MERCURY CONCENTRATIONS IN FISH AND SEDIMENT IN RESURRECTION CREEK, ALASKA, JULY 2008

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Chugach National Forest and TEAMS Enterprise Unit personnel conducted a study to measure mercury concentrations in fish and sediment in Resurrection Creek and its side channels. This study was conducted to assess the presence of mercury in the system as it pertains to past and proposed stream restoration projects on Resurrection Creek. Mercury was likely used on Resurrection Creek by placer miners in the early twentieth Century.

Fish and sediment samples were collected at 13 sites on July 8-10, 2008, including 6 sites along the *Restored Reach*, 6 sites along the *Proposed Restoration Reach*, and 1 site from an upstream *Reference Reach*. Total mercury concentrations in whole-body fish samples ranged from 0.0404 ppm to 0.366 ppm (dry weight basis) in the *Restored Reach* and from 0.0701 to 0.652 ppm (dry weight basis) in the *Proposed Restoration Reach*. Methylmercury was not measured in the fish samples, but most likely comprised nearly 100% of the total mercury in the fish tissue. Total mercury concentrations in sediment samples ranged from 28.1 to 243 ppb (dry weight basis) in the *Restored Reach* and from 34.9 to 106 ppb (dry weight basis) in the *Proposed Restoration Reach*. Methylmercury comprised 0 to 4.9% of the total mercury in these samples.

Mercury concentrations measured in fish at all sites were relatively low and were considerably less than the 1.0 ppm FDA action level. Mercury concentrations measured in sediment at all sites were below the NOAA preliminary screening levels, with the exception of 1 sample. Mercury levels in fish and sediment at some sites were slightly elevated over reference levels. This may be the result of mercury in the system deposited during historic mining. Mercury levels in fish and sediment were similar to those measured in Resurrection Creek in 2004. Mercury levels were low compared to levels measured in fish in degraded and non-degraded systems throughout North America. Results from this study suggest that mercury levels measured in sediment in Resurrection Creek pose little risk to drinking water contamination or aquatic species. Sampling efforts to date have not detected any large concentrations of mercury.

1 INTRODUCTION

Resurrection Creek is located on Alaska's Kenai Peninsula, near the town of Hope (**figure 1**). Resurrection Creek is the site of extensive gold placer mining over the past century, and historic placer mining operations beginning in the early 1900's resulted in numerous tailings piles, channelization, and loss of floodplain functionality. It is unknown how much mercury was used for mercury amalgamation during these placer mining operations. Any mercury that may still be in the system is likely in localized areas within the tailings piles.

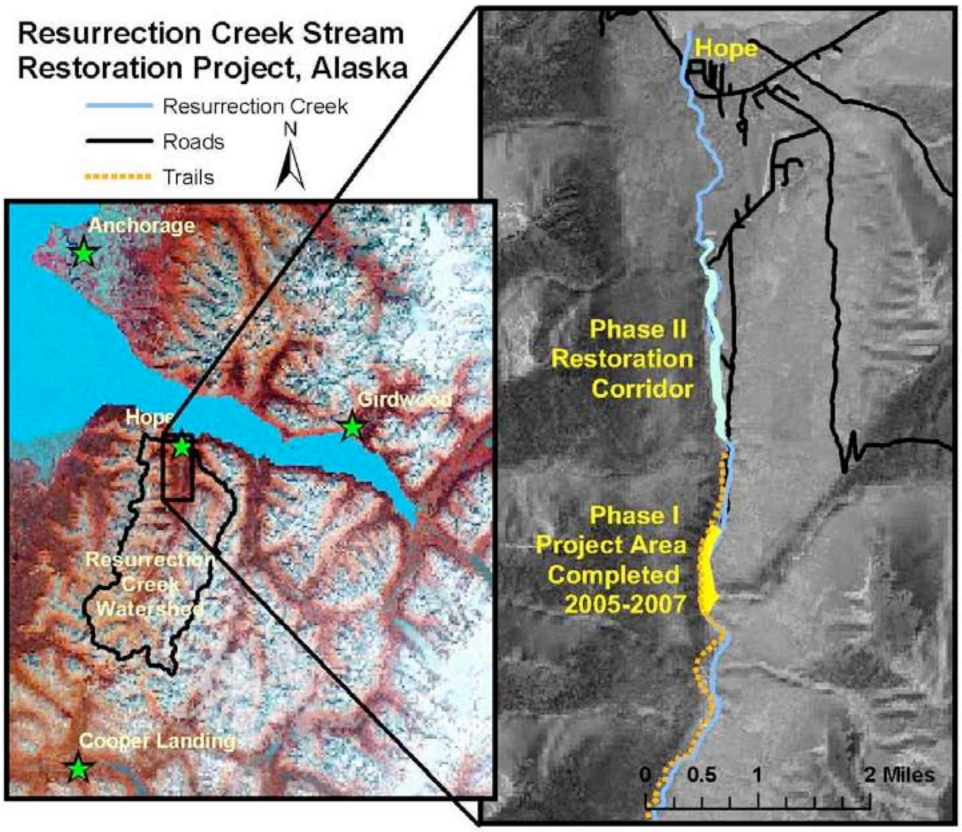


Figure 1: Location of the Resurrection Creek Stream Restoration Project area.

Following successful completion of the Phase I *Resurrection Creek Stream and Riparian Restoration Project* in 2005 and 2006 (the *Restored Reach*) (USDA Forest Service, Chugach National Forest, 2004), the Chugach National Forest is planning Phase II of this project, on a 2-mile reach of Resurrection Creek about 3 miles upstream of Hope (the *Proposed Restoration Reach*). The purpose of this restoration project is to restore the channel to its natural, self-maintaining form, restore functionality to the floodplain, and provide and improve stream habitat for fish and riparian habitat for mammals and birds. This will require redistributing and removing the tailings piles, creating new channel segments, and restoring the channel and floodplain.

The release of mercury into the environment during channel and floodplain construction activities has been a potential concern in this area. Because of this, mercury levels were sampled in 2004, prior to the Phase I project, in fish and sediment at 8 sites throughout the project area (MacFarlane, 2004a; MacFarlane, 2004b). These levels were compared to samples from a reference reach as well as other studies throughout the country. Results showed that mercury concentrations were relatively low. Although mercury levels were slightly elevated over background levels, they were below the levels that would be considered harmful.

The proposed Phase II restoration project would occur in similar site conditions as the Phase I restoration project, and the two areas have similar mining histories, but the presence of mercury has never been determined in the *Proposed Restoration Reach*. Also, mercury levels have not been assessed following restoration of the *Restored Reach*, knowing that restoration activities had the potential to disturb any mercury that may have been within the tailings piles. This study was developed to investigate mercury levels in fish and sediment at representative sites within both project areas. This study includes the following objectives:

- Sample fish and sediment within the *Proposed Restoration Reach* to determine the levels of mercury in the system prior to conducting channel restoration, and compare to reference conditions.
- Sample fish and sediment throughout the *Restored Reach* to determine the levels of mercury present in the system two years after completion of channel restoration activities, and compare to the levels measured in 2004.
- Compare mercury levels within these two reaches to mercury levels documented by previous studies, regional studies, national studies, and published reports of threshold effects levels and standards.

2 CONTEXT

History: Resurrection Creek experienced a gold rush in the early 1900's. The town of Hope served as a mining camp for the numerous placer mining operations that operated on Resurrection Creek, Bear Creek, and the lower portion of Palmer Creek. Miners used hydraulic mining and heavy equipment to move parts of the channel and mine the channel material, resulting in large tailings piles deposited on the floodplains, some as high as 40 feet. Overall, approximately 4 square miles of Resurrection Creek were highly disturbed, from about 2 miles to about 6.5 miles upstream of the mouth.

Mercury Amalgamation: Placer mining generally resulted in a slurry of heavier materials, or "black sands," that included tiny specs of gold that settle out during the sorting process. Elemental mercury was used during these operations to extract the tiny gold particles from the slurry because of its properties that allow it to bond to gold, making a mercury amalgam. In the process, it is likely that some of this mercury was spilled directly into the stream or the mine tailings. It is unknown how much mercury was spilled into the environment in the early 1900's. In California in the late 19th Century, an estimated 10 to 30% of the mercury used was lost during the placer mining process, leaving thousands of pounds of mercury at each placer mine site (Saiki, 2003).

Mercury: Mercury is naturally present in the environment from geologic sources as well as anthropogenic sources such as industrial metal manufacturing and fuel combustion, runoff from mercury mines, and gold mining. Mercury in the atmosphere is also distributed globally from industrial and combustion sources. Although mercury in its elemental form can pass through organisms relatively quickly, it can have toxic effects, especially for eggs and fish during early life stages (Matz, 2003). Mercury generally remains in soils for long periods of time, slowly releasing mercury compounds to the environment. In Resurrection Creek, any elemental mercury spilled into the river likely settled into the substrate because of its high density and low solubility. Alluvial deposits from Resurrection Creek comprise a thin layer, in places less than 3 feet thick, over a clay layer possibly deposited by a glacially dammed lake that existed during the Pleistocene. It is likely that any mercury that has settled into the alluvial gravels will ultimately stop at this clay layer.

