven years. The Arctic grayling population in Fish Creek 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

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 (Weber Scannell et al. 2000). The targeted sample size for each spring and fall sample period is six fish.

The purposes of sampling adult Dolly Varden for element concentration is to monitor changes in tissue concentrations 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 2016 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 data for all fish handled from 1999 to 2016.

- 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).

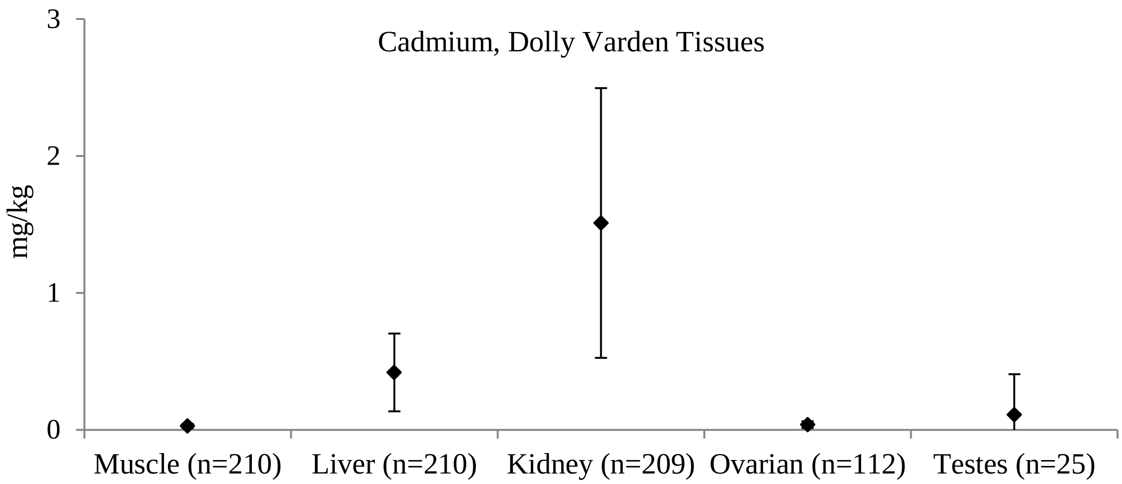


Figure 46. Average cadmium (± 1SD) concentration (dry weight) in Dolly Varden tissues (1999–2016).

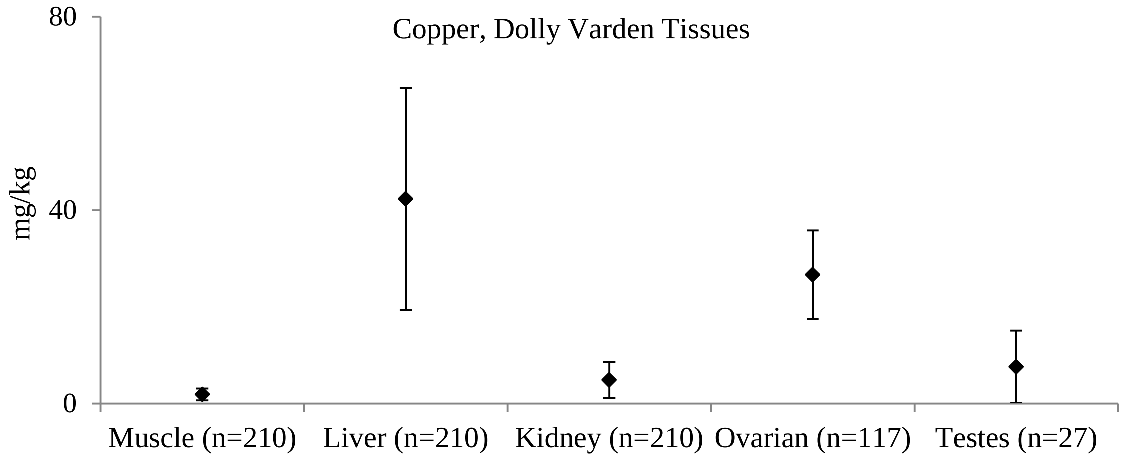


Figure 47. Average copper (± 1SD) concentration (dry weight) in Dolly Varden tissues (1999–2016).

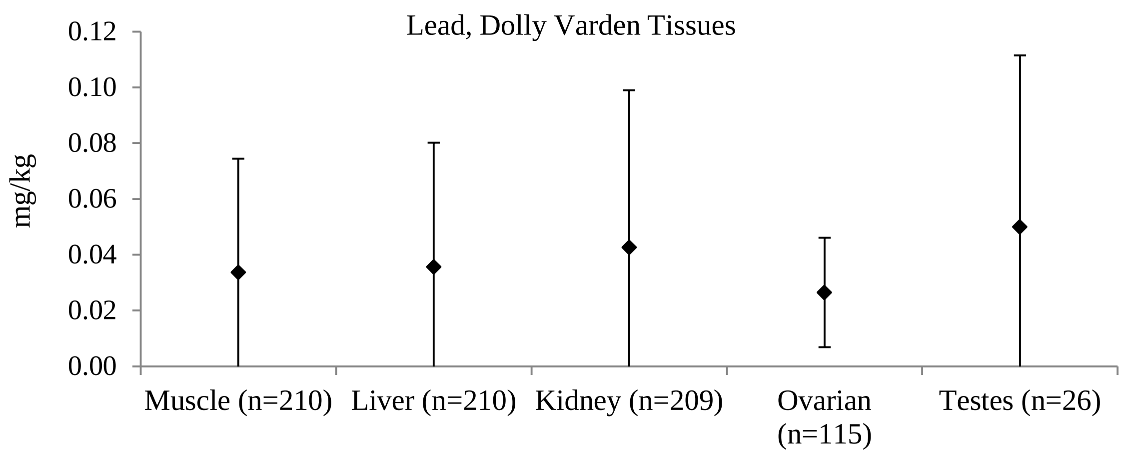


Figure 48. Average lead (± 1SD) concentration (dry weight) in Dolly Varden tissues (1999–2016).

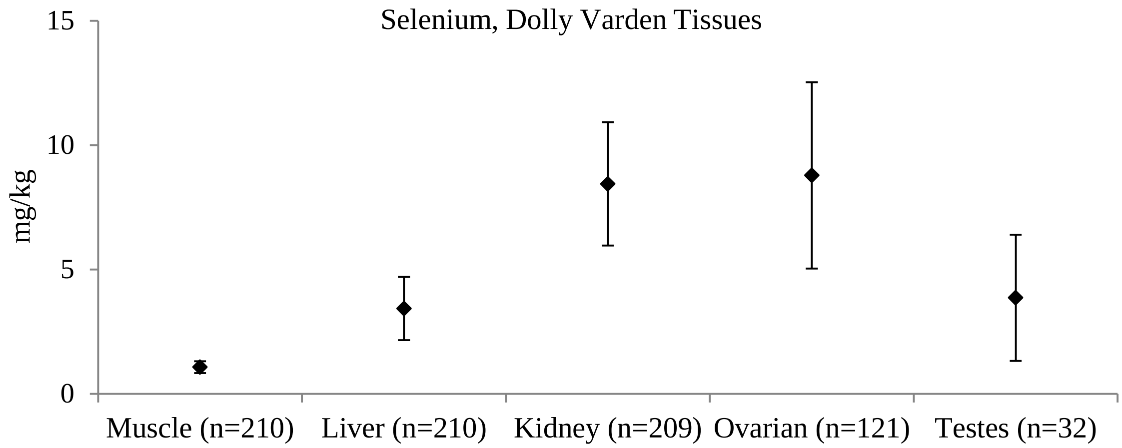


Figure 49. Average selenium (± 1SD) concentration (dry weight) in Dolly Varden tissues (1999–2016).

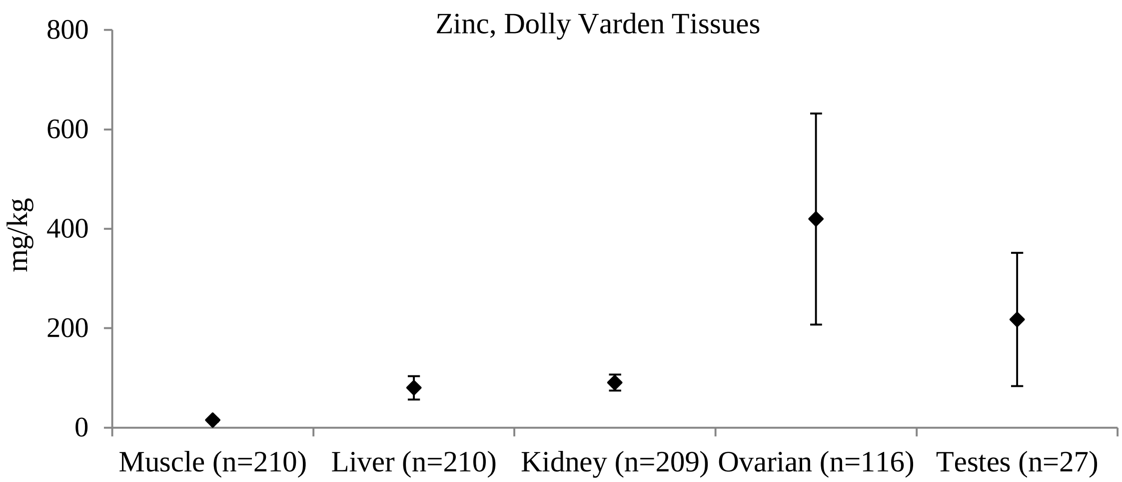


Figure 50. Average zinc (± 1SD) concentration (dry weight) in Dolly Varden tissues (1999–2016).

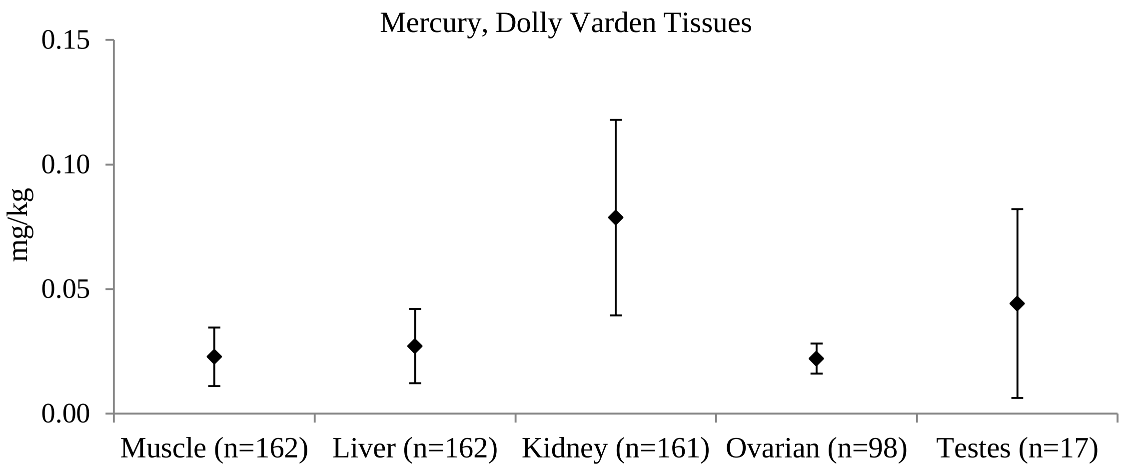


Figure 51. Average mercury (± 1SD) concentration (dry weight) in Dolly Varden tissues (2003–2016).

Average cadmium concentrations in adult Dolly Varden kidney tissue has been variable since sampling began in 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.

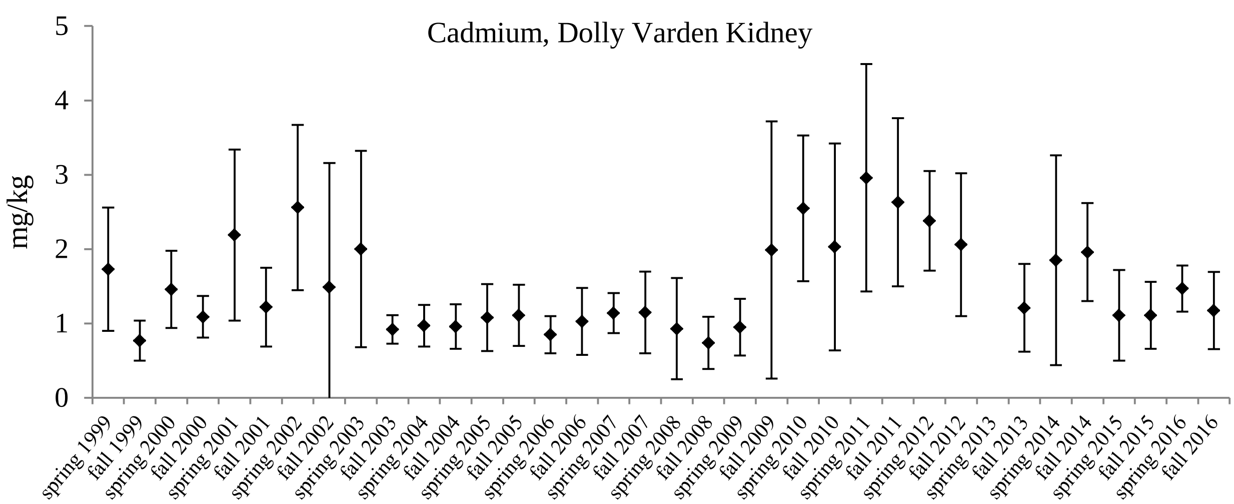


Figure 52. Average cadmium (± 1SD) concentrations (dry weight) in Dolly Varden kidney tissues from 1999 to 2016.

Average selenium concentrations in Dolly Varden ovaries are higher for fall fish (10.5 mg/kg) than for spring fish (6.2 mg/kg) (Figure 53).

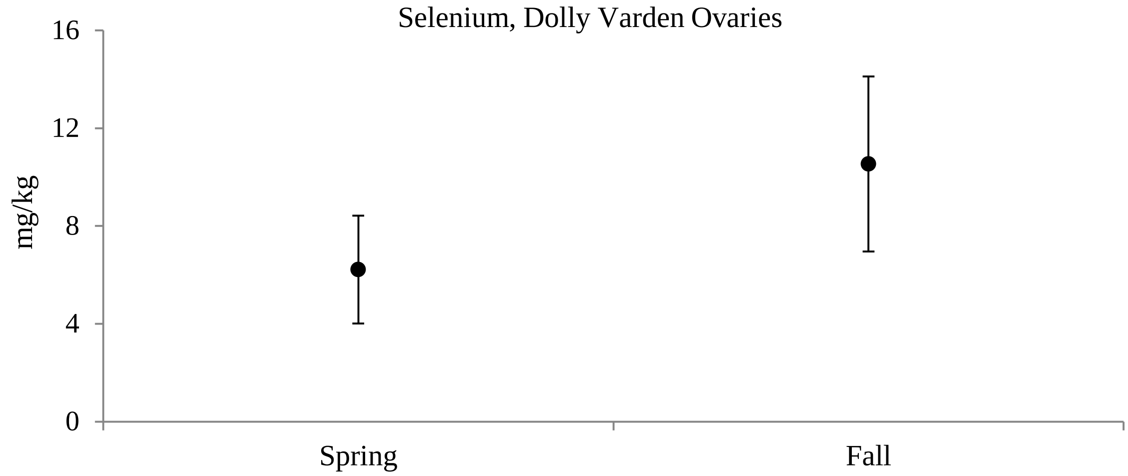


Figure 53. Average selenium (± 1SD) concentrations (dry weight) in Dolly Varden ovaries from 1999 to 2016.

