Measuring Mercury Trends in Freshwater Fish in Washington State

2008 Sampling Results

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Cover photo: Brook trout (*Salvelinus fontinalis).*

Measuring Mercury Trends in Freshwater Fish in Washington State

2008 Sampling Results

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Waterbody Number: see Appendix A

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Abstract

This report presents results from the fourth year of a long-term monitoring effort by the Washington State Department of Ecology (Ecology) to measure mercury trends in resident freshwater fish tissue. Six sites per year for five years (30 sites total) are assessed to characterize temporal trends.

In 2008, 60 individual bass and 30 composite samples representing 6 additional species were analyzed from 6 lakes: Goodwin, Horsethief, Leland, Loomis, McIntosh, and Nahwatzel. Water and sediment samples were also collected to evaluate selected parameters that may influence mercury uptake in fish tissue.

Consistent with previous Ecology mercury fish tissue reports, mercury concentrations were generally related to fish age and size within a particular waterbody. Bass had higher concentrations than other species analyzed. Thirty percent of individual bass tested did not meet the EPA's recommended water quality criterion of 300 ppb. All composite samples (met) were below this threshold.

Spearman Rank and Pearson correlation matrices were used to examine relationships between water and sediment variables to standard-sized bass concentrations over the first 4 years of monitoring, 2005-08. Environmental variables displaying the strongest relationships with fish tissue concentrations were sediment mercury concentration (+), pH (-), and alkalinity (-).

Consistent with earlier findings, eastern Washington bass have lower mercury concentrations than bass in western Washington. The average mercury concentration in a standard-size fish (356 mm) from western Washington (335 ppb) is significantly higher than a standard-size fish from eastern Washington (139 ppb).

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Introduction

Background

Mercury is a naturally occurring substance whose environmental abundance has greatly increased due to human activity. Consequences of this include increased health risks to humans and wildlife due to mercury's persistent, bioaccumulative, and toxic nature. Concerns about these risks have led governments at all levels to recognize and address the problems associated with the use and disposal of mercury.

Mercury is widespread in the environment, being released to the atmosphere from various sources and transported globally. Natural sources of mercury include weathering of mercury-bearing rocks and soil, volcanic activity, forest fires, and degassing from water surfaces. Anthropogenic sources include combustion of fossil fuels, metals production, and industrial processes. Lake sediment records show that atmospheric mercury has tripled over the last 150 years, suggesting that two-thirds of atmospheric mercury is of anthropogenic origin (Morel et al., 1998; Mason et al., 1994).

In humans, mercury can affect the nervous system, with children and developing fetuses being most at risk (EPA, 2000). Concern with these health risks resulted in the 2002 Washington State Legislature funding the Washington State Departments of Ecology (Ecology) and Health (DOH) to develop a plan targeting mercury as the first chemical in the state's *Proposed Strategy to Continually Reduce Persistent, Bioaccumulative Toxins (PBTs) in Washington State* (Gallagher, 2000).

Ecology and DOH developed the *Washington State Mercury Chemical Action Plan* (Peele, 2003) in 2003. This plan summarized current information on mercury in Washington and made recommendations for reducing mercury emissions in Washington.

Criteria for Protection of Human Health

Various criteria have been developed concerning mercury concentrations in fish tissue in order to meet differing needs. Commonly used mercury criterions are described below.

EPA's Recommended Criterion

The Environmental Protection Agency (EPA) current recommended water quality criterion for methylmercury is 300 ppb ww (wet weight) (EPA, 2001). This is the maximum advisable concentration of methylmercury in fish and shellfish to protect consumers among the general population based on 17.5 grams/day of fish consumption. EPA expects the criterion to be used (1) as guidance by states and authorized tribes, and (2) by EPA in establishing or updating water quality standards for waters of the United States.

National Toxics Rule

Washington's water quality standards criteria for toxic contaminants were issued to the state in EPA's 1992 National Toxics Rule (NTR) (40CFR131.36) (CFR, 2004). The NTR criterion for mercury in fish tissue is 825 ppb ww.

Washington's water quality standards further state that risk-based criteria for carcinogenic substances be based on a risk level of 10^{-6}. A risk level is an estimate of the number of cancer cases that would be caused by exposure to a specific contaminant. At a risk level of 10^{-6}, one person in a million would be expected to contract cancer due to long-term exposure to a specific contaminant. These risks are upper-bound estimates, while true risks may be as low as zero. Exposure assumptions include an acceptable risk level and the consumer's body weight, length of exposure, and fish consumption rate. The NTR criteria are based on a fish consumption rate of 6.5 grams/day.

EPA Screening Values

EPA developed screening values (SVs) for carcinogenic and non-carcinogenic substances to help prioritize areas that may present risks to human populations from fish consumption. The EPA SVs are 400 ppb ww for recreational fishers and 49 ppb ww for subsistence fishers. The SVs are considered guidance only; they are not regulatory thresholds (EPA, 2000).

Assumptions about exposure to contaminants were also used in developing the EPA SVs. The SV approach is similar to that used for developing the NTR with 2 assumptions: the cancer risk level (10^{-5}) and the consumption rate (17.5 grams/day for recreational fishers and 142.4 grams per day for subsistence fishers). Screening values for non-carcinogenic effects are calculated using toxicological data from a variety of tests.

Previous Studies on Mercury in Washington State

Several studies have described the extent and severity of mercury contamination in fish throughout Washington, many of which led to issuance of fish consumption advisories. A brief overview of selected fish tissue studies is included below.

Mercury Trends Monitoring – Fish Tissue

As part of the current project, Ecology measured fish tissue concentrations and collected ancillary data (complete description located in *Study Design*) since 2005. Findings from each year's report are summarized below.

2007

Mercury concentrations were measured in 60 individual fish and 32 fish composite samples. Seventy-three percent of individuals and 28% of composites sampled did not meet (exceeded) the EPA recommended water quality criterion of 300 ppb. A single four-year-old female bass from Lake Ozette contained a mercury concentration of 1800 ppb. This sample was the highest concentration recorded in a largemouth bass during the first three years of the project (Furl and Meredith, 2008).

2006

Mercury concentrations were measured in 60 individual fish and 30 composite samples. A total of 17% of individuals and 3% of composites sampled exceeded the EPA recommended water quality criterion. Largemouth bass and northern pikeminnow were the only species exceeding EPA criterion. A single nine-year-old female bass from Mason Lake contained a mercury concentration of 952 ppb (Furl, 2007).

2005

Mercury levels were assessed in 60 individual fish during the first year of the monitoring project. The study found mercury levels to be within typical ranges (0 - 300 ppb) detected in previous fish tissue studies conducted within the state. Less than 10% of samples exceeded the EPA recommended criterion (Furl et al., 2007).

Statewide Bass Study

Fischnaller et al. (2003) examined mercury in 185 bass and sediment from 20 sites across Washington. Samples of muscle tissue from bass confirmed that elevated levels of mercury are prevalent across Washington. Many fish exceeded one or more criteria for protection of human health. About 23% of fish, representing 14 of 20 sites, exceeded the EPA criterion (300 ppb). A single ten-year-old fish from Samish Lake had a muscle tissue mercury level of 1280 ppb, exceeding the NTR criterion (825 ppb). The study recommended implementing a long-term monitoring plan for mercury in fish. This study was the basis of DOH's issuance of a statewide fish consumption advisory for largemouth and smallmouth bass (McBride, 2003).

Lake Whatcom Studies

Paulson (2004) examined sources of mercury in sediments, water, and fish for 8 lakes in Whatcom County, Washington. An atmospheric deposition model was developed to allow comparison of deposition patterns in the lakes sampled. Mercury emissions from known sources in the area (e.g., waste incinerators, a sewage-sludge incinerator, a chlor-alkali plant) were modeled as part of this effort. Relationships between point source deposition and mercury concentrations in bass could not be established.

Serdar et al. (2001) examined mercury concentrations in 273 fish from 6 finfish and 1 crayfish species at Lake Whatcom. Mercury levels were elevated in smallmouth bass. These data were used in developing a fish consumption advisory for Lake Whatcom (Lake Whatcom Cooperative Management Program, 2001). Serdar et al. (2001) recommended a monitoring program to routinely characterize mercury levels in fish throughout Washington.

A frequency distribution of all data for mercury in freshwater fish tissue (n = 1934) located in Ecology's Environmental Information Management (EIM) database is included in Figure 1.

A total of 120 samples were non-detects, and their concentrations were set to zero for calculating cumulative frequency. Concentrations ranged from 0 – 1920 ppb.

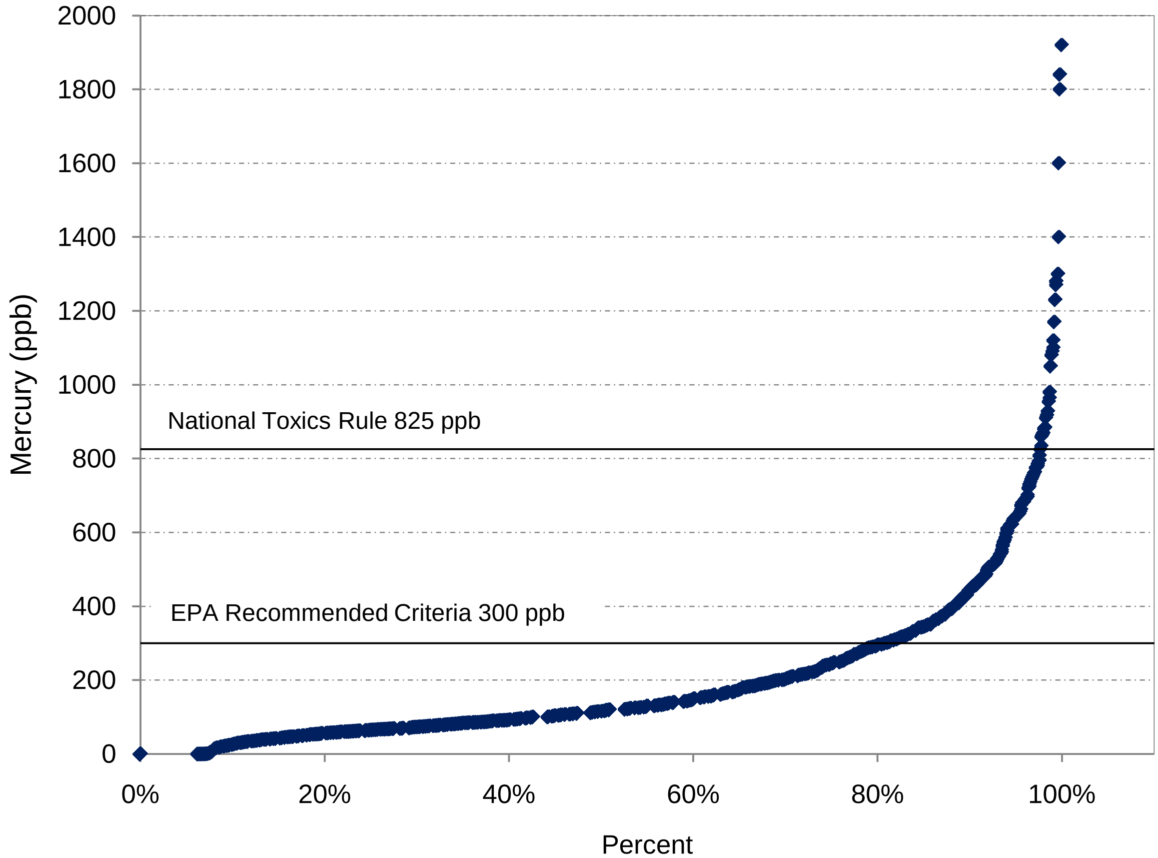

Figure 1. Frequency Distribution of All Mercury Concentrations in Freshwater Fish. *Available in EIM (accessed July 1, 2009).*

Methods

Study Design

This report presents results from the fourth year of a long-term study seeking information on mercury trends in fish tissue across the state. Fish, sediment, and water samples were collected from 6 waterbodies (Figure 2) statewide.

Specific goals of the study include:

- Determine mercury levels in edible tissue from 10 individual bass and/or walleye from 6 waterbodies per year over a 5-year period. A total of 30 sites will be sampled over a 5-year period, and sampling at each of these sites will be repeated every 5 years for long-term trend characterization.
- Collect ancillary data on the sites where fish were collected to better understand patterns, dynamics, and changes in fish tissue mercury levels over space and time. Ancillary data will include:
  1. Fish length, weight, sex, and age.
  2. Lake morphological and hydrological characteristics.
  3. Alkalinity, dissolved organic carbon (DOC), and chlorophyll concentrations from top and bottom waters; vertical profiles of temperature, dissolved oxygen, conductivity, and pH.
  4. Three surficial sediment grabs analyzed for mercury, total organic carbon (TOC), and grain size.
- Determine mercury concentrations in composite samples (3-5 fish) from 2 other fish species that are present at the sites where bass and/or walleye are collected.

Site Information

Figure 2 displays the 2008 study lakes: Lake Goodwin, Horsethief Lake, Leland Lake, Loomis Lake, McIntosh Lake, and Lake Nahwatzel. Fish were collected in October and November, 2008.

Lakes were selected considering numerous criteria including: proximity to known mercury sources, popularity among anglers, availability of target fish species, and inclusion in the Fischnaller et al. (2003) mercury screening study.

Table 1 contains physical information for each waterbody. The project plan discusses complete site selection considerations (Seiders, 2006).

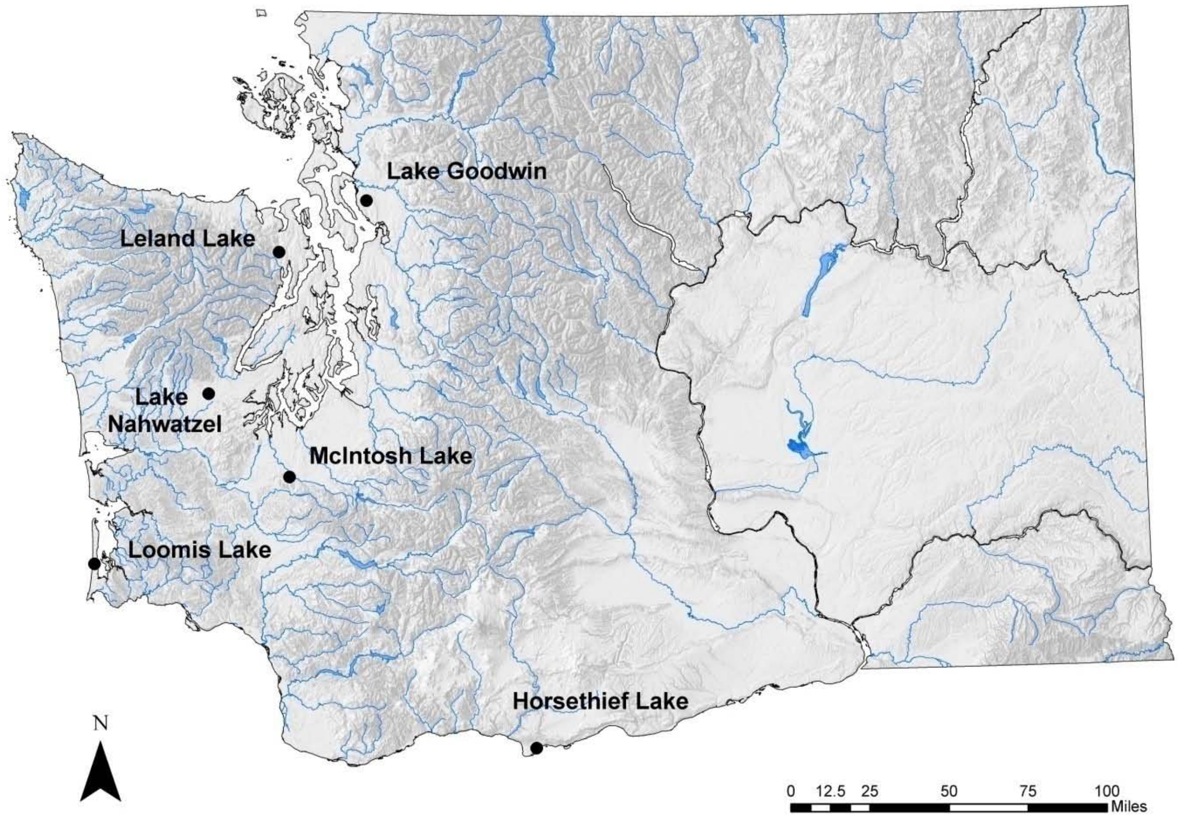

Figure 2. 2008 Study Lakes.

