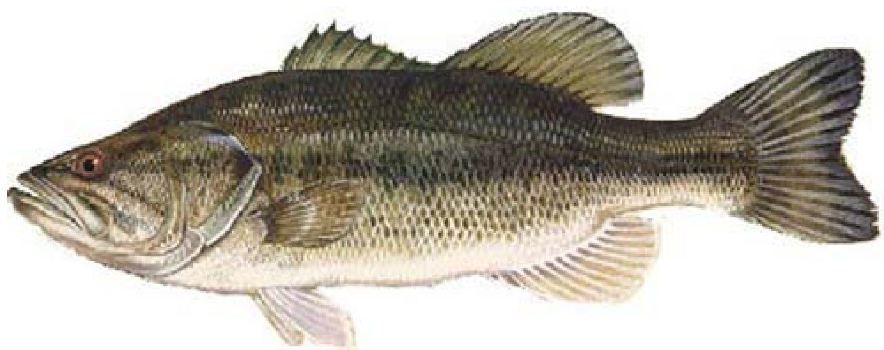
Mercury in Edible Fish Tissue and Sediments from Selected Lakes and Rivers of Washington State



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WASHINGTON STATE DEPARTMENT OF ECOLOGY

Mercury in Edible Fish Tissue and Sediments from Selected Lakes and Rivers of Washington State

by
Stephen Fischnaller, Paul Anderson, and Dale Norton

Washington State Department of Ecology
Environmental Assessment Program
Olympia, Washington 98504-7710

EIM Project Number: PAND0001

Waterbody Numbers

American Lake	WA-12-9010	Kitsap Lake	WA-15-9150	Palmer Lake	WA-49-9270
Banks Lake	WA-42-9020	Loomis Lake	WA-24-9040	Lake Samish	WA-03-9160
Black Lake	WA-23-9010	Lake Meridian	WA-09-9160	Lake Terrell	WA-01-9120
Bonaparte Lake	WA-49-9050	Moses Lake	WA-41-9250	Upper Long Lake	WA-54-9040
Deer Lake	WA-59-9040	Newman Lake	WA-57-9020	Vancouver Lake	WA-28-9090
Duck Lake	WA-22-9030	Offut Lake	WA-13-9110	Walla Walla River	WA-32-1010
Fazon Lake	WA-01-9020	Okanogan River	WA-49-1040		

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List of Acronyms

AET	Apparent Effects Threshold, sediment quality value
APHA	American Public Health Association
DOH	Washington State Dept. of Health
dw	Dry weight
EA Program	Environmental Assessment Program, Washington State Dept. of Ecology
EIM	Ecology's Environmental Information Management database
EPA	United States Environmental Protection Agency
TRC	EPA Fish Tissue Residual Criteria
GPS	Global Positioning System
Hg	Mercury
LEL	Least Effects Level, sediment quality value
MEL	Manchester Environmental Laboratory, Washington State Dept. of Ecology
NAD	North American Datum of 1983, describing a state plane coordinate system
NTR	EPA National Toxics Inventory
PBT	Persistent bioaccumulative toxin
ppb	Parts per billion (pbt = µg/Kg or µg/L)
QC	Quality control
RPD	Relative percent difference
SQV	Sediment quality value
TEL	Threshold Effects Level, sediment quality value
TOC	Total organic carbon
USGS	United States Geological Survey
WAC	Washington Administrative Code
WDFW	Washington State Dept. of Fish and Wildlife
ww	Wet weight

Abstract

During 2001 and 2002, the Washington State Department of Ecology conducted a screening survey for mercury concentrations in fish tissue and sediments from selected lakes and rivers across Washington State. The project was conducted in support of the goals of the *Washington State Mercury Chemical Action Plan* to continually reduce the use and release of anthropogenic mercury, and to minimize human exposure to mercury (Peele 2003).

This project follows two earlier studies in Washington State, in which elevated mercury levels were identified in fish tissue collected from Lake Whatcom (Serdar et al. 1999; 2001).

In this current study, concentrations of total mercury and percent lipids were measured in edible muscle from 185 bass, collected from 18 lakes and two rivers. Largemouth bass (*Micropterus salmoides*) and smallmouth bass (*Micropterus dolomieu*) were chosen as the target species due to their wide distribution, predatory nature, and known tendency to bioaccumulate mercury in muscle.

Sediment samples also were collected and analyzed for total mercury and total organic carbon. Water quality measurements were made to evaluate selected parameters which may affect the methylation of mercury.

Mercury concentrations found in tissue varied widely among waterbodies and individual fish within the same waterbody. Mercury levels in sediment also varied widely among waterbodies, with the highest concentrations occurring in western Washington.

Mercury concentrations in tissue were shown to have a strong correlation with fish age, weight, and length. Only one of the 185 fish collected contained a mercury concentration (1280 µg/Kg ww) which exceeded the National Toxics Rule criterion of 825 µg/Kg ww. However, 23% of the fish collected contained mercury concentrations at or above the revised EPA Fish Tissue Residual Criterion (TRC) for methylmercury of 300 µg/Kg ww. Additionally, 51% of the fish collected were found to contain mercury concentrations at or above a draft Washington State Department of Health (DOH) Interim Fish Tissue Criterion of 150 µg/Kg ww.

Average tissue mercury concentrations exceeded the TRC in 35% of the waterbodies sampled and exceeded the DOH Interim Fish Criterion in 70% of the waterbodies sampled.

Acknowledgements

Many people generously contributed their time and expertise to this project. The authors would like to express their appreciation to everyone who helped, including the following:

- John Sneva and Lucinda Morrow, from the Washington State Department of Fish and Wildlife Scale Laboratory, analyzed fish aging structures.
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  - Stuart Magoon, Dean Momohara, Pam Covey, Karin Feddersen, and other staff at the Manchester Environmental Laboratory processed and analyzed samples.
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  - Bill Ehinger performed much of the statistical analysis on the project data.
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  - Joan LeTourneau formatted and edited the final report.

Introduction

This study was undertaken as part of the Persistent Bioaccumulative Toxin (PBT) Strategy being implemented by the Washington State Department of Ecology (Ecology). As part of this initiative, the *Washington State Mercury Chemical Action Plan* was created to identify sources of mercury in Washington and to identify and prioritize strategies for further mercury reduction (Peele 2003). The present study represents the first statewide survey for mercury in fish tissue and freshwater sediments.

Mercury concentrations found in sediments and waters of Washington State can be attributed to both natural and anthropogenic (human-caused) sources. While natural sources of mercury exist, approximately 70 to 80% of current mercury emissions may be due to human activities (EPA 1997; Mason et al. 1994; and Fitzgerald and Mason 1996). Human activities that result in mercury emissions vary widely; however, disposal of various consumer products and the combustion of fossil fuels are the primary anthropogenic sources of environmental mercury identified in Washington (Peele 2003) and the United States (EPA 1997). Natural sources of mercury include the erosion of soils and rocks by wind and water, degassing from enriched rocks and soils, volcanoes, and geothermal systems.

Natural and anthropogenic sources contribute to an ongoing atmospheric load of elemental mercury that circles the globe. Primarily in a gaseous state, mercury is carried on atmospheric currents until being deposited back to land or water on particles or through precipitation (Gustin et al. 2000; Schuster et al. 2002). Degassing of mercury from surface waters also occurs within this cycle, moving mercury in the opposite direction from super-saturated waters back into the atmosphere (Morel et al. 1998; Gustin et al. 2000; Yake 2003).

Due to the constant mixing and recycling of mercury among oceanic, atmospheric, and terrestrial pools, it is difficult to differentiate what portion of mercury comes from natural sources and what portion comes from anthropogenic sources (Yake 2003). Mercury is not evenly distributed in the environment, and its influx to a given area may vary from day to day depending on weather, atmospheric deposition, runoff, erosion, and anthropogenic emissions.

Chemical species of mercury commonly found in sediments and water include elemental mercury, ionic mercury (often bound to chloride, sulfide, and organic acids) and organic mercury (such as methylmercury). It is methylmercury that is of special concern, as this is the form that is easily absorbed in living tissues and is known to bioaccumulate and biomagnify in animals and humans. Nearly all mercury that bioaccumulates in upper trophic level fish is methylmercury (EPA 2001b; Groetsch et al. 2002).

Humans of all ages are susceptible to chronic mercury poisoning, which may occur when fish that contain elevated levels of mercury are frequently ingested (Hightower 2002). As bioaccumulation of this heavy metal occurs, metabolic and neurological damages may result. Women of child-bearing age who may become pregnant, and children under six years of age, are especially susceptible to mercury poisoning, which may harm developing nervous systems in fetuses and young children, permanently affecting the ability to learn. Adults exposed to high levels of mercury also can suffer from central nervous system problems and adverse effects on the cardiovascular system (DOH 2001).

Human health concerns over mercury contamination in Lake Whatcom fish were raised following a 1998 survey in which one composite sample of smallmouth bass was found to contain mercury at 500 µg/Kg ww (Serdar et al. 1999). A comprehensive survey of contaminants in Lake Whatcom and Whatcom Creek watersheds followed, involving the Washington State Department of Ecology (Ecology), Washington State Department of Fish and Wildlife (WDFW) and Washington State Department of Health (DOH). Concentrations of mercury found in individual fish ranged from 100 to 1840 µg/Kg ww (Serdar et al. 2001). Average mercury concentrations found in smallmouth bass ranged from 200 to 860 µg/Kg ww over the three basins in Lake Whatcom.

These findings prompted concern about the limited information available on mercury levels in fish from other lakes and rivers across the state. Data also were lacking on factors that might influence mercury uptake by fish. Although positive correlations with age, weight, and length were identified for several Lake Whatcom fish species, the extent to which these relationships applied to other waterbodies was unknown.

To begin addressing these data gaps, Ecology's Environmental Assessment (EA) Program conducted a study to evaluate mercury levels in fish and sediments from 18 lakes and two rivers across the state. Largemouth bass (*Micropterus salmoides*) and smallmouth bass (*Micropterus dolomieu*) were chosen as the target species due to their wide distribution and tendency to bioaccumulate and biomagnify mercury.

Goals for this study included the following:

- Provide regional screening-level data for mercury concentrations in edible fish tissue, which can be used in conjunction with existing data to evaluate the need for additional consumption advisory studies in Washington State.
- Increase the amount of data available for evaluation of variables that may be associated with mercury concentrations in fish, such as fish length, weight, sex, age, and lipid content. This information is needed to guide the design of a long-term trend monitoring component for Ecology's Washington State Toxics Monitoring Program, as well as to evaluate the effectiveness of the *Washington State Mercury Chemical Action Plan* at reducing mercury levels in the environment.
- Collect additional information on factors that may affect mercury uptake in fish, such as water chemistry and mercury concentrations in sediment.

Data resulting from this project has been provided to DOH for use in evaluating health risks associated with consumption of freshwater fish by recreational fishers.

Methods

Sampling Design

Fish, sediment, and water samples were collected from 18 lakes and two rivers (Figure 1 and Table 1). Waterbodies were selected for sampling based on the following:

- Spatial distribution of lakes across Washington State.
- Use of lakes for recreational fishing.
- Availability of large and smallmouth bass as target species.
- Availability of public access with boat launching facilities.
- Ability to obtain scientific collection permits.

The sampling goal was to collect ten individual fish of one species from each waterbody, of either largemouth bass (*Micropterus salmoides*) or smallmouth bass (*Micropterus dolomieu*). The first ten bass of either species that met or exceeded a minimum size of ten inches were retained for analysis. A minimum size was selected in order to provide adquate tissue for chemical analysis. Ten inches also is just under the miminum size most anglers prefer to catch based on work conducted by WDFW in Lake Whatcom (Gabelhouse 1984).

Fish samples from 20 waterbodies were obtained over a 16-month period, from June 18, 2001 to November 6, 2002. This included samples from ten waterbodies, which were obtained from previous EA Program studies. The remaining ten sites were sampled between September and November 2002.

Fish samples were analyzed individually in order to obtain estimates of variance within the fish populations. Analysis of individual samples also allowed for the comparison of fish age and size variables to mercury concentrations.

Three sediment samples were collected from each of the 20 waterbodies where fish were obtained. Due to the small number of sediment samples collected from each of the three waterbodies and the often wide area over which fish were collected, bass habitat was not used as the pimary criteria in selecting sampling locations. Instead, sediment sampling locations within each waterbody were selected for proximity to inlets, outlets, and the center of basins or waterways where sediment deposition may be occuring and elevated levels of mercury might be found. Sediments were collected from bass habitat when the fish were present in the vicinity of inlets and outlets, and when an inlet or outlet could not be identified.

Sediment samples were collected over a two-month period, between September 16 and November 26, 2002, and analyzed individually for total mercury and total organic carbon. Sampling locations within each waterbody are shown in Appendix Figures A1 to A5.

Water quality data were collected at each sediment sampling site for pH, dissolved oxygen, temperature, conductivity, bottom depth, and turbidity (Secchi). A single water sample was collected approximately one meter off the bottom and analyzed for alkalinity and hardness.

Table 1. Waterbodies Sampled by Region.

Waterbody	County	Species Collected	Number Fish Collected	Number Sediment Samples Collected
Northwest Region				
Lake Terrell	Whatcom	LMBS	10	3
Fazon Lake	Whatcom	LMBS	10	3
Lake Samish	Whatcom	LMBS	10	3
Kitsap Lake	Kitsap	LMBS	10	3
Lake Meridian	King	LMBS	8	3
Southwest Region				
American Lake	Pierce	LMBS	4	3
Black Lake	Thurston	LMBS	10	3
Offut Lake	Thurston	LMBS	10	3
Duck Lake	Grays Harbor	LMBS	10	3
Loomis Lake	Pacific	LMBS	10	3
Vancouver Lake	Clark	LMBS	10	3
Central Region				
Palmer Lake	Okanogan	LMBS	10	3
Bonaparte Lake	Okanogan	LMBS	3	3
Okanogan River	Okanogan	SMBS	10	3
Banks Lake	Grant	LMBS	10	3
Eastern Region				
Newman Lake	Spokane	LMBS	10	3
Moses Lake	Grant	LMBS	10	3
Deer Lake	Stevens	LMBS	10	3
Walla Walla River	Walla Walla	SMBS	10	3
Upper Long Lake	Spokane	LMBS	10	3

LMBS = Largemouth bass
SMBS = Smallmouth bass

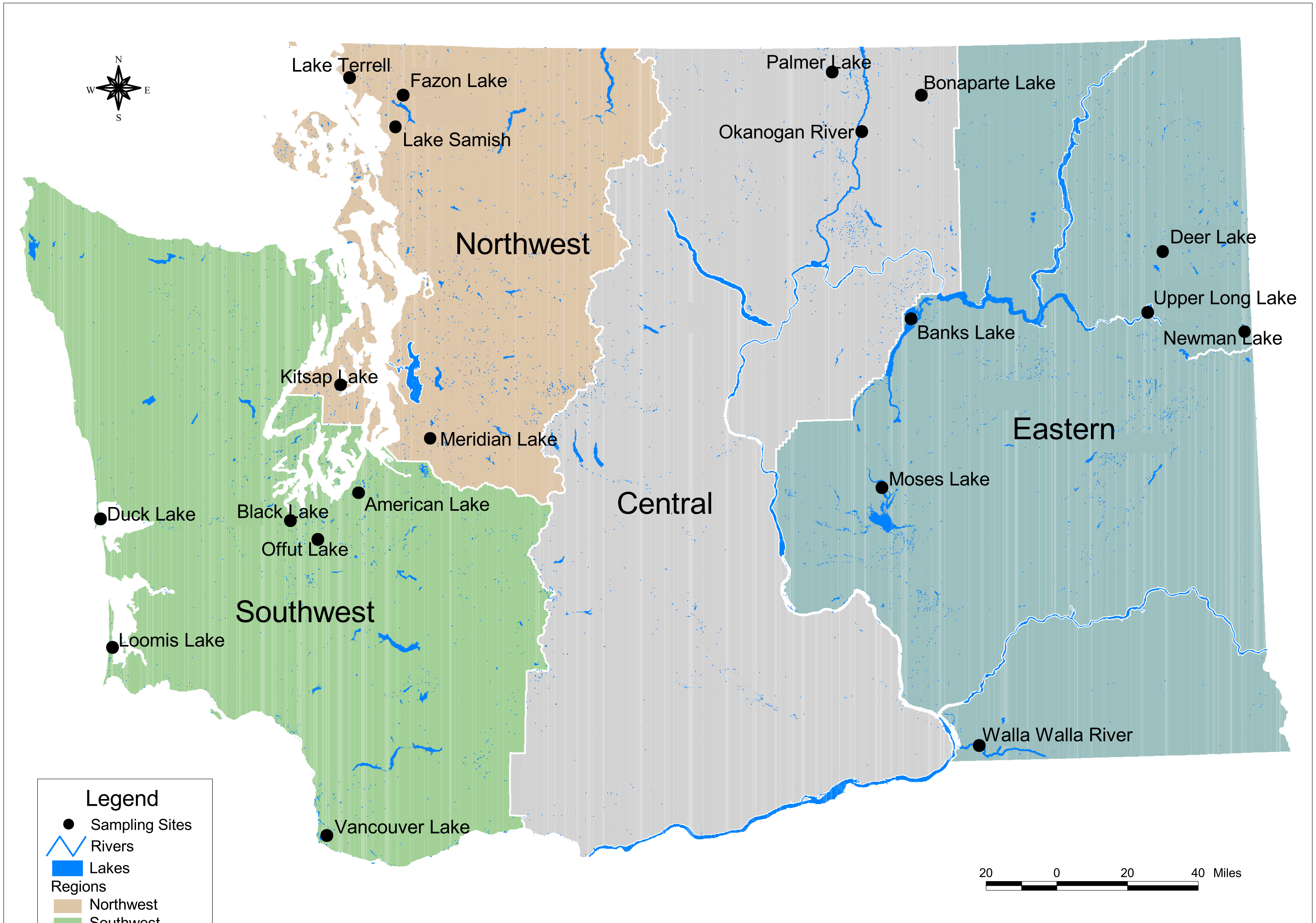

Figure 1. Mercury Survey Sites 2002

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Sample Collection

Fish

Fish were collected using a Smith-Root 16-foot electrofishing boat. Methods for collection, handling, and processing of fish samples were guided by EPA methods (EPA 2000). Upon capture, fish were placed in a holding tank, checked for a minimum size of ten inches (254 mm), and identified to species. Bass meeting the minimum size requirement were retained for 17 of 20 waterbodies. Exceptions to the size reqirement were made for Black Lake (one fish), Offut Lake (nine fish) and the Walla Walla River (one fish) when larger fish were not available (Table C1). Fish selected for retention were stunned by a blow to the head with a blunt object, rinsed in ambient water to remove foreign material, weighed, and their total length measured.

Individual fish were then double-wrapped in aluminum foil (dull side in), labeled, placed in large plastic zip-lock bags, and assigned unique identification numbers. All fish samples were packed on ice in coolers and transported to the Ecology storage facilities within 24 to 72 hours. Upon returning from the field, fish were frozen at -18˚C until processed.

Sediment

Sediment samples were collected using a 0.02 m^2 stainless steel petite ponar grab, using a single grab for most of the waterbodies where sediments were soft. Multiple, composite grabs were necessary only for a few areas where harder bottoms were encountered or extensive plant growth was present. Overlying water was siphoned off, and the top 2 cm of sediment from each individual grab was removed with a stainless steel spoon, placed in a stainless steel bowl, and homogenized by stirring. Sediments in contact with the side walls of the grab were not retained for analysis. Sub-samples of the homogenized sediment were then placed in 4-oz. glass jars (with Teflon lid liners) that had been previously cleaned to EPA QA/QC specifications for mercury (EPA 1990). Separate sub-samples of sediment were also placed in 2-oz. glass jars for total organic carbon (TOC) analysis. Duplicate field samples were prepared by filling two additional jars with homogenized sediment from the same mixing bowl.

Chemically clean sampling equipment was used to collect and manipulate sediments. Sampling equipment was pre-cleaned by washing with Liquinox® detergent followed by sequential rinses with hot tap water, deionized water, 10% Baker Instra-Analyzed® nitric acid, and deionized water. Equipment was allowed to air dry before being wrapped in aluminum foil (dull side in) until used in the field. Between sampling locations, cleaning of the grab consisted of a thorough brushing with on-site water.

All sediment samples were packed on ice in coolers and transported to the Ecology Manchester Environmental Laboratory (MEL) for analysis.

Water

Water samples were collected one meter off the bottom, from one location in each waterbody. A Kemmer sampler was slowly lowered to one meter off the bottom and the closure triggered. All water samples were subsequently held on ice in coolers and transported to MEL for analysis, where they were analyzed for alkalinity and hardness.

Conductivity, pH, dissolved oxygen, and water temperature were measured at all sediment collection sites using a calibrated Hydrolab. Secchi disk measurements also were recorded where depth was sufficient. Sampling site coordinates were determined in the field with a Magellan GPS 320 global positioning receiver, using the NAD 83 datum.

Tissue Sample Preparation

Tissue resection was performed by removing foil from the partially thawed specimen, scaling the fish using a stainless steel knife, removing the skin, then removing the fillet with a clean stainless steel knife or scalpel. A single fillet from one side of each fish was taken, unless tissue from both sides was needed to provide adequate material for analysis. Tissue was removed laterally, extending from the lateral line to the upper dorsal surface, then horizontally, extending from a point immediately anterior of the operculum to the base of the caudal fin. Care was taken to avoid puncturing the body cavity and internal organs. Fish scales and otoliths were extracted from individual fish and sent to WDFW for determination of fish age.

Tissue was homoginized using a Kitchen-Aid® food processor. All equipment used for tissue preparation was washed with Liquinox® detergent, followed by sequential rinses of hot tap water, 10% Baker Instra-Analyzed® nitric acid, and deionized water. This decontamination procedure was repeated between processing of each sample. Homogenized tissue from each specimen was placed in two labeled, 4-oz. glass jars with Teflon lids, cleaned to EPA QA/QC specifications (EPA 1990). Duplicate field samples were prepared by filling two additional jars with homogenized tissue from the same fish and mixing bowl.

Sample containers were then sealed in plastic bags, placed on wet ice in coolers, and transported to MEL on the following business day by courier. Chain-of-custody procedures were used with all samples. One glass jar for each sample was archived at Ecology headquarters.

Analytical Methods and Data Quality

Tissue, sediment, and water samples were analyzed by MEL using the methods listed in Table 2. All coolers were received by MEL at the proper holding temperature of 2º - 6º C, and in good condition.

Table 2. Analytes and Analytical Methods.

Analyte	Matrix	Analytical Method	Project Detection Limit
Fish Tissue			
Mercury	Fish Tissue	CVAA, EPA Method 245.5	5 µg/Kg ww
Lipids	Fish Tissue	Gravimetric	0.02%
Sediment			
Mercury	Sediment	CVAA, EPA Method 245.5	5 µg/Kg dw
TOC	Sediment	PSEP–TOC	0.1% Carbon
Water			
Mercury	Water (Rinsate Blank)	EPA Method 245.1	0.03 µg/L
pH	Water	Field-Hydrolab	0.2 pH unit
Temperature	Water	Field-Hydrolab	0.1 °C
Dissolved Oxygen	Water	Field-Hydrolab	0.2 mg/L
Conductivity	Water	Field-Hydrolab	1% of Reading
Secchi Disk Depth	Water	Secchi disk	
Alkalinity	Water	SM2320	5 mg/L
Hardness	Water	SM2340B	1 mg/L

TOC = Total Organic Carbon
CVAA = Cold Vapor Atomic Absorption
PSEP = Puget Sound Estuary Program
SM = Standard Methods
ww = Wet weight
dw = Dry weight

Quality control (QC) samples were processed throughout the project at a rate of 5% or higher. They included rinsate field blanks, field duplicates, analytical matrix spike duplicates, lab duplicates, analytical matrix spike recoveries, and standard reference materials (SRMs) of dogfish muscle (DORM-1) and Buffalo River sediment (SRM 2709). The SRMs were obtained from the National Institute of Standards and Technology (NIST).

All QC objectives were met, with the exception of four QC results for mercury analysis in tissue, which exceeded project and lab criteria. Tissue data from Duck Lake were qualified. All other data were used without qualification. A detailed discussion of QC procedures and results are available in Appendix B.

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Results

Fish Tissue

A total of 185 fish were collected from 18 lakes and two rivers across Washington State, and analyzed for total mercury and percent lipids. Of these, 96 fish were determined to be male, 84 female, and five undetermined.

The collection target of ten individual bass from each waterbody was reached for 17 of the 20 waterbodies. The exceptions were Lake Meridian (n=8), American Lake (n=4), and Bonaparte Lake (n=3). The fish length target of 254 mm (10 inches) was met for 164 of 185 fish collected (89%). Summary statistics for overall fish size, mercury, and lipid levels are listed in Table 3.

Table 3. Statewide Summary of Fish Size, Tissue Mercury, and Lipid Data.

	Fish Age	Total Fish Length	Fish Weight	Mercury in Tissue	Lipids in Tissue
	years	mm (inches)	gms (oz.)	µg/Kg ww	%
Mean	4.4	353 (13.9)	889 (31)	217	0.88
Range	1 – 17	191 – 575 (7.5 – 22.6)	86 – 3747 (3 – 132)	22 – 1280	0.19 – 7.6
Standard Deviation	3	79 (3.1)	708 (25)	179	0.96

Fish collected from Bonaparte Lake, Fazon Lake, and American Lake had the highest mean mercury concentrations (451, 447, and 404 µg/Kg ww), along with some of the longest mean total lengths (454, 439, and 430 mm). In contrast, fish collected from Offut Lake, Moses Lake and Upper Long Lake had the lowest mean mercury concentrations (80, 86, and 89 µg/Kg), with a wider range of mean total lengths (221, 447, and 395 mm). A summary of tissue mercury concentrations by individual waterbody, ordered by mean mercury concentration, is provided in Table 4.

Mercury Concentrations in Individual Fish

Mercury results for individual fish are shown by waterbody and region in Figures 2 and 3, with fish age shown at the top of each bar graph. Fish ranged in age from 1 year to 17 years, with an average of 4.4 years. Mercury concentrations in individual fish were highly influenced by fish size. Correlations between mercury concentrations and fish age, length and weight are discussed later in the report.

The highest mercury concentration (1280 µg/Kg ww) was found in a 10-year-old fish from Samish Lake. The next highest mercury concentrations were found in fish from Black Lake (792 µg/Kg), Fazon Lake (760 µg/Kg), Kitsap Lake (754 µg/Kg), and Duck Lake (736 µg/Kg). Ages for these fish were 9, 17, 12, and 9 years, respectively.

Table 4. Summary of Fish Age and Size Data and Tissue Mercury Concentrations by Waterbody. (Lakes are ordered by mean mercury concentration.)

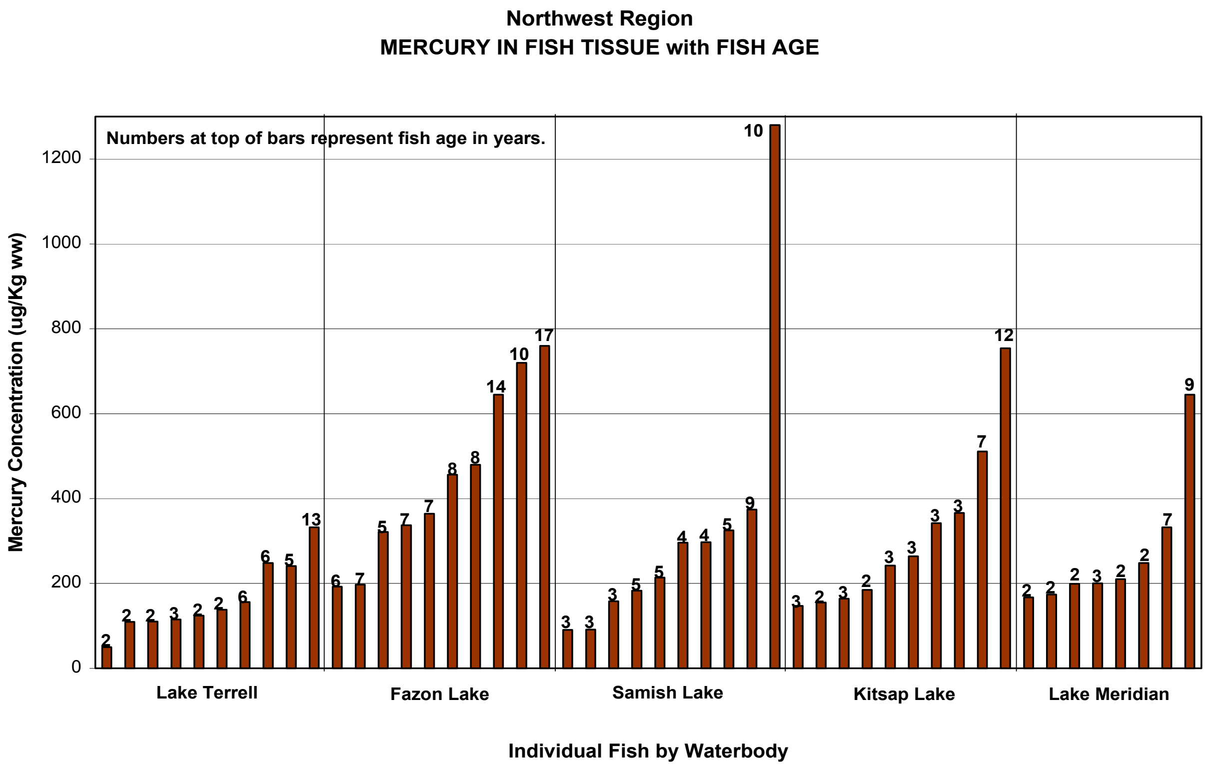
			Mean			Tissue Mercury			
Waterbody	n	Species	Age (yrs)	Length (mm)	Weight (gm)	Min (µg/Kg)	Max (µg/Kg)	Mean (µg/Kg)	Stand Dev
Offut Lake	10	LMBS	1	221	143	46.5	112	80	17
Moses Lake	10	LMBS	6	447	1908	26	181	86	48
Upper Long Lake	10	LMBS	7	395	1014	22	181	89	53
Banks Lake	10	LMBS	4	351	734	70	183	114	38
Newman Lake	10	LMBS	3	276	390	62.2	318	118	105
Palmer Lake	10	LMBS	2	307	492	78.3	250	133	44
Okanogan River	10	SMBS	4	324	531	104	312	151	65
Vancouver Lake	10	LMBS	2	306	626	46.9	540	160	185
Lake Terrell	10	LMBS	4	351	778	49.7	332	162	85
Walla Walla R.	10	SMBS	4	341	600	58	269	179	69
Duck Lake	10	LMBS	6	367	960	84.7	736	247	190
Black Lake	10	LMBS	3	322	914	113	792	254	247
Lake Meridian	8	LMBS	4	362	870	167	645	272	160
Loomis Lake	10	LMBS	4	354	761	202	460	311	78
Kitsap Lake	10	LMBS	4	380	1127	147	754	313	193
Lake Samish	10	LMBS	5	377	908	90.3	1280	331	347
Deer Lake	10	LMBS	5	384	965	239	462	331	75
American Lake	4	LMBS	5	430	1592	253	673	404	185
Fazon Lake	10	LMBS	9	439	1508	192	760	447	204
Bonaparte Lake	3	LMBS	12	454	2494	425	484	451	30

LMBS = Largemouth bass; SMBS = Smallmouth bass

Individual fish found to have the lowest mercury concentrations were collected from Upper Long Lake (22 µg/Kg), Moses Lake (26 µg/Kg), Offut Lake (47 µg/Kg), and Vancouver Lake (47 µg/Kg). Ages for these fish were 3, 2, 1, and 1 years, respectively. A complete list of fish data with associated mercury concentrations is included in Appendix Table C1.