Dolly Varden, Overwintering

Two aerial surveys to estimate the number of overwintering Dolly Varden in the Wulik River were conducted in 2016, September 15 and October 13 and 14. Surveys were conducted with an R-44 helicopter provided by Teck (DeCicco 2016). Weather conditions were excellent for all surveys with mostly clear skies and very light winds. Estimated stream flow in the Wulik River was 540 cfs on September 15, 800 cfs on October 13, and 705 cfs on October 14. During the October 2016 survey, more reliable counts in the lower river were obtained resulting in higher numbers downstream from Driver's Bar. From Driver's Bar upstream visibility was similar between the two surveys and similar numbers of fish were seen.

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), fall 2015 (71,474 fish), and fall 2016 (70,802 fish) (Figure 54 and Table 4). Similar to some recent salmon migrations in the Arctic, Dolly Varden may be delaying their migration until later in the fall, therefore aerial surveys may need to be conducted later in the season.

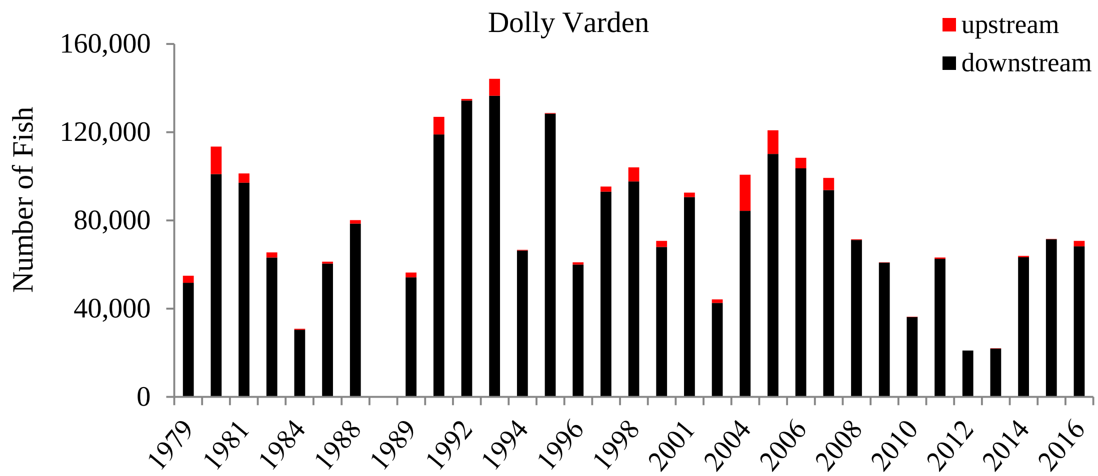


Figure 54. Aerial survey estimates of the number of Dolly Varden in the Wulik River just prior to freezeup, 1979-2016.

The number of Dolly Varden estimated in the fall in the Wulik River varies annually. Survey results in 2016 found that 96% of the fish observed were downstream of the mouth of Ikalukrok Creek. Only in 1980 and 2004 has the percentage of fish below Ikalukrok Creek been less than 90% (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 the distribution of these fish.

The ADF&G Sport Fish Division deployed a DIDSON® (Dual frequency Identification SONar) side-scanning sonar in the Wulik River in spring 2014, 2015, and 2016 to estimate the number of Dolly Varden leaving the Wulik River to feed in marine waters (Scanlon and Savereide 2014; Savereide and Scanlon 2015; Scanlon and Savereide 2016). In spring 2016, a warm spring and subsequent early breakup resulted in most of the fish leaving the Wulik River before the sonar was deployed. From 1500 on May 26th through 0900 June 3rd, the sonar counted 8,175 Dolly Varden moving downstream and 1,386 fish moving upstream with almost no fish counted during the last 3 days.

Based on the extended period of outmigration of Dolly Varden to the Chukchi Sea (possibly up to three weeks) and the logistical and time commitment required to operate the sonar and camp long enough to enumerate the entire run, it does not appear that enumerating outmigrating fish using sonar is a financially practical alternative to fall aerial surveys at this time (Savereide and Scanlon 2016).

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

	Wulik River	Wulik River		Percent of Fish
	upstream of	downstream of	Total	downstream of
Year	Ikalukrok Creek	Ikalukrok Creek	Fish	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
The population estimate (mark/recapture) for winter 1988/1989 for fish				
>400 mm was 76,892 (DeCicco 1990a)				
The population estimate (mark/recapture) for winter 1994/1995 for fish				
>400 mm was 361,599 (DeCicco 1996b)				
Fall 2000 and 2003 aerial surveys were not made due to weather.				

Chum Salmon, Spawning

ADF&G conducts annual aerial surveys to assess the distribution of adult chum salmon in Ikalukrok Creek from its confluence with the Wulik River upstream to Dudd Creek (Figure 55, and Appendix 9). In fall 2016, several surveys were flown using an R-44 helicopter. On August 4 between 300 and 400 chum salmon were estimated in the lower 30 km of the river, the majority of which were located in the lower 11 km. DeCicco (2016) flew two more surveys. On September 15, he estimated 913 live and dead chum salmon and in early October only a few chum salmon (about 167) were seen. Weather conditions were excellent with mostly clear skies and very light winds. All chum salmon observed were 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 other datasets.

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 may have recovered to pre-mining numbers by the mid-1990s and at the latest by the early 2000s.

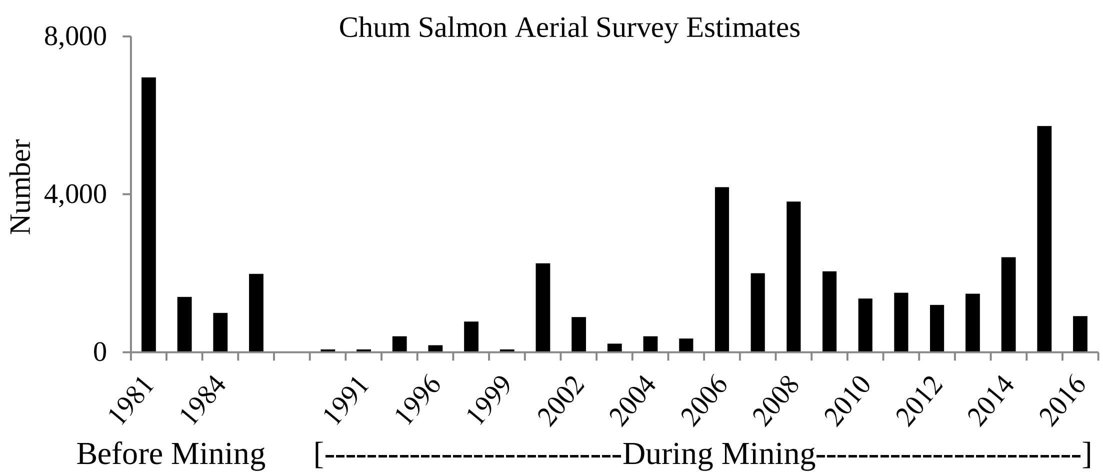


Figure 55. Peak estimates of chum salmon in Ikalukrok Creek. Note, the 1981 count was an estimate based on extrapolation from aerial photographs.

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 11). 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.

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

Minnow traps are the preferred sampling gear for juvenile Dolly Varden because they are very effective for the species and age classes present, the gear is suitable for sample areas in large to small streams, the effort is uniform across sample sites, variability due to sampler-induced bias is reduced, and there is very low fish mortality. Mortalities do occur and these are associated with flow increases or a large juvenile (> 150 mm FL) becoming gilled in the entrance to the minnow trap. Juvenile Dolly Varden generally are the most numerous fish species present and are distributed most widely in the sample area. The project objective is to assess the numbers of fish using streams over time and to sample juvenile Dolly Varden for whole body element analyses from selected streams. Data relevant to whole body element analyses of juvenile Dolly Varden were presented in a previous section of this report.

Dolly Varden Catches and Metrics

The relative abundance of juvenile Dolly Varden varies considerably among sample years (Appendix 11); 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 2016, the CPUE was highest in Anxiety Ridge (53.4 fish/24 hours) and Buddy creeks (88.7 fish/ 24 hours) and lowest in North Fork Red Dog Creek where no fish were caught (Figure 56).

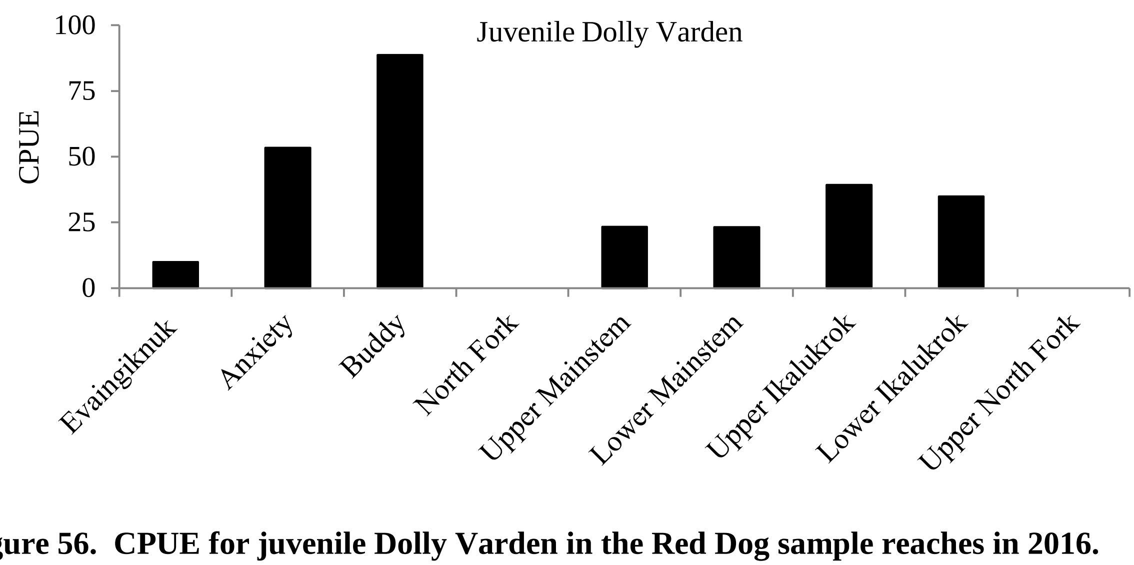


Figure 56. CPUE for juvenile Dolly Varden in the Red Dog sample reaches in 2016.

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 2016 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.

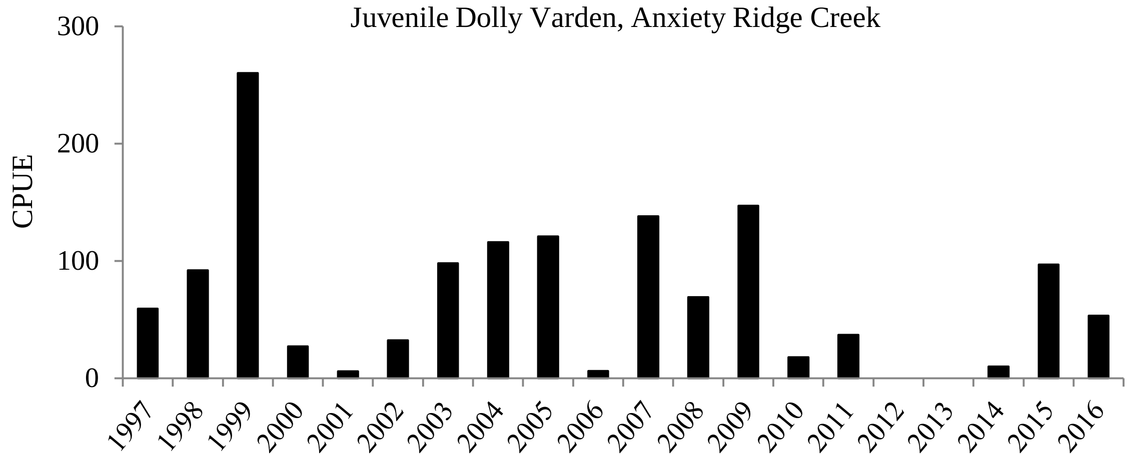


Figure 57. CPUE of juvenile Dolly Varden in Anxiety Ridge Creek, 1997–2016.

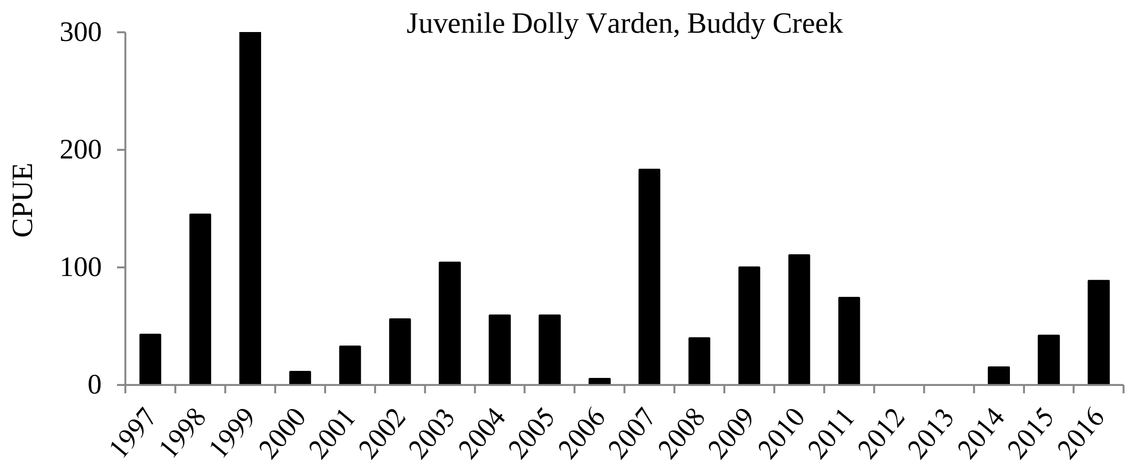


Figure 58. CPUE of juvenile Dolly Varden in Buddy Creek, 1997–2016.

The CPUE for lower Mainstem Red Dog Creek from 1997 to 2016 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.

