MERCURY CONCENTRATIONS IN FISH IN RESURRECTION CREEK, ALASKA

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ABSTRACT

- Chugach National Forest personnel measured mercury concentrations in fish in Resurrection Creek to assess the presence or absence of mercury in the system. Mercury was likely used by placer miners in the early twentieth Century.

- The proposed Resurrection Creek restoration will restore the channel and floodplains to their natural condition. The presence of mercury is a concern because it may be released into the environment when channel sediments and tailings piles are moved.

- Sculpin were sampled at 6 sites in the Resurrection Creek project reach and 2 sites in the upstream reference reach, and coho fry were sampled at 1 site in the project reach.

- Total mercury concentrations, on a wet weight basis, ranged from 0.0297 ppm to 0.143 ppm in the main channel and side channels of the project reach, and 0.0315 ppm to 0.0318 ppm in the reference reach side channels. Methylmercury most likely comprised nearly 100% of the total mercury in these samples.

- The mercury concentrations in Resurrection Creek fish are considerably lower than the 1.0 ppm FDA "action level", where the FDA restricts consumption of fish.

- Mercury concentrations were the highest in the samples taken from the small artificial side channels on both sides of the project reach. The samples taken in the main channel of the project reach and the side channels in the reference reach showed considerably lower concentrations of total mercury.

- Concentrations of methylmercury are higher in fish in the ponds of the side channels likely because of increased methylation associated with warmer water temperatures, decreased oxygen, and increased organic matter.

- The coho sample showed lower concentrations of total mercury than the sculpin sample from the same location.

- Mercury levels in the reference reach and the main channel of the project reach were similar to the levels measured in sculpin sampled throughout the Cook Inlet Basin. Mercury concentrations measured in the project reach side channels were 2 to 4 times these reference levels.

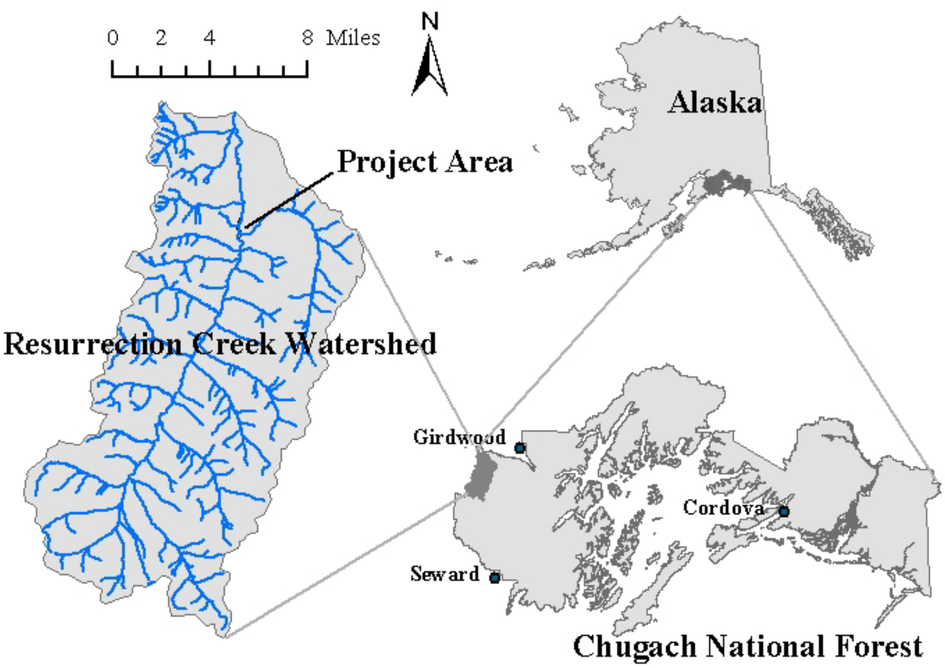
- These elevated mercury levels in the project reach side channels are likely the result of mercury in the system deposited during gold mining efforts. Nevertheless, these levels are quite low compared to levels measured in fish in degraded as well as non-degraded systems throughout North America.

- Data suggest that mercury levels in fish and water in Resurrection Creek and its side channels are likely not high enough to be toxic to developing eggs and fry.

INTRODUCTION

The Chugach National Forest is planning a large-scale stream restoration project on Resurrection Creek, north of Hope, Alaska (**figure 1**). Resurrection Creek is the site of extensive gold placer mining over the past century, and placer mining operations in the early 1900's resulted in numerous tailings piles, channelization, and loss of floodplain functionality. Although it is unknown how much mercury was used for mercury amalgamation during these placer mining operations, some mercury may still be in the system, likely within the tailings piles. This study was conducted to address concerns that some of this mercury might be released into the environment during channel restoration. The objectives of this study were to sample fish to determine the presence or absence of mercury in the system, to sample fish in different areas throughout the project reach and compare mercury levels to those in a reference reach, and to compare mercury levels in sculpin and coho salmon.

Figure 1: Location of the Resurrection Creek project area.



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 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. The tailings piles have greatly confined the channel and its floodplain and remain largely unvegetated because of the coarse nature of the material and the lack of fine sediment. 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 volcanic eruptions and other geologic sources, as well as anthropogenic sources such as industrial metal manufacturing and fuel combustion, runoff from mercury mines, and mercury used for gold mining. Mercury in the atmosphere is distributed globally. In 1995, the annual emission of mercury from the US from industrial and combustion sources totaled 158 tons (US Environmental Protection Agency, 1997). 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. In the project area, the 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 sediment 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 neurodevelopment 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 has decreased since the 1980's but still occurs in some areas. Between 1999 and 2002, personnel from the Chugach National Forest constructed a series of side channels and small ponds about 5 miles upstream of the mouth, amongst the large tailings piles on both sides of the channel and fed by French drains that filter water from Resurrection Creek. These side channels were constructed to improve rearing habitat for juvenile salmon in Resurrection Creek. These channels and associated ponds currently support moderate populations of salmon fry, as well as sculpin and other fish species, and represent some of the only slow-water pool habitat in the project reach.

Restoration: The Chugach National Forest is planning a large-scale restoration project for 0.8 miles of the Resurrection Creek channel and floodplain upstream and downstream of the Palmer Creek confluence. This area is referred to as the "project reach," and a reference reach exists about a mile upstream (**see figure 4**). 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 a new channel, and restoring the channel and floodplain.

Documentation: This study assesses of the presence or absence of mercury in the system prior to conducting restoration. Chugach National Forest personnel are currently developing an Environmental Impact Statement for the restoration project. Detailed studies of all aspects of the area were also recently conducted as part of the Resurrection Creek Watershed Association Hydrologic Condition Assessment (Kalli and Blanchet, 2001) and the Resurrection Creek Landscape Analysis (Hart Crowser, Inc., 2002).

