Technical Report No. 11-04 (Revised)

Revised Edition:

Aquatic Biomonitoring at the Pebble Prospect, 2010

by

Kate J. Harper, Josh M. Brekken, Jeanette M. Alas, Ronald C. Benkert, and Stormy B. Haught

South Fork Koktuli River Monitoring Reach

December 2013

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

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in Technical Reports by the Division of Habitat. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations

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

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AQUATIC BIOMONITORING AT THE PEBBLE PROSPECT, 2010

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PREFACE

In February 2014 staff discovered an error pertaining to mean aquatic invertebrate density, velocity, and depth calculations for the SFK reach and UT reach. This revision contains corrections to paragraph five of the Executive Summary; section 4. Aquatic Invertebrates (specifically Figures 13 and 17 and related text, and Table 4 and related text); and Appendix 2.

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ACKNOWLEDGMENTS

We thank the Pebble Limited Partnership for their financial and logistical support for the 2010 aquatic biomonitoring work. We specifically acknowledge the assistance provided by Ken Taylor, Jane Whitsett, Gernot Wober, Jim Male, and Gary DeScheutter.

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EXECUTIVE SUMMARY

The Alaska Department of Fish and Game (ADF&G), Division of Habitat, began an aquatic biomonitoring program in the Pebble Prospect claim block in the summer of 2010. Monitoring sites were established on the North Fork Koktuli River (NFK reach), South Fork Koktuli River (SFK reach), and Upper Talarik Creek (UT reach), downstream of the Pebble Prospect. At each site, we collected data on channel characteristics, stream discharge, periphyton (measured as chlorophyll-a concentrations), aquatic invertebrates (density and community composition), metals concentrations in juvenile Dolly Varden *Salvelinus malma*, and fish presence. The goal of this biomonitoring program is to collect baseline data at long-term monitoring locations that can be used to assess biological conditions and monitor changes over time.

Based on the geomorphology data, all sample reaches were classified as Rosgen C4 stream types. Rosgen C4 stream types are described as slightly entrenched, meandering, gravel-dominated, riffle-pool channels with a developed floodplain, point bars and other depositional features present; and are susceptible to shifts in both lateral and vertical stability (Rosgen 1994). From a management perspective, C4 streams are typically very sensitive to disturbance with good recovery potential, have a high sediment supply, are very susceptible to streambank erosion, and are highly dependent on vegetation as a controlling influence (Rosgen 1994).

During the 2010 monitoring season, measured flows were similar to the 2005–2009 United States Geological Survey gage averages, with one exception; high precipitation in the fall of that year caused higher maximum peak flows. Streamflow in the North Fork Koktuli tends to be the most dynamic of the three streams, with large peaks in flow during precipitation or runoff events, while Upper Talarik streamflow is characterized by more stable flow throughout the year.

Chlorophyll-a concentrations ranged from 0.64 mg/m^2 (SFK reach) to 38.98 mg/m^2 (UT reach). Mean chlorophyll-a concentrations were highest in the UT reach, which had a mean concentration of 18.83 mg/m^2. The NFK reach and SFK reach were similar, with chlorophyll-a concentrations averaging 3.30 mg/m^2 and 2.50 mg/m^2.

The density of aquatic invertebrates was highest in the SFK reach and lowest in the UT reach. The high densities in the SFK reach reflect large numbers of copepods and cladocerans, which are lake-dwelling or slow-water species. The UT reach had the greatest percentage of pollution-sensitive taxa, followed closely by the NFK reach. Chironomids, an important food source for fish, were most abundant in the NFK reach, closely followed by the UT reach.

Juvenile Dolly Varden were sampled from each stream reach and analyzed for whole-body metals concentrations. In general, UT reach fish showed lower concentrations of metals than NFK reach and SFK reach fish. UT reach fish had the lowest mean concentrations of all metals with the exception of antimony and mercury. Mean lipid and solid content was similar across all three stream reaches.

A total of five fish species were found in the three biomonitoring sites, and species assemblages varied slightly by site. Juvenile coho salmon *Oncorhynchus kisutch*, Chinook salmon *O. tshawytscha*, and Dolly Varden were present at all three sites. In addition to the two dominant species (coho salmon and Dolly Varden), rainbow trout *O. mykiss* and sculpin species *Cottus cognatus* or *C. aleuticus* were present at the UT reach, and sculpin species were also found at the NFK reach.

Catch per unit effort (CPUE), using minnow traps, was greatest for coho salmon in the UT reach, while CPUE for Dolly Varden was greatest in the NFK reach, and CPUE for Chinook salmon was greatest in the SFK reach.

Species-specific condition factors were similar among streams. Fulton's condition factor for Dolly Varden ranged from 0.87 (SFK reach) to 0.96 (NFK reach). Coho salmon had calculated condition factors of 1.16 (UT reach) and 1.53 (NFK reach). Comparisons of condition factors apply only within a species but can then be compared across locations and over time. In 2010, the NFK reach had higher condition factors than the other reaches did for both Dolly Varden and coho salmon.

1. INTRODUCTION

The Pebble Prospect claim block is located about 32 km northwest of the village of Iliamna, Alaska, in the Lake and Peninsula Borough (Figure 1). More specifically, the Pebble Prospect is located at the headwaters of the Upper Talarik Creek and South Fork Koktuli River drainages, and adjacent to the headwaters of the North Fork Koktuli River drainage. This is a transitional area between two ecoregions, the Bristol Bay–Nushagak Lowlands and the Interior Forested Lowlands and Uplands (Gallant et al. 1995). The mean annual temperature is 34.9º F (July mean of 55.8º F and January mean of 16.4º F) as measured near Iliamna Lake (Alaska Climate Research Center 2012). The area has a mean precipitation of 25.09 inches and a mean snowfall of 55.2 inches (Alaska Climate Research Center 2012). The general vegetation consists of alder and willow stands, low shrub/scrub habitat, and various sedges and grasses, including tussock-forming species. The area is inhabited by a number of large mammals, including brown bear, black bear, gray wolf, coyote, caribou, moose, wolverine, red fox, river otter, and beaver. Additionally, the streams in the area are home to all five species of Pacific salmon and numerous resident fish species, such as Dolly Varden, rainbow trout, Arctic grayling, and others.

The Pebble Prospect is a copper-gold-molybdenum deposit located on state land. The Pebble Prospect consists of two contiguous deposits. Pebble West is a near-surface resource of about 4.1 billion metric tons, while Pebble East is a significantly deeper deposit that contains higher-grade ore of about 3.4 billion metric tons (ADNR 2013). It is considered to be one of the largest copper-gold porphyry deposits in the world (PLP 2011, Chapter 1).

The Pebble Prospect is in the advanced exploration stage. The exploratory drilling program and feasibility study for developing the Pebble Prospect is being conducted by Pebble Limited Partnership (PLP), a joint venture between Northern Dynasty Minerals, LLC and Anglo American. There are currently no mining proposals or permit applications for development of the Pebble Prospect.

The Alaska Department of Fish and Game (ADF&G), Division of Habitat, developed a pilot monitoring program for the purpose of collecting baseline data on a select number of parameters that reflect stream condition. Starting a monitoring program now will provide a data set that incorporates natural variability over time. If monitoring continues until project development, this baseline data will allow for a comparison with data collected during and after mine development and operation.

ADF&G began the pilot monitoring program in the PLP mine claim block in the summer of 2010. Currently, three biomonitoring sites have been established downstream but in close proximity to the potential mine site. Monitoring sites were established on the North Fork Koktuli River (NFK reach), South Fork Koktuli River (SFK reach), and Upper Talarik Creek (UT reach), at elevations ranging from 760–999 ft above sea level (Figure 2). Each monitoring site is a stream reach that was established using the Field Survey Procedures for Characterization of River Morphology by Rosgen (1996a). The Rosgen method calls for including a stream length that is equal to 20–30 channel widths (or two meander wavelengths). The following criteria were considered when selecting the location of the biomonitoring sites: located near an established stream gage, located on a relatively stable stream reach, wadeable at all but the highest flows, and located outside and downstream of the anticipated mine footprint. Additional sites, as well as a reference site, may be added in the future as funding resources and staff time allow.

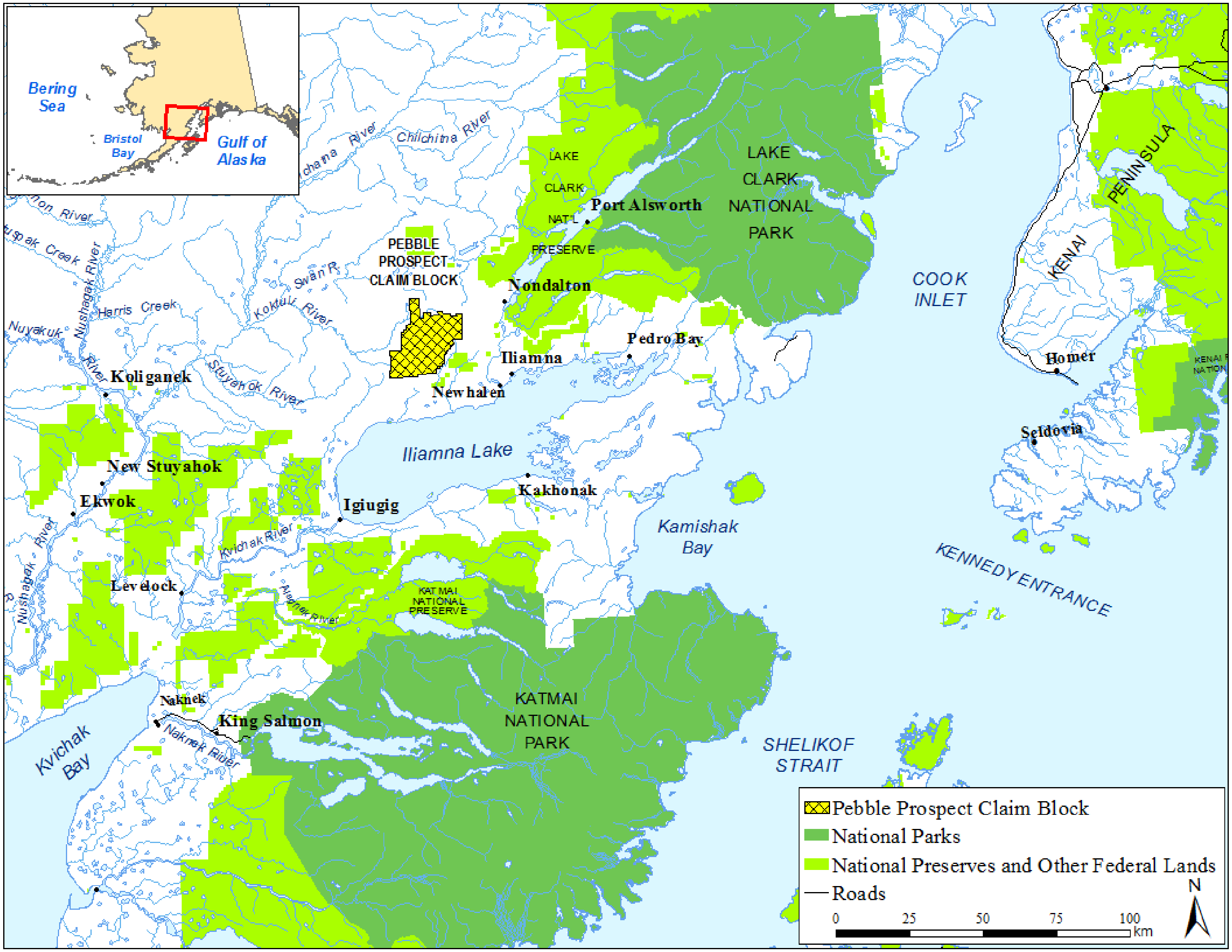

Figure 1. Location of the Pebble Prospect claim block, Southwest Alaska.

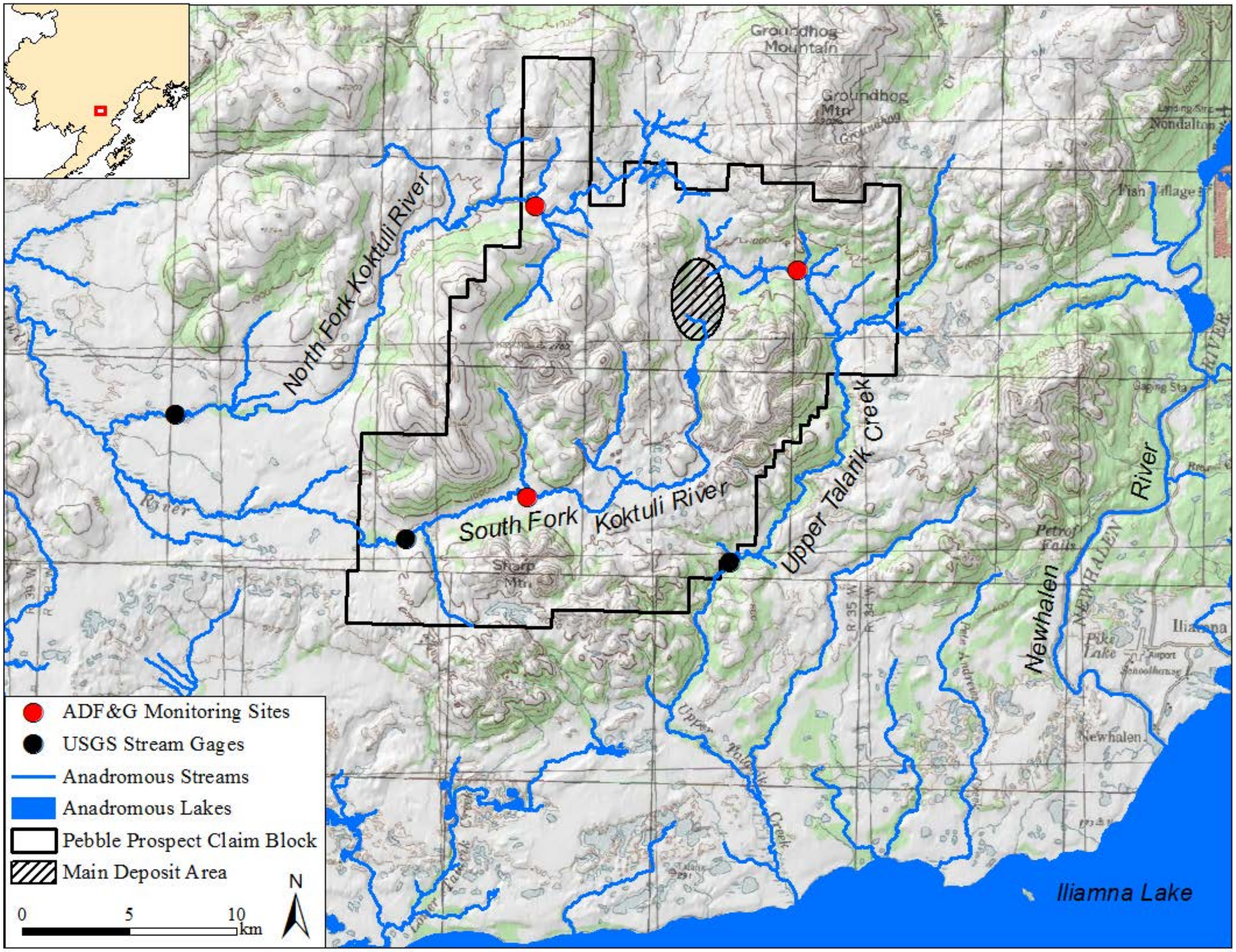

Figure 2. Locations of Alaska Department of Fish and Game (ADF&G) aquatic biomonitoring sites and United States Geological Survey (USGS) stream gages.

The aquatic biomonitoring program includes the following parameters and associated metrics:

- Geomorphology (channel cross sections, particle-size distribution)
- Hydrology (stream discharge)
- Periphyton (chlorophyll-a concentrations)
- Aquatic invertebrates (density and community composition)
- Metals concentrations (whole-body metals analysis of juvenile Dolly Varden)
- Fish presence (mean fork length, length frequency distribution, catch per unit effort, weight-length relationships, Fulton's condition factor).

2. GEOMORPHOLOGY AND HYDROLOGY

OVERVIEW

Fluvial geomorphology is the study of rivers and streams and the processes that shape them. These processes can include natural events that span millennia, such as deglaciation, or human-induced development activities, such as the creation of a dam, that can have more immediate effects. The main job of a river is to transport both water and sediment and to dissipate energy. The channel size, shape, and pattern will adjust over time to accommodate the water and sediment load. By monitoring a number of basic geomorphic characteristics, we can assess how stable the stream is and how it may respond to development activities (Leopold 1994; Rosgen 1994).

Fluvial processes and geomorphology are important because they can create, maintain, or alter fish habitat. Sediment sorting, through selective transport, is the process that creates spawning habitat for anadromous salmonids, as well as quality habitat for benthic organisms, which are an important food source for fish. Additionally, the pattern and spacing of riffles, runs, pools, and glides are determined by fluvial processes, and each serve different functions for fish and invertebrate habitat.

Monitoring can indicate the stream's current stability by establishing whether the stream is aggrading (building up of bed elevation by deposition over time), degrading (down-cutting because of bed scour), or laterally eroding, and at what rate. Changes in streamflow, width, velocity, depth, slope, roughness of channel materials, sediment volumes, and sediment sizes, brought on by activities in the watershed, can directly affect the stability of streams. Changes in stability in turn may result in changes to water quality, changes in diversity and quality of available fish habitat, and land loss through erosional processes (Meehan 1991; Waters 1995). While these processes and changes naturally occur over the millennia as climatic regimes shift, human development has the ability to rapidly accelerate these processes. Geomorphology data can provide insight into how development activities within the watershed could change the geomorphology of these streams and rivers; additionally, an understanding of the processes at work in a given stream system can also greatly increase the likelihood that habitat restoration and mitigation projects are successful and long lasting.

The Rosgen Stream Classification System is widely used, with much literature available describing the methods involved (Rosgen 1994). The foundation of the Rosgen approach is to measure a number of variables in the field that allow for the determination of the stream type.