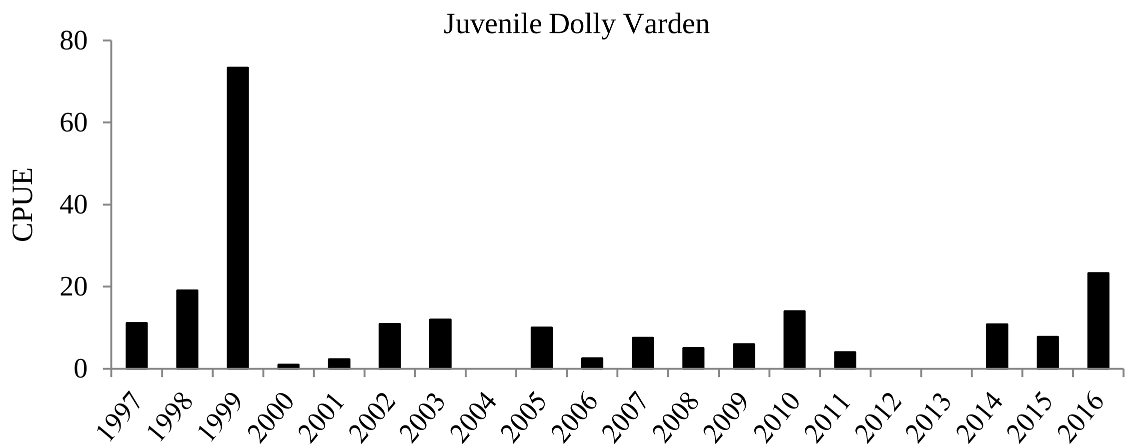


Figure 59. CPUE of juvenile Dolly Varden in Lower Mainstem Red Dog Creek. Note, sampling was not done in 2012 and 2013 due to high water.

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 2016) had an average freshwater residency of 2.9 ± 0.6 years (1 SD, n = 145). Based on length frequency distributions for juvenile Dolly Varden captured in 2016, it is likely most fish were age 1+. Small Dolly Varden (< 70 mm FL) captured in late July and August likely were age-0 and in 2016 only five were < 70 mm FL (Figure 60). In previous sample years (1997 to 2016 – excluding 2012 and 2013 when minnow traps were not fished due to high water), some age-0 fish were present in the catches in 14 out of 18 years.

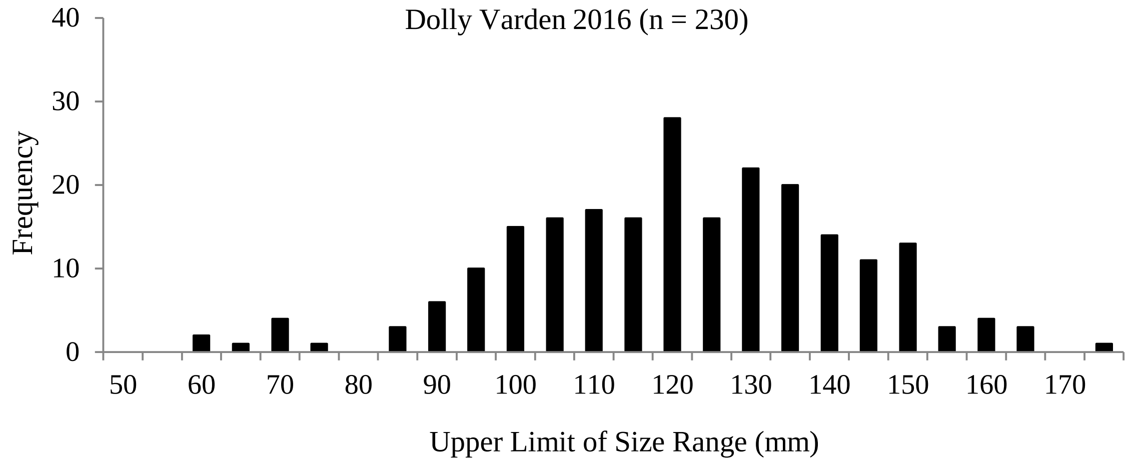


Figure 60. Length frequency distribution of Dolly Varden in the Ikalukrok Creek drainage in fall 2016.

In the catches of Dolly Varden in the Ikalukrok Creek drainage some fish are captured that are > 145 mm FL. Some of these fish are resident and have not been to the marine environment. These resident fish are identified by their coloration (orange dots and white edges on the pelvic fins) and sexual condition (milt observed). 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. In spring 2016, six Dolly Varden were caught that averaged 163 mm FL (Figure 61). Many of the Dolly Varden caught in North Fork Red Dog Creek are freshwater resident fish.

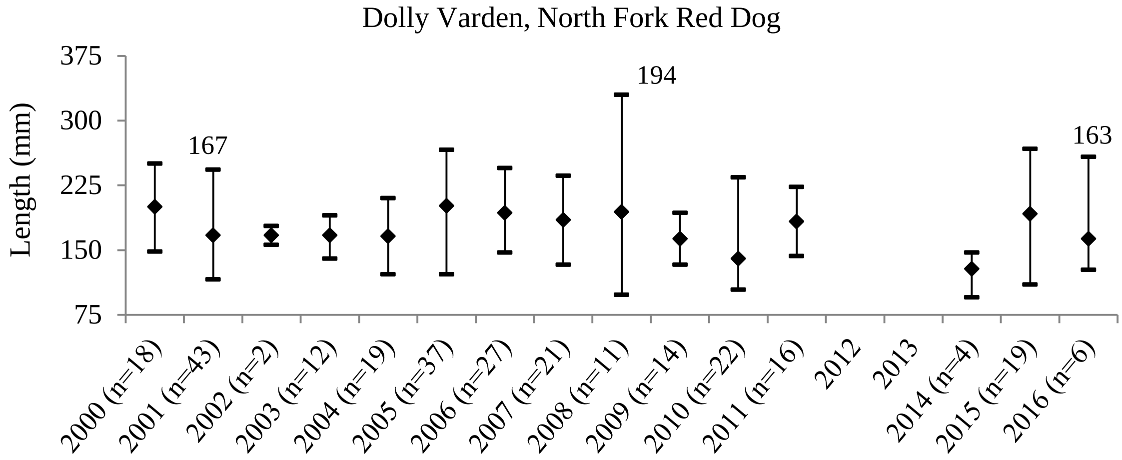


Figure 61. Dolly Varden caught in fyke nets fished in North Fork Red Dog Creek in spring during the Arctic grayling spawning run. Average, maximum, and minimum lengths are shown for each sample year. Selected average lengths are shown.

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 as using Mainstem Red Dog Creek and no fish mortality events have been observed (Appendix 12).

Arctic Grayling, Spawning

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 and EPA approved TDS limit of 1,500 mg/L at Station 151.

Two fyke nets were set to capture Arctic grayling in North Fork Red Dog Creek from May 18 to 22, 2016. One fyke net was set to capture upstream moving fish while the second fyke net was placed to capture downstream moving fish. Flows were low which allowed the fyke nets to effectively capture fish for the duration of the sampling event (Figure 62). Water temperatures ranged from about 3 to 9°C. Most of the fish caught were moving upstream (159 out of 175 fish).

Figure 62. Fyke nets in North Fork Red Dog Creek, May 2016.

Limited spawning could have started on May 12 when the water temperature exceeded 3.0°C (Figure 63). Based on the temperature data and the catch of spent females in the main fyke net, it appears that spawning was substantially complete in Mainstem Red Dog Creek by May 20 (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. 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.

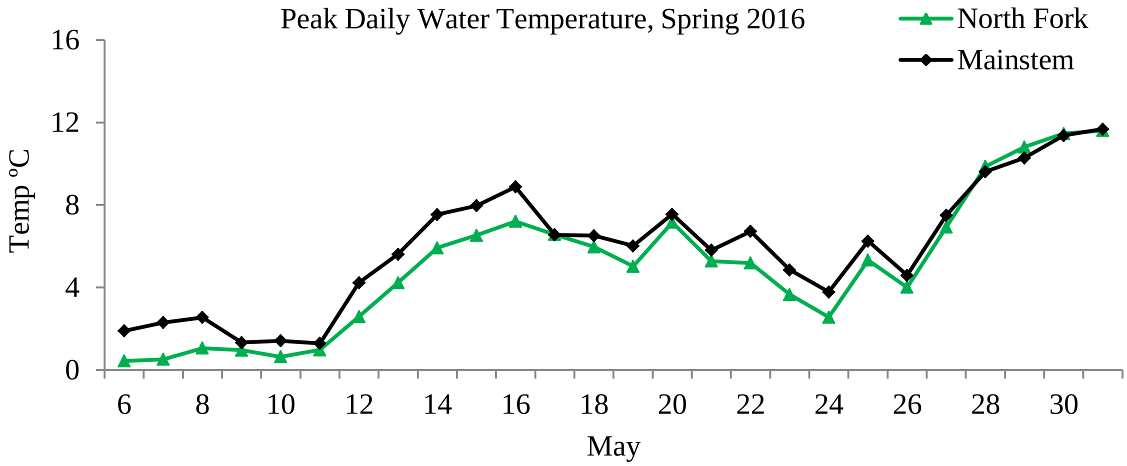


Figure 63. Peak daily water temperatures in North Fork Red Dog (Station 12) and Mainstem Red Dog (Station 151) creeks, May 2016.

Arctic Grayling, Fry

Since 1992, the relative abundance of Arctic grayling fry in North Fork Red Dog Creek has been estimated (Appendix 13). In 2016, spawning in North Fork Red Dog Creek was substantially complete by May 20, and water flows were low, indicating that spawning success was good. Visual surveys for Arctic grayling fry are conducted in early July and again in late-July or early August. In 2016, Arctic grayling fry were not observed.

Arctic Grayling, Catches and Metrics

In spring 2016, catches were highest when sampling began on May 18, then decreased until sampling ceased (Figure 64). A total of 175 Arctic grayling were captured in North Fork Red Dog Creek with fyke nets, of which 111 fish were immature (Figure 65). Recruitment of immature fish to North Fork Red Dog Creek has been strong since 2007 and may be due in part to juvenile fish leaving Bons Pond and returning to North Fork Red Dog Creek (Figure 66).

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

[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.

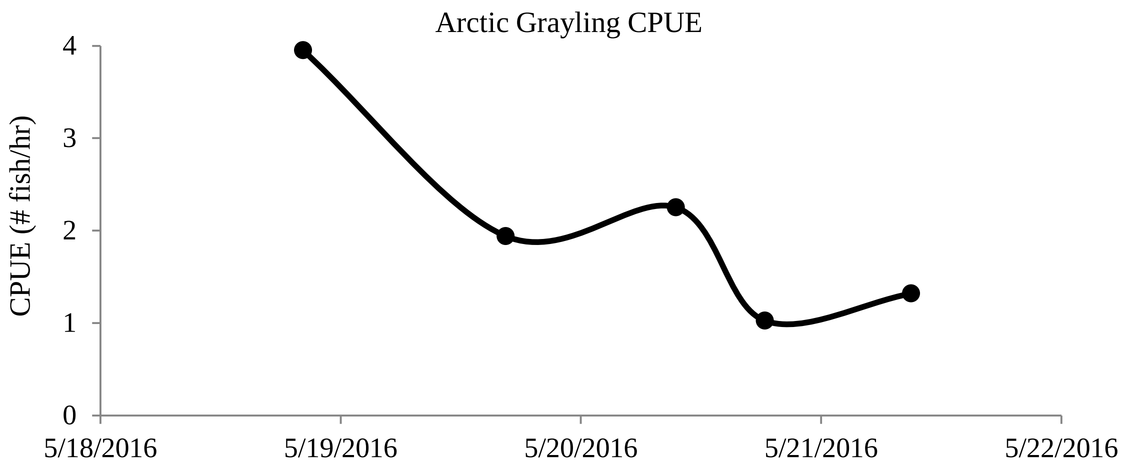


Figure 64. The CPUE of Arctic grayling in North Fork Red Dog Creek in spring 2016.

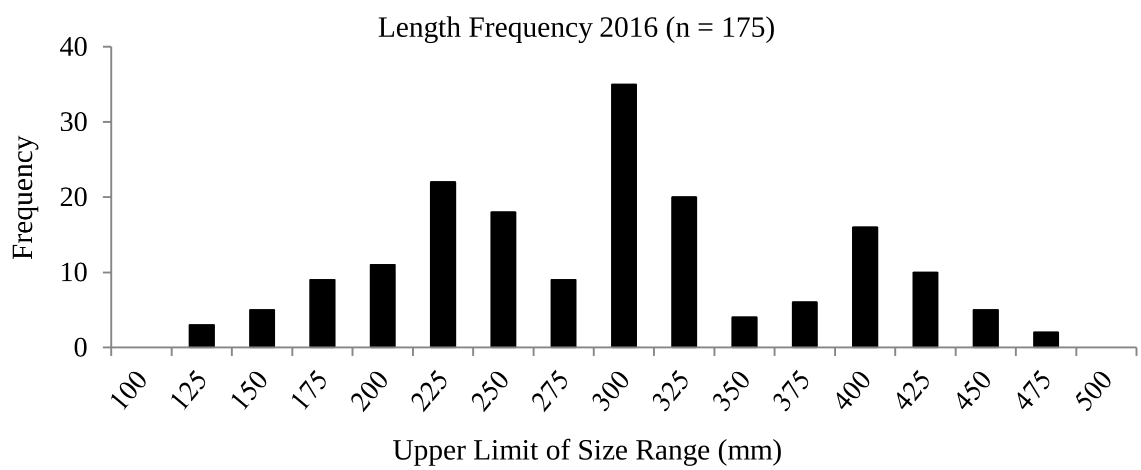


Figure 65. Length frequency distribution of Arctic grayling in spring 2016.

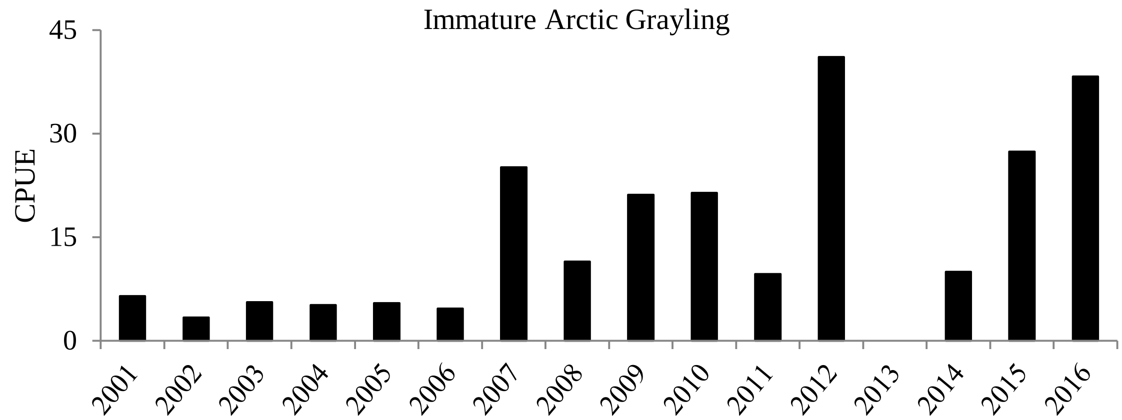


Figure 66. Average CPUE (fish/day) of immature Arctic grayling in North Fork Red Dog Creek from spring 2001 to spring 2016. No sampling was done due to high water in spring 2013.

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.