Table 1. Location and Physical Data for 2008 Study Lakes.

Lake	Goodwin	Horsethief	Leland	Loomis	McIntosh	Nahwatzel
County	Snohomish	Klickitat	Jefferson	Pacific	Thurston	Mason
Drainage (sq mi)	5.17	----	5.71	1.44	2.26	6.2
Altitude (ft)	324	160	190	17	336	440
Surface Area (acres)	560	92	110	170	93	270
Lake Volume (acre-ft)	13,000	----	1400	830	700	4600
Maximum Depth (ft)	50	----	20	9	11	25
Mean Depth (ft)	23	----	13	5	8	17

Sample Collection

In all, 185 fish encompassing 8 species were collected from the 2008 study lakes. A total of 60 individual fish along with 30 composite samples were analyzed by Manchester Environmental Laboratory (MEL) for total mercury. Information on collection goals and attainment for each waterbody are included in Table 2. Detailed information on all fish collected is included in Appendix C.

Table 2. Summary of Goals for the 2008 Collection Effort.

Collection Goal	Lake					
	Goodwin*	Horsethief	Leland	Loomis	McIntosh	Nahwatzel
10 individual bass or walleye	+	+	+	+	+	+
3 composites (3-5 fish) for each of 2 different species	NA	+	+	NA	+	+
3 sediment samples	NA	+	+	+	+	+
2 water samples	NA	+	+	+	+	+
1-2 hydrolab profile	NA	+	+	+	+	+

* Water and sediment sampling for Lake Goodwin will occur during the 2009 sampling season.
NA = Collection goal not met.
+ = Collection goal met.

Field Procedures

Fish

The collection, handling, and processing of fish tissue samples for analysis were guided by methods described in:

- EPA's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories* (EPA, 2000).
- Ecology's Environmental Assessment Program (EAP) *Standard Operating Procedures for Resecting Finfish Whole Body, Body Parts or Tissue Samples* (Sandvik, 2006).

Ecology crews collected fish using boat electrofishing and gill netting. Fish were inspected to ensure that they were acceptable for further processing (e.g., no obvious damage to tissues, skin intact). Acceptable fish were euthanized by a blow to the head with a dull object, rinsed in ambient water to remove foreign material from their exterior, weighed to the nearest gram, and their total lengths measured to the nearest millimeter. Individual fish were then double-wrapped in foil and placed in a plastic zip-lock bag along with a sample identification tag. The bagged specimens were placed on ice in the field. Fish remained on ice for a maximum of 24-72 hours and then were frozen and held at –20° C at Ecology facilities in Lacey, Washington for processing at a later date.

For processing, fish were removed from the freezer, partially thawed, slime and scales removed, rinsed in tap water, and rinsed in deionized water. Fish were then filleted with the skin left on and cut into small cubes. The tissue was passed 3 times through a Kitchen-Aid food grinder and homogenized by stirring to a consistent texture and color. Subsamples from the homogenate were placed into previously cleaned 2-ounce glass containers (I-Chem 200®). Sample jars were assigned a laboratory identification number and transported to MEL for analyses. Excess homogenate was placed in an appropriate container, labeled, and archived frozen at –20° C.

After fillets were removed, the sex of the fish was determined (when possible) and recorded. Otoliths and scales were removed from fish that were analyzed individually and sent to Washington Department of Fish and Wildlife (WDFW) biologists to determine age.

All utensils used for processing tissue samples were cleaned to prevent contamination of the sample. Utensils included stainless steel bowls, knives, and tissue grinding appliances having plastic, wood, bronze, and stainless steel parts. All utensils for fish tissue sampling were cleaned with the following procedure: hand wash with soap (Liquinox) and hot water, hot tap water rinse, 10% nitric acid rinse, and a final deionized water rinse. Utensils were air-dried and wrapped in aluminum foil until used. Fish were filleted and tissues processed on the dull side of heavy-duty aluminum foil covering a nylon cutting board laid on the workbench. Each fish was processed on a new/clean sheet of aluminum foil with cleaned utensils to prevent contamination from one sample to the next.

Sediment

The collection, handling, and processing of sediment samples was guided by *Recommended Protocols for Measuring Conventional Sediment Variables in Puget Sound* (EPA, 1986) and EAP's *Standard Operating Procedures* for *Freshwater Sediment Sampling* (Blakley, 2008). Profundal sediment samples were collected with a single grab using a 0.02 m^2 stainless steel petite ponar. The overlying water was siphoned away, and the top two centimeters were removed with a stainless steel spoon.

Sub-samples were homogenized on the boat using stainless steel bowls and spoons and then placed in pre-cleaned jars according to MEL protocol (MEL, 2008). Samples were packed in ice and shipped to MEL within 96 hours. All utensils used to collect and prepare samples were cleaned in the same manner as utensils used in fish tissue processing.

Water

Two water samples were obtained at the deepest part of the lake using a one-liter Kemmerer sampler. The samples were obtained at the mid-points of the hypolimnion and epilimnion in stratified lakes. At well-mixed lakes, the samples were obtained at 10-15% and 85-90% of total depth. Samples were retrieved and placed in the proper pre-cleaned bottles for analysis of alkalinity, chlorophyll, and DOC.

Conductivity, pH, dissolved oxygen, and water temperature were measured at the water sampling sites using a Hydrolab® following EAP's *Standard Operating Procedures for Hydrolab® DataSonde® MiniSonde® Multiprobes* (Swanson, 2007). All units were calibrated prior to field use, and Winkler titrations were performed as a measure of quality control for the dissolved oxygen readings.

Laboratory Procedures

MEL analyzed all samples with the exception of grain size which was performed by Columbia Analytical Services (CAS). Table 3 contains information on the analytical methods used to perform laboratory analyses.

Table 3. Analytes and Analytical Methods.

Analyte	Matrix	Method
Mercury	Tissue	CVAA, EPA 245.6
Mercury	Sediment	CVAA, EPA 245.5
Total Organic Carbon		PSEP-TOC
Grain Size		PSEP, Sieve and Pipette
Alkalinity	Water	SM2320B
Dissolved Organic Carbon		EPA 415.1
Chlorophyll		SM10200H3M

CVAA = Cold Vapor Atomic Absorption.
PSEP = Puget Sound Estuary Protocol.
SM = Standard Method.

Total mercury, as opposed to methylmercury, has been the target analyte used in other fish tissue studies in Washington due to its relative simplicity and lower cost. Methylmercury, the bioaccumulative and toxic form of mercury in fish tissue, accounts for more than 95% of the mercury in fish tissue where it is associated with muscle proteins (Bloom, 1995; Driscoll et al., 1994).

Data Quality Assessment

Results from MEL included case narratives (Momohara, 2009) describing results from the quality control and quality assurance procedures used during analyses. These include holding times, instrument calibration, method blanks, matrix spikes, laboratory duplicates, laboratory control samples, and Standard Reference Material (SRM) 1946 (Lake Superior fish tissue) from the National Institute of Standards and Technology.

Overall data quality was generally good for samples analyzed by MEL and CAS. A complete description of quality assurance tests and measurement quality objectives (MQOs) can be found in Appendix B.

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Results

Results and ancillary data for fish, sediment, and water samples collected in 2008 are graphically presented below. Complete results for all samples are located in Appendix C.

Fish

Individual Bass

Figures 3 and 4 display length and weight of the individual fish tested for mercury. Above the bars is the length/weight of the smallest fish expressed as a percentage of the largest fish. Target length range for individual fish as outlined by the project plan is 250-460 mm.

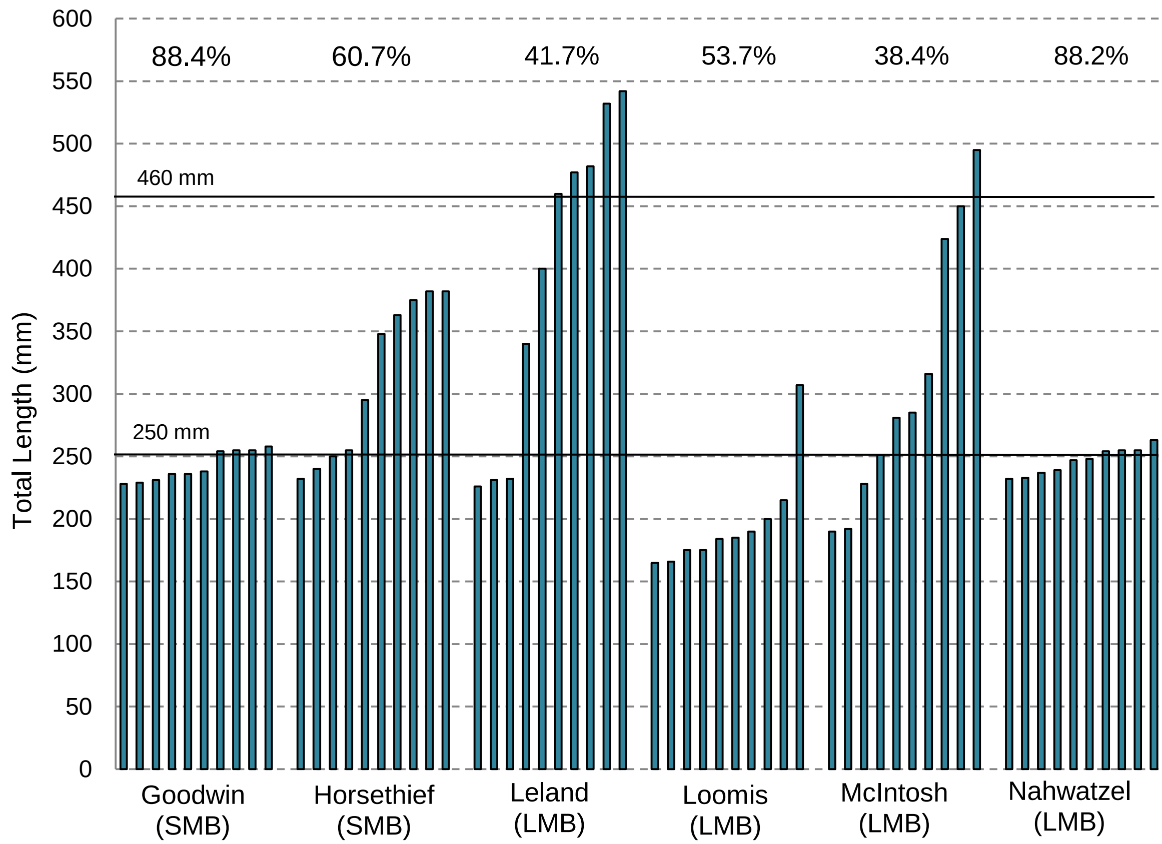

Figure 3. Total Lengths of Individual Bass.
(LMB = largemouth bass; SMB = smallmouth bass.)

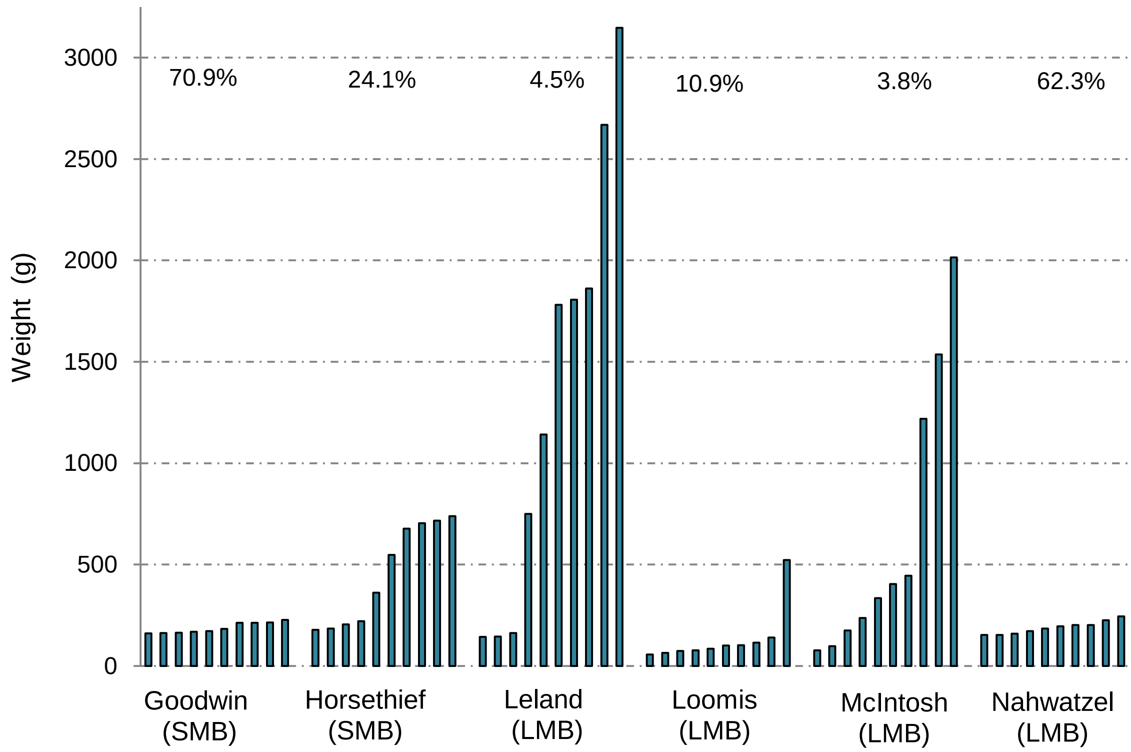

Figure 4. Weights of Individual Bass.
(LMB = largemouth bass; SMB = smallmouth bass.)

Fish length varied considerably by study lake. While all 6 lakes contained at least one fish within the target range, Nahwatzel, Loomis, and Goodwin contained an average fish size less than 250 mm. Range in length also varied widely between lakes. Goodwin and Nahwatzel contained the smallest length ranges, with the smallest fish being approximately 88% the length of the largest fish. McIntosh and Leland contained a much larger size range, with smallest fish being approximately 40% the length of the largest fish.

Fish weight contained the same overlying spread in data as length. The weight ranges were even greater than length when expressed as the smallest fish percentage of the largest fish. The smallest fish at Leland and McIntosh were less than 5% of the weight of the largest fish. Variations in length and weight must be considered when interpreting mercury concentrations as fish size, along with age, have a large effect on mercury concentrations (Furl and Meredith, 2008; Furl, 2007; Furl et al., 2007; Fischnaller et al., 2003; Serdar et al., 2001). Boxplots displaying the normality of fish length and weight data are found in Appendix C.

Figure 5 displays mercury concentrations in the tissue samples along with the age of each fish.