Lipid Content in Fish Tissue

Lipid content in fish tissue ranged from 0.14 to 7.6%, with an average of 0.89% (Table 3). The two fish with the lowest lipid content of 0.14 and 0.19% were collected from the Walla Walla River and Upper Long Lake. They were five and three years old, and had mercury concentrations of 263 and 22 µg/Kg, respectively. Fish with the two highest lipid contents of 7.54 and 7.63% were both collected from Lake Bonaparte. They were both 12 years old and had mercury concentrations of 443 and 484 µg/Kg. These two lipid values are unusually high for bass, compared to results from the remaining fish analyzed. A complete listing of lipid data is included in Appendix Table C1. A discussion of these data is presented later in this report.



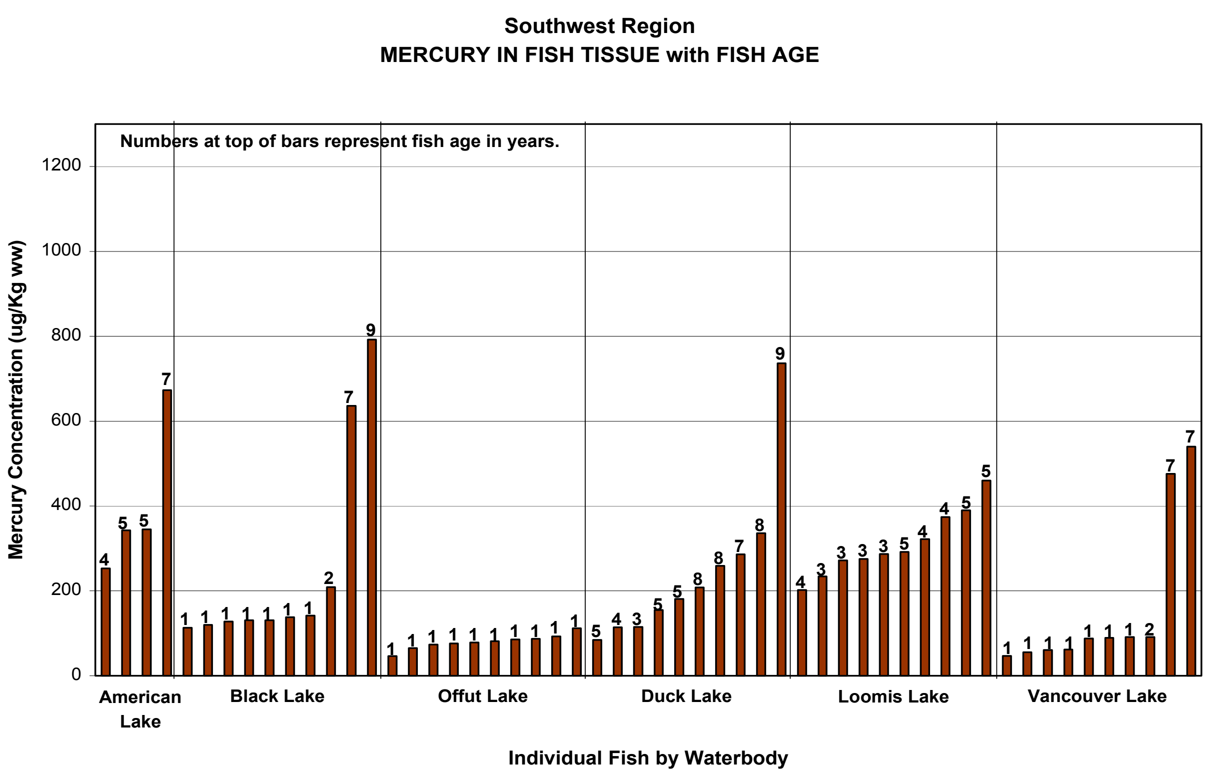
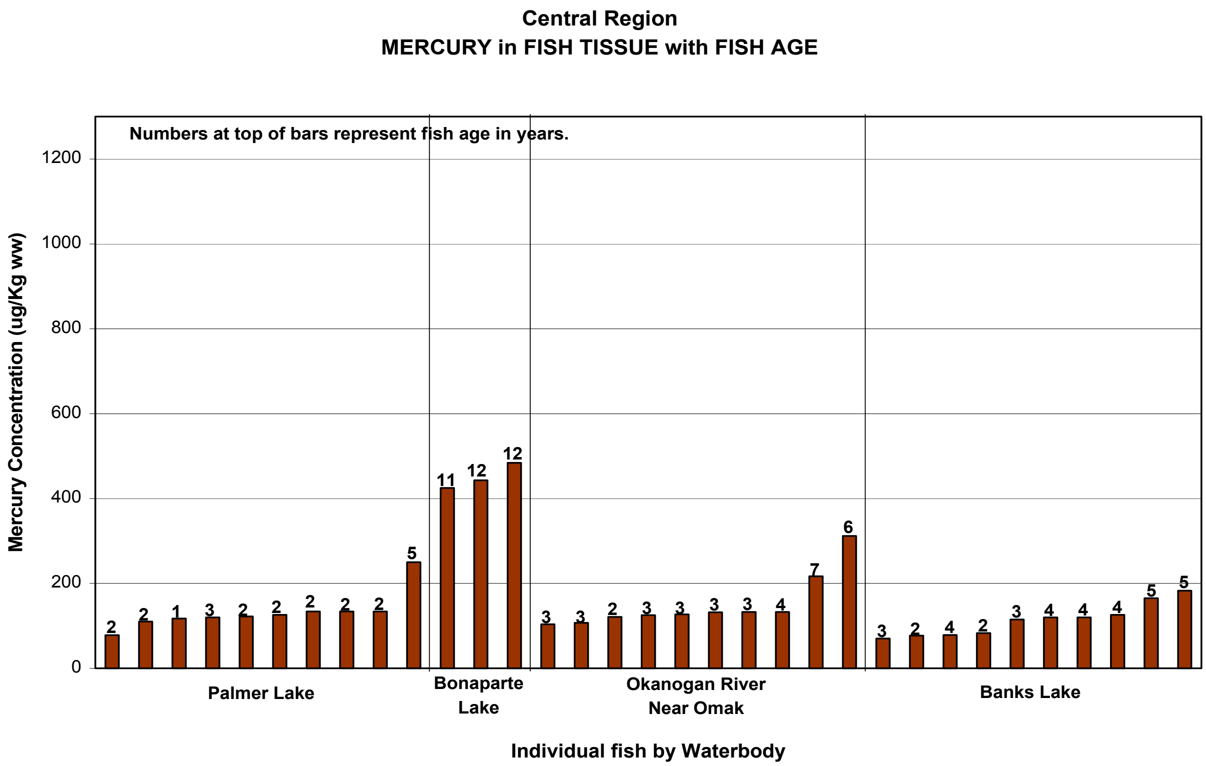


Figure 2. Mercury in Fish – Northwest and Southwest Regions



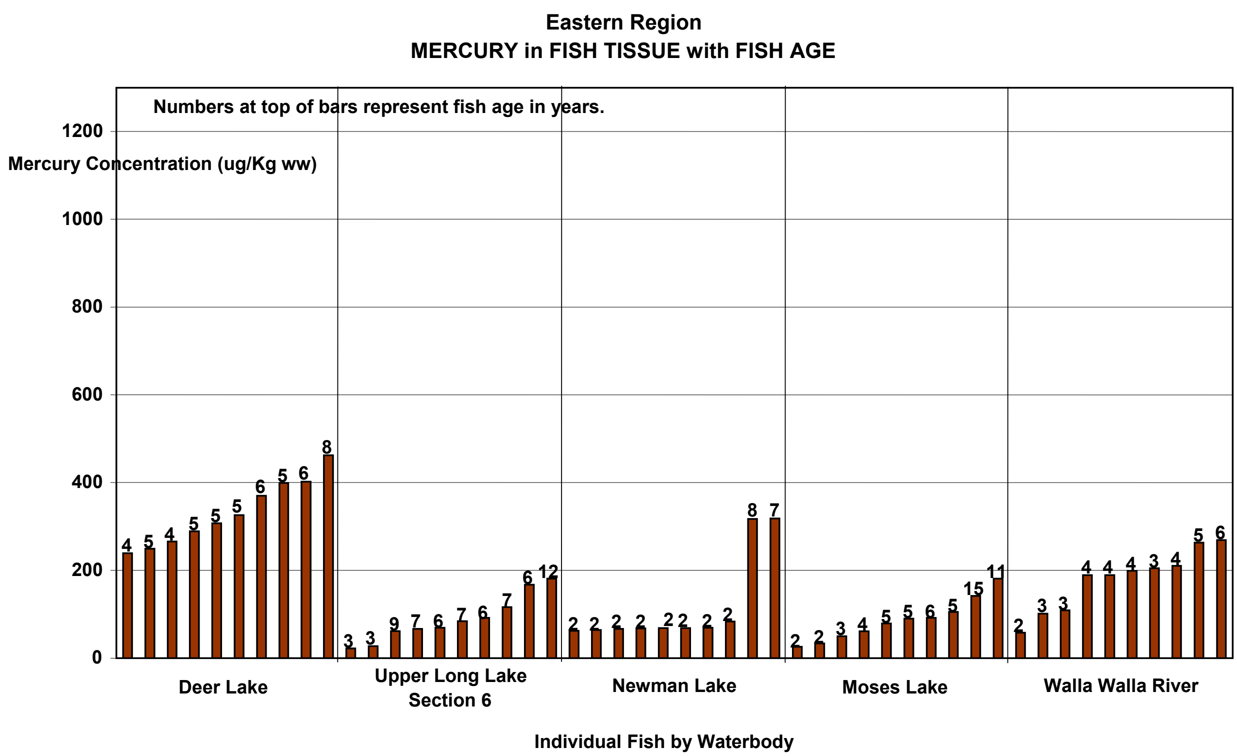


Figure 3. Mercury in Fish – Central and Eastern Regions

Sediment

A total of 60 sediment samples were collected from the 20 waterbodies where fish were obtained. Sediments were analyzed for total recoverable mercury and total organic carbon (TOC). Overall values for mercury concentrations and TOC percentages are listed below in Table 5.

Table 5. Summary of Sediment Mercury and TOC Levels.

	Sediment Mercury (µg/Kg dw)	TOC (%)
Mean	90	9.5
Range	5 – 481	0.8 – 28.0

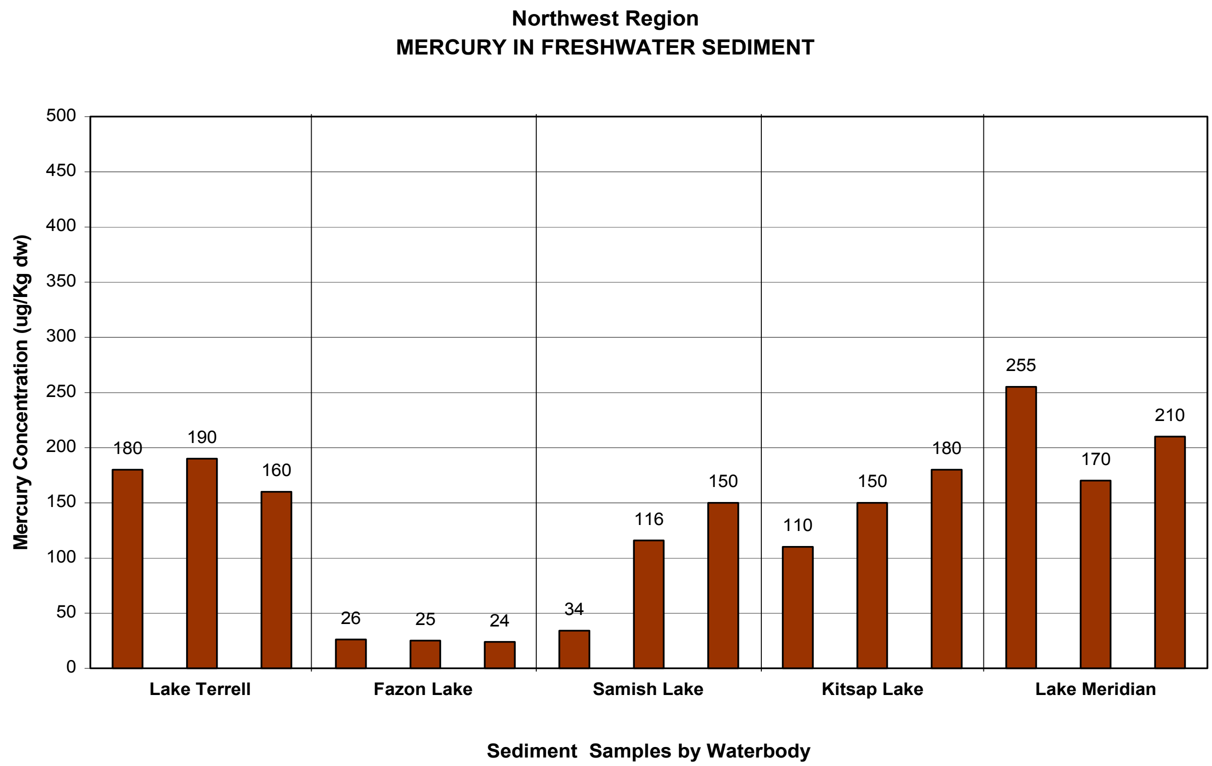
Mercury concentrations found in sediment are listed by waterbody in Table 6. Sediment samples collected from the Okanogan River and Banks Lake had the lowest mercury concentrations, while samples collected from Lake Meridian and American Lake had the highest mercury levels.

Table 6. Mercury Concentrations in Freshwater Sediment by Waterbody.

		Mercury Concentrations (µg/Kg dw)			
Waterbody	n	Minimum	Middle	Maximum	Mean
Okanogan River	3	5 U	6	10	7
Banks Lake	3	5 U	12	18	12
Walla Walla River	3	13	13	14	13
Black Lake	3	18	25	27	23
Fazon Lake	3	24	25	26	25
Moses Lake	3	21	22	37	27
Newman Lake	3	5 U	37	44	29
Upper Long Lake	3	11	31	58	33
Deer Lake	3	35	62	69	55
Palmer Lake	3	27	34	110	57
Vancouver Lake	3	28	68	88	61
Bonaparte Lake	3	64	71	86	74
Lake Samish	3	34	116	150	100
Duck Lake	3	69	110	130	103
Kitsap Lake	3	110	150	180	147
Loomis Lake	3	18	200	230	149
Offut Lake	3	61	200	250	170
Lake Terrell	3	160	180	190	177
Lake Meridian	3	170	210	255	212
American Lake	3	100	400	481	327

U = Not detected at reporting limit shown

Mercury concentrations found in individual sediment samples within each region are shown in Figures 4 and 5. The two highest mercury concentrations in individual sediment samples (481 and 400 µg/Kg dw) were found in samples collected from American Lake. The next highest mercury concentrations were found in sediments from Lake Meridian, Offut Lake, and Loomis Lake (255, 250, and 230 µg/Kg). The lowest mercury concentrations (maximum values) were found in sediments collected from the Okanogan River, Walla Walla River, and Banks Lake (9.7, 14, and 18 µg/Kg). A complete list of the project sediment data is included in Appendix Table C2.



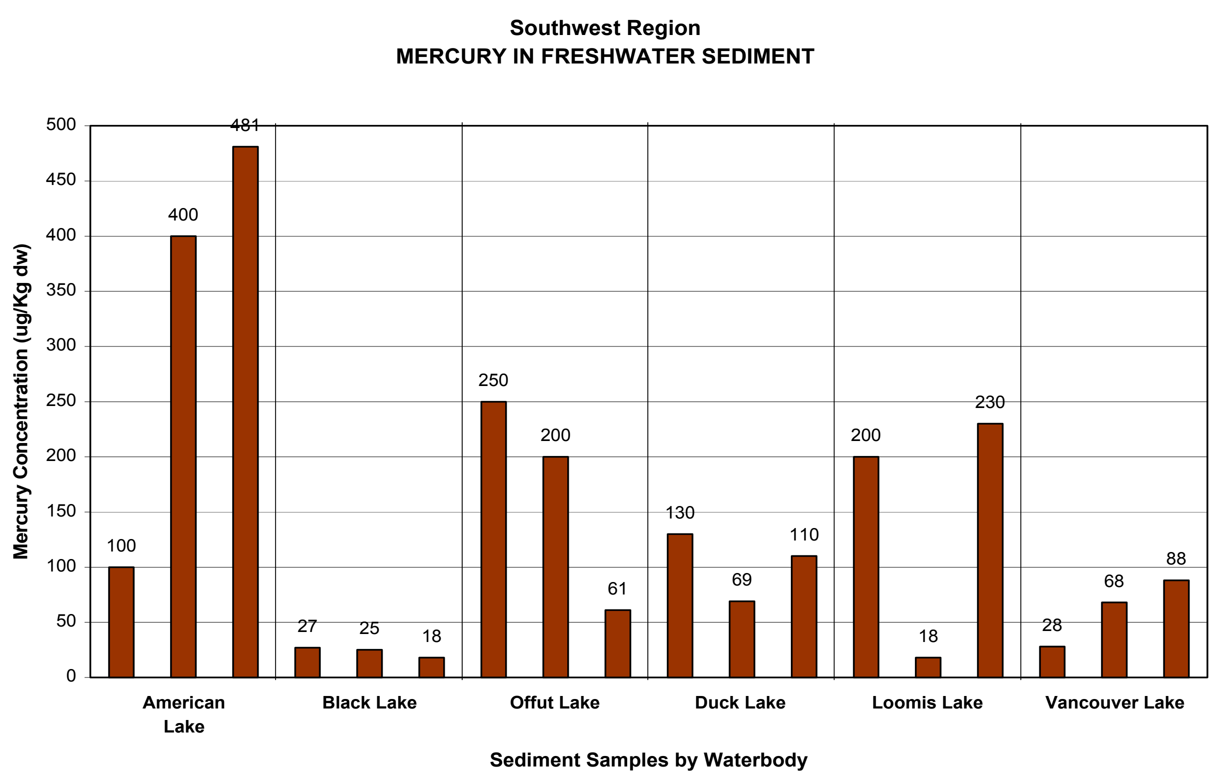


Figure 4. Mercury in Freshwater Sediment – Northwest and Southwest Regions

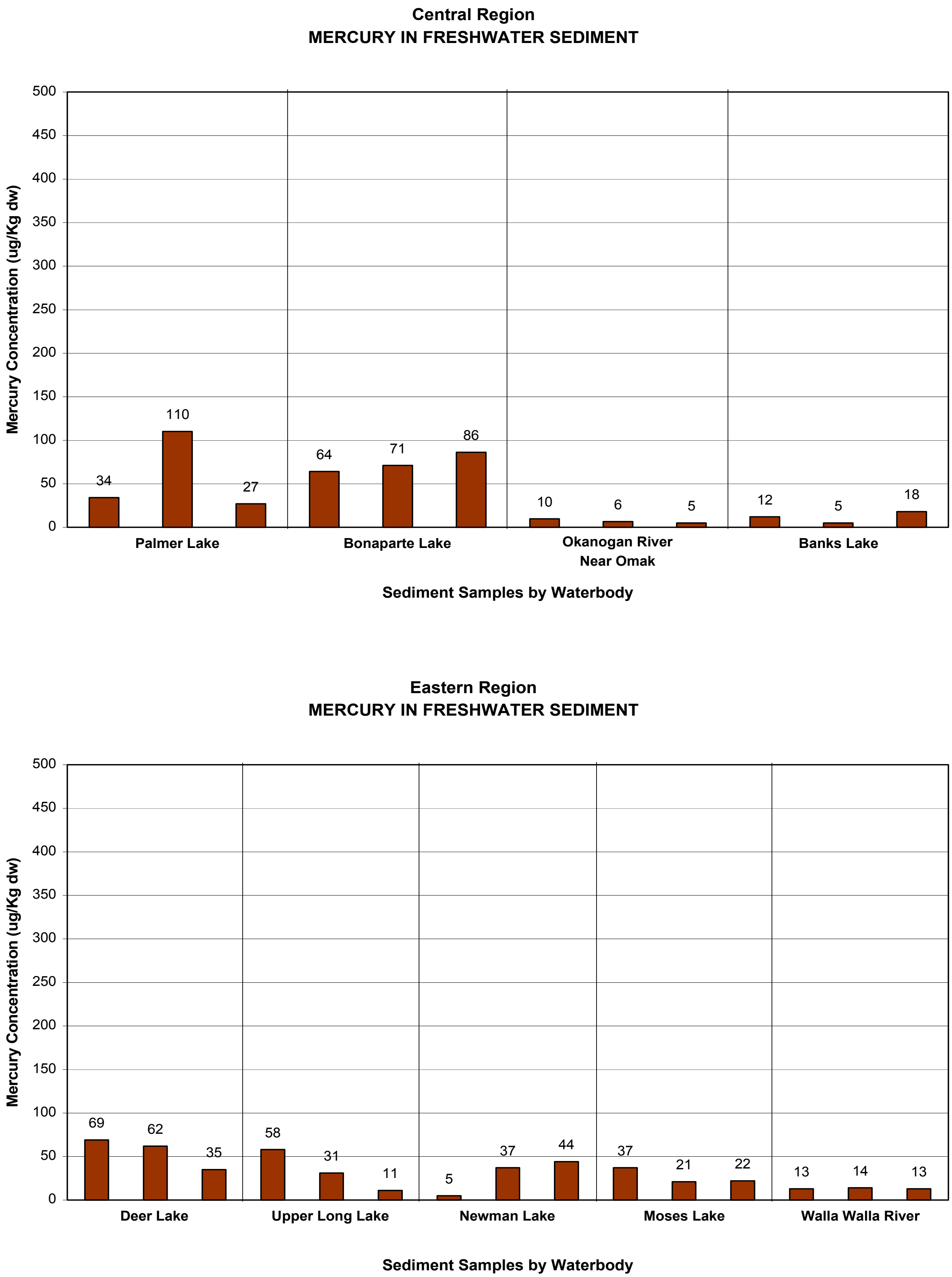


Figure 5. Mercury in Freshwater Sediment – Central and Eastern Regions

Water Quality

Water quality measurements were taken one meter off the bottom, at each of these three sediment sampling locations within each waterbody. Data were recorded for pH, dissolved oxygen, conductivity, water temperature, and turbidity (Secchi disc). A single water sample also was collected one meter off the bottom at one of the three locations and analyzed for alkalinity and hardness. Resulting water quality data are summarized in Table 7. A complete list of water quality data is included in Appendix Table C2.

The pH values for Lake Meridian (9.8), Lake Terrell (8.8), and Lake Samish (8.6) are high, exceeding the upper regulatory limit of 8.5 for Washington State (WAC 173-201A-030). The average conductivity value obtained from Fazon Lake (418 µS/cm) is also elevated. All other water quality values are within expected ranges.

Table 7. Water Quality Data.

Waterbody	Mean Temp (°C)	Mean DO (mg/L)	Secchi (meters)	Mean pH	Mean Conductivity (µS/cm)	Alkalinity (mg/L)	Hardness (mg/L)
American Lake	10.1	9.0	3.5	7.7	101	44	42.2
Lake Meridian	14.8	8.0	>DOW	9.8	93	38	37.7
Lake Terrell	17.1	10.8	2.3	8.8	100	41	41.5
Offut Lake	19.5	7.3	2.6	7.3	59	24	23.0
Loomis Lake	14.9	9.2	1.2	7.5	167	40	36.1
Kitsap Lake	10.5	8.5	3.3	7.5	88	45	45.1
Duck Lake	15.3	9.1	1.2	7.6	167	50	41.0
Lake Samish	18.2	8.9	2.0	8.6	62	22	22.2
Bonaparte Lake	9.6	8.9	4.7	8.2	196	108	100
Vancouver Lake	13.8	9.7	0.3	8.1	130	58.3	62.6
Palmer Lake	13.6	8.8	3.2	8.0	225	97.6	107
Deer Lake	9.3	8.2	7.0	7.6	70	40	33.4
Upper Long Lake	14.6	8.9	>DOW	8.1	213	79.5	86.5
Newman Lake	18.8	8.8	1.2	7.8	46	15	15.0
Moses Lake	12.0	10.0	>DOW	8.1	268	121	109
Fazon Lake	16.6	2.8	2.6	7.2	418	56.4	106
Black Lake	16.4	6.3	2.8	6.8	86	40	37.8
Walla Walla River	14.9	9.2	>DOW	8.2	303	121	109
Banks Lake	18.6	8.0	4.8	8.0	121	57.5	63.3
Okanogan River	18.9	8.5	>DOW	8.3	286	126	141

DO = Dissolved oxygen
>DOW = Greater than depth of water

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Discussion

Mercury in Fish Tissue

Fish Age, Weight, and Length Relationships to Mercury Concentrations

Correlations between fish age, weight and length and mercury concentrations were evaluated using a linear regression quadratic model within a 95% confidence interval. Comparisons yielding probability values of less than 0.05 were considered to demonstrate a correlation. These results are shown in Appendix Table D1 for 17 of the 20 waterbodies sampled. Regression results were not reported for the remaining three waterbodies due to catches that were either too small in number, or of limited age range, to be statistically valid. Too few fish were collected from American Lake and Bonaparte Lake, while all fish collected from Offut Lake were all the same age.

When mercury concentrations and fish age were compared, significant positive correlations were demonstrated for 16 of the 17 waterbodies analyzed, indicating that mercury concentrations in fish increase with fish age. Loomis Lake was the exception ($r^2 = 0.204$, $p = 0.187$), for which a correlation between mercury concentrations and fish age was not demonstrated. This result was heavily influenced by two outlying data points (Appendix Figure D10).

Comparisons between mercury concentrations in fish tissue and fish weights also demonstrated a significant correlation for 15 of 17 waterbodies, indicating that mercury concentrations in fish increase with fish weight. Significant correlations were not obtained for Loomis Lake ($r^2 = 0.001$, $p = 0.414$) and Deer Lake ($r^2 = 0.318$, $p = 0.109$). Regression curves for both of these waterbodies were heavily influenced by outlying data points. If a larger number of fish had been collected from these waterbodies, the comparison results may well have been different.

The third comparison for mercury concentrations and fish length demonstrated a significant correlation for 15 of 17 waterbodies, indicating that mercury concentrations increase with fish length. A positive correlations was not demonstrated for Loomis Lake ($r^2 = 0.064$, $p = 0.329$) or Deer Lake ($r^2 = 0.330$, $p = 0.102$). As with the other non-significant comparisons, the regression curves for these lakes were heavily influenced by outlying data points, and may change with a larger sample size.

Overall, mercury concentrations were found to increase with fish age, weight, and length. These findings are consistent with observations from other studies that have showed that predatory fish, such as freshwater bass, bioaccumulate mercury over time (Serdar et al. 2001; Håkanson et al. 1988).

Projected Mercury Concentrations for a Standard-size Fish

As stated above, mercury concentrations were strongly correlated with fish age, length, and weight. Since the fish collected varied in size, it was necessary to normalize mercury concentrations from tissue prior to projecting mercury concentrations for a standard-size fish and ranking the results by waterbody. The approach used was to select a size variable, use the selected size variable to develop a standard-size fish, then calculate a best estimate for mercury concentrations in the standard-size fish for each waterbody and rank the results.

To select a size variable, regression coefficients for fish age, weight, and length were compared and found to have similar strong, positive correlations to mercury concentrations found in tissue (Appendix Table D1). After considering each of these size variables, length was selected over weight due to the ease with which it can be measured in the field. The age variable was not selected as it is reported in categorical one-year intervals.

A standard fish length (total) was then developed by looking at fish lengths (Appendix Figure D1) and the regression curves for each waterbody (Appendix Figures D19 – D31). A standard fish length of 356 mm (14 inches) was subsequently selected as the smallest length which bisected the largest number of positive regression slopes.

Projected mercury concentrations for a standard-length fish were then calculated for each of the 15 waterbodies from which a positive correlation between mercury concentrations and fish length were demonstrated. The regression formula used to project the mercury concentration for a standard 356-mm fish for each waterbody is shown below, with the calculation for Kitsap Lake fish used as an example. The length variable used in this formula is fixed at 356-mm total length. The regression coefficients (Constant, B1, and B2) are regression products which are different for each waterbody. They are listed in Appendix Table D2 for 17 waterbodies, along with mercury concentrations projected for a 356-mm fish (total length).

Regression Formula:

Log10 [Hg] = Constant + [B1 * Log10(Length)] + [B2 * (Log10(Length))²]

Log10 [Hg] = Constant + [B1 * Log10(356 mm)] + [B2 * (Log10(356 mm))²]

Kitsap Lake Calculations:

Log10 [Hg] = 51.389 + [-41.323 * Log10(356 mm)] + [8.660 * (Log10(356 mm))²]

Log10 [Hg] = 2.3311

Tissue [Hg] at 356 mm = 214 µg/Kg ww

As previously described, a correlation between mercury concentrations in tissue and fish length was not found for Deer Lake and Loomis Lake. Consequently, regression coefficients were not used to project mercury levels for these lakes. Instead, projected mercury concentrations for these waterbodies were calculated by extrapolating from selected mercury data associated with fish lengths of 356 mm ± 20 mm. Projected mercury concentrations for fish from these lakes are labeled with a “J.”

Mercury concentrations projected for a 356-mm fish are ranked in magnitude for 17 waterbodies and shown in Figure 6. This method of comparison represents a single value for each waterbody, without consideration for sample variance. As a result, the differences shown in projected mercury concentrations between waterbodies may or may not be statistically significant.