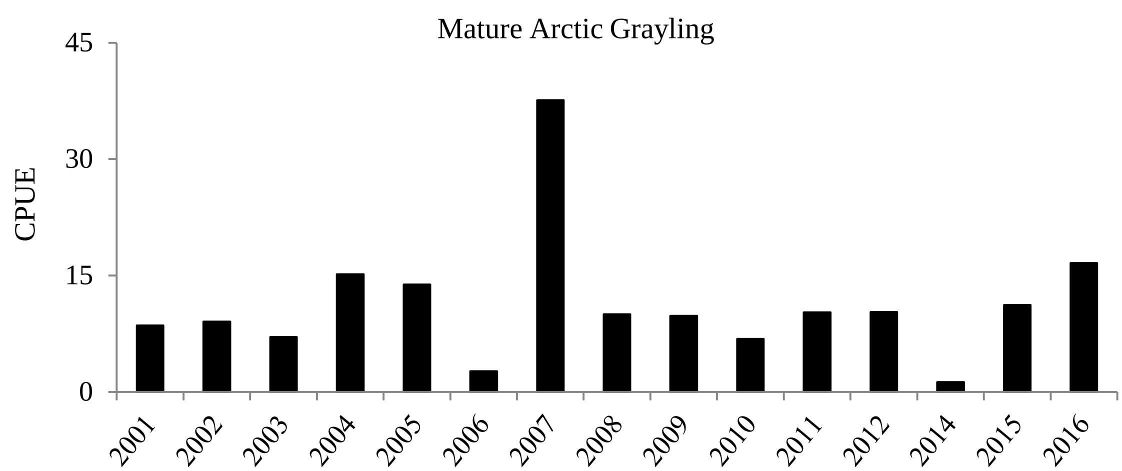


Figure 67. Average CPUE (fish/day) of mature Arctic grayling in North Fork Red Dog Creek from spring 2001 to spring 2016. No sampling was done due to high water in spring 2013.

Some of the Arctic grayling caught in the North Fork Red Dog Creek are fish that were marked in Bons Pond. The percentage of marked fish coming from Bons Pond in the 2016 sample was 0% (Figure 68). Since 2008, a decrease in the percentage of Bons Pond Arctic grayling being captured in North Fork Red Dog Creek has been noted. This decrease is due, in part, to the fact that the number of fish $\geq$ 200 mm FL in Bons Pond also has been declining since 2007 with a slight increase for the 2015 estimate.

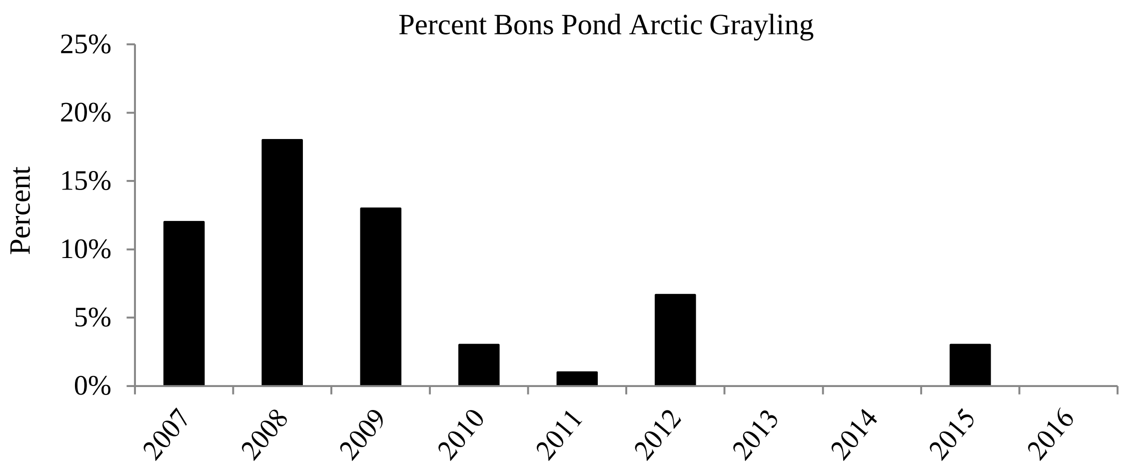


Figure 68. Percent of Bons Pond marked fish caught in North Fork Red Dog Creek.

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).

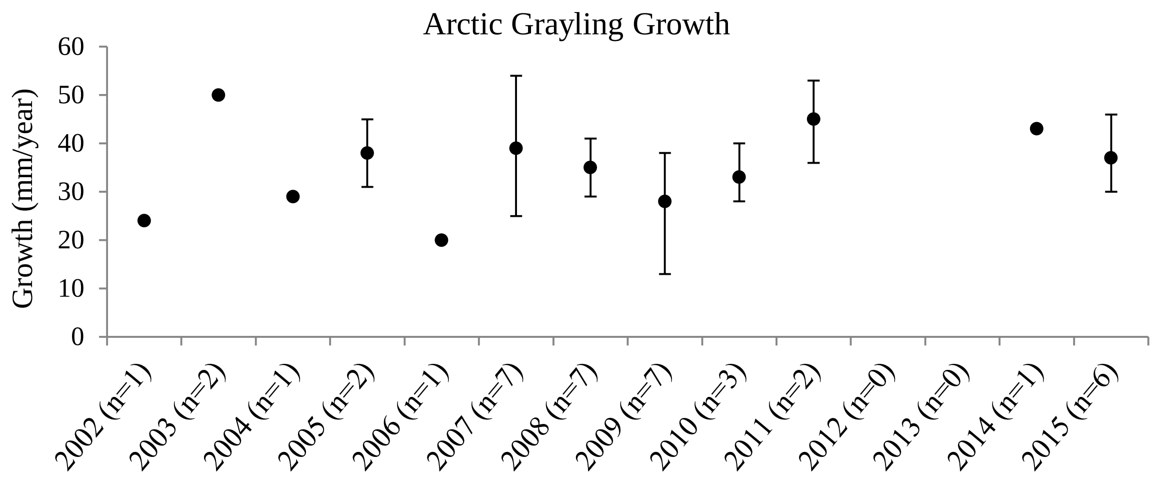


Figure 69. Average, maximum, and minimum annual growth of Arctic grayling in North Fork Red Dog Creek for fish between 250 and 300 mm FL when marked.

The population of Arctic grayling in North Fork Red Dog Creek, pre-mining, is not known. A population estimate is attempted annually, however in some years the number of recaptures is not adequate to make the estimate with any level of confidence. The highest population estimate was 1,422 fish in 2010 and the lowest estimate was 905 fish in 2015 (Figure 70). The confidence limits overlap for all of the population estimates suggesting that there are no substantial differences among years.

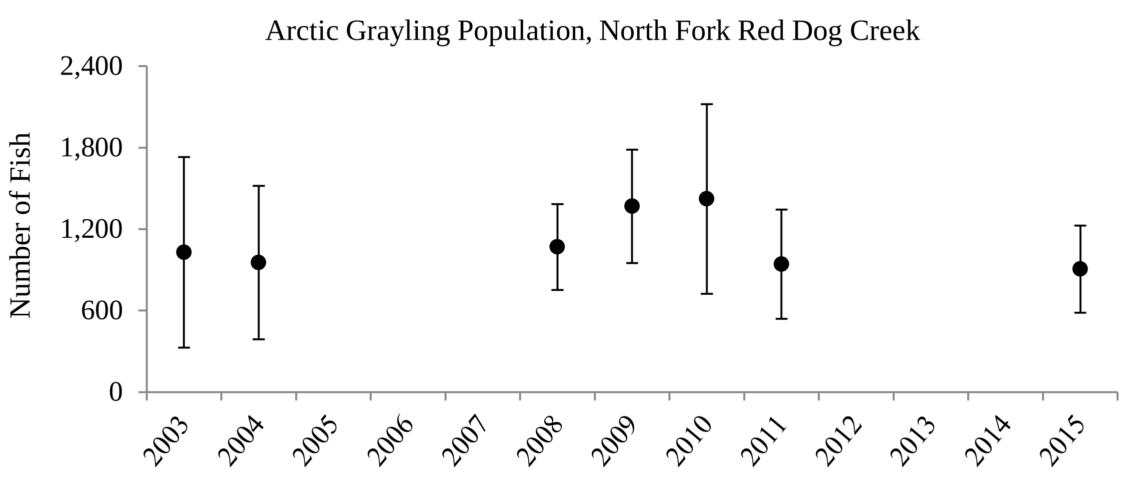


Figure 70. The estimated Arctic grayling population (95% CI) in North Fork Red Dog Creek for fish $\geq$ 200 mm FL.

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 ≥ 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. 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.

Arctic Grayling, Fry

Drift nets, which have been used to sample aquatic invertebrates in Bons Creek upstream of Bons Pond since 2004, are also effective in catching Arctic grayling fry. Each year in the summer (usually the first week of July), five drift nets are set for a duration of one hour and the contents placed in a container for later analyses (Figure 72). In six of 13 years of sampling, catches of Arctic grayling fry have been zero. The highest number of Arctic grayling fry caught in five drift nets fished for one hour was 78 in 2007 (Figure 73). Fry (about 15) were observed in the outlet of Bons Pond in early July, 2016. In most years, Arctic grayling are seen spawning in the outlet of Bons Pond and typically fry are observed in July and August.

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

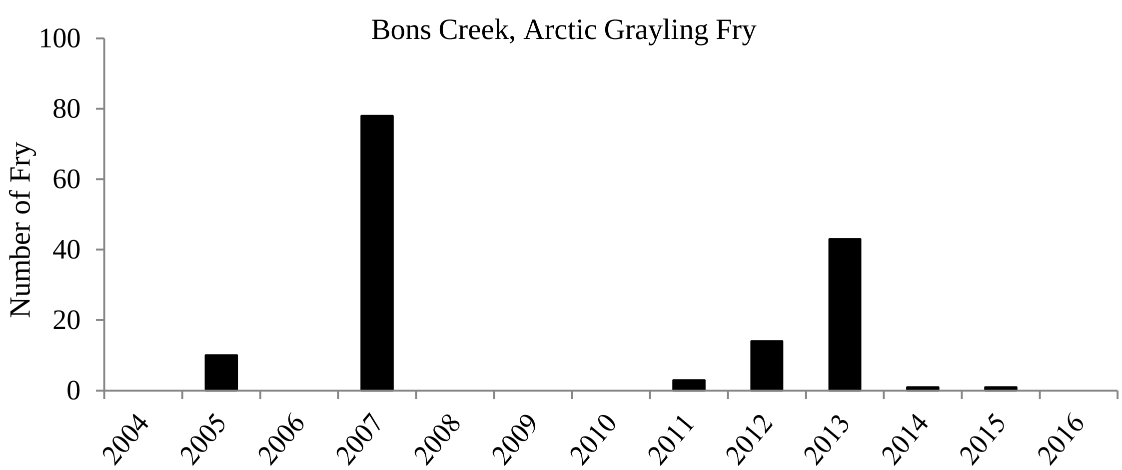


Figure 73. Number of Arctic grayling fry caught in drift nets 2004–2016.

Arctic Grayling, Catches and Metrics

A fyke net fished in Bons Creek from May 19 to May 23, 2016 caught 158 Arctic grayling; 119 of those fish were unique (not marked). A fyke net in Bons Pond and angling resulted in catches of an additional 54 Arctic grayling. The mean CPUE (#fish/day) for the fyke net in 2016 was 32 (Figure 74). The CPUE for Arctic grayling < 200 mm FL has ranged from 1 to 38 since 2006 (Figure 75) and catch rates in 2006, 2012, and 2014 were the highest. Typically, these smaller fish show up later in the sample event so the catches are affected by the length of the sample event. Sampling was not performed in 2013 due to high water.

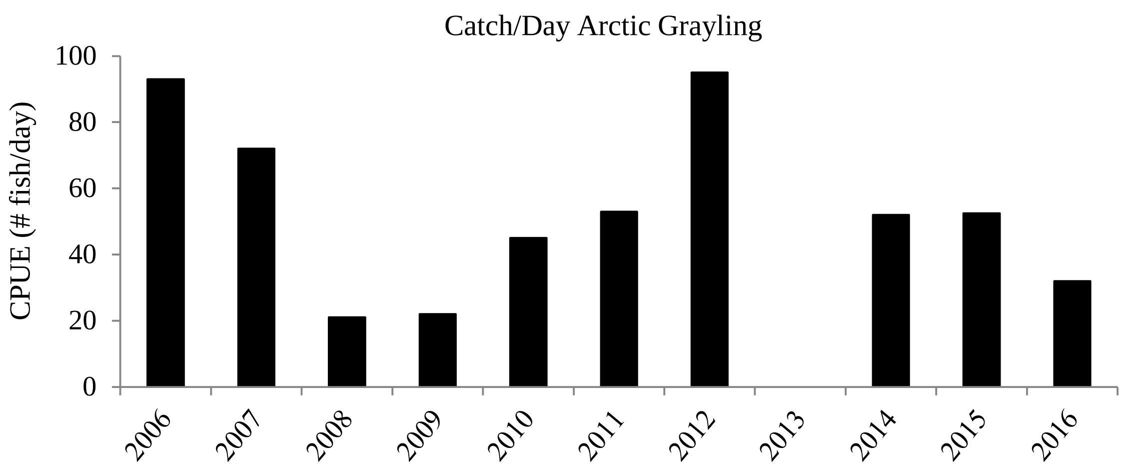


Figure 74. CPUE for all Arctic grayling in Bons Creek 2006–2016.

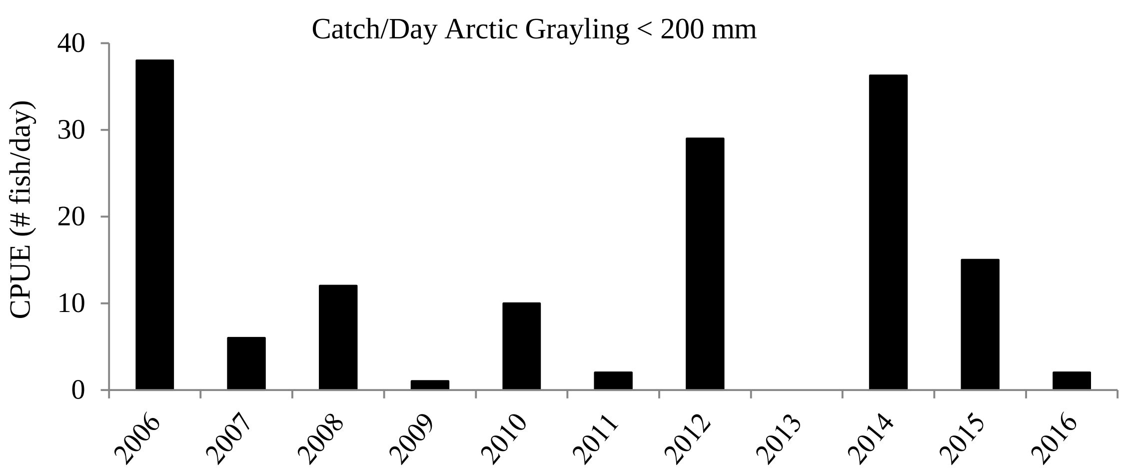


Figure 75. CPUE for Arctic grayling < 200 mm FL in Bons Creek 2006–2016.

The length frequency distribution for Arctic grayling caught in fyke nets and by angling in spring 2016 is presented in Figure 76. The current population in Bons Pond consists of a small population of mature fish and a large number of juvenile fish from various size classes. This leads us to predict that the population of fish ≥ 200 mm FL is likely to increase in future years.

