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Measuring Mercury Trends in Freshwater Fish in Washington State: 2005 Sampling Results

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For more information contact:

Publications Coordinator
Environmental Assessment Program
P.O. Box 47600
Olympia, WA 98504-7600

E-mail: jlet461@ecy.wa.gov
Phone: (360) 407-6764

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Measuring Mercury Trends in Freshwater Fish in Washington State: 2005 Sampling Results

by

Chad Furl, Keith Seiders, Darren Alkire, and Casey Deligeannis

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

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Waterbody Numbers: see Appendix A

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Abstract

Concerns about mercury in our environment have increased due to the persistent, bioaccumulative, and toxic nature of this substance. To address these concerns, a *Mercury Chemical Action Plan* was developed in 2003 by the Washington State Departments of Ecology and Health with assistance from an advisory committee representing business, health, environmental, and local government organizations.

The *Mercury Chemical Action Plan* identified the need for improved understanding of mercury's behavior in the environment in order to guide management of this environmental toxicant. The 2005 State Legislature provided funds to begin long-term monitoring of mercury in the freshwater environments of Washington. This document presents results from the first year of a long-term monitoring effort for mercury in fish tissue.

The primary goal of this project is to monitor mercury levels in edible tissue from freshwater fish at six sites per year for five years (30 sites total) to characterize temporal trends in fish tissue mercury levels.

During 2005, largemouth and smallmouth bass were collected from six sites in Washington: Liberty Lake, Long Lake (Spokane River), Loon Lake, Potholes Reservoir, Silver Lake, and the Yakima River.

Mercury concentrations in edible tissues ranged from 17 to 372 parts per billion (ppb). Fish ages and total lengths ranged from 1–12 years and 247–508 millimeters, respectively. Higher concentrations of mercury were found in the older and larger fish.

Five of the 60 fish collected contained mercury levels higher than the EPA's Recommended Fish Tissue Criterion of 300 ppb. No fish had mercury levels higher than the National Toxics Rule Criterion of 825 ppb.

Water chemistry and sediment mercury levels will be measured in subsequent years of the study to help understand patterns in fish tissue mercury levels over space and time.

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Introduction

Background

While mercury is a naturally occurring substance, human activity has increased the release of mercury into the environment. Consequences of this include increased health risks to humans and wildlife due to the persistent, bioaccumulative, and toxic nature of this substance. Concerns about these risks have led governments at international, national, state, and local levels to address the problems associated with the use and disposal of mercury.

Mercury is widespread in the environment, being released to the atmosphere from varied sources and transported globally. Mercury readily volatilizes such that 95% of atmospheric mercury is in the elemental form. Natural sources of mercury include weathering of mercury-bearing rocks and soil, volcanic activity, forest fires, and degassing from water surfaces. Anthropogenic (human-caused) sources include combustion of fossil fuels, metal 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). Mercury returns to earth mainly via precipitation, settling in surface waters and land where it cycles through the environments.

In humans, mercury affects the nervous system, with children and developing fetuses being of the highest risk for neurological damage (EPA, 2000). Concern with these health risks resulted in the 2002 Washington State Legislature directing the Washington 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). The *Washington State Mercury Chemical Action Plan* (Peele, 2003) was developed in 2003 by Ecology and DOH with assistance from an advisory committee representing business, health, environmental, and local government organizations.

The *Mercury Chemical Action Plan* (CAP) provides a thorough description of mercury in the environment including natural and anthropogenic sources, occurrence and biogeochemical cycling, mercury use and emissions in Washington, a summary of health effects and concerns, and fish consumption advisories in Washington due to mercury-contaminated fish. The Mercury CAP also addresses Clean Water Act Section 303d listings of waterbodies impaired by mercury, a review of research projects looking at mercury in Washington, the regulatory structures and numerical criteria that address mercury, and recommendations for reducing mercury emissions in Washington.

One of the goals of the PBT Strategy and Mercury CAP was to develop information needed for understanding the behavior of PBTs in the environment and deciding how to reduce PBTs. Several studies helped to initially characterize mercury levels in Washington's environment. These studies and the Mercury CAP determined that a long-term commitment to monitoring mercury in Washington's environment was needed. The information gained from this long-term monitoring effort will be useful in understanding the fate of mercury in our environment and evaluating the effectiveness of Washington's Mercury CAP.

In 2005, the Legislature began funding long-term monitoring of mercury in the environment to compare specific tasks:

- Determine mercury levels in edible tissue from ten individual fish of the same species (bass and/or walleye) from six sites per year for long-term trend characterization. Sampling at each of these sites will be repeated every five years such that a total of 30 sites will be sampled over a five-year period.
- Sediment cores from three lakes per year will be collected to assess depositional history of mercury in Washington. This sediment coring effort was developed as a separate, yet related, project and began in the summer of 2006.

Problem Statement

The lack of a long-term monitoring effort for mercury in fish tissue hampers efforts to understand the scope of fish tissue contamination and develop reasonable expectations for managing mercury sources to reduce their levels in freshwater environments. A long-term monitoring effort of mercury in freshwater fish tissue is needed to:

- Identify temporal and spatial patterns in fish tissue mercury levels.
- Identify factors affecting pollutant loading such as source, transport, and fate mechanisms.
- Develop understanding of contaminant behavior to inform decision-making to improve environmental conditions.
- Educate the public, public health authorities, and natural resource managers.
- Meet requirements of the federal Clean Water Act Section 303(d) to assess the quality of Washington's waters.
- Assess the effectiveness of pollutant management actions.
- Evaluate the need for consumption advisories.

Previous Studies on Mercury in Washington

Several studies described the extent and severity of mercury contamination in fish throughout Washington State, many of which led to issuance of fish consumption advisories.

Fischnaller et al. (2003) examined mercury in bass and sediment from 20 sites across Washington. Samples of muscle tissue from bass confirm that elevated levels of mercury are prevalent across the state. The study recommended implementing a long-term monitoring plan for mercury in fish.

Mercury concentrations were positively correlated with increasing fish size, age, weight, and length in about 90% of sites sampled. These findings were consistent with other studies, demonstrating that bioaccumulation of mercury occurs in upper trophic level predatory species, such as bass. The technique of adjusting fish tissue mercury concentrations to a standard fish size was useful in comparing tissue mercury levels among sites. A weak correlation was found between mercury concentrations and lipids such that lipids analysis in future studies was deemed unnecessary.

Many fish exceeded one or more criteria for protection of human health. In this study, about 23% of 185 fish representing 14 of 20 sites exceeded the EPA Recommended Fish Tissue Criterion of 300 ug/kg wet weight (EPA, 2001). A single ten-year-old fish from Samish Lake had a muscle tissue mercury level of 1280 ug/kg wet weight. This result exceeded the National Toxics Rule criterion of 825 ug/kg ww (CFR, 2004) and FDA's Action Level of 1000 ug/kg ww (FDA, 1985). The FDA's Action Level criterion is used to remove fish from commercial markets. This study was the basis of DOH's issuance of a statewide fish consumption advisory for largemouth and smallmouth bass (McBride, 2003).

Munn et al. (1995) investigated mercury and other metals in walleye, bass, and trout from Lake Roosevelt. Spatial differences in mercury concentrations in fish tissue were discovered throughout the lake. The report attributes these spatial differences to the unique areas of spawning and foraging where bioavailability of mercury differs due to local physical and chemical differences. Elevated mercury levels in walleye led DOH to issue a fish consumption advisory for Lake Roosevelt (USGS, 1997).

Serdar et al. (2001) examined mercury concentrations in 273 fish from six finfish and one crayfish species in Lake Whatcom. Mercury levels were elevated in smallmouth bass. These data were used to develop a fish consumption advisory for Lake Whatcom (McBride, 2003). Serdar et al. (2001) recommended a monitoring program to routinely characterize mercury levels in fish throughout Washington.

Norton (2004) investigated mercury levels in surface water, surficial sediments, and sediment cores of Lake Whatcom, in cooperation with the U.S. Geological Survey and the Whatcom County Health Department (Paulson, 2004). Findings suggest that mercury levels began increasing around 1900, may have peaked in the late 1990s, and appear to be declining. This study recommended that mercury levels in fish from Lake Whatcom be monitored periodically to determine if mercury levels decline over time. This study also recommended monitoring bottom waters for methyl mercury and total mercury to help evaluate compliance with water quality target concentrations in the lake and to prevent excessive bioaccumulation of mercury in fish.

Paulson (2004) examined sources of mercury in sediments, water, and fish in eight lakes of Whatcom County. 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 (discrete) source deposition and mercury concentrations in bass could not be established.