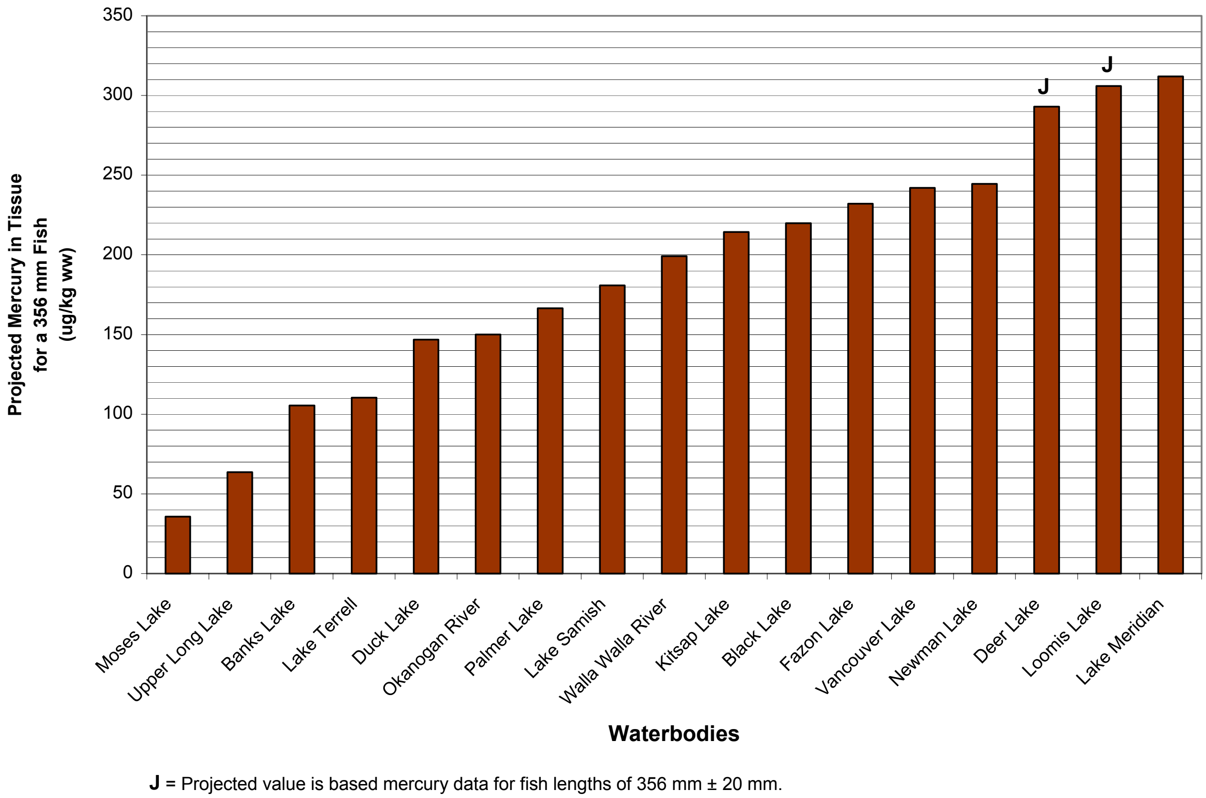

Figure 6. Mercury Concentrations Projected for a 356-mm Fish by Waterbody

Mercury Concentrations in Fish Tissue Compared between Waterbodies

An ANOVA was performed, with the $\log_{10}$ of fish length as a covariant, to determining if differences exist between adjusted mean mercury concentrations after fish length and the sample variance have been considered. Only 15 waterbodies with adequate data and significant correlations between fish length and mercury concentrations were included in this comparison. American, Bonaparte, Offut, Loomis, and Deer lakes were excluded. A Bonferroni adjustment was used to compensate for errors associated with multiple comparisons.

Out of 105 comparisons between waterbodies, fish from Moses, Upper Long, and Banks lakes were found to have adjusted mean mercury concentrations which were significantly lower than most of the other waterbodies (Table 8). The adjusted mean for Moses Lake was found to be significantly lower than all other waterbodies except Upper Long Lake, for which no difference was detected. Similarly, the adjusted mean for Upper Long Lake was found to be significantly lower than all other waterbodies except Moses Lake. The adjusted mercury mean for Banks Lake fish also was significantly lower than all other waterbodies (excluding Moses and Upper Long lakes) except Terrell, Newman, and Vancouver lakes, for which no difference was detected. Moses, Upper Long, and Banks lakes are reservoirs that receive a variable, but usually large, volume of water exchange during the year. Increased flushing in these waterbodies could be a partial explanation for the lower mercury levels measured in fish tissue.

Table 8. Significant Differences Between Adjusted Mercury Concentrations.

		Banks	Black	Duck	Fazon	Kitsap	Meridian	Samish	Terrell	Moses	Newman	Okanogan River	Palmer	Upper Long	Vancouver	Walla Walla R
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Banks	1	--														
Black	2	S	--													
Duck	3	S		--												
Fazon	4	S			--											
Kitsap	5	S				--										
Meridian	6	S					--									
Samish	7	S						--								
Terrell	8		S						--							
Moses	9	S	S	S	S	S	S	S	S	--						
Newman	10									S	--					
Okanogan R	11	S								S		--				
Palmer	12	S								S			--			
Upper Long	13	S	S	S	S	S	S	S	S		S	S	S	--		
Vancouver	14									S				S	--	
Walla Walla R	15	S								S				S		--

S = A significant difference was detected between waterbodies
Blank = No significant difference was detected

Fish Tissue Criteria

Nearly all of the methylmercury ingested by fish and humans is absorbed through the gastrointestinal tract. Methylmercury is able to pass through the lipid membranes of cells and readily binds to amino acids in fish muscle (EPA 2001a; Oliveira-Ribeiro et al. 1999). As a result, nearly all (95 to 98%) of mercury bioaccumulating in upper trophic-level fish is methylmercury (EPA 2001b; Groetsch et al. 2002; Morel et al. 1998). Because of this, total mercury concentrations in tissue are comparable to methylmercury and will be considered equivalent for this report.

Mercury concentrations found in the present study were compared to three fish tissue criteria:

1. EPA National Toxics Rule of 825 µg/Kg ww (EPA 1980)
2. EPA 2001 Revised Fish Tissue Residual Criterion (TRC) for methylmercury of 300 µg/Kg ww (EPA 2001b)
3. Draft Washington State DOH Interim Fish Criterion of 150 µg/Kg ww (McBride 2003).

These criteria represent the concentration of mercury in fish that should not be exceeded for the protection of human health, based on total fish consumption rates for the general adult population (EPA 2001c). The values are all based on the same reference dose (0.1 µg methyl-mercury/Kg body weight–day) for non-cancer human health effects, but differ due to the utilization of different consumption rates.

The EPA National Toxics Rule (NTR) is based on a total fish consumption rate of 6.5 grams per day, or 198 grams of fish per month. The EPA Fish Tissue Residual Criterion is based on a total fish and shellfish consumption rate of 17.5 grams of fish per day, or 532 grams per month (EPA 2001b). A draft DOH Interim Fish Criterion, being developed for Washington State, is based on an average consumption rate of six 8-ounce meals of fish per month, which is equivalent to 44.8 grams per day, or 1361 grams of fish per month.

Average Mercury Concentrations

Mercury concentrations from fish were averaged for each waterbody and compared to the above fish tissue criteria. None of the mean mercury levels from fish in this project exceeded the NTR. However, 35% of waterbodies sampled had mean mercury levels in fish exceeding the EPA Fish Tissue Residual Criterion of 300 µg/Kg ww. Additionally, 70% of the waterbodies contained fish with mean mercury concentrations exceeding the draft DOH Interim Fish Criterion of 150 µg/Kg ww.

Mercury Concentrations from Individual Fish

A cumulative frequency distribution plot of mercury concentrations for individual fish is shown in Figure 7. Percentages of individual tissue samples with mercury concentrations exceeding these criteria are listed below in Table 9. Of 185 fish collected, 23% contained total mercury levels at or above the recommended EPA Fish Tissue Residual Criterion for methylmercury. When compared to the draft DOH Interim Fish Criterion, 51% of the fish collected contained total mercury concentrations at or exceeding this level.

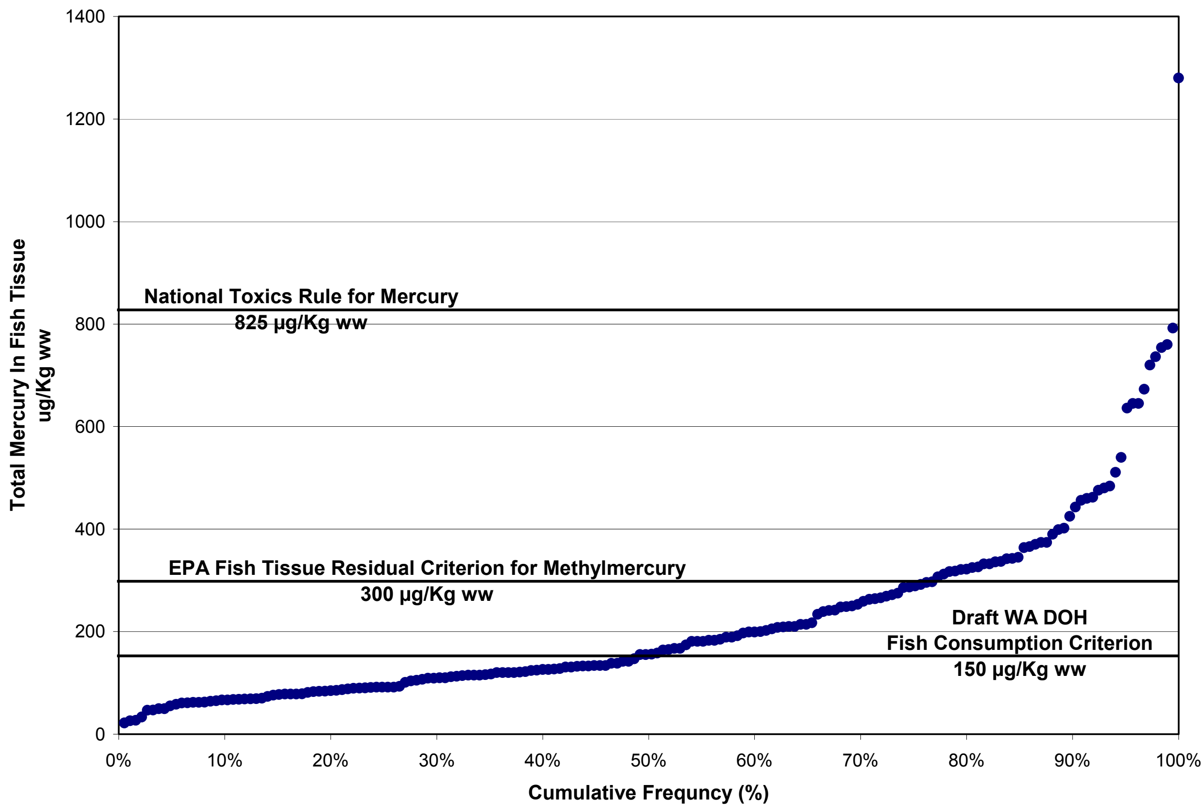

Figure 7. Cumulative Frequency Distribution of Mercury Concentrations in Fish

Table 9. Samples Exceeding Fish Tissue Consumption Criteria

Waterbody	n	NTR Number of Fish with Mercury > 825 µg/Kg ww	TRC Number of Fish with Mercury > 300 µg/Kg ww	DOH Number of Fish with Mercury > 150 µg/Kg ww
Northwest Region				
Lake Terrell	10	0	1	4
Lake Meridian	8	0	2	8
Kitsap Lake	10	0	4	9
Lake Samish	10	1	3	8
Fazon Lake	10	0	8	10
Southwest Region				
Offut Lake	10	0	0	0
Vancouver Lake	10	0	2	2
Duck Lake	10	0	2	7
Black Lake	10	0	2	3
Loomis Lake	10	0	4	10
American Lake	4	0	3	4
Central Region				
Banks Lake	10	0	0	2
Palmer Lake	10	0	0	1
Okanogan River	10	0	1	2
Bonaparte Lake	3	0	3	3
Eastern Region	10			
Moses Lake	10	0	0	1
Upper Long Lake	10	0	0	2
Newman Lake	10	0	2	2
Walla Walla River	10	0	0	7
Deer Lake	10	0	6	10
Total Fish	185	1	43	95
% Exceeding Criteria		0.5%	23%	51%
Total Waterbodies	20	0	14	19
% Exceeding Criteria		0%	70%	95%

Section 303d Listing

Per Ecology's Water Quality Program Policy 1-11, *Assessment of Water Quality for the Section 303(d) List*, a waterbody will be placed in Category 2 (Waters of Concern) when any one tissue sample exceeds the NTR criteria. One fish contained a mercury concentration which exceeded the NTR of 825 µg/Kg ww. This fish was collected from Lake Samish and was 10 years old. Therefore, Lake Samish should be considered for placement in the Waters of Concern category on the 2002 303(d) list.

Currently, for a waterbody to be placed in Category 5 (Impaired) of the 303(d) list, a minimum of three individual fish tissue samples or a single composite of at least five fish would need to exceed the NTR of 825 µg/Kg ww. As previously discussed, other lower tissue criteria are being considered for use in Washington State. Depending on the criteria level chosen and implemented, a number of other waterbodies sampled in this study could qualify for inclusion in Category 5 of the 303(d) list in the future.

Lipid Content in Fish Tissue Compared to Mercury Concentrations

Mercury concentrations in tissue do not appear to correlate significantly with lipid content. This is based on a Pearson correlation coefficient ($r = 0.2720$), which shows only a small positive correlation between mercury concentrations and lipid content (Appendix Figure D36).

Mercury in Sediment

Available Sediment Quality Values

Washington State is currently developing numerical freshwater sediment standards. In the interim, Ecology uses best professional judgment on a case-by-case basis to evaluate freshwater sediment quality. Towards this end, Washington uses a range of North American freshwater sediment quality values (SQVs) to evaluate mercury concentrations in sediments, ranging from levels where biological effects are known to frequently occur down to a level below which biological effects rarely occur. The higher of these values are used to evaluate potential cleanup sites, while the lower values are used to evaluate a potential no-effects impact level for sediment-dwelling organisms.

Four SQVs were used in this study to evaluate mercury concentrations found in sediments. These levels are described in Table 10. They begin with values that represent the most severe biological effects and end with values that represents the lowest effects level (SAIC and Avocet Consulting 2002).

Table 10. Selected Freshwater Sediment Quality Values for Mercury (SAIC and Avocet Consulting 2002).

Freshwater Sediment Quality Guideline	Mercury Concentration µg/Kg dw	Meaning
Apparent Effects Threshold (AET)	560	Level above which adverse effects have always been observed in bioassays.
Probable Effects Level (PEL)	490	Level above which adverse effects frequently occur in bioassays and benthic communities.
Lowest Effects Level (LEL)	200	Level at which adverse effects are seen in 5% of benthic species.
Threshold Effects Level (TEL)	170	Level below which adverse effects rarely occur in bioassays and benthic communities.

PEL and TEL values are based on a combination of data sets, which are derived from acute and chronic bioassays, benthic community studies, spiked sediment bioassays, equilibrium partitioning values, and SQVs from other jurisdictions.

Environment Canada has adopted the PEL and TEL sediment quality guidelines for use as freshwater sediment criteria in Canadian provinces that do not have their own criteria. Ontario additionally considers sediments to be degraded when contaminant levels exceed the LEL. For sediment contaminant levels falling between the LEL and TEL, biological assessment tools are recommended to establish what action, if any, is needed for a particular waterbody.

Sediment Mercury Concentrations Compared to Sediment Quality Values

Mercury concentrations found in sediment samples from the present study were compared to the four SQVs listed in Table 10. A cumulative frequency distribution plot of mercury concentrations in individual samples is shown in Figure 8. A complete list of sediment data is included in Appendix Table C2.

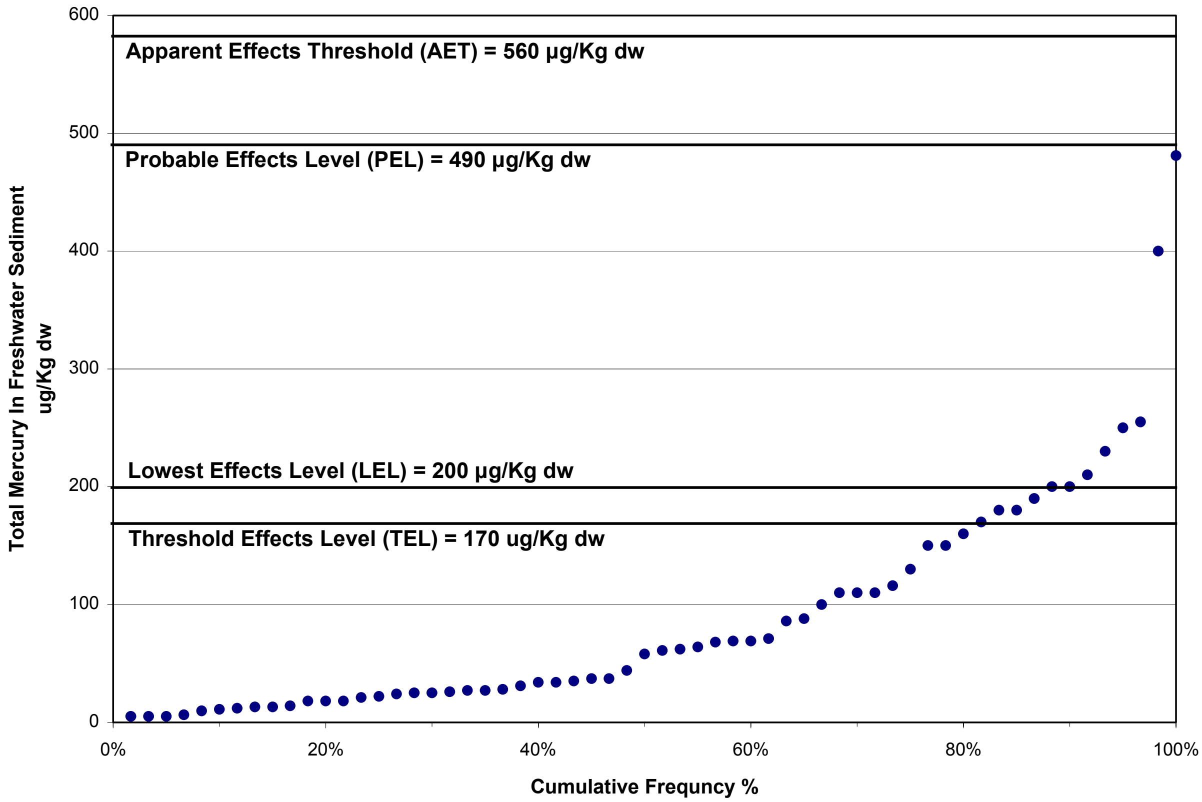

Figure 8. Cumulative Frequency Distribution of Mercury Concentrations in Sediment

In general, mercury concentrations in sediments were found to be low, with 80% of the samples having mercury levels below the TEL. None of the mercury concentrations from the sediment samples exceeded the AET or the PEL. However, 13% of sediment samples were found to contain mercury concentrations equal to or greater than the LEL, while 20% of samples contained mercury concentrations that equaled or exceeded the TEL (Table 11).

Of the 20 waterbodies sampled, 20% (four) were found to have at least one sediment sample with a mercury concentration that equaled or exceeded the LEL, indicating the potential for some biological impacts. Waterbodies with these elevated mercury concentrations include Lake Meridian, Offut Lake, Loomis Lake, and American Lake. Two of the sediment samples from American Lake were found to have elevated mercury concentrations (400 and 481 µg/Kg) approaching the PEL value of 490 µg/Kg, the level above which adverse biological effects are known to frequently occur. Sediments in these four lakes should be considered for further evaluation (bioassay) to assess the potential for sediment toxicity.

Table 11. Samples Exceeding Freshwater Sediment Quality Values for Mercury

Waterbody	n	AET No. Sediment Samples with [Hg] > 560 µg/Kg dw	PEL No. Sediment Samples with [Hg] > 490 µg/Kg dw	LEL No. Sediment Samples with [Hg] ≥ 200 µg/Kg dw	TEL No. Sediment Samples with [Hg] ≥ 170 µg/Kg dw
Northwest Region					
Lake Terrell	3	0	0	0	2
Lake Meridian	3	0	0	2	3
Kitsap Lake	3	0	0	0	1
Lake Samish	3	0	0	0	0
Fazon Lake	3	0	0	0	0
Southwest Region					
Offut Lake	3	0	0	2	2
Vancouver Lake	3	0	0	0	0
Duck Lake	3	0	0	0	0
Black Lake	3	0	0	0	0
Loomis Lake	3	0	0	2	2
American Lake	3	0	0	2	2
Central Region					
Banks Lake	3	0	0	0	0
Palmer Lake	3	0	0	0	0
Okanogan River	3	0	0	0	0
Bonaparte Lake	3	0	0	0	0
Eastern Region					
Moses Lake	3	0	0	0	0
Upper Long Lake	3	0	0	0	0
Newman Lake	3	0	0	0	0
Walla Walla River	3	0	0	0	0
Deer Lake	3	0	0	0	0
Total Samples	60			8	12
% Exceeding Criteria		0%	0%	13%	20%
Total Waterbodies	20			4	6
% Exceeding Criteria		0%	0%	20%	30%

Two additional waterbodies (Terrell and Kitsap) were found to have sediments with mercury concentrations that equaled or exceeded the TEL, but were less than the LEL. The mercury concentration in at least one sample from each of these lakes (190 and 180 µg/Kg) fell just under the LEL sediment quality value of 200 µg/Kg.

Sediment mercury concentrations were below the TEL for 70% (14) of the waterbodies sampled. In all, 30% (six) of the waterbodies were found to have at least one sediment sample with a mercury concentration that equaled or exceeded the TEL.

For perspective, historical freshwater sediment mercury data from Ecology's SEDQUAL database showed a mean mercury level for Washington State of 374 µg\Kg dw, with a range of 6 to 950 µg\Kg. This database includes mercury results that were obtained from dredging materials, source control monitoring, cleanup sites, and ambient monitoring. Because the SEDQUAL database includes data from a number of sites known to be contaminated with mercury, this mean is probably biased to the high side.

All mean sediment mercury values obtained from waterbodies sampled during this study were below the SEDQUAL mean of 374 µg\Kg, with American Lake having the highest mean mercury value at 327 µg\Kg. Two individual sediment samples collected from American Lake (400 and 481 µg\Kg) exceeded the SEDQUAL mean, further indicating elevated mercury levels.

Recognizing that the SEDQUAL mean mercury concentration is biased to the high side, an additional mean value (184 µg\Kg) for mercury in freshwater sediment was calculated from Ecology's Environmental Information Management (EIM) database. This database also contains sample results from areas of concern. As a result, the EIM mean mercury concentration for sediment also may be elevated above background levels, but is provided for additional perspective.

Sediment samples collected from five waterbodies during this study had mercury concentrations exceeding the EIM mean of 184 µg\Kg. These included American Lake (400 and 481 µg\Kg), Offut Lake (250 and 200 µg\Kg), Loomis Lake (230 and 200 µg\Kg), Meridian Lake (255 and 210 µg\Kg) and Lake Terrell (190 µg\Kg).

Sediment Mercury Concentrations Compared to TOC Percentages

Mercury concentrations in sediment appear to correlate moderately with total organic carbon (TOC) percentages. This is based on a Pearson correlation coefficient ($r = 0.5991$), which shows a moderate, positive correlation between mercury concentrations and TOC percentages (Appendix Figure D37).

Comparison of Fish and Sediment Mercury Concentrations

A consistent relationship between mercury concentrations in fish and sediment is not evident in data from this study (Table 12). Elevated mercury concentrations (≥ TRC and ≥ TEL) were found in both tissue and sediment samples for five of the 20 waterbodies sampled (Meridian, Loomis, American, Terrell, and Kitsap). One additional waterbody (Offut Lake) was found to have elevated sediment concentrations, but tissue concentrations for this lake were below the TRC (all fish collected were one year of age). The remaining 14 waterbodies were found to have elevated mercury concentrations in sediment, while fish from nine of these waterbodies had mercury concentrations above the TRC (Samish, Fazon, Vancouver, Duck, Black, Okanogan, Bonaparte, Newman, and Deer), and five had concentrations below the TRC but above the draft DOH Interim Fish Criterion (Banks, Palmer, Moses, and Upper Long).

Table 12. Mercury Concentrations Exceeding (≥) Fish Tissue Criteria and Sediment Quality Values.

Number of Waterbodies	Mercury Concentrations	
	Tissue	Sediment
5	≥ TRC	≥ TEL
1	< TRC	≥ TEL
9	≥ TRC	< TEL
5	< TRC and ≥ DOH	< TEL

Mercury in tissue: TRC = 300 µg/Kg ww; and DOH Interim Fish Criterion = 150 µg/Kg ww
Mercury in sediment: TEL = 170 µg/Kg dw

The lack of a consistent pattern between mercury concentrations in tissue and sediment is most likely due to a combination of factors:

1. The variability of sediment mercury concentrations within individual waterbodies indicates that mercury is not evenly distributed in sediments and that three samples may be too few to represent an entire lake.
2. Mercury is known to accumulate in tissue with age; however, individual fish also may be exposed to different levels of mercury over their lifetimes, thus contributing to the variance of mercury concentrations in a fish population.
3. Mercury concentrations in tissue are likely influenced by additional biological and chemical processes that control the methylation of mercury within waterbodies.
4. The amount of flushing a waterbody receives may impact the concentration of methylmercury available for uptake into the food chain.

This lack of a consistent pattern between mercury concentrations observed in tissues and sediments is consistent with literature indicating that sulfate-reducing bacteria are responsible for the methylation of mercury in anoxic sediments, while photochemical reactions are responsible for both methylation and demethylation of mercury in oxygenated, sunlit waters (Morel et al. 1998; Smith et al. 1996). Total mercury and methylmercury concentrations have also been reported to be highest in areas with fine-grain sediment and enriched organic matter (Sunderland and Gobas 2002). Since almost 100% of mercury in fish tissue is methylmercury, the processes controlling the methylation of metallic mercury within a waterbody are likely to be an important linkage between mercury concentrations in sediment and fish.

Water Quality

Results obtained for all water quality measurements were within expected ranges, with the exception of high pH measurements that were obtained from Lake Meridian (9.8), Lake Terrell (8.8), and Lake Samish (8.6). Elevated pH values such as these are often indicative of wastewater discharge or nonpoint pollution (Butkus 2002). The average conductivity value for Fazon Lake was also high (417.5 µS/cm); however, this elevated value may be due to a low oxygen condition of the lake at the time of sampling (2.8 mg/L) and the associated release of ions.

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Conclusions

Mercury in Fish Tissue

Fish collected during this study ranged in age from one to 17 years, with the higher mercury concentrations generally found in older fish. Mercury concentrations in tissue were shown to be positively correlated with fish size, increasing with fish age, weight, and length in approximately 90% of the waterbodies sampled. These findings are consistent with other studies, demonstrating that bioaccumulation and biomagnification of mercury occurs in upper-trophic-level predatory species, such as bass (Håkanson et al. 1988; Rose et al. 1999; Serdar et al. 2001; and Mueller and Serdar 2002).

Mercury concentrations found in fish were compared to three human health fish tissue criteria. One ten-year-old fish from Samish Lake had a mercury concentration exceeding the National Toxics Rule of 825 µg/Kg ww. This mercury concentration (1280 µg/Kg ww) also exceeded the U.S. Food and Drug Administration action level of 1000 µg/Kg ww, which is used for removing contaminated fish from the marketplace (FDA 1985). Approximately 23% of the fish, from 70% of the waterbodies sampled, contained mercury concentrations that exceeded the EPA Fish Tissue Residual Criterion of 300 µg/Kg ww. And finally, approximately 51% of the fish, from 95% of the waterbodies sampled, contained mercury concentrations that exceeded a draft Washington State DOH Interim Fish Criterion of 150 µg/Kg ww.

To fairly compare mercury in fish tissue among waterbodies, concentrations were adjusted for a standard length fish of 356 mm (14 inches). Moses, Upper Long, and Banks lakes had the lowest adjusted mercury levels, while Meridian, Loomis, and Deer lakes had the highest.

When adjusted mercury concentrations were compared using an ANOVA, Moses, Upper Long, and Banks lakes were found to have mercury concentrations significantly lower than most of the other waterbodies. Moses, Upper Long, and Banks lakes are reservoirs that receive a variable, but usually large, volume of water exchange during each year. Increased flushing in these waterbodies could be a partial explanation for the lower mercury levels measured in fish tissue.

A comparison of mercury concentrations and lipid percentages in tissue showed only a small, positive correlation (Appendix Figure D36). Based on these data, additional analysis for lipids is not needed in conjunction with future mercury studies.

Mercury in Sediment

Mercury concentrations from freshwater sediments varied among waterbodies and individual samples. Concentrations were compared to four sediment quality values: the Apparent Effects Threshold (AET), Probable Effects Level (PEL), Least Effects Level (LEL), and Threshold Effects Level (TEL). All mercury concentrations were below the two higher sediment quality values (AET and PEL), indicating they were below concentrations know to frequently cause observable biological effects (SAIC and Avocet Consulting 2002).

In general, mercury concentrations for the majority of sediments were low, with 80% of samples having mercury concentrations below the TEL. Concentrations below the TEL rarely cause adverse biological effects (SAIC and Avocet Consulting 2002). Above the TEL, adverse biological effects begin to occur with increasing frequency. Concentrations in 13% of the sediment samples, from 20% of the waterbodies sampled, were greater than or equal to the LEL sediment quality value of 200 µg/Kg dw. This is the level at which adverse effects are estimated to occur in 5% of benthic species. Mercury concentrations at or above the LEL were found in Meridian, Offut, Loomis, and American lakes, indicating the potential for biological impacts.

For perspective, a mean mercury value of 374 µg\Kg was calculated from Ecology's SEDQUAL database, which contains data from a range of areas, including sites known to be contaminated with mercury. All mercury concentrations obtained from sediments sampled during this study were below the SEDQUAL mean, except for two samples from American Lake. Mercury concentrations in these samples (400 and 481 µg\Kg) exceeded the SEDQUAL mean, indicating elevated mercury levels.

Using an additional comparison value, sediment samples collected from five waterbodies during this study were found to have mercury concentrations exceeding the EIM mean of 184 µg\Kg. These included American Lake (400 to 481 µg\Kg), Offut Lake (250 and 200 µg\Kg), Loomis Lake (230 and 200 µg\Kg), Meridian Lake (255 and 210 µg\Kg) and Lake Terrell (190 µg\Kg). All of these samples have potentially elevated mercury levels.

A moderate correlation appears to exist between mercury concentrations in sediment and TOC percentages (Appendix Figure D37). Additional data are needed to further define this correlation.

Comparison of Fish and Sediment Mercury Concentrations

Comparisons between mercury concentrations in tissue and sediment did not show a consistent pattern. This is expected, given the small sediment sampling size, the complex nature of the methylation and demethylation processes, the potential interaction with other pollutants (Sutherland 2002; Bonzongo 2002), and the uptake of methylmercury into the food chain.

While a consistent correlation between mercury concentrations in fish and sediment was not shown, fish collected from five lakes with sediment mercury levels above the TEL sediment quality value (Meridian, Loomis, American, Terrell, and Kitsap) also had elevated mercury concentrations exceeding the EPA Fish Tissue Residual Criterion (TRC).

Water Quality

As discussed above, elevated pH measurements obtained from Lake Meridian, Lake Terrell, and Lake Samish may indicate potential discharges of septic waste or nonpoint pollution (Butkus 2002). Controls limiting discharges into these lakes need to be reviewed, and preventive measures need to be implemented or strengthened.

Recommendations

- Fish tissue and sediment data from this project confirm that elevated mercury concentrations are prevalent in Washington State bass. Based on these findings, a long-term monitoring plan for mercury in fish needs to be developed and implemented. Limited analysis of mercury levels in additional game species commonly consumed by recreational fishers also should be considered for inclusion in the program.

- Data contained in this report should be used by the Washington State Department of Health to aid in development of a fish consumption risk assessment for bass in Washington State. Consideration should be given for the development and issuance of a statewide fish consumption advisory for bass.