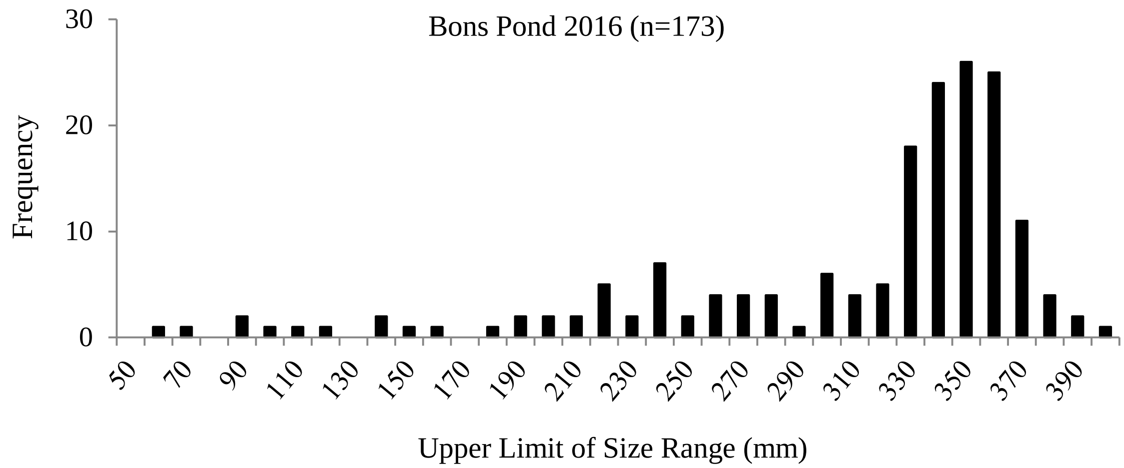


Figure 76. Length frequency distribution of Arctic grayling in Bons Pond in spring 2016.

At low flows, the pool at the base of the falls on Bons Creek is isolated and fish become trapped. In early August 2016, sampling (angling) was conducted in the pool and 88 Arctic grayling (147 to 374 mm FL) were caught. The fish were moved to Bons Creek. Sixty two of these fish were ≤ 250 mm FL (Figure 77).

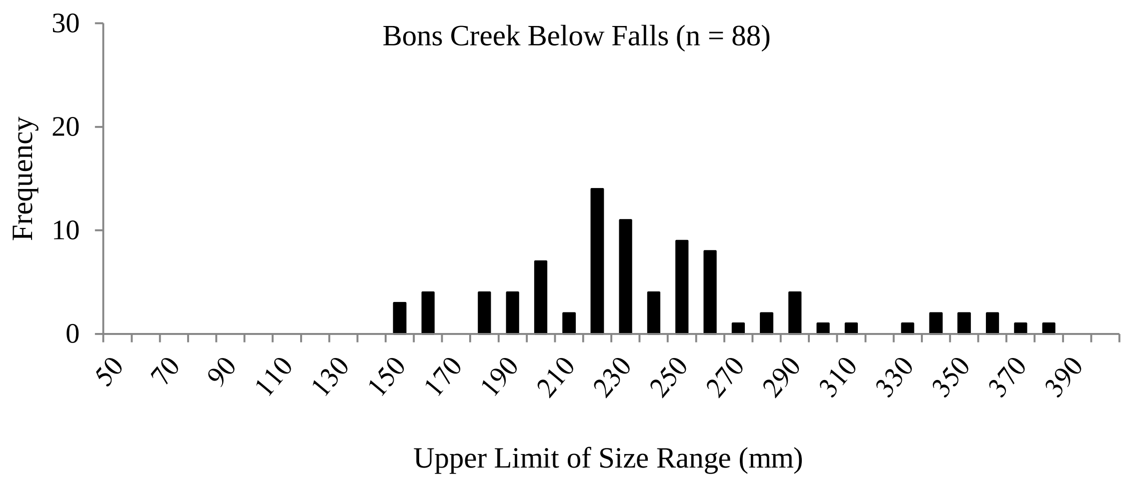


Figure 77. Length frequency distribution of Arctic grayling in Bons Creek in fall 2016.

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 fish marked from 200 to 249 mm FL. Average annual growth for fish ≥ 250 mm FL at marking are presented in Figure 78. Average annual growth rates in 2014 and 2015 were 17 and 14 mm. Higher growth rates in 2011, 2014, and 2015 probably are related to the population decline which resulted in the availability of more food for individual fish.

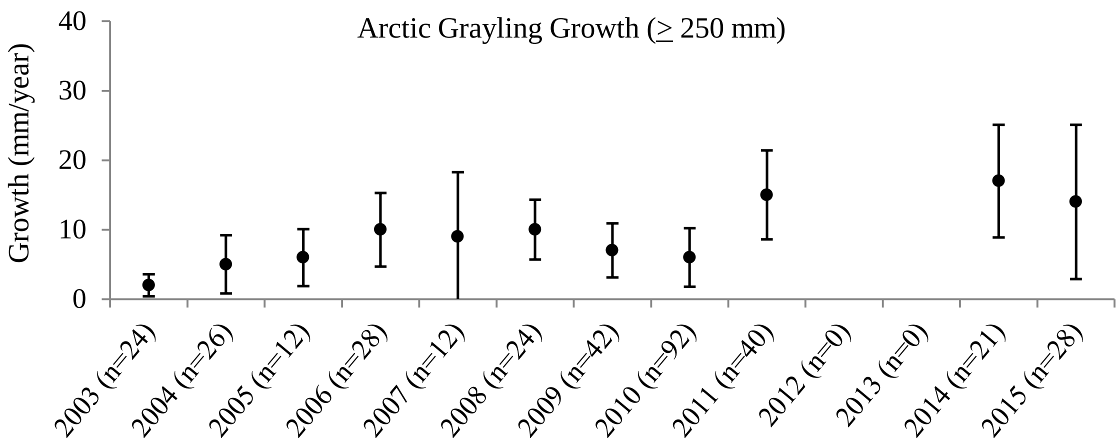


Figure 78. Average annual growth (± 1SD) of Arctic grayling ≥ 250 mm FL at time of marking.

The 2015 Arctic grayling population in Bons Pond was estimated by using 2015 as the mark event and spring 2016 as the recapture event. In spring 2015, there were 164 marked fish that were either recaptures or new marks. In spring 2016, 139 Arctic grayling were caught, 29 of which were recaptures from the spring 2015 mark event. Based on these values, the estimated Arctic grayling population for 2015 was 769 fish (95% CI, 552 to 986) ≥ 200 mm FL. The population estimates show a continuous decrease in the population beginning in 2005 (Figure 79). 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, and in 2015 the number of Arctic grayling ≥ 200 mm FL increased to 769 fish.

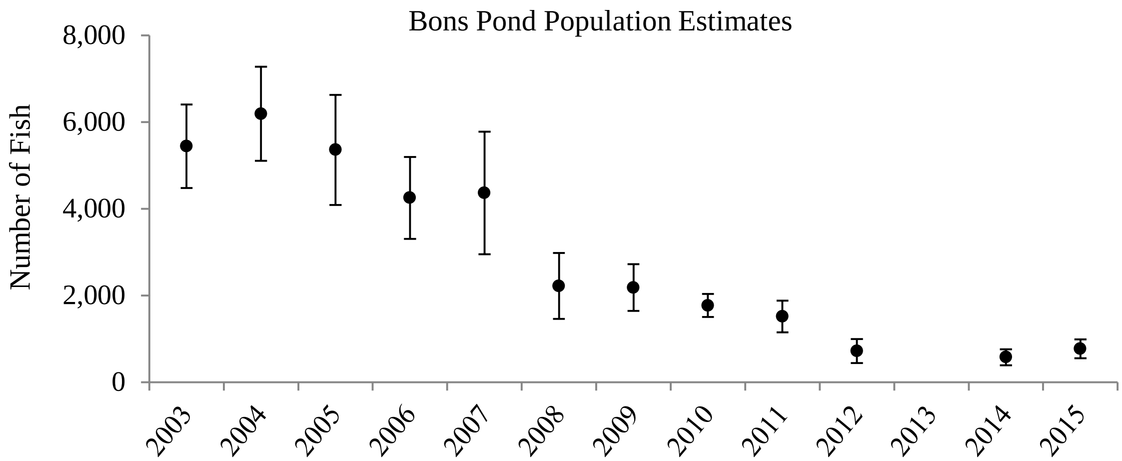


Figure 79. Estimated Arctic grayling population (95% CI) in Bons Pond for fish $\geq$ 200 mm FL.

Slimy Sculpin

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 2016, three slimy sculpin (116, 104, and 150 mm TL) were caught. These large sculpin are likely following the Arctic grayling to feed on their eggs and they probably 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 80. There is no apparent trend with CPUE which ranges from zero to a high of five in fall, 2009.

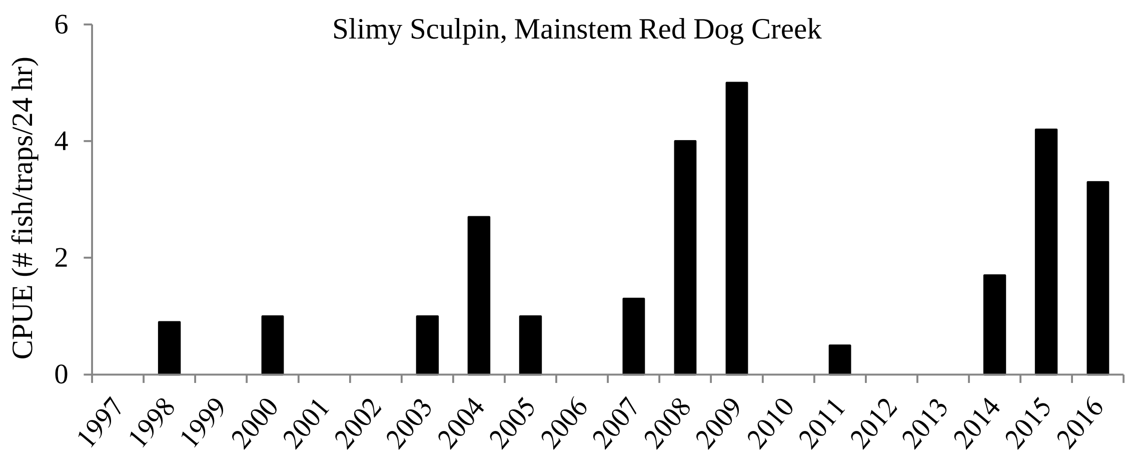


Figure 80. CPUE of slimy sculpin caught in Mainstem Red Dog Creek at the sample reach in the vicinity of Station 10 near the mouth of the creek. No sampling in 2012 and 2013 due to high water.

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 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 81). 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.

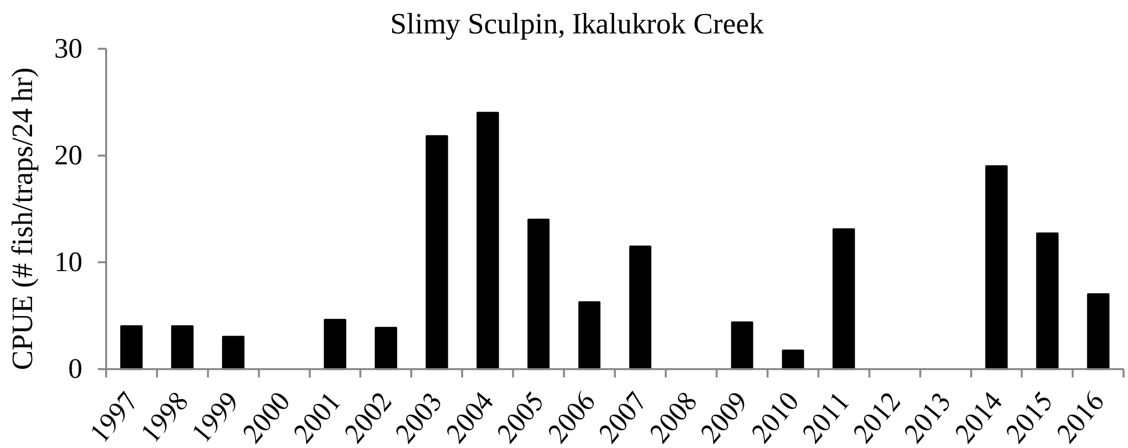


Figure 81. CPUE of slimy sculpin caught in Ikalukrok Creek at Station 7 (1997 to 2009) and Station 160 (2010, 2011, and 2014–2016). No sampling occurred in 2012 and 2013 due to high water.

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Appendix 1. Summary of Red Dog Mine Development and Operations, 2014-2016.[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

●On April 8, 2014, 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

●On May 5, 2014, 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)

●On May 28, 2014, 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

●On June 5, 2014, 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

●In the July 26 to August 2, 2014, field trip, 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

●On December 1, 2014, 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 et al. 2016

Appendix 1 (continued).

2015

●On January 6, 2015, 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
●On January 22, 2015, 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
●On February 10, 2015, 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 on February 28, 2015
●Discharge through Outfall 001 to Middle Fork Red Dog Creek began on May 12, 2015 and ended on September 19, 2015
●on 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
●On 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
●On 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
●On September 30, DNR by letter extended the approval of the Red Dog Mine Reclamation Plan
●On October 22, ADF&G by letter provided a summary of Wulik River and Ikalukrok Creek aerial surveys for Dolly Varden and chum salmon
●On 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, 2016
●On April 15, 2016, 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, 2016 and ended on September 24, 2016
●The spring spawning migration of Arctic grayling in Bons Pond/Bons Creek and North Fork Red Dog Creek was sampled from May 28 to 23, 2016. 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
●Between July 2 and 5, 2016, 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
●Between August 4 and 7, 2016, 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
●On September 28, 2016, DNR issued the reclamation plan approval
●On September 28, 2016, 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, 2016. 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 2. Periphyton Standing Crop, Red Dog Mine monitoring sites, 2016.