Methylmercury: Bacteria within stream sediments transform elemental mercury into methylmercury, a highly toxic form of mercury. This process is not limited to stream sediments but generally occurs under anaerobic conditions. Methylmercury is readily absorbed or ingested by organisms, and it is transported to all organs, particularly affecting the nervous system. Mercury toxicity has the largest effect on neuro-development of fertilized eggs and young developing fish. In adult fish, the uptake of methylmercury is predominantly through the diet (Wiener and Spry, 1996). Mercury in fish is stored in fat, which exists in muscle tissue and under the skin. Methylmercury has a biological half life, or the time required for half of the methylmercury to leave the body, of about 44 to 80 days in humans (US Environmental Protection Agency, 1997), although the half life is species specific. Because methylmercury bioaccumulates in organisms, levels of mercury in fish can be orders of magnitude higher than mercury concentrations in water and sediments, and larger, older fish have higher levels of methylmercury. Biomagnification of methylmercury causes predatory species and fish at higher trophic levels to have higher methylmercury concentrations than their prey.

Recent History: Large scale mining efforts in Resurrection Creek ceased in the 1940's, but resumed to a lesser degree with the higher gold prices of the 1980's. Mining activity decreased after the 1980's but still occurred in some areas. A resurgence of mining has occurred recently as a result of high gold prices. The *Restored Reach* is located within an area that is now withdrawn from mineral entry. A short section of Resurrection Creek downstream of the *Restored Reach* includes private lands and a recreational mining area. Much of the lower 4 miles of Resurrection Creek lies on active mining claims, including numerous claims owned by the Hope Mining Company. The proposed Phase II restoration project would occur within a designated "restoration corridor" through these active mining claims, in which mining would not occur once the stream restoration project is completed. Large scale mining occurred on some of these Hope Mining Company claims in 2008.

3 HYDROLOGIC CONDITIONS

Detailed studies of the area have been conducted as part of the *Resurrection Creek Watershed Association Hydrologic Condition Assessment* (Kalli and Blanchet, 2001), the *Resurrection Creek Landscape Analysis* (Hart Crowser, Inc., 2002), the *Resurrection Creek Stream and Riparian Restoration Project Environmental Impact Statement* (USDA Forest Service, Chugach National Forest, 2004). Additional information is provided in *Mercury Concentrations in Fish in Resurrection Creek, Alaska* (MacFarlane, 2004a) and *Mercury Concentrations in Water and Sediment in Resurrection Creek, Alaska* (MacFarlane, 2004b).

The Resurrection Creek watershed covers about 103,230 acres (161 square miles) on the northern side of the Kenai Peninsula. Resurrection Creek flows north into Turnagain Arm, and elevations in the project areas are less than 500 feet. The valley is glacially carved, with terraces of alluvial deposits. Glaciers are no longer present in the watershed. This area has a cool and moist climate. The average mean temperature at Hope, Alaska is about 37 degrees F (Western Regional Climate Center, 2003). Hope receives about 22 inches of annual precipitation, increasing to about 40 inches at the head of the watershed. The Resurrection Creek watershed lies in a rain shadow created by the Kenai Mountains and receives considerably less precipitation than the watersheds to the east.

The lower portion of Resurrection Creek is a Low Gradient Floodplain Channel (FP4) (USDA Forest Service, Alaska Region, 1992), with a gradient less than 2% and a cobble and gravel substrate. Portions of the channel that were not placer mined have well-developed floodplains, but the mining-impacted channels are confined on one or both sides of the channel by high, steep gravel and cobble tailings piles. These tailings piles do not allow for channel migration and decrease floodplain functionality.

Historic flow data indicate an average mean daily flow of 274 cfs (US Geological Survey, 2003). The flow regime in Resurrection Creek is primarily controlled by summer snowmelt. Peak flows, averaging about 800 cfs, generally occur in late June to early July. Heavy fall rainstorms result in high magnitude, low duration peak flow events and a secondary peak in the hydrograph in October. These fall peaks are generally not as large as the summer snowmelt runoff peak. The bankfull flow is about 1,000 cfs. Winter flows from December to April remain at about 100 cfs.

Past sources of water quality data include USGS data from 1950 to 1971 (US Geological Survey, 2003), data collected in 1980 at placer mining sites (Blanchet, 1981), and the previous mercury sampling preceding the Phase I restoration project (MacFarlane, 2004a; MacFarlane, 2004b). Sampling in 1980 detected elevated levels of lead and mercury in sites downstream of mining activity. The 2004 mercury sampling indicated slightly elevated levels of mercury in sediment and fish, but within what would be considered the range of normal levels.

4 SAMPLING LOCATIONS AND METHODS

Sample mediums

Mercury concentrations can be analyzed in soil, sediment, water, fish tissue, or other organic samples. It is unknown exactly where mercury might have been deposited by miners. If present, mercury probably exists only in localized areas in the channel substrate or in localized areas within the sediments and soils of the tailings piles.

Sampling water within the project area would give an inaccurate characterization of the mercury levels within the project area because water flushes through the area relatively quickly. Sampling for mercury in water samples in 2004 indicated very low levels of mercury in the water because of the short transit time through the project area and the lack of organic materials in the water to which mercury could be bonded (MacFarlane, 2004b). Sampling soil or sediment within the tailings piles could be potentially misleading because of the highly localized nature of any potential mercury deposits, and a meaningful sampling program would require a large number of samples.

Sampling resident fish living in the project area would provide the most efficient sampling medium to indicate the presence or absence of mercury in the system, because they ingest mercury from the stream sediments and bioaccumulate methylmercury in their tissue. Mercury concentrations in fish are likely to be orders of magnitude higher than those in the water, and fish living in the ponds on the side channels may encounter any mercury that exists within the tailings piles.

Although sampling stream sediments is more subject to localized variations in mercury distribution, any mercury present in the system would likely be within the sediments of the main channel or side channels because of its high density. Sediment sampled in the same locations as the fish samples would provide context for the fish samples and some indication of the presence or absence of mercury in the system.

Fish and sediment samples were taken at each sampling site. Slimy sculpin (*Cottus cognatus*) were sampled because they are an abundant resident fish that feeds directly on the channel substrate (**figure 2**). Dolly Varden (*Salvelinus malma*) were sampled because they are resident fish and typically found in the ponds where mercury concentrations are expected to be greatest. Although juvenile coho (*Oncorhynchus kisutch*) are not resident fish in Resurrection Creek, they were sampled as well because they reside within the project areas for up to 3 years, and were abundant at most of the sampling sites. Although Crawford and Luoma (1993) suggested sampling fish livers to analyze trace elements, whole body samples were analyzed because of the small size of the majority of fish captured. Frenzel (2000) used similar methods to sample slimy sculpin in the Cook Inlet Basin for organic compounds and trace elements.

Figure 2: Slimy sculpin (*Cottus cognatus*), coho fry (*Oncorhynchus kisutch*), and Dolly Varden (*Salvelinus malma*).

Sample locations

Fish and sediment samples were collected from a total of 13 sites on July 8-10, 2008 (**figure 3**); 6 samples from the *Restored Reach* (samples labeled RC1), 6 samples from the *Proposed Restoration Reach* (samples labeled RC2), and 1 sample from the upstream *Reference Reach* (sample labeled REF):

1) **RC1-1**: A fish sample was taken from "*Channel 1*" at the downstream end of the first island and along the right bank channel margin. A sediment sample was taken along the right bank channel margin. The water temperature was 5°C. The stream flow was estimated to be 75 cfs, and the water was clear and fast-flowing. Average water depth was 2-3 feet, and the bottom sediment consisted of sand and gravel.

2) **RC1-2**: A fish sample was taken from the pond that drains into the "*Meander 5*" side channel. A sediment sample was taken from the south end of the pond, along the bank. The stream flow entering the pond from a small side channel was estimated to be 3 cfs. The water was slightly murky with deep muck on the bottom which clouded the water when disturbed. The water temperature was 5°C.

3) **RC1-3**: A fish sample was taken from the "*Meander 4*" side channel pond on the east side of Resurrection Creek. A sediment sample was taken from the south side of the pond near the bank. The water temperature was 5.5°C. The stream flow into the pond was estimated at 10 cfs and at 3 cfs out of the pond. The water was slightly murky.

4) **RC1-4**: A fish sample was taken from the "*Meander 3*" eastern side channel at the log step. A sediment sample was taken from the right bank on a small point bar upstream of the log step. The stream flow was estimated to be approximately 15 cfs. The water temperature was 5.5°C.

5) **RC1-5**: A fish sample was taken at the "*Meander 2*" eastern side channel pond. A sediment sample was taken near the pond inlet and consisted of silt, sand, and organics. Water temperature was 5°C. Flow into and out of the pond was estimated at 14 cfs and 10 cfs, respectively.

6) **RC1-6**: A fish sample was taken at the upper pond on the western side channel adjacent to "*Meander 2*". A sediment sample was taken along the pond margins. The water temperature was 5°C. The stream flow into and out of the pond was estimated at 20 cfs and 15 cfs, respectively.