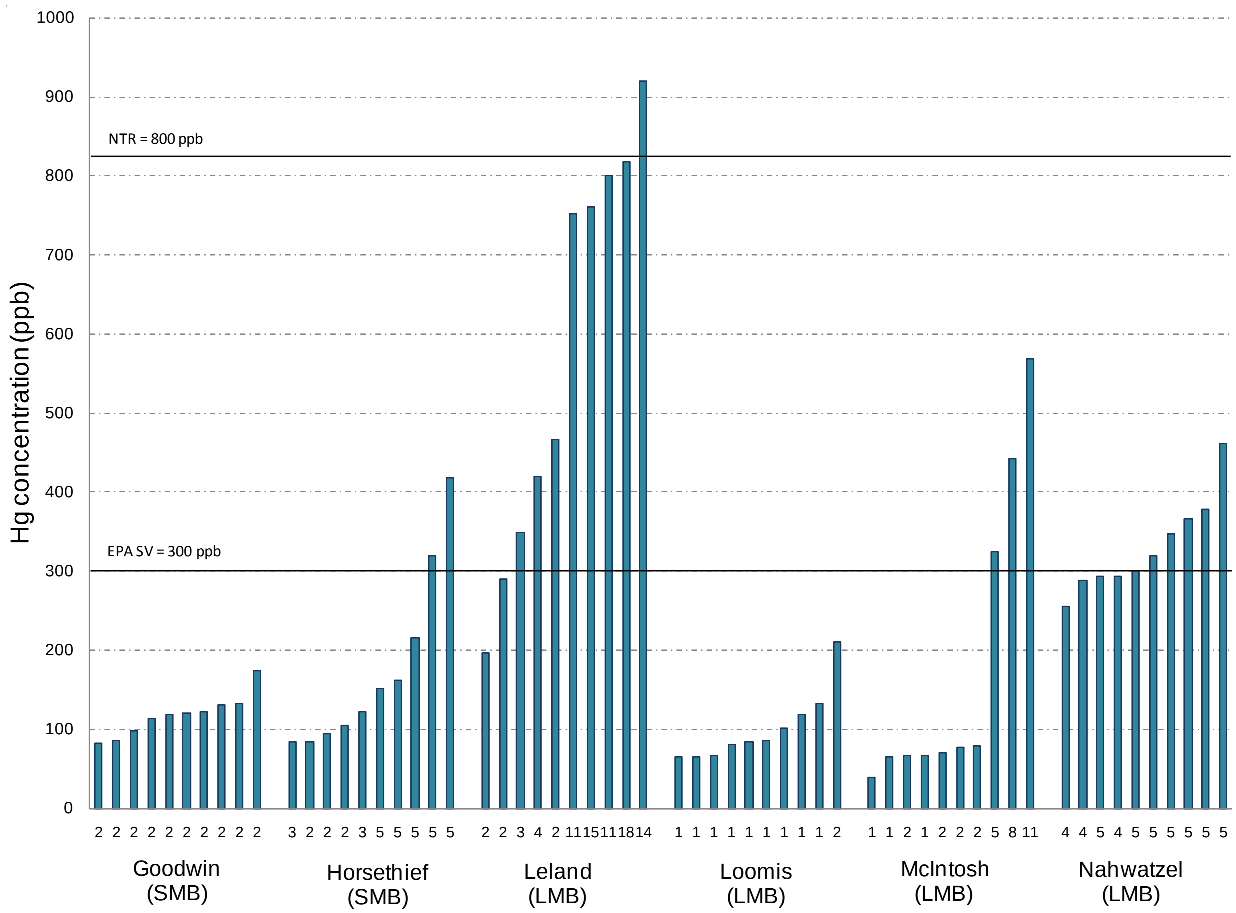

Figure 5. Mercury Concentrations and Ages of Individual Bass.
(LMB = largemouth bass; SMB = smallmouth bass)

Mercury concentrations in individual bass ranged from 39.8 ppb (McIntosh Lake) to 920 ppb (Leland Lake). No walleye were retained for individual analysis despite being targeted. Approximately 30% of the individual fish exceeded EPA's recommended mercury criteria of 300 ppb. Thirteen of the 18 fish exceeding the EPA criterion were from Leland Lake and Lake Nahwatzel. A single largemouth bass from Leland Lake exceeded the NTR criterion of 825 ppb.

Figure 6 is a boxplot graphically displaying the normality (minimum, 25th percentile, median, 75th percentile, and maximum) of mercury concentrations in the individual bass.

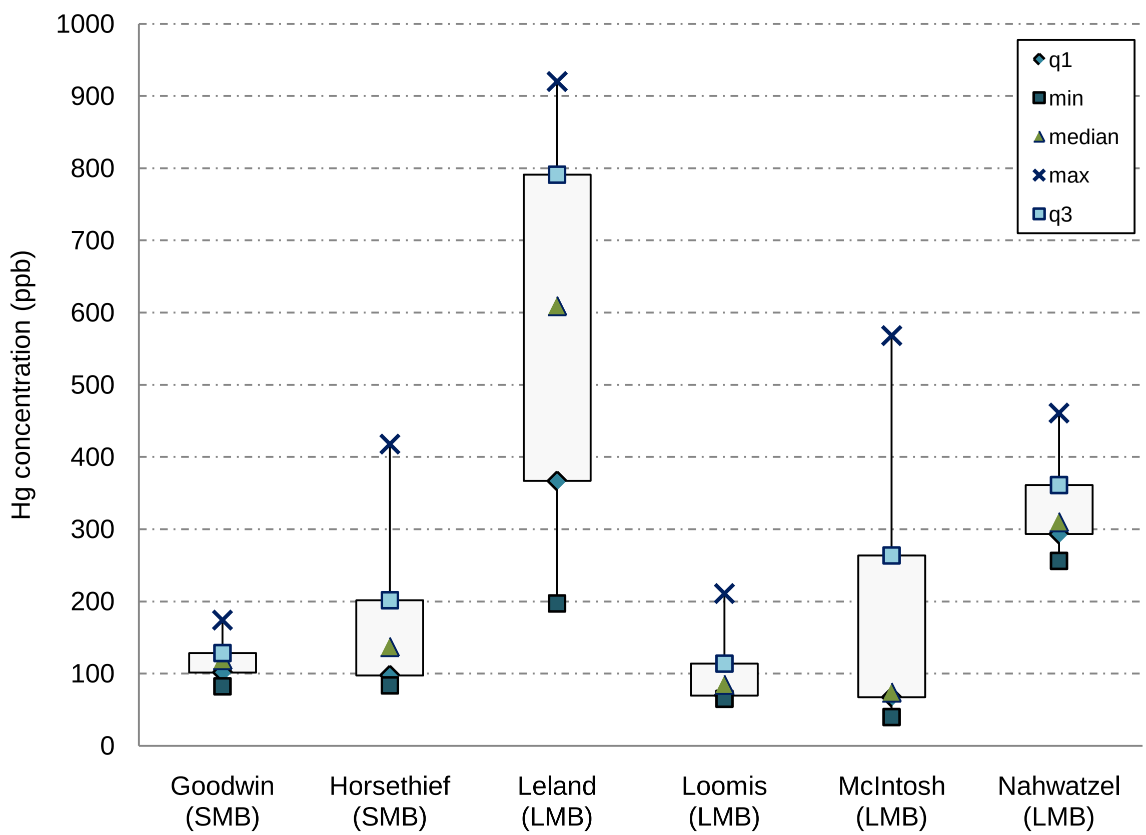

Figure 6. Boxplots of Mercury Concentrations in Individual Bass.
(LMB = largemouth bass; SMB = smallmouth bass; q^1 *=25th percentile;* q^3 *= 75th percentile)*

Table 4 contains summary statistics on the physical attributes and mercury concentrations for the individual fish collected from each lake.

Table 4. Summary Statistics for Individual Bass.

Lake	Statistic	Total Length (mm)	Weight (g)	Age (yr)	Mercury (ppb)
Goodwin (SMB)	Mean	242	188	2	117.7
	Std. Dev.	12	26	0	26.4
	Minimum	228	161	2	82
	Maximum	258	227	2	174
Horsethief (SMB)	Mean	312	453	3.7	175.7
	Std. Dev.	64	246	1.4	112.1
	Minimum	232	178	2	84
	Maximum	382	738	5	418
Leland (LMB)	Mean	392	1361	7.2	577.5
	Std. Dev.	126	1073	6.5	259.5
	Minimum	226	143	1	197
	Maximum	542	3148	18	920
Loomis (LMB)	Mean	196	134	1.1	101.0
	Std. Dev.	42	139	0.3	44.8
	Minimum	165	57	1	65
	Maximum	307	522	2	211
McIntosh (LMB)	Mean	311	654	3.5	180.2
	Std. Dev.	109	684	3.4	192.0
	Minimum	190	77	1	40
	Maximum	495	2015	11	568
Nahwatzel (LMB)	Mean	246	189	4.7	330.4
	Std. Dev.	11	31	0.5	59.5
	Minimum	232	152	4	256
	Maximum	263	244	5	461
All Lakes	Mean	283	496	3.7	247.1
	Std. Dev.	96	667	3.5	215.7
	Minimum	165	57	1	40
	Maximum	542	3148	18	920

SMB = smallmouth bass.
LMB = largemouth bass.
Std. Dev. = standard deviation.

Composite Fish

Mercury concentrations for composite fish samples are graphed in Figure 7. Physical data describing average size for fish composites are included in Appendix C.

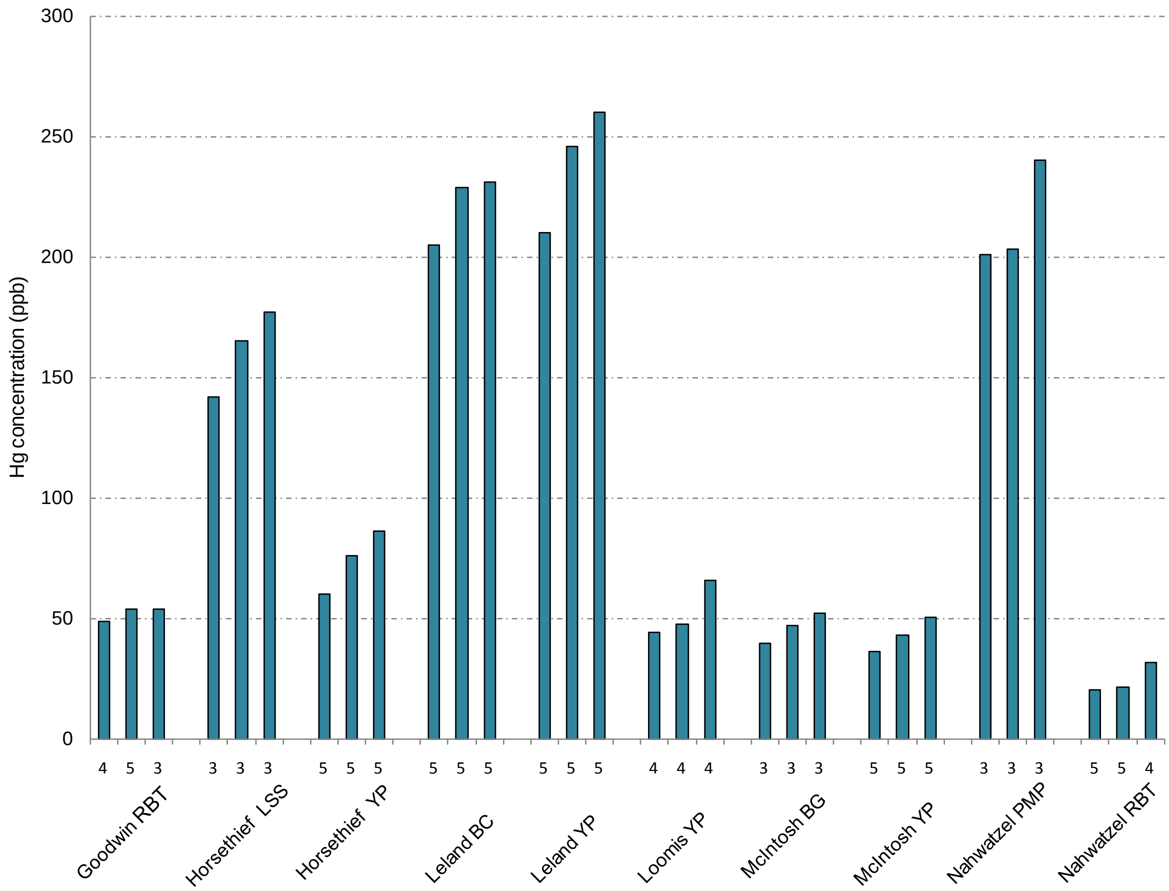

Figure 7. Mercury Concentrations in Composite Fish Samples.
(BC = black crappie; BG = bluegill; LSS = largescale sucker; PMP = pumpkinseed; RBT = rainbow trout; YP = yellow perch)

Composite sample mercury concentrations ranged from 20 ppb (Lake Nahwatzel rainbow trout) to 260 ppb (Leland Lake yellow perch). Patterns in composite mercury concentrations were generally similar to the patterns displayed by individual bass. The highest concentrations were found in Leland Lake black crappie and yellow perch and Lake Nahwatzel pumpkinseed. No composite samples tested exceeded the EPA guidelines of 300 ppb.

Sediment

Three sediment grabs were obtained from each study lake with the exception of Goodwin. Sediment analyses included mercury, TOC, and grain size. Three additional replicate grabs were retrieved at McIntosh. Averaged results for McIntosh do not include replicate samples. Figures 8 and 9 display the mean and range of mercury, percent fines (< 62 u), and TOC in sediments.

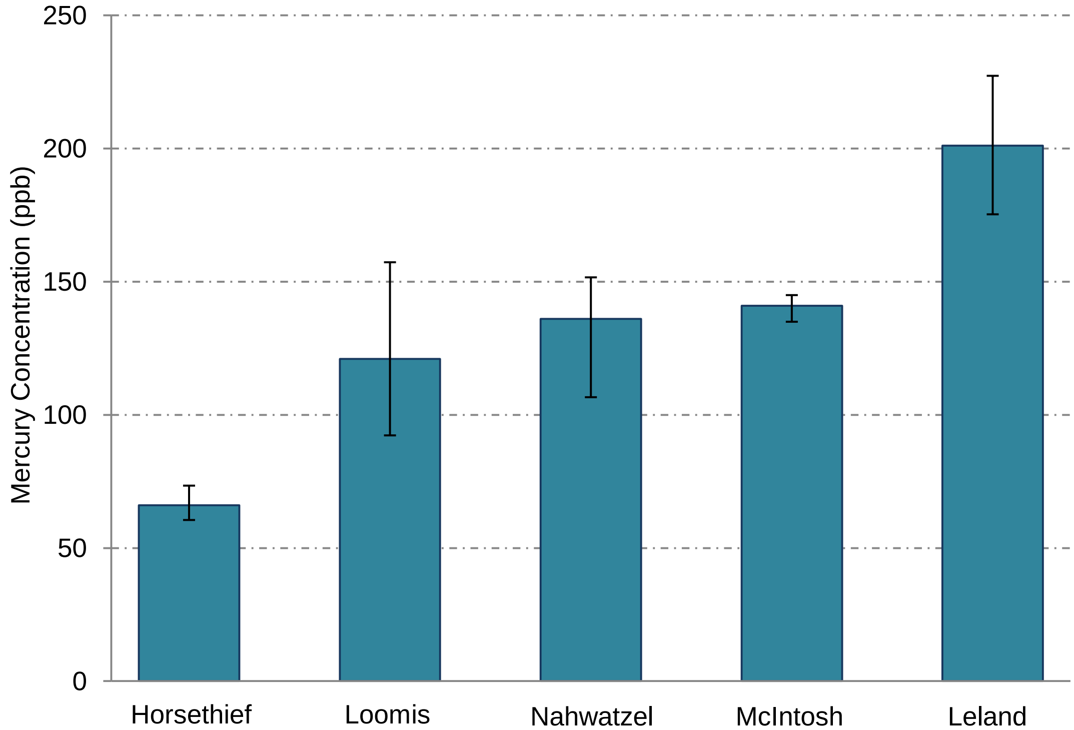

Figure 8. Average Mercury Concentrations in Sediments.
(Error bars reflect range of concentration.)