2014 Chloro Results - Red Dog		IDL = 0.12 mg/m^2	Linear Check Maximum = 20.18mg/m^2				Phaeo			
		EDL = 0.11 mg/m^2					Corrected			
Daily			Date	Date	Vial	**Chl a**	**Chl a**	**664/665**	Chl b	Chl c
Vial #	Site/Volume (liters)	Station /Site	Collected	Analyzed	Chl a	**mg/m^2**	**mg/m^2**	**Ratio**	mg/m^2	mg/m^2
Blank 32	Blank			12/07/16	0.00	0.00	0.00		0.00	0.00
33	Bons U/S Bons Pond		7/2/16	12/07/16	2.24	8.95	8.33	1.66	0.00	0.29
35	Bons U/S Bons Pond		7/2/16	12/07/16	0.55	2.19	2.03	1.66	0.00	0.17
37	Bons U/S Bons Pond		7/2/16	12/07/16	0.23	0.91	0.85	1.67	0.03	0.08
39	Bons U/S Bons Pond		7/2/16	12/07/16	0.40	1.60	1.17	1.46	0.00	0.08
41	Bons U/S Bons Pond		7/2/16	12/07/16	0.62	2.46	2.24	1.64	0.00	0.26
43	Bons U/S Bons Pond		7/2/16	12/07/16	0.95	3.79	3.20	1.57	0.00	0.15
45	Bons U/S Bons Pond		7/2/16	12/07/16	1.39	5.58	5.23	1.67	0.00	0.37
47	Bons U/S Bons Pond		7/2/16	12/07/16	1.32	5.28	4.59	1.59	0.19	0.32
49	Bons U/S Bons Pond		7/2/16	12/07/16	0.68	2.74	2.56	1.67	0.01	0.16
51	Bons U/S Bons Pond		7/2/16	12/07/16	0.81	3.24	3.10	1.69	0.00	0.13
89	Buddy C. U/S Haul Rd.	Station 221	7/4/16	12/07/16	1.29	5.17	4.81	1.65	0.32	0.30
91	Buddy C. U/S Haul Rd.	Station 221	7/4/16	12/07/16	0.05	0.18	0.11	1.33	0.00	0.04
93	Buddy C. U/S Haul Rd.	Station 221	7/4/16	12/07/16	0.50	1.99	1.82	1.63	0.21	0.13
95	Buddy C. U/S Haul Rd.	Station 221	7/4/16	12/07/16	0.93	3.73	3.52	1.67	0.08	0.19
97	Buddy C. U/S Haul Rd.	Station 221	7/4/16	12/07/16	0.81	3.24	3.10	1.69	0.00	0.19
99	Buddy C. U/S Haul Rd.	Station 221	7/4/16	12/07/16	0.62	2.50	2.46	1.72	0.12	0.19
101	Buddy C. U/S Haul Rd.	Station 221	7/4/16	12/07/16	0.17	0.68	0.75	1.88	0.06	0.04
103	Buddy C. U/S Haul Rd.	Station 221	7/4/16	12/07/16	1.47	5.88	5.45	1.65	0.00	0.59
105	Buddy C. U/S Haul Rd.	Station 221	7/4/16	12/07/16	0.17	0.67	0.64	1.67	0.14	0.11
107	Buddy C. U/S Haul Rd.	Station 221	7/4/16	12/07/16	1.69	6.77	6.51	1.66	2.77	0.17
109	Ik U/S Mainstem RD	Station 9	7/4/16	12/07/16	0.96	3.84	3.42	1.62	0.00	0.44
111	Ik U/S Mainstem RD	Station 9	7/4/16	12/07/16	1.21	4.85	4.49	1.66	0.00	0.50
113	Ik U/S Mainstem RD	Station 9	7/4/16	12/07/16	4.21	16.83	15.70	1.67	0.00	0.77
117	Ik U/S Mainstem RD	Station 9	7/4/16	12/07/16	0.61	2.43	2.24	1.66	0.00	0.23
119	Ik U/S Mainstem RD	Station 9	7/4/16	12/07/16	0.87	3.47	3.31	1.69	0.00	0.36
121	Ik U/S Mainstem RD	Station 9	7/4/16	12/07/16	0.98	3.93	3.63	1.65	0.00	0.49
123	Ik U/S Mainstem RD	Station 9	7/4/16	12/07/16	0.94	3.75	3.52	1.67	0.00	0.29
125	Ik U/S Mainstem RD	Station 9	7/4/16	12/07/16	0.52	2.06	2.03	1.73	0.00	0.15
127	Ik U/S Mainstem RD	Station 9	7/4/16	12/07/16	2.32	9.28	8.54	1.65	0.00	0.86
129	Ik U/S Mainstem RD	Station 9	7/4/16	12/07/16	0.90	3.61	3.42	1.68	0.00	0.40
113 Double	Duplicate Sta 9 of #113	Station 9	7/4/16	12/07/16	4.24	16.96	15.91	1.67	0.00	0.92
131	Blank[b]			12/07/16	0.00	0.00	0.00		0.00	0.00
4	Blank			12/08/16	0.02	0.08	0.21		0.09	0.22
78	N. Fork Red Dog	Station 12	7/5/16	12/08/16	0.73	2.91	2.78	1.68	0.08	0.17
80	N. Fork Red Dog	Station 12	7/5/16	12/08/16	0.66	2.65	2.46	1.66	0.00	0.21
82	N. Fork Red Dog	Station 12	7/5/16	12/08/16	1.24	4.94	4.49	1.63	0.36	0.17
84	N. Fork Red Dog	Station 12	7/5/16	12/08/16	0.81	3.24	3.10	1.69	0.00	0.29
86	N. Fork Red Dog	Station 12	7/5/16	12/08/16	0.84	3.36	2.67	1.51	0.26	0.15
88	N. Fork Red Dog	Station 12	7/5/16	12/08/16	1.72	6.87	6.09	1.60	0.85	0.22
90	N. Fork Red Dog	Station 12	7/5/16	12/08/16	1.26	5.02	4.70	1.66	0.56	0.16
92	N. Fork Red Dog	Station 12	7/5/16	12/08/16	1.44	5.78	5.55	1.70	0.00	0.18
94	N. Fork Red Dog	Station 12	7/5/16	12/08/16	1.13	4.54	3.95	1.59	0.33	0.12
96	N. Fork Red Dog	Station 12	7/5/16	12/08/16	0.59	2.37	2.24	1.68	0.04	0.08
Blank				12/08/16	0.01	0.04	0.11		0.05	0.06
Blank				12/09/16	0.01	0.04	0.11		0.05	0.06
48	Middle Fork Red Dog C.	Station 20	7/5/16	12/09/16	0.01	0.05	0.11		0.00	0.00
49	Middle Fork Red Dog C.	Station 20	7/5/16	12/09/16	0.01	0.05	0.11		0.00	0.00
50	Middle Fork Red Dog C.	Station 20	7/5/16	12/09/16	0.01	0.05	0.11		0.00	0.00
51	Middle Fork Red Dog C.	Station 20	7/5/16	12/09/16	0.01	0.05	0.11		0.00	0.00
52	Middle Fork Red Dog C.	Station 20	7/5/16	12/09/16	0.02	0.09	0.21		0.03	0.05
53	Middle Fork Red Dog C.	Station 20	7/5/16	12/09/16	0.01	0.04	0.11		0.05	0.06
54	Middle Fork Red Dog C.	Station 20	7/5/16	12/09/16	0.02	0.09	0.21		0.00	0.00
55	Middle Fork Red Dog C.	Station 20	7/5/16	12/09/16	0.02	0.09	0.21		0.03	0.05
56	Middle Fork Red Dog C.	Station 20	7/5/16	12/09/16	0.01	0.04	0.11		0.05	0.06
57	Middle Fork Red Dog C.	Station 20	7/5/16	12/09/16	0.01	0.05	0.11		0.00	0.00

[b] Value below detection limit

Appendix 2 (continued).

58	Bons U/S Buddy C	Station 220	7/4/16	12/09/16	2.52	10.07	7.69	1.48	1.19	1.04
60	Bons U/S Buddy C	Station 220	7/4/16	12/09/16	0.82	3.28	2.88	1.59	0.62	0.03
62	Bons U/S Buddy C	Station 220	7/4/16	12/9/2016	0.56	2.23	2.14	1.69	0.10	0.10
64	Bons U/S Buddy C	Station 220	7/4/16	12/9/2016	2.33	9.31	8.65	1.63	2.97	0.13
66	Bons U/S Buddy C	Station 220	7/4/16	12/9/2016	1.08	4.31	3.20	1.46	0.36	0.09
68	Bons U/S Buddy C	Station 220	7/4/16	12/9/2016	0.12	0.50	0.53	1.83	0.07	0.10
70	Bons U/S Buddy C	Station 220	7/4/16	12/9/2016	3.38	13.53	12.50	1.64	2.03	0.47
72	Bons U/S Buddy C	Station 220	7/4/16	12/9/2016	2.49	9.95	7.05	1.43	1.07	0.47
74	Bons U/S Buddy C	Station 220	7/4/16	12/9/2016	1.95	7.79	6.84	1.59	0.81	0.13
76	Bons U/S Buddy C	Station 220	7/4/16	12/9/2016	1.18	4.72	3.31	1.42	0.33	0.07
78	Upper N.F. Red Dog C.		7/4/16	12/9/2016	0.39	1.55	1.50	1.70	0.03	0.16
80	Upper N.F. Red Dog C.		7/4/16	12/9/2016	0.43	1.72	1.60	1.65	0.18	0.14
82	Upper N.F. Red Dog C.		7/4/16	12/9/2016	0.45	1.82	1.82	1.74	0.06	0.15
84	Upper N.F. Red Dog C.		7/4/16	12/9/2016	0.41	1.64	1.60	1.71	0.07	0.11
86	Upper N.F. Red Dog C.		7/4/16	12/9/2016	0.48	1.91	1.82	1.68	0.09	0.21
88	Upper N.F. Red Dog C.		7/4/16	12/9/2016	0.19	0.77	0.75	1.70	0.09	0.10
90	Upper N.F. Red Dog C.		7/4/16	12/9/2016	0.20	0.81	0.75	1.64	0.07	0.09
92	Upper N.F. Red Dog C.		7/4/16	12/9/2016	0.57	2.28	2.14	1.67	0.00	0.32
94	Upper N.F. Red Dog C.		7/4/16	12/9/2016	0.25	1.00	0.96	1.69	0.06	0.13
96	Upper N.F. Red Dog C.		7/4/16	12/9/2016	0.38	1.53	1.39	1.62	0.27	0.16
98	Ik D/S Dudd C.	Station 160	7/4/16	12/9/2016	1.32	5.29	4.81	1.63	0.67	0.13
100	Ik D/S Dudd C.	Station 160	7/4/16	12/9/2016	1.45	5.79	5.02	1.58	0.66	0.26
102	Ik D/S Dudd C.	Station 160	7/4/16	12/9/2016	1.15	4.62	4.17	1.62	0.43	0.25
104	Ik D/S Dudd C.	Station 160	7/4/16	12/9/2016	0.49	1.97	1.82	1.65	0.00	0.16
106	Ik D/S Dudd C.	Station 160	7/4/16	12/9/2016	2.65	10.59	9.72	1.63	1.65	0.23
110	Ik D/S Dudd C.	Station 160	7/4/16	12/9/2016	1.58	6.33	5.77	1.63	0.79	0.22
112	Ik D/S Dudd C.	Station 160	7/4/16	12/9/2016	1.75	7.01	5.98	1.56	1.33	0.17
114	Ik D/S Dudd C.	Station 160	7/4/16	12/9/2016	1.99	7.97	7.05	1.59	1.42	0.21
116	Ik D/S Dudd C.	Station 160	7/4/16	12/9/2016	2.60	10.42	9.08	1.58	2.21	0.17
118	Ik D/S Dudd C.	Station 160	7/4/16	12/9/2016	1.63	6.54	5.77	1.59	1.01	0.17
Blank 120	Blank[b]			12/9/2016	0.00	0.00	0.00		0.00	0.00
3	Blank			12/13/2016	0.01	0.04	0.11		0.05	0.06
4	Buddy C. Below Falls		7/5/16	12/13/2016	7.72	30.89	27.02	1.59	4.75	0.77
6	Buddy C. Below Falls		7/5/16	12/13/2016	4.98	19.94	16.13	1.52	2.94	0.62
8	Buddy C. Below Falls		7/5/16	12/13/2016	3.58	14.33	11.75	1.53	2.29	0.30
10	Buddy C. Below Falls		7/5/16	12/13/2016	2.36	9.45	8.12	1.58	0.54	0.46
12	Buddy C. Below Falls		7/5/16	12/13/2016	4.38	17.51	12.92	1.45	2.48	0.44
14	Buddy C. Below Falls		7/5/16	12/13/2016	2.25	9.01	8.54	1.68	0.27	0.51
18	Buddy C. Below Falls		7/5/16	12/13/2016	3.05	12.22	10.89	1.61	0.70	0.46
20	Buddy C. Below Falls		7/5/16	12/13/2016	3.14	12.56	11.32	1.63	0.00	1.18
22	Buddy C. Below Falls		7/5/16	12/13/2016	1.10	4.41	4.17	1.67	0.14	0.24
24	Buddy C. Below Falls		7/5/16	12/13/2016	4.38	17.53	15.59	1.61	1.55	0.98
45	Mainstem Red Dog	Station 10	7/5/16	12/13/2016	0.15	0.60	0.53	1.63	0.00	0.02
47	Mainstem Red Dog	Station 10	7/5/16	12/13/2016	0.75	3.01	2.67	1.61	0.00	0.29
49	Mainstem Red Dog	Station 10	7/5/16	12/13/2016	0.09	0.37	0.32	1.60	0.00	0.08
51	Mainstem Red Dog	Station 10	7/5/16	12/13/2016	0.13	0.50	0.43	1.57	0.00	0.13
53	Mainstem Red Dog	Station 10	7/5/16	12/13/2016	0.35	1.40	0.85	1.33	0.62	1.10
55	Mainstem Red Dog	Station 10	7/5/16	12/13/2016	0.24	0.96	0.85	1.62	0.00	0.17
57	Mainstem Red Dog	Station 10	7/5/16	12/13/2016	0.11	0.45	0.53	2.00	0.01	0.04
59	Mainstem Red Dog	Station 10	7/5/16	12/13/2016	0.14	0.55	0.43	1.50	0.00	0.12
61	Mainstem Red Dog	Station 10	7/5/16	12/13/2016	0.18	0.73	0.75	1.78	0.00	0.16
63	Mainstem Red Dog	Station 10	7/5/16	12/13/2016	0.16	0.64	0.64	1.75	0.00	0.08
85	Blank			12/13/2016	0.01	0.04	0.11		0.05	0.06
Double 14	Buddy Creek Below Falls		7/5/16	12/13/2016	2.25	9.02	8.54	1.68	0.18	0.54

[b] Value below detection limit

Appendix 3. Aquatic Invertebrate Drift Samples, 2016.

	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	24	24	18	20	23	17	5	20	25	25
Total Ephemeroptera	15	39	103	2	156	43	1	32	145	27
Total Plecoptera	60	24	13	28	57	2	0	1	50	3
Total Trichoptera	0	2	0	0	0	0	0	0	0	1
Total aquatic Diptera	85	411	584	169	265	358	29	85	248	100
Misc. aquatic species	186	124	110	54	64	28	1	74	33	138
% Ephemeroptera	4%	7%	13%	1%	29%	10%	2%	17%	30%	10%
% Plecoptera	17%	4%	2%	11%	11%	0%	1%	0%	11%	1%
% Trichoptera	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
% Aquatic Diptera	25%	69%	72%	67%	49%	83%	96%	44%	52%	37%
% other	54%	21%	14%	21%	12%	6%	1%	39%	7%	51%
% EPT	22%	11%	14%	12%	39%	10%	3%	17%	41%	12%
% Chironomidae	23%	25%	71%	64%	47%	51%	88%	28%	47%	33%
% Dominant Aquatic Taxon	24%	42%	61%	41%	38%	40%	64%	21%	33%	24%
Volume of water (m^3)	611	758	219	694	1049	811	46	115	387	262
Average water (m^3)/net	122	152	44	139	210	162	11	23	77	52
StDev of water volume	69	64	34	100	137	75	7	9	45	24
Estimated total inverts/m^3 water	7.6	5.4	24.7	2.9	3.9	3	3.1	14.4	7.8	10.5
Estimated aquatic inverts/m^3 water	2.9	4.0	18.6	1.8	2.6	2.7	2.6	8.4	6.2	5.1
average inverts/m^3 water	7.9	5.5	22.9	3	4.2	3.4	5.7	13	7.6	10.7
Average aquatic inverts/m^3 water	2.81	4.13	16.99	1.89	2.86	3	4.31	7.86	5.82	5.56
StDev of aquatic invert density	0.53	1.16	6.10	0.31	0.61	1.35	5.02	4.26	1.55	1.65
Total aquatic inverts	1743	3059	4061	1278	2714	2151	119	969	2390	1347
Total terrestrial inverts	2905	1058	1333	760	1389	254	24	681	618	1407
Total inverts	4648	4117	5394	2038	4103	2405	143	1650	3008	2754
% Sample aquatic	38%	74%	75%	63%	66%	89%	83%	59%	79%	49%
% Sample terrestrial	63%	26%	25%	37%	34%	11%	17%	41%	21%	51%
Average # aquatic inverts/net	349	612	812	256	543	430	30	194	478	269
Stdev aquatic inverts/net	205	278	883	158	325	113	19	139	329	91
Average # terrestrial inverts/net	581	212	267	152	278	51	6	136	124	281
Average # inverts/net	930	823	1079	408	821	481	36	330	602	551
StDev inverts/net	524	424	1145	287	489	122	18	276	386	296
Total Larval Arctic Grayling/site	0	0	0	0	0	1	0	0	0	0
Total Larval Slimy Sculpin/site	0	0	0	2	5	5	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, 2016.