- Elevated mercury concentrations in sediment were found at Meridian, American, Offut, Loomis, Terrell, and Kitsap lakes, indicating the potential for biological impacts. Additional sediment sampling is recommended for these waterbodies to further characterize mercury concentrations. Sediment bioassays also are recommended to evaluate the potential for sediment toxicity in Meridian, Offut, Loomis, and American lakes, since they had samples that exceeded the Lowest Effects Level.

- Lake Samish should be considered for inclusion in Category 2, *Waters of Concern*, on the federal Clean Water Act draft 2002 303(d) list. This recommendation is based on a single fish tissue sample result that exceeded the EPA National Toxics Rule for mercury.

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Appendices

A. Sampling Site Locations

B. Quality Assurance Data

C. Biological Data and Water Quality Measurements

D. Statistical Comparisons

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Appendix A.

Sampling Site Locations

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Table A1. Station Locations for Sediment and Water Quality Samples

Waterbody	Waterbody No.	Station ID	Latitude	Longitude	Depth (m)
American Lake	WA-12-9010	Amer01	47°07'14"	122°34'14"	6.4
		Amer02	47°06'37"	122°35'12"	8.5
		Amer03	47°07'39"	122°33'54"	17.0
Banks Lake	WA-42-9020	Banks01	47°56'31"	119°01'23"	14.2
		Banks02	47°52'12"	119°06'37"	6.3
		Banks03	47°49'35"	119°08'29"	4.0
Black Lake	WA-23-9010	Black01	46°59'00"	122°59'02"	3.3
		Black02	46°59'17"	122°58'56"	3.3
		Black03	46°59'42"	122°58'42"	3.0
Bonaparte Lake	WA-49-9050	Bona01	48°48'15"	119°02'52"	10.3
		Bona02	48°47'56"	119°03'21"	5.1
		Bona03	48°47'38"	119°03'36"	6.8
Deer Lake	WA-59-9040	Deer01	48°07'28"	117°34'43"	6.5
		Deer02	48°06'39"	117°34'35"	12.1
		Deer03	48°07'03"	117°35'50"	8.5
Duck Lake	WA-22-9030	Duck01	46°58'54"	124°08'49"	2.4
		Duck02	46°57'56"	124°08'27"	2.5
		Duck03	46°5950"	124°08'45"	ND
Fazon Lake	WA-01-9020	Fazon01	48°51'55"	122°22'12"	2.8
		Fazon02	48°52'00"	122°21'55"	3.6
		Fazon03	48°51'56"	122°22'05"	3.9
Kitsap Lake	WA-15-9150	Kitsap01	47°33'59"	122°42'20"	2.1
		Kitsap02	47°34'06"	122°41'59"	3.9
		Kitsap03	47°34'44"	122°42'31"	7.0
Loomis Lake	WA-24-9030	Loomis01	46°25'32"	124°02'24"	0.7
		Loomis02	46°26'41"	124°02'28"	1.5
		Loomis03	46°27'09"	124°02'33"	1.2
Lake Meridian	WA-09-9160	Meridian01	47°22'07"	122°08'38"	2.8
		Meridian02	47°21'39"	122°09'09"	2.0
		Meridian03	47°21'32"	122°08'46"	3.3
Moses Lake	WA-41-9250	Moses01	47°14'04"	119°26'21"	1.3
		Moses02	47°04'47"	119°19'17"	8.6
		Moses03	47°07'37"	119°17'36"	1.5
Newman Lake	WA-57-9020	Newman01	47°46'10"	117°05'06"	1.3
		Newman02	47°47'40"	117°06'17"	1.5
		Newman03	47°4646"	117°0652"	4.5
Offutt Lake	WA-13-9110	Offutt01	46°54'49"	122°49'51"	2.3
		Offutt02	46°55'01"	122°49'44"	3.1
		Offutt03	46°54'57"	122°49'12"	1.4
Okanogan River	WA-49-1040	Okanog01	48°10'37"	119°40'34"	3.1
		Okanog02	48°30'13"	119°30'15"	2.5
		Okanog03	48°55'16"	119°25'11"	1.5
Palmer Lake	WA-49-9270	Palmer01	48°54'41"	119°38'33"	4.4
		Palmer02	48°53'03"	119°36'27"	12.2
		Palmer03	48°52'50"	119°37'29"	8.9
Lake Samish	WA-03-9160	Samish01	48°40'24"	122°24'05"	6.1
		Samish02	48°39'34"	122°22'21"	5.5
		Samish03	48°39'07"	122°22'26"	5.2
Lake Terrell	WA-01-9090	Terrell01	48°51'44"	122°40'53"	1.4
		Terrell02	48°51'51"	122°41'09"	1.8
		Terrell03	48°52'05"	122°41'05"	1.7
Upper Long Lake	WA-54-9040	Long01	47°49'49"	117°37'34"	3.8
		Long02	47°48'12"	117°33'03"	0.5
		Long03	47°47'43"	117°32'01"	2.0
Vancouver Lake	WA-28-9090	Vancouv01	45°42'01"	122°42'58"	2.8
		Vancouv02	45°40'29"	122°44'22"	1.7
		Vancouv03	45°40'08"	122°42'23"	1.1
Walla Walla River	WA-32-1010	Walla01	46°03'08"	118°45'30"	1.0
		Walla02	46°04'07"	118°49'22"	0.8
		Walla03	46°04'04"	118°49'27"	0.8

ND = No Data   Datum: NAD83

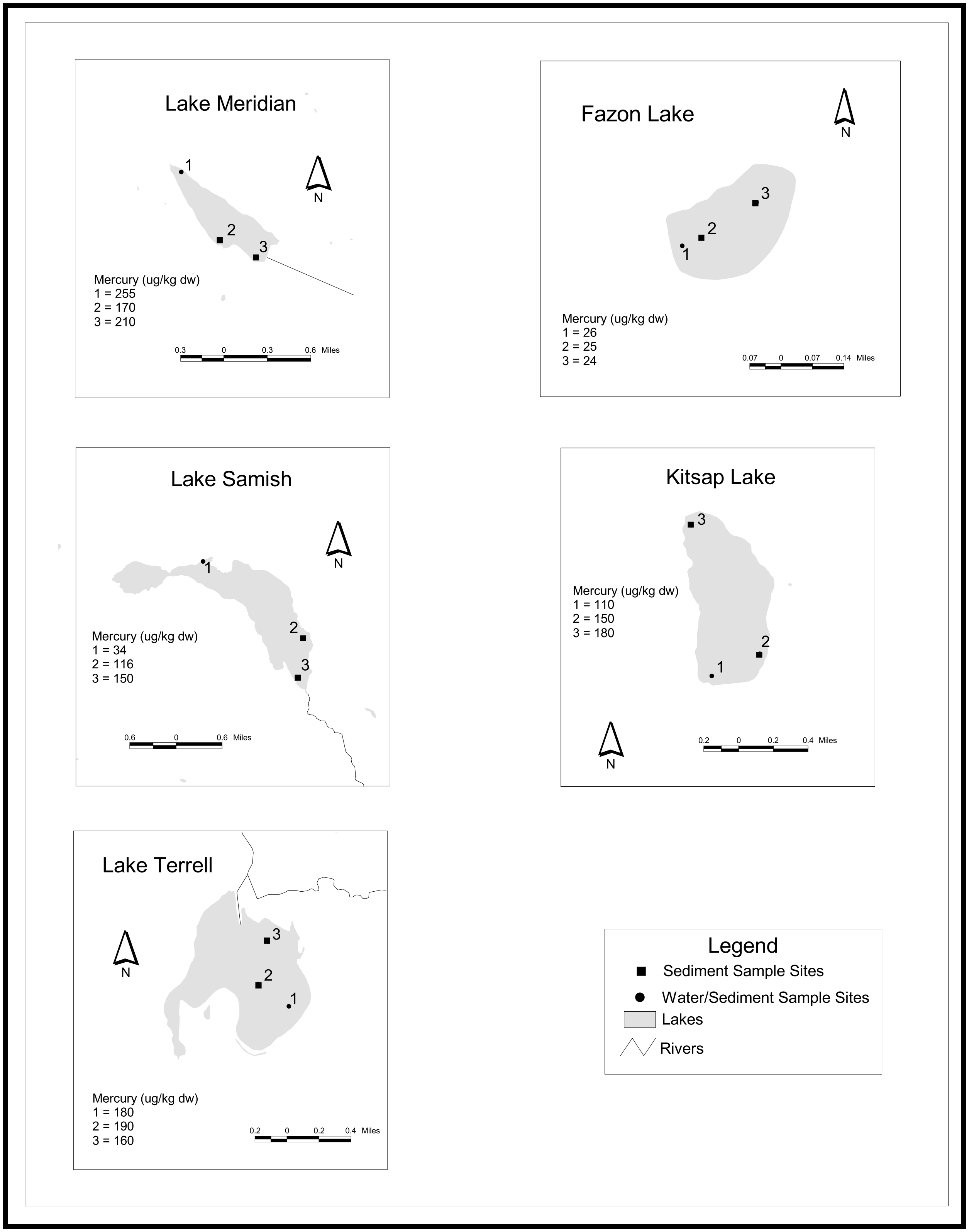

Figure A1. NW Region Water and Sediment Sampling Sites

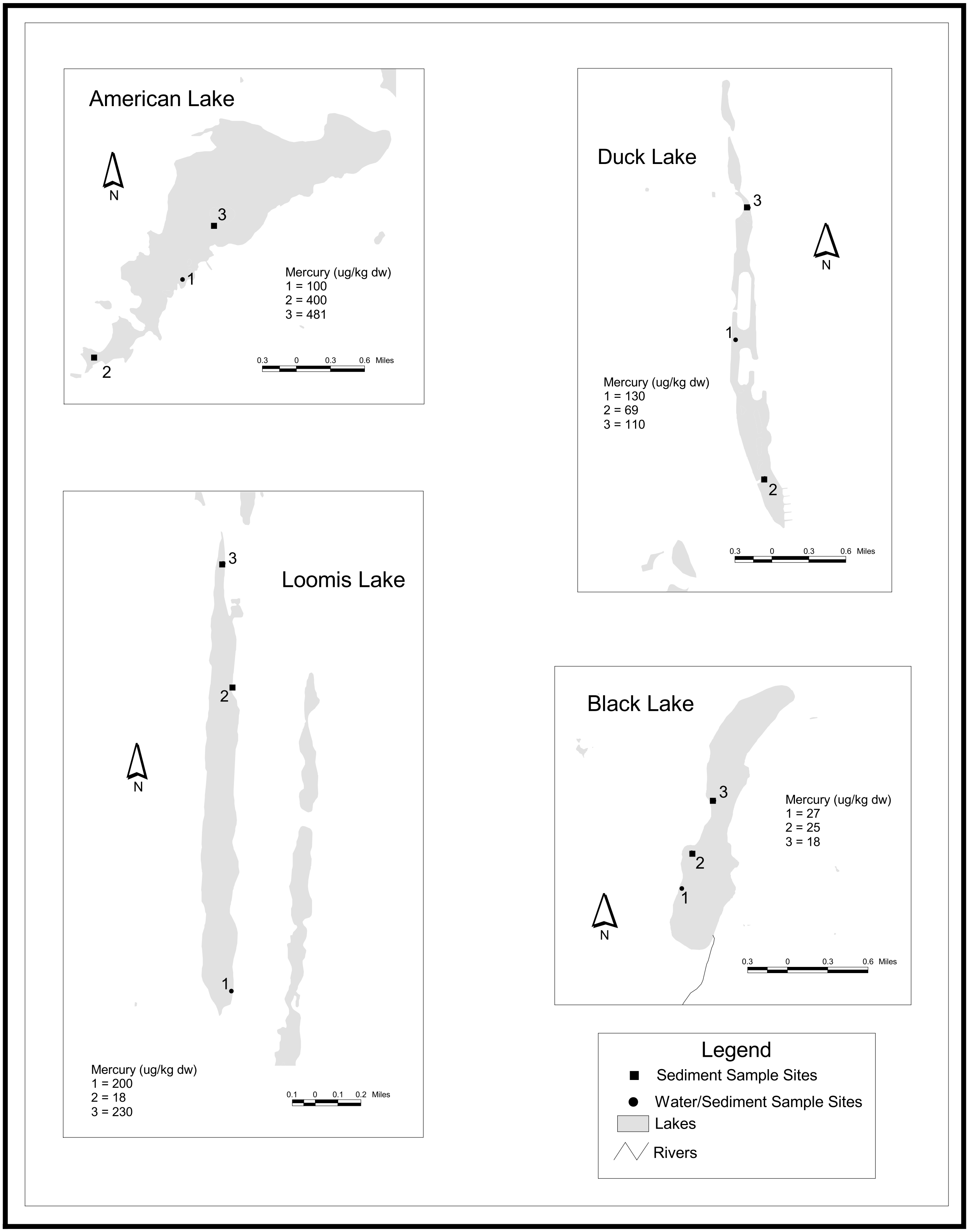

Figure A2. SW Region Water and Sediment Sampling Sites

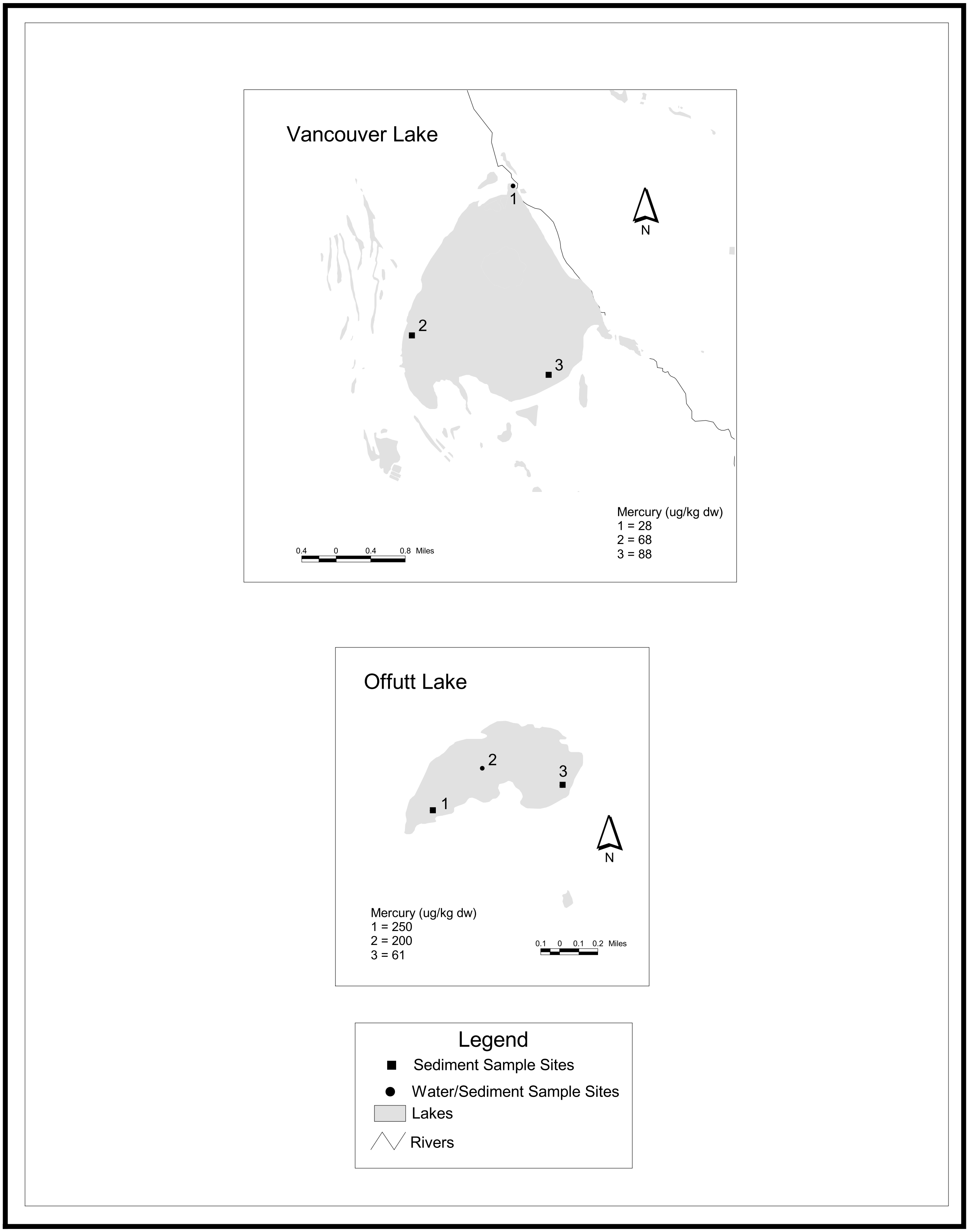

Figure A3. SW Region Water and Sediment Sampling Sites

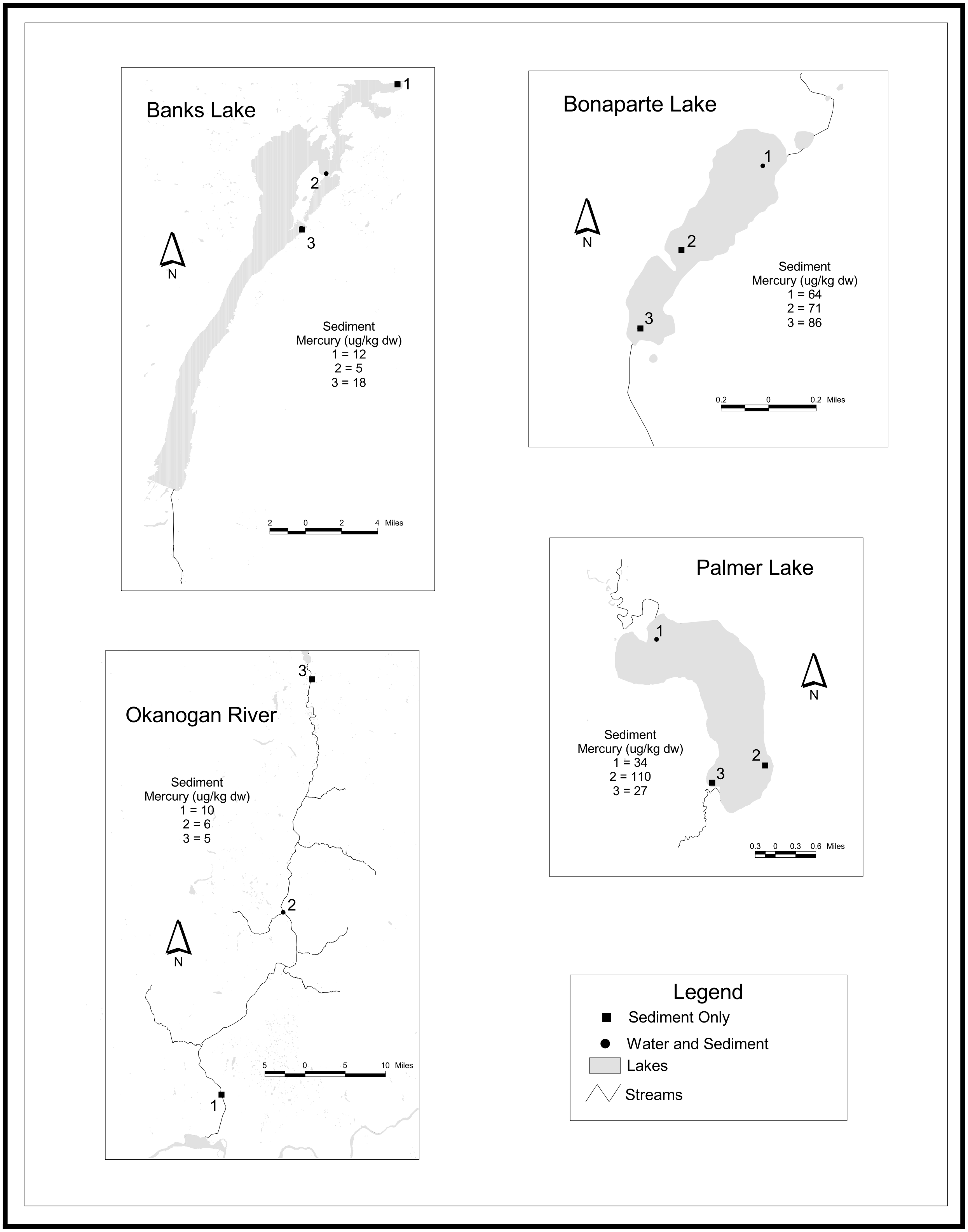

Figure A4. Central Region Water and Sediment Sampling Sites

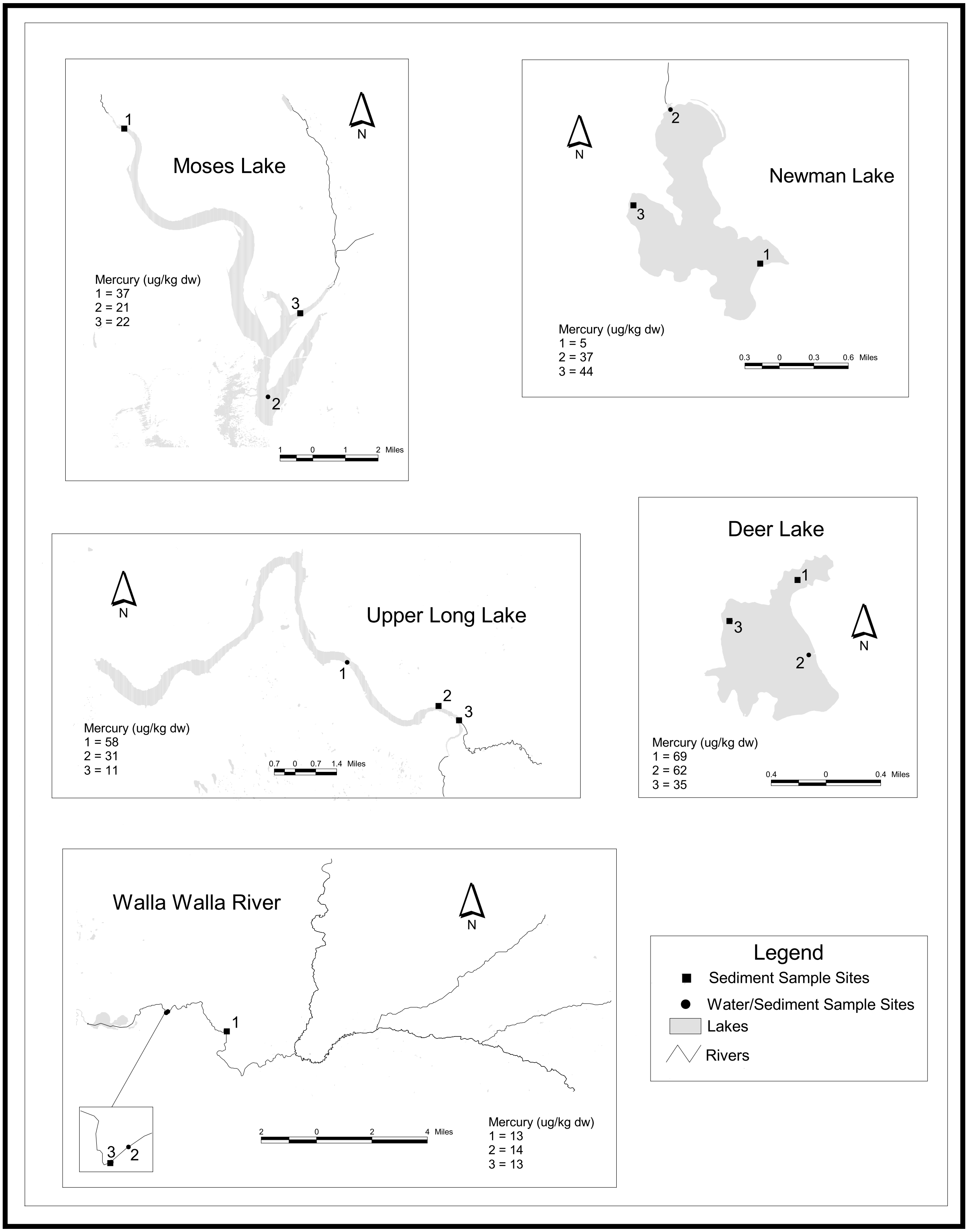

Figure A5. Eastern Region Water and Sediment Sampling Sites

Appendix B.

Quality Assurance Data

Fish Tissue Analyses for Mercury
Sediment Analyses for Mercury
Method and Rinsate Blanks
Water Quality Measurements
TOC and Lipids Analyses

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Fish Tissue Analyses for Mercury

Tissue Holding Times

Approximately 43% of fish tissue samples were analyzed within the 28-day holding time for mercury recommended by EPA (EPA 1995), with actual holding times ranging from 14 to 330 days, with a mean of 68 days. The EPA 28-day holding time for mercury is based on the volatile nature of mercury in unfrozen water samples and does not apply to frozen tissue samples. An unpublished WDFW study found no significant change for mercury in frozen fish tissue over a four- to 86-day period.

Precision

Overall precision for mercury analysis of tissue samples was assessed through the analysis of field duplicate samples, which were collected at a frequency of 8%, exceeding the project goal of 5%. The average relative percent difference (RPD) was 10% for field duplicate samples, with a RPD range of 1 to 59% (Table B1). One field duplicate RPD value of 59% (samples 88444 and 88535 for Samish14) exceeded the laboratory and project limit of ± 20%. Two other RPD values for field duplicate samples analyzed on the same date were within acceptable limits of ± 20% (8 and 19%), and data were not qualified. All other project RPD results for mercury analysis in field duplicate tissue samples were within acceptable laboratory limits of ± 20%, indicating an acceptable overall precision for sample collection and analysis.

Method precision in fish tissue was assessed through the analysis of analytical matrix spike duplicates, which were processed at a frequency of 8%, meeting the project goal of 5%. The average RPD for matrix spike duplicates was 6%, with a range of 0 to 20%. All matrix spike RPD values for analysis of mercury in tissue met the project limit of ± 20%.

Analytical precision for mercury in fish tissue was assessed through the analysis of lab duplicate samples, which were processed at a frequency of just under 6%, meeting the project goal of 5%. The average RPD for lab duplicate samples was 10%, with a range of 0 to 44% (Table B2). Two lab duplicate RPD values of 44% and 37% (samples 88536 for Terrell13 and 178115 for Om28) exceeded the laboratory and project limit of ± 20%. However, results from duplicate spiked samples were acceptable, and data were not qualified. All other project RPD results for laboratory duplicates were within acceptable laboratory limits of ± 20%, indicating an acceptable level of analytical precision.

Accuracy

Method accuracy and matrix interference were assessed through the use of analytical matrix spike recoveries, which were processed at a frequency of 8.6%, exceeding the project goal of 5%. The average recovery was 92%, with a range of 75 to 150% (Table B1). Matrix spike duplicate mercury results for Duck Lake (samples 428465 LMX1 and 428465 LMX2) exceeded the laboratory recovery goal of ± 25%. Mercury results for tissue samples from Duck Lake fish were qualified as estimates. All other recovery values met laboratory and project limits.

Method Bias

Analysis of a standard reference material (dogfish muscle) was used to estimate method bias for analysis of mercury in tissue. Reference material samples were processed at a rate of 7%, exceeding the project goal of 5%. The average recovery was 99.9%, with a range of 85 to 114% (Table B3). Results for one sample (M2322BG4, for American Lake samples) exceeded the project limit of ± 10%, possibly the result of a non-homogenous matrix, as it is difficult to obtain a truly homogenous mix with fish tissue. Results for laboratory fortified blanks were well within acceptable limits, and American Lake data were not qualified. Recoveries of mercury from standard reference material for all other samples were within the project limit of ± 10%.

Sediment Analyses for Mercury

All sediment samples were analyzed within the 28-day holding time for mercury recommended by EPA (EPA 1995), with actual holding times of sediment samples ranging from 7 to 24 days, with a mean of 16 days.

Overall precision was assessed through the analysis of field duplicate samples, which were collected at a frequency of 5%, meeting the project goal of 5%. The average relative percent difference (RPD) was 2% for field duplicate samples, with a RPD range of 0 to 5% (Table B4). Overall precision for sediment sampling and analysis was high.

Method and analytical precision of mercury in sediment was assessed through the analysis of analytical matrix spike duplicates, which were processed at a frequency of 10%, exceeding the project goal of 5% (Table B4). The average RPD for matrix spike duplicates was 2%, with a range of 1 to 4%. All matrix spike RPD values for analysis of mercury in sediment met the project limit of ± 20%, indicating a high level of method precision and analytical precision.

Method accuracy and matrix interference were assessed through the use of analytical matrix spike recoveries, which were processed at a frequency of 10%, exceeding the project goal of 5%. The average recovery was 95%, ranging from of 90 to 104% (Table B4), indicating a high level of method accuracy, free of any significant matrix interference.

Analysis of standard reference material (NIST SRM 2709) was used to estimate method bias for the analysis of mercury in sediment. Reference material samples were processed at a rate of 5%, meeting the project goal of 5% (Table B4). The average recovery of mercury from SRM 2709 was 96%, ranging from 92 to 101%, meeting the project goal for method bias of ± 10%.

Method and Rinsate Blanks

Rinsate field blanks were used to verify that mercury contamination was not introduced from sampling equipment or as a result of sampling methods. Rinsate blanks were collected at a frequency of 6%, exceeding the project goal of 5%. No analytically significant levels of mercury were detected in rinsate blanks associated with equipment used to collect and process tissue or sediment samples (Table B2), indicating that outside contamination from sampling equipment and methods is not an issue for these data.

Water Quality Measurements

Water Analyses for Alkalinity and Hardness

One alkalinity sample from Moses Lake (438467, Moses2) was analyzed outside of its holding time, and the result was qualified as an estimate. All other alkalinity analyses were performed within established EPA holding times. All QC data for alkalinity and hardness analyses were within acceptable laboratory and project limits, and these data can be used without qualification.

Field Measurements

Hydrolab instrument arrays were calibrated prior to each week's use, using commercial standard solutions, then rechecked for calibration at the end of each sampling period. Only successfully calibrated Hydrolabs were used in the field. Differences obtained between pre-sampling and post-sampling calibration readings were within project limits. Water quality measurements can be used without qualification.

TOC and Lipid Analyses

Lab duplicate and field duplicate results obtained for lipids had high RPD values averaging 40% and 28%, respectively (Table B6). These high RPD values may have resulted from the non-homogenous nature of tissue samples. Data are usable as reported.

Lab duplicate results obtained for TOC analyses were excellent (2.4%), meeting the project goal of 10% (Table B7). The average RPD for field duplicates was higher (20%), exceeding the project goal of 10%. These elevated RPD values may be due to the non-homogenous nature of sediment samples. Recovery of TOC from lab fortified blanks was excellent, averaging 95%. TOC data can be used without qualification.