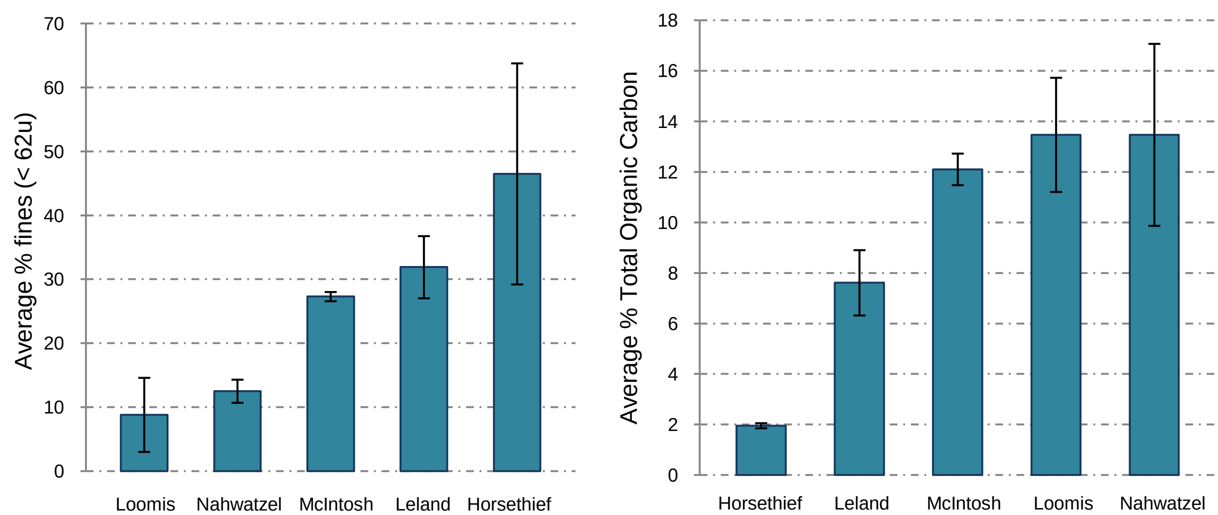

Figure 9. Average Percent Fines and Average Percent Total Organic Carbon in Sediments.
(Error bars reflect range of concentration.)

Mercury concentrations, percent TOC, and grain size composition varied widely among the 6 lakes. However, all 3 parameters were found within ranges previously recorded in mercury trends monitoring reports (Furl and Meredith, 2008; Furl, 2007). Average mercury sediment concentrations ranged from 66–201 ppb. Percent TOC ranged from 2.0-13.5. Grain size composition ranged from 8.8-46.5 percent fines (< 62u).

Water

Results from the upper and lower water grab samples are displayed in Table 5. Replicate samples were taken from McIntosh Lake, but were not averaged into the displayed values.

Table 5. Upper and Lower Water Grabs.

Lake	Collection Date	Depth (meter)	Chl-a (ug/L)	Alkalinity (mg/L)	DOC (mg/L)
Horsethief	7/8/2008	6.0	1.9	46	2.2
		14.5	0.69	48	2.0
Leland	7/9/2008	1.0	25.7	32	10.3
		5.0	3.0	35	10.1
Loomis	7/10/2008	0.0	2.6	33	7.0
		1.0	3.0	33	7.0
McIntosh	7/7/2008	0.5	8.3	23	4.3
		2.0	8.4	23	3.9
Nahwatzel	7/11/2008	1.0	1.4	7.4	2.0
		5.0	2.0	7.3	2.0

Chl-a = chlorophyll-a.
DOC = dissolved organic carbon.
Note: Water and sediment data from Goodwin Lake will be collected in 2009.

Discussion

Relationships Between Mercury Concentrations and Fish Size and Age

Mercury concentrations were regressed against fish length, weight, and age using simple linear regression to examine the variability explained by each of the physical parameters. Coefficients of determination (r^2) are displayed in Table 6, and scatterplots are located in Appendix D.

Table 6. Coefficients of Determinations (r^2) for Simple Linear Regressions with Mercury Concentrations.

Lake	r^2 Value		
	Length	Weight	Age
Goodwin	**0.029**	**0.0003**	----
Horsethief	0.452	0.425	0.507
Leland	0.765	0.689	0.841
Loomis	0.915	0.863	0.744
McIntosh	0.834	0.911	0.975
Nahwatzel	0.697	0.683	**0.346**

Bolded values indicate $p > 0.05$.

Each of the physical parameters explained a large amount of the variance (generally > 50%) in mercury concentrations (when $p < 0.05$). No significant relationships between mercury concentrations and length, weight, and age were apparent at Goodwin Lake.

Standard-Sized Fish Concentrations and Factors Affecting Bioaccumulation

Multiple regression analysis was used to estimate mercury concentrations for a standard-sized bass to allow for comparisons between lakes after fish length was considered. The same technique for estimating standard-sized concentrations was used in previous Washington State mercury reports (Furl and Meredith, 2008; Furl, 2007; Furl et al., 2007; Fischnaller et al., 2003).

A standard-sized 356-mm fish was estimated by calculating the following multiple regression formulas:

$$Log_{10}(Hg) = M + \{B1 * Log_{10}(356\ mm)\} + \{B2 * (Log_{10}(356\ mm))^2\}$$
$$10^{Log_{10}(Hg)} = Hg\ Concentration\ at\ 356mm$$

Figure 10 displays results using the multiple regression formula to calculate standard size (356-mm) bass for the first four years of mercury trends studies.

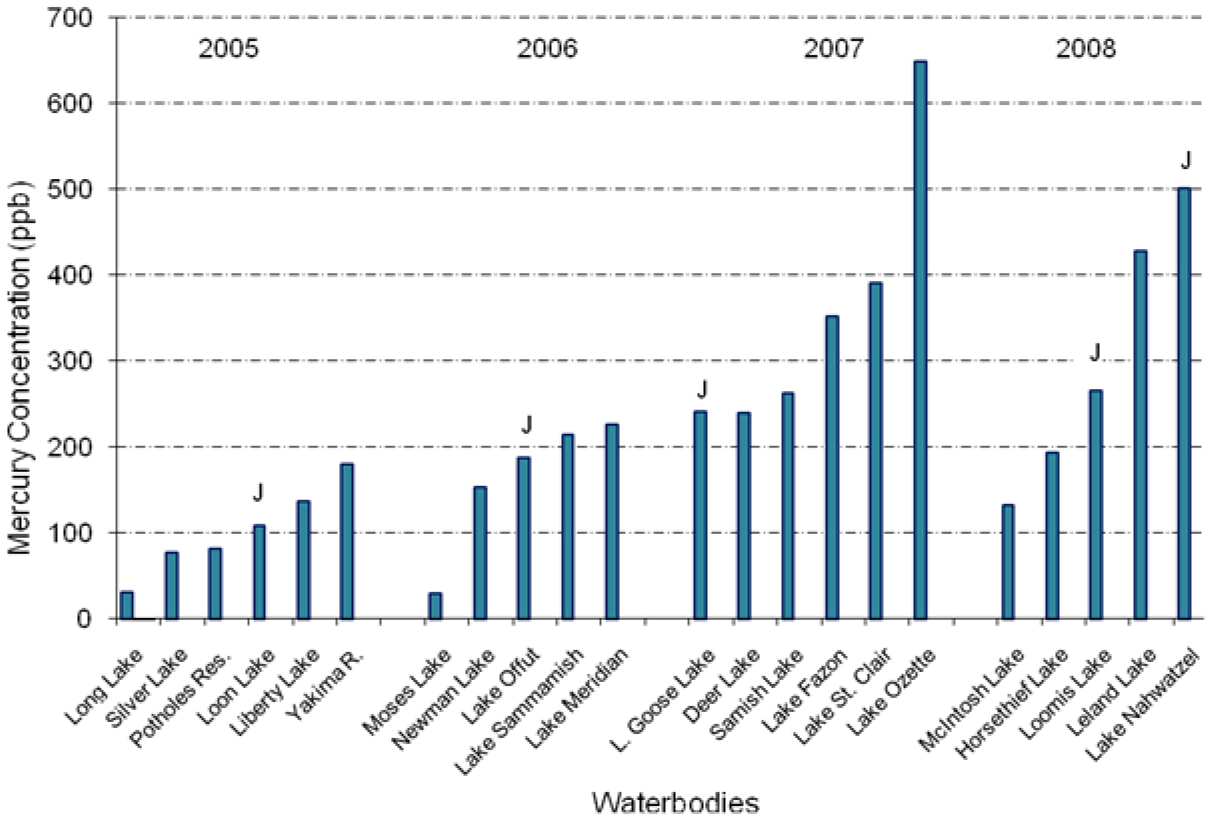

Figure 10. Projected Mercury Concentrations for a 356-mm Bass.
(J = Concentrations were not estimated using multiple regression.)

Regression coefficients (M, B1, B2), products, and standardized mercury concentrations are listed in Appendix D. Concentrations for Loon, Lower Goose, and Loomis Lakes were estimated using simple linear regression. A positive relationship between size and mercury concentration was apparent for these lakes, but no fish within the 356-mm size class were retained. The standard-sized concentration for Offutt Lake was estimated from samples near 356-mm. No relationship was found between length and mercury at Offutt Lake making it unsuitable for regression estimates.

No 356-mm size estimates were made for Goodwin Lake. Fish from Goodwin were not within the 356-mm size range, and a positive relationship between mercury and size was not apparent.

A standard-size concentration of 500 ppb was assigned to Lake Nahwatzel. Standard-size bass concentrations at Lake Nahwatzel were highly elevated (844 ppb) using simple linear regression. The simple linear regression estimate was extrapolated well beyond the range of sizes recorded in the dataset (232 – 263 mm) (Figure 11).

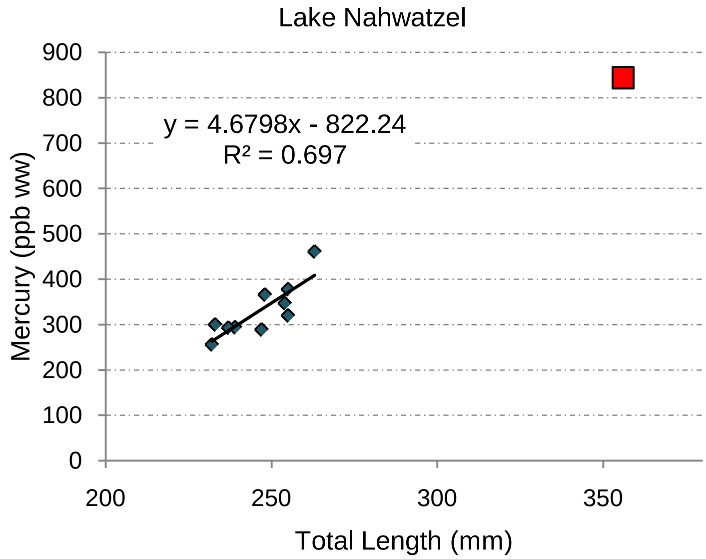

Figure 11. Scatterplot of Mercury Concentrations versus Length for Lake Nahwatzel.
(The square indicates standard size (356-mm) bass concentration as determined through linear regression.)

Mercury concentrations from the Lake Ozette and Leland Lake fish within the Lake Nahwatzel size range were plotted (Figure 12). High concentrations (> 800 ppb) along with a greater size range have been measured in both Leland and Ozette, allowing for more accurate estimations.

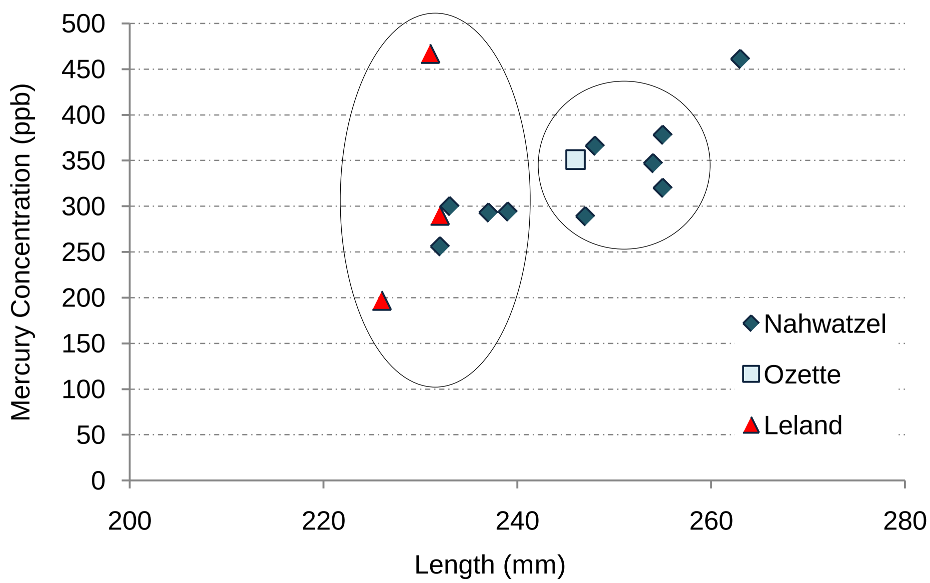

Figure 12. Mercury Concentrations for Nahwatzel, Ozette, and Leland Bass for the 220–280-mm Size Range.

Concentrations in Lake Nahwatzel bass were found to be both lower and higher than concentrations in similar sized fish from Ozette and Leland. The scatterplot indicates tissue concentrations at all 3 lakes are similar across the 230–260-mm size range. Standard-sized bass concentrations at Ozette and Leland are 648 and 428 ppb respectively.

Tissue Mercury Correlations with Environmental Variables

Correlation matrices were produced to evaluate relationships between 15 water, sediment, and morphology variables and standard-sized (356 mm) mercury concentrations. Data from previous mercury monitoring reports (2005, 2006, and 2007) were included in the correlation analysis, for a total of 21 waterbodies. The statewide dataset was sub-divided into eastern and western waterbodies for additional correlation analysis.

Correlations were performed on $\log_{10}$ transformed data using Pearson and Spearman Rank. The Pearson correlation can be affected by outliers which may greatly increase or decrease the strength of the relationship. Spearman Rank is a non-parametrical test (used when normality of the data is unknown) which ranks data in order of increasing value before calculating coefficients.

Hydrolab measurements (pH, temperature, and conductivity) were divided into top and bottom values, similar to the water grabs. Hydrolab values from depths 1-3 meters below the surface represented the "top" measurement, while 0.5 – 2 meters off the bottom substrate of the waterbody were used as the "bottom" measurement. Alkalinity and DOC measures were averaged (from top and bottom water grabs) since depth did not affect their values. Table 7 displays correlation coefficients (r) for the 2 tests on all 3 datasets.

Variables correlating the strongest with standard-sized fish concentrations from the statewide dataset included mercury in sediments (+) and alkalinity (-). Surface area also displayed a strong inverse relationship using the Pearson correlation.

No parameters had a consistently strong relationship (> +0.5 or < -0.5) across all 3 geographical groups using both correlation tests. The strongest relationships across all 3 groups were found with sediment mercury concentration (+), upper water column pH (-), and alkalinity (-).

Over the first four years of monitoring, average sediment mercury concentrations have contained considerable variability between the 3 sediment grabs (6% – 90% relative percent difference) at each site, and may not be representative of true concentrations. Additionally, larger scale studies have not found mercury concentrations in sediments to correlate well with fish tissue concentrations (Hanten et al., 1998 and Grieb et al., 1990).

The effects of low pH and alkalinity have been well established with elevated levels of mercury in fish (Hanten et al., 1998; Grieb et al., 1990; and Hrabik and Watras, 2002). The increased accumulation of mercury in low-pH systems is attributed to increased microbial methylation in acidic waters (Xun et al., 1987). The inverse relationship with alkalinity and mercury levels is likely related to a waterbody's inability to neutralize acidic inputs when alkalinity is very low.

Table 7. Correlation Matrix Displaying Coefficient Values for Relationships between Standard-Sized Fish Mercury Concentrations and Sediment, Water, and Morphology Variables.