HYDROLOGIC CONDITIONS

Watersheds: The Resurrection Creek watershed covers about 103,230 acres (161 square miles) on the northern side of the Kenai Peninsula. Resurrection Creek flows north about 24 miles into Turnagain Arm, and elevations in the watershed range from sea level to about 5,000 feet. The valley and side valleys are glacially carved U-shaped valleys, but glaciers are no longer present in the watershed. Numerous high gradient tributaries flow into Resurrection Creek, and the largest tributary, Palmer Creek, occupies a hanging valley east of the project area.

Climate: The Resurrection Creek watershed 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. Hope receives about 90 inches of snow annually, also increasing with elevation. Most of the precipitation falls as rain in August, September, and October, and winters receive more precipitation than summers.

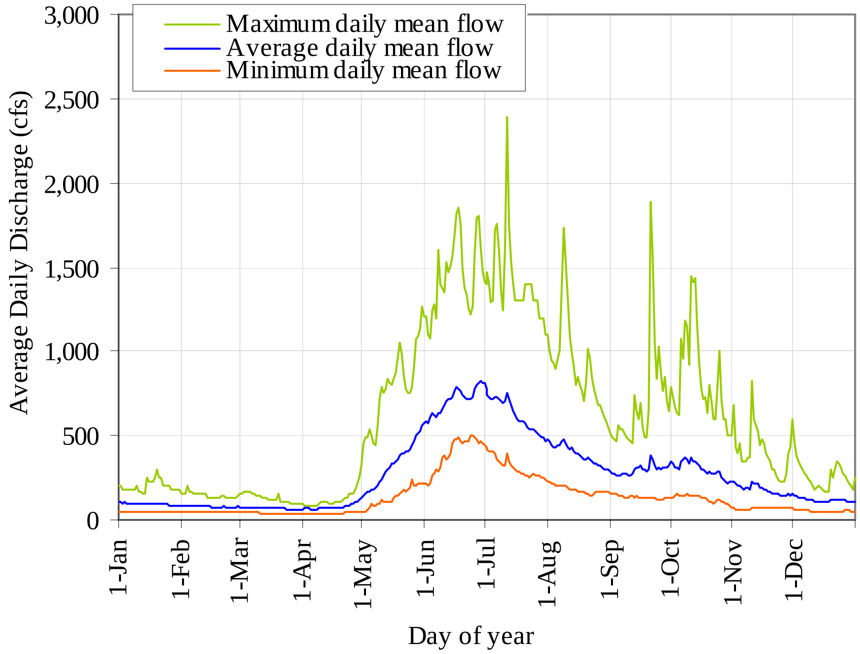
Streams: Based on the Region 10 stream classification system (USDA Forest Service, Alaska Region, 1992), Resurrection Creek progresses from a Moderate Gradient Mixed Control (MM) channel in its upper reaches to a Floodplain (FP) channel in its lower reaches, with several short canyon sections along its length. The channel within the project area is a Low Gradient Floodplain Channel (FP4), 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 channels in the project area, as well as mined areas downstream, are confined on one or two 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. Palmer Creek joins Resurrection Creek near the upstream end of the project reach. This channel has a high gradient as it descends from a hanging valley, resulting in an alluvial fan at the confluence.

Side Channels: Near the upstream end of the project reach and upstream of the Palmer Creek confluence, two French drains on the east side of Resurrection Creek feed 2 small side channels (**see figure 4**). "Channel 1," the longer channel to the east, is interconnected by several small ponds, re-entering Resurrection Creek about 750 feet downstream. The French drain feeding Channel 1 does not function properly, and flows are generally very low. "Channel 2" contains 3 small ponds and is only about 400 feet long, fed by a functioning French drain. Beavers persistently build small dams on these channels. On the west side of Resurrection Creek, the "Beaver Pond Channel" starts near the Palmer Creek confluence and re-enters Resurrection Creek about 2700 feet downstream, at the end of the project reach. This channel has a series of small and large beaver ponds. A portion of the channel splits to join Resurrection Creek about 800 feet downstream of the French drain.

Streamflows: A stream gauge was in operation on Resurrection Creek upstream of Hope from 1967 to 1986. The average mean daily flow was 274 cfs (US Geological Survey, 2003). The flow regime in Resurrection Creek is primarily controlled by summer snowmelt (**figure 2**). 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. Winter flows from December to April remain at about 100 cfs. Ice buildup in the channel is common, and ice dam breakout floods can occur in the winter. The 2-year flow is about 1230 cfs, and the 10-year flow is about 2390 cfs (Curran et al., 2003).

Water quality: Water quality data were collected on Resurrection Creek near Hope from 1950 to 1959 and from 1968 to 1971 (US Geological Survey, 2003). These data indicate no violations of the state standards for fish and wildlife (Alaska Department of Environmental Conservation, 2003). Data collected in 1980 at placer mining sites on Resurrection and Palmer Creeks showed elevated levels of manganese and lead in the mining wash water, elevated levels of lead in Resurrection Creek downstream of the mining, and elevated levels of lead in Palmer Creek upstream of the mining (Blanchet, 1981). Lead concentrations were as high as 0.17 ppm, and manganese concentrations reached 0.22 ppm. We are not aware of any existing data for mercury in water, fish, or soils of Resurrection Creek.

Figure 2: Resurrection Creek hydrograph, USGS station 15267900. Period of record 1967-1986.



SAMPLING LOCATIONS AND METHODS

Sample mediums: Mercury concentrations can be analyzed in soil, sediment, water, fish tissue, or other organic samples. If mercury was spilled by miners, it would likely be concentrated in certain areas, but the locations of these areas are unknown. Therefore, mercury, if present, probably exists only in localized areas in the channel substrate or in localized areas within the sediments and soils of the tailings piles.

Soil and sediment sampling was not conducted for this preliminary study. In order to adequately characterize the spatial variability of mercury concentrations, it would be necessary to collect numerous soil samples across the project area and at a variety of depths for each sampling location. Such sampling would be expensive and would require considerable ground disturbance. Water sampling was not conducted because of the limited possibilities of identifying sediment or organics-bound mercury in water samples. Water flushes through the project reach relatively quickly and is not likely to represent concentrations of methylmercury that might be present in the system. Downstream water uses from Resurrection Creek for human consumption are currently very limited.

We concluded that resident fish living in the project area would provide the most efficient sampling medium for this preliminary study 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 mercury that exists within the tailings piles. Additionally, fish with high mercury concentrations would be of high concern to sport and subsistence anglers on Resurrection Creek. The artificial side channels in the project reach, where a majority of the fish were sampled, are representative of the types of disturbance planned in the proposed Resurrection Creek channel and floodplain restoration efforts. If necessary, additional future sampling of soils and sediments could provide more information about the locations and concentrations of any mercury in the channel and tailings piles.

Fish samples: Slimy sculpin (*Cottus cognatus*) were the primary species sampled because they are an abundant resident fish that feeds directly on the channel substrate (**figure 3**). 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 sculpin. Frenzel (2000) used similar methods to sample slimy sculpin in the Cook Inlet Basin for organic compounds and trace elements. To examine differences between fish species, coho salmon fry (*Oncorhynchus kisutch*) were also sampled at one sample site. Very few Dolly Varden were present in the project reach during the time of sampling.