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

Sample	Date	Length	Weight	Units		Cadmium	Lead	Mercury	Selenium	Zinc	% Solids
Number	Collected	(mm)	(g)	dry weight	MDL	0.07[c]	0.07[c]	0.01	0.07[c]	1.48[c]	
052216 BPAGJ 01	5/22/2016	191	70.2	mg/Kg		0.11	1.91	0.07	14.4	70.4	26.7
052216 BPAGJ 02	5/22/2016	187	68.9	mg/Kg		0.14	1.12	0.05	10.4	83.7	27.6
052216 BPAGJ 03	5/22/2016	188	67.1	mg/Kg		0.11	1.95	0.05	15.8	145.0	26.7
052216 BPAGJ 04	5/22/2016	151	35.1	mg/Kg		0.15	0.96	0.05	13.9	82.0	27.2
052216 BPAGJ 05	5/22/2016	140	30.6	mg/Kg		0.07	0.39	0.04	11.0	130.0	28.4
052216 BPAGJ 06	5/22/2016	143	30.3	mg/Kg		0.22	1.38	0.04	13.6	107.0	27.5
052216 BPAGJ 07	5/22/2016	177	56.3	mg/Kg		0.11	1.79	0.06	9.1	107.0	27.9
070316 BPAGJ 08	7/3/2016	160	43	mg/Kg		0.08	0.31	0.03	17.4	142.0	25.4
070316 BPAGJ 09	7/3/2016	151	39.4	mg/Kg		0.32	0.71	0.02	16.2	141.0	25.2
070316 BPAGJ 10	7/3/2016	165	55.3	mg/Kg		0.12	0.43	0.05	13.0	98.0	25.4
070316 BPAGJ 11	7/3/2016	168	54.9	mg/Kg		0.19	0.34	0.04	15.2	78.3	26.7
070316 BPAGJ 12	7/3/2016	165	49.3	mg/Kg		0.11	0.33	0.04	14.1	114.0	27.4
070316 BPAGJ 13	7/3/2016	164	47.5	mg/Kg		0.12	0.16	0.04	14.7	56.4	25.0
070316 BPAGJ 14	7/3/2016	164	53.5	mg/Kg		0.18	0.21	0.04	13.1	76.1	28.4
070316 BPAGJ 15	7/3/2016	153	40.3	mg/Kg		0.12	0.53	0.05	13.5	124.0	24.4

[c] 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, 2016.

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

Sample Number	Date Collected	Length (mm)	Weight (g)	Units dry weight	MDL	Cadmium 0.09[c]	Lead 0.09[c]	Mercury 0.008[c]	Selenium 0.09[c]	Zinc 1.76[c]	% Solids
080516 BUDDY JDV 01	8/5/2016	138	22.3	mg/Kg		0.22	0.22	0.06	7.59	147	22.8
080516 BUDDY JDV 02	8/5/2016	135	20.1	mg/Kg		0.27	1.29	0.05	6.88	151	22.4
080516 BUDDY JDV 03	8/5/2016	102	9.5	mg/Kg		0.45	0.45	0.04	4.92	172	26.4
080516 BUDDY JDV 04	8/5/2016	105	10.5	mg/Kg		0.23	1.00	0.04	5.79	146	22.1
080516 BUDDY JDV 05	8/5/2016	126	18.5	mg/Kg		0.13	0.22	0.05	7.01	134	23.1
080516 BUDDY JDV 06	8/5/2016	98	9.6	mg/Kg		0.41	1.08	0.04	5.27	182	22.2
080516 BUDDY JDV 07	8/5/2016	128	17.6	mg/Kg		0.22	0.22	0.07	5.76	150	23.1
080516 BUDDY JDV 08	8/5/2016	116	13.9	mg/Kg		0.26	0.57	0.05	7.77	227	22.9
080516 BUDDY JDV 09	8/5/2016	110	11.7	mg/Kg		0.11	0.11	0.03	4.16	119	27.4
080516 BUDDY JDV 10	8/5/2016	98	8.7	mg/Kg		0.24	0.19	0.05	5.69	200	20.9
080516 BUDDY JDV 11	8/5/2016	96	9.2	mg/Kg		0.45	6.25	0.06	5.00	196	26.4
080516 BUDDY JDV 12	8/5/2016	130	19.5	mg/Kg		0.30	0.34	0.04	5.98	166	23.4
080516 BUDDY JDV 13	8/5/2016	94	8	mg/Kg		0.41	0.29	0.04	4.81	163	24.1
080516 BUDDY JDV 14	8/5/2016	130	19.9	mg/Kg		0.28	1.99	0.05	5.64	187	21.1
080516 BUDDY JDV 15	8/5/2016	92	8.1	mg/Kg		0.32	0.16	0.03	6.06	160	24.9
080516 ANXIETY JDV 01	8/5/2016	120	16.8	mg/Kg		0.22	0.27	0.11	5.66	152	22.6
080516 ANXIETY JDV 02	8/5/2016	120	16.6	mg/Kg		0.19	0.14	0.12	4.40	167	21.6
080516 ANXIETY JDV 03	8/5/2016	104	10.5	mg/Kg		0.20	0.40	0.11	5.20	167	20.0
080516 ANXIETY JDV 04	8/5/2016	115	14.5	mg/Kg		0.17	0.09	0.15	5.11	140	23.5
080516 ANXIETY JDV 05	8/5/2016	113	14.4	mg/Kg		0.09	0.30	0.13	5.38	125	23.4
080516 ANXIETY JDV 06	8/5/2016	109	13.3	mg/Kg		0.18	0.36	0.12	5.52	158	22.1
080516 ANXIETY JDV 07	8/5/2016	119	15.1	mg/Kg		0.10	0.44	0.17	6.10	140	20.5
080516 ANXIETY JDV 08	8/5/2016	115	15.3	mg/Kg		0.23	1.24	0.10	5.35	108	25.8
080516 ANXIETY JDV 09	8/5/2016	125	16.4	mg/Kg		0.17	0.13	0.12	4.26	179	23.0
080516 ANXIETY JDV 10	8/5/2016	110	11.8	mg/Kg		0.21	0.21	0.12	6.21	136	24.0
080516 ANXIETY JDV 11	8/5/2016	114	12.3	mg/Kg		0.14	0.41	0.29	5.45	147	22.0
080516 ANXIETY JDV 12	8/5/2016	123	17.1	mg/Kg		0.19	0.85	0.17	4.74	175	21.1
080516 ANXIETY JDV 13	8/5/2016	117	14.6	mg/Kg		0.16	0.69	0.13	5.16	128	24.6
080516 ANXIETY JDV 14	8/5/2016	118	15	mg/Kg		0.22	0.22	0.11	4.16	119	22.6
080516 ANXIETY JDV 15	8/5/2016	119	15.8	mg/Kg		0.08	0.16	0.13	4.86	128	24.3
080616 LOWER MS JDV 01	8/6/2016	136	22.6	mg/Kg		2.95	1.69	0.07	16.09	178	20.7
080616 LOWER MS JDV 02	8/6/2016	140	23.4	mg/Kg		2.96	2.96	0.06	13.32	151	22.6
080616 LOWER MS JDV 03	8/6/2016	116	14.4	mg/Kg		2.27	3.70	0.04	17.82	181	23.8
080616 LOWER MS JDV 04	8/6/2016	120	15.2	mg/Kg		0.40	0.44	0.04	6.22	171	22.5
080616 LOWER MS JDV 05	8/6/2016	123	16.9	mg/Kg		0.85	1.92	0.04	13.80	195	23.4
080616 LOWER MS JDV 06	8/6/2016	139	23.4	mg/Kg		1.09	1.05	0.06	10.50	185	22.0
080616 LOWER MS JDV 07	8/6/2016	102	9.6	mg/Kg		1.75	1.60	0.07	16.50	263	20.6
080616 LOWER MS JDV 08	8/6/2016	112	13	mg/Kg		3.61	3.00	0.05	9.87	240	22.7
080616 LOWER MS JDV 09	8/6/2016	131	19.4	mg/Kg		1.31	1.76	0.04	14.10	248	22.1
080616 LOWER MS JDV 10	8/6/2016	113	12.4	mg/Kg		1.07	2.01	0.04	4.15	158	22.4
080616 LOWER MS JDV 11	8/6/2016	116	13.2	mg/Kg		2.12	2.17	0.04	9.42	192	22.6
080616 LOWER MS JDV 12	8/6/2016	138	21.8	mg/Kg		0.73	0.77	0.05	9.10	145	23.4
080716 UPPER MS JDV 13	8/7/2016	112	12.4	mg/Kg		1.02	1.48	0.16	11.90	154	21.6
080716 UPPER MS JDV 14	8/7/2016	138	23.4	mg/Kg		1.18	15.90	0.04	7.40	141	26.2
080716 UPPER MS JDV 15	8/7/2016	110	11.9	mg/Kg		1.87	3.94	0.04	10.80	222	24.6

[c] 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, Red Dog Mine, 2016.

Sample Number	Location	Date Collected	Length (mm)	Weight (g)	Age	Tissue	Selenium (mg/kg)	% Solids
051916BPAGA01	Bons Pond	5/19/2016	340	478.8	10	Ovaries	33.4	29.1
051916BPAGA02	Bons Pond	5/19/2016	314	361.9		Ovaries	29.2	21.7
051916BPAGA03	Bons Pond	5/19/2016	337	408.9	12	Ovaries	28.1	25.1
051916BPAGA04	Bons Pond	5/19/2016	350	574.9	17	Ovaries	18.6	13.4
051916BPAGA05	Bons Pond	5/19/2016	330	405.8	11	Ovaries	26.3	26.5
051916BPAGA06	Bons Pond	5/19/2016	337	408.4	10	Ovaries	27.0	23.4
051916NFAGA01	North Fork Red Dog Creek	5/19/2016	352	513.4	9	Ovaries	12.5	24.8
052016NFAGA02	North Fork Red Dog Creek	5/20/2016	386	627.2	14	Ovaries	16.1	25.7
052016NFAGA03	North Fork Red Dog Creek	5/20/2016	346	440.0	14	Ovaries	12.2	26.8
052016NFAGA04	North Fork Red Dog Creek	5/20/2016	408	722.3	18	Ovaries	8.9	27.7
052016NFAGA05	North Fork Red Dog Creek	5/20/2016	332	457.6	10	Ovaries	31.9	27.5
052016NFAGA06	North Fork Red Dog Creek	5/20/2016	382	582.2	10	Ovaries	27.6	28.5

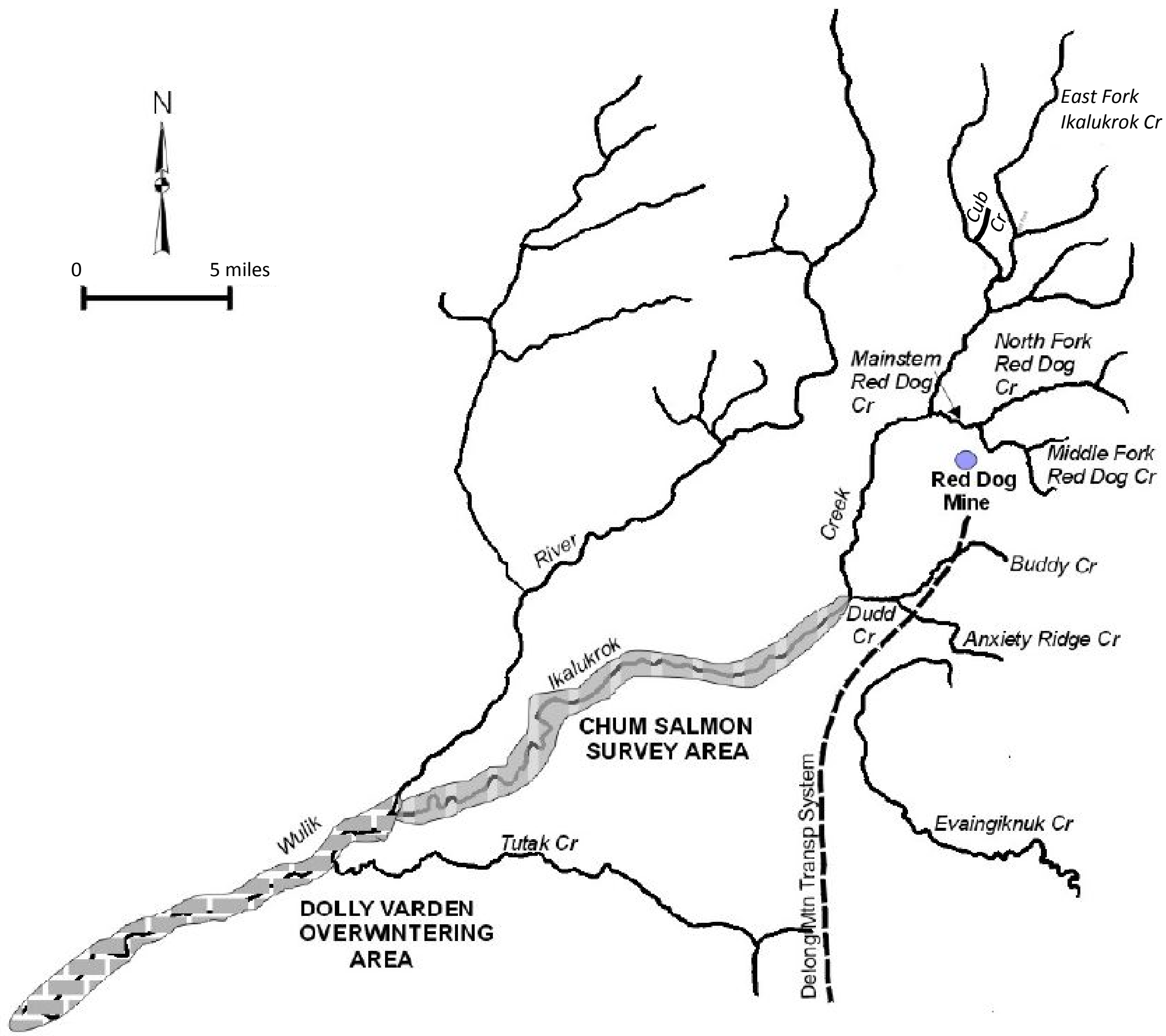
Appendix 7. Dolly Varden Element Data, Wulik River, May 2016.