Table B1. Tissue Matrix Spikes and Field Duplicates for Mercury

Analytical Matrix Spikes

Sample No.	Recovery	RPD
408413 LMX1	75%	20%
408413 LMX2	92%	
428465 LMX1	150%	17%
428465 LMX2	126%	
448506 LMX1	86%	0%
448506 LMX2	86%	
448510 LMX1	83%	2%
448510 LMX2	85%	
458526 LMX1	99%	3%
458526 LMX2	96%	
458535 LMX1	98%	4%
458535 LMX2	102%	
468548 LMX1	84%	0%
468548 LMX2	84%	
468567 LMX1	104%	9%
468567 LMX2	95%	
78530 LMX1	75%	1%
78530 LMX2	76%	
78532 LMX1	80%	6%
78532 LMX2	85%	
88491 LMX1	82%	0%
88491 LMX2	82%	
88536 LMX1	120%	0%
88536 LMX2	120%	
88535 LMX1	95%	18%
88535 LMX2	79%	
98537 LMX1	98%	9%
98537 LMX2	90%	
178105 LMX1	84%	1%
178105 LMX2	83%	
178125 LMX1	84%	1%
178125 LMX2	83%	
Mean:	92%	6%

Field Duplicates

Sample No.	Result (µg/Kg ww)	RPD
178105	312	2%
178115	307	
428462	736	11%
428465	656	
448479	460	3%
448486	476	
448487	269	3%
448498	277	
448516	181	9%
448520	166	
458535	317	3%
458542	308	
468553	754	1%
468554	763	
468563	484	11%
468564	541	
78411	126	19%
78531	153	
78419	210	8%
78532	194	
88436	73.6	1%
88534	74.7	
88444	214	59%
88535	392 J	
98464	720	4%
88538	690	
88456	115	20%
88536	93.9	
98462	760	2%
98537	775	
	Mean:	10%

Table B2. Tissue Lab Duplicates and Rinsate Field Blanks

Lab Duplicates

Sample No.	Result (µg/Kg ww)	RPD
78530	37.3	4%
78530	35.9	
78531	153	1%
78531	155	
78532	194	9%
78532	213	
78533	162	1%
78533	161	
88535	392	0%
88535	392	
88536	93.9	44%
88536	147	
88538	690	12%
88538	775	
98537	775	0%
98537	775	
98539	62.8	2%
98539	64	
178115	307	37%
178115	211	
458536	64.1	2%
458536	65.7	
	Mean:	10%

Rinsate Field Blanks

Sample No.	Result (µg/L)	Units
388241	0.03	ppb
408409	0.03 U	ppb
408420	0.03 U	ppb
418436	0.03 U	ppb
448485	0.03 U	ppb
448497	0.03 U	ppb
448521	0.03 U	ppb
458543	0.03 U	ppb
468555	0.03 U	ppb
468560	0.03 U	ppb
468565	0.03 U	ppb

U = analyte not detected at detection limit shown

Analytical Matrix Spikes in Field Blanks

Sample No.	Recovery	RPD
388241 LMX1	103%	4%
388241 LMX2	107%	
418438 LMX1	101%	4%
418438 LMX2	96.8%	
468565 LMX1	102%	0%
468565 LMX2	102%	
Mean:	102%	3%

Laboratory Fortified Blanks

Sample No.	Recovery
M2280WDL1	102%
M2280WDB1	102%
M2296BG1	98%
M2309BG1	102%
M2309BG2	103%
M2309BG5	102%
M2316BG5	101%
M2317WDL2	99%
M2317WDL3	96%
M2322BG1	101%
M2322BG3	97%
M2331DL5	96%
Mean:	99.8%

Fortified Blanks on Field Blanks

Sample No.	Recovery
M2284WG1	105%
M2203WG1	99.5%
M2323WG1	99.6%
Mean:	101%

Table B3. Standard Reference Materials for Mercury

Analysis of Dogfish Muscle (DORM)

Sample No.	Recovery	Sample No.	Recovery
M2296BG2	96.9%	M2051BG1	95%
M2309BG3	106%	M2065BG1	88%
M2309BG4	98.6%	M2065BG2	105%
M2309BG6	103%	M2072BG2	101%
M2316BG6	110%	M2133BG1	87%
M2322BG2	109%	M2092BG1	85%
M2322BG4	114%		
		Mean:	99%

Analysis of Sediment
Standard Reference Material
(NIST SRM 2709)

Sample No.	Recovery
M2280SG3	99%
M2303SG5	93%
M2308SL2	101%
M2323SG2	92%
M2336SG4	98%
Mean:	96%

Table B4. Sediment Matrix Spikes and Field Duplicates

Analytical Matrix Spikes

Sample No.	Recovery	RPD
388249 LMX1	95%	1%
388249 LMX2	94%	
408402 LMX1	97%	2%
408402 LMX2	99%	
418498 LMX1	103%	1%
418498 LMX2	104%	
438474 LMX1	90%	3%
438474 LMX2	93%	
468559 LMX1	96%	1%
468559 LMX2	95%	
488570 LMX1	87%	4%
488570 LMX2	90%	
Mean:	95%	2%

Field Duplicates

Sample No.	Result (µg/Kg dw)	RPD
388242	58	5%
388249	61	
418434	110	0%
418435	110	
438468	21	0%
438470	21	
	Mean:	2%

Laboratory Fortified Blanks

Sample No.	Recovery
M2277SG2	96%
M2280SG2	100%
M2303SG4	103%
M2308SL1	100%
M2323SG1	103%
M2336SG3	93%
Mean:	99%

Table B5. Hardness and Alkalinity QC Data

Hardness Analytical Matrix Spikes

Sample No.	Recovery	RPD
388229	98%	2%
388229	99%	
Mean:	99%	

Hardness Field Duplicates

Sample No.	Result (mg/L)	RPD
388250	86.5	0%
388251	86.5	
Mean:	86.5	

Hardness Fortified Blanks (Lab LCS)

Sample No.	Recovery
M2280WDL1	102%
M2317WDL2	99%
M2317WDL3	96%
M2331DL5	96%
Mean:	98%

Alkalinity Fortified Blanks (Lab LCS)

Sample No.	Recovery
GLC2273ALK1	102%
GLC2273ALK2	103%
GLC2266ALK1	96%
GLC2266ALK2	102%
GLC2280ALK3	96%
GLC2280ALK4	103%
GLC2282ALK1	98%
GLC2282ALK2	101%
GLC2291ALK1	97%
GLC2291ALK2	103%
GLC2301ALK1	96%
GLC2301ALK2	100%
GLC2309ALK1	95%
GLC2309ALK2	101%
GLC2323ALK1	101%
GLC2323ALK2	101%
GLC2346ALK1	93%
GLC2346ALK2	101%
Mean:	99%

Alkalinity Lab Duplicates

Sample No.	Result (mg/L)	RPD
2468557	45	0%
2468557	45	
388248	15	0%
388248	15	
398231	56.4	0.2%
398231	56.5	
408401	38	3%
408401	37	
418438	40	0%
418438	40	
428442	48	2%
428442	49	
	Mean:	0.8%

Alkalinity Field Duplicates

Sample No.	Result (mg/L)	RPD
388250	79.9	1%
388251	79.5	
Mean:	79.7	

Table B6. QC Results for Lipids Analysis

Lab Duplicates for Lipids Analysis

Sample No.	Result (% Lipids)	RPD
418421	1.9	34%
418421 LDP1	1.35	
448483	0.53	62%
448483 LDP1	0.28	
448487	0.76	84%
448487 LDP1	0.31	
448510	1.12	7%
448510 LDP1	1.2	
458535	0.59	43%
458535 LDP1	0.91	
468561	8.09	15%
468561 LDP1	6.98	
468567	1.52	36%
468567 LDP1	1.06	
	Mean:	40%

Field Duplicates for Lipids Analysis

Sample No.	Result (% Lipids)	RPD
428462	0.50	17%
428465	0.42	
448479	0.85	19%
448486	0.70	
448487	0.76	67%
448498	0.38	
448516	1.01	26%
448520	0.78	
458535	0.59	25%
458542	0.46	
468553	0.57	29%
468554	0.76	
468563	8.09	12%
468564	7.17	
	Mean:	28%

Table B7. QC Results for TOC Analysis

Lab Duplicates for TOC Analysis

Sample No.	Result (% TOC)	RPD
388238 LDP1	1.25	3%
388238 LDP2	1.29	
388238 LDP1	1.26	2%
388238 LDP2	1.28	
	Mean:	2.4%

Field Duplicates for TOC Analysis

Sample No.	Result (% TOC)	RPD
388242	2.58	15%
388249	3.01	
388242	2.55	27%
388249	3.33	
418434	19.8	13%
418435	17.4	
438468	3.10	25%
438470	4.00	
	Mean:	20%

Fortified Blanks (Lab LCS)

Sample No.	Recovery (%)
GLC3045TC104	97.3
GLC2045TC104	97.1
GLC3041TOC70	95.7
GLC3041TC104	96.0
GLC3055TOC70	98.1
GLC2055TC104	98.8
GLC3064TC70A	91.1
GLC3064TC70	89.1
Mean:	95.4

Appendix C.

Biological Data and Water Quality Measurements

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Table C1. Fish Data with Mercury and Lipid Concentrations from Individual Fish

Waterbody	Field ID	LAB #	Collection Date	Fish Species	Total Length (mm)	Fork Length (mm)	Fish Weight (gm)	Fish Age (yrs)	Sex	Mercury (µg/Kg ww)	Lipids (%)
Lake Terrell	Terrel16	88459	9/26/01	LMBS	297	-	433	2	F	49.7	0.72
	Terrel14	88457	9/26/01	LMBS	307	-	465	2	M	109	0.75
	Terrel15	88458	9/26/01	LMBS	297	-	396	2	F	110	0.80
	Terrel13	88456	9/26/01	LMBS	346	-	616	3	F	115	0.44
	Terrel18	98461	9/26/01	LMBS	260	-	232	2	M	124	0.31
	Terrel17	98460	9/26/01	LMBS	288	-	372	2	M	138	0.32
	Terrel12	88455	9/26/01	LMBS	420	-	1307	6	U	156	1.10
	Terrel10	88453	9/26/01	LMBS	430	-	1288	6	F	248	1.28
	Terrel11	88454	9/26/01	LMBS	430	-	1362	5	F	241	1.44
	Terrel09	88452	9/26/01	LMBS	431	-	1313	13	U	332	0.36
				Median	327		541	2.5		131	0.74
				Mean	351		778	4.3		162	0.75
				Std. Dv.	70		474	3.5		85	0.41
Fazon Lake	Fazon10	88471	9/26/01	LMBS	354	-	671	6	F	192	0.44
	Fazon08	88469	9/26/01	LMBS	376	-	656	7	M	197	0.48
	Fazon09	88470	9/26/01	LMBS	362	-	590	5	F	321	0.46
	Fazon06	88467	9/26/01	LMBS	386	-	820	7	F	337	0.52
	Fazon07	88468	9/26/01	LMBS	380	-	779	7	M	364	0.53
	Fazon04	88465	9/26/01	LMBS	472	-	1632	8	F	456	0.63
	Fazon05	88466	9/26/01	LMBS	418	-	1088	8	M	480	0.48
	Fazon02	98463	9/26/01	LMBS	557	-	3310	14	F	645	1.26
	Fazon03	98464	9/26/01	LMBS	513	-	1783	10	F	720	1.14
	Fazon01	98462	9/26/01	LMBS	575	-	3747	17	F	760	1.10
				Median	402		954	7.5		410	0.53
				Mean	439		1508	8.9		447	0.70
				Std. Dv.	84		1145	3.8		204	0.33

Table C1. Fish Data with Mercury and Lipid Concentrations from Individual Fish

Waterbody	Field ID	LAB #	Collection Date	Fish Species	Total Length (mm)	Fork Length (mm)	Fish Weight (gm)	Fish Age (yrs)	Sex	Mercury (µg/Kg ww)		Lipids (%)
Samish Lake	Samish20	88450	9/10/01	LMBS	328	-	522	3	F	90.3		0.45
	Samish21	88451	9/12/01	LMBS	255	-	270	3	M	91.2		0.75
	Samish19	88449	9/10/01	LMBS	330	-	626	3	F	158		0.67
	Samish15	88445	9/12/01	LMBS	390	-	992	5	M	183		1.40
	Samish14	88444	9/12/01	LMBS	410	-	1061	5	F	214	J	0.89
	Samish16	88446	9/12/01	LMBS	384	-	936	4	F	296		1.82
	Samish17	88447	9/12/01	LMBS	381	-	903	4	F	297		2.11
	Samish18	88448	9/12/01	LMBS	378	-	820	5	M	325		0.53
	Samish12	88442	9/12/01	LMBS	466	-	1513	9	M	374		1.06
	Samish13	88443	9/10/01	LMBS	446	-	1440	10	F	1280		2.59
				Median	383		920	4.5		255		0.98
				Mean	377		908	5.1		331		1.23
				Std. Dv.	61		383	2.5		347		0.73
Kitsap Lake	Kitsap05	468548	10/31/02	LMBS	355	343	780	3	F	147		1.18
	Kitsap08	468551	10/31/02	LMBS	321	310	547	2	F	155		0.43
	Kitsap07	468550	10/31/02	LMBS	355	345	857	3	M	164		0.44
	Kitsap09	468552	10/31/02	LMBS	310	300	473	2	M	185		0.66
	Kitsap03	468546	10/31/02	LMBS	376	365	1004	3	M	242		1.71
	Kitsap04	468547	10/31/02	LMBS	380	372	1123	3	F	264		2.38
	Kitsap02	468545	10/31/02	LMBS	362	350	971	3	M	342		0.81
	Kitsap06	468549	10/31/02	LMBS	410	398	1236	3	F	366		0.48
	Kitsap01	468544	10/31/02	LMBS	431	420	1563	7	M	511		0.93
	Kitsap10	468553	10/31/02	LMBS	495	466	2716	12	M	754		0.57
				Median	369	358	988	3.0		253		0.74
				Mean	380	367	1127	4.1		313		0.96
				Std. Dv.	54	50	643	3.1		193		0.64

Table C1. Fish Data with Mercury and Lipid Concentrations from Individual Fish

Waterbody	Field ID	LAB #	Collection Date	Fish Species	Total Length (mm)	Fork Length (mm)	Fish Weight (gm)	Fish Age (yrs)	Sex	Mercury (µg/Kg ww)	Lipids (%)
Meridian Lake	Merid03	78418	12/5/01	LMBS	322	309	538	2	F	167	0.37
	Merid01	78416	12/5/01	LMBS	314	302	446	2	F	174	0.53
	Merid05	78420	12/5/01	LMBS	315	302	442	2	F	199	0.49
	Merid06	78421	12/5/01	LMBS	344	330	604	3	M	200	0.44
	Merid04	78419	12/5/01	LMBS	317	306	446	2	M	210	0.47
	Merid02	78417	12/5/01	LMBS	330	320	597	2	F	248	0.38
	Merid08	78423	12/5/01	LMBS	493	473	2238	7	F	332	1.22
	Merid07	78422	12/5/01	LMBS	458	443	1645	9	M	645	0.25
				Median	326	315	568	2.0		205	0.46
				Mean	362	348	870	3.6		272	0.52
				Std. Dv.	72	69	684	2.8		160	0.30
American Lake	Amer4	468569	7/30/02	SMBS	416	-	1331	4	M	253	0.57
	Amer3	468568	7/30/02	LMBS	445	-	1863	5	F	343	1.26
	Amer2	468567	7/30/02	LMBS	441	-	1796	5	F	345	1.52
	Amer1	468566	7/30/02	LMBS	416	-	1377	7	F	673	0.23
				Median	429		1587	5.0		344	1
				Mean	343		1418	4.2		275	1
				Std. Dv.	16	-	277	1.3		185	0.60
Black Lake	Black08	418428	10/7/02	LMBS	265	260	352	1	M	113	1.30
	Black05	418425	10/7/02	LMBS	265	260	321	1	M	120	0.67
	Black10	418430	10/7/02	LMBS	250	245	292	1	M	128	0.89
	Black06	418426	10/7/02	LMBS	250	245	249	1	F	131	1.63
	Black09	418429	10/7/02	LMBS	275	274	337	1	M	131	1.18
	Black07	418427	10/7/02	LMBS	265	260	285	1	F	138	1.53
	Black04	418424	10/7/02	LMBS	275	270	357	1	M	142	1.48
	Black03	418423	10/7/02	LMBS	345	340	790	2	M	209	0.57
	Black02	418422	10/7/02	LMBS	495	485	2750	7	F	636	1.32
	Black01	418421	10/7/02	LMBS	530	515	3405	9	F	792	1.90
				Median	270	265	345	1.0		135	1.31
				Mean	322	315	914	2.5		254	1.25
				Std. Dv.	104	101	1161	3.0		247	0.43

Table C1. Fish Data with Mercury and Lipid Concentrations from Individual Fish

Waterbody	Field ID	LAB #	Collection Date	Fish Species	Total Length (mm)	Fork Length (mm)	Fish Weight (gm)	Fish Age (yrs)	Sex	Mercury (µg/Kg ww)		Lipids (%)
Offut Lake	Offut06	88437	12/26/01	LMBS	220	212	143	1	M	46.5		0.96
	Offut10	88441	12/26/01	LMBS	191	184	86	1	F	65.1		0.80
	Offut05	88436	12/26/01	LMBS	226	218	157	1	M	73.6		0.89
	Offut07	88438	12/26/01	LMBS	215	208	118	1	F	76		0.68
	Offut09	88440	12/26/01	LMBS	205	198	108	1	M	78.4		0.80
	Offut08	88439	12/26/01	LMBS	218	210	141	1	F	81.3		0.57
	Offut02	78433	12/26/01	LMBS	225	218	152	1	M	85.6		0.30
	Offut03	78434	12/26/01	LMBS	228	220	155	1	M	86.8		0.31
	Offut04	78435	12/26/01	LMBS	223	215	143	1	M	93		0.55
	Offut01	78432	12/26/01	LMBS	255	247	229	1	M	112		0.96
				Median	222	214	143	1.0		80		0.74
				Mean	221	213	143	1.0		80		0.68
				Std. Dv.	17	16	38	0.0		17		0.24
Duck Lake	Duck03	428457	10/10/02	LMBS	295	290	403	5	M	84.7	J	0.84
	Duck05	428459	10/10/02	LMBS	310	305	514	4	F	114	J	0.72
	Duck02	428456	10/10/02	LMBS	310	305	475	3	F	115	J	0.69
	Duck09	428463	10/10/02	LMBS	355	345	775	5	M	155	J	0.95
	Duck07	428461	10/10/02	LMBS	365	360	915	5	M	181	J	1.28
	Duck06	428460	10/10/02	LMBS	405	390	1195	8	F	208	J	1.29
	Duck04	428458	10/10/02	LMBS	390	385	1197	8	F	259	J	0.90
	Duck10	428464	10/10/02	LMBS	400	390	1427	7	M	286	J	1.75
	Duck01	428455	10/10/02	LMBS	410	405	1242	8	M	336	J	0.73
	Duck08	428462	10/10/02	LMBS	430	420	1461	9	F	736	J	0.50
				Median	378	373	1055	6.0		195		0.87
				Mean	367	360	960	6.2		247		0.97
				Std. Dv.	48	46	400	2.0		190		0.37

Table C1. Fish Data with Mercury and Lipid Concentrations from Individual Fish

Waterbody	Field ID	LAB #	Collection Date	Fish Species	Total Length (mm)	Fork Length (mm)	Fish Weight (gm)	Fish Age (yrs)	Sex	Mercury (µg/Kg ww)		Lipids (%)
Loomis Lake	Loomis07	448481	10/11/02	LMBS	370	365	974	4	M	202		0.38
	Loomis06	448480	10/11/02	LMBS	320	310	519	3	M	234		0.31
	Loomis10	448484	10/11/02	LMBS	330	325	566	3	M	272		0.27
	Loomis08	448482	10/11/02	LMBS	330	320	564	3	M	275		0.56
	Loomis02	448476	10/11/02	LMBS	330	325	616	3	F	287		1.36
	Loomis04	448478	10/11/02	LMBS	375	370	938	5	M	292		0.38
	Loomis01	448475	10/11/02	LMBS	365	355	832	4	F	322		0.35
	Loomis09	448483	10/11/02	LMBS	360	350	767	4	F	374		0.53
	Loomis03	448477	10/11/02	LMBS	370	360	809	5	F	390		0.36
	Loomis05	448479	10/11/02	LMBS	385	380	1029	5	F	460		0.85
				Median	363	353	788	4.0		290		0.38
				Mean	354	346	761	3.9		311		0.54
				Std. Dv.	23	24	186	0.9		78		0.34
Vancouver Lake	Vancouv 3	408412	10/3/02	LMBS	260	252	300	1	F	46.9		0.47
	Vancouv 1	408410	10/3/02	LMBS	269	265	360	1	M	55.3		0.41
	Vancouv 2	408411	10/3/02	LMBS	282	270	371	1	M	60.9		0.50
	Vancouv 4	408413	10/3/02	LMBS	270	265	338	1	M	61.8		0.62
	Vancouv 5	408414	10/3/02	LMBS	285	280	412	1	M	87.9		0.40
	Vancouv 7	408416	10/3/02	LMBS	260	253	324	1	M	89.2		0.38
	Vancouv 8	408417	10/3/02	LMBS	265	260	310	1	M	91.3		0.55
	Vancouv 6	408415	10/3/02	LMBS	290	280	423	2	F	91.4		0.64
	Vancouv 9	408418	10/3/02	LMBS	470	455	2013	7	M	476		0.59
	Vancouv 10	408419	10/3/02	LMBS	405	390	1405	7	M	540		0.35
				Median	276	268	366	1.0		89		0.49
				Mean	306	297	626	2.3		160		0.49
				Std. Dv.	72	69	590	2.5		185		0.11

Table C1. Fish Data with Mercury and Lipid Concentrations from Individual Fish

Waterbody	Field ID	LAB #	Collection Date	Fish Species	Total Length (mm)	Fork Length (mm)	Fish Weight (gm)	Fish Age (yrs)	Sex	Mercury (µg/Kg ww)	Lipids (%)
Palmer Lake	Palmer06	448505	10/15/02	LMBS	285	275	381	2	M	78.3	0.61
	Palmer07	448506	10/15/02	LMBS	275	265	343	2	M	110	0.56
	Palmer09	448508	10/15/02	LMBS	285	280	251	1	M	117	0.70
	Palmer02	448501	10/15/02	LMBS	335	330	661	3	M	120	0.38
	Palmer08	448507	10/15/02	LMBS	290	280	381	2	M	122	0.86
	Palmer10	448509	10/15/02	LMBS	290	285	345	2	F	126	1.00
	Palmer03	448502	10/15/02	LMBS	295	290	406	2	M	134	0.49
	Palmer04	448503	10/15/02	LMBS	300	295	453	2	M	134	0.47
	Palmer05	448504	10/15/02	LMBS	310	305	502	2	M	134	0.57
	Palmer01	448500	10/15/02	LMBS	400	395	1193	5	M	250	0.60
				Median	293	288	394	2.0		124	0.59
				Mean	307	300	492	2.3		133	0.62
				Std. Dv.	37	38	270	1.1		44	0.19
Bonaparte Lake	Bona02	468562	10/16/02	LMBS	470	460	2801	11	F	425	7.10
	Bona01	468561	10/16/02	LMBS	450	440	2681	12	F	443	7.54
	Bona03	468563	11/6/02	LMBS	442	430	2000	12	F	484	7.63
				Median	450	440	2681	12.0		443	7.54
				Mean	319	313	1917	8.0		304	4.94
				Std. Dv.	14	15	432	0.6		30	0.30
Okanogan River nr Omak	OM-44	8111	11/6/01	SMBS	290	-	309	3	M	104	1.01
	OM-46	8113	11/6/01	SMBS	270	-	273	3	F	107	0.76
	OM-48	8114	11/6/01	SMBS	260	-	218	2	M	121	1.06
	OM-42	8112	11/6/01	SMBS	288	-	303	3	U	125	0.93
	OM-29	8108	9/17/01	SMBS	315	-	412	3	F	127	0.81
	OM-41	8109	11/6/01	SMBS	308	-	388	3	M	132	0.88
	OM-30	8110	9/17/01	SMBS	296	-	332	3	M	133	0.60
	OM-40	8107	11/6/01	SMBS	360	-	641	4	F	133	1.04
	OM-39	8106	11/6/01	SMBS	421	-	1102	7	F	217	1.80
	OM-28	8105	9/17/01	SMBS	433	-	1330	6	F	312	2.36
				Median	302		360	3.0		130	0.97
				Mean	324		531	3.7		151	1.13
				Std. Dv.	61		382	1.6		65	0.54

Table C1. Fish Data with Mercury and Lipid Concentrations from Individual Fish

Waterbody	Field ID	LAB #	Collection Date	Fish Species	Total Length (mm)	Fork Length (mm)	Fish Weight (gm)	Fish Age (yrs)	Sex	Mercury (µg/Kg ww)	Lipids (%)
Banks Lake	Banks06	78406	11/7/01	LMBS	348	340	671	3	F	70	0.71
	Banks09	78409	11/7/01	LMBS	307	292	456	2	M	77.2	0.84
	Banks07	78407	11/7/01	LMBS	345	330	677	4	M	78.4	0.43
	Banks10	78410	11/7/01	LMBS	293	285	430	2	M	82.8	0.81
	Banks08	78408	11/7/01	LMBS	334	320	701	3	M	115	0.81
	Banks02	78412	11/7/01	LMBS	371	355	807	4	M	120	0.40
	Banks05	78415	11/7/01	LMBS	354	342	709	4	M	120	0.42
	Banks01	78411	11/7/01	LMBS	364	350	764	4	M	126	0.53
	Banks04	78414	11/7/01	LMBS	384	362	887	5	F	165	0.99
	Banks03	78413	11/7/01	LMBS	406	387	1242	5	F	183	0.67
				Median	351	341	705	4.0		118	0.69
				Mean	351	336	734	3.6		114	0.66
				Std. Dv.	34	31	228	1.1		38	0.21
Deer Lake	Deer10	458531	10/24/02	LMBS	369	360	832	4	F	239	0.55
	Deer05	458526	10/24/02	LMBS	390	380	1078	5	F	249	0.98
	Deer04	458525	10/24/02	LMBS	364	354	814	4	F	266	1.42
	Deer08	458529	10/24/02	LMBS	368	359	880	5	M	289	0.66
	Deer09	458530	10/24/02	LMBS	382	376	960	5	F	307	0.56
	Deer02	458523	10/24/02	LMBS	370	360	906	5	F	326	0.89
	Deer07	458528	10/24/02	LMBS	406	400	1109	6	F	370	1.28
	Deer06	458527	10/24/02	LMBS	368	360	774	5	M	399	0.34
	Deer01	458522	10/24/02	LMBS	400	390	1090	6	M	402	0.77
	Deer03	458524	10/24/02	LMBS	418	402	1203	8	M	462	0.98
				Median	376	368	933	5.0		317	0.83
				Mean	384	374	965	5.3		331	0.84
				Std. Dv.	19	18	147	1.2		75	0.34

Table C1. Fish Data with Mercury and Lipid Concentrations from Individual Fish

Waterbody	Field ID	LAB #	Collection Date	Fish Species	Total Length (mm)	Fork Length (mm)	Fish Weight (gm)	Fish Age (yrs)	Sex	Mercury (µg/Kg ww)	Lipids (%)
Upper Long Lake (Section 6)	ULL-50 c	8125	6/18/01	LMBS	312	-	436	3	M	22	0.19
	ULL-52 c	8124	6/18/01	LMBS	330	-	514	3	M	27	0.21
	ULL-45 c	8118	6/18/01	LMBS	428	-	1406	9	M	61.8	0.93
	ULL-43 c	8117	6/18/01	LMBS	434	-	1264	7	F	66.5	0.69
	ULL-46 c	8121	6/18/01	LMBS	392	-	832	6	F	69	0.61
	ULL-54 c	8119	6/19/01	LMBS	425	-	1088	7	M	84	0.99
	ULL-53 c	8120	6/19/01	LMBS	414	-	908	6	F	91.5	0.40
	ULL-48 c	8123	6/18/01	LMBS	382	-	936	7	M	116	1.01
	ULL-56 c	8122	6/19/01	LMBS	392	-	852	6	F	167	0.25
	ULL-47 c	8116	6/18/01	LMBS	441	-	1902	12	M	181	1.63
				Median	403		922	6.5		77	0.65
				Mean	395		1014	6.6		89	0.69
				Std. Dv.	44		431	2.6		53	0.46
Newman Lake	Newman06	458537	8/8/02	LMBS	238	-	197	2	M	62.2	0.30
	Newman05	458536	8/8/02	LMBS	236	-	187	2	M	64.1	0.24
	Newman07	458538	8/8/02	LMBS	241	-	198	2	F	66.5	0.35
	Newman10	458541	8/8/02	LMBS	236	-	180	2	M	67.7	0.27
	Newman09	458540	8/8/02	LMBS	246	-	206	2	M	68.1	0.29
	Newman08	458539	8/8/02	LMBS	250	-	217	2	M	68.2	0.23
	Newman02	458533	7/23/02	LMBS	236	-	166	2	F	69.1	0.21
	Newman03	458534	7/23/02	LMBS	251	-	210	2	F	83.3	0.32
	Newman04	458535	8/8/02	LMBS	437	-	1440	8	F	317	0.59
	Newman01	458532	7/23/02	LMBS	386	-	895	7	F	318	0.22
				Median	244		202	2.0		68	0.28
				Mean	276		390	3.1		118	0.30
				Std. Dv.	73		430	2.3		105	0.11

Table C1. Fish Data with Mercury and Lipid Concentrations from Individual Fish

Waterbody	Field ID	LAB #	Collection Date	Fish Species	Total Length (mm)	Fork Length (mm)	Fish Weight (gm)	Fish Age (yrs)	Sex	Mercury (µg/Kg ww)	Lipids (%)
Moses Lake	Moses06	448515	10/22/02	LMBS	322	315	699	2	M	26	0.73
	Moses04	448513	10/22/02	LMBS	355	340	738	2	M	33.3	0.77
	Moses03	448512	10/22/02	LMBS	420	411	1362	3	F	49.7	0.84
	Moses05	448514	10/22/02	LMBS	395	383	1252	4	M	61.1	1.27
	Moses10	448519	10/22/02	LMBS	440	430	1660	5	M	78.6	0.45
	Moses01	448510	10/22/02	LMBS	500	490	2413	5	F	89.9	1.12
	Moses09	448518	10/22/02	LMBS	495	480	2655	6	F	91.5	0.98
	Moses02	448511	10/22/02	LMBS	465	455	2080	5	F	105	1.77
	Moses08	448517	10/22/02	LMBS	505	490	2585	15		142	0.92
	Moses07	448516	10/22/02	LMBS	570	555	3636	11	F	181	1.01
				Median	453	443	1870	5.0		84	0.95
				Mean	447	435	1908	5.8		86	0.99
				Std. Dv.	76	74	937	4.1		48	0.36
Walla Walla River (Lower)	WWR-142	448488	9/11/02	SMBS	240	-	182	2	M	58	0.39
	WWR-69	448491	7/29/02	SMBS	313	-	412	3	M	101	0.53
	WWR-70	448493	7/29/02	SMBS	267	-	278	3	M	109	0.31
	WWR-106	448492	7/30/02	SMBS	382	-	750	4	F	189	0.24
	WWR-107	448495	7/30/02	SMBS	354	-	607	4	F	189	0.37
	WWR-137	448490	9/11/02	SMBS	370	-	708	4	M	199	1.38
	WWR-111	448489	7/31/02	SMBS	309	-	399	3	Ind	205	0.59
	WWR-120	448496	7/31/02	SMBS	358	-	677	4	M	210	0.22
	WWR-109	448494	7/31/02	SMBS	375	-	829	5	M	263	0.14
	WWR-110	448487	7/31/02	SMBS	442	-	1158	6	F	269	0.76
				Median	356		642	4.0		194	0.38
				Mean	341		600	3.8		179	0.49
				Std. Dv.	59		290	1.1		69	0.36