Figure 3: Slimy sculpin (*Cottus cognatus*).

Sample locations: A total of 8 fish samples were taken on September 15, 2003 (**figure 4**), including 6 samples from the project reach and 2 samples from the upstream reference reach:

1) **CH1-SC**: A sculpin sample was taken from Channel 1 in "Pool 1", the 5th pond downstream of the French drain. Channel 1 had no incoming flow from the French drain, but a small trickle was flowing between the ponds further downstream in the channel. Pool 1 was 2 to 3 feet deep, and the bottom sediment consisted of deep muck that clouded the water when disturbed.

2) **CH2-SC**: A sculpin sample was taken from Channel 2 in the "Berm pool," immediately downstream of the French drain for Channel 2. This channel had a moderate flow from the French drain. The Berm pool was about 3 feet deep, with clear water, but deep muck on the bottom clouded the water when disturbed.

3) **CH2-CO**: A duplicate sample of coho fry was also taken from the Berm pool of Channel 2.

4) **BP1-SC**: A sculpin sample was taken on the Beaver Pond Channel, along a 300 foot reach of the upstream portion of the channel. This site was in a narrow channel with clear water, a cobble and gravel substrate, and low to moderate amounts of fine sediment.

5) **BP2-SC**: A sculpin sample was taken on the Beaver Pond Channel, in a beaver pond about 600 feet upstream of the end of the channel. This site was a large, mostly drained beaver pond with deep deposits of fine sediment and muck on the bottom and on the banks, clouding the water when disturbed.

6) **RC1-SC**: A sculpin sample was taken in a riffle of the main Resurrection Creek channel, in the upstream portion of the project reach near the outlet of Channel 2. This riffle was several inches deep, with a gravel and cobble substrate, clear water, and very few fine sediments. The flow in Resurrection Creek was relatively low.

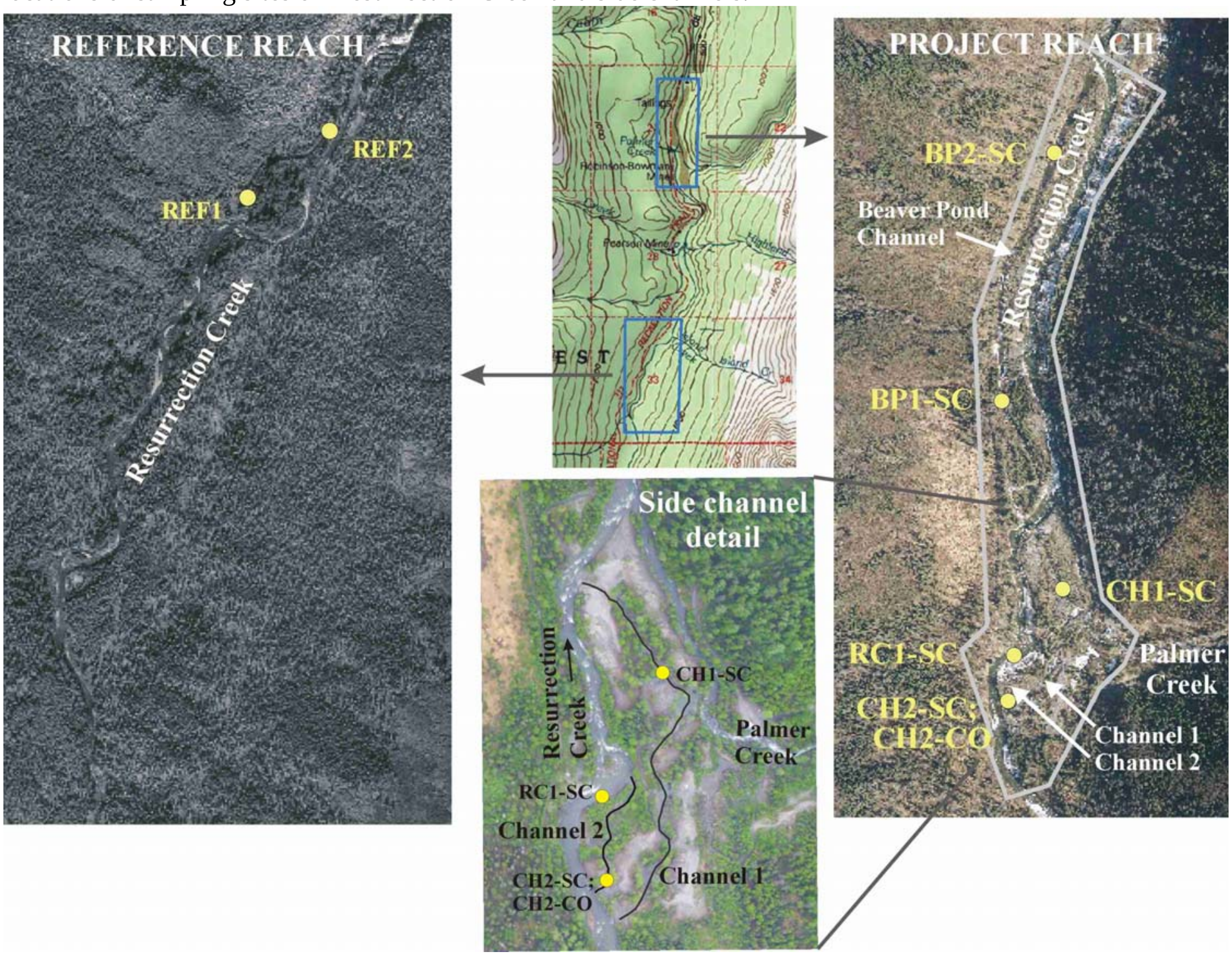
7) **REF1**: A sculpin sample was taken in a 200 foot reach of the upstream portion of the reference reach side channel, about 1 mile upstream of the project reach. This side channel was 12 to 20 feet wide with small pools up to 3 feet deep, and a cobble to small boulder substrate. Large woody debris was present, and the water was clear.

8) **REF2**: A sculpin sample was taken in the lower 250 feet of the reference reach side channel, about 1 mile upstream of the project reach. Site conditions were similar to those at REF1.

Sampling methods: 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. In the project reach side channel sites, fish were captured using electro-fishing equipment and collected in mesh nets. At the Resurrection Creek main channel site and the two reference reach sites, fish were caught by hand. Whole fish were placed in 500 mL wide-mouth plastic sample bottles that were provided by the lab, labeled, and placed in zip-lock bags. Fish samples and open sample bottles were handled only with non-powdered latex gloves, changed before each sample to prevent any cross contamination. Each sample required at least 5 grams of material, with one 15 gram sample required to conduct quality control. Because of the small size of many of the sculpin and coho fry, many fish were sampled at most sites. Samples were immediately frozen overnight, packed in a cooler with ice, and sent via overnight delivery to the laboratory for analysis.