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Study Design

Goals and Objectives

1. The primary goal of this project is to monitor mercury levels in edible tissue from freshwater fish over time to characterize temporal trends in mercury levels. Objectives for meeting this goal are to:

    - Determine mercury concentrations in ten individual fish from six sites per year on an approximate five-year sampling frequency. Thirty sites will be sampled over a single five-year period. Target fish species are bass (primary) and walleye (secondary).

    - Collect ancillary data on the fish and sites to better understand patterns, dynamics, and changes in fish tissue mercury levels over space and time. Examples of ancillary data are fish length, weight, sex, and age; physical and chemical characteristics of sites such as morphometry, water chemistry, and surficial sediment mercury levels; and fish community information, where available.

The detection and quantification of such trends will require many years of monitoring. A critical factor for the success of this project will be sustaining funding over time.

2. A secondary goal of this project is to provide information about mercury levels in fish species other than bass and walleye. This information will help DOH craft more informative recommendations for fish consumption advisories. Data from other species may also provide information about mercury trends at each site. The objective for meeting this goal is to:

    - Determine mercury concentrations in composite samples from two other fish species that are present at the sites where bass and/or walleye are collected. Species commonly targeted by consumers will be selected. For each species, three composite samples of 3-5 fish per composite sample will be collected. Again, fish from a total of 30 sites will be collected over each five-year period.

Bass were the only species collected in 2005 for the trend effort due to limited resources being available that year. Future efforts will include collection of walleye, composite samples of two other fish species, surficial sediment samples, and surface waters.

Site and Fish Species Selection

Ten fish were collected from each of the six sites in 2005: Liberty Lake, Lower Long Lake (Spokane River), Loon Lake, Potholes Reservoir, Silver Lake, and the Yakima River (Figure 1). Table 1 contains information for each of these sites while the project plan discusses site selection considerations (Seiders, 2006). Table A1 includes specific site location along with Ecology's waterbody identification number (WBID) and EIM's "User Location ID".

Fish were collected between September and November, 2005, concurrent with efforts for other projects such as the Washington Department of Fish and Wildlife (WDFW) Warmwater Fish Program surveys, Ecology's Washington State Toxics Monitoring Program (Seiders and Yake, 2002), and Ecology's baseline survey of flame retardants (polybrominated diphenyl ethers, or PBDEs) in freshwater fish and water (Johnson et al, 2006).

Figure 1. Sample Sites for 2005 Fish Collection.

Table 1. 2005 Site Characteristics.

Name	Liberty Lake	Long Lake	Loon Lake	Potholes Reservoir	Silver Lake	Yakima River*
County	Spokane	Spokane	Stevens	Grant	Cowlitz	Benton
Drainage area (sq mi)	13.3	-	14.1	3920.0	39.3	6120.0
Altitude (ft)	2053	1536	2381	1046	484	410
Surface area (acres)	713	45,227	1130	28,000	2300	-
Lake volume (acre-ft)	16,300	243,342	51,500	500,000	13,000	-
Mean depth (ft)	23	50	46	18	6	6
Max depth (ft)	30	180	100	140	10	10

* Yakima River near Horn Rapids Dam

Methods

Field Procedures

The collection, handling, and processing of fish tissue samples for analysis were guided by methods described in the EPA's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories* (EPA, 2000). Fish were collected by Ecology and/or Washington State Department of Fish and Wildlife (WDFW) crews using boat electrofishing and netting (gill or fyke nets).

Ten or more smallmouth or largemouth bass within 250mm to 460mm were collected at each site when possible. Fish were inspected to ensure that they were acceptable for further processing (e.g., no obvious damage to tissues, skin intact). These 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 (–20° C) and held at Ecology facilities in Lacey, Washington for processing at a later date.

Fish tissue samples were then prepared for laboratory analysis. Fish were removed from the freezer, partially thawed, slime and scales removed, rinsed in tap water, and followed by a rinse in deionized water. Fish were then filleted with the skin left on. Fillets were cut into small cubes and passed three times through a Kitchen-Aid food grinder. The ground tissue was homogenized by stirring to a consistent texture and color. Subsamples from the homogenate were taken and placed into 2- or 4-ounce glass containers (I-Chem 200®) that were previously cleaned. Sample jars were assigned a laboratory identification number and transported to the laboratory 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 and sent to WDFW biologists who determined the age of individual fish. Prior to filleting, a section of the caudal or other fin was removed and preserved in ethanol and sent to WDFW for DNA archiving. This archive sample was taken at WDFW's request.

All utensils used for processing tissue samples were cleaned to prevent contamination of the sample. Utensils included bowls, knives, and tissue grinding appliances containing plastic, wood, bronze, and stainless steel parts. All utensils for fish tissue sampling were cleaned with the following procedure: hand washed 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.

Laboratory Procedures

All tissue samples were analyzed at Ecology's Manchester Environmental Laboratory using method EPA 245.6, a Cold Vapor Atomic Absorption (CVAA) method. In 2003, Fischnaller et al. reported mercury concentrations in fish tissue using method EPA 245.5 CVAA. A future investigation is planned to determine the accuracy of comparing tissue results analyzed by different methods. Total mercury has been the target analyte used in other fish tissue studies in Washington, largely due to the relative simplicity and lower cost as compared to methylmercury. 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 Manchester Laboratory included a Case Narrative (Momohara, 2006) that described results from the quality control and quality assurance procedures used during sample analyses, such as holding times, instrument calibration, method blanks, matrix spikes, laboratory duplicates, laboratory control samples, and Standard Reference Material 1946 (Lake Superior fish tissue) from the National Institute of Standards and Technology.

The Case Narrative indicated that the analytical system performed adequately and that data met objectives for quality control. No difficulties were encountered in analyses of the samples, and all results were deemed useable as qualified. All data met Measurement Quality Objectives described in the project plan (Seiders 2006).

Summary results from laboratory duplicates, matrix spikes, and standard reference material analyses can be found in Appendix C.

Results

Largemouth bass were collected at two sites, and smallmouth bass were collected at the remaining four sites. Table 2 summarizes mercury concentrations, fish sizes, and fish ages for each of the six survey sites. Data for individual fish are found in Appendix Table D1.

Table 2. Summary Statistics for Fish Tissue Samples.

Waterbody	Species	n	Statistic	Mercury (ug/Kg)	Total Length (mm)	Weight (gm)	Age (yrs)
Liberty Lake	SMB	10	Mean	153.9	374.9	763.9	3.8
			Std. Dev.	28.5	19.5	137.1	0.4
			Min.	110	349	635	3
			Max.	204	410	1077	4
Long Lake (lower)	SMB	10	Mean	55.2	389.5	981.3	4.7
			Std. Dev.	34.8	44.4	332.0	1.5
			Min.	17	333	459	3
			Max.	100	468	1625	7
Loon Lake	LMB	10	Mean	279.8	451.2	1751.1	9.8
			Std. Dev.	50.2	23.9	324.8	1.6
			Min.	192	425	1289	7
			Max.	372	490	2381	12
Potholes Reservoir	SMB	10	Mean	118.3	385.8	909.4	4.1
			Std. Dev.	74.8	83.8	611.1	2.4
			Min.	35	247	193	1
			Max.	285	508	2066	8
Silver Lake	LMB	10	Mean	79.9	339.8	602.6	3.4
			Std. Dev.	43.8	41.9	246.5	1.3
			Min.	34	267	256	2
			Max.	150	396	1011	5
Yakima River	SMB	10	Mean	158.5	348.7	617.6	2.9
			Std. Dev.	80.2	41.2	258.0	1.1
			Min.	81	304	379	2
			Max.	354	427	1088	5

SMB = smallmouth bass
LMB = largemouth bass
n = number (sample size)
Std. Dev. = standard deviation

Figure 2 displays mercury levels of individual fish with fish age shown at the bottom of each bar. Mercury concentration and ages varied across sites. Loon Lake yielded fish that were larger, older, and had higher mercury levels (mean of 279.8 ppb) than the other sites. Fish from Liberty Lake (mean 153.9 ppb) and the Yakima River (158.5 ppb) had the next highest mean mercury levels. Smallmouth bass from Long Lake had the lowest levels of mercury (mean 55.2 ppb). Mercury levels in fillet tissue ranged from undetected (at 17 ppb) in two Long Lake smallmouth bass to 372 ppb in a 12-year-old Loon Lake female largemouth bass.