The identification of the stream type assists managers in determining how stable the stream is, how it may respond to development activities, and what types of restoration activities have the highest likelihood of long-term success. The primary delineative criteria for the major Rosgen stream types are the entrenchment ratio, width/depth ratio, sinuosity, and slope (Rosgen 1996b). Calculations of these criteria rely on the identification of "bankfull." *Bankfull* is defined as the incipient elevation on the bank where flooding begins. Bankfull discharge is related to channel dimensions such as width and channel patterns such as meander length, radius of curvature, belt width, and meander width. Once a channel type is determined, a stream's present state of stability can be assessed by comparing the existing channel type to the valley type. Valley type is determined based on geomorphic features that can be observed from topographic maps, aerial photography, or personal familiarity with landforms and stream systems in the area of interest. Each valley type has natural stream types that indicate the system is in equilibrium; if other stream types are observed, the system is most likely in disequilibrium.

Additionally, monitoring stream discharge provides an empirical understanding of the volumetric effects of water withdrawal activities, as well as information that can be used to predict changes to stream geomorphology in the event of altered flow.

METHODS

During the 2010 monitoring season, a geomorphic evaluation of each site was conducted. The Rosgen method calls for establishing a monitoring reach that is equal to 20–30 channel widths (or two meander wavelengths). Each monitoring reach was classified to Level II of the Rosgen stream classification system (Rosgen 1994). The classification is determined from a number of field-measured variables, such as the entrenchment ratio, width/depth ratio, sinuosity, and channel material (particle size D_{50}). Riffle cross-sections and particle-size distributions were measured at each monitoring reach to determine these values.

Riffle cross-sections were developed by imbedding rebar stakes on opposite streambanks, adjacent to a riffle, forming a transect perpendicular to the channel. A temporary benchmark was also set on one side of the channel and used for relative elevation during the survey. Bankfull widths and cross-sectional depth profiles were measured between the rebar stakes using standard survey techniques (Harrelson et al. 1994) and plotted using Microsoft Excel® software. Bankfull area, mean bankfull depth, width/depth ratio, and maximum bankfull depth were calculated for each riffle cross-section from the profile data. Sinuosity was calculated using aerial photography (2006 imagery) and measuring the stream length and related valley length for at least two meander wavelengths centered on each monitoring reach.

Particle-size distributions of the streambed were determined by conducting pebble counts (Wolman 1954). Sediment samples of the streambed material were taken from the surface layer of the streambed (bed armor). Collected particles were grouped by size ranges (i.e., particles in 2–4 mm range were grouped, 4–5.7 mm particles were grouped, and so on) according to the field form provided in Rosgen (1996b). Particle-size distributions were plotted using the upper end of these ranges (e.g., particles measuring 3.5 mm were grouped in the 2–4 mm range and plotted as 4 mm particles) and log-normal plots of grain size versus cumulative percent. Particle-size diameters are reported for the D_{16}, D_{50}, D_{84}, and D_{100} values. D_{50} represents the median particle size of the bed material, while the D_{100} represents the largest particle size measured. Rosgen stream-channel classifications were determined for each sample reach using measurements obtained from cross sections and particle-size distribution.

Daily mean stream discharge data from 2005 through 2009 was obtained from stream gages maintained by the United States Geological Survey on the North Fork Koktuli River, South Fork Koktuli River, and Upper Talarik Creek, located downstream from ADF&G monitoring reaches (Figure 2, Table 1). Stream-gage information, including past archives and real-time flow, is available at http://waterdata.usgs.gov/nwis. These hydrology data were compared to measured discharge during 2010.

Table 1. United States Geological Survey (USGS) stream-gage details.

Stream	USGS gage no.	Drainage area (m^2)	Elevation (ft)
North Fork Koktuli River	15302250	105.62	613
South Fork Koktuli River	15302200	69.1	775
Upper Talarik Creek	15300250	86.6	425

Source: USGS 2013.

RESULTS

The stream length of each reach is 353 m (1,160 ft) for the NFK reach, 174 m (570 ft) for the SFK reach, and 70 m (230 ft) for the UT reach. Riffle cross-sections show a streambed profile of each sample reach (Figures 3–5), and selected channel parameters are reported in Table 2.

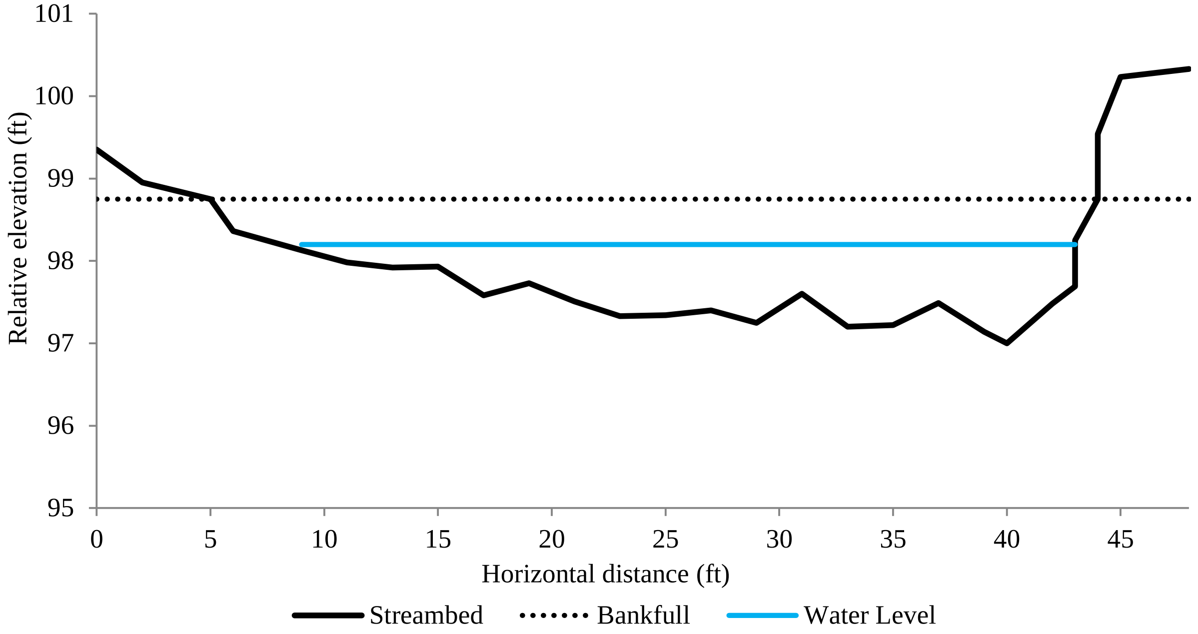

Figure 3. North Fork Koktuli monitoring reach riffle cross-section.

Note: A temporary benchmark was used for relative elevation. The downstream view of the cross-sectional profile is depicted in the figure, and the water level shown is the level at the time of survey.

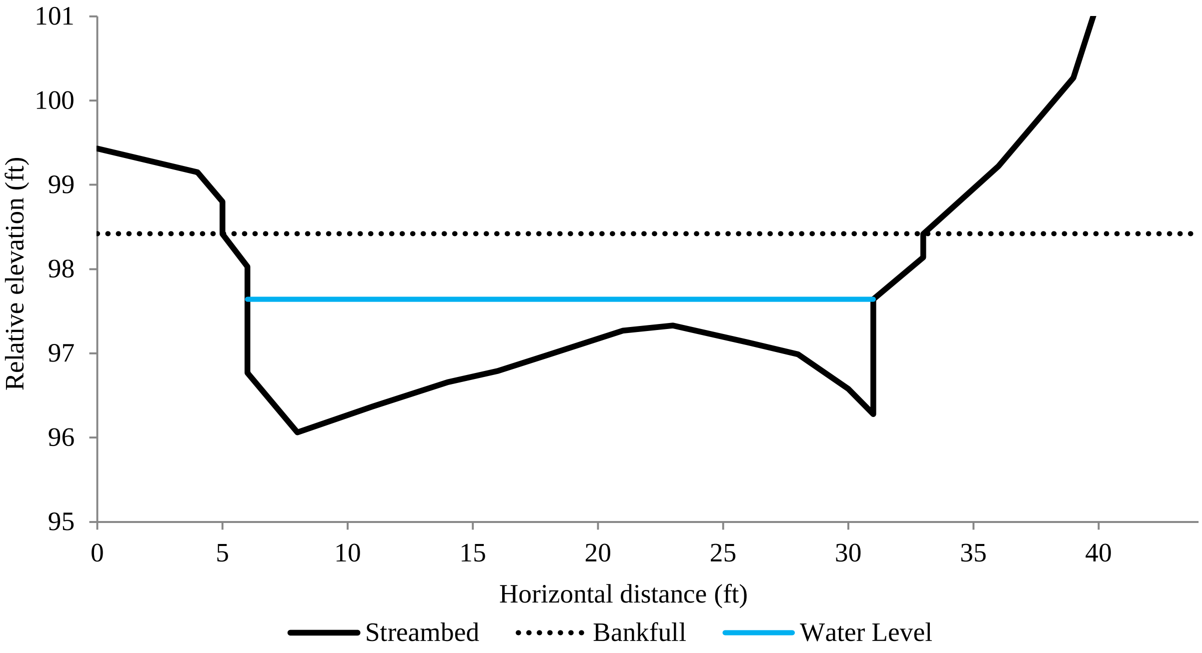

Figure 4. South Fork Koktuli monitoring reach riffle cross-section.

Note: A temporary benchmark was used for relative elevation. The downstream view of the cross-sectional profile is depicted in the figure, and the water level shown is the level at the time of survey.

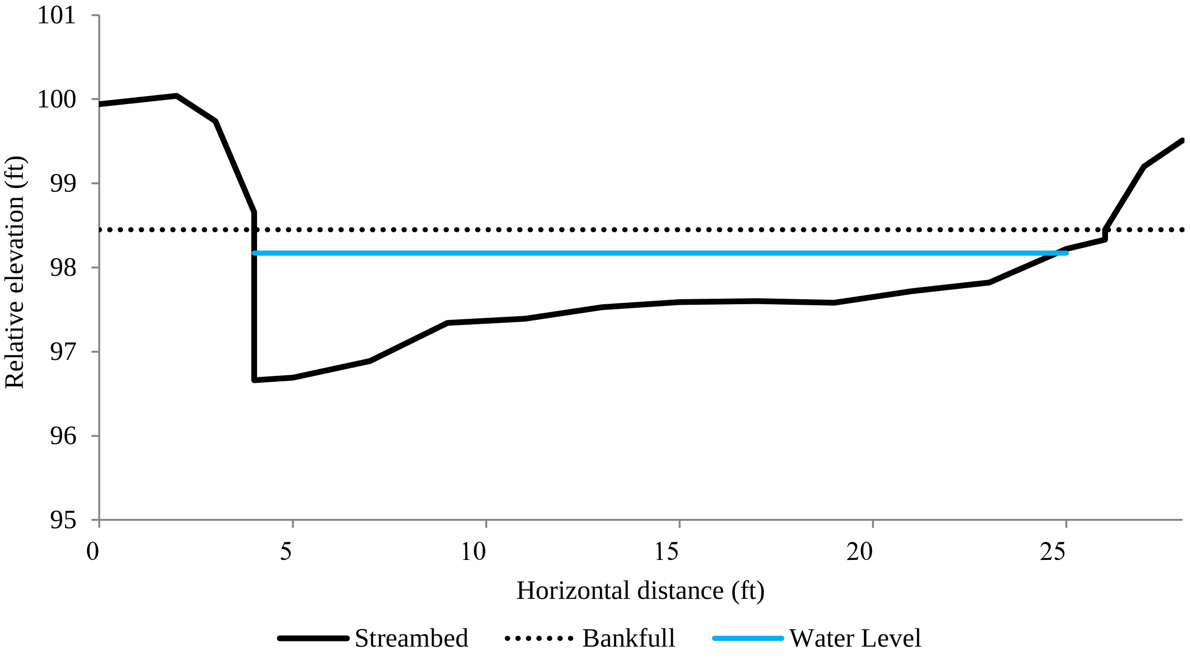

Figure 5. Upper Talarik monitoring reach riffle cross-section.

Note: A temporary benchmark was used for relative elevation. The downstream view of the cross-sectional profile is depicted in the figure, and the water level shown is the level at the time of survey.

Table 2. Calculated and measured values for geomorphology parameters from stream monitoring reaches and riffle cross-sections.

Stream reach	Bankfull area (ft^2)	Bankfull width (ft)	Mean bankfull depth (ft)	Width/depth ratio	Maximum bankfull depth (ft)	Sinuosity
North Fork Koktuli	44.31	38.6	1.15	33.63	1.75	1.27
South Fork Koktuli	41.42	28.1	1.47	19.06	2.36	2.05
Upper Talarik	20.44	22.25	0.92	24.22	1.79	1.52

The NFK reach has the largest bankfull area, indicating it transports the most water through its reach, and the UT reach has the smallest bankfull area. The NFK reach has the greatest bankfull width (38.6 ft), and the SFK reach has the most depth (mean = 1.47 ft, maximum = 2.36 ft) and the highest sinuosity (2.05).

The entrenchment ratio was not calculated for the NFK reach because of difficulties obtaining the width of the flood-prone area needed for this calculation. The entrenchment ratio for the SFK reach and UT reach was greater than 2.2, classifying them as slightly entrenched (Rosgen 1996b). All three stream reaches are classified as having a moderate to high width/depth ratio (>12) with the NFK reach approaching very high (>40). The NFK reach (1.27) is classified as having a moderate to high sinuosity (>1.2), and the SFK reach (2.05) and UT reach (1.52) have high sinuosity (>1.5). These measurements combined with field observations and Rosgen's descriptions of different channel types (Rosgen 1994) indicate that all three stream reaches are C stream types.

The particle-size distribution plots for all three sites are presented in Figure 6, and a summary of particle-size diameter distribution is presented in Table 3. All three stream reaches have similar D_{16} values. Based on the other D values, the NFK reach has larger substrate than the other stream reaches and has the largest overall particle size (Figure 6, Table 3). The median particle sizes (D_{50}) of all three reaches indicate that their channel bed material is gravel, which is given the number 4 (Rosgen 1994).

Mean daily discharge in cubic feet per second (cfs) for 2005–2009, measured by United States Geological Survey gages located downstream of our stream reaches, ranged from 38 cfs at South Fork Koktuli River to 1,060 cfs at North Fork Koktuli River (Figure 7). Minimum and maximum flows at the gaging stations, 2005–2009 were as follows:

Stream	Date	Minimum flow (cfs)	Date	Maximum flow (cfs)
North Fork Koktuli River	3/28/2007	32	5/13/2009	2,050
South Fork Koktuli River	3/28/2007	23	5/13/2009	1,510
Upper Talarik Creek	4/2010 Multiple dates	86	5/13/2009	1,250

Source: USGS 2013

During the 2010 monitoring season, flows were similar to the 2005–2009 averages, with the exception of higher maximum peak flows because of an abundance of fall precipitation (Figures 8–10).

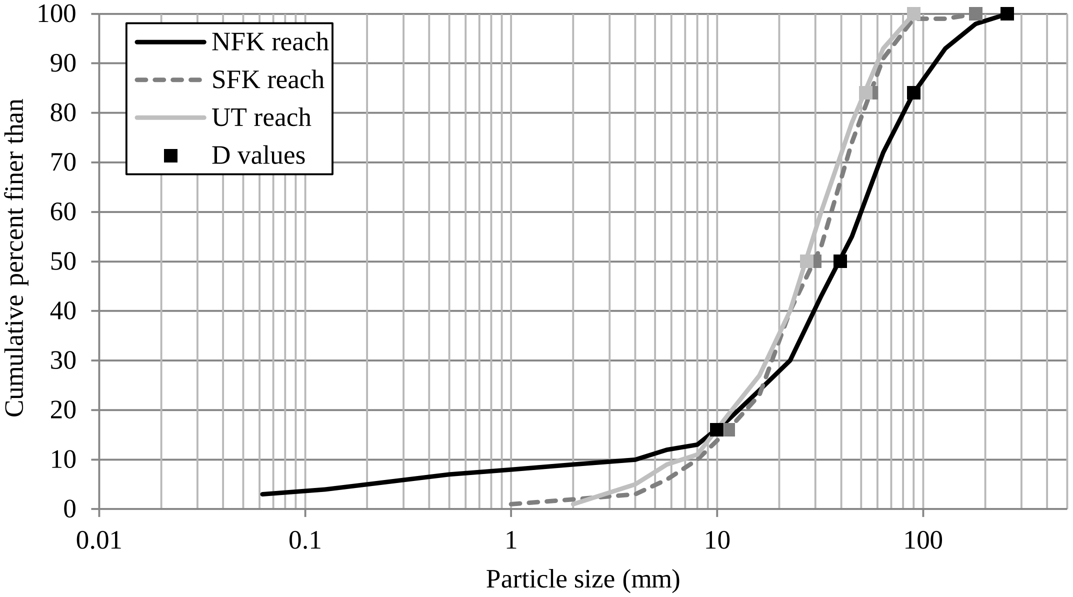

Figure 6. Particle-size distribution for the North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches.

Note: Particle sizes are graphed using the upper value in each size range. D_{100} is reported as the highest value in its size range; all other D values were determined with Microsoft Excel® by entering the corresponding *y*-axis value using the add-in Interactive Chart Display by TM Consulting (http://www.tushar-mehta.com/excel/software/interactive_chart_display/).

Table 3. Particle-size distribution in monitoring reaches.

Stream reach	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	D_{100} (mm)
North Fork Koktuli	10	40	90	256
South Fork Koktuli	11	30	56	180
Upper Talarik	10	27	53	90

Note: D_{100} is reported as the highest value in its size range; all other D values were determined with Microsoft Excel® by entering the corresponding *y*-axis value using the add-in Interactive Chart Display by TM Consulting (http://www.tushar-mehta.com/excel/software/interactive_chart_display/).