Variable Grouping	Parameter	Statewide		Eastern		Western	
		Pearson Coefficient	Spearman Rank Coefficient	Pearson Coefficient	Spearman Rank Coefficient	Pearson Coefficient	Spearman Rank Coefficient
Sediment	Mercury	**0.633**	**0.713**	0.261	0.2	**0.676**	0.382
	Total Organic Carbon	0.373	0.413	0.152	0.018	-0.16	-0.018
Water	pH - Top	-0.425	-0.423	**-0.64**	**-0.721**	-0.2	-0.373
	pH - Bottom	-0.353	-0.355	**-0.72**	**-0.529**	0.059	-0.042
	Temperature - Top	0.408	0.486	0.292	0.248	0.425	0.236
	Temperature - Bottom	-0.289	-0.23	-0.399	-0.2	-0.269	0.03
	Conductivity - Top	-0.336	-0.256	-0.343	-0.37	-0.121	-0.145
	Conductivity - Bottom	-0.086	-0.029	-0.008	-0.248	0.169	0.297
	DOC	0.322	0.226	0.309	0.176	-0.026	0.009
	Alkalinity	**-0.62**	**-0.516**	-0.436	-0.479	-0.446	-0.364
Morphology	Lake Volume	-0.337	-0.277	**-0.546**	**-0.595**	0.147	0.009
	Surface Area	**-0.549**	-0.426	**-0.731**	**-0.683**	-0.099	-0.045
	Drainage Area	-0.427	-0.335	**-0.824**	-0.486	-0.072	-0.082
	Maximum Depth	-0.058	-0.084	-0.361	**-0.513**	0.47	0.309
	Mean Depth	0.176	0.147	-0.132	0.05	**0.512**	0.418

DOC = Dissolved organic carbon.
Bolded values indicate strong relationships (> +0.5 or < -0.5).

Trends Assessment

Spatial

Waterbodies with estimated standard-size concentrations from the first 4 years of the study were mapped (Figure 13) to examine spatial differences across the state.

As noted in the 2007 report, fish tissue concentrations in western Washington were elevated when compared to eastern Washington. Western Washington waterbodies were compared to eastern Washington waterbodies using a two-tailed t-test to see if significant differences exist. The test showed a significant difference ($t = 2.67$, $p < 0.05$) between the 2 groups, with a higher average in western Washington (335.4 to 139.3). Site selection was not randomized for evaluation of differences between eastern and western Washington.

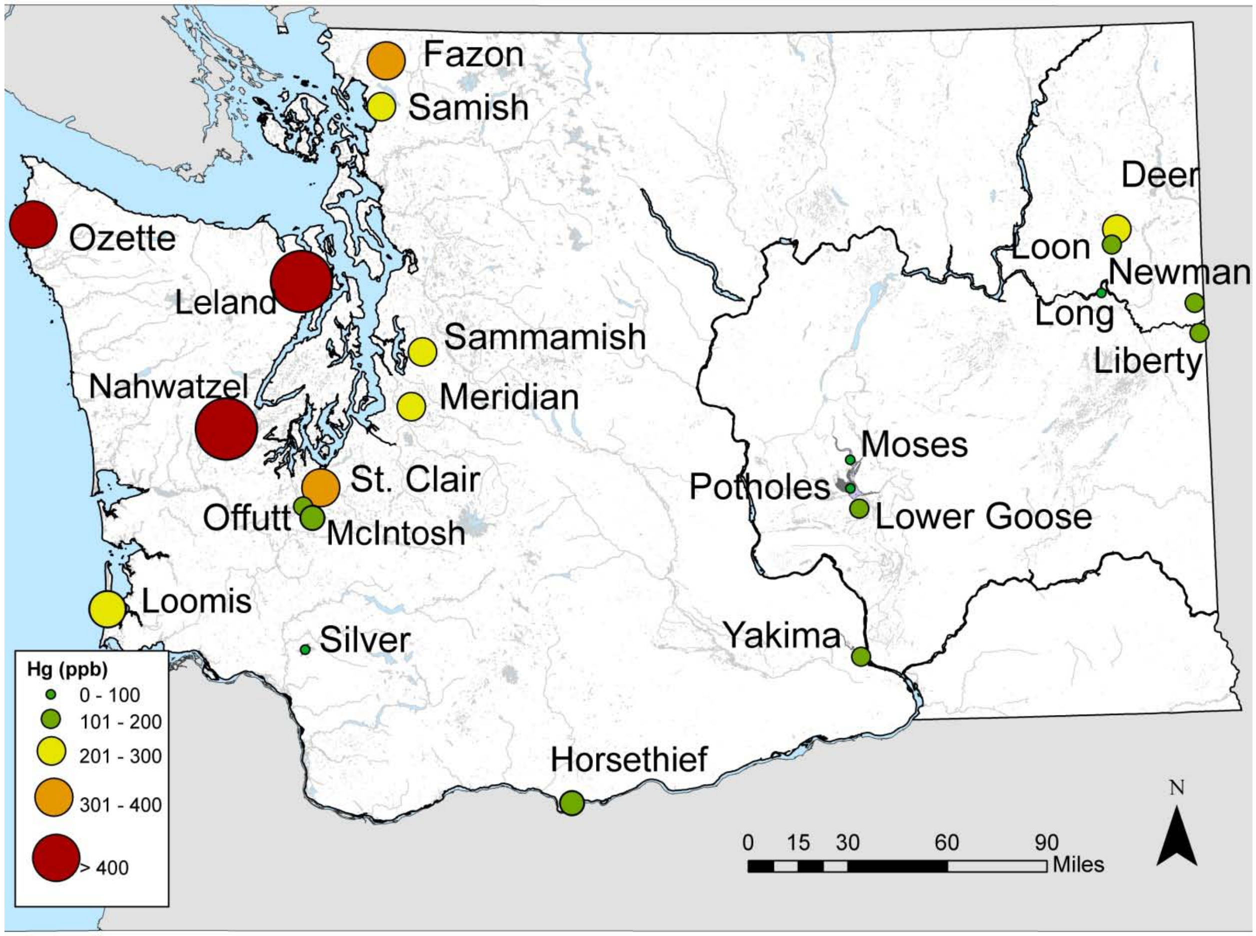

Figure 13. Map of Standard-Sized Bass Concentrations, 2005-2008.

Atmospheric Deposition

Ongoing measurements of mercury wet deposition are occurring at 2 mercury deposition network (MDN) sites located in Washington State. The Makah station is located 15 kilometers from the north end of Lake Ozette and has been operating since March 2007. The second station is located in Seattle (near Lake Sammamish in Figure 13). Wet deposition measurements have been conducted at the Seattle station since 1996. Precipitation samples were collected and analyzed using methods specified by the network protocol (Welker and Vermette, 1996).

Mercury wet deposition and precipitation values for the 2 Washington State MDN stations are presented in Table 8. The Makah station measured slightly higher mercury deposition than the Seattle station over the first 12 months of operation. Over the same time period, precipitation at the Makah station was nearly 3 times greater than the Seattle station. Wet deposition values for the 10-month period starting March 2008 were similar at both stations. Precipitation ratios between sites were similar to the first year of monitoring (2007), although the sites have received less precipitation. Yearly wet deposition at the Seattle station averaged 6.38 $\mu g/m^2$ (Standard deviation = 0.80) from 2001 – 2006 (http://nadp.sws.uiuc.edu/mdn/).

Table 8. Wet Deposition of Mercury and Precipitation Data from MDN Stations in Washington State, 2007 and 2008.

MDN Station	March 2007 – February 2008 (12 months)		March 2008 – December 2008 (10 months)	
	Wet Deposition (µg/m^2)	Precipitation (cm)	Wet Deposition (µg/m^2)	Precipitation (cm)
WA03 – Makah	7.59	223	4.31	101
WA13 - Seattle	6.55	77	4.88	38

Includes preliminary data not available on the web.

The highest estimated standard-sized fish tissue concentrations of mercury found during the first 4 years of monitoring were at Leland Lake, Lake Nahwatzel, and Lake Ozette. All 3 lakes are located within the Olympic Peninsula and removed from large population centers. Atmospheric deposition of mercury has been similar at the Makah fish hatchery and urban Seattle. Causes of the elevated tissue values are unknown; Furl et al. (2009) found that high sedimentation rates caused by logging within the Ozette drainage increase mercury fluxes to the lake. All 3 lake drainages have experienced substantial logging over the past 50 years.

Human Health Criteria Exceedances

While the criterion recommended by EPA in 2001 for mercury in freshwater fish is 300 ppb, the NTR criterion of 825 ppb ww remains as the value used in Washington's water quality standards for regulatory purposes. DOH's process for establishing fish consumption advisories uses an approach similar to the EPA's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories Vol. 1-4* (EPA, 2000). Information about DOH's data evaluation of fish toxics data is detailed in Appendix E. Summary statistics displaying percentages of fish samples analyzed by this study exceeding various criteria are included in Table 9.

Table 9. Percent of Individual and Composite Fish Samples From the 2008 Study Lakes That Exceeded Human Health Criteria.

Criteria	Percent Exceeding Criteria	
	Individual	Composite
EPA Screening Values for Subsistence Fisherman (49 ppb)	98	67
EPA Recommended Criteria (300 ppb)	30	0
EPA Screening Values for Recreational Fisherman (400 ppb)	18	0
National Toxics Criteria (825 ppb)	2	0

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Conclusions

During 2008, 60 individual bass and 30 composite samples were analyzed for total mercury as part of the fourth year of a 5-year study to gather information on mercury trends in resident freshwater fish from Washington State.

In addition to fish tissue, water and sediment samples were collected to evaluate other factors that may influence mercury uptake in fish.

Fish samples were obtained from the following 6 lakes in 2008: Lake Goodwin, Horsethief Lake, Leland Lake, Loomis Lake, McIntosh Lake, and Lake Nahwatzel.

Consistent with previous Ecology mercury fish tissue studies, mercury concentrations were generally related to fish age and size within a particular waterbody, and bass had higher concentrations than other species present. Thirty percent of individual bass tested did not meet (exceeded) the EPA's recommended water quality criterion of 300 ppb. All fish composite samples met this threshold.

Other significant findings include:

- Spearman Rank and Pearson correlation matrices were produced examining relationships between water and sediment variables to standard-sized (356-mm) bass over the first 4 years of monitoring, 2005-08. Environmental variables displaying the strongest relationships were sediment mercury concentration (+), pH (-), and alkalinity (-).

- A continued pattern of widespread low mercury levels in fish tissue was apparent in eastern Washington waterbodies when compared to western Washington. Based on a standard-sized (356-mm) bass, concentrations in western Washington (335 ppb) were significantly higher than eastern Washington (139 ppb) using an unpaired t-test.

- During the first 4 years of monitoring, the highest estimated mercury levels in standard-sized fish tissue were found at Leland Lake, Lake Nahwatzel, and Lake Ozette. All 3 lakes are located within the Olympic Peninsula and removed from large population centers. Causes of elevated tissue values are unknown.

Recommendations

As a result of the 2008 study, recommendations for future mercury trends studies include:

- Sample waterbodies in regions where data are lacking in the 5^{th} year of the project, 2009. Current areas of the state lacking data include northeast, southeast, and southwest Washington.

- Continue to seek walleye for individual trends analysis.

- Use bass, walleye, or northern pikeminnow samples to determine whether a waterbody has not met National Toxics Rule or EPA criterion. These species typically have the highest mercury concentrations within Washington waterbodies.

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Appendices

A. Sample Site Descriptions

B. Quality Assurance Data

C. Biological, Sediment, and Water Quality Measures

D. Statistical Analyses

E. Fish Tissue Data Evaluation by Ecology and DOH

F. Glossary, Acronyms, and Abbreviations

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Appendix A. Sample Site Descriptions

Table A-1. Sample Site Descriptions for the 2008 Study.

Site Name (Lake)	Latitude*	Longitude*	WBID	County	EIM "User Location ID"	WRIA
Goodwin	48.142404	-122.297485	WA-07-9280	Snohomish	Goodwin-F	7
Horsethief	45.645736	-121.10236	---	Klickitat	Horsethief-F	3
Leland	47.895425	-124.043303	WA-17-9050	Jefferson	Leland-F	17
Loomis	46.43935	-124.043303	WA-24-9040	Pacific	Loomis-F	24
McIntosh	46.867972	-122.763758	WA-13-9090	Thurston	McIntosh-F	13
Nahwatzel	47.243021	-123.333259	WA-22-9060	Mason	Nahwatzel-F	22

*NAD83 HARN.
WBID - Waterbody Identification.
EIM - Ecology's Environmental Information Management Database.
WRIA - Water Resource Inventory Area.

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Appendix B. Quality Assurance Data

Fish

MEL performed fish tissue analyses for mercury from January 7 – 23, 2009. Samples were received by the laboratory frozen and in good condition. Analyses were performed within EPA established holding times. Data quality was assessed through MQOs outlined in the project plan (Seiders, 2006). Table B-1 lists the quality assurance test along with its quality objective.

Table B-1. Measurement Quality Objectives for Fish Tissue Analysis.

Parameter	Matrix	Reporting Limit	Accuracy	Check Standard (% recovery limit)	Duplicate Sample (RPD)	Matrix Spike (% recovery limit)
Mercury, total	Tissue	0.017 mg/kg, wet	+/- 15% of SRM value	80-120%	<20%	75-125%

All MQOs were met with the exception of a single SRM analysis. No action was taken since LCS, blanks, matrix spike (MS), and MS duplicates were recovered at acceptable rates.

Table B-2. Matrix Spike Recoveries and Duplicates.

Sample Number	Recovery (%)	RPD (%)
B09A029-MS1 B09A029-MSD1	102 102	0.0
B09A1243-MS1 B09A124-MSD1	113 109	3.6
B09A148-MS1 B09A148-MSD1	99 102	3.0
B09A148-MS2 B09A148-MSD2	102 104	1.9
M08L014-MS1 M08L014-MSD1	99 103	4.0
Mean	103.5	2.5

Table B-3. Laboratory Blanks.

Sample Number	Result (ppb)
B09A029-BLK1	0.0170 U
B09A124-BLK1	0.0170 U
B09A148-BLK1	0.0170 U
B09A148-BLK2	0.0170 U
M08L014-BLK1	0.0125 U

U - undetected at the level indicated.

Table B-4. Standard Reference Material.

Sample Number	Recovery (%)
B09A029-SRM1	104
B09A124-SRM1	110
B09A148-SRM1	101
B09A148-SRM2	100
M08L014-SRM1	143

Table B-5. Laboratory Control Samples.

Sample Number	Recovery (%)
B09A029-BS1	104
B09A124-BS1	113
B09A148-BS1	108
B09A148-BS2	108
M08L014-BS1	108

Sediment

Sediment analyses were conducted during July and August, 2008. MEL received the samples in good condition and at the proper temperature range. MEL performed analyses of mercury and TOC. Columbia Analytical Resources conducted the grain size analysis. All analyses were performed within established holding times. MQOs for sediment analyses as outlined by the project plan appear in Table B-6.

Table B-6. Measurement Quality Objectives for Sediment Analysis.

Parameter	Matrix	Reporting Limit	Check Standard (% recovery limit)	Duplicate Sample (RPD)	Matrix Spike (% recovery limit)
Mercury, Total	Sediment	0.005 mg/kg, dry	85-115%	<20%	75-125%
Total Organic Carbon	Sediment	0.10%	80-120%	<20%	75-125%
Grain Size	Sediment	1%	N/A	<20%	N/A

Quality control for mercury was assessed by examining matrix spikes, field replicates, laboratory blanks, and laboratory control samples. Quality control for TOC was assessed by field replicates, laboratory blanks, and laboratory duplicates. Results for quality control samples appear in Tables B-7 through B-15. Quality assurance for grain size was assessed through triplicate analysis of samples from another project. The triplicate analysis met quality objectives (<20% RPD).

Mercury

Mercury sediment sample concentrations varied widely within different locations at each lake (Table B-11), but the relative percent difference (RPD) between field samples and field replicates was low (Table B-8).

Table B-7. Mercury Matrix Spikes.

Sample Number	Recovery (%)	RPD (%)
08284444 LMX1 08284444 LMX2	92 95	3.2
08294432 LMX1 08294432 LMX2	91 92	1.1

Table B-8. Mercury Field Replicates.