Laboratory methods: Laboratory analyses were conducted by Columbia Analytical Services, Kelso, WA. Whole body fish samples were homogenized, and moisture content was measured for each sample by freeze-drying. The freeze-dried samples were analyzed for mercury content according to Method 1631 (US Environmental Protection Agency, 2002) and an addendum defining the digestion process for solid samples (US Environmental Protection Agency, 2001). To analyze mercury concentrations, mercury was reduced to an elemental state and purged onto a gold trap, forming a mercury-gold amalgam. The amalgam was then heated, and the elemental mercury was released into an Atomic Fluorescence Spectrometer. The method detection limit for this analysis was 0.04 to 0.2 parts per billion for wet weight analyses, and 0.2 to 1.0 parts per billion for dry weight analyses. Quality control was conducted on one sample by measuring the percent recovery of a matrix spike.

Figure 4: Locations of sampling sites on Resurrection Creek and side channels.



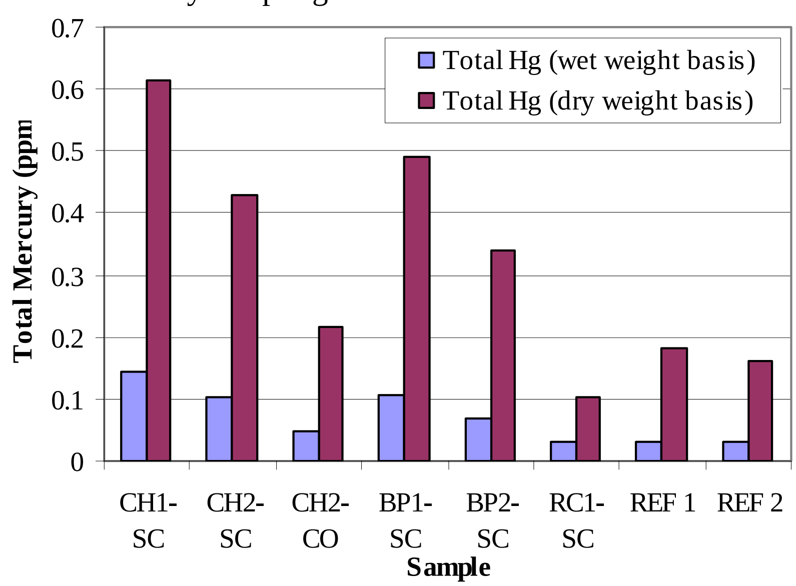
RESULTS OF SAMPLING

Water contents of the samples ranged from 17.4 to 24.3 percent, and total mercury concentrations were reported on a wet weight basis as well as a dry weight basis. Total mercury concentrations ranged from 0.0693 ppm to 0.143 ppm wet weight basis for sculpin in the side channels of the project reach (Channel 1, Channel 2, and Beaver Pond Channel) (**table 1, figure 5**). The highest mercury levels were measured for sculpin in Pool 1 of Channel 1. The sculpin sample from the main Resurrection Creek channel showed a concentration of 0.0297 ppm. The sample of coho fry from the Berm Pool of Channel 2 showed a total mercury concentration of 0.0471 ppm. The reference reach sculpin samples showed concentrations of 0.0315 and 0.0318 ppm. Mercury concentrations on a dry weight basis are roughly proportional to those on a wet weight basis.

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

SAMPLE	PERCENT TOTAL SOLIDS	TOTAL MERCURY, WET WT BASIS (ppm)	TOTAL MERCURY, DRY WT BASIS (ppm)	SAMPLE NOTES
CH1-SC	23.2	0.143	0.615	4 sculpin, 50-60mm, 6 grams total
CH2-SC	24.3	0.104	0.429	15 sculpin, 40-60mm, 22 grams total
CH2-CO	21.8	0.0471	0.216	5 coho fry, 60mm, 14 grams total
BP1-SC	21.6	0.106	0.492	3 sculpin
BP2-SC	20.5	0.0693	0.338	10 sculpin, mostly <50mm
RC1-SC	29.1	0.0297	0.102	1 sculpin, 100mm, 28g, hand-caught
REF 1	17.4	0.0315	0.181	3 sculpin, 5 grams total, hand-caught
REF 2	19.9	0.0318	0.16	10 sculpin, hand-caught

Figure 5: Results of mercury sampling in fish in Resurrection Creek.



DISCUSSION

Factors that affect mercury levels

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. Lakes and ponds are likely to retain mercury longer than streams and rivers. 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 are 70% of mercury concentrations in fish fillet samples. Schwarzbach et al. (2001) also measured higher mercury concentrations in muscle tissue samples than whole body samples, and showed that the percentage of mercury as methylmercury is greater in muscle tissue than in 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

Unless otherwise specified, mercury concentrations in this discussion are reported in terms of wet weight basis for consistency with other studies. Total mercury concentrations in fish from Resurrection Creek ranged from 0.0297 ppm to 0.143 ppm. The percentage of the total mercury as methylmercury in these samples is unknown, but it is assumed that nearly all of the mercury in these 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. 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 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, methylmercury levels in the fish samples were 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 and geologic sources of mercury are present in some Alaskan rivers and streams. Marine and freshwater Alaskan fish sampled statewide showed methylmercury levels well below 1 ppm, with salmon showing levels below 0.1 ppm (Alaska Department of Environmental Conservation, Division of Environmental Health, 2003).

Spatial trends

Mercury levels in fish measured in the project reach side channels were higher than those measured in the reference reach. This would be 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. The highest mercury concentration was measured in Channel 1, which had only a trickle of flow between the ponds because of a poorly functioning French drain inlet. Although many different factors are involved, the ponds had stagnant conditions of higher water temperatures, higher concentrations of bacteria, and lower oxygen levels that likely lead to increased methylation of mercury. Also, the sample site on Channel 1 is completely surrounded by mine tailings piles, or possible locations where mercury could have been spilled. Mercury concentrations and methylation in Channel 2 and the Beaver Pond channel are somewhat less than in Channel 1, likely because both these channels receive adequate flow, resulting in lower water temperatures and higher oxygen levels. However, these channels do lie between tailings piles and include small ponds where methylation can occur. The sample in the main channel had the lowest concentration of total mercury. This may be the result of high 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.

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). Some studies have demonstrated that mercury concentrations increase by a factor of 2 to 3 between trophic levels (Cabana and Rasmussen, 1994; Muir, 2003). Power et al. (2002) demonstrated a 5.4 times increase in mercury concentrations between trophic levels in Stewart Lake, Canada, but noted that this exceeds trophic level increases measured in southern ecosystems.

Based on only 1 sample, the mercury concentration was lower in the coho sample (CH2-CO) than in the sculpin samples. The mercury level in this coho sample was only slightly higher than the levels in sculpin from the reference reach side channel. However, the limited sample size is not sufficient to draw concrete conclusions. The large sculpin sampled in the main channel of the project reach (RC1-SC) was about twice the length of most other samples, but showed the lowest mercury concentrations. This result is contrary to what would be expected based on the process of bioaccumulation with age and size, suggesting that mercury levels, methylation, and the uptake of mercury by fish in the main channel of Resurrection Creek are very low.