7) **RC2-1**: A fish sample was taken along a side channel adjacent to the main channel. A sediment sample was taken along the side channel margins. The water temperature was 5°C. The stream flow through the side channel was clear, fast-flowing, and estimated at 20 cfs.

8) **RC2-2**: A fish sample was taken along a side channel adjacent to the main channel. A sediment sample was taken along the side channel margins. The water temperature was 5°C. The stream flow through the side channel was clear, fast-flowing, and estimated at 25 cfs.

9) **RC2-3**: A fish sample was collected in the mining drainage ditch adjacent to the old bridge abutments. This ditch is an active mining ditch recently created for mining operations occurring just upstream. A sediment sample was also taken from the ditch. The water temperature was 8°C. The stream flow was estimated at 5-7 cfs, and water clarity was turbid from the ongoing mining operations.

10) **RC2-4**: A fish sample was taken in a large settling pond, part of the active Hope Mining Company ditch system. Recent signs of beaver activity were present. A sediment sample was taken along the bank of the pond. The water temperature was 10°C. The stream flow into the pond was estimated at 5-7 cfs.

11) **RC2-5**: A fish sample was taken along a settling pond, part of the active Hope Mining Company ditch system. A sediment sample was taken along the bank of the pond. The water temperature was 11°C. No flow was seen entering or exiting the pond.

12) **RC2-6**: A fish sample was taken in the final pond of the active Hope Mining Company ditch system. This pond was recently bisected by the construction of a new mining road, and samples were taken from the pond closest to the main channel. A sediment sample was taken along the banks. The water temperature was 4°C. No flow was seen entering or exiting the pond.

13) **REF-1**: A fish sample and a sediment sample were taken along a side channel about 2 miles upstream of the *Restored Reach*, in a location that represents reference conditions, or conditions unaffected by mining. This location was approximately 1/2 mile upstream of the reference reach site from the 2004 mercury studies. The sediment sample was taken in a depositional zone. The water temperature was 6°C. The stream flow was estimated at 30-35 cfs.

Sampling methods

All sampling bottles and equipment were pre-cleaned at the laboratory prior to shipping. Bottles were kept in double zip-lock bags. Because these samples were analyzed for ultra-trace levels of mercury, "ultra-clean" techniques were used when handling bottles and conducting sampling to prevent contamination of the samples (US Environmental

Protection Agency, 1996). Sample bottles were handled only wearing non-powdered latex gloves by the sampler designated "clean hands." The field assistant, designated "dirty hands," handled only the outside of the outer zip-lock bag, never touching the sampling bottles. Latex gloves were changed at each sample site.

Small sculpin, coho fry, and chinook fry were abundant in the side channel ponds. Few fish were found in the main channel of Resurrection Creek. At most sites, fish were captured using electro-fishing equipment and collected in mesh nets. At one pond site located in the *Proposed Restoration Reach* (RC2-6), fish were caught by rod and reel. Whole fish were placed in wide-mouth sample bottles, and bottles were labeled and placed in double zip-lock bags. Because of the small size of many of the individual fish, most fish samples consisted of numerous fish. Samples were immediately packed in a cooler with ice, frozen overnight, and sent via overnight delivery to the laboratory for analysis.

Sediment samples were collected in wide-mouth glass jars. Sediment was scooped from the substrate using a laboratory-cleaned wide-mouth jar. Samples were capped immediately, labeled, and placed in a double zip-lock bag. These samples were placed on ice in a cooler, frozen overnight, and sent via overnight delivery to the laboratory for analysis.

Laboratory Methods

Fish samples were analyzed by Columbia Analytical Services, Kelso, WA. Whole body fish samples were homogenized, and moisture content was measured for each sample, as received, by freeze-drying. The freeze-dried fish samples were analyzed for total mercury content (dry weight basis) according to Method 1631 (US Environmental Protection Agency, 2002) and an addendum defining the digestion process for solid samples (US Environmental Protection Agency, 2001). The method detection limit for this analysis was 0.5 parts per billion for dry weight analyses. Quality control was conducted on two samples by measuring the percent recovery of a matrix spike.

Sediment samples were also analyzed by Columbia Analytical Services, Inc., in Kelso, Washington. Percent solids were determined. Total mercury in sediment (dry weight basis) was analyzed using EPA Method 1631E (US Environmental Protection Agency, 2002). The method detection limit for this analysis was 0.2 parts per billion for dry weight analyses. Quality control included analysis of sample blanks and measurement of the percent recovery of a matrix spike in 1 sample duplicate.

Methylmercury analyses in sediment were subcontracted by Brooks Rand, LLC, in Seattle, WA. The method detection limit for this analysis was 0.02 parts per billion for dry weight analysis. Quality control included analysis of sample blanks and measurement of the percent recovery of a matrix spike in 1 sample duplicate.

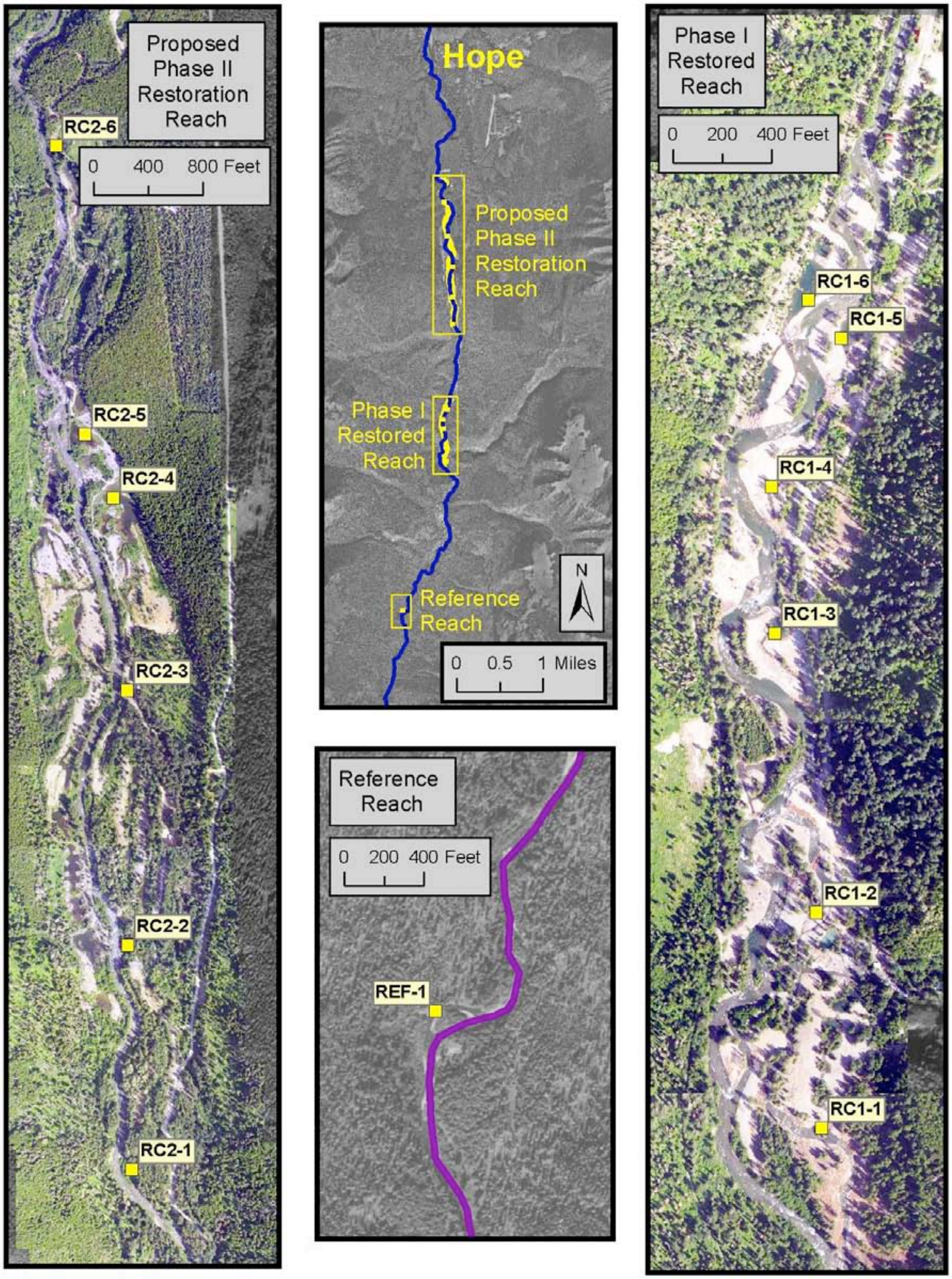


Figure 3: Locations of the July 2008 sampling sites along Resurrection Creek.

5 RESULTS

During the July 2008 sampling, the flow in Resurrection Creek was moderate to high, and the water was relatively clear. The flow in the reference reach was about 1 foot below bankfull. Air temperature remained in the low 50s Fahrenheit, and skies were overcast.

Fish samples

A total of 251 fish with an average length of 49 mm and ranging in size from 18 to 300 mm were collected for the analysis. The fish species collected included juvenile coho salmon (206 individuals), sculpin (27), Dolly Varden (14) and Chinook (4).