Sample Number	Field ID	Result (ppb)	Sample Number	Field ID	Result (ppb)
08294432 08294433 08294434	CON-SED1 CON-SED2 CON-SED3	0.103 0.099 0.062	08294437 08294438 08294439	CON-SED1R CON-SED2R CON-SED3R	0.096 0.099 0.072
	Mean	0.088		Mean	0.089
	RPD of results	49.2%		RPD of results	31.2%
				RPD of Means	**1.54%**

Sample Number	Field ID	Result (ppb)	Sample Number	Field ID	Result (ppb)
08284443 08284444 08284445	MCI-SED1 MCI-SED2 MCI-SED3	0.145 0.135 0.143	08284448 08284449 08284450	MCI-SED1R MCI-SED2R MCI-SED3R	0.142 0.142 0.151
	Mean	0.141		Mean	0.145
	RPD of results	7.1%		RPD of results	6.1%
				RPD of Means	**2.80%**

Table B-9. Mercury Laboratory Blanks.

Sample Number	Result (ppb)
MB08205H1 MB08205H2	0.0050 U 0.0050 U

U - undetected at the level indicated.

Table B-10. Mercury Laboratory Control Samples.

Sample Number	Recovery (%)
ML08205H1	100
ML08205H2	108

Table B-11. 2008 Mercury in Sediments Results.

Lake Conconully		Horsethief Lake		Leland Lake		Loomis Lake		McIntosh Lake		Lake Nahwatzel	
Field ID	Result (ppb)	Field ID	Result (ppb)	Field ID	Result (ppb)	Field ID	Result (ppb)	Field ID	Result (ppb)	Field ID	Result (ppb)
CON-SED1	103	HR-SED1	64.3	LEL-SED1	175	LM-SED1	113	MCI-SED1	145	NAH-SED1	152
CON-SED2	98.6	HR-SED2	60.9	LEL-SED2	200	LM-SED2	92	MCI-SED2	135	NAH-SED2	150
CON-SED3	62.3	HR-SED3	73.8	LEL-SED3	227	LM-SED3	157	MCI-SED3	143	NAH-SED3	107
CON-SED1R	96.4							MCI-SED1R	142		
CON-SED2R	99.2							MCI-SED2R	142		
CON-SED3R	72.4							MCI-SED3R	151		
Mean	88.7		66.3		200.7		120.7		143.0		136.3
RPD[1]	49.2		19.2		25.9		52.2		11.2		34.7
RSD[2]	0.0		0.0		0.0		0.0		0.0		0.0

[1] RPD = (max - min) / (mean) * 100.
[2] RSD = 100 * (sd / mean).

Total Organic Carbon

Table B-12. TOC Laboratory Control Samples.

Sample Number	Recovery (%)
GL08205T1	84
GL08198T1	91

Table B-13. TOC Field Replicates.

Sample Number	Field ID	Result (%)	Sample Number	Field ID	Result (%)
08294432	CON-SED1	3.17	08294437	CON-SED1R	3.44
08294433	CON-SED2	3.61	08294438	CON-SED2R	3.63
08294434	CON-SED3	4.98	08294439	CON-SED3R	4.28
	Mean	3.9		Mean	3.8
	RPD of results	44.4%		RPD of results	21.8%
				RPD of Means	3.5%
Sample Number	**Field ID**	**Result (%)**	**Sample Number**	**Field ID**	**Result (%)**
08284443	MCI-SED1	12.3	08284448	MCI-SED1R	12.4
08284444	MCI-SED2	11.4	08284449	MCI-SED2R	10.8
08284445	MCI-SED3	12.6	08284450	MCI-SED3R	13.2
	Mean	12.1		Mean	12.1
	RPD of results	10.0%		RPD of results	20.0%
				RPD of Means	0.3%

Table B-14. TOC Laboratory Blanks.

Sample Number	Result (%)
GB08198T1	0.1 U
GB08205T1	0.1 U

U - undetected at level indicated

Table B-15. TOC Laboratory Duplicates.

Sample Number	Result (%)	RPD (%)
08284466	1.830 1.840	0.5
08294432	3.540 3.820	7.6

Water

Measurement quality objectives (MQOs) for water analyses are presented in Table B-16.

Table B-16. MQOs for Water Analysis.

Parameter	Matrix	Reporting Limit	Check Standard (% recovery limit)	Duplicate Sample (RPD)	Matrix Spike (% recovery limit)
Dissolved Organic Carbon	water	1 mg/L	80-120%	<20%	75-125%
Alkalinity	water	5 mg/L	80-120%	<10%	N/A
Chlorophyll a	water	0.05 ug/L	80-120%	< 10%	N/A

N/A = not available.

Quality assurance for water samples was assessed through field replicates, laboratory blanks, and laboratory control samples. Quality Assurance/Quality Control objectives were met for all analyses, except for chlorophyll replicates. No action was taken since the control sample and blank were conducted within limits. Results are outlined in tables B-17 – B-23.

Dissolved Organic Carbon

Table B-17. DOC Field Replicates.

Sample Number	Result (mg/L)	Sample Number	Result (mg/L)	RPD (%)
08284441-T1	4.3	08284446-T2	4.1	4.8
08284442-B1	3.9	08284447-B2	4.2	7.4
08294430-T1	4.1	08294435-T2	4.2	2.4
08294431-B1	4.3	08294436-B2	4.3	0.0

Table B-18. DOC Laboratory Blanks.

Sample Number	Result (mg/L)
GB08199T2	1.0 U
GB08206T1	1.0 U

U - undetected at level indicated.

Table B-19. DOC Laboratory Control Samples.

Sample Number	Recovery (%)
GL08199T2	99
GL08206T1	98

Alkalinity

Table B-20. Alkalinity Field Replicates.

Sample Number	Result (mg/L)	Sample Number	Result (mg/L)	RPD (%)
08284441-T1	23	08284446-T2	23	0.0
08284442-B1	23	08284447-B2	23	0.0
08294430-T1	44	08294435-T2	44	0.0
08294431-B1	41	08294436-B2	41	0.0

Table B-21. Alkalinity Laboratory Blanks.

Sample Number	Result (mg/L)
GB08196K1	5 U
GB08206K1	5 U

U - undetected at level indicated.

Table B-22. Alkalinity Laboratory Control Samples.

Sample Number	Recovery (%)
GL08196K1	98
GL08206K1	97

Table B-23. Alkalinity Laboratory Duplicates.

Sample Number	Result (mg/L)	RPD (%)
08284463	48 48	0.0
08284468	7.3 7.3	0.0

Chlorophyll

Table B-27. Chlorophyll Field Replicates.

Sample Number	Result (ug/L)	Sample Number	Result (ug/L)	RPD (%)
08284441-T1	8.3	08284446-T2	8.2	1.2
08284442-B1	8.4	08284447-B2	16	62.3
08294430-T1	5.5	08294435-T2	6.1	10.3
08294431-B1	1.2	08294436-B2	1.5	22.2

Table B-28. Chlorophyll Laboratory Blank.

Sample Number	Result (ug/L)
GB08213Y1	0.097

Appendix C. Biological, Sediment, and Water Quality Measures

Table C-1. Individual Fish Data by Lake.

Lake	Species Code	Collection Date	Total Length (mm)	Weight (gm)	Age	Fulton's Fish Condition Index	Sex	Mercury (ppb)
Goodwin	SMB	11/12/08	238	182	2	1.35	F	123
Goodwin	SMB	11/12/08	255	215	2	1.30	F	133
Goodwin	SMB	11/12/08	254	212	2	1.29	M	130
Goodwin	SMB	11/12/08	236	171	2	1.30	M	120
Goodwin	SMB	11/12/08	258	227	2	1.32	M	86
Goodwin	SMB	11/12/08	231	164	2	1.33	M	98
Goodwin	SMB	11/12/08	236	161	2	1.22	M	82
Goodwin	SMB	11/12/08	228	169	2	1.43	M	174
Goodwin	SMB	11/12/08	255	212	2	1.28	M	118
Goodwin	SMB	11/12/08	229	162	2	1.35	M	113
Horsethief	SMB	12/3/08	382	677	5	1.21	M	151
Horsethief	SMB	12/3/08	382	716	5	1.28	F	418
Horsethief	SMB	12/3/08	375	738	5	1.40	M	162
Horsethief	SMB	12/3/08	363	704	5	1.47	F	215
Horsethief	SMB	12/3/08	295	361	3	1.41	F	84
Horsethief	SMB	12/3/08	348	547	5	1.30	F	320
Horsethief	SMB	12/3/08	255	204	3	1.23	F	123
Horsethief	SMB	12/3/08	250	221	2	1.41	F	84
Horsethief	SMB	12/3/08	240	185	2	1.34	M	95
Horsethief	SMB	12/3/08	232	178	2	1.43	M	105
Leland	LMB	10/15/08	340	749	3	1.91	M	349
Leland	LMB	10/15/08	400	1141	4	1.78	F	420
Leland	LMB	10/15/08	231	143	2	1.16	F	467
Leland	LMB	10/15/08	226	144	2	1.25	M	197
Leland	LMB	10/15/08	232	162	2	1.30	M	290
Leland	LMB	10/15/08	542	3148	11	1.98	F	752
Leland	LMB	10/15/08	532	2668	18	1.77	F	818
Leland	LMB	10/15/08	460	1807	11	1.86	M	801
Leland	LMB	10/15/08	482	1862	15	1.66	M	761
Leland	LMB	10/15/08	477	1781	14	1.64	M	920

Lake	Species Code	Collection Date	Total Length (mm)	Weight (gm)	Age	Fulton's Fish Condition Index	Sex	Mercury (ppb)
Loomis	LMB	11/5/08	307	522	2	1.80	M	211
Loomis	LMB	11/5/08	215	140	1	1.41	F	132
Loomis	LMB	11/5/08	185	85	1	1.34	M	83
Loomis	LMB	11/5/08	175	77	1	1.44	M	86
Loomis	LMB	11/5/08	166	64	1	1.40	M	65
Loomis	LMB	11/5/08	165	57	1	1.27	M	66
Loomis	LMB	11/5/08	200	114	1	1.43	F	102
Loomis	LMB	11/5/08	190	102	1	1.49	M	81
Loomis	LMB	11/5/08	184	100	1	1.61	M	118
Loomis	LMB	11/5/08	175	74	1	1.38	M	65
McIntosh	LMB	10/14/08	285	334	2	1.44	M	80
McIntosh	LMB	10/14/08	251	236	2	1.49	M	77
McIntosh	LMB	10/14/08	495	2015	11	1.66	M	568
McIntosh	LMB	10/14/08	450	1536	5	1.69	F	325
McIntosh	LMB	10/14/08	424	1219	8	1.60	M	443
McIntosh	LMB	10/14/08	316	445	2	1.41	F	71
McIntosh	LMB	10/14/08	281	404	2	1.82	M	67
McIntosh	LMB	10/14/08	228	174	1	1.47	F	40
McIntosh	LMB	10/14/08	190	77	1	1.12	M	65
McIntosh	LMB	10/14/08	192	97	1	1.37	F	67
Nahwatzel	LMB	10/13/08	239	171	4	1.25	M	294
Nahwatzel	LMB	10/13/08	232	152	4	1.22	M	256
Nahwatzel	LMB	10/13/08	247	185	4	1.23	F	289
Nahwatzel	LMB	10/13/08	233	159	5	1.26	F	300
Nahwatzel	LMB	10/13/08	255	201	5	1.21	M	378
Nahwatzel	LMB	10/13/08	263	244	5	1.34	F	461
Nahwatzel	LMB	10/13/08	254	202	5	1.23	M	347
Nahwatzel	LMB	10/13/08	248	196	5	1.28	M	366
Nahwatzel	LMB	10/13/08	237	153	5	1.15	F	293
Nahwatzel	LMB	10/13/08	255	225	5	1.36	-	320

Table C-2. Composite Fish Data by Lake.

Lake	Species Code	Collection Date	Average Total Length (mm)	Average Weight (gm)	Fulton's Fish Condition Index	Number of Fish in Composite	Mercury (ppb)
Goodwin	RBT	11/12/08	350	522	1.22	4	48.5
Goodwin	RBT	11/12/08	372	620	1.19	5	53.7
Goodwin	RBT	11/12/08	346	446	1.08	3	54.1
Leland	BC	10/15/08	170	76	1.54	5	205
Leland	BC	10/15/08	193	117	1.61	5	229
Leland	BC	10/15/08	183	95	1.56	5	231
Leland	YP	10/15/08	208	112	1.25	5	210
Leland	YP	10/15/08	190	88	1.28	5	246
Leland	YP	10/15/08	201	102	1.27	5	260
Loomis	YP	11/5/08	170	68	1.37	4	44.3
Loomis	YP	11/5/08	196	99	1.31	4	47.5
Loomis	YP	11/5/08	221	155	1.39	4	65.5
Horsethief	LSS	10/21/08	538	1934	1.24	3	142
Horsethief	LSS	10/21/08	571	1894	1.01	3	165
Horsethief	LSS	10/21/08	489	1304	1.10	3	177
Horsethief	YP	10/21/08	241	177	1.26	5	60.1
Horsethief	YP	10/21/08	233	161	1.28	5	75.8
Horsethief	YP	10/21/08	256	220	1.3	5	86.3
McIntosh	BG	10/14/08	126	38	1.81	3	39.4
McIntosh	BG	10/14/08	155	75	1.98	3	47.3
McIntosh	BG	10/14/08	148	60	1.86	3	52.1
McIntosh	YP	10/14/08	133	27	1.13	5	36.5
McIntosh	YP	10/14/08	150	37	1.09	5	43.2
McIntosh	YP	10/14/08	162	46	1.07	5	50.2
Nahwatzel	PMP	10/13/08	139	57	2.08	3	201
Nahwatzel	PMP	10/13/08	155	78	2.09	3	203
Nahwatzel	PMP	10/13/08	161	92	2.22	3	240
Nahwatzel	RBT	10/13/08	312	321	1.06	5	20.2 U
Nahwatzel	RBT	10/13/08	328	367	1.04	5	21.3 U
Nahwatzel	RBT	10/13/08	340	424	1.08	4	31.7

U = Not detected at indicated level.

Table C-3. Water and Sediment Results.

Lake	Collection Date	Field ID	Depth (m)	Sediment			Water		
				Mercury (ppb)	TOC (%)	Grain Size (% fines)*	Chl-a (ug/L)	Alkalinity (mg/L)	DOC (mg/L)
Horsethief	7/8/2008	HR-SED1	-	64.3	2.06	66.1	-	-	-
	7/8/2008	HR-SED2	-	60.9	1.94	40.0	-	-	-
	7/8/2008	HR-SED3	-	73.8	1.86	33.4	-	-	-
	7/8/2008	HR-T1	6.0	-	-	-	1.9	46.0	2.2
	7/8/2008	HR-B1	14.5	-	-	-	0.7	48.0	2.0
Leland	7/9/2008	LEL-SED1	-	175.0	6.14	32.3	-	-	-
	7/9/2008	LEL-SED2	-	200.0	8.12	36.5	-	-	-
	7/9/2008	LEL-SED3	-	227.0	8.57	26.8	-	-	-
	7/9/2008	LEL-T1	1.0	-	-	-	25.7	32.0	10.3
	7/9/2008	LEL-B1	5.0	-	-	-	3.0	35.0	10.1
Loomis	7/10/2008	LM-SED1	-	113.0	13.7	3.9	-	-	-
	7/10/2008	LM-SED2	-	92.0	11.1	7.3	-	-	-
	7/10/2008	LM-SED3	-	157.0	15.6	15.2	-	-	-
	7/10/2008	LM-T1	0.0	-	-	-	2.6	33.0	7.0
	7/10/2008	LM-B1	1.0	-	-	-	3.0	33.0	7.0
McIntosh	7/7/2008	MCI-SED1	-	145.0	12.3	27.5	-	-	-
	7/7/2008	MCI-SED2	-	135.0	11.4	26.5	-	-	-
	7/7/2008	MCI-SED3	-	143.0	12.6	27.9	-	-	-
	7/7/2008	MCI-SED1R	-	142.0	12.4	no data	-	-	-
	7/7/2008	MCI-T1	0.5	-	-	-	8.3	23.0	4.3
	7/7/2008	MCI-B1	2.0	-	-	-	8.4	23.0	3.9
	7/7/2008	MCI-T2	0.5	-	-	-	8.2	23.0	4.1
	7/7/2008	MCI-B2	2.0	-	-	-	16.0	23.0	4.2
Nahwatzel	7/11/2008	NAH-SED1	-	152.0	13.6	12.3	-	-	-
	7/11/2008	NAH-SED2	-	150.0	17.0	10.8	-	-	-
	7/11/2008	NAH-SED3	-	107.0	9.8	14.4	-	-	-
	7/11/2008	NAH-T1	1.0	-	-	-	1.4	7.4	2.0
	7/11/2008	NAH-B1	5.0	-	-	-	2.0	7.3	2.0

* % fines = < 62 u.