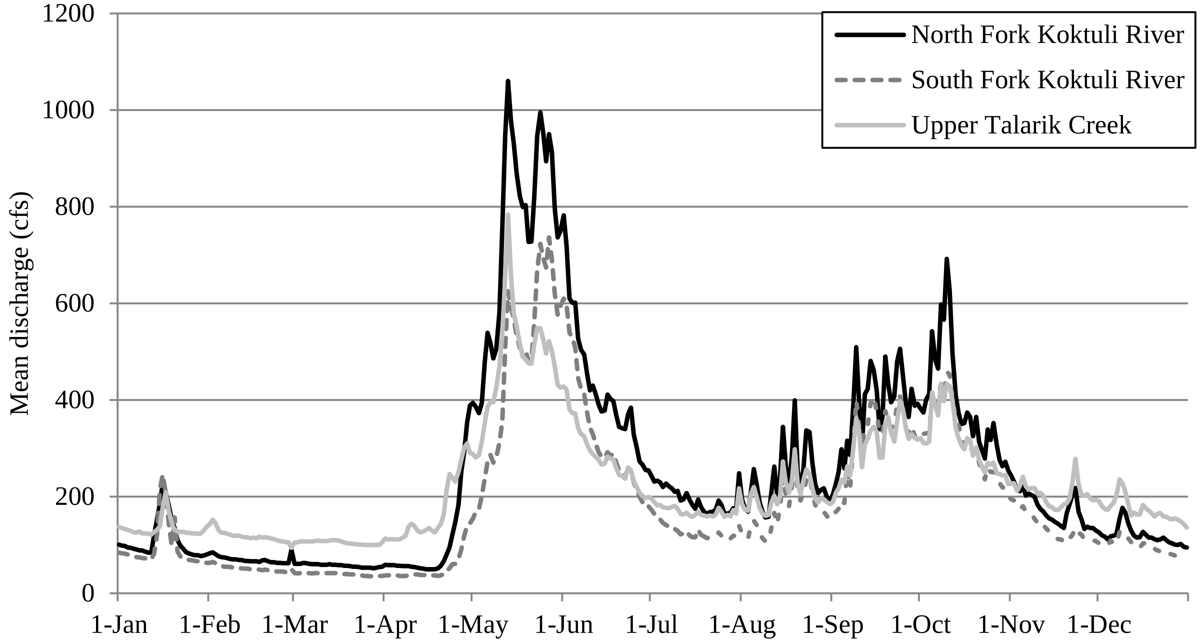

Figure 7. Mean daily discharge in cubic feet per second (cfs) from United States Geological Survey gages on the North Fork Koktuli River, South Fork Koktuli River, and Upper Talarik Creek, 2005–2009 (USGS 2013).

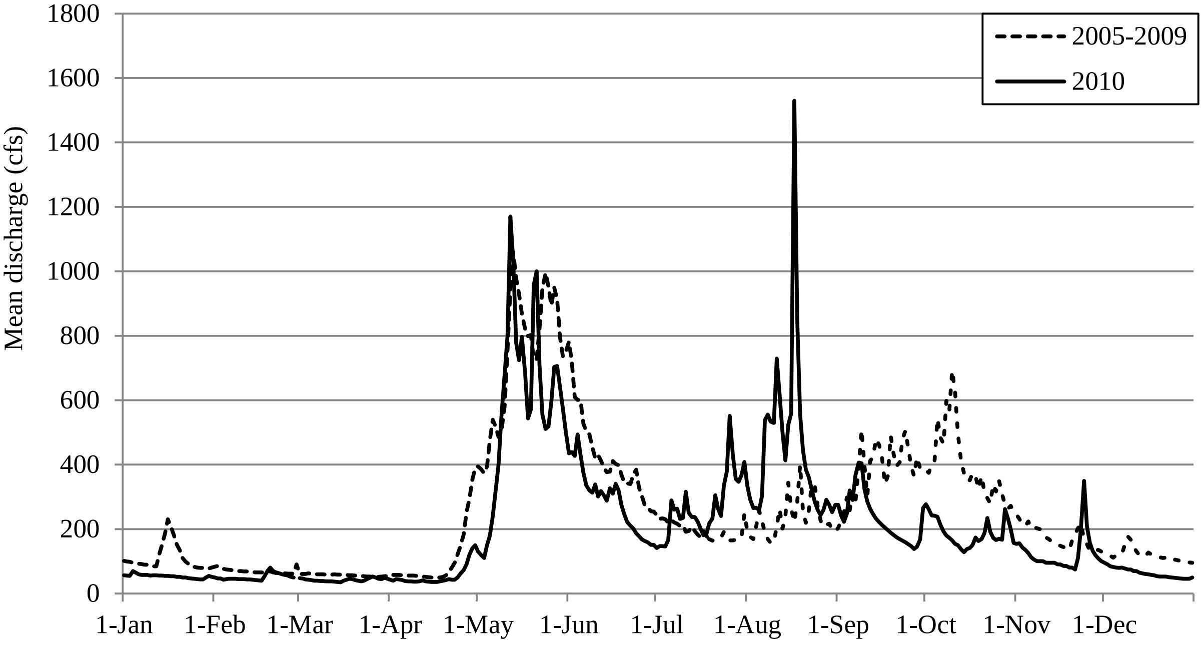

Figure 8. Mean daily discharge in cubic feet per second (cfs) from the United States Geological Survey gage on the North Fork Koktuli River for 2005–2009 and 2010 (USGS 2013).

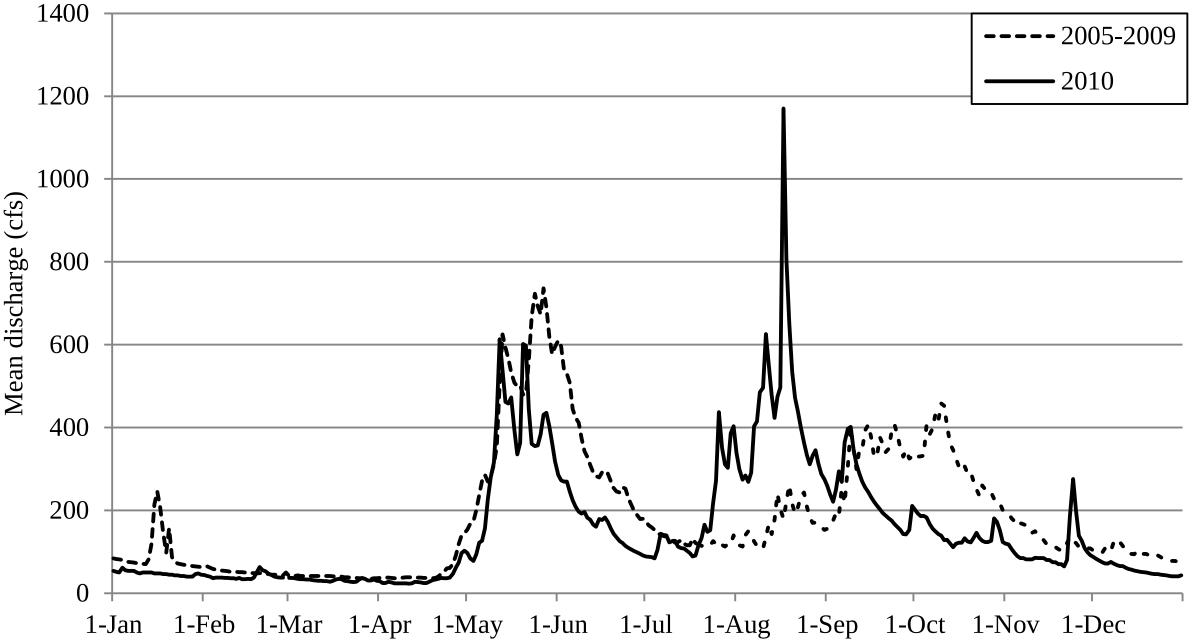

Figure 9. Mean daily discharge in cubic feet per second (cfs) from the United States Geological Survey gage on the South Fork Koktuli River for 2005–2009 and 2010 (USGS 2013).

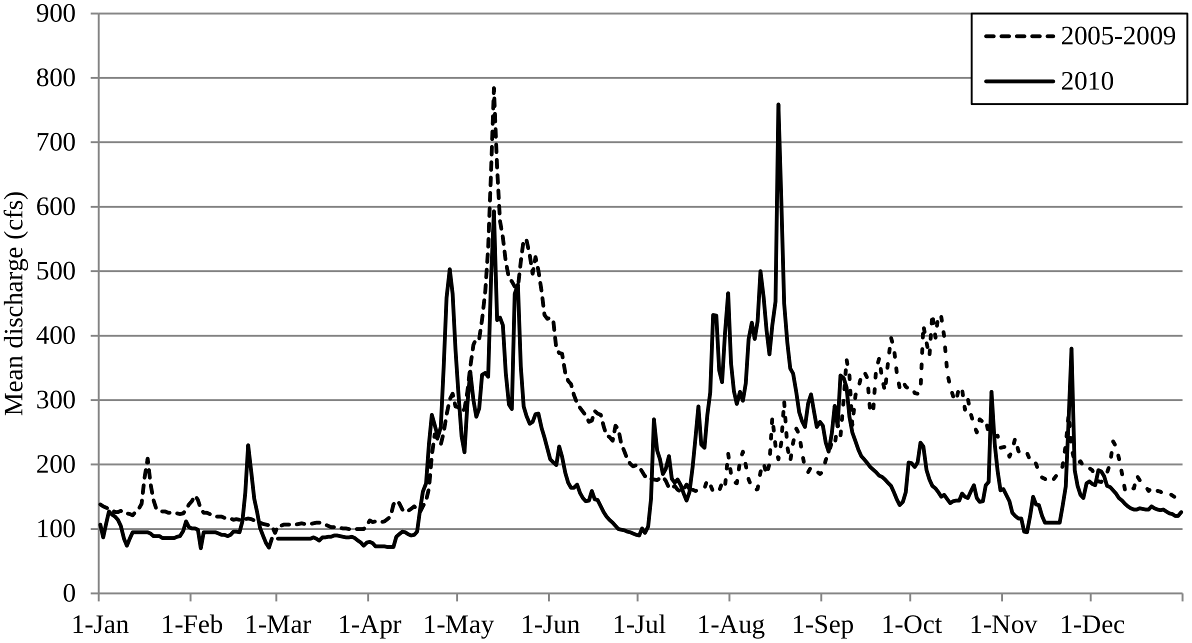

Figure 10. Mean daily discharge in cubic feet per second (cfs) from the United States Geological Survey gage on Upper Talarik Creek for 2005–2009 and 2010 (USGS 2013).

DISCUSSION

Using the Rosgen stream-channel classification system, all sample reaches are classified as C4 stream types in Glacial Trough valleys. The monitoring reaches used for the stream classification are a short segment of the entire stream. However, overflights and foot surveys suggest that the Rosgen C4 classification at the reach level is generally characteristic of the streams on a larger scale, especially in adjacent stream segments upstream and downstream of the monitoring reaches. Because the streams occur in similar geologic landscapes and climate with similar vegetation patterns, it is not unusual that they have the same classification. Additionally, having the same classification does not mean they are the same, but this fact suggests that they would respond similarly to like changes in their respective watersheds.

The monitored reaches and adjacent stream segments are riffle-pool channels with well-developed floodplains and point bar features. These alluvial C4 stream types are very susceptible to scour and erosion, and they can be significantly altered and rapidly destabilized by channel disturbances and changes in the flow or sediment regimes of the contributing watershed (Rosgen 1996b; Ward et al. 2008; Lord et al. 2009). For example, a net increase of flow in the streams will increase the sediment transport rate, alter deposition rates, and change the stream’s equilibrium. Changes to sediment transport and deposition rates could negatively affect spawning gravel quality and location (Meehan 1991; Waters 1995). This will be an important consideration in future monitoring and watershed planning. Biennial geomorphology measurements are sufficient to continue establishment of a dataset for baseline conditions, but annual or more frequent measurements and additional sites may be desired if flow rates or sediment regimes are altered in these streams.

The most prevalent, natural (i.e., stable) stream types for Glacial Trough valleys are Rosgen C or D channel types. Rosgen F or G channel types are most often observed in Glacial Trough valleys under disequilibrium conditions. Therefore, channel adjustments indicating a shift in stream type from a Rosgen C channel to an F or G channel type would indicate that enough disturbance has occurred in the watershed to exceed the stability threshold of the stream, resulting in degradation, aggradation, and other instability consequences.

Stream gages show that the three streams respond similarly to environmental conditions. Each stream exhibits an annual bimodal flow regime, with increases in runoff driven by spring freshets and fall precipitation. Based on stream discharge, measured bankfull area, and substrate size, the North Fork Koktuli River is the largest of the three systems and has the largest overall particle size. Streamflow in North Fork Koktuli River tends to be the most dynamic of the three streams, with large peaks in flow during precipitation or runoff events, while Upper Talarik Creek is characterized by more stable flow throughout the year, probably because of a greater influence from groundwater sources. Peak flows in the South Fork Koktuli River may be moderated somewhat by Frying Pan Lake.

3. PERIPHYTON

OVERVIEW

Periphyton consists of algae, fungi, bacteria, protozoa, and other organic matter that are found in streams growing on channel substrates, such as cobble and larger rocks. Periphyton are primary producers, or autotrophs, meaning they convert energy from the sun into autochthonous organic matter, which often forms the base of the stream food web. The presence of periphyton in a stream system is evidence of *in situ* productivity.

Periphyton are sensitive to changes in water quality and are often used in monitoring studies to detect early changes in aquatic communities because of their short life cycles and rapid reproduction rates (Barbour et al. 1999). Periphyton are sessile, meaning they stay in one location and either tolerate the existing physical conditions or die (Lowe and LaLiberte 2006). Periphyton are directly affected by the physical factors (i.e., flow, velocity, sediment load) and chemical factors (i.e., water quality) of the stream system they inhabit (Barbour et al. 1999).

Benthic algae are often the largest component of the periphyton community in a sunlit stream (Lowe and LaLiberte 2006). Benthic algae help support the stream food web, remove nutrients from the water column, and—on a micro-habitat scale—reduce current velocity and stabilize sediments (Allan and Castillo 2007). Proximate factors that may influence benthic algae and the periphyton community include light, nutrients, water chemistry, current velocity, temperature, availability of different substrate types, and the abundance of grazers (i.e., invertebrates and fish that consume algae off of rocks or the streambed).

Periphyton biomass can be monitored to detect changes in *in situ* productivity in waters downstream of the Pebble Prospect. Because chlorophyll-a is the most abundant pigment in plants and is proportional to the biomass, the absorbance of chlorophyll-a is often measured as a surrogate for biomass and referred to as *standing crop* (Allan and Castillo 2007). Measuring the chlorophyll-a concentrations over time will allow for long-term comparisons and the detection of any changes in primary productivity within the streams.

METHODS

Periphyton were sampled directly from submerged cobble, located in a riffle section of the stream, within each of the three biomonitoring locations. Sampling was scheduled during a time of moderate-to-low flow to ensure that the submerged cobble had been wetted continuously for the previous 30 days. The United States Environmental Protection Agency's (USEPA) Rapid Bioassessment Protocols for Streams and Wadeable Rivers were followed, but more replicates per site were used to increase sample precision (Barbour et al. 1999). This modified approach, described below, follows the protocols as detailed in Ott et al. (2010). Ten flat rocks, larger than 25 cm^2, were collected from a submerged riffle area of the streambed that was suspected to have been underwater for the previous 30 days. A 5 cm x 5 cm square of high-density flexible foam was placed in the middle portion of the rock. All material around the foam square was scrubbed with a toothbrush and rinsed from the rock with a squeeze bottle filled with clean water collected from the stream. This scrubbing process was repeated twice, with the toothbrush being rinsed clean between each step. The foam square was removed from the rock, and algae remaining on the rock was brushed with a clean toothbrush and rinsed with water into a filter receptacle with a 0.45 µm glass fiber filter. The rock was brushed and rinsed twice, and the material on the toothbrush was also rinsed onto the filter with clean stream water. Any material on the foam square, including that in contact with the rock, was not rinsed into the filter receptacle. The foam square was rinsed with clean water before being used on the next rock. Water was removed from the filter using a hand vacuum pump. After extracting most of the water (i.e., ¼ inch of water remains above the glass fiber filter), 3 to 5 drops of saturated $MgCO_3$ were added. Prior to use, the $MgCO_3$ bottle was shaken and the saturated liquid removed with an eye dropper and applied to the sample; care was taken to avoid applying solid $MgCO_3$ to the sample. The $MgCO_3$ was added while gently swirling the filter receptacle to ensure the entire sample received a light coating. Pumping continued until the water was gone and the filter began to wrinkle or appear dry. The $MgCO_3$ was added to prevent acidification and additional conversion of chlorophyll-a to phaeophytin. If the water was not moved through the filter within a few minutes, then a second glass fiber filter with another vacuum pump was used and excess water transferred to the second filter receptacle. Each additional filter required to collect the sample was preserved with $MgCO_3$ as outlined above. The receptacle on top of the vacuum pump was then removed and the glass filter folded over so the sample material was protected on the inside of the filter. If two filters were used, then these were placed face-to-face with the sample material on the inside and the two filters folded in half. Alternatively, multiple filters used for one rock were folded separately, as above, and stored together. The glass fiber filter(s) were then placed on a paper coffee filter, and the coffee filter was folded to completely cover the fiber filter(s). The dry coffee filters were used to absorb any residual water that may have been present. The filters were then placed in a properly labeled, sealable plastic bag, and silica gel desiccant was added. The sample bag was then placed in a cooler with ice in order to keep the filters cool and dark while in the field to prevent sample degradation. Immediately upon return to Iliamna, the samples were frozen, and they were kept frozen until analyzed. Periphyton samples were sent to the ADF&G office in Fairbanks and were processed in the exact manner described in Ott et al. (2010). In short, samples were analyzed using a spectrophotometer and a standardized reference solution derived from fresh spinach leaves. Total chlorophyll-a, -b, and -c were calculated using the tri-chromatic equation (American Public Health Association 1992).