The total percentage as solids was reported for each sample, as received, and the lab measured dry weight total mercury concentrations for each sample. Because each sample jar contained the fish sample as well as varying quantities of water, the percentage of solids *as received* does not reflect the percentage of solids of the whole body fish samples. Using these numbers to calculate the wet weight basis total mercury would be misleading, as the water included within the samples would have diluted the wet weight concentration. Therefore, wet weight total mercury concentrations were estimated using an assumed fish tissue moisture content of 78.5%, following the methodology used by US Environmental Protection Agency (1999). Wet weight mercury concentrations were calculated using the following formula:

Wet weight conc. = Dry weight conc. x *(1 - decimal % moisture content)*

Estimated wet weight concentrations allow for rough comparisons with other studies.

Total mercury concentrations in the 2008 fish samples ranged from 0.0404 parts per million (ppm) to 0.652 ppm, averaging 0.241 ppm (dry weight basis) (**table 1, table 2, figure 4**). The highest total mercury level measured in the fish samples was in sample RC2-3, which is located in an active mining drainage ditch adjacent to the main channel in the *Proposed Restoration Reach*. The lowest total mercury level measured in the fish samples was in sample REF-1, the *Reference Reach* sample.

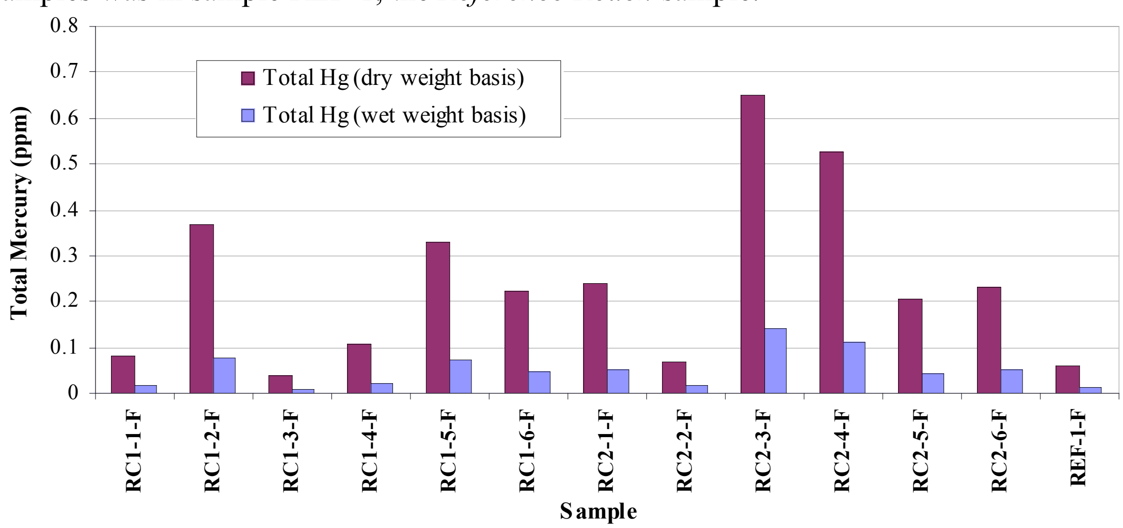


Figure 4: Results of the July 2008 mercury sampling in fish in Resurrection Creek.

Table 1: Results of the July 2008 mercury sampling in fish in Resurrection Creek.

SAMPLE	TOTAL PERCENT SOLIDS, *as received*	TOTAL MERCURY, DRY WT BASIS (ppm)	TOTAL MERCURY, WET WT BASIS (ppm) – estimated*	SAMPLE NOTES
Restored Reach				
RC1-1-F	9.9	0.0821	0.018	side channel, mostly coho
RC1-2-F	15.1	0.366	0.079	pond, mostly coho
RC1-3-F	13.9	0.0404	0.0087	pond, 1 Dolly Varden & 1 coho
RC1-4-F	9.9	0.107	0.023	Side channel, mostly coho
RC1-5-F	14.4	0.329	0.071	pond, all coho
RC1-6-F	10.6	0.222	0.048	Pond, mostly coho
Proposed Restoration Reach				
RC2-1-F	8.73	0.238	0.051	side channel, mostly coho
RC2-2-F	12.5	0.0701	0.015	side channel, mostly coho
RC2-3-F	18.1	0.652	0.14	drainage ditch, mostly sculpin
RC2-4-F	16.5	0.527	0.11	pond, mostly sculpin
RC2-5-F	17.0	0.205	0.044	pond, mostly coho
RC2-6-F	11.1	0.232	0.050	pond, 1 landlocked Chinook
Reference Reach				
REF-1-F	2.9	0.0592	0.013	side channel, all coho
** Wet weight mercury concentrations assume 78.5% moisture content of fish samples.*				

Table 2: Comparisons of total mercury concentrations in fish by reach and by date.

	Dry weight total mercury concentration (ppm)				Wet weight total mercury concentration (ppm) *		
	Low	High	Average		Low	High	Average
All Data - 2008	0.0404	0.652	0.241		0.0087	0.14	0.052
***Restored Reach* – 2008**	0.0404	0.366	0.191		0.0087	0.079	0.041
***Proposed Restoration Reach* – 2008**	0.0701	0.652	0.321		0.015	0.14	0.069
***Reference Reach* - 2008**	0.0592	0.0592	0.0592		0.013	0.013	0.013
All Data - 2004 **	0.102	0.615	0.317		0.0297	0.143	0.0703
Project Reach* – 2004 *	0.102	0.615	0.365		0.0297	0.143	0.0832
Reference Reach* – 2004 *	0.160	0.181	0.171		0.0315	0.0318	0.0317
** Wet weight mercury concentrations for 2008 samples assume 78.5% moisture content of fish samples ** Data from MacFarlane (2004a)*							

Sediment Samples

Sediment sample substrates were predominantly sand and silt with some gravel in the *Restored Reach* sites, and predominantly sand, silt, and organic material in the *Proposed Restoration Reach* sites. The sediment samples ranged from 13.6 to 88.0 percent solids.

Total mercury concentrations in sediment are reported only as dry weight basis. Total mercury concentrations in the 2008 sediment samples ranged from 28.1 to 243 parts per billion (ppb) (dry weight basis) (**table 3, table 4, figure 5**). The highest total mercury concentration was recorded in the *Restored Reach* side channel pond (RC1-5), and the lowest concentration was recorded in the *Restored Reach* Meander 4 side channel pond (RC1-3).

Methylmercury concentrations in the 2008 sediment samples ranged from non-detectible to 3.37 ppb (dry weight basis), comprising 0.0 to 4.9% of the total mercury in each sample (**table 3, table 4, figure 5**). The highest methylmercury concentration was found in the *Restored Reach* Meander 2 eastern side-channel pond (RC1-5), and the lowest concentration was found in the Meander 2 western side-channel pond (RC1-6). Methylmercury comprised less than 1 percent of the total mercury in 11 out of 13 sites.

Table 3: Results of the July 2008 mercury sampling in sediment in Resurrection Creek.

SAMPLE	TOTAL PERCENT SOLIDS	TOTAL MERCURY, DRY WT BASIS (ppb)	METHYL-MERCURY, DRY WT BASIS (ppb)	% OF TOTAL AS METHYL-MERCURY	SAMPLE NOTES
Restored Reach					
RC1-1-S	61.4	59	0.17	0.3	Side channel (sand and silt)
RC1-2-S	86.3	44.3	0.06	0.1	Pond (silt, sand, sm gravel, org muck)
RC1-3-S	66.5	28.1	1.37	4.9	Pond (silt, sand, sm gravel, org muck)
RC1-4-S	35.9	87.1	0.54	0.6	Side channel (silt, sand, organics)
RC1-5-S	13.6	243	3.37	1.4	Pond (silt, sand, organics)
RC1-6-S	88.0	34.1	ND (0.02)	0.0	Pond (silt, sm gravel, organics)
Proposed Restoration Reach					
RC2-1-S	65.1	48.1	0.12	0.2	Side channel (silt, sand, organics)
RC2-2-S	63.1	51.6	0.12	0.2	Side channel (silt, sand, organics)
RC2-3-S	54.5	96.7	0.57	0.6	Mining drainage ditch (silt, sand, org)
RC2-4-S	48.8	68.1	0.27	0.4	Pond (silt, sand, organics)
RC2-5-S	40.7	106	0.87	0.8	Pond (silt, sand, organics)
RC2-6-S	73.2	34.9	0.04	0.1	Pond (silt, sand, organics)
Reference Reach					
REF-1-S	72.6	34.5	0.09	0.3	Side channel (silt, sand, organics)

Table 4: Comparisons of mercury concentrations in sediment by reach and by date.