Comparisons to other studies

Numerous studies of mercury in fish have been conducted. A national survey of mercury concentrations in fish fillet samples indicated a wide variability of mercury concentrations, ranging as high as 8.94 ppm for largemouth bass, but the state-averaged values for a variety of species ranged from about 0.02 ppm to 1.4 ppm (US Environmental Protection Agency, 1999). In other studies, mercury levels in fish in watersheds impaired by point sources of mercury pollution were considerably higher than those measured in Resurrection Creek (**figure 6**). 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 in fish fillet samples in a Lake Pillsbury, California where mercury mines were present in the watershed. These fish bioaccumulated high levels of mercury despite the fact that no mercury was detected in the water itself. Schwarzbach et al. (2001) measured mercury concentrations in streams of the Cache Creek watershed ranging from 0.098 to 1.66 ppm for whole body fish samples downstream of a superfund mercury mine.

Mercury levels in sculpin in Resurrection Creek are also lower than the mercury levels in a variety of fish species in systems with minimal anthropogenic input of mercury (**figure 6**). Mercury from industrial sources that enters the atmosphere can be distributed to watersheds globally. Geologic sources of mercury can also increase mercury levels in water bodies, although this is a minimal source of mercury in Resurrection Creek. Various studies in areas with no point sources of mercury pollution have shown mercury concentrations averaging 0.37 ppm for muscle tissue in a variety of fish species in western Alaska (Duffy, 1997), between 0.07 and 0.59 ppm for muscle tissue in a variety of species in Stewart Lake in arctic northeastern Canada (Power et al., 2002), and between 0.07 and 0.49 ppm 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 sculpin in Resurrection Creek with various species of fish in impaired and unimpaired watersheds nationwide.

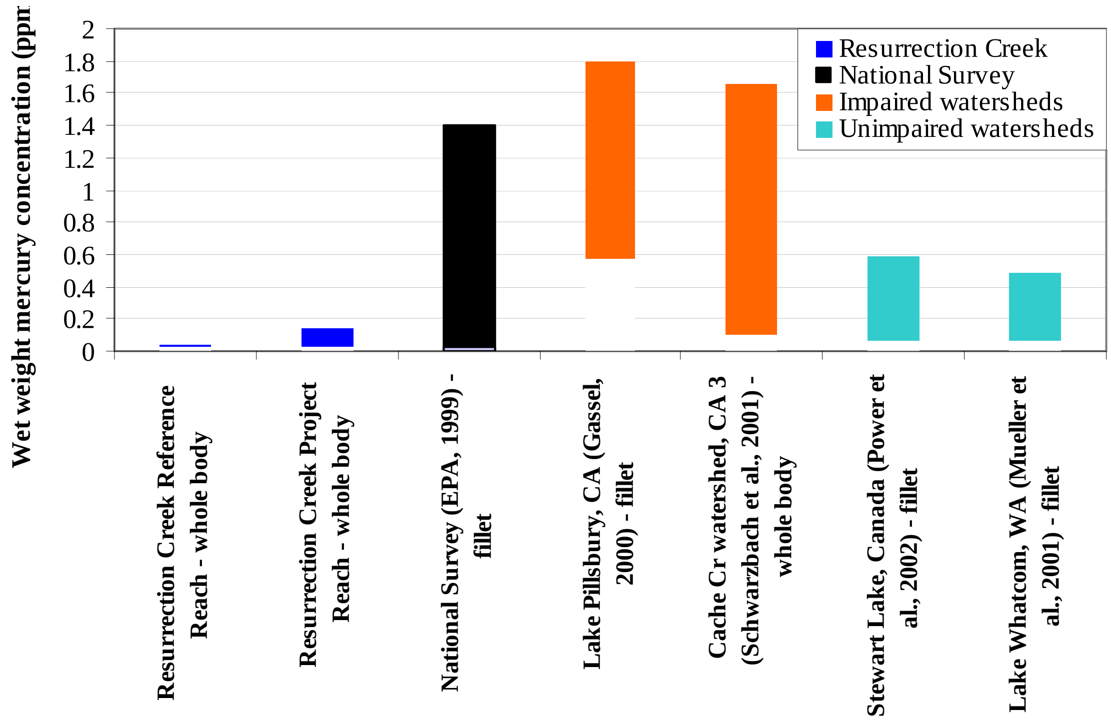
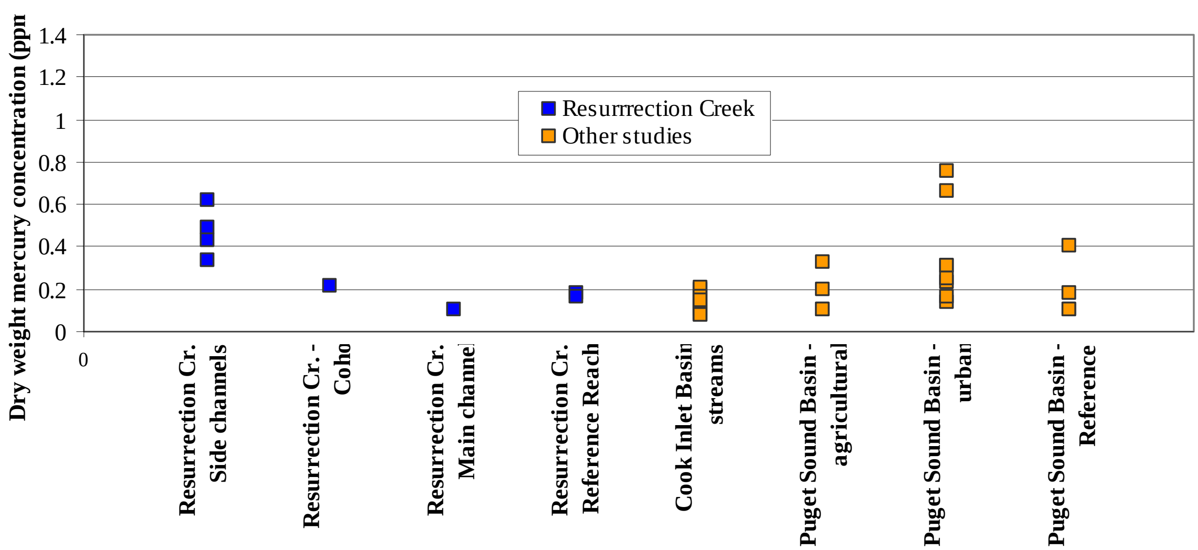


Figure 7: Comparison of *dry weight*, whole body mercury concentrations in sculpin in Resurrection Creek with sculpin in Cook Inlet Basin, AK (Frenzel, 2000) and Puget Sound Basin, WA (MacCoy and Black, 1998).