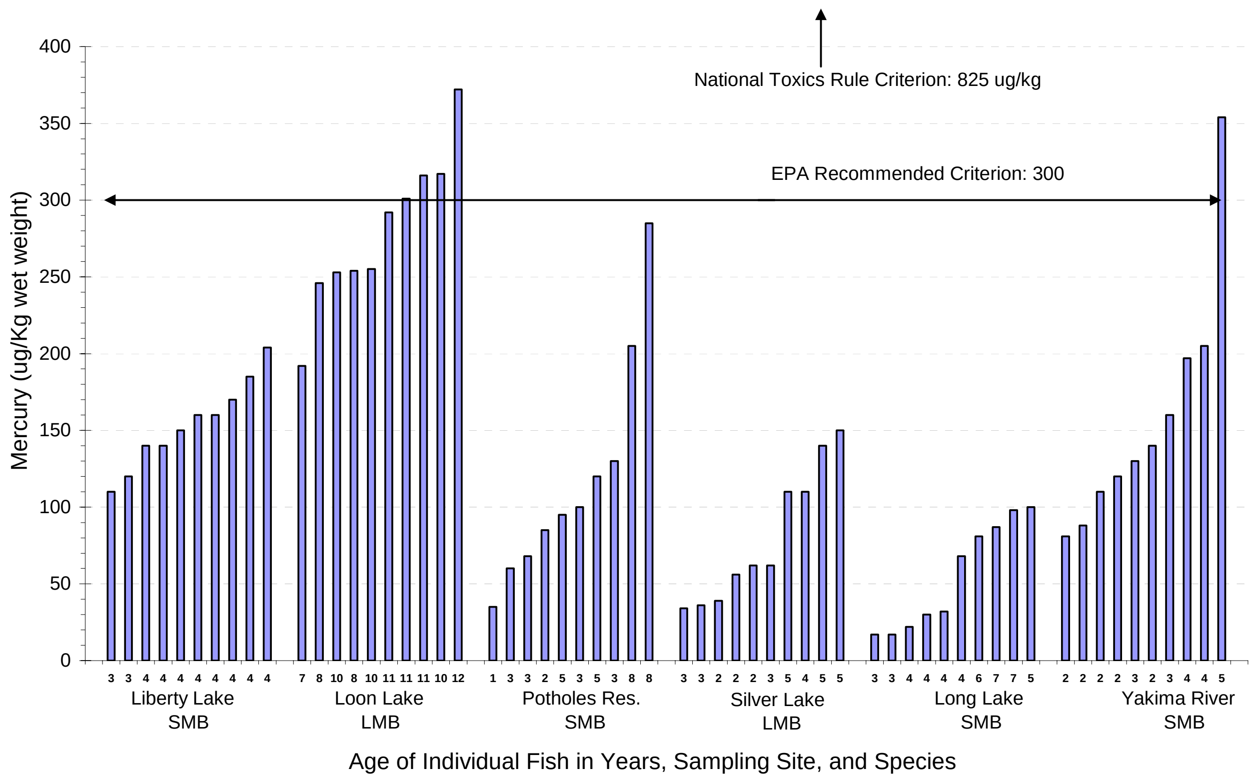

Figure 2. Individual Fish Mercury Concentration and Age.

Figure 3 graphically summarizes the minimum, 25th percentile, median, 75th percentile, and maximum mercury values for fish from each site. The boxplots help to visualize information about the distribution of the data. Mercury results for Liberty, Loon, and Long Lake sites are normally distributed. Data for Silver Lake appear slightly skewed, while Potholes Reservoir and Yakima River data are more strongly skewed towards higher mercury values.

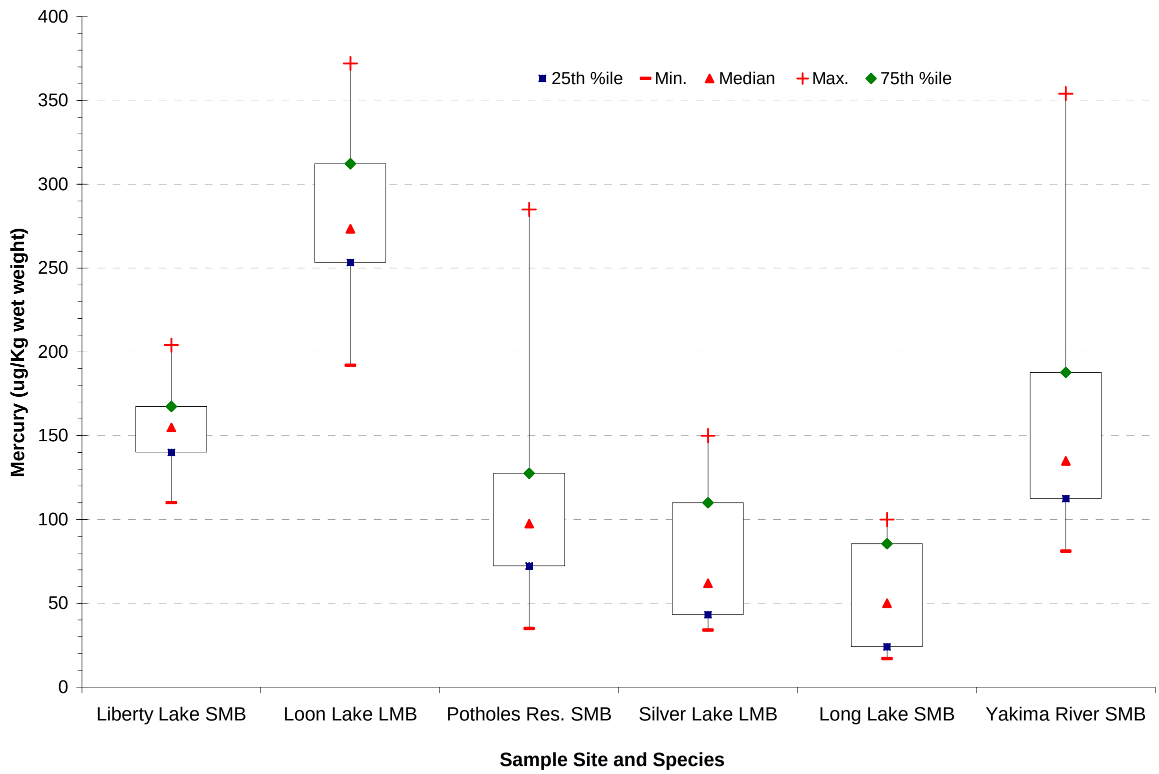

Figure 3. Boxplots of Mercury Concentration by Site.

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Discussion

Relationships of Mercury Levels to Fish Size and Age

It is well documented that mercury levels in bass are related to fish size and age (Serdar et al., 2001; Hakanson et al., 1988; Fischnaller et al., 2003). These relationships may (1) be helpful in explaining variability in tissue concentrations and (2) increase the sensitivity of trend analyses. Relationships between mercury concentrations and total length, weight, and age were examined by plotting paired values and inserting a linear regression trendline using Excel. These graphs appear in Appendix E: Figure E1 (Mercury versus Length), Figure E2 (Mercury versus Weight), and Figure E3 (Mercury versus Age).

Comparisons between mercury concentrations and length yielded positive correlations of varying strength from all six lakes. The strongest relationship between the two variables was discovered at Loon Lake ($r^2 = 0.7356$, $p = .002$).

When mercury concentrations and weight were compared, similar relationships were discovered as with length. Mercury levels positively correlated with increases in weight. Loon Lake again contained the strongest correlation of the six lakes ($r^2 = 0.9445$, $p < 0.01$).

As with length and weight, mercury concentrations correlated positively with fish age. All six study sites displayed positive correlations of varying degrees for age and mercury content. The Yakima River site contained the strongest correlation of the sites ($r^2 = 0.8104$, $p < 0.01$).

The maximum mercury concentration (354 ppb) from the Yakima River site was determined to be an outlier using the Grubbs' Outlier test. The bass was the oldest (age 5) with near average length (341 mm) and weight (599 g) when compared to the other nine fish in the data set. Using the Grubbs' outlier test (Barnett and Lewis, 1994),

$$z_i = \frac{|\ x_i - \bar{x}\ |}{s}$$

the z value for the sample point (354 ppb) was 2.44, placing it as an outlier. Therefore, the data point was excluded from regression equations displaying mercury concentrations with the independent variables length, weight, and age. Although the data point is not included in the graphs, it is an important piece of information linking bioaccumulation to older fish. The fish should be considered in subsequent and future analysis, as the data point may have not been an outlier if a larger sample would have been taken.

Overall, mercury concentrations were shown to increase in fish tissue as the fish gained size and age. These findings are consistent with other studies presenting the bioaccumulation of mercury in predatory fish occupying upper trophic levels (Serdar et al., 2001; Håkanson et al., 1988; Fischnaller et al., 2003).