LMBS - Largemouth bass (*Micropterus salmoides*), SMBS - Smallmouth bass (Micropterus dolomieu)

M - male, F - female, U - undetermined

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Table C2. Analytical Results for Sediment and Water Quality Samples

Waterbody	Field ID	LAB #	Collection Date	Analysis Date	Matrix	Temperature	Dissolved Oxygen	pH	Conductivity	Secchi	Bottom Depth (Meters)	Sediment Hg (ppb)	Total Organic Carbon %
Lake Terrell	Terrell01	398238	9/24/02	10/8/02	Sediment	17.3	11.13	8.80	101	2.07	4.5	180	21.70
	Terrell02	398240	9/23/02	10/8/02	Sediment	16.8	10.38	8.79	100	2.30	6.0	190	19.60
	Terrell03	398241	9/24/02	10/8/02	Sediment	17.2	11.01	8.88	100	2.40	5.5	160	17.60
					Median	17.2	11.0	8.8	100	2.3		180	19.60
					Mean	17.1	10.8	8.8	100	2.3		177	19.63
					Std. Dv.	0.2	0.4	0.0	0	0.2		15	2.05
Fazon Lake	Fazon01	398230	9/24/02	10/8/02	Sediment	16.9	4.66	7.27	402	2.43	9.3	26	25.70
	Fazon02	398232	9/24/02	10/8/02	Sediment	16.9	3.45	7.31	401	2.75	12.0	25	23.90
	Fazon03	398233	9/24/02	10/8/02	Sediment	16.1	0.25	7.03	450	2.59	13.0	24	28.00
					Median	16.9	3.5	7.3	402	2.6		25	25.70
					Mean	16.6	2.8	7.2	418	2.6		25	25.87
					Std. Dv.	0.5	2.3	0.2	28	0.2		1	2.06
Lake Samish	Samish01	398234	9/23/02	10/8/02	Sediment	17.9	9.23	8.52	62	2.40	20.0	34	2.67
	Samish02	398236	9/24/02	10/8/02	Sediment	18.5	8.84	8.63	62	2.15	18.0	116	5.00
	Samish03	398237	9/25/02	10/8/02	Sediment	18.4	8.60	8.63	62	1.55	17.0	150	8.17
					Median	18.4	8.8	8.6	62	2.2		116	5.00
					Mean	18.2	8.9	8.6	62	2.0		100	5.28
					Std. Dv.	0.3	0.3	0.1	0	0.4		60	2.76
Kitsap Lake	Kitsap01	468556	11/13/02	11/20/02	Sediment	10.4	8.35	7.46	87	> DOW	7.0	110	19.8
	Kitsap02	468558	11/13/02	11/20/02	Sediment	10.4	8.55	7.52	88	3.40	13.0	150	12.1
	Kitsap03	468559	11/13/02	11/20/02	Sediment	10.5	8.58	7.56	87	3.20	7.0	180	8.4
					Median	10.4	8.6	7.5	87	3.3		150	12.10
					Mean	10.5	8.5	7.5	87	3.3		147	13.43
					Std. Dv.	0.0	0.1	0.1	0	0.1		35	5.82
Meridian Lake	Meridian01	408400	10/1/02	10/8/02	Sediment	16.5	9.05	7.53	89	> DOW	2.8	255	12.6
	Meridian02	408402	10/1/02	10/8/02	Sediment	13.5	7.50	10.92	96	> DOW	2.0	170	21.3
	Meridian03	408403	10/1/02	10/8/02	Sediment	14.3	7.47	10.82	95	> DOW	3.3	210	20.4
					Median	14.3	7.5	10.8	95	nd		210	20.4
					Mean	14.8	8.0	9.8	93	nd		212	18.1
					Std. Dv.	1.5	0.9	1.9	4	nd		43	4.78

> DOW = Greater than depth of water

Table C2. Analytical Results for Sediment and Water Quality Samples

Waterbody	Field ID	LAB #	Collection Date	Analysis Date	Matrix	Temperature	Dissolved Oxygen	pH	Conductivity	Secchi	Bottom Depth (Meters)	Sediment Hg (ppb)	Total Organic Carbon %
American Lake	Amer1	488570	11/26/02	12/3/02	Sediment	10.2	10.46	8.03	101	2.60	6.4	100	18.7
	Amer2	488571	11/26/02	12/3/02	Sediment	9.7	6.94	7.58	101	4.60	8.5	400	15.0
	Amer3	488572	11/26/02	12/3/02	Sediment	10.3	9.47	7.51	101	3.25	17.1	481	16.2
					Median	10.2	9.5	7.6	101	3.3		400	16.20
					Mean	10.1	9.0	7.7	101	3.5		327	16.63
					Std. Dv.	0.3	1.8	0.3	0	1.0		201	1.89
Black Lake	Black01	418496	10/7/02	10/31/02	Sediment	16.4	6.40	6.69	86	3.00	11.0	27	0.55
	Black02	418497	10/7/02	10/31/02	Sediment	16.3	6.51	6.86	86	2.50	11.0	25	0.80
	Black03	418498	10/7/02	10/31/02	Sediment	16.5	6.12	6.95	86	> DOW	10.0	18	2.65
					Median	16.4	6.4	6.9	86	2.8		25	0.80
					Mean	16.4	6.3	6.8	86	2.8		23	1.33
					Std. Dv.	0.1	0.2	0.1	0	0.4		5	1.15
Offutt Lake	Offut01	388230	9/16/02	10/8/02	Sediment	19.1	5.46	7.31	59	3.75	1.7	250	18.5
	Offut02	388231	9/16/02	10/8/02	Sediment	19.5	8.38	7.38	59	2.90	3.1	200	13.4
	Offut03	388232	9/16/02	10/8/02	Sediment	19.8	8.20	7.15	59	1.25	1.9	61	6.87
					Median	19.5	8.2	7.3	59	2.9		200	13.40
					Mean	19.5	7.3	7.3	59	2.6		170	12.92
					Std. Dv.	0.4	1.6	0.1	0	1.3		98	5.83
Duck Lake	Duck01	418431	10/9/02	10/31/02	Sediment	15.3	8.17	7.57	162	1.30	2.4	130	15.6
	Duck02	418433	10/9/02	10/31/02	Sediment	15.1	9.47	7.66	177	1.10	2.5	69	7.0
	Duck03	418434	10/9/02	10/31/02	Sediment	15.4	9.52	7.60	161	nd	-	110	19.3
					Median	15.3	9.5	7.6	162	1.2		110	15.6
					Mean	15.3	9.1	7.6	167	1.2		103	13.97
					Std. Dv.	0.1	0.8	0.0	9	0.1		31	6.31
Loomis Lake	Loomis01	418437	10/11/02	10/31/02	Sediment	14.2	9.11	7.64	165	> DOW	0.7	200	24.4
	Loomis02	418439	10/11/02	10/31/02	Sediment	15.4	9.86	7.47	170	1.20	1.5	18	1.9
	Loomis03	418440	10/11/02	10/31/02	Sediment	15.3	8.75	7.42	166	1.10	1.2	230	25.7
					Median	15.3	9.1	7.5	166	1.2		200	24.4
					Mean	14.9	9.2	7.5	167	1.2		149	17.33
					Std. Dv.	0.6	0.6	0.1	3	0.1		115	13.38

Table C2. Analytical Results for Sediment and Water Quality Samples

Waterbody	Field ID	LAB #	Collection Date	Analysis Date	Matrix	Temperature	Dissolved Oxygen	pH	Conductivity	Secchi	Bottom Depth (Meters)	Sediment Hg (ppb)	Total Organic Carbon %
Vancouver Lake	Vancouv01	408404	10/3/02	10/8/02	Sediment	14.7	8.26	7.37	129	0.25	2.8	28	1.07
	Vancouv02	408406	10/3/02	10/8/02	Sediment	13.6	10.62	8.38	130	0.25	1.7	68	1.72
	Vancouv03	408407	10/3/02	10/8/02	Sediment	13.1	10.29	8.50	131	0.25	1.1	88	1.88
					Median	13.6	10.3	8.4	130	0.3		68	1.72
					Mean	13.8	9.7	8.1	130	0.3		61	1.56
					Std. Dv.	0.8	1.3	0.6	1	0.0		31	0.43
Palmer Lake	Palmer01	428445	10/15/02	11/6/02	Sediment	13.6	8.88	7.85	222	3.50	4.4	34	1.5
	Palmer02	428447	10/15/02	11/6/02	Sediment	13.5	8.34	7.94	222	3.00	12.2	110	5.7
	Palmer03	428448	10/15/02	11/6/02	Sediment	13.7	9.28	8.23	230	3.10	8.9	27	2.8
					Median	13.6	8.9	7.9	222	3.1		34	2.80
					Mean	13.6	8.8	8.0	225	3.2		57	3.33
					Std. Dv.	0.1	0.5	0.2	5	0.3		46	2.15
Bonaparte Lake	Bona01	428451	10/16/02	11/6/02	Sediment	9.5	8.24	8.16	195	5.00	9.7	64	16.5
	Bona02	428453	10/16/02	11/6/02	Sediment	9.9	9.33	8.29	193	4.60	5.1	71	13.0
	Bona03	428454	10/16/02	11/6/02	Sediment	9.5	9.00	8.24	199	4.60	6.8	86	18.9
					Median	9.5	9.0	8.2	195	4.6		71	16.50
					Mean	9.6	8.9	8.2	196	4.7		74	16.13
					Std. Dv.	0.3	0.6	0.1	3	0.2		11	2.97
Okanogan River	Okanog01	388233	9/17/02	10/8/02	Sediment	19.6	8.72	8.09	287	3.00	3.1	10	0.34
	Okanog02	388234	9/17/02	10/8/02	Sediment	17.5	7.94	8.06	302	> DOW	2.5	6	0.10
	Okanog03	388235	9/17/02	10/8/02	Sediment	19.5	8.95	8.60	270	> DOW	1.5	5	0.13
					Median	19.5	8.7	8.1	287	nd		6	0.13
					Mean	18.9	8.5	8.3	286	nd		7	0.19
					Std. Dv.	1.2	0.5	0.3	16	nd		2	0.13
Banks Lake	Banks01	388236	9/18/02	10/8/02	Sediment	18.6	7.72	7.92	118	7.00	14.2	12	0.49
	Banks02	388237	9/18/02	10/8/02	Sediment	19.0	8.27	8.02	121	3.75	6.3	5	0.14
	Banks03	388238	9/19/02	10/8/02	Sediment	18.2	8.01	8.00	125	3.50	4.0	18	1.34
					Median	18.6	8.0	8.0	121	3.8		12	0.49
					Mean	18.6	8.0	8.0	121	4.8		12	0.66
					Std. Dv.	0.4	0.3	0.1	3	2.0		7	0.62

Table C2. Analytical Results for Sediment and Water Quality Samples

Waterbody	Field ID	LAB #	Collection Date	Analysis Date	Matrix	Temperature	Dissolved Oxygen	pH	Conductivity	Secchi	Bottom Depth (Meters)	Sediment Hg (ppb)	Total Organic Carbon %
Deer Lake	Deer01	438471	10/25/02	11/6/02	Sediment	7.4	5.01	7.50	70	6.50	-	69	4.9
	Deer02	438472	10/25/02	11/6/02	Sediment	10.3	9.76	7.71	71	7.50	10.7	62	4.9
	Deer03	438474	10/25/02	11/6/02	Sediment	10.3	9.80	7.64	69	> DOW	7.4	35	2.3
					Median	10.3	9.8	7.6	70	7.0		62	4.90
					Mean	9.3	8.2	7.6	70	7.0		55	4.03
					Std. Dv.	1.7	2.8	0.1	1	0.7		18	1.50
Upper Long Lake	Long01	388242	9/20/02	10/8/02	Sediment	18.0	8.64	8.33	173	2.00	3.8	58	2.55
	Long02	388243	9/20/02	10/8/02	Sediment	14.3	8.87	7.98	193	> DOW	0.5	31	1.54
	Long03	388244	9/20/02	10/8/02	Sediment	11.7	9.15	8.03	275	> DOW	2.0	11	2.22
					Median	14.3	8.9	8.0	193	nd		31	2.22
					Mean	14.6	8.9	8.1	213	nd		33	2.10
					Std. Dv.	3.2	0.3	0.2	54	nd		24	0.52
Newman Lake	Newman01	388245	9/19/02	10/8/02	Sediment	19.2	9.19	8.03	46	1.00	1.3	5	19.80
	Newman02	388246	9/19/02	10/8/02	Sediment	18.7	9.34	7.85	46	1.25	1.5	37	8.63
	Newman03	388247	9/19/02	10/8/02	Sediment	18.4	7.85	7.40	46	1.25	4.5	44	9.12
					Median	18.7	9.2	7.9	46	1.3		37	9.12
					Mean	18.8	8.8	7.8	46	1.2		29	12.52
					Std. Dv.	0.4	0.8	0.3	0	0.1		21	6.31
Moses Lake	Moses01	438466	10/22/02	11/6/02	Sediment	11.0	9.86	7.67	280	> DOW	1.3	37	11.7
	Moses02	438468	10/21/02	11/6/02	Sediment	12.4	3.43	8.01	214	2.70	8.6	21	3.1
	Moses03	438469	10/21/02	11/6/02	Sediment	12.5	16.70	8.70	310	nd	2.2	22	2.8
					Median	12.4	9.9	8.0	280	nd		22	3.10
					Mean	12.0	10.0	8.1	268	nd		27	5.87
					Std. Dv.	0.8	6.6	0.5	49	nd		9	5.05
Walla Walla River (Lower)	Walla01	398242	9/27/02	10/8/02	Sediment	14.5	9.03	8.08	312	> DOW	1.0	13	0.82
	Walla02	398243	9/27/02	10/8/02	Sediment	15.4	9.28	8.34	294	> DOW	0.8	14	0.79
	Walla03	398244	9/27/02	10/8/02	Sediment	nd	nd	nd	nd	nd	-	13	0.95
					Median	14.9	9.2	8.2	303	nd		13	0.82
					Mean	14.9	9.2	8.2	303	nd		13	0.85
					Std. Dv.	0.6	0.2	0.2	12	nd		1	0.09

Appendix D.

Statistical Comparisons

Comparison of Mercury Concentrations and Fish Size

Table D1. Fish Size Compared to Mercury Concentrations in Tissue

Waterbody	n	Tissue Mercury Compared to					
		Fish Age		Fish Weight		Fish Length	
		r^2	p	r^2	p	r^2	p
Northwest Region							
Lake Terrell	10	0.579	0.020	0.546	0.026	0.620	0.014
Lake Samish	10	0.635	0.012	0.608	0.016	0.546	0.026
Kitsap Lake	10	0.655	0.010	0.782	0.002	0.779	0.002
Fazon Lake	10	0.575	0.021	0.744	0.004	0.782	0.002
Lake Meridian	8	0.899	0.001	0.604	0.043	0.659	0.029
Southwest Region							
Duck Lake	10	0.732	0.004	0.794	0.002	0.869	0.000
Black Lake	10	0.987	0.000	0.985	0.000	0.989	0.000
Vancouver Lake	10	0.916	0.000	0.884	0.000	0.860	0.000
Loomis Lake	10	0.204	0.187	0.001	0.414	0.064	0.329
Offutt Lake	10	Regression data not reported due to insufficient data.					
American Lake	4	Not reported due to a small catch size and insufficient data.					
Central Region							
Banks Lake	10	0.629	0.013	0.606	0.016	0.634	0.012
Okanogan River	10	0.670	0.009	0.907	0.000	0.872	0.000
Palmer Lake	10	0.602	0.017	0.593	0.018	0.614	0.015
Bonaparte Lake	3	Not reported due to a small catch size and insufficient data.					
Eastern Region							
Moses Lake	10	0.949	0.000	0.909	0.000	0.905	0.000
Upper Long Lake	10	0.541	0.027	0.522	0.031	0.573	0.021
Walla Walla River	10	0.806	0.001	0.804	0.001	0.772	0.002
Newman Lake	10	0.982	0.000	0.956	0.000	0.976	0.000
Deer Lake	10	0.627	0.013	0.318	0.109	0.330	0.102
All Data	185	0.425	< 0.001	0.397	< 0.001	0.409	< 0.001

Bolded p-values in body of table represent comparisons which did not show a correlation within a 95% confidence interval (p > .05).

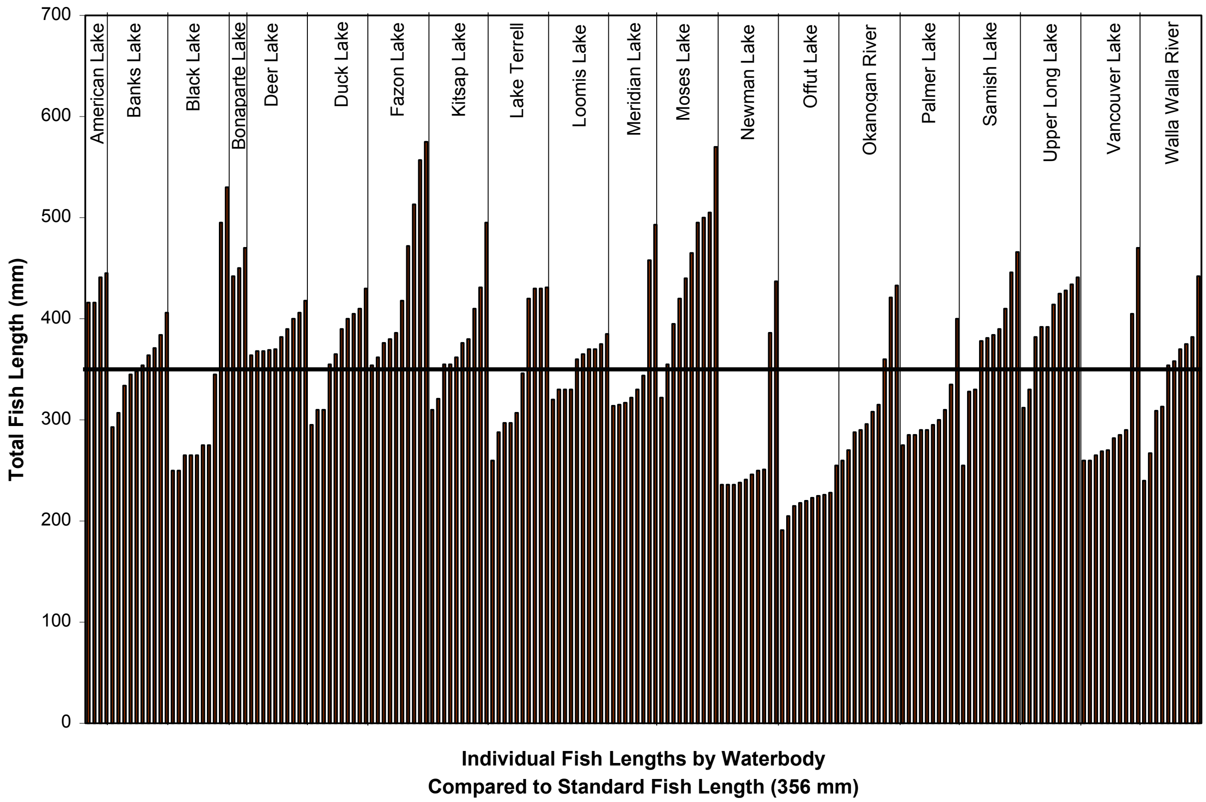

Figure D1. Individual Fish Lengths by Waterbody

Table D2. Adjusted Mercury Levels for a Standard Length Fish.

Waterbody	n	Regression Coefficients			Fish Tissue Mercury at 356 mm Total Length		r^2	P
		Constant	B1	B2	Log_{10}	µg/Kg ww		
Northwest Region								
Lake Terrell	10	136.928	-108.235	21.701	2.0431	110	0.620	0.014
Lake Samish	10	56.859	-46.504	9.839	2.2572	181	0.546	0.026
Kitsap Lake	10	51.389	-41.323	8.660	2.3311	214	0.779	0.002
Fazon Lake	10	-69.444	51.988	-9.345	2.3658	232	0.782	0.002
Lake Meridian	8	-136.423	105.210	-19.896	2.4941	312	0.659	0.029
Southwest Region								
Duck Lake	10	186.380	-148.817	30.029	2.1666	147	0.869	0.000
Black Lake	10	29.486	-23.702	5.120	2.3422	220	0.989	0.000
Vancouver Lake	10	-45.818	33.971	-5.910	2.3838	242	0.860	0.000
Loomis Lake	10	137.189	-107.801	21.557	2.4740	306 J	0.064	0.329
Offutt Lake	10	Insufficient data. Fish collected were all one-year-old fish.					0.174	0.213
American Lake	4	Insufficient data. Not reported due to a small catch size.						
Central Region								
Banks Lake	10	153.540	-122.163	24.605	2.0232	105	0.634	0.012
Okanogan River	10	67.503	-53.361	10.879	2.1762	150	0.872	0.000
Palmer Lake	10	53.912	-43.179	8.983	2.2213	166	0.614	0.015
Bonaparte Lake	3	Insufficient data. Not reported due to a small catch size.						
Eastern Region								
Moses Lake	10	-5.208	1.987	0.260	1.5543	36	0.905	0.000
Upper Long Lake	10	-336.949	259.323	-49.601	1.8033	64	0.573	0.021
Walla Walla River	10	-43.712	34.253	-6.357	2.2994	199	0.772	0.002
Newman Lake	10	-45.382	35.269	-6.485	2.3884	245	0.976	0.000
Deer Lake	10	635.086	-491.462	95.450	2.5150	293 J	0.330	0.102

Regression Formula: $\text{Log10 [Hg]} = \text{Constant} + \text{B1} * \text{Log10(Length)} + \text{B2} * (\text{Log10(Length)})^2$

$\text{Log10 [Hg]} = \text{Constant} + \text{B1} * 2.4048 + \text{B2} * 5.7832$

* - Fish collected had a bimodal size distribution.

J - A relationship between tissue mercury levels and fish length was not shown for Deer Lake and Loomis Lake. Mercury concentrations for a 356-mm fish (total length) were estimated from mercury data associated with lengths of 356 mm ± 20 mm.

◊ - An adjusted tissue mercury value is not available. This value could not reliably be predicted for American Lake and Bonaparte Lake due to an inadequate sampling size. All fish collected from Offut Lake were one year old.

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Regression Plots for Mercury Concentrations and Fish Age