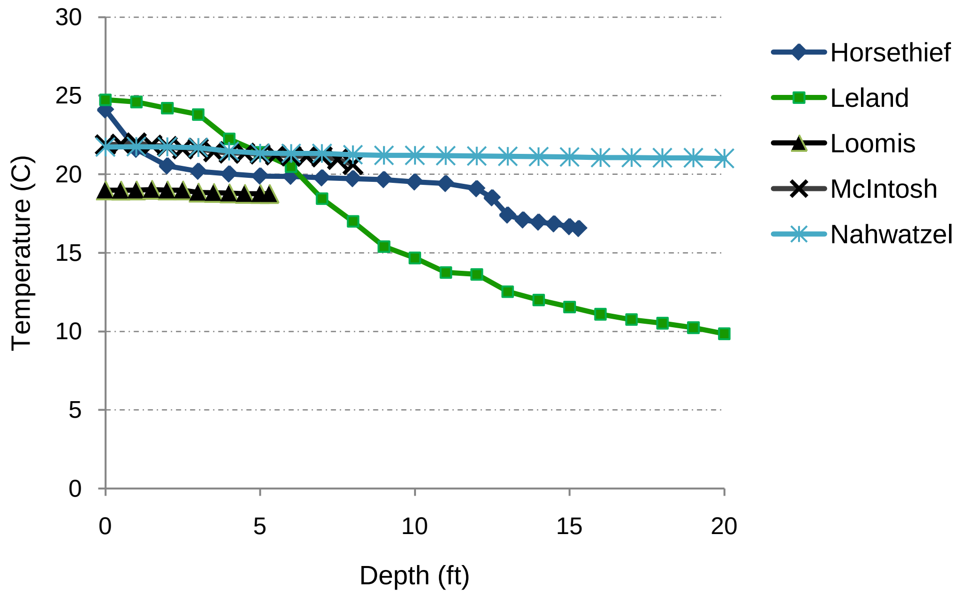

Figure C-1. Temperature Profile for 2008 Study Lakes.

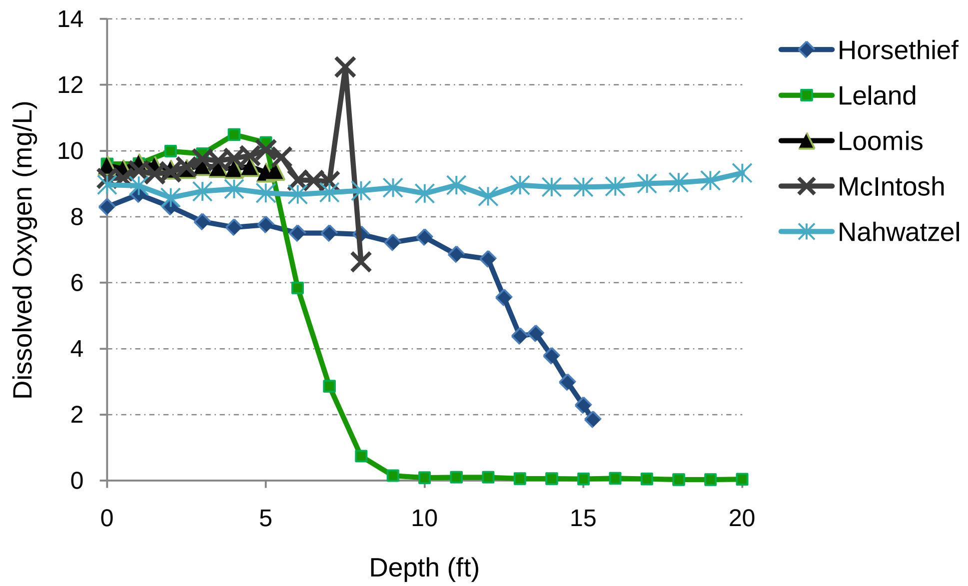

Figure C-2. Dissolved Oxygen Profile for 2008 Study Lakes.

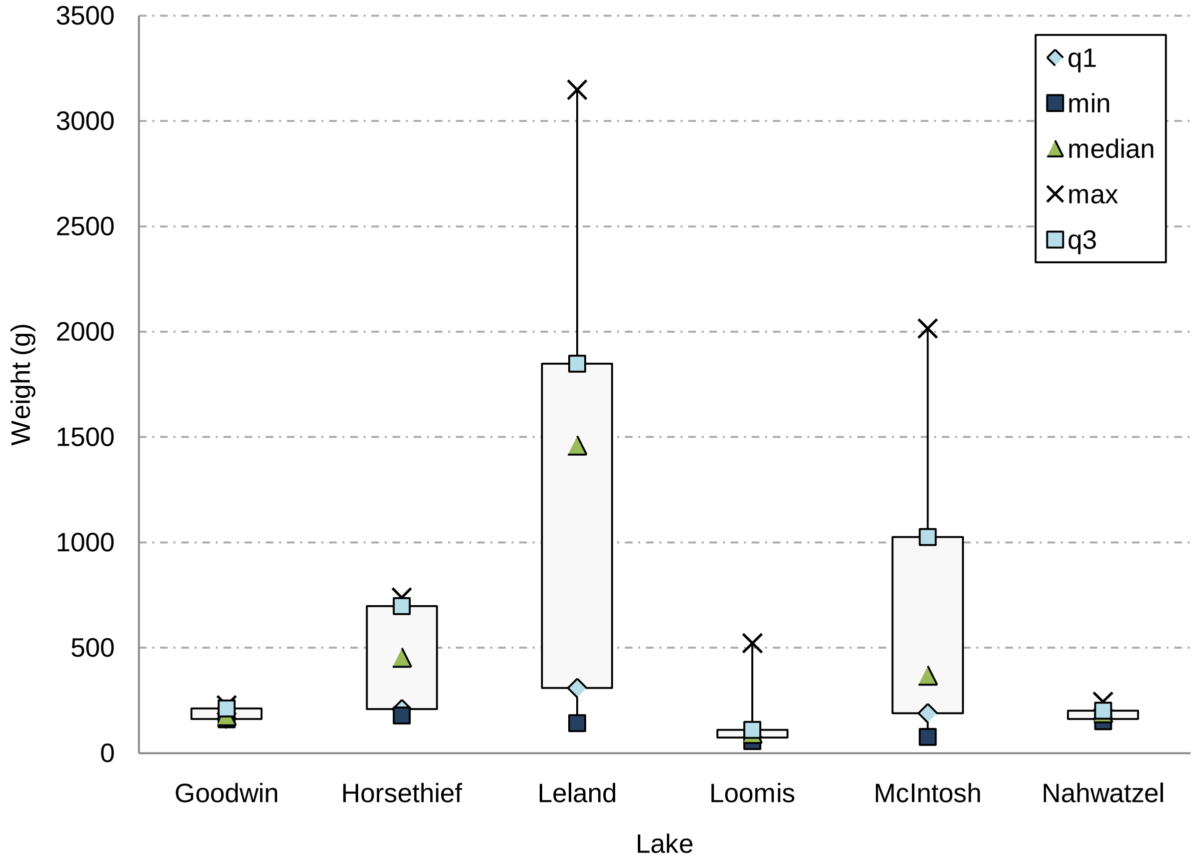

Figure C-3. Boxplot of Weight for Individual Bass.
(q^1 = 25th percentile; Q^2 = 75th percentile)

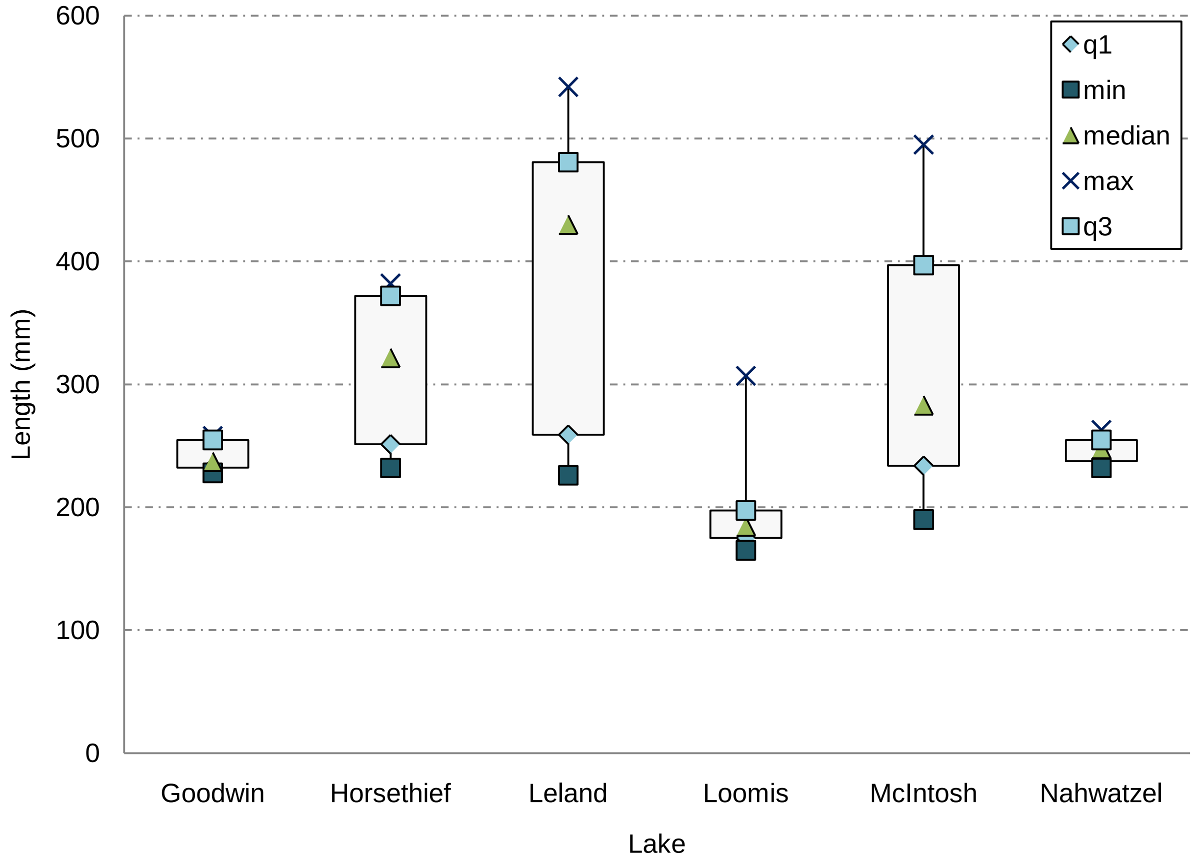

Figure C-4. Boxplot of length for individual Bass.
(q^1 = 25th percentile; Q^2 = 75th percentile)

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Appendix D. Statistical Analyses

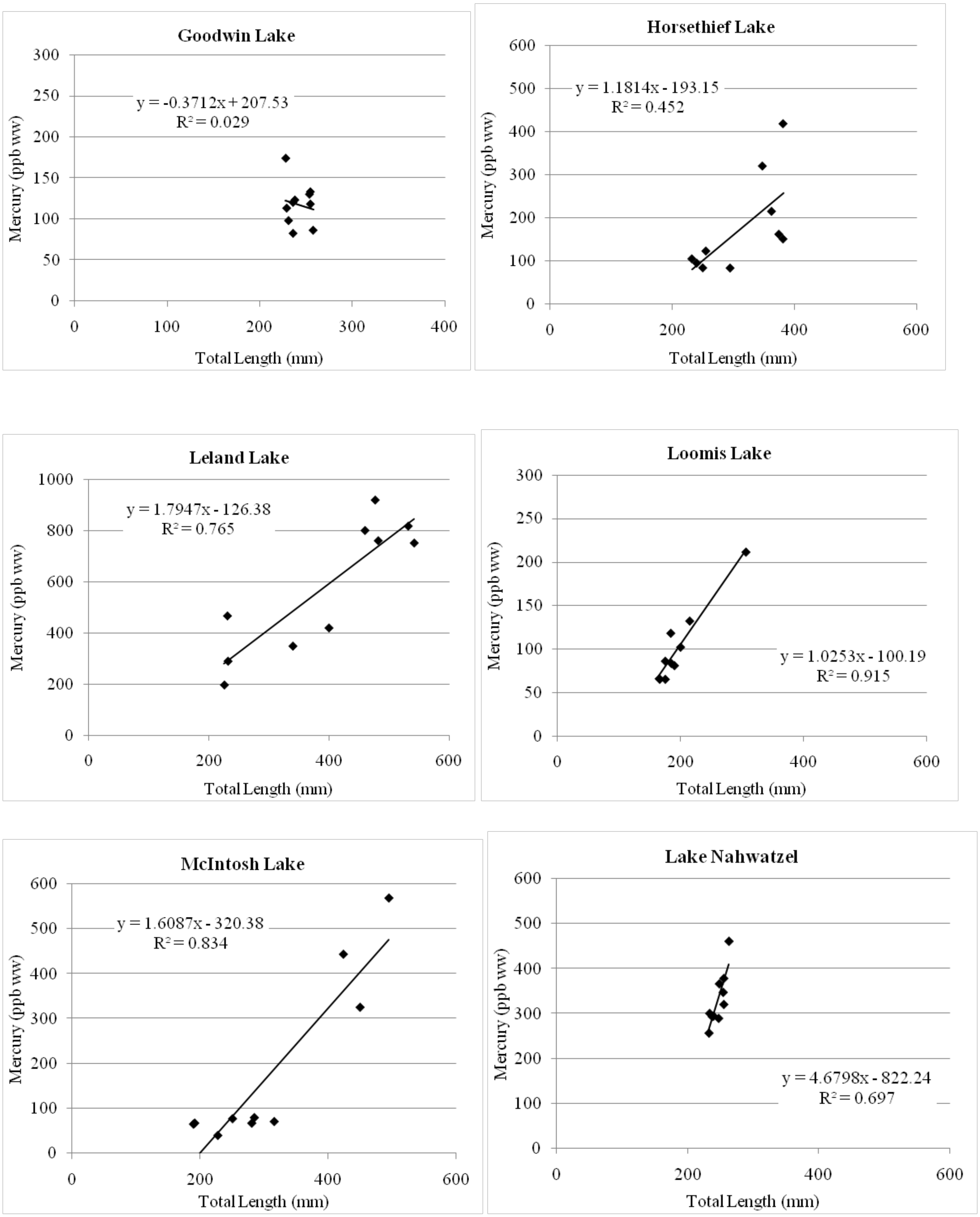

Figure D-1. Simple Linear Regression Plots for Mercury and Fish Length.