Target Size Range

Relationships among physical characteristics and mercury concentrations can be helpful to explain sampling variance and add strength to some statistical methods for trend detection. While a range of sizes is preferred to help establish such relationships, too wide a range may confound analyses. Keeping the size range as tight as possible can help reduce variance in estimates of mean concentrations. A balance between a broad and narrow range of fish sizes will be sought as fish are collected, while also considering other factors.

Target size ranges as discussed in the project plan were determined by considering historical data, usefulness for long-term monitoring, angler-preferred size ranges, and fishing regulations. The target size range is expressed in total length of an individual fish (250 mm to 460 mm, or about 10 to 18 inches) and in terms of the spread or range of the group of fish collected: the length of the smallest fish should be at least 75% the length of the largest fish (Seiders, 2006).

Figure 4 shows the total length of individual fish collected in 2005. About 88% (53 of 60) fish met the target size range of 250 mm to 460 mm. Seven fish were outside this target range at four sites (Long Lake, Loon Lake, Potholes Reservoir, and Silver Lake). Considering the size and distribution of the sample (n) at each of these sites, the impact of these seven fish appear to be negligible.

The guideline of the smallest fish being at least 75% the length of the longest fish was met at two of the six sites. The smallest fish at Liberty and Loon Lakes were 85% and 87% the length of the longest fish, respectively. The smallest fish at Long Lake, the Yakima River, and Silver Lake were 71%, 71%, and 67% the length of the longest fish, respectively. Potholes Reservoir yielded the widest size range of fish with the smallest being 49% the length of the longest.

Implications for future trends analyses using the broad size range of fish from the Potholes Reservoir are unclear. The sizes of fish from this site are somewhat evenly distributed from the smallest to the largest, although the two largest and one smallest fish lie outside of the target range for total length. Neither the largest or smallest fish qualified as an outlier using the Grubbs' Test. Future sampling at these sites (in 2010) should endeavor to collect individuals that are of similar size and size range in order to normalize data.

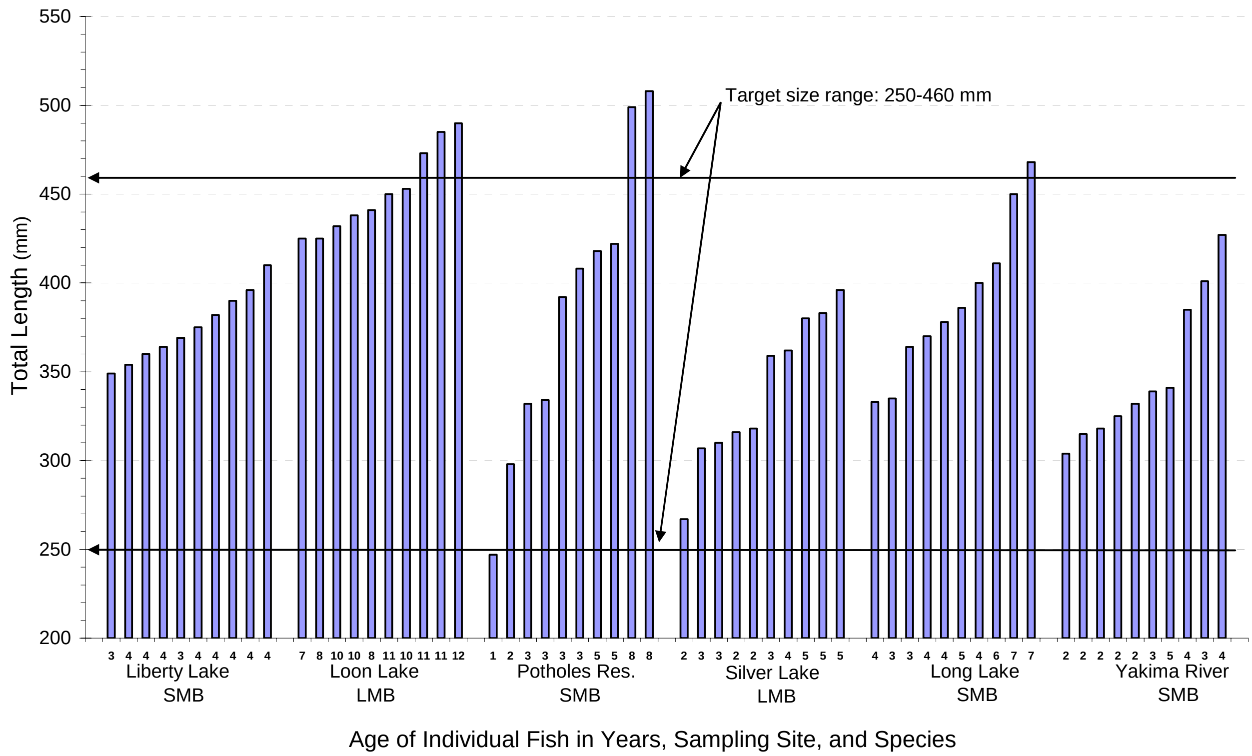

Figure 4. Individual Fish Lengths and Age.

Trend Assessment

To allow for spatial and temporal trends analyses, mercury concentrations for each lake were projected through a multiple regression equation to a standard-size fish. The regression analysis used was the same method used by Fischnaller et al. (2003) to determine mercury in a standard-size fish.

To determine mercury concentrations for a standard fish length of 356 mm, the following multiple regression formula was calculated:

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

$$10^{Log_{10}(Hg)} = Hg\ Concentration\ at\ 356mm$$

Regression coefficients (M, B1, B2), products, and mercury concentrations for the projected 356mm length are listed in Appendix E, Table E4. Figure 5 displays mercury concentrations for the standardized fish for the current study and the Fischnaller et al. (2003) study.

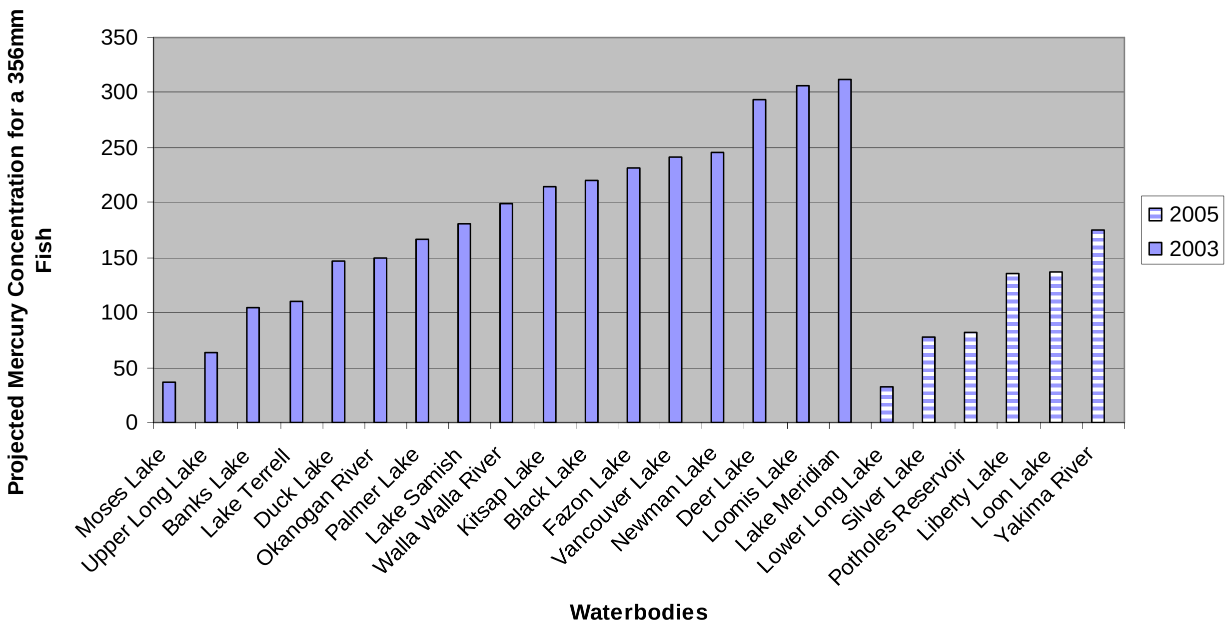

Figure 5. Projected Mercury Concentrations for a 356-mm Fish.

The 356-mm value bisected positive regression slopes for length vs. mercury concentrations at all lakes, with the exception of Loon Lake. Loon Lake mercury concentrations were standardized by extrapolating mercury concentrations from the linear regression formula obtained from plotting paired values of length vs. concentration. Deer Lake and Loomis Lake were standardized in a similar manner in 2003 without using the multiple regression analysis.