Sample results are reported as a mean for each stream. A confidence interval (CI) of 95% was calculated for each mean by multiplying the standard error by 1.96, then adding and subtracting that value to and from the sample mean. Standard errors were calculated by dividing the standard deviations (SD) by the square root of the sample size (*n*). Standard deviations of the data were calculated for each stream using Microsoft Excel®.

RESULTS

Periphyton sampling was conducted on the SFK reach on August 4, 2010, the NFK reach on August 5, 2010, and the UT reach on September 1, 2010. In 2010, chlorophyll-a concentrations ranged from 0.64 mg/m^2 (SFK reach) to 38.98 mg/m^2 (UT reach) (Appendix 1). Mean chlorophyll-a concentrations were highest in the UT reach with 18.83 mg/m^2 (n = 10, SD = 15.06) (Figure 11). The NFK reach and SFK reach samples were similar, with mean chlorophyll-a concentrations of 3.30 mg/m^2 (n = 7, SD = 3.01) at the NFK reach and 2.50 mg/m^2 (n = 10, SD = 1.87) at the SFK reach. Although 10 samples were collected for each site, the laboratory deemed three samples from the NFK reach unsuitable for processing because of the excessive presence of algal macrophytes.

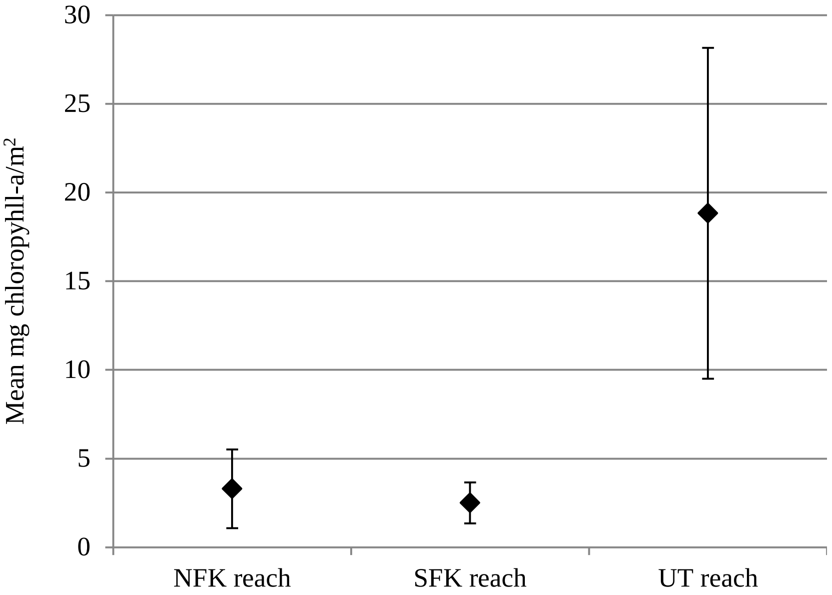

Figure 11. Mean chlorophyll-a concentrations ± 95% CI for North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches.

DISCUSSION

Chlorophyll-a concentrations indicate primary production is highest in the UT reach. This could be attributable to Upper Talarik Creek's more stable water flow through the year and across years or to the later date of the sample collection at this site. High water levels prohibited sampling of the UT reach in early August when the other two reaches were sampled. The stable flow in Upper Talarik Creek is likely linked to the influence of groundwater in this system, which provides for higher flows during the typical winter low-flow period exhibited by other streams in the region. Other factors unique to Upper Talarik Creek (e.g., water temperatures, stream geomorphology) are also likely influences on the higher primary production.

4. AQUATIC INVERTEBRATES

OVERVIEW

Aquatic invertebrates are ubiquitous in almost all streams and rivers. Examples of aquatic invertebrates include arthropods (insects, mites, scuds, crayfish, etc.), mollusks (snails, limpets, mussels, clams, etc.), annelids (segmented worms and leeches), nematodes (roundworms), and turbellarians (flatworms). Most invertebrates are benthic, meaning they spend all or part of their lifecycle near or attached to the different substrates located on the streambed (bedrock, cobble, finer sediments) or on other submerged surfaces (woody debris or vegetation). However, aquatic invertebrates do drift in the water column for multiple reasons, and these drifting invertebrates are an important food supply for fish, including salmonids. Taxa that regularly can be found drifting include Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies), Diptera (true flies, midges), and Amphipoda (scuds). In any stream system, there will be a volume of constant drift. Constant drift occurs when invertebrates become accidentally dislodged from their benthic substrate. Additional invertebrate drift occurs under certain undesirable conditions, such as high discharge or drought (Anderson and Lehmkuhl 1968), ice (Brittain and Eikeland 1988), avoidance of contaminants such as pesticides (Davies and Cook 1993; Schulz and Liess 1999), and oil spills (Miller et al. 1986), or other poor water quality conditions, such as low dissolved oxygen and changes in pH or temperature (Brittain and Eikeland 1988). Drift may also occur in times of heavy competition for food (Hildebrand 1974) or as a mode of predator avoidance (Peckarsky 1979, 1980; Flecker 1992; Lagarrigue et al. 2002). Regardless of the mechanism that causes it, drift is necessary for the dispersal of invertebrates throughout the stream system (Allan 1995).

Aquatic invertebrates are useful indicators of changing environmental conditions (Barbour et al. 1999; Hodkinson and Jackson 2005). Invertebrate taxa have varying degrees of tolerance to different environmental conditions (e.g., low dissolved oxygen, high turbidity, low pH) (Barbour et al. 1999; Hodkinson and Jackson 2005). Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), collectively known as EPT, are three of the most pollution-sensitive aquatic insect orders. The total number of EPT species in a given sample is often calculated and used as a measure of stream health (Resh and Jackson 1993; Resh 2008; Durst and Jacobs 2010). Other taxa, like Diptera (order) and Chironomidae (family), are considered moderately tolerant of impaired water quality (Barbour et al. 1999). The numbers of Diptera and Chironomidae are often included in studies because of their relative abundance in most streams and because their relative abundance is expected to increase in response to environmental perturbation (Barbour et al. 1999). Relative abundance, expressed as percentage of community composition, is preferred to absolute abundance because it captures some of the interaction among taxa (Plafkin et al. 1989; Barbour et al. 1999). Monitoring the number of sensitive (intolerant) taxa and tolerant taxa over time will help identify any trends in the overall condition of the stream and determine if any changes in water quality or land use are having observable effects on the stream biota. Also, the relative abundance of the most dominant taxon is a useful metric of redundancy within the invertebrate community; a high or increasing level of redundancy is typically indicative of the dominance of a pollution-tolerant organism and a decrease in diversity (Plafkin et al. 1989).

Because aquatic invertebrates are an important food source for fish (Groot and Margolis 1991; Bogan et al. 2012), changes observed in the invertebrate community can serve as early indicators of potential problems that may eventually affect fish.

METHODS

A modified version of the rapid bioassessment technique developed by the USEPA (Barbour et al. 1999) was used. The modification consists of more replicates to retain more quantitative features in the sampling program. Driftnets were used because they were the most effective method reported by Ott et al. (2010).

At each of the three monitoring sites, five driftnets were installed in riffle habitat with the open end of the net facing upstream. Nets were placed along a transect perpendicular to the flow (Figure 12) and were numbered from right (1) to left (5) looking downstream. All the streams sampled were wide enough to allow the placement of the five nets adjacent to each other. The driftnets used were 45.7 cm (18 in) wide by 30.5 cm (12 in) deep with 350 µm mesh size, and they were made of Nitex nylon, with stainless steel mesh for the collecting cod end. The driftnets were placed with the long edge on the stream bottom. The nets were placed adjacent to each other where possible, but small gaps existed if stake placement had to be altered to allow for placement around larger rocks, for example. The water depth at the inlet to the driftnet and the mean water velocity in the mouth of each net were measured with a flow meter and recorded to allow for invertebrate density calculations.

Figure 12. Driftnet configuration for macroinvertebrate sampling, South Fork Koktuli monitoring reach.

After one hour, the driftnets were removed and placed along the stream margin with the open end on the streambank and the cod end in the water to keep the sample wetted. Materials in the net were flushed into the cod end by splashing water on the outside of the net. After all debris and insects were rinsed from the net into the cod end, the water was decanted and the contents transferred to a labeled sample container. Ninety percent denatured ethanol was added to the containers to completely submerge and preserve the samples. This process was repeated for the remaining four nets. The five labeled sample containers were then placed in a plastic bag. Samples were packaged and brought back to Anchorage and then delivered to the University of Alaska, Alaska Natural Heritage Program – Aquatic Ecology laboratory for sorting and identification.

RESULTS

Invertebrate sampling was conducted on the SFK reach on August 3, 2010, the NFK reach on August 31, 2010, and the UT reach on September 2, 2010. In 2010, the density of aquatic invertebrates was highest in the SFK reach (13.04/m^3) and lowest in the UT reach (0.46/m^3) (Figure 13). The high density in the SFK reach reflects large numbers of copepods and cladocerans, which were not present in high numbers in the other two systems (Appendix 2).

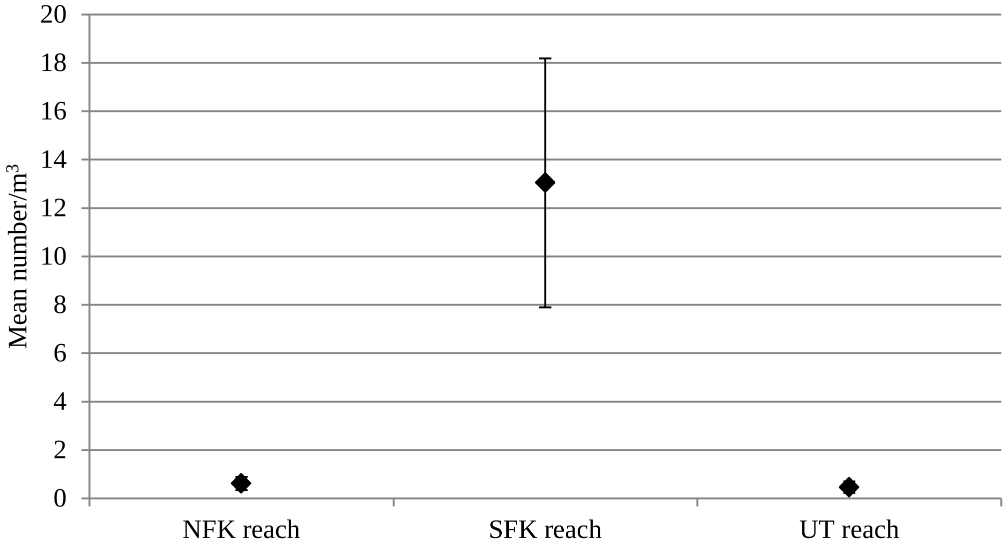

Figure 13. Mean aquatic invertebrate density per cubic meter ± 95% CI in North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches.

Taxa richness (number of unique taxa) for all aquatic invertebrates was 33 at the UT reach and NFK reach and 31 at the SFK reach. EPT taxa richness was also similar across sites with 13 taxa at the UT reach and NFK reach and 12 taxa at the SFK reach (Appendix 2).

The SFK reach had the highest abundance of EPT (567 organisms) but the lowest percent composition of EPT (6.0%) (Table 4). The SFK reach also had the highest relative abundance (4,191 organisms) and greatest percent composition (44.2%) of a single dominant aquatic taxon (Table 4). The SFK reach's dominant taxon was the order Cladocera. The SFK reach had the highest abundance yet lowest percent composition of Ephemeroptera (169 organisms; 1.8%) and Plecoptera (348 organisms; 3.7%); the SFK reach also had the lowest abundance and lowest percent composition of Trichoptera (50 organisms; 0.5%) (Table 4; Figure 14). The NFK reach (36.9%) and UT reach (38.6%) show similar percent composition of EPT, with the NFK reach having a greater percentage of Ephemeroptera and a lower percentage of Trichoptera than the UT reach (Table 4; Figure 14). The NFK reach (4.5%) and UT reach (5.7%) had similar percent composition of Plecoptera (Table 4; Figure 14). The dominant taxon in the NFK reach was Podocopa, a subclass of Ostracoda, and in the UT reach the dominant taxon was Orthocladinae, a subfamily of Chironomidae (Table 4).

Table 4. Percent composition and total abundance (in parenthesis) of Ephemeroptera, Plecoptera, Trichoptera (EPT), and dominant taxon from driftnet samples.

	NFK reach	SFK reach	UT reach
EPT taxa	36.9% (255)	6% (567)	38.6% (224)
Ephemeroptera	23.3% (161)	1.8% (169)	13.6% (79)
Plecoptera	4.5% (31)	3.7% (348)	5.7% (33)
Trichoptera	9.1% (63)	0.5% (50)	19.3% (112)
Dominant taxon	15.5% (107)	44.2% (4,191)	12.8% (74)

Note: NFK reach = North Fork Koktuli monitoring reach; SFK reach = South Fork Koktuli monitoring reach; UT reach = Upper Talarik monitoring reach.

Note: Invertebrates were identified to the lowest practical taxonomical level.

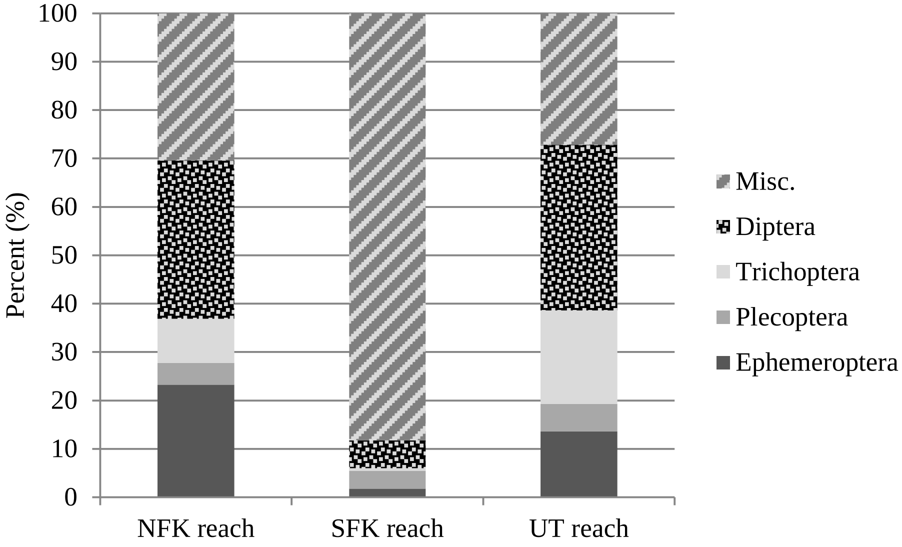

Figure 14. Aquatic invertebrate community composition in North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches.

Ephemeroptera make up the largest percentage of the EPT community in the NFK reach, Plecoptera are the largest percentage in the SFK reach, and Trichoptera are the largest percentage in the UT reach (Figure 15). EPT composed a greater percentage of the community than Chironomidae at all three monitoring sites (Figure 16). The SFK reach had the lowest percentages of both EPT (6.0%) and Chironomidae (5.4%). Chironomidae composition was similar in the NFK reach (23.6%) and UT reach (19.3%) (Figure 16).

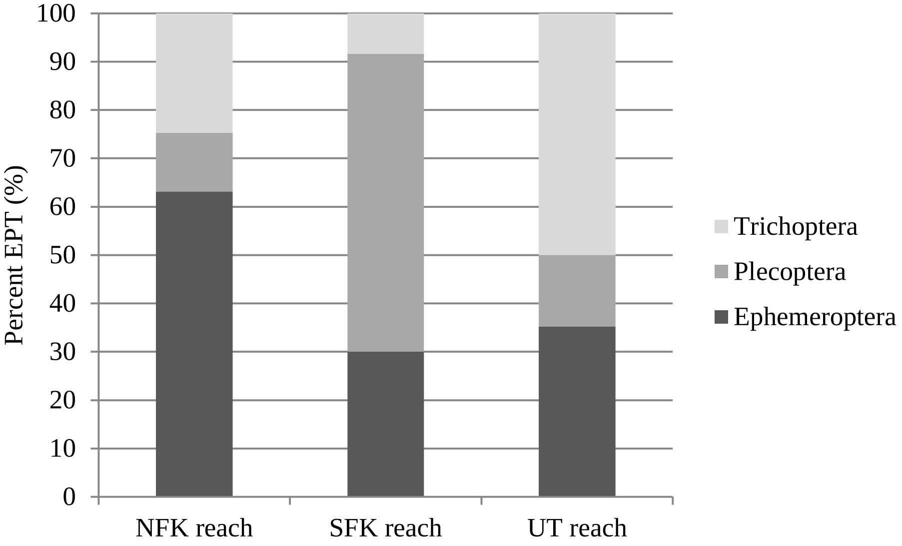

Figure 15. Aquatic invertebrate Ephemeroptera, Plecoptera, and Trichoptera (EPT) composition in North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches.

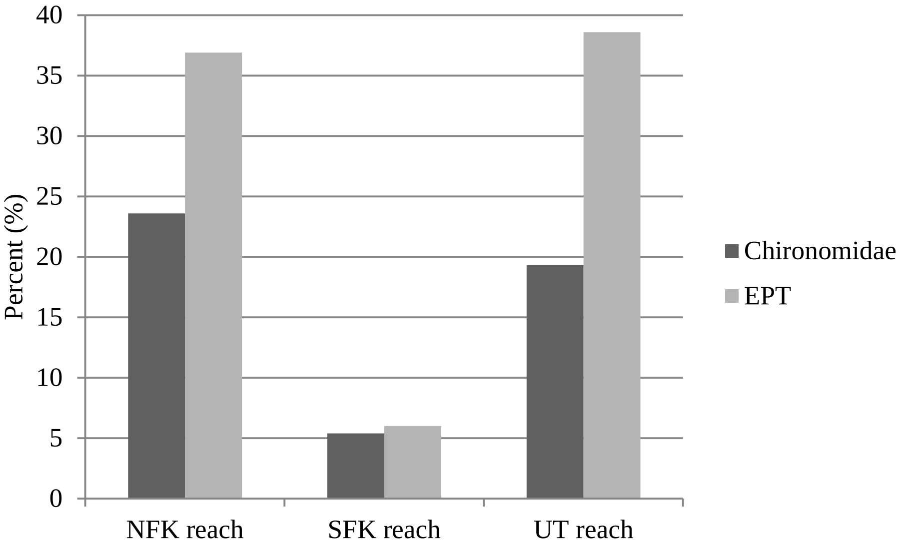

Figure 16. Percent Chironomidae and percent Ephemeroptera, Plecoptera, and Trichoptera (EPT) in North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches.