Mercury concentrations are most commonly analyzed in sportfish, but several studies have shown relatively low concentrations of mercury 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. With similar environmental factors, these mercury concentrations are similar to those measured in the Resurrection Creek reference reach, the main channel sample, and the coho sample. However, mercury levels in the Resurrection Creek project reach side channel samples were about 2 to 4 times higher than those of the fish in the Cook Inlet samples (**figure 7**). 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). Mercury concentrations in the Resurrection Creek reference sites are similar to those of the Puget Sound reference sites, and samples from the project reach side channels have similar mercury concentrations as those from the Puget Sound urban channels (**figure 7**).

Wet weight mercury concentrations in sculpin from Stewart Lake, northeastern Canada, averaged 0.07 ppm, with no input of mercury other than from atmospheric and geologic sources (Power et al., 2002). These concentrations are similar to those measured in sculpin in the Resurrection Creek project reach. However, it is likely that lakes concentrate mercury more effectively than streams, and the Stewart Lake samples would naturally show higher mercury concentrations than the Resurrection Creek samples.

All of these data suggest that mercury concentrations in the side channels of the Resurrection Creek project reach are elevated above reference levels because of the presence of mercury from gold mining operations, but mercury levels are still relatively low. Because they are small, omnivorous bottom feeders, resident sculpin in Resurrection Creek are likely to have lower mercury concentrations than large, resident, predatory fish would have under similar environmental conditions. Assuming a biomagnification factor of 2 to 5 between trophic levels in Resurrection Creek, larger predatory fish that ingested only sculpin in the project reach would theoretically still have mercury concentrations less than the 1.0 ppm FDA action level.

Mercury levels in developing fish

Fish embryos and young developing fish are more sensitive to mercury toxicity than adult fish (Wiener and Spry, 1996). Mercury and methylmercury can be transferred into fish eggs through direct contact of the fertilized eggs with contaminated water, or maternally during oogenesis. Both elemental mercury and methylmercury can be toxic to eggs and developing embryos. However, research has shown that only exceedingly high concentrations of mercury in water, generally orders of magnitude higher than the concentrations measured in most fresh waters, will cause lethal effects to young developing fish and eggs (Wiener and Spry, 1996). Servizi and Martens (1978) showed that mercury concentrations of 2.5 µg/L in water caused malformation in sockeye and pink salmon embryos, with mortality occurring at concentrations of 4.3 µg/L. Mercury concentrations in the water of Resurrection Creek and its side channels are likely very low, as methylmercury must be attached to dissolved organic material to exist in water, and elemental mercury is highly insoluble. In a study involving Cook Inlet streams where sculpin and Dolly Varden showed similar mercury concentrations as the sculpin in the Resurrection Creek project reach, total mercury concentrations in the water ranged from 0.0025 to 0.0098 µg/L (Krabbenhoft et al., 1999). Such low mercury concentrations in the water are not likely to have direct toxic effects on fertilized eggs or developing fish. Mercury concentrations in the stream sediments are also likely to be considerably lower than those measured in the fish samples, similar to other data collected in Cook Inlet streams (Frenzel, 2000).

The maternal transfer of mercury to eggs poses a greater risk of mercury toxicity in developing fish than from direct exposure to contaminated water. Mercury transferred to eggs in this manner can affect development of embryos, leading to malformation and the ultimate survival of young fish. However, research has shown that the amount of mercury transferred maternally is very small, resulting in mercury concentrations in the eggs that are only a very small percentage of those in the parents (Wiener and Spry, 1996). More research is needed to quantify these processes.

Lethal concentrations of mercury measured in fish eggs can vary. Birge et al. (1979) showed that concentrations of mercury as low as 0.07 to 0.10 ppm wet weight in fertilized eggs can be lethal to rainbow trout embryos. In that study, the lethal levels for eggs and embryos were less than 1% of the mercury concentrations considered toxic for adult trout. However, Servizi and Martens (1978) showed that lethal effects to sockeye and pink salmon eggs occurred when mercury concentrations in the eggs reached 3.79 ppm, with malformation resulting at concentrations of 1.87 ppm. Because of the low concentrations of mercury measured in mature sculpin in Resurrection Creek and the low percentage of mercury that has been shown to be transferred to the eggs, mercury passed maternally to the eggs is likely to be at concentrations considerably lower than those that would be toxic to fertilized eggs.

CONCLUSIONS

Although many factors were not considered in this analysis and sample sizes were not sufficiently high for statistical analyses, these results are a reasonable representation of mercury concentrations in fish throughout the project reach and reference reach. Based on this study, mercury levels in sculpin are very low in the reference reach and the main channel of the project reach, consistent with mercury levels in sculpin regionally. Mercury levels in sculpin in the side channels of the project reach are somewhat elevated over reference levels as a result of mercury in the system, likely from mercury used in past placer mining operations. However, mercury levels are considerably lower than levels measured in areas with mercury input from mercury mines and placer mines in California. Higher mercury levels in sculpin in the project reach side channels are likely the result of methylation processes that occur in the channel sediments. Mercury methylation rates are likely to be higher in the more stagnant conditions of the side channels.

Despite the relatively low concentrations of mercury in sculpin in the project reach, localized deposits of mercury may exist within the tailings piles or at depth below the bed surface. Because elemental mercury that settles into the bed sediment likely stops at the shallow clay layer, disturbance of this layer may release mercury into the environment. Releases of mercury into the lower portions of Resurrection Creek would not affect drinking water, as no human consumptive uses of the water in Resurrection Creek currently exist. Also, sport fishing opportunities exist for salmon, but because salmon spend most of their lives in the ocean, they have limited exposure to any mercury in this system. The effects of mercury toxicity on fertilized eggs and developing fish is the largest concern for the presence of mercury in the system.

Protocols for the cleanup of mercury should be in place during the channel restoration process in case visible concentrations of mercury are found in the channel sediments or tailings piles. Further sampling should be conducted within a year after the restoration project to assess any increased concentrations in mercury in resident fish. Because it takes time for mercury to methylate and bioaccumulate in fish, the effects of the project on mercury concentrations, if any, would probably not be evident for at least several months after completion. Although they are scarce in the project reach, sampling Dolly Varden would provide information about mercury concentrations in fish of higher trophic levels. Further sampling of fish in the reference reach would provide a better basis for comparing impaired and reference conditions.

ACKNOWLEDGEMENTS

Thanks to Dave Blanchet (Chugach National Forest) and Angela Matz (US Fish and Wildlife Service) for reviewing this document and providing additional information, and to Sean Stash, Eric Johansen, Larry Winter, Ruth D’Amico, and Justin Gerding for help collecting samples.