	Dry weight total mercury concentration (ppb)				Dry weight Methylmercury concentration (ppb)		
	Low	High	Average		Low	High	Average
All Data - 2008	28.1	243	72.0		0.02	3.37	0.59
Restored Reach – 2008	28.1	243	82.6		0.02	3.37	0.92
Proposed Restoration Reach – 2008	34.9	106	67.6		0.04	0.87	0.33
Reference Reach - 2008	34.5	34.5	34.5		0.09	0.09	0.09
**Project Reach - 2004 **	27.2	141	71.4		0.07	2.29	1.02
*** Data from MacFarlane (2004b)*							

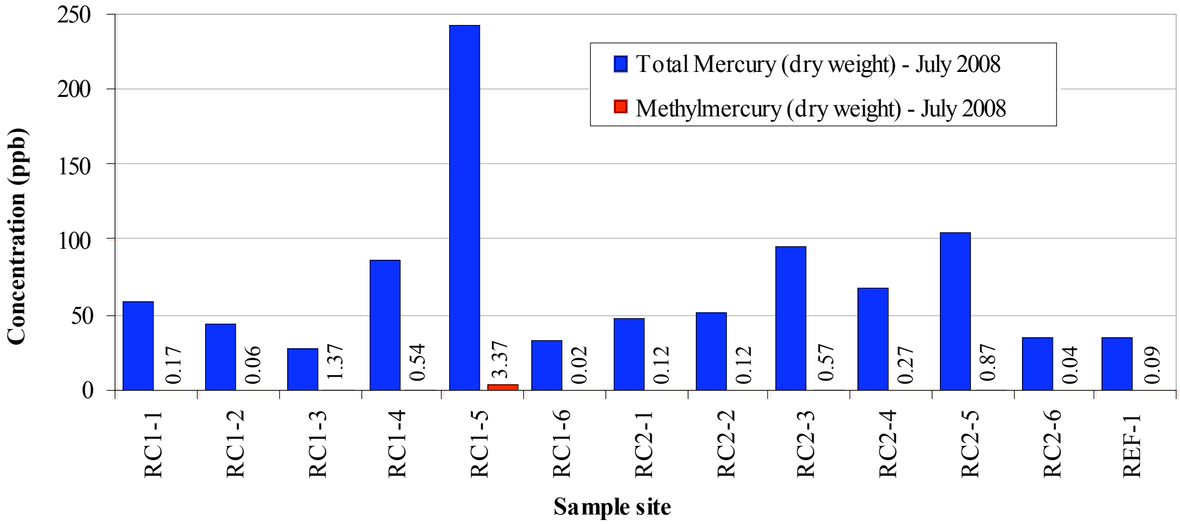


Figure 5: Results of the July 2008 mercury sampling in sediment in Resurrection Creek.

6 DISCUSSION

Mercury in Fish

Factors that affect mercury levels in fish

Many factors other than natural and anthropogenic sources of mercury in the environment can influence mercury concentrations in fish samples. Biologic factors include the size, age, and species of fish. Methylmercury bioaccumulates and biomagnifies in larger and older fish. The half life of methylmercury in fish is species specific, and storage of methylmercury in fish tissue depends on the distribution of fat in the tissue. Ocean, lake, and stream habitats each have different physical properties that affect the input and retention of mercury in the system. Water quality parameters also affect methylmercury concentrations and uptake rates in fish. Elevated water temperatures, low pH, anaerobic conditions, and dissolved organic carbon concentrations increase rates of methylation of mercury (US Environmental Protection Agency, 1997; Power et al., 2002). Krabbenhoft et al. (1999) showed that the density of nearby wetlands was the most important factor increasing methylation rates. The location of sampling in relation to point sources of mercury contamination also clearly has a large effect on mercury levels in fish (Schwarzbach et al., 2001).

Differences in the sample preparation techniques of whole body, fillet, and liver analysis can also account for differences in measured mercury concentrations in fish. Bevelheimer et al. (1997) showed empirically that mercury concentrations in whole body fish samples were 70% of mercury concentrations in fish fillet samples. Schwarzbach et al. (2001) also measured higher mercury concentrations and higher percentages as methylmercury in muscle tissue samples than whole body samples. Also, liver samples are likely to have higher mercury concentrations than muscle tissue. However, these trends can vary between species.

Mercury levels in fish

Although methylmercury was not measured in the 2008 fish samples from Resurrection Creek, it is assumed that nearly all of the mercury in these fish samples is methylmercury. Numerous studies have shown that 90-100% of the mercury in fish tissue is methylmercury (Wiener and Spry, 1996; US Environmental Protection Agency, 1997; Gassel, 2000; Schwarzbach et al., 2001). Methylmercury is most likely to be present in fish because it bioaccumulates in tissue, whereas elemental mercury can pass through organisms relatively quickly. However, generally only a very small percentage of the total mercury in stream water and sediments is methylmercury (Wiener and Spry, 1996).

The Food and Drug Administration (FDA) "action level," the level at which the government may take legal action to remove fish from the market, is 1.0 ppm methylmercury (wet weight basis) in the edible portion of fish tissue (US Food and Drug Administration, 2000). Lethal wet weight concentrations of mercury in whole body fish samples have been shown to be about 5 ppm for brook trout and 10 ppm for rainbow trout (Wiener and Spry, 1996). Although whole fish were sampled in Resurrection Creek rather than fillets, wet weight methylmercury levels in the 2008 fish samples (0.0087 ppm to 0.14 ppm) were still considerably less than the FDA “action level.”

Fish sampled throughout Alaska generally show low concentrations of mercury, as industrial sources of mercury in Alaska are minimal, although mercury from placer gold mining, geologic sources, and atmospheric deposition are present in some Alaskan rivers and streams. Marine and freshwater Alaskan fish sampled statewide have showed methylmercury levels well below 1 ppm. A 2003 fish monitoring project showed mercury levels in salmon below 0.1 ppm (Alaska Department of Environmental Conservation, Division of Environmental Health, 2003).

Biological trends

Studies have shown that mercury levels increase with the size and age of fish through the process of bioaccumulation (Gassel, 2000; Schwarzbach et al., 2001; Power et al., 2002). Also, biomagnification causes predatory species to have higher concentrations of mercury than bottom feeders (US Environmental Protection Agency, 1999). Studies have demonstrated that mercury concentrations increase by a factor of 2 to 5 between trophic levels (Cabana and Rasmussen, 1994; Power et al., 2002; Muir, 2003).

In this study, although the sample size was not sufficient for statistical analysis, it appears that no real correlation exists between mercury levels and the size or species of the fish sampled. The two sites with the highest mercury levels contained samples of fish at a larger average length then most others sites, indicating some bioaccumulation with age and size. However, the largest fish sampled, at greater than three times the average length of most other samples, showed relatively low mercury concentrations. These results suggest that the distribution of any mercury in the system could be localized.

Spatial trends

In the 2008 Resurrection Creek study, mercury levels measured in fish were higher in the *Restored Reach* and *Proposed Restoration Reach* samples than the *Reference Reach* sample. This is expected because aside from a few small prospecting claims, the *Reference Reach* is upstream of any placer mining areas where mercury may have been used. Dry weight mercury levels in the fish samples averaged 0.321 ppm in the *Proposed Restoration Reach*, 0.191 ppm in the *Restored Reach*, and 0.0592 ppm in the Reference Reach. Although the ranges of concentrations between the *Proposed Restoration Reach* and the *Restored Reach* were overlapping, the *Proposed Restoration Reach* contained the samples with the highest mercury concentrations (**figure 4**).

The highest total mercury concentrations were measured at sites RC2-3 and RC2-4 in the *Proposed Restoration Reach*, both part of an active settling pond and ditch system for an active mining operation. Several factors may have contributed to the higher mercury levels measured in the fish at these sites. Higher water temperatures, increased organic material, increased bacterial activity, and lower oxygen levels associated with this settling pond system may have led to increased methylation of mercury. Active mining and recent disturbance occurring just upstream could have also released mercury that was stored in the tailings piles into the system.

The lower mercury levels measured at the sample sites that are more connected to the main channel may be the result of higher flows that flush mercury downstream or cause it to settle deep into the channel substrate, or decreased methylation because of cold temperatures, oxygenated water, lack of organic material, and low levels of bacteria in the channel sediments.

Comparisons to other studies

The mercury concentrations measured in the 2008 Resurrection Creek fish samples were comparable to those measured in 2004 (MacFarlane, 2004a) (**table 3, figure 6, figure 7**). Dry weight total mercury concentrations in fish ranged from 0.102 to 0.615 ppm in 2004, and from 0.0404 ppm to 0.652 ppm in 2008. Although the 2008 study captured larger predatory fish and resident fish than the 2004 samples, and biomagnification would assume greater mercury concentrations, fish in the 2008 study still contained relatively low mercury concentrations.

Mercury levels measured in fish in Resurrection Creek in 2008 were considerably lower than mercury levels from a variety of studies nationwide where fish were impaired by point sources of mercury pollution (**figure 6**). A national survey of mercury concentrations in fish fillet samples indicated state-averaged values for a variety of species ranged from about 0.02 ppm to 1.4 ppm *wet weight basis* (US Environmental Protection Agency, 1999). Mercury has been a large concern in northern California, where mercury was used for placer gold mining, and mercury mines contribute polluted runoff to streams and lakes. Gassel (2000) measured mercury concentrations of 0.57 to 1.8 ppm *wet weight basis* in fish fillet samples in Lake Pillsbury, California where mercury mines were present in the watershed. Schwarzbach et al. (2001) measured mercury concentrations in streams of the Cache Creek watershed ranging from 0.098 to 1.66 ppm *wet weight basis* for whole body fish samples downstream of a superfund mercury mine.