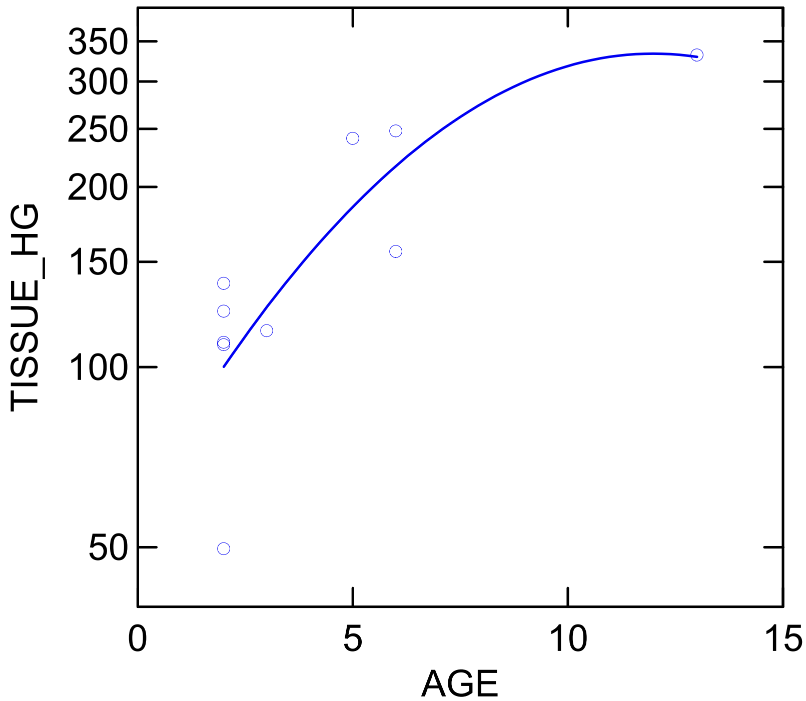

Figure D2. Lake Terrell Mercury vs Fish Age

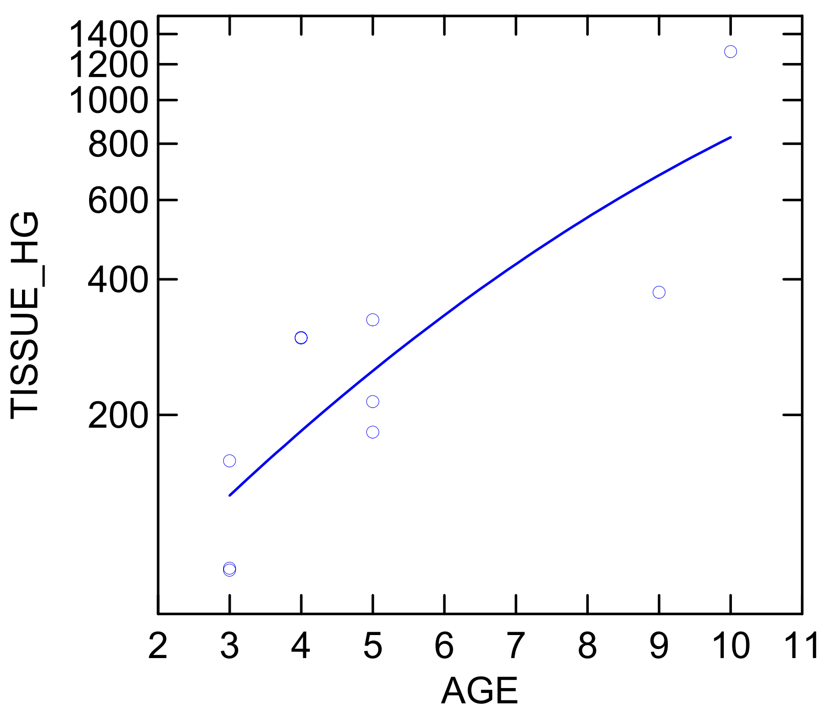

Figure D3. Lake Samish Mercury vs Fish Age

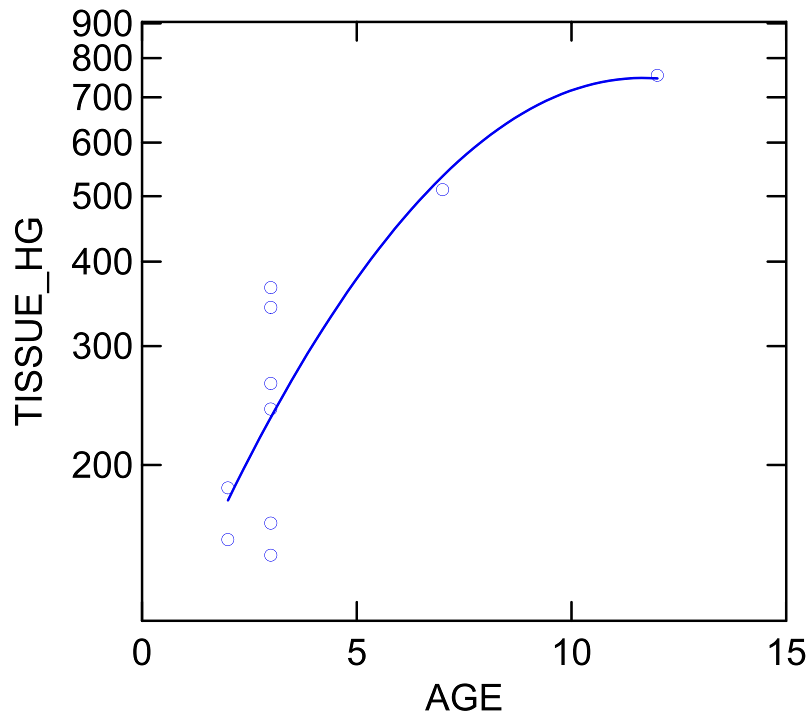

Figure D4. Kitsap Lake Mercury vs Fish Age

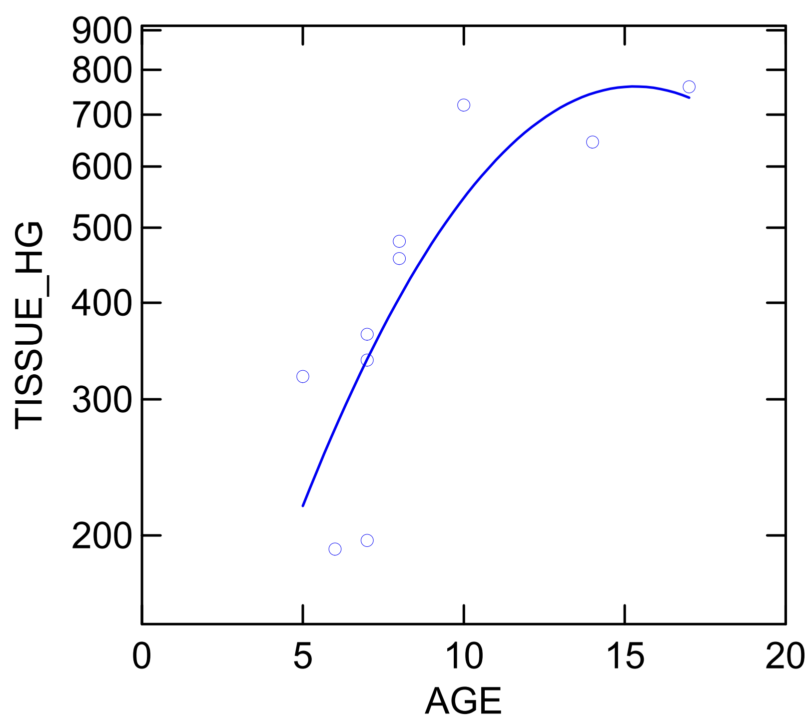

Figure D5. Fazon Lake Mercury vs Fish Age

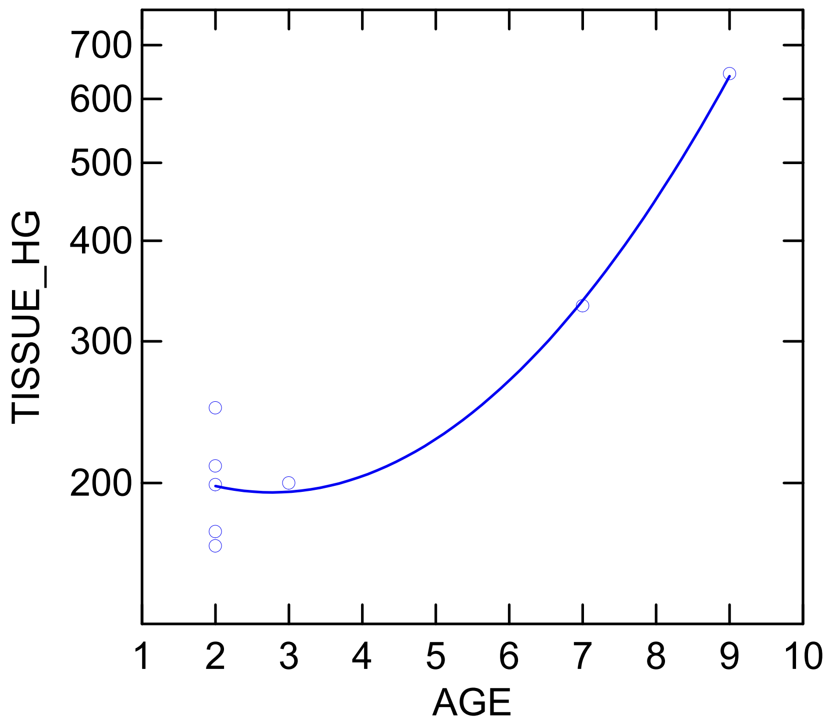

Figure D6. Lake Meridian Mercury vs Fish Age

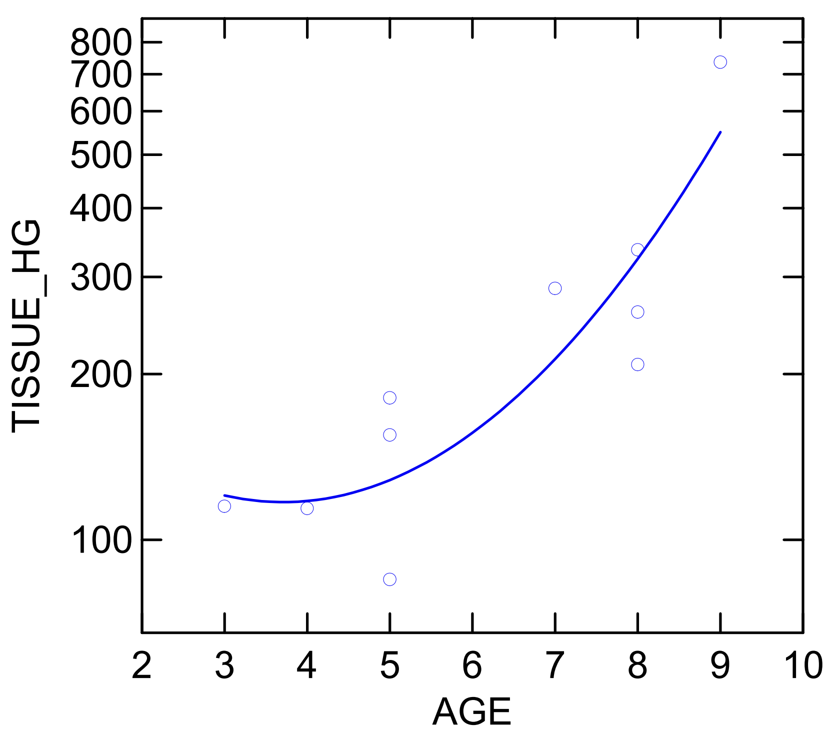

Figure D7. Duck Lake Mercury vs Fish Age

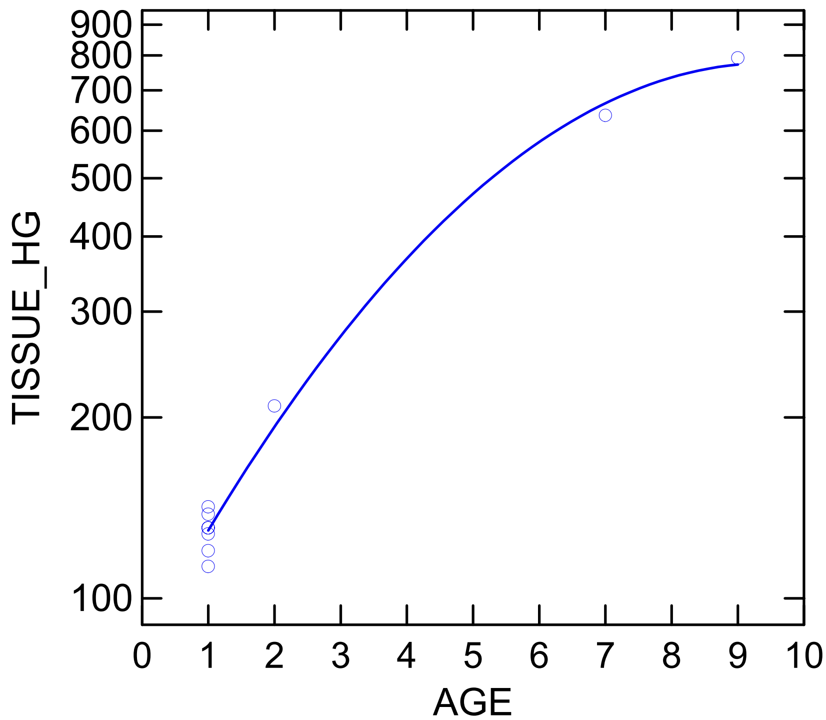

Figure D8. Black Lake Mercury vs Fish Age

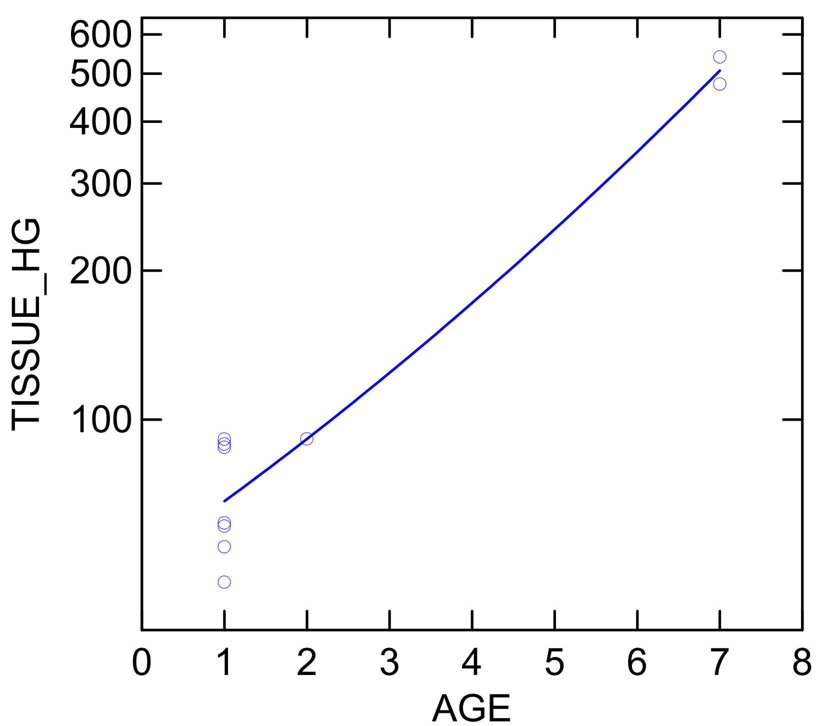

Figure D9. Vancouver Lake Mercury vs Fish Age

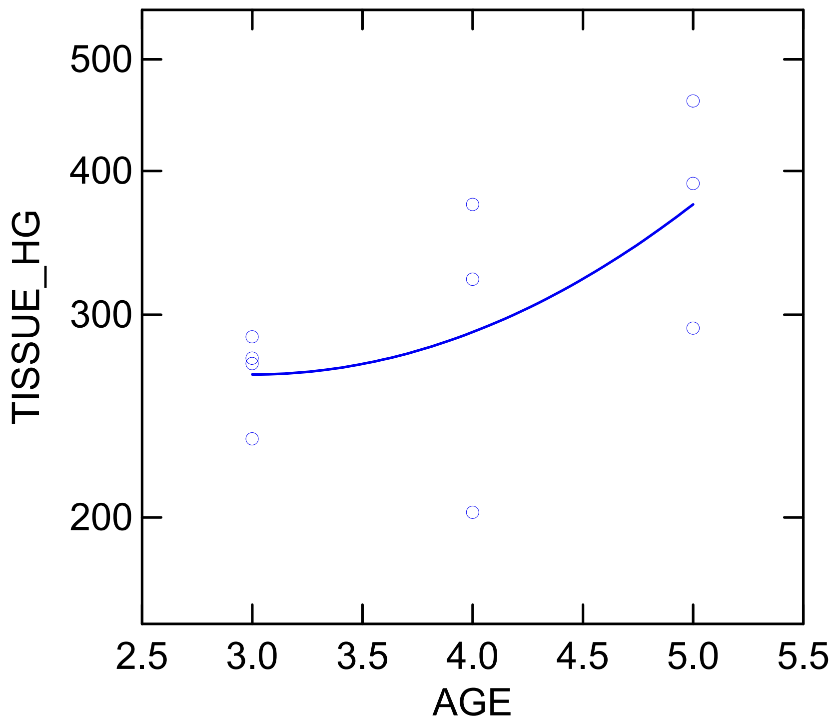

Figure D10. Loomis Lake Mercury vs Fish Age

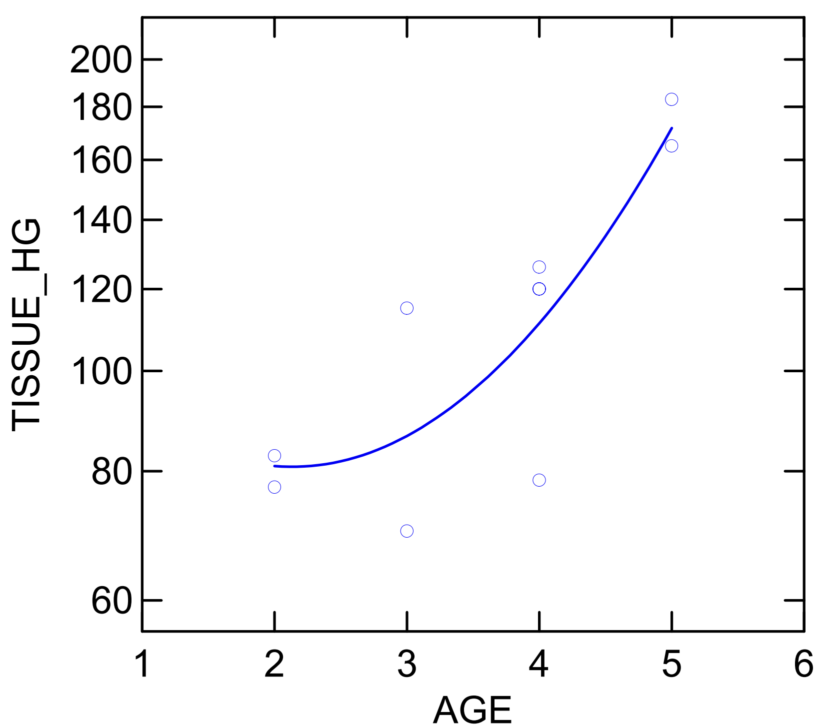

Figure D11. Banks Lake Mercury vs Fish Age

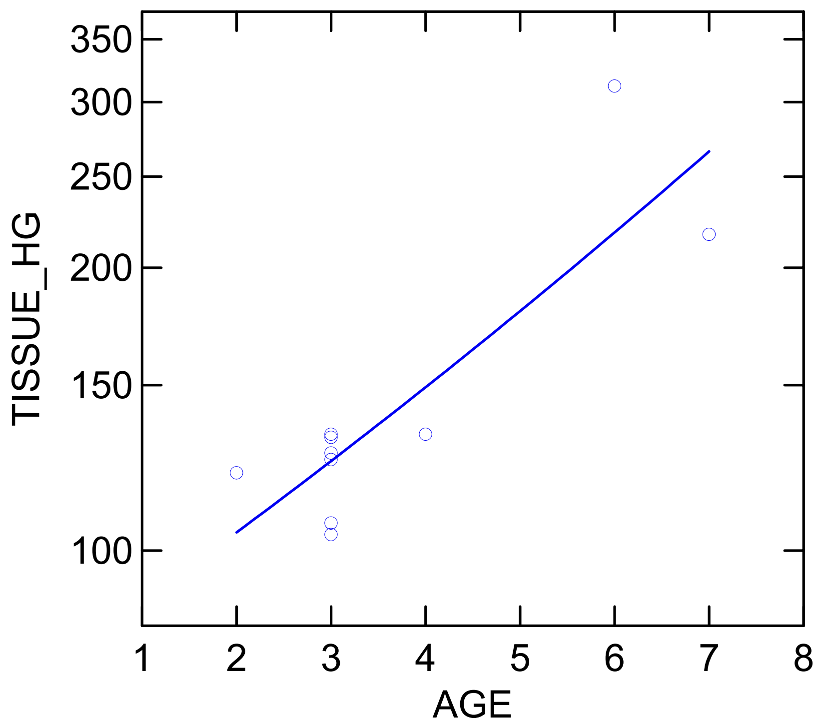

Figure D12. Okanogan River Mercury vs Fish Age

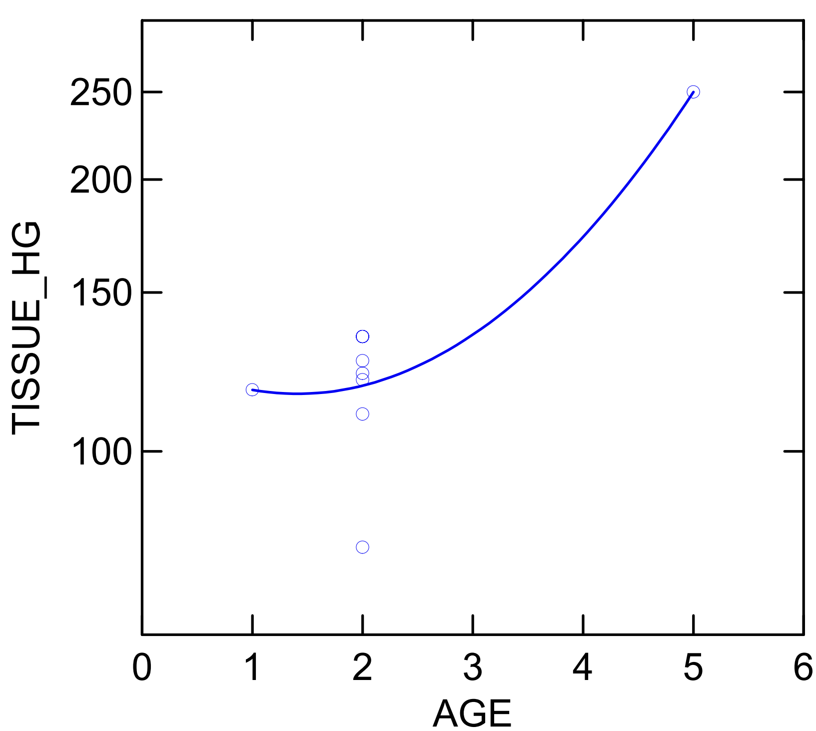

Figure D13. Palmer Lake Mercury vs Fish Age

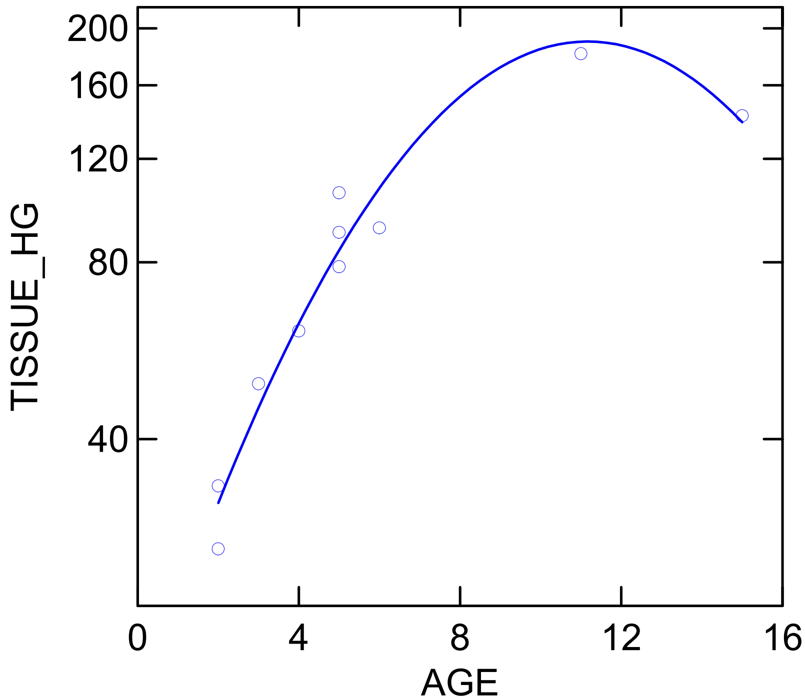

Figure D14. Moses Lake Mercury vs Fish Age

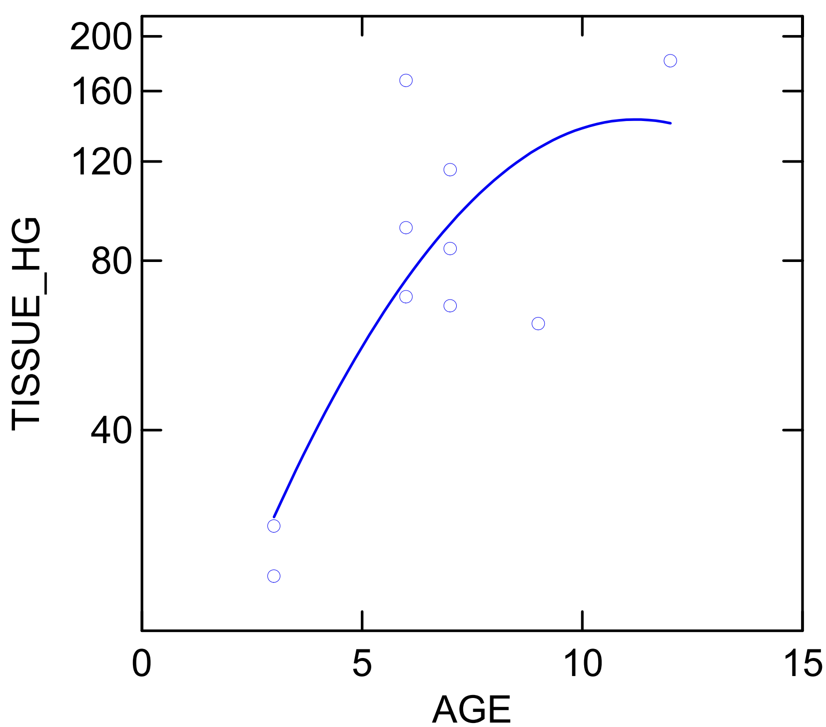

Figure D15. Upper Long Lake Mercury vs Fish Age

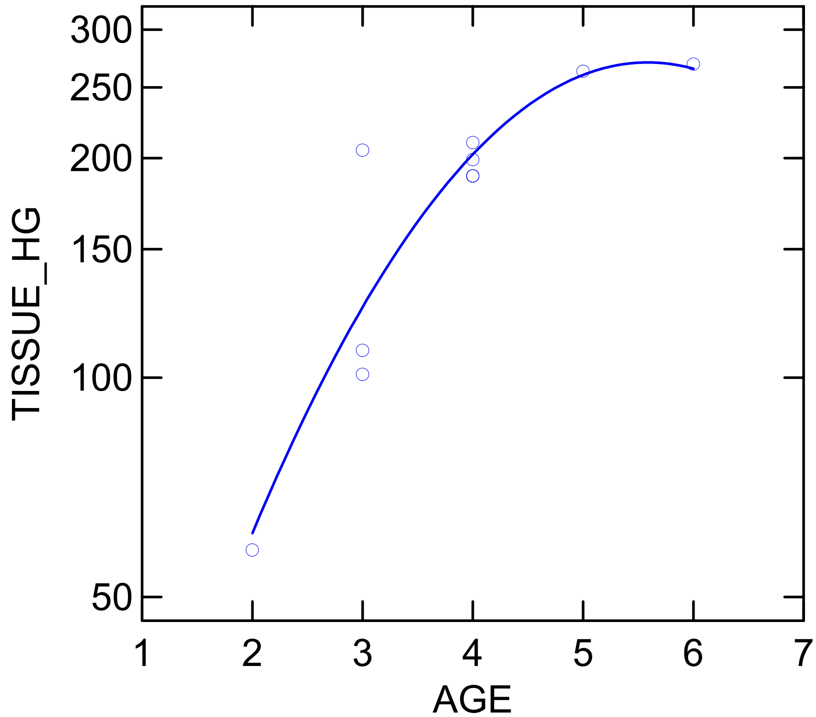

Figure D16. Walla Walla River Mercury vs Fish Age

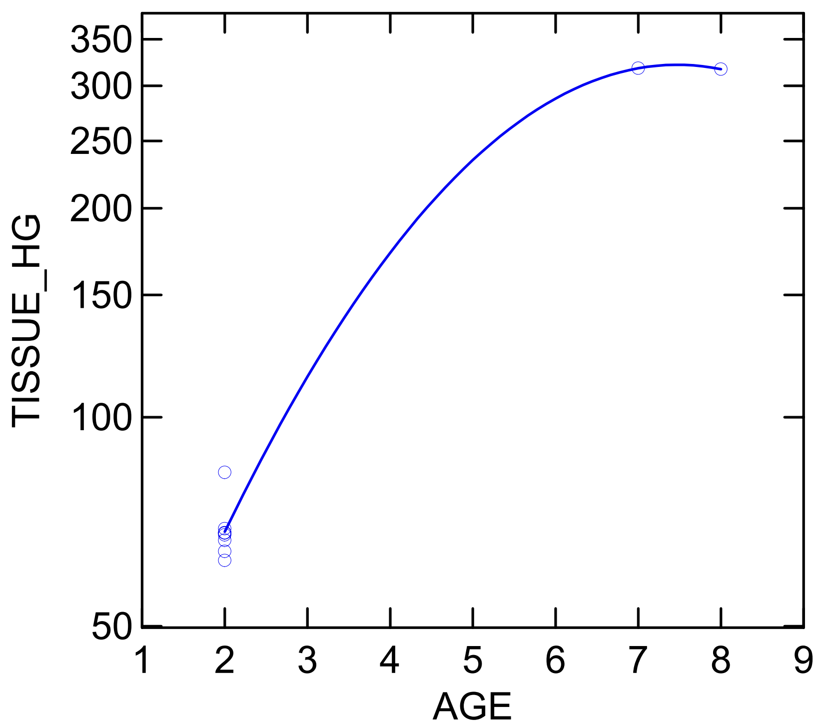

Figure D17. Newman Lake Mercury vs Fish Age

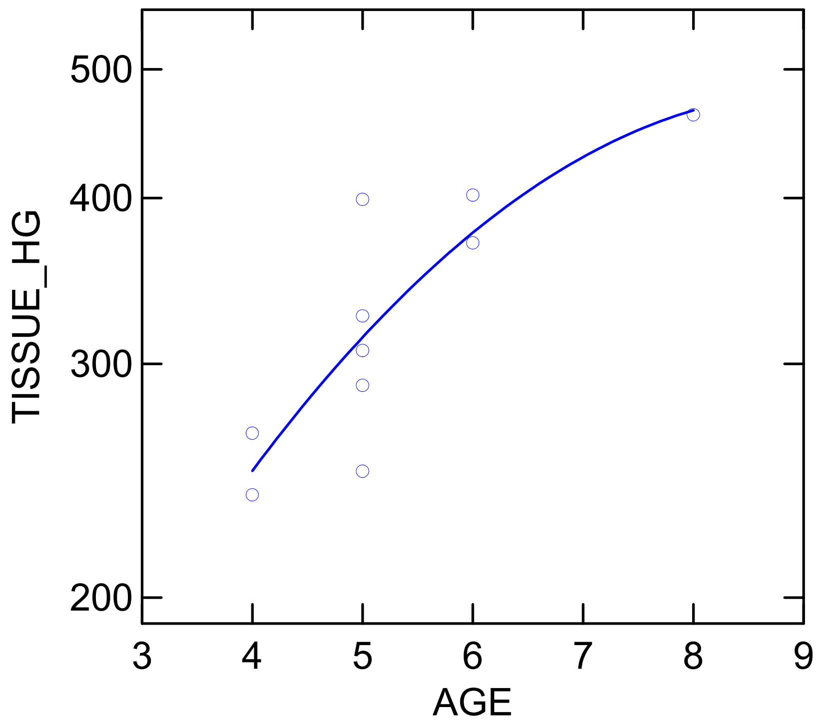

Figure D18. Deer Lake Mercury vs Fish Age

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Regression Plots for Mercury Concentrations and Fish Length