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APPENDIX A: PHOTOGRAPHS OF SAMPLE SITE LOCATIONS

CH1-SC: Channel 1 Pool 1, Sculpin

CH2-SC: Channel 2 Berm Pool, Sculpin AND
CH2-CO: Channel 2 Berm Pool, Coho

RC1-SC: Resurrection Creek Main Channel, Sculpin

BP1-SC: Upstream Beaver Pond Channel, Sculpin

BP2-SC: Downstream Beaver Pond Channel, Sculpin

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: Jeff Christian, Laboratory Director

Columbia Analytical Services INC.
An Employee-Owned Company

CHAIN OF CUSTODY

Sediment and Tissue Chemistry

1317 South 13th Ave. • Kelso, WA 98626 • (360) 577-7222 • FAX (360) 636-1068

SR#: 07155

PAGE 1 OF 1 COC #: ______

00000005

PROJECT NAME: RESURRECTION CREEK - HG IN FISH

PROJECT NUMBER:

PROJECT MANAGER: BILL MACFARLANE

COMPANY/ADDRESS: CHUGACH NATIONAL FOREST, 3301 'C' ST, SUITE 300, ANCHORAGE, AK 99503

PHONE #: (907) 743-9434 FAX #: (907) 743-9480

SAMPLER'S SIGNATURE: William A MacFarlane

SAMPLE I.D.	DATE	TIME	LAB I.D.	MATRIX	NUMBER OF CONTAINERS	☐ Total Volatile Solids ☐ Total Solids	TOC ☐ (ASTM D4129M) ☐ PSEP	Grain size ☐ PSEP ☐ ASTM D422	Sulfide ☐ Total (9030M) ☐ PSEP ☐ Water Soluble	☐ AVS ☐ SEM (metals list below)	Ammonia ☐ Total (350.1m) ☐ Plumb ☐ Pore water	Metals (list below)	Pesticides (8081-L)	PCBs (8082-L) ☐ Aroclors ☐ Congeners	Semivolatiles ☐ GC/MS SIM (PAH) ☐ 8270-L	Organotins ☐ Bulk ☐ Pore Water ☐ TBT only	Volitiles (8260)	Dioxins ☐ 1613 ☐ 8290	TPH ☐ GRO ☐ DRO ☐ RRO	☐ Lipids	Tissue Sample Preparations (Instructions below)				REMARKS
CH1-SC	9/15/03	13:50		Tissue	1							X									X				SCULPIN (4)
CH2-CO	9/15/03	14:50		Tissue	1							X									X				COHO (5)
RC1-SC	9/15/03	17:00		Tissue	1							X									X				SCULPIN (1)
CH2-SC	9/15/03	14:50		Tissue	1							X									X				SCULPIN (15)
REF 2	9/15/03	14:20		Tissue	1							X									X				SCULPIN (10)
REF 1	9/15/03	15:38		Tissue	1							X									X				SCULPIN (3)
BP1-SC	9/15/03	17:45		Tissue	1							X									X				SCULPIN (3)
BP2-SC	9/15/03	18:15		Tissue	1							X									X				SCULPIN (10)

REPORT REQUIREMENTS

- ___ I. Routine Report: Method Blank, Surrogate, as required
- X II. Report Dup., MS, MSD as required
- ___ III. Data Validation Report (includes all raw data)
- ___ IV. CLP Deliverable Report
- ___ V. EDD

INVOICE INFORMATION

P.O. # ______

Bill To: William MacFarlane, Chugach National Forest, 3301 'C' ST, SUITE 300, ANCHORAGE, AK 99503

TURNAROUND REQUIREMENTS

- ___ 24 hr. ___ 48 hr.
- ___ 5 Day
- X Standard (10-15 working days)
- ___ Provide FAX Results

______ Requested Report Date

Circle which metals are to be analyzed: (Hg circled)

SMS Metals: As Cd Cr Cu Pb Hg Ag Zn
CA Metals: Ag As Cd Cr Cu Hg Ni Pb Se Zn
SEM Metals: Cd Cu Pb Hg Ni Zn

SPECIAL INSTRUCTIONS/COMMENTS: FOR ALL SAMPLES:
WHOLE BODY HOMOGENIZATION
TOTAL Hg ON WHOLE-BODY COMPOSITE (0.1 mg/kg MDL, wet wt)
MOISTURE CONTENT OF WHOLE-BODY COMPOSITE

RELINQUISHED BY:	RECEIVED BY:	RELINQUISHED BY:	RECEIVED BY:
Signature: Will A MacFarlane; Date/Time: 9/16/03 0800	Signature: Tracy Black; Date/Time: 9/17/03 1000	Signature: ; Date/Time:	Signature: ; Date/Time:
Printed Name: WILLIAM A. MACFARLANE; Firm: USDA FOREST SERVICE	Printed Name: Black; Firm: CAS	Printed Name: ; Firm:	Printed Name: ; Firm:

Columbia Analytical Services Inc.
Cooler Receipt And Preservation Form

Project/Client U.S Forest Serv. Work Order K23 07155

Cooler received on 9-17-03 and opened on 9-17-03 by [signature]

1. Were custody seals on outside of cooler? If yes, how many and where? 1 FB. (Y) N
2. Were seals intact and signature & date correct? (Y) N
3. Is the shipper's airbill available and filed? If no, record airbill number UPS 12 3VW 685 (Y) N
4. COC # 01 8775 6426.

   Temperature of cooler(s) upon receipt: 1.1

   Temperature Blank: 5.9
5. Were custody papers properly filled out (ink, signed, etc.)? (Y) N
6. Type of packing material present Gel ice, newspaper.
7. Did all bottles arrive in good condition (unbroken)? (Y) N
8. Were all bottle labels complete (*i.e.* analysis, preservation, etc.)? (Y) N
9. Did all bottle labels and tags agree with custody papers? (Y) N
10. Were the correct types of bottles used for the tests indicated? (Y) N
11. Were all of the preserved bottles received at the lab with the appropriate pH? ~~Y N~~
12. Were VOA vials checked for absence of air bubbles, and if present, noted below? Y N
13. Did the bottles originate from CAS/K or a branch laboratory? (Y) N
14. Are CWA Microbiology samples received with > ½ the 24 hr. hold time remaining from collection? Y N
15. Was Cl2/Res negative? ~~Y N~~

Explain any discrepancies:

RESOLUTION:

Samples that required preservation or received out of temperature:

Sample ID	Reagent	Volume	Lot Number	Bottle Type	Rec'd out of Temperature	Initials
					000006	

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: U.S.Forest Service
Project: Resurrection Creek- Hg in Fish
Sample Matrix: Tissue

Service Request: K2307155
Date Collected: 9/15/03
Date Received: 9/17/03

Solids, Total

Prep Method: NONE
Analysis Method: Freeze Dry
Test Notes:

Units: PERCENT
Basis: Wet

Sample Name	Lab Code	Date Analyzed	Result	Result Notes
CH1-SC	K2307155-001	10/7/03	23.2	
CH2-CO	K2307155-002	10/7/03	21.8	
RC1-SC	K2307155-003	10/7/03	29.1	
CH2-SC	K2307155-004	10/7/03	24.3	
REF 2	K2307155-005	10/7/03	19.9	
REF 1	K2307155-006	10/7/03	17.4	
BP1-SC	K2307155-007	10/7/03	21.6	
BP2-SC	K2307155-008	10/7/03	20.5	

Approved By: ____ Date: 10/10/03

1A/052595

COLUMBIA ANALYTICAL SERVICES, INC.