An Analysis of Variance (ANOVA) was performed for the adjusted mercury concentrations for the 2005 lakes to determine if significant differences exist among mercury concentrations after length was considered. The ANOVA between adjusted mercury means found Lower Long Lake, Silver Lake, and Potholes Reservoir to be significantly below the remainder of the dataset that included the Yakima River, Loon Lake, and Liberty Lake. An ANOVA of the lakes in the 2003 study led Fischnaller et al. (2003) to theorize that increased flushing of reservoirs and rivers would partially explain lower mercury concentrations. The 2005 ANOVA does not fully support that claim, with the Yakima River having significantly greater mercury concentrations than the reservoirs.

Other factors to be considered in future analyses for trends and causes of trends include (1) identification of local and global sources of mercury, and (2) site characteristics that affect local mercury dynamics (e.g., watershed and in-lake mercury methylation processes, lake trophic status and changes over time, fish community, and food-web structure). As more information on these factors is found, all sites and target species will need to be evaluated for how conducive they are for long-term monitoring of mercury levels (for many decades).

Criteria for Protection of Human Health

Criteria for Mercury

Various criteria have been developed for mercury in fish tissue in order to meet differing needs:

- *EPA Recommended Criterion:* 300 ppb ww (based on 17.5 grams/day consumption rate).
- *National Toxics Rule:* 825 ppb ww (based on 6.5 grams/day consumption rate).
- *EPA Screening Values:* 400 ppb ww for recreational fishers and 49 ppb ww for subsistence fishers (based on freshwater fish consumption rates of 17.5 and 142.4 grams/ day, respectively).

These criteria are summarized below and compared with mercury levels found in fish collected in 2005. Appendix F discusses how Ecology and the Washington State Department of Health evaluate fish tissue data to meet the different mandates these agencies have.

EPA's Recommended Criterion

The EPA's current recommended water quality criterion for methylmercury is 300 ppb (EPA, 2001). This is the maximum advisable concentration of methylmercury in fish and shellfish to protect consumers among the general population. EPA expects the criterion to be used as guidance by states and authorized tribes as well as by EPA in establishing or updating water quality standards for waters of the United States.

National Toxics Rule

Washington's water quality standards for toxic substances (WAC 173-201A-040[5]) define human-health-based water quality criteria by referencing 40 CFR 131.36, also known as the National Toxics Rule (NTR). 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 consumption rate. The NTR criteria are based on a consumption rate of 6.5 grams/day.

EPA Screening Values

Screening values (SVs) for carcinogenic and non-carcinogenic substances were developed by EPA to aid in the prioritization of areas that may present risks to human populations from fish consumption. The EPA 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 two different 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.

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 wet weight remains to be the value used in Washington's water quality standards for regulatory purposes.

Five of the 60 samples exceeded EPA's recommended criterion of 300 ppb. The highest value, 372 ppb, was found in a 12-year-old female largemouth bass from Loon Lake. EPA's screening value for subsistence fishers, 49 ppb, was exceeded in 51 (85%) of the samples. No samples exceeded the NTR criterion of 825 ppb or EPA's screening value for recreational fishers of 400 ppb. Mercury was detected in all but two tissue samples.

While smallmouth and largemouth bass are subject to the same EPA recommended criteria (300 ppb) and National Toxics Rule criteria (825 ppb), it is important to distinguish limits of usefulness for cross-comparison between the species. Although the fish have similar habitat, feeding traits, and trophic level, additional data on both species will be needed to assess (1) how mercury accumulates differently in the two species and (2) the usefulness of direct comparisons between the two.

Summary and Conclusions

This was the first year of a five-year study to gather information on mercury trends in Washington State. Forty smallmouth bass and 20 largemouth bass were collected from six sites across Washington: Liberty Lake, Long Lake (Spokane River), Loon Lake, Potholes Reservoir, Silver Lake, and the Yakima River. Fish fillet tissue from these sites was analyzed for total mercury content.

Results showed that mercury concentrations in bass were generally highest in older, longer, and heavier fish. In fact, positive correlations were found between mercury concentrations and fish age, length, and weight in all waterbodies sampled. These data are consistent with other studies displaying the bioaccumulation of mercury in predatory species occupying upper trophic levels (Serdar et al., 2001; Håkanson et al., 1988; Fischnaller et al., 2003).

Approximately 8% of the 60 fish sampled (5 fish) contained mercury concentrations higher than the EPA Recommended Fish Tissue Criterion (300 ppb). Four of these fish were bass from Loon Lake where they contained an average mercury concentration of 327 ppb. All four of the bass were female averaging 11 years of age, 470 mm in length, and weighing 2033 grams. Although these fish exceed the EPA's Recommended Criterion, the mercury concentrations are not uncommon for a fish of that age and size. No fish had mercury levels above the National Toxics Rule Criterion (825 ppb) or the U.S. Food and Drug Administration action level (1000 ppb).

Only one other fish had a mercury concentration above EPA's 300 ppb recommended criterion: a female smallmouth bass collected from the Yakima River near Horn Rapids Dam. This fish was the oldest (age 5) in the Yakima data set, with near average length (341 mm) and weight (599 g), and a mercury concentration of 354 ppb. Only one other fish from the Yakima River had mercury content over 200 ppb.

Mercury concentrations in fish collected in 2005 are within typical ranges for Washington (Fischnaller et al., 2003; Paulson 2004; Serdar et al., 2001; Munn et al., 1995). As more data are collected from a variety of watersheds, spatial and temporal trends will be easier to quantify. Future sampling efforts should continue to seek diverse waterbodies (e.g., effluent-dominated streams, pristine lakes, urban lakes) in different areas of the state.

Recommendations

As a result of this study, the following recommendations are made:

- Partner with other Washington State Department of Ecology (Ecology) programs to conduct a comprehensive inventory of statewide, regional, and global sources that may be affecting mercury levels in Washington. Such an inventory is needed to (1) better understand sources, transport, and fate of mercury as related to monitoring sites, (2) select monitoring sites conducive to detecting trends in fish tissue, and (3) help distinguish changes in mercury levels to determine efficacy of the *Washington State Mercury Chemical Action Plan*.

- Analyze existing mercury-in-fish data available from Ecology, EPA, and USGS to aid in understanding trends, levels in specific regions, differences in mercury levels among fish communities, and help direct sampling.

- Collect additional information about site and watershed characteristics to help determine factors that affect levels of mercury in environments (e.g., watershed and in-lake mercury methylation processes, lake trophic status and changes over time, fish community and food-web structure). Bioaccumulation of mercury is driven by many factors, and the relative contributions of each are poorly defined; however, these mechanisms may be better understood as information is gained during this five-year project.

- Mercury concentrations higher than the EPA's Recommended Fish Tissue Criterion (300 ppb) were discovered at Loon Lake and the Yakima River (near Horn Rapids Dam). Collection of fish from multiple trophic levels within these waterbodies should continue to determine if, in fact, mercury contamination is an issue.

- Both smallmouth and largemouth bass have been collected and analyzed for mercury content in this and historical studies. To evaluate the usefulness of the data for comparing mercury concentrations between these two species, smallmouth and largemouth bass should be collected concurrently, when available, from the same waterbody.

- Consider adding yellow perch (*Perca flavescens*) as a target species for this study because of its widespread occurrence in Washington. Perch may frequently be found in adequate numbers where largemouth bass, smallmouth bass, and walleye are scarcer. The use of yellow perch in other states' mercury monitoring efforts would also allow greater nationwide comparison.

- Future efforts concerning trends analyses should continue to sample the same species whenever possible in these waterbodies: Liberty Lake, Long Lake (Spokane River), Loon Lake, Potholes Reservoir, Silver Lake, and the Yakima River.

- Continue funding for this long-term monitoring project for many years into the future.

References

Barnett, V. and T. Lewis, 1994. Outliers in Statistical Data, Third Edition. John Wiley and Sons. New York, NY.

Bloom, N. 1995. Considerations in the Analysis of Water and Fish for Mercury. In National Forum on Mercury in Fish: Proceedings. U.S. Environmental Protection Agency, Office of Water, Washington D.C. EPA Publication No. 823-R-95-002.

CFR, 2004. Code of Federal Regulations, Title 40, Part 131, Section 36: Toxics Criteria for Those States Not Complying with Clean Water Act Section 303(3)(2)(B). Revised July 1, 2004. frwebgate.access.gpo.gov/cgi-bin/get-cfr.cgi.

EPA, 2000. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories - Volume 1: Field Sampling and Analysis, Third Edition. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. Publication No. EPA-823-B-00-007. www.epa.gov/ost/fishadvice/volume1/

EPA, 2001. Water Quality Criterion for the Protection of Human Health: Methylmercury. U.S. Environmental Protection Agency, Office of Science and Technology, Washington, D.C. Publication No. EPA-823-R-01-001.