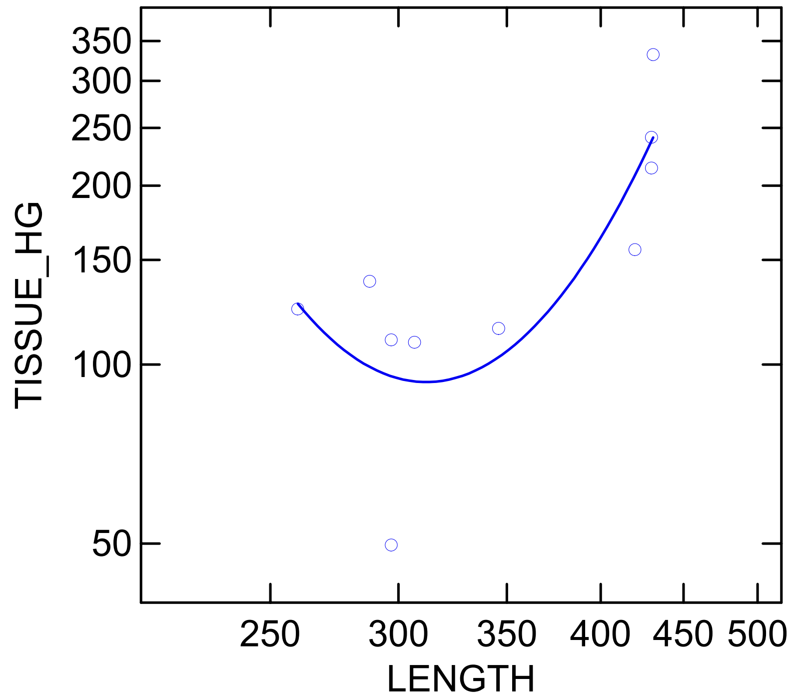

Figure D19. Lake Terrell Mercury vs Fish Length

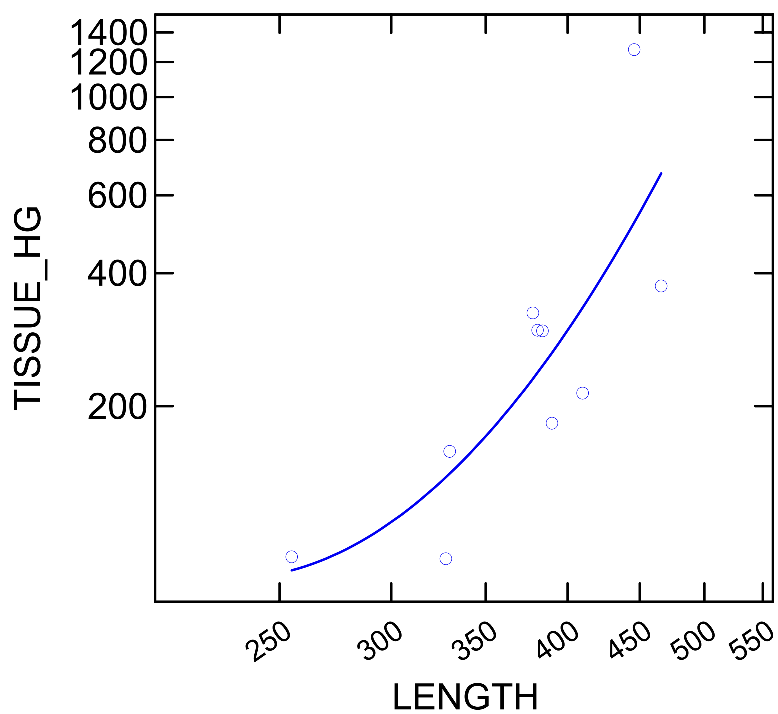

Figure D20. Lake Samish Mercury vs Fish Length

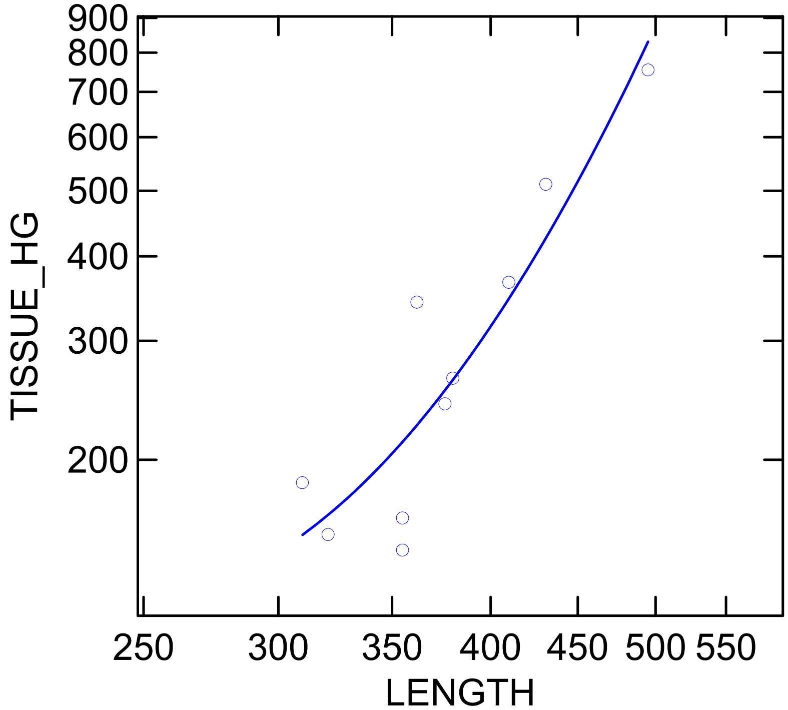

Figure D21. Kitsap Lake Mercury vs Fish Length

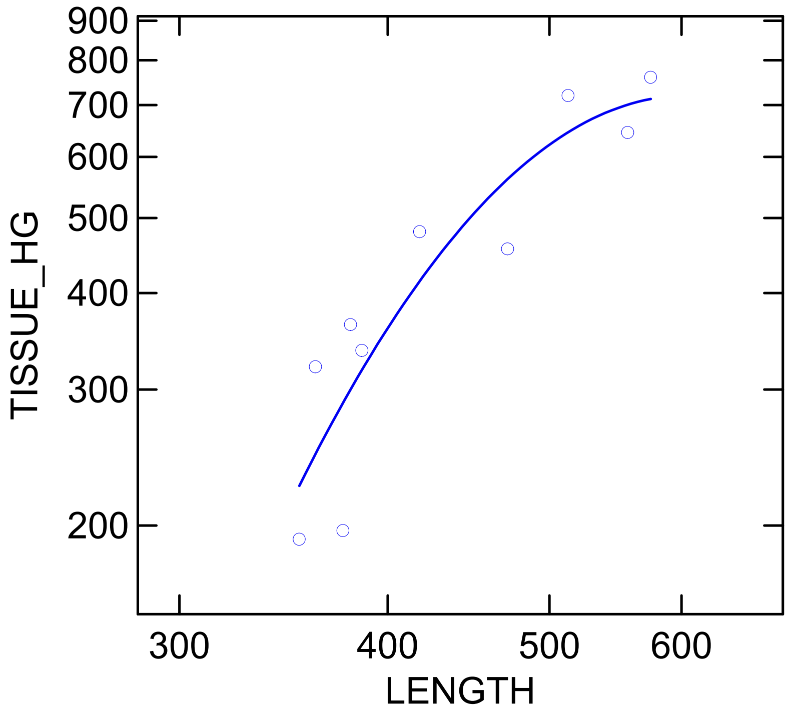

Figure D22. Fazon Lake Mercury vs Fish Length

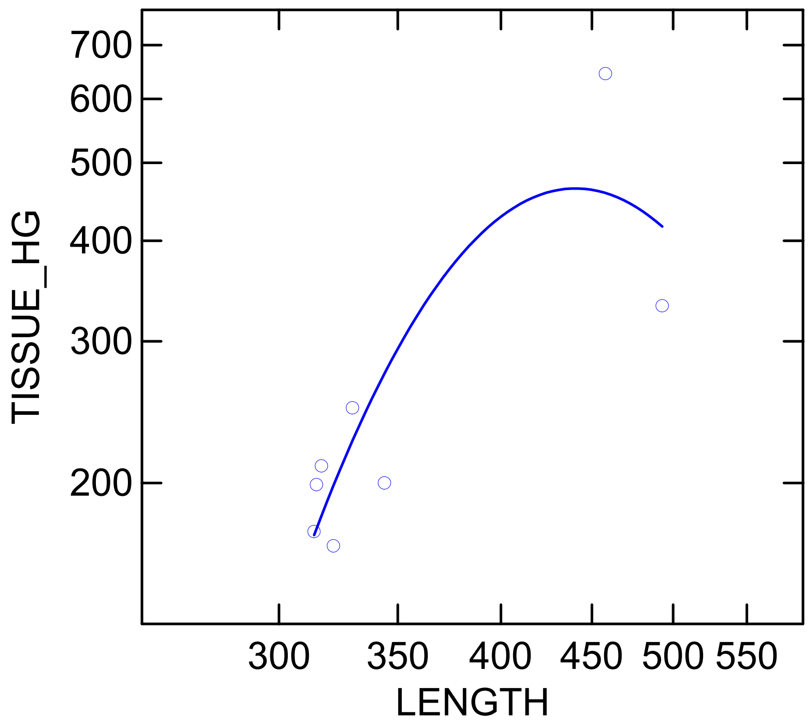

Figure D23. Lake Meridian Mercury vs Fish Length

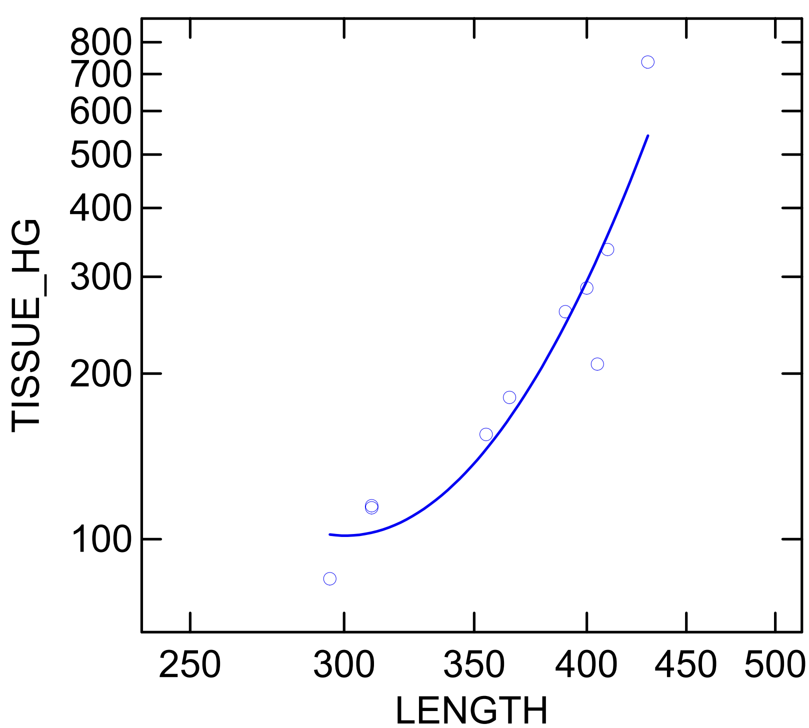

Figure D24. Duck Lake Mercury vs Fish Length

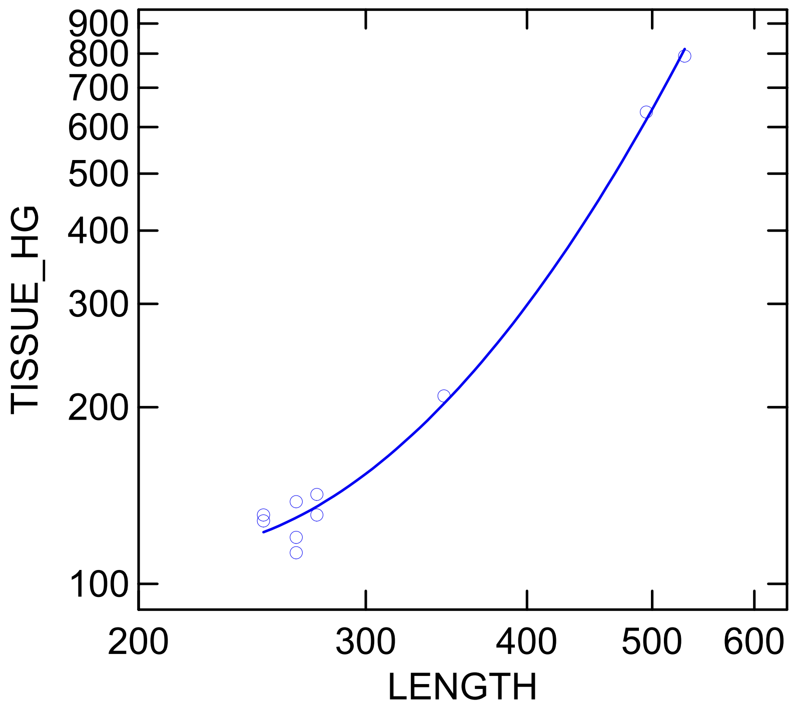

Figure D25. Black Lake Mercury vs Fish Length

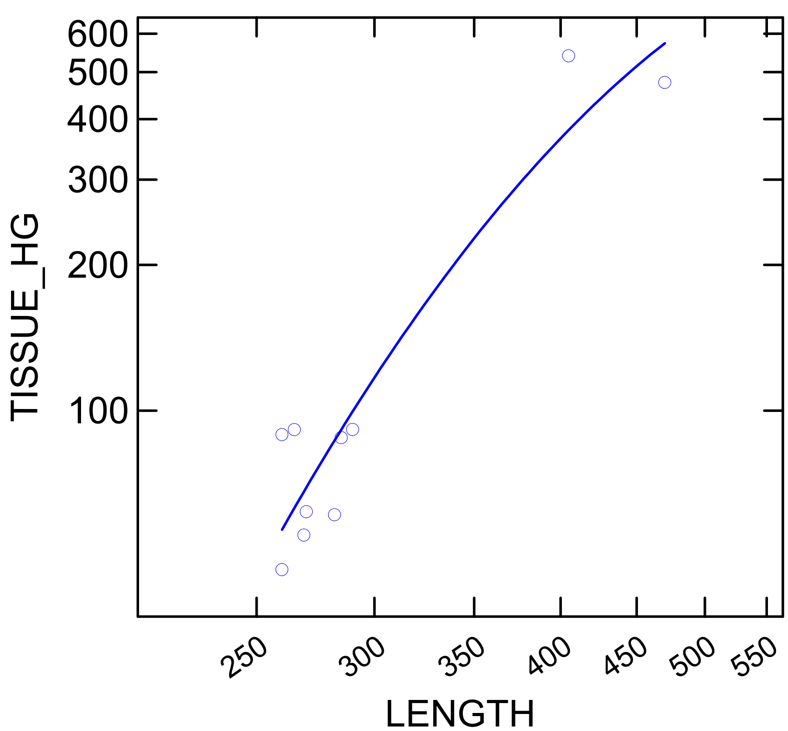

Figure D26. Vancouver Lake Mercury vs Fish Length

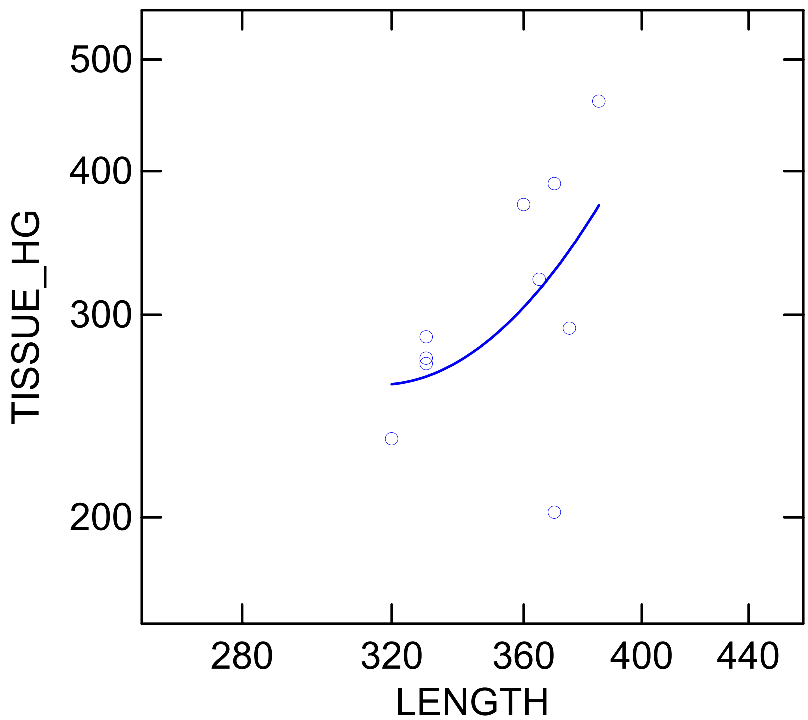

Figure D27. Loomis Lake Mercury vs Fish Length

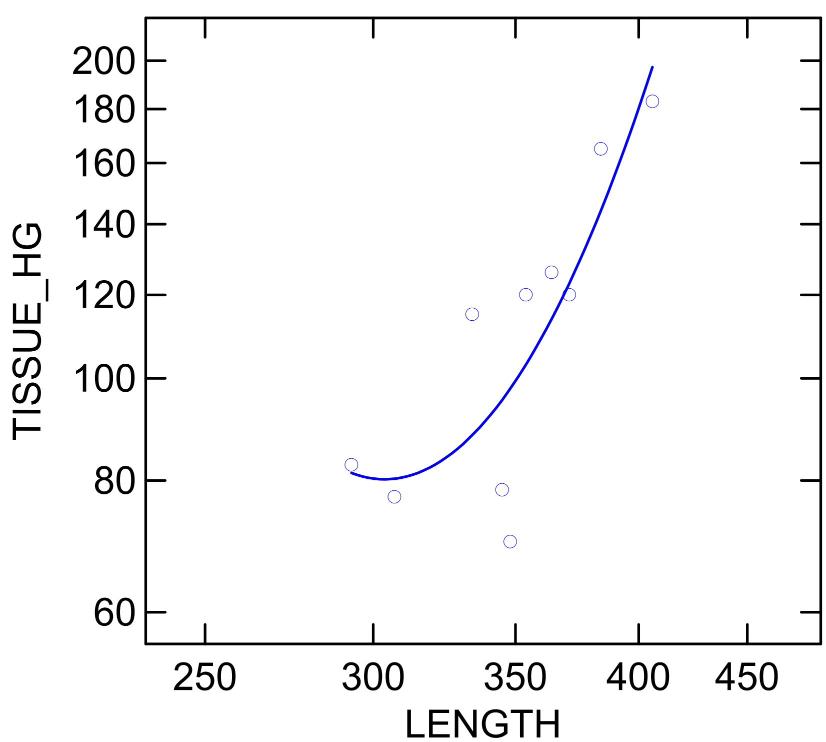

Figure D28. Banks Lake Mercury vs Fish Length

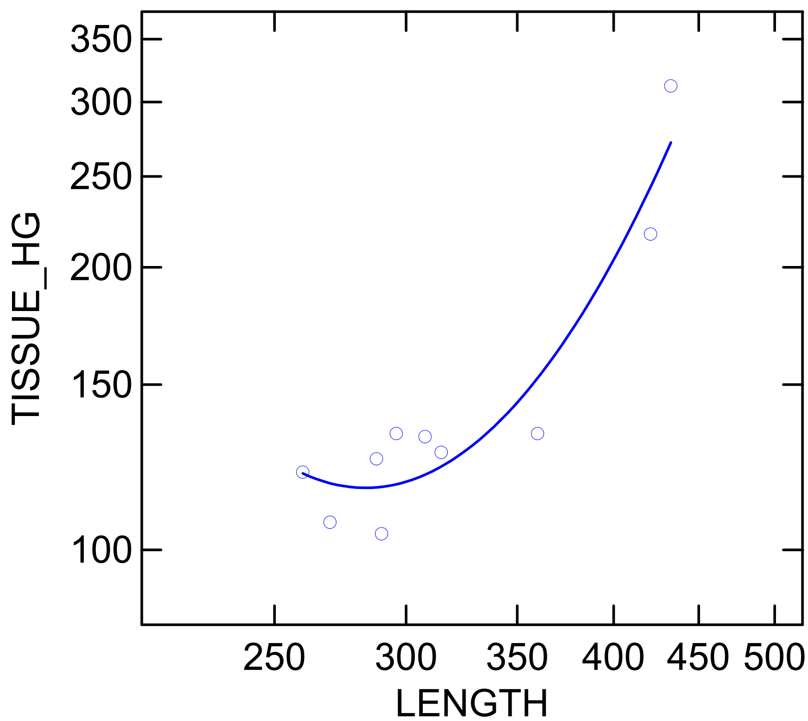

Figure D29. Okanogan River Mercury vs Fish Length

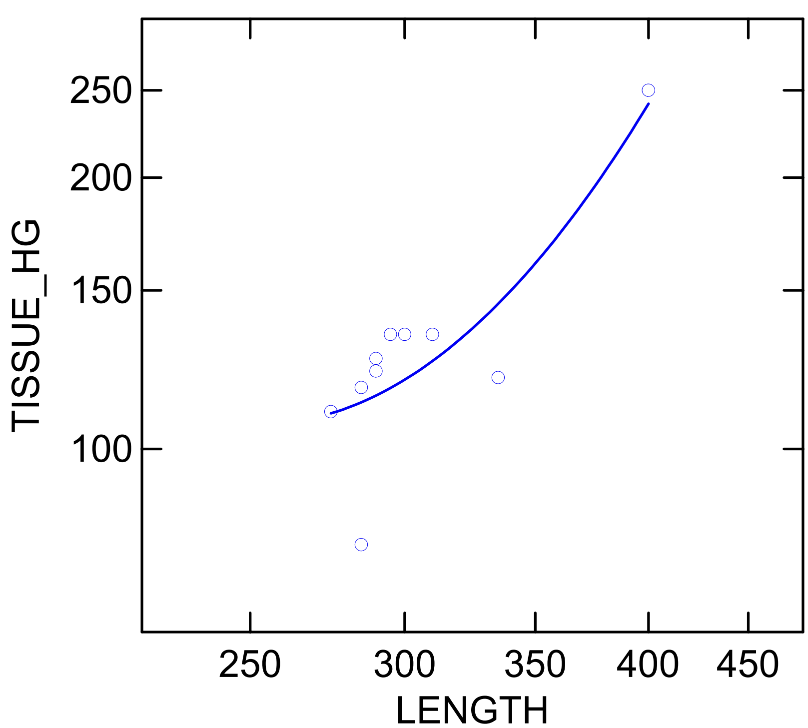

Figure D30. Palmer Lake Mercury vs Fish Length

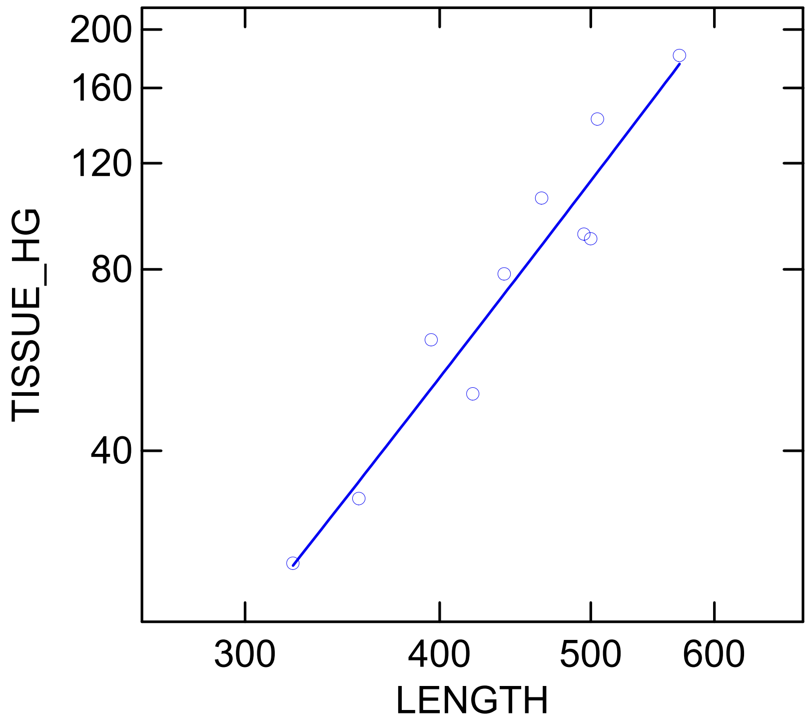

Figure D31. Moses Lake Mercury vs Fish Length

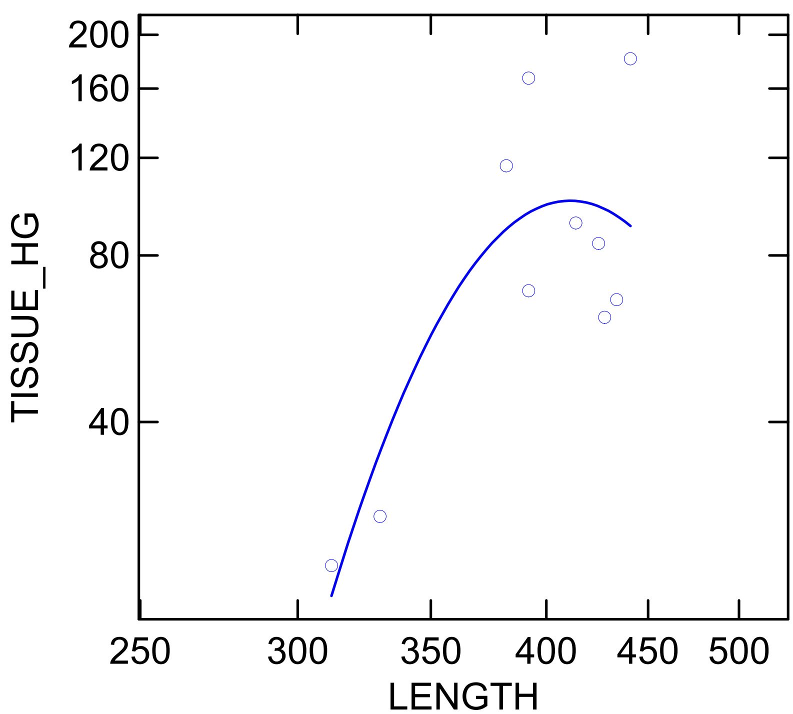

Figure D32. Upper Long Lake Mercury vs Fish Length

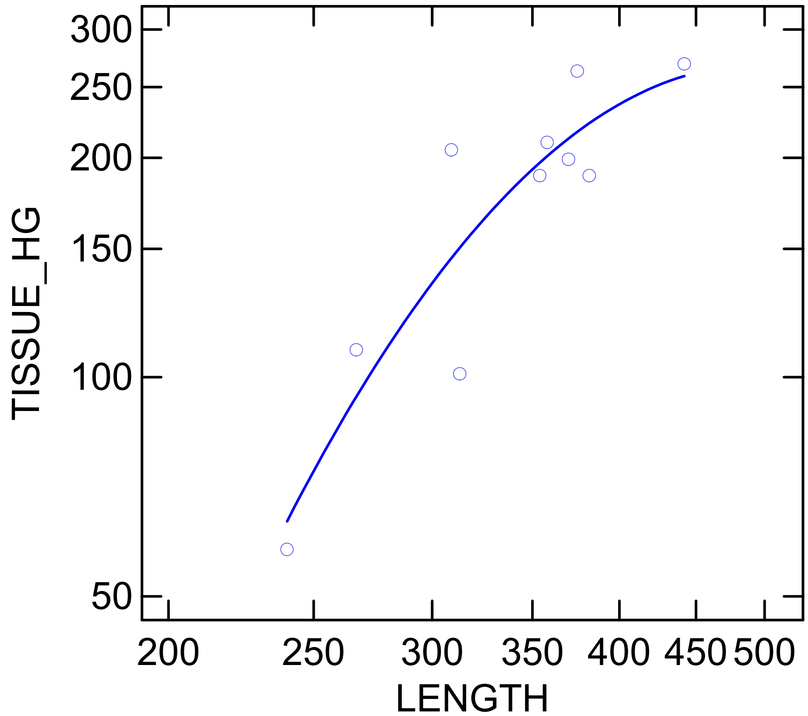

Figure D33. Walla Walla River Mercury vs Fish Length

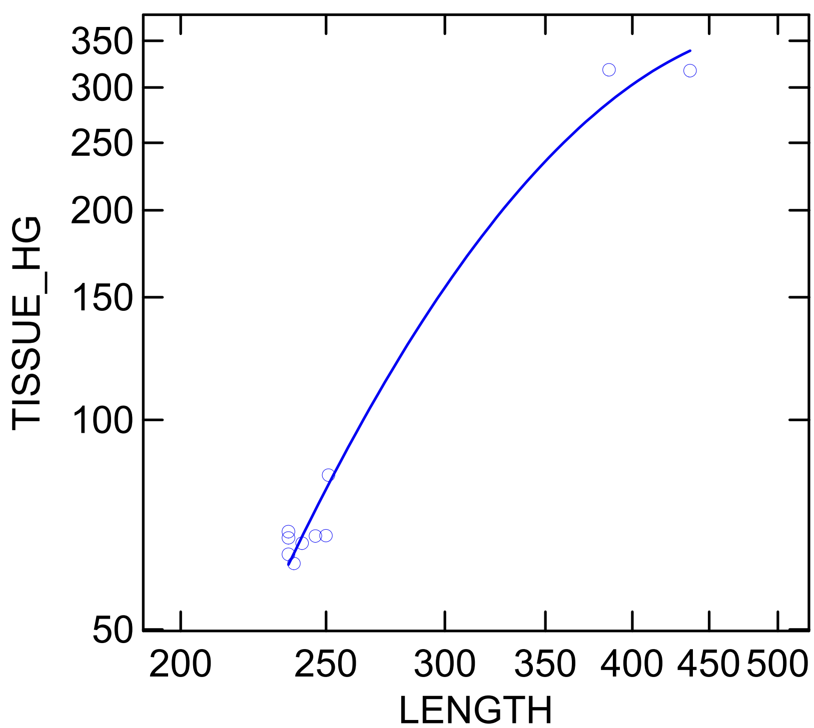

Figure D34. Newman Lake Mercury vs Fish Length

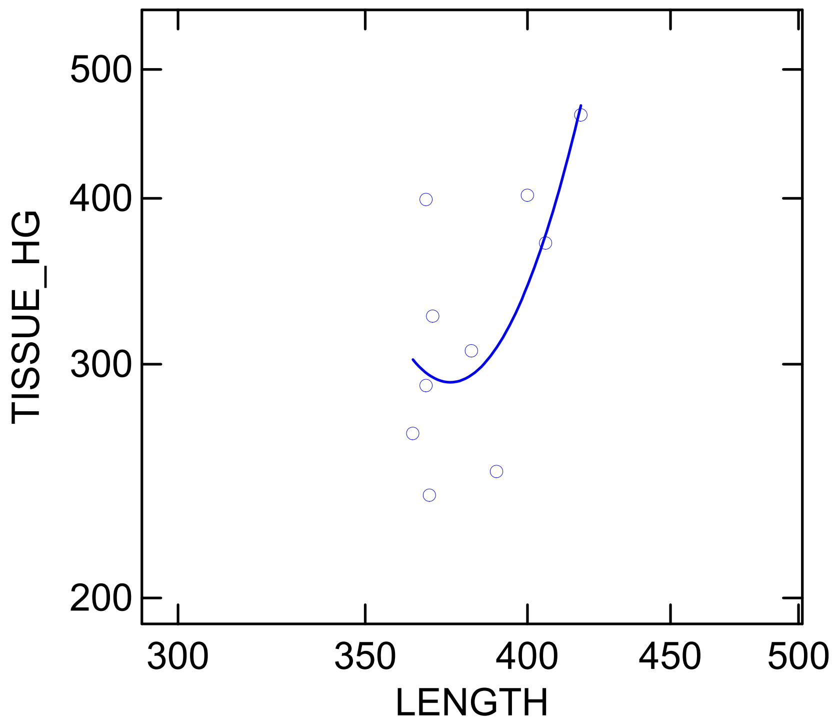

Figure D35. Deer Lake Mercury vs Fish Length

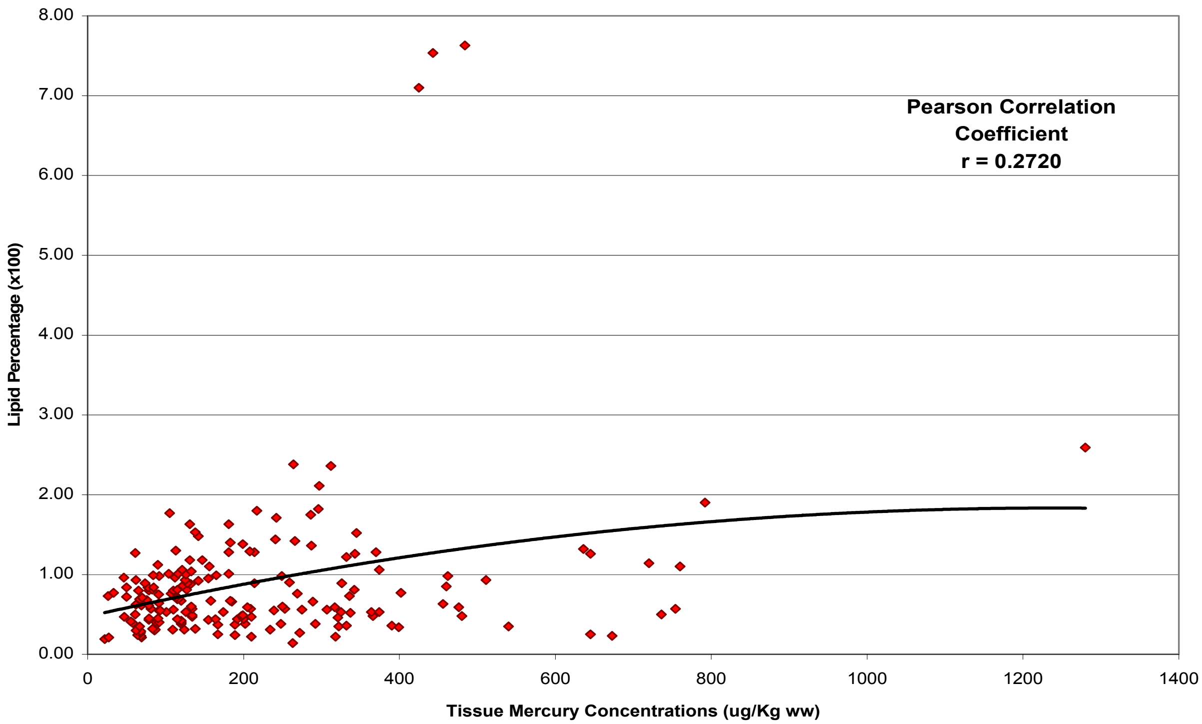

Figure D36. Lipid Percentages vs Mercury Concentrations in Tissue

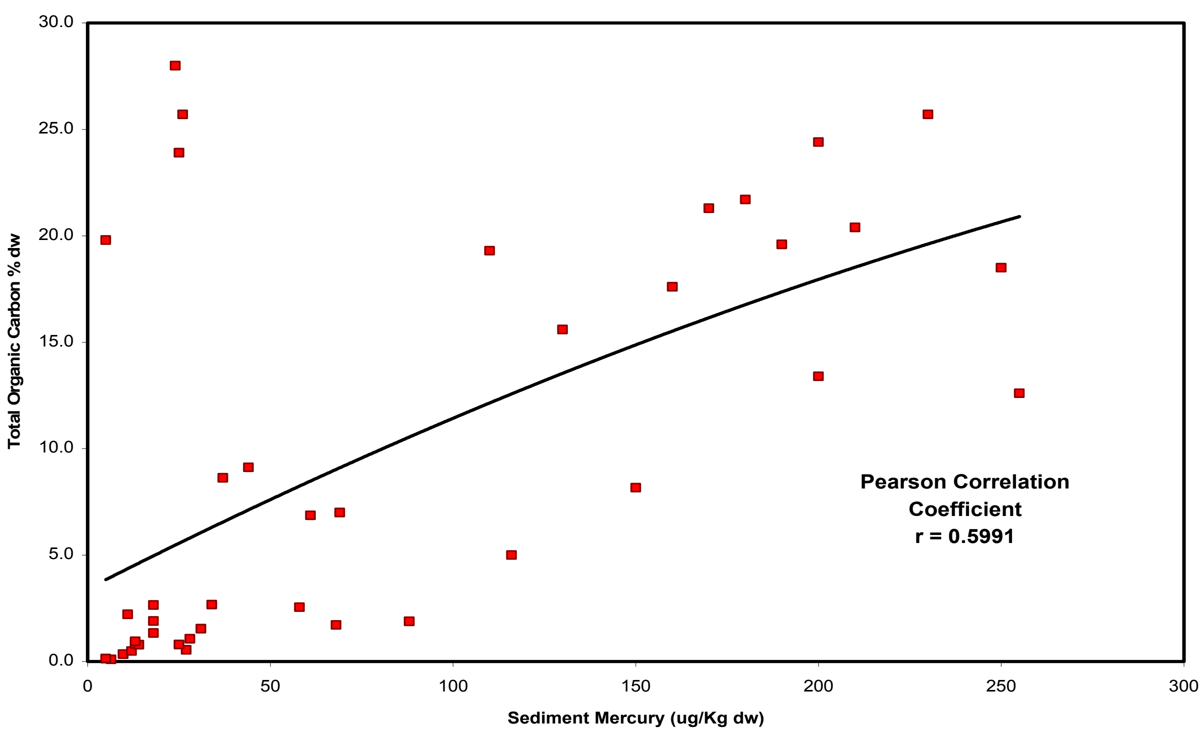

Figure D37. TOC Percentages vs Mercury Concentrations in Sediment