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	051916WUDVA01	Dolly	Female	895.0	449	1.50	2.90	< 0.1	7.01	84.1	0.08	20.1
Kidney	051916WUDVA02	Dolly	Male	1115.2	490	1.90	3.80	< 0.19	10.30	110.0	0.25	16.0
Kidney	051916WUDVA03	Dolly	Female	1754.2	510	1.54	3.20	< 0.11	9.80	101.0	0.09	18.8
Kidney	051916WUDVA04	Dolly	Female	1121.2	478	1.60	3.30	< 0.09	6.70	120.0	0.09	21.2
Kidney	051916WUDVA05	Dolly	Female	1600.5	497	0.98	3.40	< 0.1	8.40	86.9	0.09	20.5
Kidney	051916WUDVA06	Dolly	Male	1169.0	488	1.30	3.80	< 0.1	9.50	92.0	0.08	19.9
	duplicate of Fish #3					4.90	6.50	< 0.11	10.90	116.0	0.10	18.4
Liver	051916WUDVA01	Dolly	Female	895.0	449	0.30	30.60	< 0.06	3.30	87.2	0.13	33.7
Liver	051916WUDVA02	Dolly	Male	1115.2	490	0.40	39.70	< 0.04	5.20	107.0	0.05	25.0
Liver	051916WUDVA03	Dolly	Female	1754.2	510	0.42	55.80	< 0.07	4.60	109.0	0.06	28.3
Liver	051916WUDVA04	Dolly	Female	1121.2	478	0.37	62.30	< 0.07	3.90	113.0	0.05	26.8
Liver	051916WUDVA05	Dolly	Female	1600.5	497	0.27	31.10	< 0.06	3.30	89.5	0.03	32.5
Liver	051916WUDVA06	Dolly	Male	1169.0	488	0.73	68.20	< 0.09	6.30	140.0	0.11	22.0
	duplicate of Fish #3					0.43	51.10	< 0.07	4.60	104.0	0.06	27.6
Muscle	051916WUDVA01	Dolly	Female	895.0	449	< 0.07	< 0.36	< 0.07	1.04	11.8	0.04	27.9
Muscle	051916WUDVA02	Dolly	Male	1115.2	490	< 0.07	1.20	< 0.07	0.93	15.9	0.04	28.9
Muscle	051916WUDVA03	Dolly	Female	1754.2	510	< 0.07	2.90	< 0.07	1.00	19.9	0.03	27.6
Muscle	051916WUDVA04	Dolly	Female	1121.2	478	< 0.07	1.12	< 0.07	1.00	14.9	0.03	26.8
Muscle	051916WUDVA05	Dolly	Female	1600.5	497	< 0.08	1.50	< 0.08	1.30	17.0	0.02	25.9
Muscle	051916WUDVA06	Dolly	Male	1169.0	488	< 0.08	1.20	< 0.08	1.00	16.2	0.02	25.9
	duplicate of Fish #3					< 0.06	0.86	< 0.06	0.72	10.9	0.03	35.0
Reproductive	051916WUDVA01	Dolly	Female	895.0	449							
Reproductive	051916WUDVA02	Dolly	Male	1115.2	490							
Reproductive	051916WUDVA03	Dolly	Female	1754.2	510	< 0.11	28.20	< 0.11	13.70	426.0	0.02	21.9
Reproductive	051916WUDVA04	Dolly	Female	1121.2	478	< 0.09	27.80	< 0.09	6.30	509.0	0.02	23.5
Reproductive	051916WUDVA05	Dolly	Female	1600.5	497	< 0.10	25.00	< 0.1	12.30	861.0	0.02	20.0
Reproductive	051916WUDVA06	Dolly	Male	1169.0	488							
	duplicate of Fish #3	Dolly				< 0.07	15.90	< 0.07	8.10	263.0	0.02	24.1

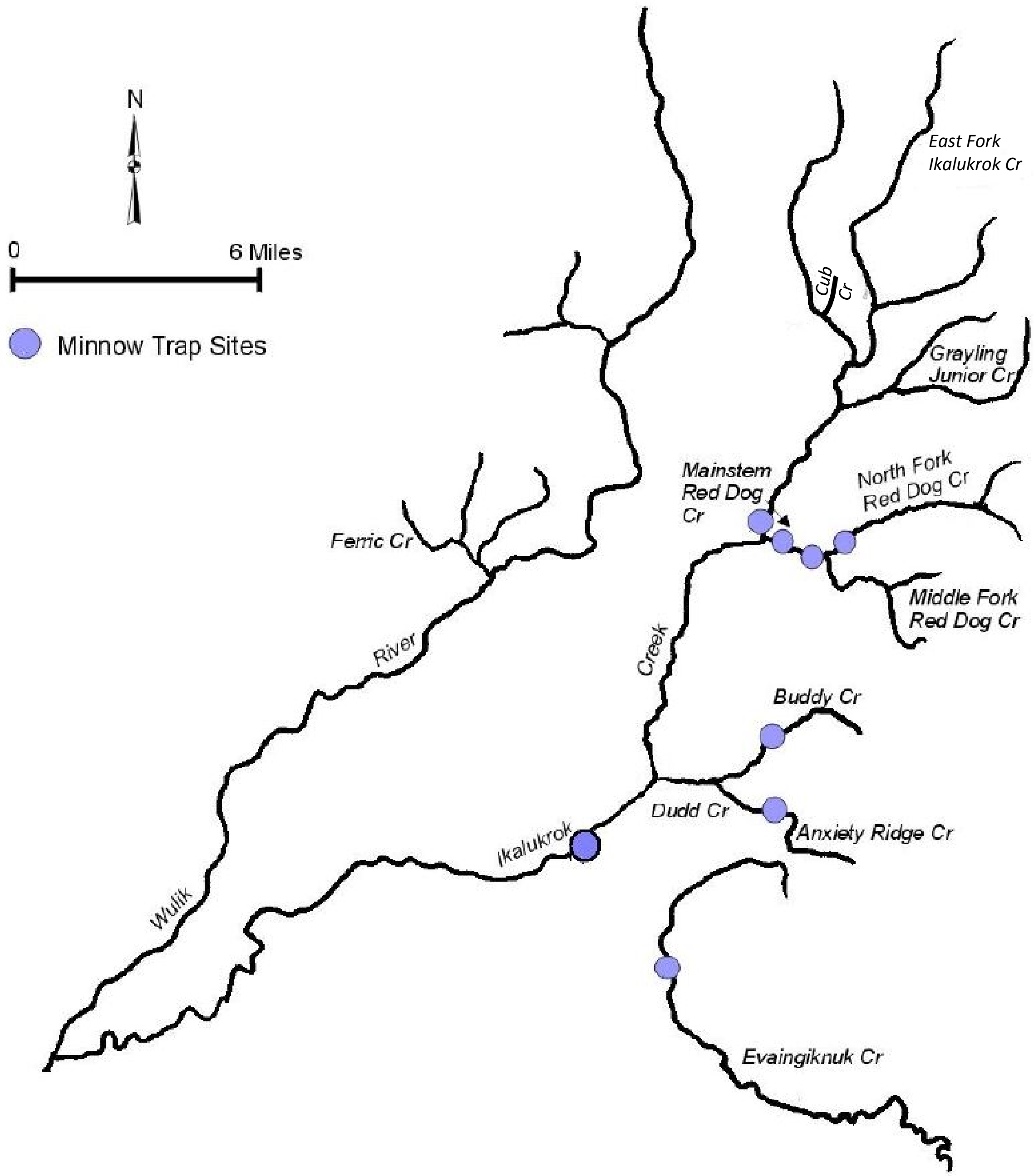
Appendix 8. Dolly Varden Element Data, Wulik River, September 2016.

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	091616WUDVA01	Dolly	Male	1360.5	502	2.10	4.70	0.36	12.40	118.0	0.07	16.9
Kidney	091616WUDVA02	Dolly	Female	1721.9	524	0.99	4.50	< 0.09	9.10	90.6	0.06	21.3
Kidney	091616WUDVA03	Dolly	Male	2244.9	580	0.67	4.90	< 0.1	8.80	103.0	0.09	20.8
Kidney	091616WUDVA04	Dolly	Male	2903.7	620	1.40	2.90	< 0.1	7.10	86.5	0.18	20.7
Kidney	091616WUDVA05	Dolly	Female	2360.8	546	0.79	4.70	< 0.1	11.20	107.0	0.08	19.1
Kidney	091616WUDVA06	Dolly	Male	3084.7	643	1.10	2.90	< 0.1	8.22	97.1	0.08	20.9
	duplicate of Fish #5					0.52	2.10	< 0.1	10.20	101.0	0.08	19.3
Liver	091616WUDVA01	Dolly	Male	1360.5	502	0.44	34.50	< 0.06	6.00	73.7	0.04	31.6
Liver	091616WUDVA02	Dolly	Female	1721.9	524	0.17	19.00	< 0.05	3.30	55.5	0.03	41.8
Liver	091616WUDVA03	Dolly	Male	2244.9	580	0.12	16.00	< 0.05	2.49	52.5	0.03	40.6
Liver	091616WUDVA04	Dolly	Male	2903.7	620	0.16	26.90	< 0.03	2.00	39.9	0.04	57.6
Liver	091616WUDVA05	Dolly	Female	2360.8	546	0.19	35.70	< 0.04	2.60	54.2	0.02	47.4
Liver	091616WUDVA06	Dolly	Male	3084.7	643	0.28	39.50	< 0.05	3.50	60.3	0.04	40.0
	duplicate of Fish #5					0.20	39.10	< 0.05	3.60	65.2	0.04	39.9
Muscle	091616WUDVA01	Dolly	Male	1360.5	502	< 0.10	3.10	< 0.1	1.60	29.9	0.06	19.7
Muscle	091616WUDVA02	Dolly	Female	1721.9	524	< 0.05	1.31	< 0.05	0.89	14.4	0.02	38.1
Muscle	091616WUDVA03	Dolly	Male	2244.9	580	< 0.05	1.70	< 0.05	0.66	12.7	0.03	42.6
Muscle	091616WUDVA04	Dolly	Male	2903.7	620	< 0.05	0.79	< 0.05	0.70	10.5	0.03	43.0
Muscle	091616WUDVA05	Dolly	Female	2360.8	546	< 0.05	1.00	< 0.05	0.71	9.8	0.05	39.6
Muscle	091616WUDVA06	Dolly	Male	3084.7	643	< 0.05	< 0.25	< 0.05	0.76	8.9	0.10	39.5
	duplicate of Fish #5					< 0.05	3.60	< 0.05	0.86	14.3	0.03	38.5
Reproductive	091616WUDVA01	Dolly	Male	1360.5	502							
Reproductive	091616WUDVA02	Dolly	Female	1721.9	524	< 0.08	18.80	< 0.08	13.70	310.0	0.03	24.3
Reproductive	091616WUDVA03	Dolly	Male	2244.9	580							
Reproductive	091616WUDVA04	Dolly	Male	2903.7	620	< 0.23	6.80	< 0.23	9.90	260.0	0.07	8.8
Reproductive	091616WUDVA05	Dolly	Female	2360.8	546	< 0.09	37.80	< 0.09	11.90	680.0	0.02	22.5
Reproductive	091616WUDVA06		Male	3084.7	643							
	duplicate of Fish #5					< 0.09	36.20	< 0.09	13.30	718.0	0.02	21.3

Appendix 9. Dolly Varden and Chum Salmon Aerial Survey Index Areas, Red Dog Mine, 2016.



Appendix 10. Juvenile Dolly Varden Sampling Sites, Red Dog Mine, 2016.



Appendix 11. Juvenile Dolly Varden Sampling Sites, Red Dog Mine, 1997-2016.

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
Evaingiknuk (Noatak Tributary)	54	27	38	2	7	20	64	71	29	4	67	21	16	48	36	17	13	8
Anxiety Ridge	68	94	271	27	6	33	98	116	121	8	115	75	147	18	43	7	93	61
Buddy	48	154	306	11	34	57	104	59	59	5	183	43	100	115	77	18	47	88
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
Upper North Fork Red Dog Creek																2	32	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
Mainstem (Sta 10)	10	21	66	1	3	12	12	0	10	3	6	5	6	14	8	13	15	21
Ikalukrok Creek (Sta 7/160)	13	51	55	31	6	17	17	27	36	2	25	7	30	10	32	7	10	24
Ikalukrok Creek (Sta 9)	3	44	41	5	2	18	3	12	0	5	7	3	11	37	12	2	11	17
Total Catch Dolly Varden	210	473	880	91	68	170	300	288	269	35	406	167	320	261	217	65	196	238

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 staion 151 and one trap at station 12

Appendix 12. Observations and catches of Arctic grayling in Mainstem Red Dog Creek below the confluence of North Fork Red Dog and Middle Fork Red Dog creeks 2012-2015.[d]

7/8/2012 – Observed Arctic grayling fry near Station 10, broad distribution in vicinity of drift nets, several small schools of 15 to 20 fry.

7/30/2013 – Arctic grayling fry were not observed near Station 10.

7/28/2014 – One Arctic grayling fry observed near Station 10, about 40 mm FL, several 300 mm Arctic grayling observed moving upstream, smaller Arctic grayling (200 to 300 mm) common (five to seven is backwaters and pools throughout the minnow bucket sample reach).

8/1/2015 – One juvenile Arctic grayling (105 mm FL) was caught in a minnow bucket at Station 151.

[d] Prior years observations and catches can be found in Ott et al. 2016

Appendix 13. Arctic grayling fry observations, North Fork Red Dog Creek, 2007-2016.[e]

Year	Relative Abundance of Fry	Comments
2007	high	Spawning 90% done by June 3, followed by low water with very little rainfall until mid-August, fry numerous, hundreds seen in shallow water along stream margin, fry averaged 64 mm in early August.
2008	low	Spawning 90% done by June 9, most fish probably spawned in Mainstem Red Dog Creek, no fry seen along stream margins.
2009	low	Most fish probably spawned in Mainstem Red Dog Creek, breakup late, very few fry seen in July or August, fry observed in the reach just upstream of Station 151 indicate some spawning success in North Fork Red Dog Creek.
2010	moderate	Breakup early, water flows low, moderate numbers of fry seen in North Fork Red Dog Creek in July, grayling fry caught in minnow buckets on August 16.
2011	low	Spawning probably began on June 9, 2011 – no fry were seen in July and in late August a few fry (less than 5) were observed in backwaters.
2012	low	Observed small numbers (2 to 3) of fry along stream margins and in several pools.
2013		No observations made due to extremely high water.
2014	low	Arctic grayling fry observed in most back waters, about 20 mm.
2015	low	No Arctic grayling fry were observed in early June or late July.
2016	low	No Arctic grayling fry were observed in early July or August.

[e] Prior observations can be found in Ott et al. 2016