Mean velocity in front of the driftnets, measured in feet per second (fps), was the same at the NFK reach and UT reach (2.07 fps), and lower at the SFK reach (1.65 fps) (Figure 17). Depth at the NFK reach and UT reach was the same (0.78 ft), while depth at the SFK reach was slightly lower (0.60 ft).

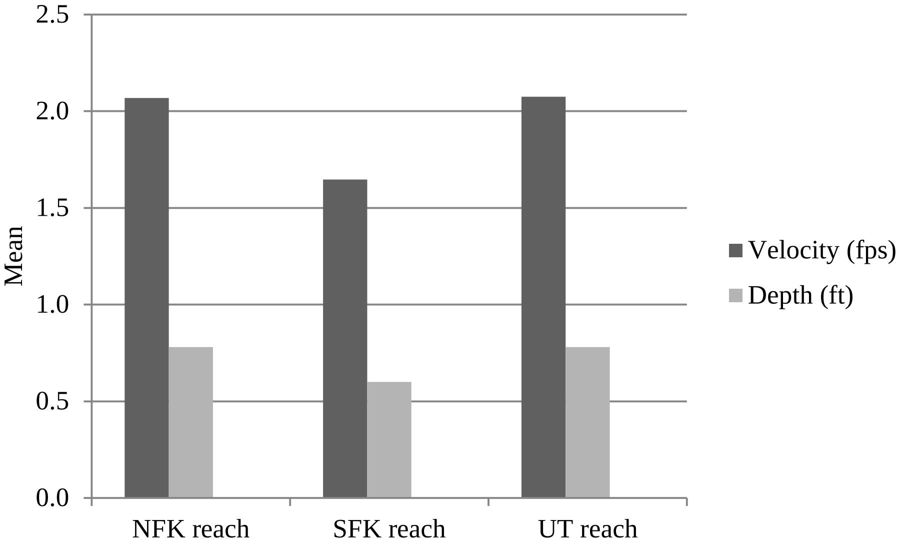

Figure 17. Mean water velocity (feet per second) and depth (feet) in front of driftnets used for invertebrate sample collection in North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches.

DISCUSSION

The NFK reach and UT reach were similar in invertebrate abundance and density, invertebrate taxa richness, EPT abundance and percent composition, and Chironomidae abundance and percent composition. The SFK reach had the highest invertebrate abundance and density yet the lowest taxa richness. The SFK reach also has the greatest abundance of EPT but lowest percent composition of EPT. EPT and chironomid abundance at the SFK reach was more than double the abundance at both the NFK reach and UT reach combined (Appendix 2). However, EPT percent composition at the SFK reach are masked by high numbers of other taxa, such as cladocerans and copepods, which are probably attributable to the proximity of Frying Pan Lake. The SFK reach also had the highest total EPT taxa count and the highest percentage of dominant aquatic taxa by more than double the other two monitoring reaches (Table 4).

Taxa richness was similar across sites with a range between 31 and 33 taxa. A similar study, conducted by Bogan et al. (2012) of wadeable streams in the Lake Iliamna watershed and the Mulchatna watershed, using D-net kick and jab collection methods, showed a mean of 17 taxa per stream in the Lake Iliamna watershed and 25 taxa per stream in the Mulchatna watershed. The overall range in taxa richness for both watersheds was 9–37. PLP also conducted an assessment of taxa richness at 17 sites near the Pebble Project, over a period of three years, using driftnets, Alaska Stream Condition Index kick net, and Surber methods. Not all 17 sites were sampled every year. Results ranged from 3 to 31 taxa (PLP 2011, Chapter 15).

The percentage of EPT was similar in the UT reach (38.6%) and NFK reach (36.9%) and much lower in the SFK reach (5.4%), compared with a range of 0% to 91% EPT in the study by PLP (2011, Chapter 15). Oswood (1989) summarized data from multiple studies (using multiple methods) of interior Alaskan streams and rivers and found EPT percentages ranging from 16.9% (Northwest region) to 27.7% (Yukon region). Studies from the Southwest region of Alaska were not included, but Oswood (1989) reported EPT percentages for Southcentral Alaska at 25.6%. The percentage of Chironomidae was similar between the UT reach (19.3%) and NFK reach (23.6%) and lowest in the SFK reach (5.4%) in 2010 using driftnets, compared with a range of 0% to 99% reported by PLP (2011, Chapter 15).

It is important to understand that locations in these monitoring studies vary in stream order, elevation, and sometimes habitat type. Additionally, sites with lower percentages of EPT may have a similar abundance of EPT organisms as the other locations, but the percentages are skewed by high abundance of other organisms. This was true for the SFK reach in our monitoring study. The PLP (2011, Chapter 15), Oswood (1989), and Bogan et al. (2012) studies also utilized different macroinvertebrate collection methods during different seasons than our 2010 biomonitoring methods and are not directly comparable, but they do provide some reference for general comparisons.

5. METALS CONCENTRATIONS IN FISH

OVERVIEW

Water bodies in the region of an ore deposit can exhibit higher than normal background metals concentrations. These water bodies may naturally exceed water quality standards (Runnels et al. 1992; USGS 1996; Kelley and Taylor 1997; Graham and Kelley 2009). Mining activities have the potential to further elevate metals concentrations (Ripley et al. 1996; Brumbaugh et al. 2007; Nabi Bidhendi et al. 2007), which can have deleterious effects on fish (Baldwin et al. 2003; Farag et al. 2003; Holm et al. 2005; Harper et al. 2009; McIntyre et al. 2012). The toxicity of metals on different species of fish varies; toxicity may be acute or chronic and may impair a host of physiological functions as well as behavior. Copper is perhaps one of the most well-studied metals for its effects on salmonids, and it has been shown to cause decreased growth and changes in olfactory responses, swimming performance, and avoidance behavior (Scannell 2009).

Metals concentrations can be monitored through water quality samples and fish tissue analysis. While both methods have their merits, sampling fish tissue may provide a more integrative assessment of background metals concentrations prior to mine construction and operation. Fish tissue analysis also includes measures of fish condition, such as percent solids and percent lipids (Post and Parkinson 2001; Weber et al. 2003; Hanson et al. 2010; Rinella et al. 2012). Lipid storage (fat reserves) is essential for many physiological functions, notably for overwintering (Cunjak 1988; Thompson et al. 1991; Cunjak et al. 1998; Biro et al. 2004), sexual maturity (Silverstein et al. 1997; Shearer and Swanson 2000), and migration (Cooke et al. 2006). Percent solids represent the non-water content (dry weight) of the fish and include constituents such as fat reserves, protein, carbohydrates, and ash. Dry weight can be used as an index of fish condition because it directly relates to nutritional reserves of the fish (Sutton et al. 2000).

To monitor the naturally occurring levels of metals in fish, it is important to sample fish that have been in the study area for a known period of time. Anadromous species, such as salmon, present problems because the adults travel extensive distances through the marine environment to reach their natal streams. Metals concentrations in adult salmon cannot be exclusively attributed to the time spent within the study area. While it is unknown if Dolly Varden *Salvelinus malma* in these systems are resident or anadromous, anadromous Dolly Varden do not migrate out of freshwater for several years, making juvenile Dolly Varden a suitable species for sampling. The objectives of the juvenile fish sampling are to determine the baseline of naturally occurring metals concentrations in fish that have reared in each monitoring reach.

METHODS

Juvenile Dolly Varden were collected in each of the three monitoring reaches using 10 minnow traps baited with salmon eggs (Figure 18). Late summer or early fall is the preferred time to sample because it allows juvenile Dolly Varden to have the maximum residency time within the monitoring reach before moving to overwintering areas.

Figure 18. Baited minnow trap deployed in a monitoring reach.

Whirlpacks were used as bait sacks and filled with commercially available salmon roe. Minnow traps were baited by perforating the sac at the time the traps were set and securing them in the minnow trap. Rocks from the streambed were placed inside each minnow trap both to anchor the trap and to provide refuge for captured fish. Traps were numbered, marked with flagging, and placed in the stream in moving water. Backwater areas and pools were avoided because juvenile Dolly Varden prefer higher-velocity water.

Traps were fished for as close to 24 hours as logistics allowed. Traps were checked starting with the most downstream trap to minimize the chance of recapturing the same fish in a subsequent trap. For each reach, a maximum of 15 juvenile Dolly Varden, between 90 and 140 mm fork length (FL), were retained for whole-body metals analyses. Fish were selected from this length range to ensure that minimum weight requirements for laboratory analyses were met and to minimize age-related variability. Those fish retained for metals analyses were measured in millimeters to fork length using a measuring board and weighed individually with a digital scale to the nearest tenth of a gram. All fish not retained were returned to the sample reach. Retained fish were handled with nitrile gloves, and each fish was placed individually in a numbered sealable plastic bag and stored in an insulated cooler with an ice pack.

Juvenile Dolly Varden were transported back to Iliamna, where they were immediately frozen. Fish were then packaged and shipped to Anchorage, where they were placed in the freezers at the ADF&G office. The fish were kept in their sealed bags in a sealed container in the freezer at ADF&G until prepared for shipment to Columbia Analytical Services, Inc. for analyses. ADF&G maintained written chain of custody for the samples. At the laboratory, whole-body fish samples were homogenized, freeze-dried, and ground prior to metals analyses.

Juvenile Dolly Varden were tested for the following metals concentrations: antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, silver, thallium, and zinc. Additionally, total percent solids and percent lipids were measured for each fish to assess body condition. Metal concentrations were calculated on a dry-weight basis, and percent lipids and solids were calculated on a wet-weight basis. Columbia Analytical Services, Inc. performed the analyses according to their National Environmental Laboratory Accreditation Program–approved quality assurance program.

For samples with metal concentrations below their respective Method Detection Limit (MDL), half the MDL was used during calculations and comparisons. Two-sample *t*-tests with Bonferonni's correction were conducted using Microsoft Excel® to compare the concentrations of certain metals between stream reaches and identify significant differences.

RESULTS

Fish sampling occurred between August 30 and September 2, 2010. Fifteen juvenile Dolly Varden were collected from the SFK reach; fewer than 15 fish were collected from the NFK reach (14) and UT reach (10). In general, metals concentrations from fish in the UT reach were lower than those of fish from the NFK reach and SFK reach; fish from the UT reach had the lowest mean concentrations of all metals except for antimony and mercury (Table 5, Figure 19).

Mean concentrations of beryllium, chromium, mercury, nickel, silver, and zinc were highest in fish from the NFK reach; arsenic, cadmium, copper, lead, molybdenum, selenium, and thallium were highest in fish from the SFK reach; only antimony was highest in fish from the UT reach (Table 5, Figure 19). Four of the metals tested resulted in fish with concentrations below their respective MDL: antimony (62% of samples tested were below MDL), beryllium (15% of samples tested were below MDL), selenium (8% of samples tested were below MDL), and silver (87% of samples tested were below MDL) (see Appendix 3). Zinc concentrations were an order of magnitude higher than the next highest metals, which were copper and chromium (Table 5, Figure 19).

Cadmium concentrations at the SFK reach were significantly different than the NFK reach and UT reach (Table 6). Selenium concentrations at the UT reach were significantly different than the NFK reach and SFK reach (Table 6).

Table 5. Means and SD (in parenthesis) of whole-body metals concentrations (mg/kg) and body condition (percent) in juvenile Dolly Varden from North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches.

Metal	NFK reach	SFK reach	UT reach
Antimony (Sb)	0.024 (0.030)[a]	0.030 (0.041)[a]	0.038 (0.041)[a]
Arsenic (As)	1.05 (0.75)	1.39 (1.63)	0.64 (0.33)
Beryllium (Be)	0.037 (0.030)[a]	0.030 (0.035)[a]	0.024 (0.021)[a]
Cadmium (Cd)	0.029 (0.011)	0.142 (0.067)	0.019 (0.007)
Chromium (Cr)	7.09 (6.14)	5.69 (5.75)	4.54 (5.90)
Copper (Cu)	5.50 (1.71)	8.13 (4.86)	3.64 (0.79)
Lead (Pb)	0.368 (0.317)	0.808 (0.874)	0.187 (0.119)
Mercury (Hg)	0.109 (0.022)	0.044 (0.016)	0.080 (0.031)
Molybdenum (Mo)	0.257 (0.204)	0.473 (0.400)	0.234 (0.254)
Nickel (Ni)	2.55 (1.82)	1.93 (1.45)	1.52 (1.20)
Selenium (Se)	2.5 (0.5)	3.7 (1.0)	0.8 (0.7)[a]
Silver (Ag)	0.013 (0.007)[a]	0.011 (0.004)[a]	0.011 (0.004)[a]
Thallium (Tl)	0.025 (0.010)	0.036 (0.017)	0.023 (0.016)
Zinc (Zn)	109.8 (23.5)	106.1 (14.5)	101.5 (16.8)
% Solids	23.5 (2.0)	23.8 (1.7)	23.7 (1.8)
% Lipids	2.5 (0.9)	3.1 (1.1)	3.2 (1.3)

Note: Metals concentrations were calculated on a dry-weight basis; percent solids and lipids were calculated on a wet-weight basis.

[a] Includes samples where half the Method Detection Limit was used to calculate values for metal concentrations below their respective limit.

Table 6. *P*-values for comparisons of select metals for North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches at α = 0.05.

Metal	NFK reach and SFK reach	SFK reach and UT reach	NFK reach and UT reach
Cadmium	**0.00000120**	**0.00000816**	0.02187497
Copper	0.06592717	0.00858549	0.00444425
Selenium	0.00049848	**0.00000004**[a]	**0.00000089**[a]
Zinc	0.60482628	0.47049622	0.34572349

Note: Significant differences (indicated in bold) were determined using Bonferroni's correction for a family of three tests.

[a] Contains values where half the Method Detection Limit was used for samples below their respective limits.

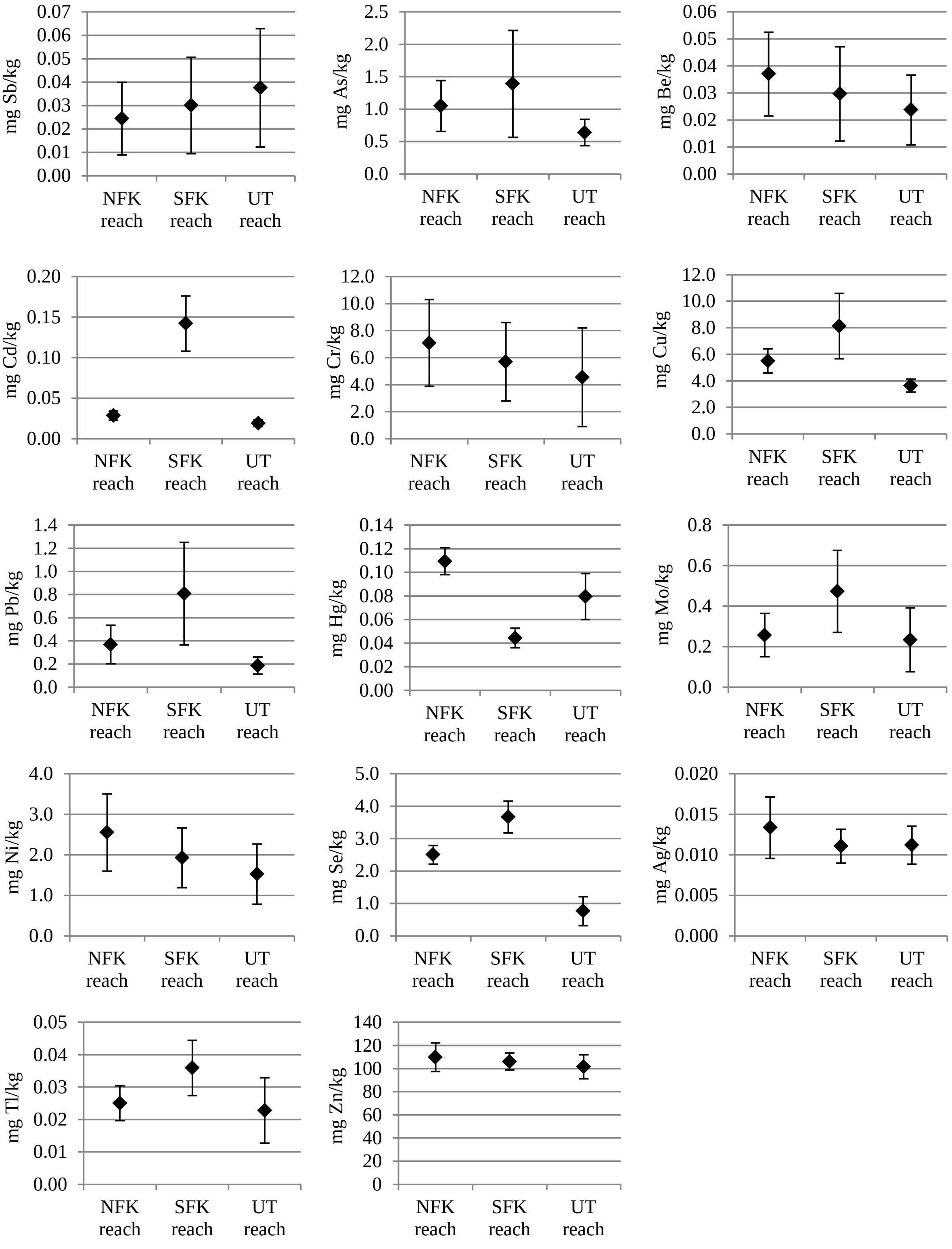

Figure 19. Mean concentrations (mg/kg) ± 95% CI of antimony (Sb), arsenic (As), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), molybdenum (Mo), nickel (Ni), selenium (Se), silver (Ag), thallium (Tl), and zinc (Zn) in juvenile Dolly Varden from North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches.