Mercury levels measured in fish in Resurrection Creek in 2008 were similar to or less than the mercury levels measured in a variety of fish species in systems with minimal anthropogenic input of mercury (**figure 6**). Various studies in areas with no point sources of mercury pollution include mercury concentrations averaging 0.37 ppm *wet weight basis* for muscle tissue in a variety of fish species in western Alaska (Duffy, 1997), concentrations between 0.07 and 0.59 ppm *wet weight basis* for muscle tissue in a variety of species in Stewart Lake in arctic northeastern Canada (Power et al., 2002), and concentrations between 0.07 and 0.49 ppm *wet weight basis* for a variety of sport fish fillet samples in Lake Whatcom, Washington (Mueller et al., 2001).

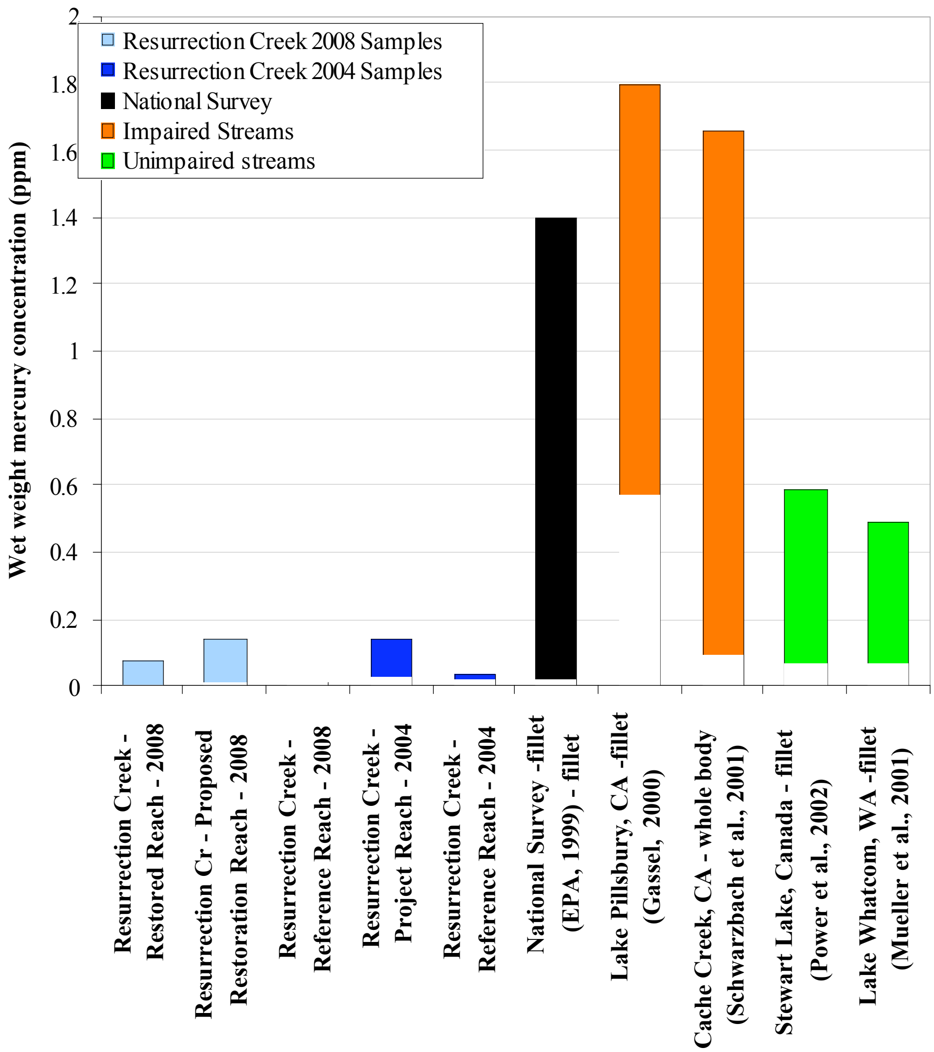


Figure 6: Comparison of *wet weight* mercury concentrations in fish in Resurrection Creek with various species of fish in impaired and unimpaired watersheds nationwide.

Several studies have measured mercury concentrations in sculpin. Frenzel (2000) measured *dry weight*, whole body mercury concentrations in slimy sculpin from throughout the Cook Inlet Basin, Alaska ranging from 0.08 to 0.21 ppm. In another study, sculpin measured in streams and rivers of the Puget Sound area in Washington showed *dry weight*, whole body mercury concentrations ranging from 0.10 to 0.76 ppm in urban and agricultural sites and 0.10 to 0.40 ppm in reference and forest sites (MacCoy and Black, 1998). With 2 exceptions, the *dry weight* mercury concentrations measured in the 2008 Resurrection Creek fish samples were comparable to the reference conditions measured in Puget Sound and up to 2 times higher than the reference conditions measured in Cook Inlet. However, the two samples that showed higher mercury levels, both within the active settling pond system, were similar to the urban sites measured in Puget Sound (**figure 7**).

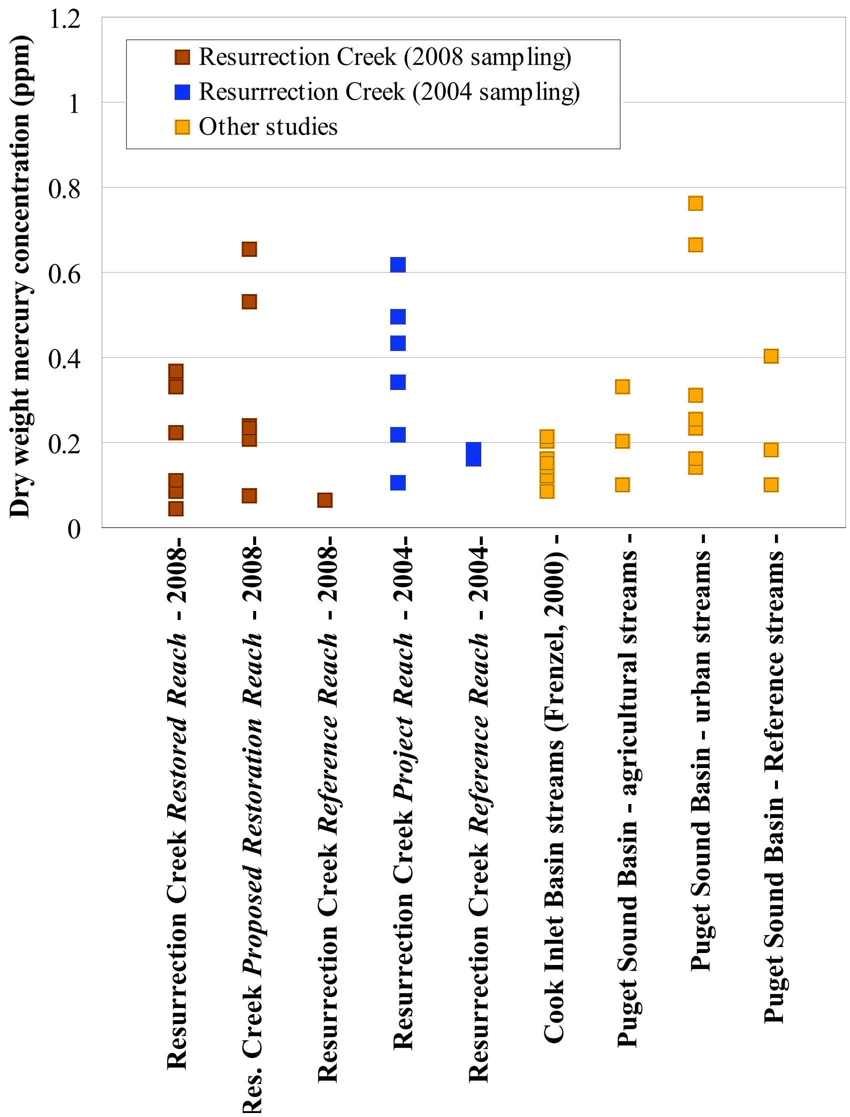


Figure 7: Comparison of *dry weight*, whole body mercury concentrations in fish in Resurrection Creek with sculpin in Cook Inlet Basin, AK (Frenzel, 2000) and Puget Sound Basin, WA (MacCoy and Black, 1998).

Mercury in Sediment

Spatial trends

Total mercury concentrations measured in the *Restored Reach* and the *Proposed Restoration Reach* were similar, although the mercury concentration in one sample in the *Restored Reach* was over 2 times higher than all other samples (**figure 8**). Methylmercury concentrations followed a similar trend (**figure 9**). In general, mercury levels in sediment were higher in the pond sites than in the side-channel sites. The fine grained sediment in the pond sites contained more organic matter to which elemental mercury could bind, possibly resulting in these higher mercury levels, while sediments in the side-channel sites consisted of mostly sand and gravel. Conditions in the pond sites also included more stagnant water and warmer temperatures, which are additional factors that can lead to increased mercury concentrations.