FDA, 1985. Action Levels for Poisonous or Deleterious Substances in Human Food and Animal Feed. U.S. Food and Drug Administration, Center for Food Safety and Applied Nutrition, Industry Programs Branch, Washington D.C.

Fischnaller, S., P. Anderson, and D. Norton, 2003. Mercury in Edible Fish Tissue and Sediments from Selected Lakes and Rivers of Washington State. Washington State Department of Ecology, Olympia, WA. Publication No. 03-03-026. www.ecy.wa.gov/biblio/0303026.html

Gallagher, M., 2000. Proposed Strategy to Continually Reduce Persistent, Bioaccumulative Toxins (PBTs) in Washington State. Washington State Department of Ecology, Olympia, WA. Publication No. 00-03-054. www.ecy.wa.gov/biblio/0003054.html

Hakanson. L., A. Nilsson, and T. Anderson, 1988. Mercury in Fish in Swedish Lakes. Environmental Pollution. 49:145-162.

Johnson, A., K. Seiders, C. Deligeannis, K. Kinney, P. Sandvik, B. Era-Miller, and D. Alkire, 2006. PBDE Flame Retardants in Washington Rivers and Lakes: Concentrations in Fish and Water, 2005-06. Washington State Department of Ecology, Olympia, WA. Publication No. 06-03-027. www.ecy.wa.gov/biblio/0603027.html

McBride, D., 2003. Statewide Bass Advisory. Washington State Department of Health, Olympia, WA. September 2003. www.doh.wa.gov/ehp/oehas/publications%20pdf/statewide_%20bass_%20advisory-2003.pdf

McBride, D., 2006. Personal communication regarding sampling strategy for this trend monitoring effort. Washington State Department of Health, Olympia, WA. February 23, 2006.

Momohara, D., 2006. Personal communication. Case Narrative for Laboratory Results for the Mercury Trends in Fish 2005 Study. April 4, 2006.

Morel, F., A. Kraepiel, and M. Amyot, 1998. The Chemical Cycle and Bioaccumulation of Mercury. Annual Reviews of Ecology and Systematics. November 1998, Volume 29: 543-566. Annual Reviews, Palo Alto, CA.

Munn, M., S. Cox, and C. Dean, 1995. Concentrations of Mercury and Other Trace Elements in Walleye, Smallmouth Bass, and Rainbow Trout in Franklin D. Roosevelt Lake and the Upper Columbia River, Washington, 1994. U.S. Geological Survey, Open-File Report 95-195, Tacoma, WA.

Norton, D., 2004. Mercury in Lake Whatcom Sediments: Spatial Distribution, Depositional History, and Tributary Inputs. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-019. www.ecy.wa.gov/biblio/0403019.html

Paulson, A.J., 2004. Sources of Mercury in Sediments, Water, and Fish of the Lakes of Whatcom County, Washington. U.S. Geological Survey Scientific Investigations Report 2004-5084. USGS, Reston, VA.

Peele, C., 2003. Washington State Mercury Chemical Action Plan. Washington State Departments of Ecology and Health, Environmental Assessment Program, Olympia, WA. Publication No. 03-03-001. www.ecy.wa.gov/biblio/0303001.html

Seiders, K., 2006. Measuring Mercury Trends in Freshwater Fish in Washington State: Quality Assurance Project Plan. Washington State Department of Ecology, Olympia, WA. Publication No. 06-03-103. www.ecy.wa.gov/biblio/0603103.html

Serdar, D., J. Johnston, K. Mueller, and G. Patrick, 2001. Mercury Concentrations in Edible Muscle of Lake Whatcom Fish. Washington State Department of Ecology, Olympia, WA. Publication No. 01-03-012. www.ecy.wa.gov/biblio/0103012.html

USGS, 1997. Are Walleye from Lake Roosevelt Contaminated with Mercury? U.S. Geological Survey, Fact Sheet No. 102-97, August 1997. U.S. Government Printing Office.

Yake, W., 2002. An Estimate of the Effectiveness of Several Approaches to Trend Detection. (Unpublished Review, March 8, 2002). Washington State Department of Ecology, Environmental Assessment Program. Olympia, WA.

Appendices

A. Sample Site Descriptions

B. Field Sampling Procedures

C. Data Quality Assessment for Fish Tissue Results

D. Fish Tissue Data

E. Statistical Comparisons

F. Fish Tissue Data Evaluation by Ecology and the Washington State Department of Health

Appendix A. Sample Site Descriptions

Table A1. Detailed Sample Site Descriptions.

Site Name	Latitude[1] (decimal degrees)	Longitude[1] (decimal degrees)	WBID[2]	County	EIM "User Location ID"[3]	WRIA	Location Description
Liberty Lake	47.6459	-117.0776	WA- 57-9010	Spokane	LIBERTY-F	57	Approx. 5 mi. NE of Spokane industrial area
Long Lake	47.8415	-117.7249	WA- 54-9040	Spokane	SPK 40.8	54	Near Lower Long Lake, river mile 40.8
Loon Lake	48.0536	-117.6319	WA- 59-9130	Stevens	LOON-F	59	20 mi. S of Chewelah off Hwy 395
Potholes Reservoir	46.9813	-119.3144	WA- 41-9280	Grant	POTHOLES-F	41	10 mi SW of Moses Lake
Silver Lake	46.2991	-122.7702	WA- 26-9110	Cowlitz	SILVERLNRCR-F	26	12 mi NE of Longview and 5 mi. E of Castle Rock
Yakima River	46.3711	-119.4364	WA- 37-1010	Benton	YAKIMARABVHR-F	37	12 mi. NW of Richland, above Horn Rapids Dam

[1] North American Datum 1983 is the horizontal datum for coordinates. Coordinates for fish tissue samples are in the central part of lake while fish were usually collected from many areas of the lake.

[2] Ecology's Water Body Identification Number (WBID)

[3] Site identification as used in Ecology's Environmental Information Management (EIM) system.

Appendix B. Field Sampling Procedures

Fish Tissue Samples

Methods for the collection, handling, and processing of fish tissue samples for analyses were guided by methods described in the EPA Field Sampling Guide (EPA 2000). Fish were collected using gill nets, fyke nets, or electrofishing with a 16' Smith-Root electrofishing boat. Fish were collected by the Washington Department of Fish and Wildlife (WDFW) crews at Potholes Reservoir and Liberty Lake. Ecology collected fish from the Yakima River and Loon, Long, and Silver Lakes.

Captured fish were identified to species, and target species were retained while non-target species were released. Retained fish were inspected to ensure they were acceptable for further processing (e.g., preferred size range, no obvious damage to tissues, skin intact).

Field preparation of individual fish involved:

- Euthanizing the fish by a blow to the head with a dull object.
- Rinsing in ambient water to remove foreign material from their exterior.
- Weighing to the nearest gram.
- Measuring the total length to the nearest millimeter.
- Double-wrapping individuals in foil with a tag identifying the date and location of capture, species, and fish identification number.
- Placing foil-wrapped fish into plastic zip-lock bags.
- Placing the bagged fish on ice in the field and transporting iced fish to the Ecology facilities in Lacey, Washington within 72 hours of collection.
- Transferring fish to a dedicated freezer and freezing to -20°C.

Frozen fish were processed at Ecology's Lacey facility on a later date to form samples to be sent to the laboratory for analysis. The edible portion of target species was used for individual samples.

The processing of fish was as follows:

- Fish were removed from the freezer and partially thawed.
- Scales were removed using the dull side of a fillet knife.
- One or two fillets were removed from the fish, depending on the fish size and sample mass required for analysis; fillets from all species included the skin.
- Fillets were cut into 1-2 cm pieces and passed through a decontaminated Kitchen-Aid model FGA food grinder two times to allow thorough grinding and homogenization of fillets from individual fish.
- Sample jars were identified with a sample ID code and pre-assigned a lab sample number; extra tissue was archived.
- Sample jars ready for analysis were returned to the freezer until transported to the laboratory.

After fillets were removed from the fish, scales and otoliths were removed for determining the age of individual fish. Scales were mounted on acetate scale cards provided by WDFW biologists while otoliths were stored in plastic trays designed for such work. All aging structures were identified, packaged according to WDFW directions, and then sent to WDFW staff in Olympia. WDFW later reported the age of individual fish on a spreadsheet or on the returned scale cards. The gender of each fish was determined by opening the abdominal cavity and identifying gonads as testes or ovary.