Mean percent solids content was nearly identical, about 24%, for all three stream reaches. Mean lipid content was similar between the SFK reach and UT reach, and lower in the NFK reach (Table 5, Figure 20).

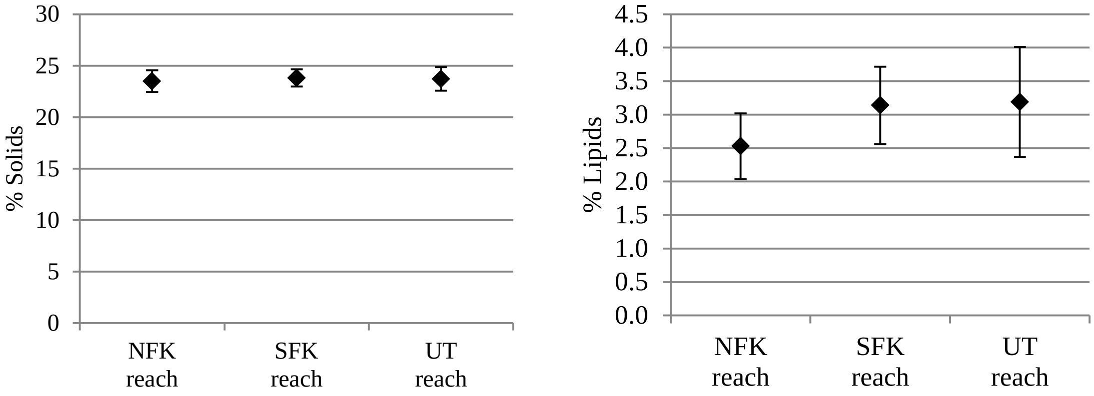

Figure 20. Mean percent ± 95% CI solid and lipid composition of juvenile Dolly Varden from North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches.

DISCUSSION

Fish captured in the UT reach had the lowest mean concentrations of all metals, except for antimony and mercury. This result suggests that Upper Talarik Creek may be the least affected by natural background levels of metals from the nearby ore deposit. This could be because of distance from the ore deposit or localized variations in geology and hydrology between the three drainages.

Concentrations of metals were compared to the data available in the Pebble Project Environmental Baseline Document (Pebble EBD), which includes data from juvenile Dolly Varden in the North Fork Koktuli River and Upper Talarik Creek for 2004 and 2005 (PLP 2011, Appendix 10.3A). Although the years and exact sampling locations differ, the same 14 metals were analyzed and found to show similarities in the range of results.

We are particularly concerned with copper, cadmium, selenium, and zinc, because of their potential toxicity to salmonids and their potential to enter water bodies from mining activities. The USEPA lists each of these metals as Priority Pollutants (USEPA 2002), and mining activities can lead to their increased concentrations in water (Eisler 1993; USEPA 2004; Mebane 2006). USEPA aquatic life criteria are reported as concentrations of pollutants in water and therefore cannot be directly compared to reported metals concentrations based on whole-body homogenizations of juvenile Dolly Varden.

Copper

The Pebble Deposit is characterized as a porphyry copper deposit (PLP 2011, Chapter 1). The Pebble EBD reports the presence of copper-rich bedrock in the headwaters of South Fork Koktuli River (PLP 2011, Chapter 10) which probably accounts for Dolly Varden from the SFK reach having the highest mean copper concentrations (8.13 mg/kg) of all three reaches. Although the Pebble EBD also reports an area rich in copper beneath a short reach near the headwaters of

Upper Talarik Creek (PLP 2011, Chapter 10), mean copper concentrations in fish from the UT reach were lower than fish from the NFK reach and SFK reach. However, no significant differences were found among stream reaches for mean copper concentrations in fish at ADF&G monitoring sites (Table 6).

A United States Geological Survey report on porphyry copper deposits lists copper as one of the elements most likely to result in issues for aquatic ecosystems from mining (John et al. 2010). Copper is perhaps one of the more studied metals. Scannell (2009) presents a literature review of copper effects on aquatic species. Most of the fish studies in this review focused on salmonids and showed the effects of chronic toxicity to include decreased growth and changes in olfactory responses, swimming performance, and avoidance behavior, among others.

Cadmium

Cadmium is a rare heavy metal that can often be found with copper and zinc (Mebane 2006). At ADF&G biomonitoring reaches, mean cadmium concentrations in fish from the SFK reach were significantly higher than fish from the NFK reach and UT reach (Table 6).

Acute toxicity from cadmium in fish largely affects ion regulation, whereas chronic toxicity is wide ranging and can affect ion regulation, oxidation, growth, survival, reproduction, immunity, endocrine function, histopathology, and behavior (McGeer et al. 2012). The USEPA (2001) found salmonids to be among the most acutely sensitive freshwater animal species to cadmium.

Selenium

Selenium naturally occurs with sulfide minerals, including copper (Eisler 1985; USEPA 2004). At ADF&G biomonitoring reaches, mean selenium concentrations in fish from the UT reach were significantly lower than fish from the NFK reach and SFK reach (Table 6).

In 2004, the USEPA proposed new chronic criteria for aquatic organisms regarding selenium, but new standards have not yet been formalized (USEPA 2004). The literature indicates there is still debate regarding guidelines for when selenium concentrations will start to negatively affect freshwater fish (Hamilton 2003). Selenium uptake by fish is dietary, and it is known to bioaccumulate in aquatic ecosystems. Selenium can be transferred to eggs maternally where, at certain concentrations, it is known to negatively affect salmonid embryo and larval development (USEPA 2004; Janz 2012). Holm et al. (2005) showed that effects to rainbow trout include craniofacial, skeletal, and fin defects, and edema. Fish have a narrow range where selenium surpasses essential needs and becomes very toxic (USEPA 2004; Janz 2012).

Zinc

There were no significant differences among stream reaches for mean zinc concentrations in fish at ADF&G monitoring sites (Table 6). Zinc is another of the metals listed by John et al. (2010) as being of concern for aquatic ecosystems from mining porphyry copper deposits. The toxicity of zinc to fish appears inversely related to water hardness (USEPA 1987; Hogstrand 2012). Toxicity is higher when uptake occurs from water through the gills, rather than from dietary means, and acute effects often concern the gills and their related functions (Hogstrand 2012).

Percent solids and percent lipids were similar across all sites, indicating Dolly Varden had similar levels of health and body condition. Percent solids in juvenile Dolly Varden collected from the ADF&G monitoring sites were similar to other juvenile Dolly Varden sampled throughout the state at other large mining projects (Kanouse 2012; Ott and Morris 2012; Timothy and Kanouse 2012). The Pebble EBD also reported similar percent solids for the juvenile Dolly Varden tested from North Fork Koktuli River and Upper Talarik Creek in 2004 and 2005 (PLP 2011, Appendix 10.3A).

Two of the juvenile Dolly Varden collected and tested for metals concentrations at the SFK reach were outside of the 90 to 140 mm target range (#SFK5 measuring 144 mm and #SFK12 measuring 148 mm). Two-sample *t*-tests were conducted comparing the concentrations of metals in these two fish to the other 13 fish collected at the SFK reach, and no statistical differences ($p > 0.05$) were found. The lack of statistical difference could be because of the relatively small sample size. However, the two Dolly Varden measuring over 140 mm appear to belong to the same age class as those measuring just below 140 mm (see next section [6. Fish Presence] for age class information and nomenclature).

6. FISH PRESENCE

OVERVIEW

Fish sampling was conducted to assess the use of streams by resident and anadromous species of fish (Figure 21). Collecting basic presence/absence data will help establish a baseline record of distribution and species composition. Additionally, fish condition (based on weight and length measurements) was recorded so that fish condition may be assessed over time. In 2010, juvenile fish were sampled concurrent with the collection of Dolly Varden for analysis of metals concentrations; however, emphasis was on the collection of Dolly Varden, and the presence of other fish was a secondary objective.

METHODS

Fish were captured at each monitoring reach using minnow traps. Fish capture and handling methods are the same as the methods listed in the previous section (5. Metals Concentrations in Fish). Ten minnow traps were set and retrieved in each stream reach. Traps were set to fish, or soak, for as close to 24 hours as site logistics allowed. Fish captured in the minnow traps were counted, identified, measured to fork length (for salmonids) or total length (for species with rounded tails, e.g. sculpin species), weighed, and then released back into the stream, unless they were retained for metals analyses. Identification of juvenile salmonids was carried out according to the Field Identification of Coastal Juvenile Salmonids (Pollard et al. 1997). Sculpin species (genus *Cottus*) were identified to species when possible but were considered as one group (sculpin species) for data analysis and presentation.

Figure 21. Fish sampling in Upper Talarik Creek.

Within each stream, length frequency histograms and mean fork lengths were calculated for all species captured (total length is reported for sculpin species). Catch per unit effort (CPUE) was calculated for coho salmon, Dolly Varden, and Chinook salmon by dividing the total catch per stream reach (C_t) by the total number of hours fished (cumulative of all traps; H_t) and multiplied by 24 for an average and normalized trap catch of fish per day (shown below). Data analyses were performed using Microsoft Excel®.

$$CPUE = \frac{Ct}{Ht} \times 24$$

Fork lengths (mm) and weights (g) of fish measured were used to calculate Fulton's condition factor (K) using the equation given in Anderson and Neumann (1996), where the wet weight of each fish measured in grams (W) is divided by the cubed fork length of fish (L) measured in millimeters, and the product is multiplied by 100,000, as follows:

$$K = \frac{W}{L^3} \times 100{,}000.$$

RESULTS

Sampling occurred within each stream reach between August 30 and September 2, 2010. Minnow traps soaked for about 21 hours at the NFK reach and about 18 hours at the SFK reach and UT reach. A total of five fish species were captured during this sampling effort, including coho salmon, Chinook salmon, Dolly Varden, rainbow trout, and sculpin species. Some of the larger sculpin captured were positively identified as slimy sculpin *C. cognatus*, while some other sculpin captured were not quickly identified to species and could have been either slimy or coastrange sculpin *C. aleuticus*. Species composition varied slightly by stream reaches (Table 7). Juvenile coho salmon, Dolly Varden, and Chinook salmon were present in all three stream reaches and were the only species collected in the SFK reach. All five species were collected in the UT reach, and all five species except rainbow trout were captured in the NFK reach.

An accurate length measurement could not be obtained on two coho salmon from the UT reach due to poor fish condition. Weights were not obtained on all fish captured because of inconsistencies in the field, but weights were obtained on all Dolly Varden retained for metals analyses (see previous section [5. Metals Concentrations in Fish]).

Dolly Varden lengths from all three monitoring reaches ranged from 48 to 159 mm (FL); only larger fish (>89 mm) were captured in the UT reach (Figure 22). Coho salmon lengths ranged from 43 to 125 mm, with most fish ≤100 mm (Figure 23). Chinook salmon lengths ranged from 86 to 144 mm; sample size was small (*n* = 15) (Figure 24). Sculpin species lengths (total) ranged from 50 to 95 mm (Figure 25).

Coho salmon CPUE (fish/day) ranged from 3.9 to 17.5 per trap and was highest in the UT reach (Table 8). Dolly Varden CPUE ranged from 1.6 to 7.4 and was highest in the NFK reach (Table 8). Chinook salmon CPUE was low (<1.1) in all three stream reaches (Table 8).

Coho salmon and Dolly Varden weight-length data, presented in Figures 26 and 27, show similar growth rates among species across drainages. Fulton's condition factor (*K*) for juvenile coho salmon was 1.53 in the NFK reach and 1.16 in the UT reach (Table 9). Juvenile coho salmon were not weighed during fish collection from the SFK reach. Dolly Varden had condition factors ranging from 0.87 (SFK reach) to 0.96 (NFK reach) (Table 9).

Table 7. Mean fork length of fish captured in minnow traps, by species.

	NFK reach		SFK reach		UT reach	
Fish species	*n*	Mean FL (mm)	*n*	Mean FL (mm)	*n*	Mean FL (mm)
Coho salmon	34	59.5	59	71.5	133	83.3[a]
Chinook salmon	6	96.7	8	116.8	1	110.0[b]
Dolly Varden	65	107.2	34	106.3	12	118.8
Rainbow trout	0	-	0	-	1	124.0[b]
Sculpin species[c]	10	61.8	0	-	19	77.4

Note: NFK reach = North Fork Koktuli monitoring reach; SFK reach = South Fork Koktuli monitoring reach; UT reach = Upper Talarik monitoring reach; *n* = sample size; FL = fork length.

[a] FL could not be obtained on two fish because of poor fish condition. Mean FL calculated using 131 coho salmon.

[b] One fish captured at this site. Mean FL represents measurement of individual fish.

[c] Mean total length reported for sculpin species.

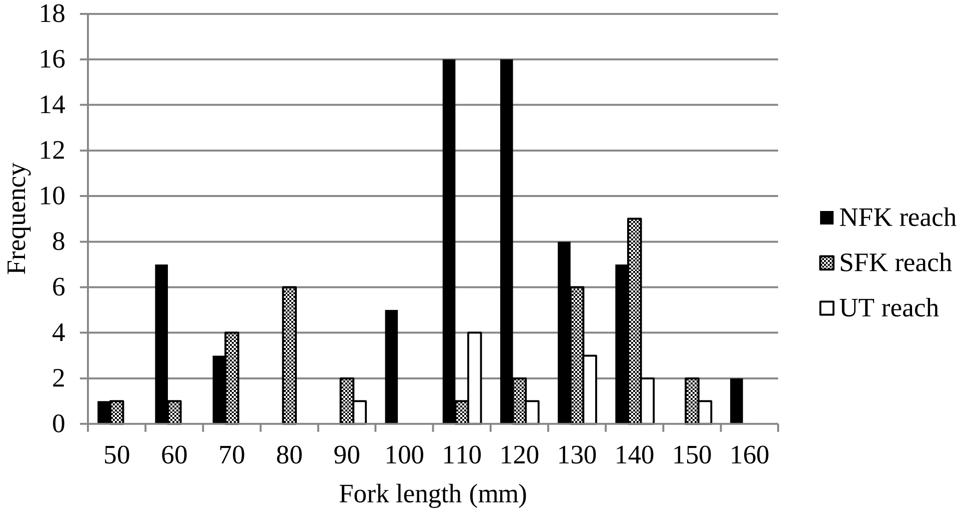

Figure 22. Length frequency distribution of Dolly Varden caught in North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches.

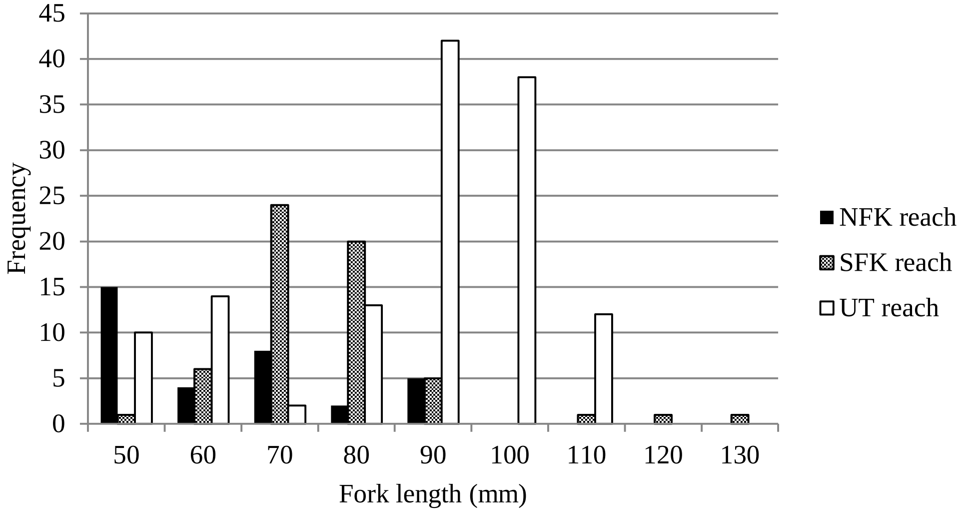

Figure 23. Length frequency distribution of coho salmon caught in North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches.

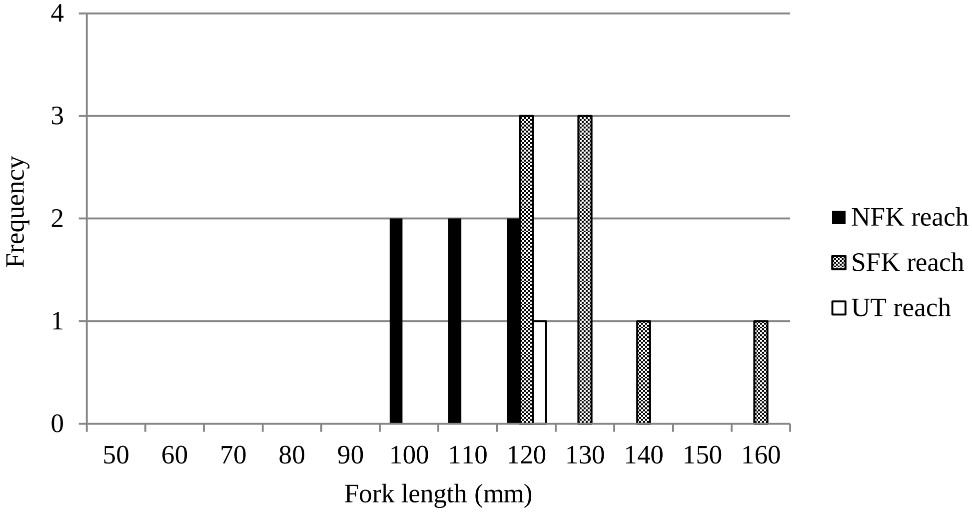

Figure 24. Length frequency distribution of Chinook salmon caught in North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches.