The highest levels of mercury in the sediment samples do not correspond with the highest levels of mercury in the fish samples among the sampling sites. Where the highest mercury concentrations in fish were measured in the active mining settling pond system sites, sediment at these sites had relatively normal mercury levels. Elemental mercury can exist in sediment by itself or attached to organic particles. Differences in total mercury concentrations in sediment samples could be attributed to local variations in sediment conditions and the distribution of mercury, whereas mercury concentrations in fish samples are more indicative of the entire area to which the fish is exposed.

Methylmercury Levels in Sediment

Methylmercury comprises only a small percentage of the total mercury measured in the sediment samples. Mercury and methylmercury concentrations measured in these samples showed a positive correlation (**figure 10**), with relatively consistent proportions of total mercury as methylmercury. However, one sample in the *Restored Reach* (RC1-3) had an abnormally high percentage of methylmercury (4.9%) and does not follow this correlation. The high methylmercury concentration could be accounted for by the high organic content of the sample, which was taken from a relatively stagnant side channel pond. Conditions of stagnant water, warm water, low dissolved oxygen, and abundant organic material can increase rates of methylation of mercury at sites such as this.

The highest concentrations of methylmercury were measured in the *Restored Reach* at a side channel pond site (RC1-5), where methylmercury levels reached 3.37 ppb, or 1.4% of the total mercury. This is a site where the total mercury and methylmercury concentrations were relatively high, and the percentage of the total mercury as methylmercury was more than twice as high as most of the other sites. This is also likely because of the high rate of methylation of mercury in the sediment at this site resulting from the stagnant conditions in that pond. Low levels of methylmercury at many of the other sites are attributed to conditions such as colder water temperatures, higher dissolved oxygen, and less stagnant water, which are not favorable for methylation of mercury.

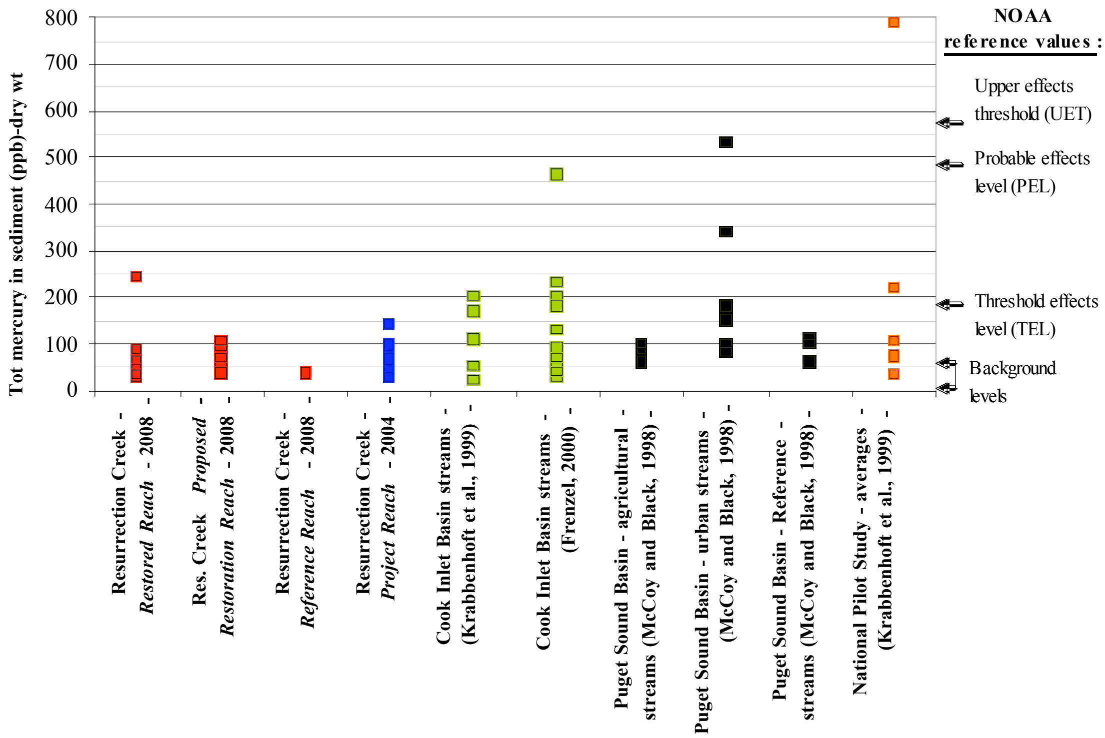


Figure 8: Comparison of ranges of total mercury levels in sediment (dry weight basis) between Resurrection Creek and other sites nationwide.

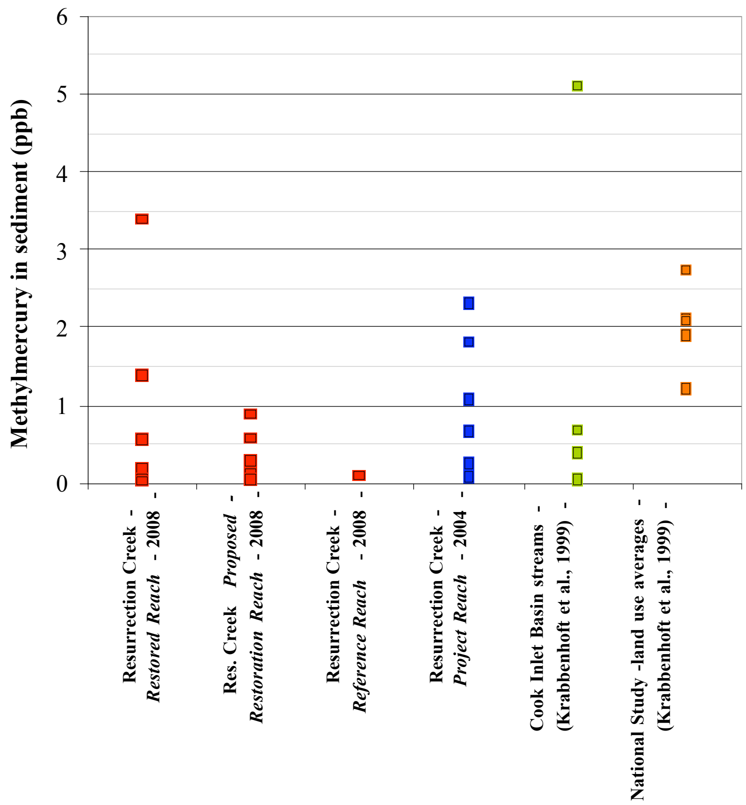
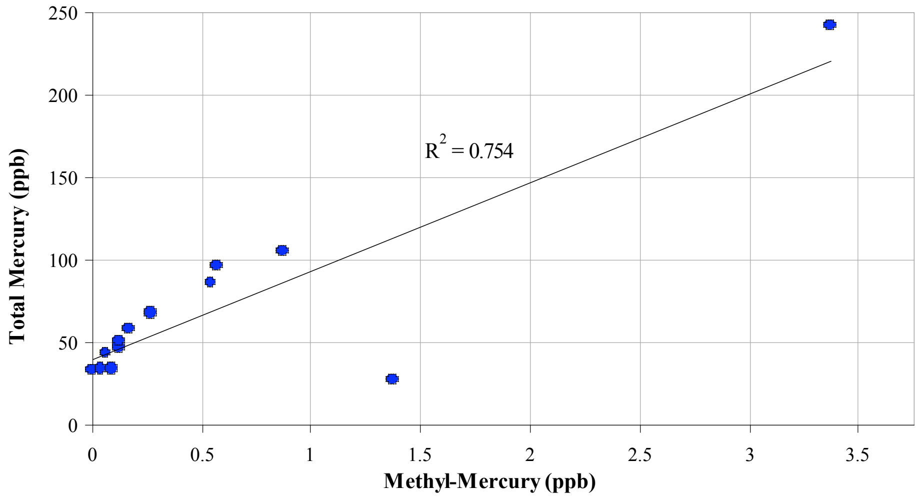


Figure 9: Comparison of ranges of methylmercury levels in sediment (dry weight basis) between Resurrection Creek and other sites nationwide.

Figure 10: Relationship between total mercury and methylmercury in the sediment samples.



Comparisons to other studies

Preliminary screening levels for mercury contamination in sediment have been suggested by the National Oceanic and Atmospheric Administration (NOAA). Although they do not represent sediment quality standards, these guidelines suggest that background levels of total mercury in sediment are 4 to 51 ppb (dry weight), the Threshold Effects Level is 174 ppb (dry weight), the Probable Effects Level is 486 ppb (dry weight), and the Upper Effects Threshold is 560 ppb (dry weight) (National Oceanic and Atmospheric Administration, 1999). Six of the 13 sites showed total mercury levels that were within what is considered the background levels. Six other sites showed levels slightly higher than what is considered background levels, but well below the Threshold Effects Level. One site in the *Restored Reach* (RC1-5) showed a total mercury concentration above the Threshold Effects Level, but well below the Probable Effects level (**figure 8**).