Decontamination Procedures

All utensils used for processing tissue samples were cleaned to prevent contamination of the sample. Utensils include bowls, knives, and tissue grinding appliances having plastic and stainless steel parts. Equipment contacting water samples during collection included glass jars and Teflon nozzles. All utensils for fish tissue and water sampling were cleaned using the following procedure:

- Soap (Liquinox) and hot water wash.
- Tap water rinse.
- 10% nitric acid rinse (omitted for water sampling devices).
- Deionized water rinse (omitted for water sampling devices).
- Solvent rinses with pesticide-grade acetone followed by hexane or methanol.
- Utensils air-dried and then packaged in aluminum foil and plastic bags to prevent contamination.

The live well on the electrofishing boat, used to temporarily store fish when captured, was rinsed and scrubbed with ambient water prior to collecting and holding fish. The live well and retrieval nets were cleaned several times during the collection season at Ecology's Lacey facilities using a general boat washing soap followed by thorough rinsing with tap water.

Field Records

Information about each sampling event was recorded in field notebooks. Notes included:

- Date and time.
- Sampling personnel.
- General sampling location.
- Latitude/longitude coordinates of sample site were taken using a Magellan Model 320 Handheld GPS or using maps contained in desktop computer GIS programs.
- General weather conditions.
- Method of sampling.
- Fish species collected.
- Weights and lengths for individual fish specimens.

Additional information was recorded at the time fish tissue samples were processed and submitted for laboratory analysis:

- Fish identification number.
- Preassigned laboratory sample number.
- Date of resection.
- Types of aging structures retained and their identification data.
- Sex of specimen.
- Which fillet(s) removed.
- Weight of fillet before grinding.
- Weight of sample transferred to sample jar.
- Whether an archive sample was retained and stored at Ecology’s Lacey facility.
- Other observations or notes about processing the sample.

Appendix C. Data Quality Assessment for Fish Tissue Results

Results from quality control and quality assurance practices for fish tissue samples indicate that the analytical system performed adequately with data meeting objectives for quality control. Quality control procedures included analysis of method blanks, control standards, matrix spikes, and matrix spike duplicates. Results from the analyses of blanks, standards, matrix spikes, and matrix spike duplicates met all acceptance criteria established by Manchester Environmental Laboratory. The precision of lab duplicate analyses, expressed as Relative Percent Difference (RPD), ranged from 0% to 8.7%. Tissue samples were analyzed within six months of collection which met requirements described in the project plan.

Tables C1 to C3 show results from matrix spike, Standard Reference Material, and lab duplicate analyses.

Table C1. Results from Matrix Spikes (%).

Sample ID	LMX1 Recovery	LMX2 Recovery	RPD
06085017	87.00	90.00	3.4
06085025	91.00	92.00	1.1
06085039	90.00	89.00	1.1
06085040	97.00	100.00	3.0
		Mean:	2.15

Table C2. Results from Standard Reference Material (%), Analysis of 1946 (Lake Superior)

Sample ID	Recovery
ML06080H3	95
ML06086H3	105
ML06089H2	105
Mean:	101.6

Table C3. Results from Laboratory Duplicates.

Sample ID	Result 1 (ug/kg ww)	Result 2 (ug/kg ww)	RPD (%)
06085000	0.14	0.15	-6.9
06085010	0.26	0.25	4.4
06085020	0.06	0.06	0.0
06085030	0.12	0.11	8.7
		Mean:	1.5

Appendix D. Fish Tissue Data

Table D1. Field Data and Mercury Concentrations for Individual Fish.

Waterbody	Field ID	Lab #	Collection Date	Process Date	Species Code [1]	Total Length (mm)	Weight (gm)	Age (yrs)	Sex	Mercury (ug/Kg ww)
Liberty Lake	LIB-01	06085000	10/10/05	1/23/06	SMB	364	648	4	F	150
Liberty Lake	LIB-02	06085001	10/10/05	1/23/06	SMB	349	636	3	F	110
Liberty Lake	LIB-03	06085002	10/10/05	1/23/06	SMB	390	879	4	F	170
Liberty Lake	LIB-05	06085003	10/10/05	1/23/06	SMB	354	635	4	F	140
Liberty Lake	LIB-07	06085004	10/11/05	1/23/06	SMB	375	733	4	F	140
Liberty Lake	LIB-08	06085005	10/11/05	1/23/06	SMB	369	709	3	M	120
Liberty Lake	LIB-10	06085006	10/11/05	1/23/06	SMB	396	832	4	M	160
Liberty Lake	LIB-11	06085007	10/11/05	1/23/06	SMB	410	1077	4	F	185
Liberty Lake	LIB-12	06085008	10/11/05	1/23/06	SMB	382	778	4	F	160
Liberty Lake	LIB-13	06085009	10/11/05	1/23/06	SMB	360	712	4	M	204
					Average	*374.9*	*763.9*	*3.8*		*153.9*
					Std. Dv.	*19.5*	*137.1*	*0.4*		*28.5*
					Median	*372.0*	*722.5*	*4.0*		*155.0*
					Min.	*349*	*635*	*3*		*110*
					Max	*410*	*1077*	*4*		*204*
					25th %ile	*361.0*	*663.3*	*4.0*		*140.0*
					75th %ile	*388.0*	*818.5*	*4.0*		*167.5*
Long Lake (lower)	3L-08	06085050	11/3/05	12/8/05	SMB	468	1625	7	F	98
Long Lake (lower)	3L-09	06085051	11/3/05	12/8/05	SMB	335	663	3	M	17
Long Lake (lower)	3L-10	06085052	11/3/05	12/8/05	SMB	386	905	5	F	100
Long Lake (lower)	3L-11	06085053	11/3/05	12/8/05	SMB	400	995	4	F	30
Long Lake (lower)	3L-12	06085054	11/3/05	12/8/05	SMB	378	966	4	M	22
Long Lake (lower)	3L-13	06085055	11/3/05	12/8/05	SMB	370	887	4	F	32
Long Lake (lower)	3L-14	06085056	11/3/05	12/8/05	SMB	364	810	3	M	17
Long Lake (lower)	3L-17	06085057	11/3/05	12/8/05	SMB	333	459	4	F	68
Long Lake (lower)	3L-18	06085058	11/3/05	12/8/05	SMB	411	1170	6	F	81
Long Lake (lower)	3L-22	06085059	11/3/05	12/8/05	SMB	450	1333	7	F	87
					Average	*389.5*	*981.3*	*4.7*		*55.2*
					Std. Dv.	*44.4*	*332.0*	*1.5*		*34.8*
					Median	*382.0*	*935.5*	*4.0*		*50.0*
					Min.	*333*	*459*	*3*		*17*
					Max	*468*	*1625*	*7*		*100*
					25th %ile	*365.5*	*829.3*	*4.0*		*24.0*
					75th %ile	*408.3*	*1126.3*	*5.8*		*85.5*
Loon Lake	LOON-01	06085010	10/26/05	1/14/06	LMB	441	1542	8	F	246
Loon Lake	LOON-02	06085011	10/26/05	1/23/06	LMB	425	1289	7	M	192
Loon Lake	LOON-03	06085012	10/26/05	1/23/06	LMB	450	1725	11	F	301
Loon Lake	LOON-04	06085013	10/26/05	1/24/06	LMB	453	2011	10	F	317
Loon Lake	LOON-05	06085014	10/26/05	1/23/06	LMB	473	1917	11	F	292
Loon Lake	LOON-06	06085015	10/26/05	1/23/06	LMB	438	1525	10	M	253
Loon Lake	LOON-07	06085016	10/26/05	1/23/06	LMB	490	2381	12	F	372
Loon Lake	LOON-08	06085017	10/26/05	1/24/06	LMB	485	2015	11	F	316
Loon Lake	LOON-09	06085018	10/26/05	1/24/06	LMB	432	1569	10	F	255
Loon Lake	LOON-10	06085019	10/26/05	1/24/06	LMB	425	1537	8	F	254
					Average	*451.2*	*1751.1*	*9.8*		*279.8*
					Std. Dv.	*23.9*	*324.8*	*1.6*		*50.2*
					Median	*445.5*	*1647.0*	*10.0*		*273.5*
					Min.	*425*	*1289*	*7*		*192*
					Max	*490*	*2381*	*12*		*372*
					25th %ile	*433.5*	*1538.3*	*8.5*		*253.3*
					75th %ile	*468.0*	*1987.5*	*11.0*		*312.3*

Table D1 (continued)