QA/QC Report

Client: U.S.Forest Service
Project: Resurrection Creek- Hg in Fish
Sample Matrix: Tissue

Service Request: K2307155
Date Collected: 9/15/03
Date Received: 9/17/03
Date Extracted: NA
Date Analyzed: 10/7/03

Duplicate Summary
Total Metals

Sample Name: RC1-SC
Lab Code: K2307155-003
Test Notes:

Units: PERCENT
Basis: Wet

Analyte	Prep Method	Analysis Method	Sample Result	Duplicate Sample Result	Average	Relative Percent Difference	Result Notes
Solids, Total	NA	Freeze Dry	29.1	27.8	28.4	5	

Approved By: ____________ Date: 10/13/03 000009

DUP/052595

07155ICP.JC2 - DUP 10/10/03

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: U.S.Forest Service
Project: Resurrection Creek- Hg in Fish
Sample Matrix: Tissue

Service Request: K2307155
Date Collected: 9/15/03
Date Received: 9/17/03

Mercury, Total

Prep Method: METHOD
Analysis Method: 1631E
Test Notes:

Units: ng/g
Basis: As Received

Sample Name	Lab Code	MRL	MDL	Dilution Factor	Date Extracted	Date Analyzed	Result	Result Notes
CH1-SC	K2307155-001	1.0	0.2	100	10/8/03	10/9/03	143	
CH2-CO	K2307155-002	0.2	0.04	20	10/8/03	10/9/03	47.1	
RC1-SC	K2307155-003	0.2	0.04	20	10/8/03	10/9/03	29.7	
CH2-SC	K2307155-004	1.0	0.2	100	10/8/03	10/9/03	104	
REF 2	K2307155-005	0.2	0.04	20	10/8/03	10/9/03	31.8	
REF 1	K2307155-006	0.2	0.04	20	10/8/03	10/9/03	31.5	
BP1-SC	K2307155-007	1.0	0.2	100	10/8/03	10/9/03	106	
BP2-SC	K2307155-008	0.2	0.04	20	10/8/03	10/9/03	69.3	
Method Blank	K2307155-MB	0.2	0.04	20	10/8/03	10/9/03	ND	

Approved By: ____ Date: 10/10/03

1A/052595

000010

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: U.S.Forest Service
Project: Resurrection Creek- Hg in Fish
Sample Matrix: Tissue

Service Request: K2307155
Date Collected: 9/15/03
Date Received: 9/17/03

Mercury, Total

Prep Method: METHOD
Analysis Method: 1631E
Test Notes:

Units: ng/g
Basis: Dry

Sample Name	Lab Code	MRL	MDL	Dilution Factor	Date Extracted	Date Analyzed	Result	Result Notes
CH1-SC	K2307155-001	5.0	1.0	100	10/8/03	10/9/03	615	
CH2-CO	K2307155-002	1.0	0.2	20	10/8/03	10/9/03	216	
RC1-SC	K2307155-003	1.0	0.2	20	10/8/03	10/9/03	102	
CH2-SC	K2307155-004	5.0	1.0	100	10/8/03	10/9/03	429	
REF 2	K2307155-005	1.0	0.2	20	10/8/03	10/9/03	160	
REF 1	K2307155-006	1.0	0.2	20	10/8/03	10/9/03	181	
BP1-SC	K2307155-007	5.0	1.0	100	10/8/03	10/9/03	492	
BP2-SC	K2307155-008	1.0	0.2	20	10/8/03	10/9/03	338	
Method Blank	K2307155-MB	1.0	0.2	20	10/8/03	10/9/03	ND	

Approved By: ____________ Date: 10/10/03

1A/052595

000011

COLUMBIA ANALYTICAL SERVICES, INC.

QA/QC Report

Client: U.S.Forest Service
Project: Resurrection Creek- Hg in Fish
Sample Matrix: Tissue

Service Request: K2307155
Date Collected: 9/15/03
Date Received: 9/17/03
Date Extracted: 10/8/03
Date Analyzed: 10/9/03

Matrix Spike/Duplicate Matrix Spike Summary
Total Metals

Sample Name: RC1-SC
Lab Code: K2307155-003S, K2307155-003SD
Test Notes:

Units: ng/g
Basis: Dry

Analyte	Prep Method	Analysis Method	MRL	Spike Level MS	Spike Level DMS	Sample Result	Spike Result MS	Spike Result DMS	Percent Recovery MS	Percent Recovery DMS	Percent Recovery CAS Acceptance Limits	Relative Percent Difference	Result Notes
Mercury	METHOD	1631E	5.0	24	24	102	124	125	92	96	70-130	<1	

Approved By: [signature] Date: 10/10/03

DMS/052595

000012

COLUMBIA ANALYTICAL SERVICES, INC.

QA/QC Report

Client: U.S.Forest Service
Project: Resurrection Creek- Hg in Fish
LCS Matrix: Water

Service Request: K2307155
Date Collected: NA
Date Received: NA
Date Extracted: 10/8/03
Date Analyzed: 10/9/03

Ongoing Precision and Recovery (OPR) Sample Summary
Total Metals

Sample Name: Ongoing Precision and Recovery (Initial)

Units: ng/L
Basis: NA

Test Notes:

Analyte	Prep Method	Analysis Method	True Value	Result	Percent Recovery	CAS Percent Recovery Acceptance Limits	Result Notes
Mercury	METHOD	1631E	50.0	56.3	113	70-130	

000013

Approved By: [signature] Date: 10/10/03

LCS/032295

COLUMBIA ANALYTICAL SERVICES, INC.

QA/QC Report

Client: U.S.Forest Service
Project: Resurrection Creek- Hg in Fish
LCS Matrix: Water

Service Request: K2307155
Date Collected: NA
Date Received: NA
Date Extracted: 10/8/03
Date Analyzed: 10/9/03

Ongoing Precision and Recovery (OPR) Sample Summary
Total Metals

Sample Name: Ongoing Precision and Recovery (Final)

Units: ng/L
Basis: NA

Test Notes:

Analyte	Prep Method	Analysis Method	True Value	Result	Percent Recovery	CAS Percent Recovery Acceptance Limits	Result Notes
Mercury	METHOD	1631E	50.0	60.4	121	70-130	

Approved By: ______________________ Date: 10/10/03 000014

LCS/032295

COLUMBIA ANALYTICAL SERVICES, INC.

QA/QC Report

Client: U.S.Forest Service
Project: Resurrection Creek- Hg in Fish
LCS Matrix: Tissue

Service Request: K2307155
Date Collected: NA
Date Received: NA
Date Extracted: 10/8/03
Date Analyzed: 10/9/03

Quality Control Sample (QCS) Summary
Total Metals

Sample Name: Quality Control Sample
Lab Code: K2307155-QCS
Test Notes:

Units: ng/g
Basis: Dry

Source: NRCC Dolt-3

Analyte	Prep Method	Analysis Method	True Value	Result	Percent Recovery	CAS Percent Recovery Acceptance Limits	Result Notes
Mercury	METHOD	1631E	3370	3540	105	76-125	

Approved By: ____________________ Date: 10/10/03 000015

LCS/032295