Total mercury and methylmercury levels in sediment in the Resurrection Creek sites sampled in 2008 are similar to levels measured in other Cook Inlet region streams (Krabbenhoft et al., 1999; Frenzel, 2000) (**figure 8, figure 9**). These levels are also similar to mercury levels in streams in agricultural and forested sites in the Puget Sound area, Washington, but lower than most of the urban sites measured in the Puget Sound area (MacCoy and Black, 1998) (**figure 8**). Mercury and methylmercury levels in sediment in the Resurrection Creek side channels are mostly within the lower range of levels measured in sediments from the national pilot study on mercury contamination (Krabbenhoft, 1999) (**figure 8, figure 9**). The percentage of the total mercury as methylmercury in the sediments in the 2008 Resurrection Creek sites ranged from 0 to 4.9%. In rural and urban sites in New England, the percentage of the total mercury as methylmercury ranged from 0.3 to 25%, with methylmercury levels reaching as high as 15.6 ppb (US Geological Survey, 2003).

7 CONCLUSIONS

Although many factors were not considered in this analysis and sample sizes were not sufficiently high for statistical analyses, these results are a representation of mercury concentrations in fish and sediment throughout the sites sampled on Resurrection Creek in 2008. This study suggests that mercury levels are very low in the *Reference Reach*, consistent with mercury levels in fish regionally. Mercury levels measured in some sites in the *Restored Reach* and the *Proposed Restoration Reach* were slightly elevated over what might be considered “reference” levels. This may be the result of mercury present within the tailings piles that was used during historic placer mining operations. However, mercury levels were considerably lower than the mercury levels measured in many impaired and unimpaired streams nationally, and mercury levels were similar to those measured on Resurrection Creek in 2004 (MacFarlane, 2004a; MacFarlane, 2004b).

Mercury levels measured in fish were all well below the FDA Action Level for fish consumption, and mercury levels in sediment were below the NOAA suggested Threshold Effects Level, with the exception of one sample. Mercury concentrations in 2 fish samples and 1 sediment sample were slightly elevated over the other samples, although still at levels that would be considered low. These slightly elevated levels may be the result of localized occurrences of mercury in the system, increased rates of methylation in pond sites as a result of a variety of conditions, or the release of mercury related to recent disturbance such as mining.

Based on the levels of mercury measured at these sites, it is possible that localized deposits of mercury may exist buried within the tailings piles. However, the risk of future stream restoration activities releasing large concentrations of mercury into the system is low. Protocols for the cleanup of mercury should be in place during any future mining or channel restoration process in case visible concentrations of mercury are found in the channel sediments or tailings piles. Further sampling is recommended one to two years following major stream restoration activities to determine whether any mercury has been released into the system.

ACKNOWLEDGEMENTS

Thanks to Eric Johansen, Ruth D’Amico, and David Pearson for their assistance in collecting the samples.

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APPENDIX A: SITE PHOTOGRAPHS

RC1-1: *Channel 1* (east side channel of Resurrection Creek)

RC1-2: *Meander 5* side channel pond

RC1-3: *Meander 4* side channel pond

RC1-4: *Meander 3* east side channel.

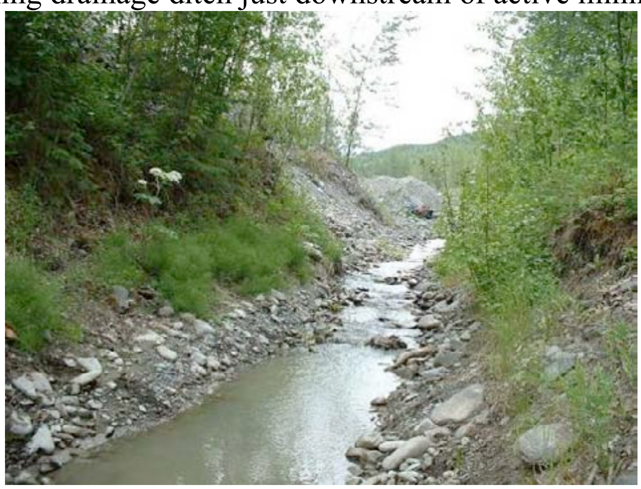
RC1-5: *Meander 2* east side channel pond

RC1-6: Upper pond on the west side channel adjacent to *Meander* 2

RC2-1: Side channel along the main channel of Resurrection Creek

RC2-2: East side channel adjacent to the main channel

RC2-3: Mining drainage ditch just downstream of active mining operations

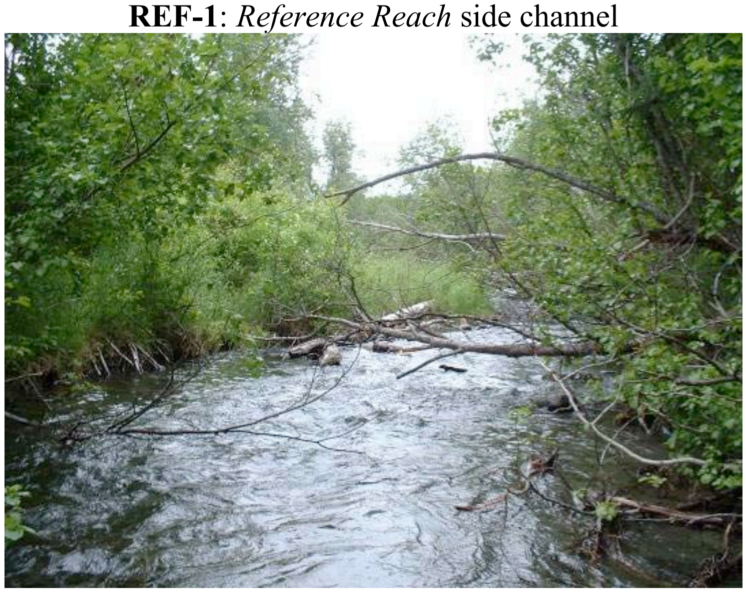


RC2-4: Large pond, part of active mining settling pond system

RC2-5: Active settling pond

RC2-6: Active settling pond

REF-1: *Reference Reach* side channel



APPENDIX B: LABORATORY DATA

Laboratory analyses were conducted by

Columbia Analytical Services, Inc.
1317 South 13th Avenue
PO Box 479
Kelso, WA 98626
Phone (360)577-7222
Fax (360) 636-1068
Contact: Harvey Jackey, Project Chemist or Jeff Christian, Laboratory Director

Laboratory data on file at

Chugach National Forest
3301 'C' Street, Suite 300
Anchorage, AK 99503
(907)743-9500
Contact: Bill MacFarlane, Hydrologist

APPENDIX C: SAMPLE SITE LOCATIONS

Sample name	Date	Habitat Type	Location (Lat/Long) (NAD83)
RC1-1	7/8/2008	side channel	149°37'59.973"W 60°50'59.156"N
RC1-2	7/8/2008	pond	149°38'1.148"W 60°51'7.736"N
RC1-3	7/8/2008	pond	149°38'5.428"W 60°51'18.823"N
RC1-4	7/8/2008	side channel	149°38'6.201"W 60°51'24.656"N
RC1-5	7/8/2008	pond	149°38'0.96"W 60°51'30.689"N
RC1-6	7/8/2008	pond	149°38'3.772"W 60°51'32.134"N
RC2-1	7/9/2008	side channel	149°37'58.718"W 60°52'22.069"N
RC2-2	7/9/2008	side channel	149°38'0.63"W 60°52'38.188"N
RC2-3	7/9/2008	ditch	149°38'2.182"W 60°52'56.537"N
RC2-4	7/9/2008	pond	149°38'5.407"W 60°53'10.376"N
RC2-5	7/9/2008	pond	149°38'9.921"W 60°53'14.896"N
RC2-6	7/9/2008	pond	149°38'15.994"W 60°53'35.546"N
REF-1	7/10/2008	side channel	149°38'46.404"W 60°49'28.183"N

APPENDIX D: FISH SPECIES AND AVERAGE LENGTH SAMPLED

		SPECIES			
SAMPLE		**CO**	**CH**	**DV**	**SC**
RC1-1	Num of samples	59	-	-	1
	Avg. Length (mm)	27	-	-	40
RC1-2	Num of samples	18	-	-	3
	Ave. Length (mm)	57	-	-	30
RC1-3	Num of samples	1	-	1	-
	Ave. Length (mm)	90	-	170	-
RC1-4	Num of samples	19	2	-	-
	Ave. Length (mm)	47	63	-	-
RC1-5	Num of samples	11	-	-	-
	Ave. Length (mm)	58	-	-	-
RC1-6	Num of samples	31	1	-	2
	Ave. Length (mm)	42	40	-	30
RC2-1	Num of samples	20	-	4	3
	Ave. Length (mm)	39	-	78	90
RC2-2	Num of samples	16	-	4	-
	Ave. Length (mm)	41	-	94	-
RC2-3	Num of samples	-	-	4	5
	Ave. Length (mm)	-	-	149	45
RC2-4	Num of samples	-	-	1	10
	Ave. Length (mm)	-	-	300	47
RC2-5	Num of samples	16	-	-	3
	Ave. Length (mm)	71	-	-	53
RC2-6	Num of samples		1	-	-
	Ave. Length (mm)	-	290	-	-
REF-1	Num of samples	15	-	-	-
	Ave. Length (mm)	38	-	-	-

Coho=CO, Chinook=CH, Dolly Varden=DV, Sculpin=SC