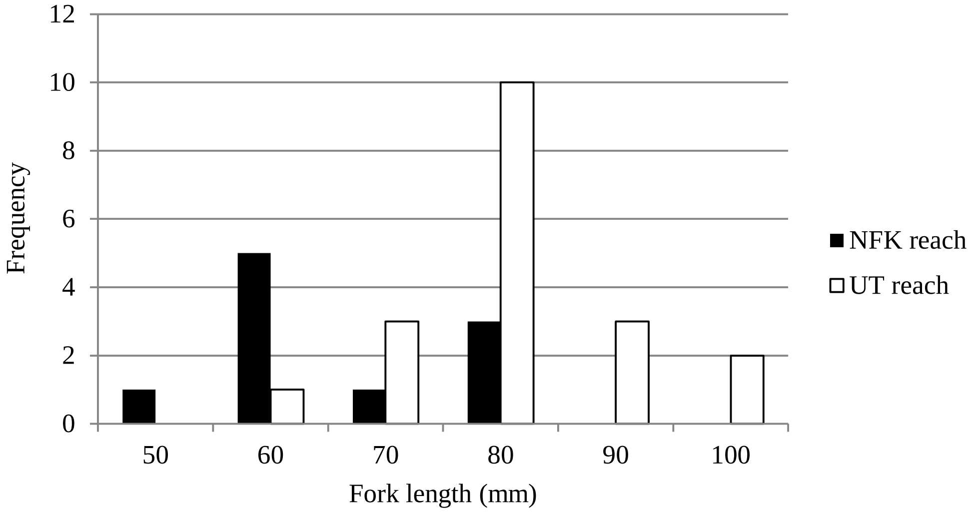

Figure 25. Length frequency distribution of sculpin species (slimy or coastrange) caught in North Fork Koktuli (NFK reach) and Upper Talarik (UT reach) monitoring reaches.

Table 8. Minnow trap CPUE (fish/day) for the three fish species common to all monitoring reaches.

Stream reach	Coho salmon	Dolly Varden	Chinook salmon
North Fork Koktuli	3.85	7.36	0.68
South Fork Koktuli	7.72	4.45	1.05
Upper Talarik	17.46	1.58	0.13

Note: CPUE calculated by dividing total catch per stream reach by the total number of hours fished (cumulative of all traps) and multiplied by 24.

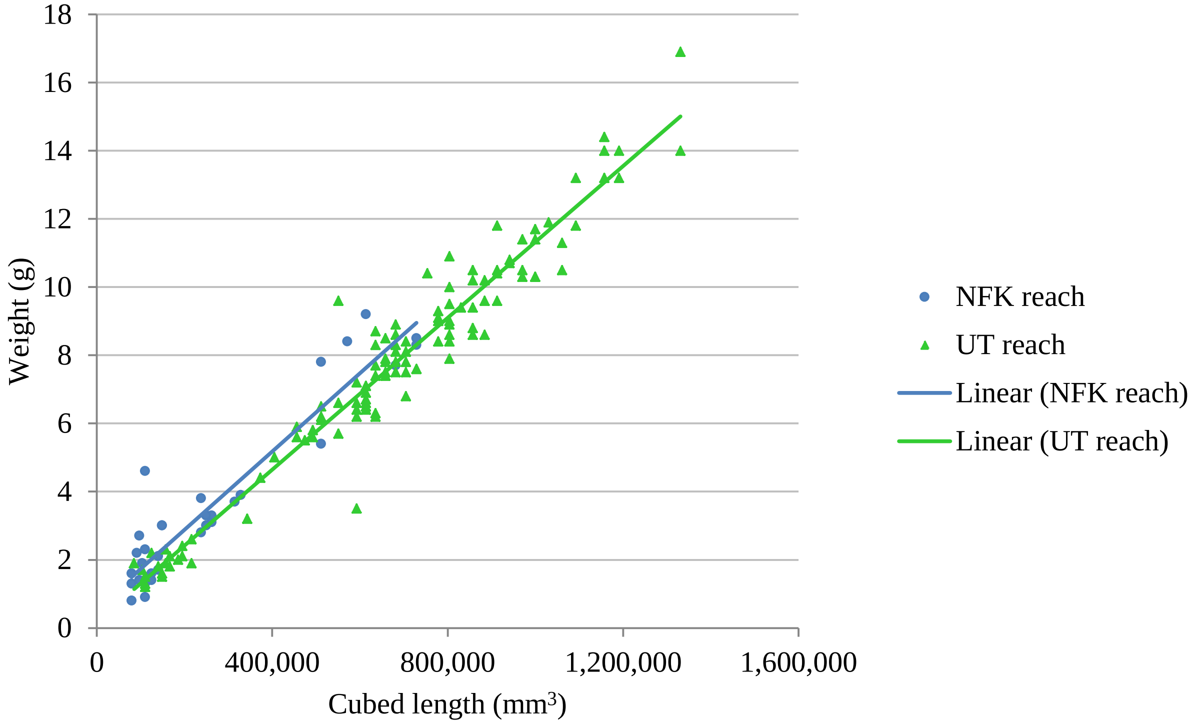

Figure 26. Coho salmon weight-length data and linear trendlines on the North Fork Koktuli (NFK reach) and Upper Talarik (UT reach) monitoring reaches.

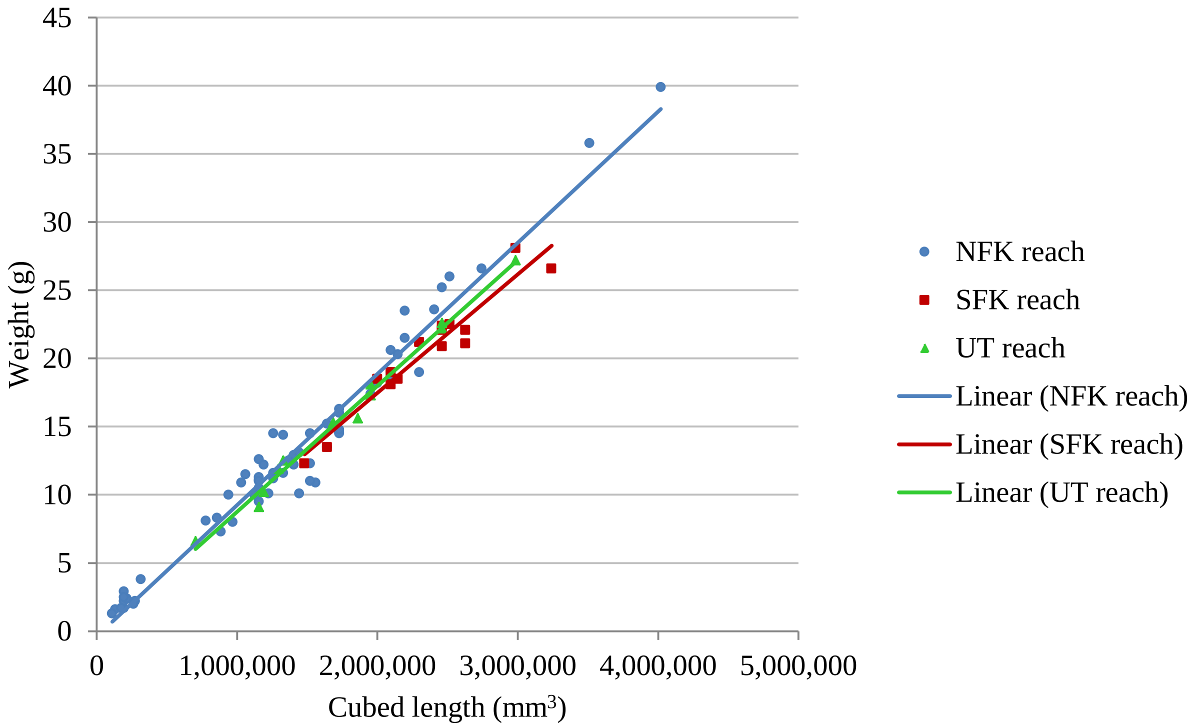

Figure 27. Dolly Varden weight-length data and linear trendlines on the North Fork Koktuli (NFK reach), South Fork Koktuli (SFK reach), and Upper Talarik (UT reach) monitoring reaches.

Table 9. Mean Fulton's condition factor, SD (in parenthesis), and sample size (*n*) for coho salmon and Dolly Varden from monitoring reaches.

Stream reach	Coho salmon	Dolly Varden
North Fork Koktuli	1.53 (0.63) *n* = 34	0.96 (0.14) *n* = 63
South Fork Koktuli	-	0.87 (0.04) *n* = 15
Upper Talarik	1.16 (0.18) *n* = 116	0.89 (0.05) *n* = 12

DISCUSSION

The primary objective of fish sampling in 2010 was the collection of juvenile Dolly Varden for metals analyses. A secondary objective was to sample the monitoring reaches for fish species presence, condition, and relative abundance using minnow traps. Minnow traps were used as an easy, repeatable, and cost-effective way to target juvenile Dolly Varden for metals analyses, while also obtaining some fish community and species data. Like all gear types, minnow traps are selective, and certain species or size classes may be absent or underrepresented in the data.

However, juvenile salmonids, which are indicators of habitat conditions and long-term effects (Barbour et al. 1999), can be successfully captured using baited minnow traps (Bryant 2000).

The three stream reaches showed variability in Dolly Varden size-class composition (Figure 22). Although we have no validation data to correlate fish lengths with age (such as scale or otolith analyses) and our sample sizes are small, the fish length histogram (Figure 22) and limited knowledge of regional Dolly Varden age class composition (Jaecks 2010; PLP 2011, Chapter 15) suggest that multiple age classes of Dolly Varden were captured in the monitoring reaches. Although clear delineations of age classes from the histograms cannot be determined, some inferences can be drawn for comparisons across the different stream reaches and with future capture data. The NFK reach and SFK reach Dolly Varden captures appear to be dominated by two age classes (possibly age 0+ and 2+ in NFK reach; age 1+ and 2+ in SFK reach), while the UT reach Dolly Varden appear to be primarily one age class (possibly age 2+). The variability between streams may be attributed to variable age-class composition between the streams, variable distribution of age classes within the streams determined by habitat selection and reach variability, or limited size of the data set. Future capture effort will increase the data set for Dolly Varden lengths and give further insight to the population age/size classes over time. In the future, a larger data set of Dolly Varden lengths may allow for statistical analyses (e.g., NORMSEP) that can better define the age classes present in the monitoring reaches. Overall, Dolly Varden captures were greatest at the NFK reach, but mean fork length was greatest at the UT reach (Table 7).

The three monitoring reaches showed variability in coho salmon size-class composition (Figure 23). Based on these histograms and knowledge of regional coho salmon age class composition (PLP 2011, Chapter 15), it appears that multiple age classes were captured in the monitoring reaches. Again, delineation of age classes from the histograms is not possible with this small data set, but some inferences can be drawn. Young of the year (0+) and age 1+ fish were captured at all three sites. Captures of coho salmon at the NFK reach appear to be age 0+ fish and age 1+ fish. The SFK reach captures were a mix of age 0+ and age 1+ fish and possibly some 2+ age fish. The UT reach captures were dominated by age 1+ coho salmon (Figure 23). The UT reach had the largest dominant age class, but the largest juvenile coho salmon were captured at the SFK reach. Overall, juvenile coho salmon captures were greatest and had the largest mean length in the UT reach (Table 7).

Chinook salmon were present at all three sites in low numbers with only one captured at the UT reach. Chinook salmon are typically more abundant in larger river systems because the adults prefer larger substrate for spawning (Meehan 1991; Quinn 2005). The NFK reach and SFK reach both have larger channels, higher flows, and larger substrate than the UT reach; Chinook salmon are known to spawn in both forks of the Koktuli River.

A single rainbow trout (FL = 124 mm) was captured in the UT reach, and no rainbow trout were captured in the other stream reaches. Sculpin species were captured at the NFK reach and UT reach but not at the SFK reach (Figure 25). Overall, sculpin species captures were greatest and had the largest mean length in the UT reach.

Dolly Varden CPUE was about four and a half times higher at the NFK reach compared to the UT reach while the opposite is true for coho salmon (Table 8; Figure 26). Although pool and backwater habitat are common in the NFK reach, riffle habitat is more prevalent in the NFK reach compared to the other two reaches and may be a factor in the higher CPUE for Dolly

Varden. Possibly, the riffle habitat is less desirable for juvenile coho salmon, which prefer calmer waters (Morrow 1980; Quinn 2005), and the reduced competition provides a niche for the adaptable Dolly Varden. Juvenile coho salmon may also be benefitting from the more moderate flows (with lower peak discharges) present in Upper Talarik Creek, compared to the other two streams, but a number of factors may be influencing the species composition of these stream reaches.

As a measure of fitness, Fulton's condition factor (*K*) was calculated for Dolly Varden and coho salmon that were weighed in the field (Table 9). Weights were not obtained on all fish captured, and the data set from 2010 is limited. The NFK reach had the highest condition factor for coho salmon (*K* = 1.53) and Dolly Varden (*K* = 0.96) (Table 9), although the condition factor was not calculated for the SFK reach coho salmon. Lengths and weights of captured fish will be recorded during future sampling events, and the calculated condition factors will be used to assess trends over time. The condition factor indicates the relative well-being of captured fish (i.e., higher *K* values indicate greater well-being) and allows for comparisons across seasons and drainages with future fish captures. Fulton's condition factor is suitable for comparing the fitness of different fish of the same species; however, comparison between species is not possible because different fish species have different shapes. In general, *K* values of coho salmon captured in the NFK reach and UT reach are equal or greater than values measured elsewhere. Milner and Bailey (1989) reported Fulton's condition factor values for juvenile coho salmon from five streams near Glacier Bay, Alaska, between 1.17 and 1.27, while values ranged from 0.84 to 1.14 from Southcentral Alaska watersheds (Hoem Neher et al. 2013). Dolly Varden *K* values from all three ADF&G monitoring reaches are generally equal to or slightly lower than values reported elsewhere. York and Milner (1999) reported juvenile Dolly Varden *K* values of 1.13 and 1.14 from a Southcentral Alaska stream, and Milner and Bailey (1989) reported a *K* value of 1.18 from a stream in the Glacier Bay area. In general, a salmonid with a Fulton's *K* value greater than or equal to 1 indicates a fish in good condition.

7. SUMMARY AND CONCLUSIONS

This report contains the methods and results of the first year of the aquatic biomonitoring plan developed for the Pebble Prospect. Information needs are likely to change as exploration and development progress and new components are added during future monitoring seasons. The objectives of 2010 monitoring at the Pebble Prospect included gaining a better understanding of the aquatic resources present in the area and establishing a baseline data record of those resources. The approach taken in this first year of monitoring was to collect information about the physical aquatic environment (geomorphology, hydrology) and three trophic levels of aquatic communities (periphyton, invertebrates, and fish), using methods that are repeatable and can be used to compare future conditions.

Information collected in 2010 characterizes these three streams in form, function, and productivity. All three streams are in a Glacial Trough valley (Type V) and are characterized as C4 under the Rosgen stream-channel classification system. C channel types are one of the most prevalent, natural stream types for a Glacial Trough valley. Rosgen (1994) describes the C4 stream type as "slightly entrenched, meandering, gravel-dominated, riffle-pool channel with a developed floodplain….characterized by the presence of point bars and other depositional features, is very susceptible to shifts in both lateral and vertical stability caused by direct channel disturbance and changes in the flow and sediment regimes of the contributing watershed.” From a management perspective, C4 streams are interpreted as being very sensitive to disturbance with good recovery potential, have a high sediment supply, are very susceptible to streambank erosion, and are highly dependent on vegetation as a controlling influence (Rosgen 1994). Rosgen C channel types are generally considered stable in Glacial Trough valleys. Future geomorphology surveys documenting a shift from a C channel type to F or G channel type would indicate stream instability.

When comparing these three streams biologically, based on 2010 data, Upper Talarik Creek appears to be the most productive because it shows the highest level of primary productivity (as measured by chlorophyll-a concentrations), the highest proportion of pollution-sensitive macroinvertebrates (EPT), and the highest catch and diversity of fish. Upper Talarik Creek appears to be a valuable and productive rearing environment for juvenile coho salmon. Upper Talarik Creek has the most stable hydrologic regime throughout the year and across years (probably because of the greater influence of groundwater). In physical comparison, based on 2010 data, North Fork Koktuli River has the highest volume, exhibits the most dynamic changes in flow, and has the largest bed material. Given these attributes and what is known regarding juvenile salmon habitat requirements, North Fork Koktuli River may be an important headwater stream for rearing juvenile Chinook salmon. South Fork Koktuli River is unique because of Frying Pan Lake. Frying Pan Lake is a large, relatively shallow lake upstream of the monitoring reach. Based on 2010 data, the SFK reach had the lowest measured primary production (chlorophyll-a concentrations), a markedly different invertebrate community (specifically, a lower percent composition of pollution-intolerant taxa, EPT, and an assemblage dominated by lake dwelling taxa, cladocerans and copepods), and the lowest fish diversity. Additionally, the SFK reach Dolly Varden had higher concentrations of several metals in 2010 (i.e., arsenic, copper, lead, molybdenum, and selenium), which makes sense because of the monitoring site’s proximity to the known ore body.

Headwater streams in Alaska serve as critical rearing and overwintering habitats for juvenile salmonids and affect overall stream productivity (Walker et al. 2007, 2009). By annually monitoring each of the three trophic levels detailed here, we hope to build a strong foundation for understanding the biological resources present and gather sufficient data to detect and evaluate changes to these systems in the future.

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Appendix 1. Periphyton standing crop, 2010.