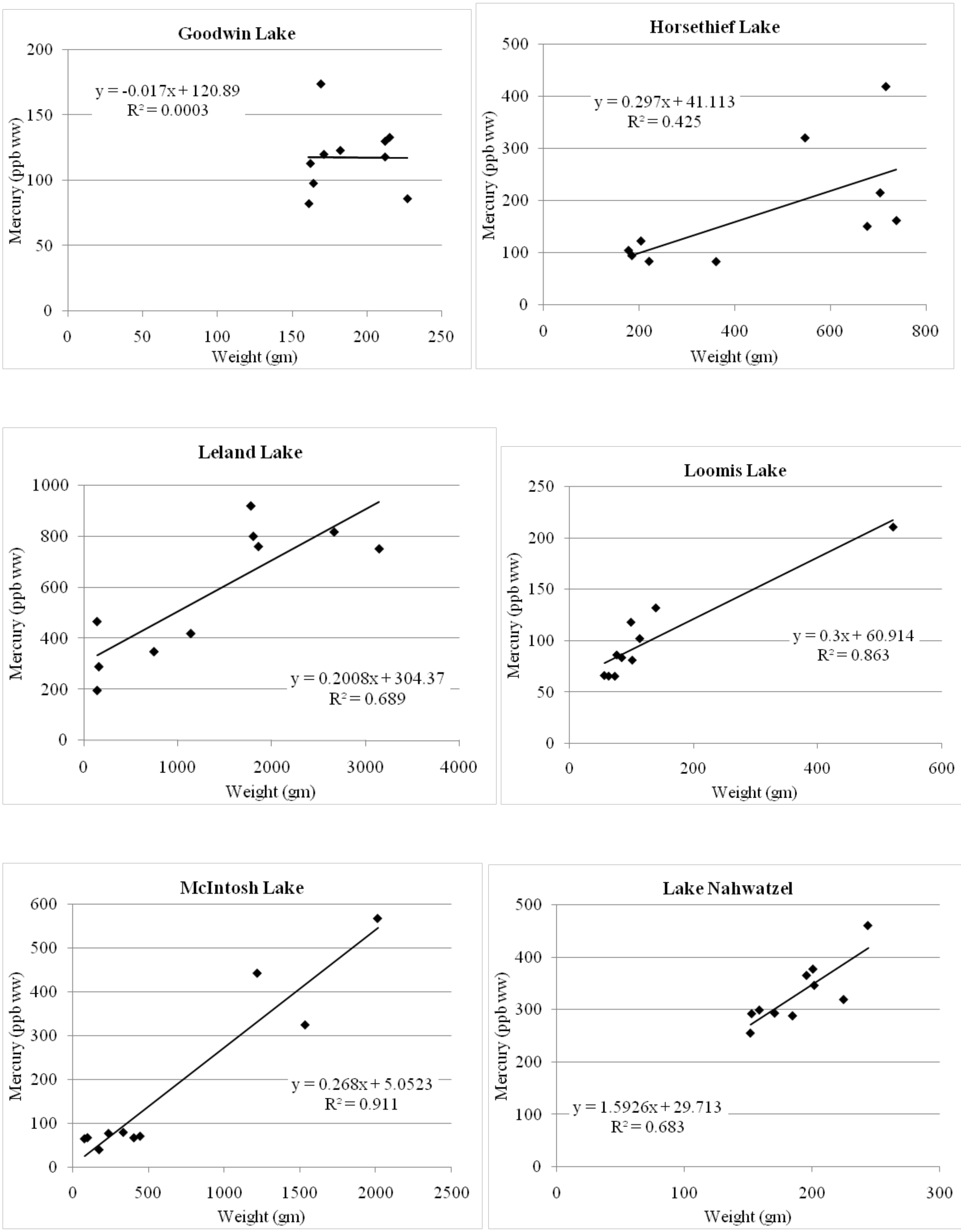

Figure D-2. Simple Linear Regression Plots for Mercury and Fish Weight.

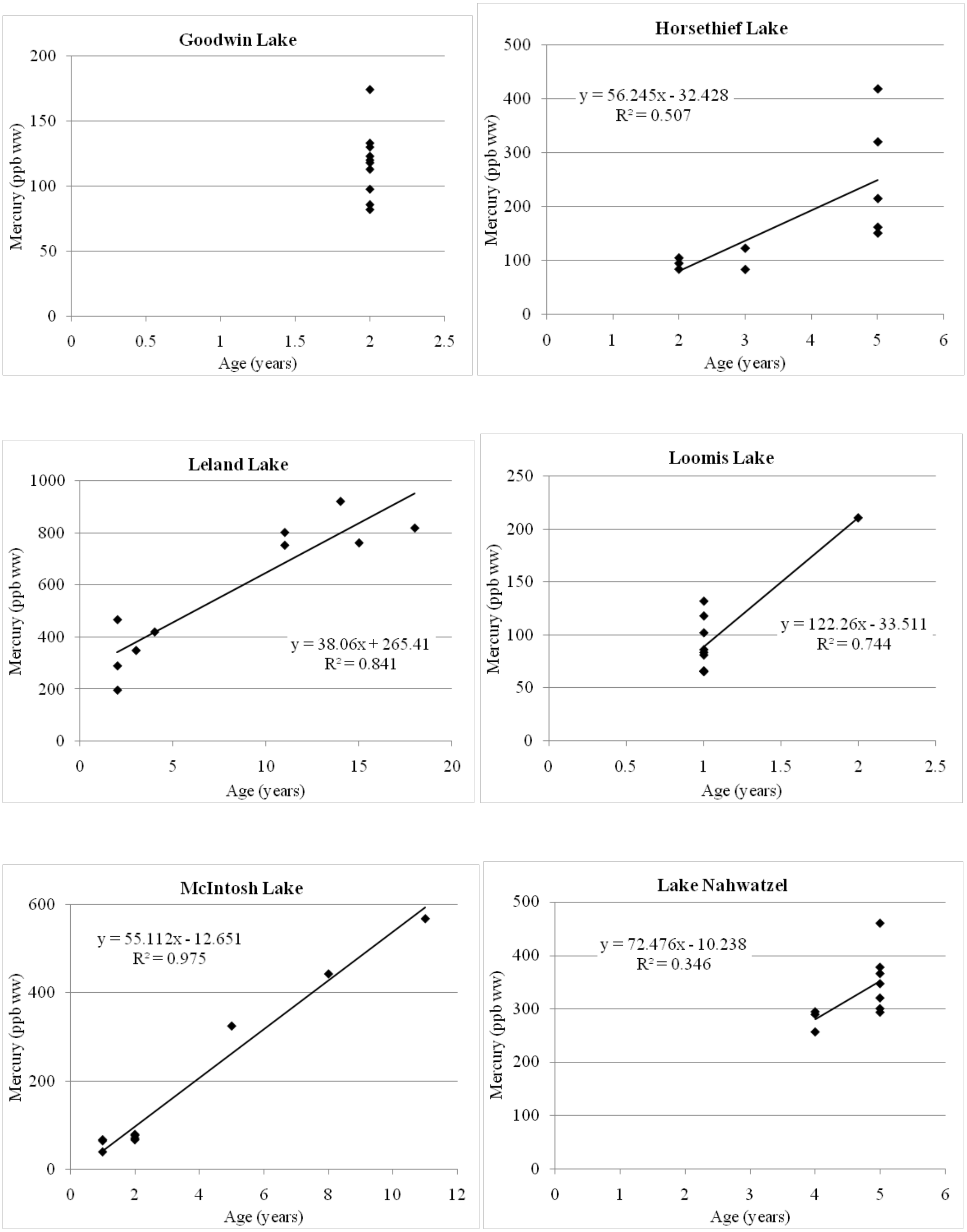

Figure D-3. Simple Linear Regression Plots for Mercury and Fish Age.

Table D-1. Adjusted Mercury Levels for a Standardized Fish Length and Weight.

Waterbody	Species	Mercury Trends Study Year	Constant	B1	B2	Mercury Concentration at 356 mm	note	p	r^2
Long Lake	SMB	2005	177.068	-139.095	27.546	31		**0.180**	0.212
Silver Lake	LMB	2005	127.366	-103.162	21.157	76		0.028	0.539
Potholes Res.	SMB	2005	19.756	-16.15	3.589	82		0.013	0.628
Loon Lake	LMB	2005	-531.81	1.799	-	109	L	0.002	0.702
Liberty Lake	SMB	2005	-41.8	32.241	-5.887	137		**0.323**	0.069
Yakima River	SMB	2005	-197.42	154.535	-29.895	180		**0.341**	0.054
Moses Lake	LMB	2006	38.322	-31.337	6.62	29		0.001	0.842
Newman Lake	LMB	2006	-271.292	209.038	-39.92	152		0.009	0.670
Lake Offut	LMB	2006	-	-	-	188	S	-	-
Lake Sammamish	LMB	2006	-11.735	8.868	-1.315	214		0.003	0.752
Lake Meridian	LMB	2006	17.004	-13.679	3.111	226		0.000	0.898
L. Goose Lake	LMB	2007	-391.469	1.777	-	241	L	0.080	0.252
Deer Lake	LMB	2007	110.547	-86.637	17.34	239		0.000	0.854
Samish Lake	LMB	2007	62.779	-50.346	10.46	261		0.003	0.763
Lake Fazon	LMB	2007	100.957	-76.873	15.012	352		0.075	0.387
Lake St. Clair	LMB	2007	31.49	-24.765	5.267	390		0.002	0.786
Lake Ozette	LMB	2007	82.929	-66.769	13.862	648		0.016	0.604
McIntosh Lake	LMB	2008	50.344	-41.406	8.821	133		0.000	0.914
Horsethief Lake	SMB	2008	55.229	-44.859	9.449	193		0.049	0.458
Loomis Lake	LMB	2008	-100.185	1.025	-	265	L	0.000	0.905
Leland Lake	SMB	2008	14.903	-10.969	2.414	428		0.007	0.694
Lake Nahwatzel	LMB	2008	-822.238	4.68	-	500	*	0.003	0.659

SMB = smallmouth bass; LMB = largemouth bass.
B1 = regression coefficient; B2 = regression coefficient; p = p value; r^2 = coefficient of determination.
L = Size range not captured; used simple linear regression without log-transformation.
S = Length did not serve as a good predictor and mercury numbers were estimated from fish near the same size.
* = See Discussion for explanation of standard-size concentration.

Regression Equation: Log10 (Mercury) = Constant + {B1 * Log10 (Length)} + {B2 * (Log10 (Length))²}

Table D-2. Results of Spatial Trends Difference in Means T-test.

Eastern Washington mean	139.3
Western Washington mean	335.4
Mean difference	196.1
95% confidence interval	42.9 - 349.3
t	2.67
df	20
Standard error of difference	73.4
p	0.0147

t = t statistic (see *Glossary*).
df = degrees freedom.
p = p value.

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Appendix E. Fish Tissue Data Evaluation by Ecology and DOH

Several federal and state agencies collect and evaluate fish tissue data in Washington State: Ecology, DOH, WDFW, EPA, and USGS. Tissue data are evaluated differently by these agencies because their mandates and roles are varied. These multiple evaluations often lead to confusion and misunderstanding among agencies and the public on how fish tissue data are used and interpreted. Most fish tissue contaminant data from Washington fish, regardless of who conducted the study, make their way to DOH for evaluation regarding the safety of consuming contaminated fish. The following is an overview of how Ecology and DOH evaluate fish tissue data to meet different needs.

Ecology

For many Ecology studies, fish tissue data are evaluated primarily to determine if (1) water quality standards are being met, and (2) potential risks to human health from consuming contaminated fish warrant further study and/or development of a fish consumption advisory. Ecology's role is to determine whether water quality standards are met and to begin the process to correct problems where standards are not met. DOH and local health departments are responsible for developing fish consumption advisories in Washington. There is some overlap in these evaluations because the water quality standards that fish tissue data are compared to were developed for the protection of human health.

Washington's water quality standards criteria for toxic contaminants were issued to the state in EPA's 1992 National Toxics Rule (NTR) (40CFR131.36). The human-health-based NTR criteria are designed to minimize the risk of effects occurring to humans from chronic (lifetime) exposure to substances through the ingestion of drinking water and consumption of fish obtained from surface waters. The NTR criteria, if met, will generally ensure that public health concerns do not arise, and that fish advisories are not needed.

The NTR criteria are thresholds that, when exceeded, may lead to regulatory action. When water quality criteria are exceeded, the federal Clean Water Act requires that the waterbody be put on a list and a water cleanup plan be developed for the pollutant causing the problem. This list is known as the "303(d) list," and the water cleanup plan results from a Total Maximum Daily Load (TMDL) study and public involvement process. Ecology uses the TMDL program to control sources of the particular pollutant in order to bring the waterbody back into compliance with the water quality standards.

DOH

While DOH supports Ecology's use of the NTR criteria for identifying problems and controlling pollutant sources so that water quality will meet standards, DOH does not use the NTR criteria to establish fish consumption advisories (McBride, 2006). DOH uses an approach similar to that in EPA's *Guidance for Assessing Chemical Contaminant Data for use in Fish Advisories Vol. 1-4* for assessing mercury, PCBs, and other contaminants (EPA, 2000).

These guidance documents provide a framework from which states can evaluate fish tissue data to develop fish consumption advisories based on (1) sound science and (2) established procedures in risk assessment, risk management, and risk communication. Neither the NTR criteria, nor the screening values found in the EPA guidance documents above, incorporate the varied risk management decisions essential to developing fish consumption advisories.

- *Risk Assessment* involves calculating allowable meal limits based on known fish contaminant concentrations. These calculations are conducted for both non-cancer and cancer endpoints using the appropriate Reference Dose (RfD) or Cancer Slope Factor (CSF), if available. These initial calculations are the starting point for evaluating contaminant data to determine whether a fish advisory is warranted. Additionally, known or estimated consumption rates help determine the potential magnitude of exposure and also highlight the sensitive groups or populations that may exist due to elevated consumption rates.

- *Risk Management* includes (but is not limited to) consideration of contaminant background concentrations, reduction in contaminant concentrations through preparation and cooking techniques, known health benefits from fish consumption, contaminant concentrations or health risks associated with replacement foods, and cultural importance of fish. Other considerations are the possible health endpoints associated with a contaminant, the strength or weaknesses of the supporting toxicological or sampling data, and whether effects are transient or irreversible.

- *Risk Communication* is the outreach component of the fish advisory. The interpretation of the data from the risk assessment and risk management components drives how and when the fish advisory recommendations are issued to the public, dependent on whether the message is targeted toward a sensitive group or a population or the general public. DOH's dual objective is how best to provide guidance to the public to increase consumption of fish low in contaminants to gain the benefits of eating fish, while steering the public away from fish that have high levels of health-damaging contaminants (e.g., mercury).

Appendix F. Glossary, Acronyms, and Abbreviations

Alkalinity: The capacity of water for neutralizing an acid solution.

Analyte: Water quality constituent being measured (parameter).

Anthropogenic: Human-caused.

Bioaccumulative pollutants: Pollutants that build up in the food chain.

Composite sample: A representative sample created by the homogenization of multiple fish.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Epilimnion: The uppermost layer of water in a lake where water temperature changes less than 1° C per one meter of depth.

Exceeded criterion: Did not meet or violated the criterion.

Hypolimnion: The deepest layer of water in a lake where water temperature changes less than 1° C per one meter of depth.

Otolith: Part of the inner ear of a fish. This structure is used to determine the age of a fish.

Parameter: Water quality constituent being measured (analyte).

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Point source: Source of pollution that discharges at a specific location.

Profundal sediment: Sediment found in the deepest zone of a lake.

Resident fish: A fish that lives in a body of water throughout its life cycle, and does not migrate.

Temporal trend: Characterize the trend over time.

t statistic: Measure of the likelihood that the actual value of the parameter is not zero.

Acronyms and Abbreviations

CAS	Columbia Analytical Services
DOC	Dissolved organic carbon
DOH	Washington State Department of Health
EAP	Environmental Assessment Program
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
g	Gram
Hg	Mercury
LCS	Laboratory control samples
MDN	Mercury deposition network
MEL	Manchester Environmental Laboratory
mg/L	Milligrams per liter
mm	Millimeter
MQO	Measurement quality objective
NTR	National Toxics Rule
PCBs	Polychlorinated biphenyls
ppb	Part per billion
RPD	Relative percent difference
SRM	Standard Reference Material
TOC	Total organic carbon
ug/L	Micrograms per liter
USGS	U.S. Geological Survey
WDFW	Washington Department of Fish and Wildlife
ww	Wet weight