Daily vial no.	Station	Date collected	Date analyzed	Vial chl-a	Chl-a (mg/m^2)	Below instrument detection limit[a] or above linear check[b]	Chl-a[c] (mg/m^2)	664/665 Ratio	Chl-b (mg/m^2)	Chl-c (mg/m^2)	Notes[d]
1	BLANK	12/9/2010	12/9/2010	0.00	-	Below detection	-	-	-	-	
2	NFK reach	8/5/2010	12/9/2010	0.41	1.64	-	1.60	1.71	0.00	0.14	1
3	NFK reach	8/5/2010	12/9/2010	0.30	1.19	-	1.07	1.63	0.00	0.01	1
4	NFK reach	8/5/2010	-	-	-	-	-	-	-	-	2
5	NFK reach	8/5/2010	12/9/2010	0.75	3.00	-	2.67	1.61	0.11	0.23	3
6	NFK reach	8/5/2010	12/9/2010	1.08	4.32	-	4.06	1.66	0.73	0.23	4
7	NFK reach	8/5/2010	12/9/2010	2.79	11.15	-	9.72	1.59	0.85	0.83	4
8	NFK reach	8/5/2010	12/9/2010	0.68	2.71	-	2.56	1.67	0.34	0.14	4
9	NFK reach	8/5/2010	12/9/2010	0.37	1.48	-	1.39	1.65	0.30	0.07	4
10	NFK reach	8/5/2010	-	-	-	-	-	-	-	-	2
11	NFK reach	8/5/2010	-	-	-	-	-	-	-	-	2
12	UT reach	9/1/2010	12/9/2010	7.75	30.99	-	28.94	1.67	0.00	2.49	5
13	UT reach	9/1/2010	12/9/2010	4.15	16.61	-	15.70	1.68	0.00	1.27	5
14	UT reach	9/1/2010	12/9/2010	9.90	39.59	-	37.70	1.69	0.00	3.04	6
15	UT reach	9/1/2010	12/9/2010	0.47	1.87	-	1.71	1.64	0.02	0.24	5
16	UT reach	9/1/2010	12/9/2010	0.62	2.47	-	2.35	1.69	0.00	0.29	5
17	UT reach	9/1/2010	12/9/2010	2.69	10.77	-	10.15	1.67	0.00	0.76	7
18	UT reach	9/1/2010	12/9/2010	9.83	39.34	-	36.21	1.65	0.00	3.07	8
19	UT reach	9/1/2010	12/9/2010	10.42	41.66	-	38.98	1.67	0.00	3.33	9
20	UT reach	9/1/2010	12/9/2010	1.93	7.72	-	7.37	1.69	0.00	1.03	5
21	UT reach	9/1/2010	12/9/2010	2.44	9.78	-	9.18	1.67	0.00	1.06	5
22	SFK reach	8/4/2010	12/9/2010	0.24	0.96	-	0.85	1.62	0.00	0.17	10
23	SFK reach	8/4/2010	12/9/2010	0.81	3.24	-	2.99	1.64	0.53	0.37	11
24	SFK reach	8/4/2010	12/9/2010	0.57	2.26	-	1.82	1.50	0.69	0.99	11
25	SFK reach	8/4/2010	12/9/2010	0.17	0.67	-	0.64	1.67	0.14	0.11	11

-continued-

Appendix 1. Page 2 of 2.

Daily vial no.	Station	Date collected	Date analyzed	Vial chl-a	Chl-a (mg/m^2)	Below instrument detection limit[a] or above linear check[b]	Chl-a [c] (mg/m^2)	664/665 Ratio	Chl-b (mg/m^2)	Chl-c (mg/m^2)	Notes[d]
26	SFK reach	8/4/2010	12/9/2010	1.17	4.67	-	4.06	1.58	0.77	1.23	11
27	SFK reach	8/4/2010	12/9/2010	0.81	3.24	-	3.10	1.69	0.00	0.32	11
28	SFK reach	8/4/2010	12/9/2010	0.53	2.13	-	2.03	1.68	0.13	0.21	11
29	SFK reach	8/4/2010	12/9/2010	2.05	8.21	-	6.84	1.53	1.99	3.20	11
30	SFK reach	8/4/2010	12/9/2010	0.44	1.77	-	1.28	1.43	0.53	1.02	11
31	SFK reach	8/4/2010	12/9/2010	0.39	1.55	-	1.39	1.62	0.04	0.06	11
32	BLANK	12/9/2010	12/9/2010	0.00	-	Below detection	-	-	-	-	-
12[e]	UT reach	9/1/2010	12/9/2010	7.76	31.04	-	29.58	1.69	0.00	2.48	-

Note: NFK reach = North Fork Koktuli monitoring reach; SFK reach = South Fork Koktuli monitoring reach; UT reach = Upper Talarik monitoring reach; Chl = chlorophyll.

[a] 0.06 Vial chlorophyll-a (Method detection limit = 0.02 vial chlorophyll-a).

[b] 21.19 Vial chlorophyll-a.

[c] Phaeophytin corrected.

[d] 1 - Glass fiber filter not folded in half sample to sample, in contact with outer filter; filters generally in poor condition, crushed, crumpled, etc.
2 - Not processed—excessive algal macrophytes
3 - 2 strands of macrophyte
4 - Same as 2/3; significantly damaged filtered
5 - Same as 2/3
6 - Same as 2/3; ¼ of sample stuck to outer filter, cut and processed
7 - Same as 2/3; damp
8 - Same as 2/3; much of sample lost to filter
9 - Same as 2/3; wet
10 - 1 strand of algae/plant material; sample in good condition
11 - Sample in good condition

[e] Sample duplicate.

Appendix 2. Aquatic invertebrate driftnet samples, 2010.

	Monitoring sites		
	NFK reach	SFK reach	UT reach
Sample date	8/31/2010	8/3/2010	9/2/2010
Aquatic invertebrate taxa richness/site	33	31	33
EPT taxa richness/site	13	12	13
% EPT	36.9%	6.0%	38.6%
% Ephemeroptera	23.3%	1.8%	13.6%
% Plecoptera	4.5%	3.7%	5.7%
% Trichoptera	9.1%	0.5%	19.3%
% Aquatic Diptera	32.7%	5.8%	34.3%
% Aquatic Chironomidae	23.6%	5.4%	19.3%
% Miscellaneous aquatic species	30.4%	88.2%	27.1%
% Dominant aquatic taxon	15.5%	44.2%	12.8%
Volume of water (m^3)	1228	754	1470
Average volume of water/net (m^3)	246	151	294
Standard deviation of water volume/net	73	20	99
Estimated total invertebrates/volume water (m^3)	0.8	13.0	0.5
Estimated aquatic invertebrates/volume water (m^3)	0.6	12.6	0.4
Average invertebrates/volume water (m^3)	0.9	13.5	0.5
Average aquatic invertebrates/volume water (m^3)	0.62	13.04	0.46
Standard deviation of aquatic invertebrate density	0.31	5.87	0.27
Total abundance of aquatic invertebrates[a]	691	9486	580
Total abundance Ephemeroptera[a]	161	169	79
Total abundance Plecoptera[a]	31	348	33
Total abundance Trichoptera[a]	63	50	112
Total abundance aquatic Diptera[a]	226	548	199
Total abundance miscellaneous aquatic species[a]	210	8371	157
Total abundance terrestrial invertebrates[a]	268	309	118
Total abundance all invertebrates[a]	959	9795	698
% Sample aquatic	72.1%	96.8%	83.1%
% Sample terrestrial	27.9%	3.2%	16.9%
Average number aquatic invertebrates/net[b]	138	1897	116
Average number Ephemeroptera/net[b]	32	34	16
Average number Plecoptera/net[b]	6	70	7
Average number Trichoptera/net[b]	13	10	22
Average number aquatic Diptera/net[b]	45	110	40
Average number miscellaneous aquatic species/net[b]	42	1674	31
Standard deviation aquatic invertebrates/net	36	671	29
Average number terrestrial invertebrates/net[b]	54	62	24
Average number invertebrates/net[b]	192	1959	140
Standard deviation of invertebrates/net	42	684	22
Total larval fish/net[b]	0	0	0

Note: NFK reach = North Fork Koktuli monitoring reach; SFK reach = South Fork Koktuli monitoring reach; UT reach = Upper Talarik monitoring reach.

[a] Corrected for subsampling.

[b] Five nets per site.

Appendix 3. Juvenile Dolly Varden whole-body total metals concentrations, 2010.

					Results (mg/kg)														Results (%)	
				Method	200.8	200.8	200.8	200.8	6010C	200.8	200.8	7471B	200.8	200.8	7010	200.8	200.8	200.8	Freeze dry	NOAA
				MRL	≤0.050	≤0.50	0.020	0.020	0.20	0.10	0.020	≤0.020	≤0.050	0.20	1.0	0.020	0.020	≤0.50	-	≤0.249
				MDL	0.020	0.04	0.004	0.005	0.08	0.03	0.005	0.004	0.007	0.02	0.3	0.020	0.002	0.08	-	≤0.249
Sample no.	Date collected	Length (mm)	Weight (g)	Analyte	Sb	As	Be	Cd	Cr	Cu	Pb	Hg	Mo	Ni	Se	Ag	Tl	Zn	Solids	Lipids
NFK1	8/31/10	130	21.5		ND	0.29	ND	0.012	0.39	3.10	0.023	0.147	0.072	0.40	2.3	ND	0.011	102	24.3	3.5
NFK1[a]	-	-	-		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3.9
NFK2	8/31/10	128	18.4		ND	0.29	ND	0.022	0.73	7.06	0.053	0.146	0.069	0.72	2.5	ND	0.015	128	20.0	1.8
NFK2[a]	-	-	-		ND	0.27	ND	0.022	0.70	7.11	0.050	NA	0.070	0.79	1.6	ND	0.016	138	NA	NA
NFK3	8/31/10	105	11.1		0.090	0.34	0.014	0.036	0.40	3.59	0.116	0.141	0.097	0.94	3.4	ND	0.045	135	20.7	2.1
NFK4	8/31/10	120	14.6		ND	0.45	0.013	0.027	1.39	3.96	0.191	0.096	0.098	0.96	3.0	ND	0.016	137	21.2	1.7
NFK5	8/31/10	105	9.5		ND	1.52	0.032	0.026	3.17	6.73	0.252	0.094	0.223	1.75	3.0	ND	0.019	160	23.1	2.7
NFK6	8/31/10	120	14.5		ND	1.13	0.040	0.024	8.43	5.38	0.339	0.117	0.243	2.69	2.1	ND	0.026	122	23.1	2.4
NFK7	8/31/10	120	16.3		0.055	1.22	0.049	0.039	13.9	6.88	1.020	0.107	0.335	5.36	2.4	0.034	0.029	84.8	23.3	2.6
NFK8	8/31/10	107	10.1		ND	0.17	ND	0.019	2.41	4.39	0.055	0.085	0.084	1.38	2.2	ND	0.014	112	22.1	2.5
NFK9	8/31/10	115	14.5		ND	0.96	0.037	0.020	17.5	4.23	0.517	0.121	0.394	6.77	2.4	ND	0.019	96.7	27.4	5.1
NFK10	8/31/10	118	13.5		0.087	2.20	0.086	0.047	12.1	9.46	0.905	0.093	0.335	3.51	1.9	0.022	0.040	94.0	25.7	2.4
NFK11	8/31/10	125	17.4		ND	2.25	0.071	0.031	9.38	5.22	0.704	0.104	0.366	2.71	1.6	0.021	0.024	86.6	24.7	2.5
NFK12	8/31/10	104	10.0		ND	2.22	0.090	0.049	9.12	6.62	0.359	0.095	0.233	3.35	3.3	ND	0.036	102	24.0	1.0
NFK13	8/31/10	105	10.5		ND	0.85	0.045	0.028	3.78	4.69	0.416	0.096	0.206	2.03	2.9	ND	0.031	99.0	24.1	2.3
NFK14	8/31/10	112	12.9		ND	0.78	0.035	0.020	16.5	5.62	0.203	0.090	0.844	3.12	2.0	ND	0.025	78.7	25.3	2.8
SFK1	8/30/10	135	22.1		ND	1.06	0.027	0.115	5.36	6.69	0.678	0.055	0.449	1.41	3.7	ND	0.025	96.7	25.6	4.4
SFK2	8/30/10	114	12.3		ND	0.33	ND	0.174	1.03	4.57	0.079	0.052	0.257	0.95	3.8	ND	0.023	104	22.0	2.7
SFK3	8/30/10	136	22.5		ND	1.79	0.035	0.177	12.6	14.2	1.950	0.038	0.612	4.48	2.7	ND	0.030	108	25.2	3.5
SFK4	8/30/10	135	22.4		ND	0.62	0.013	0.076	2.76	6.06	0.254	0.048	0.262	1.16	4.8	ND	0.027	108	23.1	3.3
SFK5	8/30/10	144	28.1		ND	1.71	0.039	0.149	16.4	9.15	1.380	0.042	0.742	4.93	4.1	ND	0.039	98.2	25.5	2.6
SFK5[a]	-	-	-		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.6
SFK6	8/30/10	126	18.5		ND	6.57	0.110	0.227	8.51	20.3	2.780	0.034	1.110	3.16	2.0	0.026	0.068	129	25.5	2.7
SFK7	8/30/10	138	21.1		0.027	1.44	0.022	0.125	1.29	9.72	0.376	0.026	0.559	1.20	3.0	ND	0.036	121	23.7	3.1
SFK8	8/30/10	128	19.0		ND	0.77	0.015	0.222	2.56	5.12	0.644	0.043	0.183	1.39	3.4	ND	0.045	111	22.6	5.5
SFK9	8/30/10	138	22.1		0.031	0.47	0.006	0.063	2.97	5.78	0.204	0.035	0.213	0.81	2.3	ND	0.012	73.0	25.6	2.4

-continued-

Appendix 3. Page 2 of 2.

					Results (mg/kg)														Results (%)	
				Method	200.8	200.8	200.8	200.8	6010C	200.8	200.8	7471B	200.8	200.8	7010	200.8	200.8	200.8	Freeze dry	NOAA
				MRL	≤0.050	≤0.50	0.020	0.020	0.20	0.10	0.020	≤0.020	≤0.050	0.20	1.0	0.020	0.020	≤0.50	-	≤0.249
				MDL	0.020	0.04	0.004	0.005	0.08	0.03	0.005	0.004	0.007	0.02	0.3	0.020	0.002	0.08	-	≤0.249
Sample no.	Date collected	Length (mm)	Weight (g)	Analyte	Sb	As	Be	Cd	Cr	Cu	Pb	Hg	Mo	Ni	Se	Ag	Tl	Zn	Solids	Lipids
SFK10	8/30/10	129	18.5		ND	0.58	0.007	0.139	2.61	4.54	0.325	0.048	0.306	1.13	4.5	ND	0.040	108	20.6	1.1
SFK11	8/30/10	132	21.2		0.151	3.23	0.110	0.298	18.1	15.1	2.280	0.085	1.540	3.72	5.0	ND	0.063	131	25.9	2.7
SFK12	8/30/10	148	26.6		ND	0.60	0.014	0.077	3.65	5.34	0.324	0.053	0.262	1.17	4.7	ND	0.029	106	22.4	2.2
SFK12[a]	-	-	-		ND	0.96	0.014	0.088	3.09	5.86	1.570	0.053	0.265	1.42	4.9	0.024	0.028	122	22.6	NA
SFK13	8/30/10	135	20.9		0.033	1.10	0.030	0.128	6.77	7.86	0.707	0.038	0.386	2.39	4.3	ND	0.034	101	22.4	2.4
SFK14	8/30/10	128	18.1		0.099	0.35	0.013	0.083	0.50	3.54	0.104	0.057	0.139	0.58	4.2	ND	0.057	106	22.8	3.4
SFK15	8/30/10	118	13.5		ND	0.29	ND	0.079	0.24	3.92	0.034	0.012	0.071	0.43	2.5	ND	0.011	90.3	24.3	5.1
UT1	9/2/10	105	9.1		0.069	0.42	0.015	0.025	2.08	3.52	0.171	0.065	0.200	1.17	0.4	ND	0.019	111	22.4	1.6
UT2	9/2/10	110	12.5		0.062	0.90	0.038	0.013	2.51	3.52	0.215	0.056	0.222	1.41	0.5	ND	0.015	95.1	23.9	3.0
UT3	9/2/10	125	17.3		0.025	0.53	0.008	0.015	1.34	3.96	0.095	0.095	0.133	0.77	0.8	ND	0.016	100	24.5	4.7
UT4	9/2/10	109	11.9		0.022	0.33	0.008	0.015	1.92	2.97	0.093	0.034	0.132	0.71	ND	ND	0.016	93.5	26.1	4.4
UT5	9/2/10	106	10.2		0.022	0.47	0.011	0.020	1.40	3.52	0.095	0.063	0.092	1.11	ND	ND	0.019	145	19.7	1.1
UT6	9/2/10	135	22.2		ND	0.94	0.008	0.027	0.71	3.54	0.160	0.149	0.109	0.82	2.0	ND	0.016	95.0	22.8	2.5
UT6[a]	9/2/10	-	-		ND	0.95	0.008	0.024	0.40	3.49	0.052	0.179	0.100	0.70	2.1	ND	0.016	92.9	22.2	NA
UT7	9/2/10	125	18.1		0.136	0.77	0.048	0.031	16.0	5.50	0.308	0.078	0.273	4.53	ND	0.022	0.068	91.1	23.8	3.9
UT8	9/2/10	123	15.6		ND	0.13	ND	0.009	0.30	2.73	0.089	0.068	0.042	0.53	1.3	ND	0.012	86.1	24.1	4.8
UT9	9/2/10	135	22.6		ND	0.70	0.037	0.017	4.07	2.97	0.177	0.104	0.205	1.77	ND	ND	0.024	93.8	26.0	3.8
UT10	9/2/10	119	15.3		ND	1.22	0.062	0.018	15.1	4.20	0.463	0.083	0.930	2.42	1.9	ND	0.023	104	23.9	2.1

Notes: NFK = North Fork Koktuli monitoring reach; SFK = South Fork Koktuli monitoring reach; UT = Upper Talarik monitoring reach; NA = Not analyzed; MRL = Method Reporting Limit; MDL = Method Detection Limit; ND = Not detected at or above MDL; Sb = Antimony; As = Arsenic; Be = Beryllium; Cd = Cadmium; Cr = Chromium; Cu = Copper; Pb = Lead; Hg = Mercury; Mo = Molybdenum; Ni = Nickel; Se = Selenium; Ag =Silver; Tl = Thallium; Zn = Zinc.

[a] Sample duplicate.