Waterbody	Field ID	Lab #	Collection Date	Process Date	Species Code [1]	Total Length (mm)	Weight (gm)	Age (yrs)	Sex	Mercury (ug/Kg ww)
Potholes Res.	POT-01	06085020	10/25/05	1/24/06	SMB	334	478	3	M	60
Potholes Res.	POT-03	06085021	10/25/05	1/5/06	SMB	422	1016	5	F	95
Potholes Res.	POT-05	06085022	10/25/05	1/5/06	SMB	499	1685	8	F	205
Potholes Res.	POT-06	06085023	10/25/05	1/5/06	SMB	418	1182	5	F	120
Potholes Res.	POT-07	06085024	10/26/05	1/5/06	SMB	408	982	3	M	100
Potholes Res.	POT-08	06085025	10/26/05	1/24/06	SMB	392	782	3	M	68
Potholes Res.	POT-09	06085026	10/26/05	1/24/06	SMB	332	371	3	F	130
Potholes Res.	POT-10	06085027	10/26/05	1/24/06	SMB	298	339	2	M	85
Potholes Res.	POT-11	06085028	10/26/05	1/5/06	SMB	508	2066	8	M	285
Potholes Res.	POT-12	06085029	10/26/05	1/24/06	SMB	247	193	1	F	35
					Average	*385.8*	*909.4*	*4.1*		*118.3*
					Std. Dv.	*83.8*	*611.1*	*2.4*		*74.8*
					Median	*400.0*	*882.0*	*3.0*		*97.5*
					Min.	*247*	*193*	*1*		*35*
					Max	*508*	*2066*	*8*		*285*
					25th %ile	*332.5*	*397.8*	*3.0*		*72.3*
					75th %ile	*421.0*	*1140.5*	*5.0*		*127.5*
Silver Lake	SILVR-02	06085030	9/22/05	1/25/06	LMB	380	1011	5	F	110
Silver Lake	SILVR-03	06085031	9/22/05	1/25/06	LMB	396	914	5	M	140
Silver Lake	SILVR-04	06085032	9/22/05	1/25/06	LMB	383	796	5	F	150
Silver Lake	SILVR-05	06085033	9/22/05	1/25/06	LMB	362	636	4	F	110
Silver Lake	SILVR-06	06085034	9/22/05	1/25/06	LMB	359	676	3	F	36
Silver Lake	SILVR-07	06085035	9/22/05	1/25/06	LMB	318	478	2	F	56
Silver Lake	SILVR-08	06085036	9/22/05	1/25/06	LMB	316	462	2	M	62
Silver Lake	SILVR-09	06085037	9/22/05	1/25/06	LMB	307	411	3	F	34
Silver Lake	SILVR-10	06085038	9/22/05	1/25/06	LMB	310	386	3	M	62
Silver Lake	SILVR-13	06085039	9/22/05	1/25/06	LMB	267	256	2	M	39
					Average	*339.8*	*602.6*	*3.4*		*79.9*
					Std. Dv.	*41.9*	*246.5*	*1.3*		*43.8*
					Median	*338.5*	*557.0*	*3.0*		*62.0*
					Min.	*267*	*256*	*2*		*34*
					Max	*396*	*1011*	*5*		*150*
					25th %ile	*311.5*	*423.8*	*2.3*		*43.3*
					75th %ile	*375.5*	*766.0*	*4.8*		*110.0*
Yakima River	YR-01	06085040	11/16/05	1/24/06	SMB	318	460	2	M	140
Yakima River	YR-02	06085041	11/16/05	12/23/05	SMB	339	508	3	M	160
Yakima River	YR-03	06085042	11/16/05	12/23/05	SMB	401	988	3	M	130
Yakima River	YR-05	06085043	11/16/05	12/23/05	SMB	341	599	5	F	354
Yakima River	YR-06	06085044	11/16/05	1/24/06	SMB	315	410	2	M	88
Yakima River	YR-08	06085045	11/16/05	12/23/05	SMB	385	839	4	F	205
Yakima River	YR-09	06085046	11/16/05	1/24/06	SMB	325	450	2	F	120
Yakima River	YR-10	06085047	11/16/05	1/24/06	SMB	332	455	2	F	81
Yakima River	YR-11	06085048	11/16/05	1/24/06	SMB	304	379	2	M	110
Yakima River	YR-12	06085049	11/16/05	12/23/05	SMB	427	1088	4	F	197
					Average	*348.7*	*617.6*	*2.9*		*158.5*
					Std. Dv.	*41.2*	*258.0*	*1.1*		*80.2*
					Median	*335.5*	*484.0*	*2.5*		*135.0*
					Min.	*304*	*379*	*2*		*81*
					Max	*427*	*1088*	*5*		*354*
					25th %ile	*319.8*	*451.3*	*2.0*		*112.5*
					75th %ile	*374.0*	*779.0*	*3.8*		*187.8*

[1] SMB = Smallmouth bass; LMB = Largemouth bass.

Appendix E. Statistical Comparisons

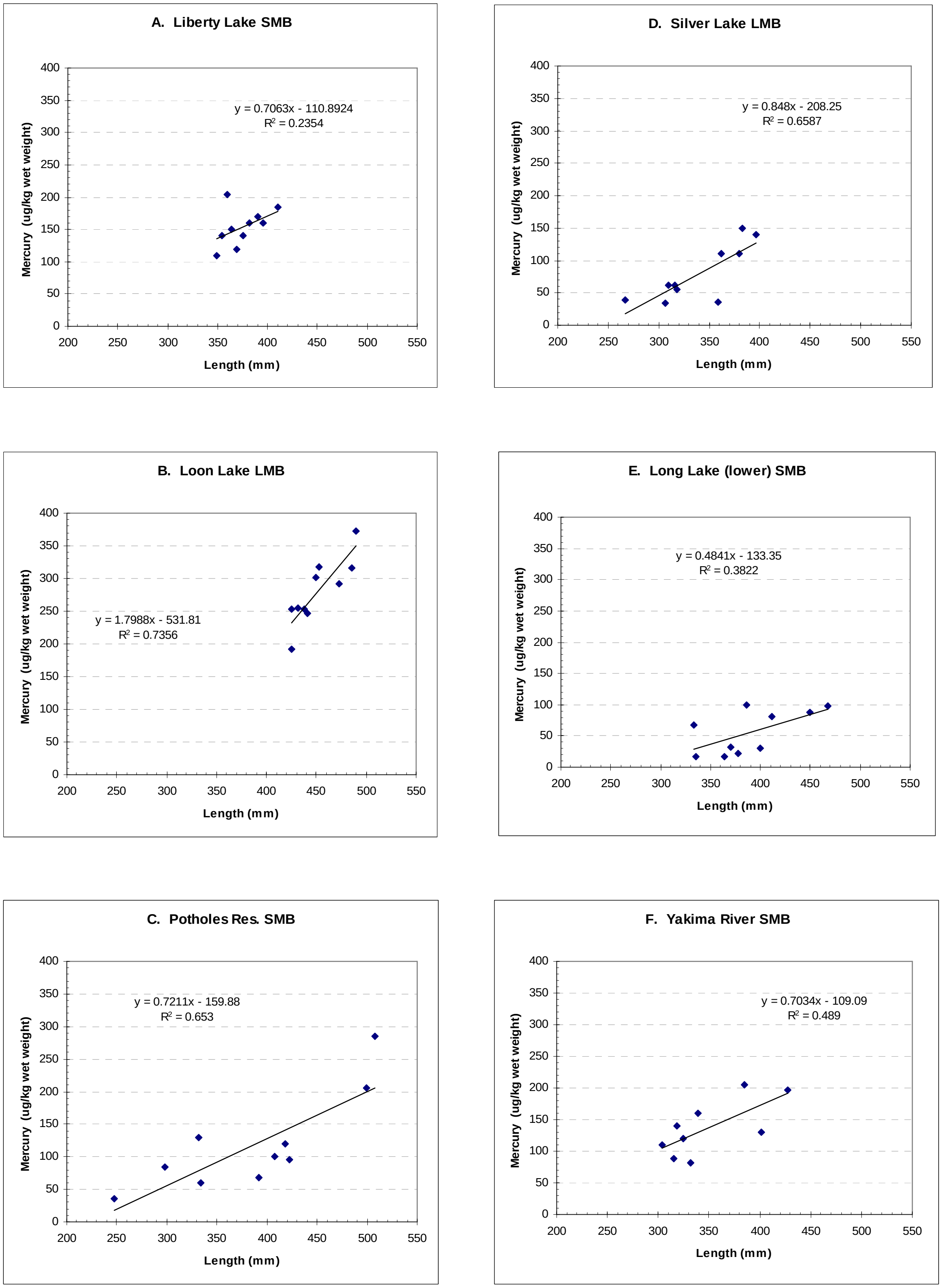

Figure E1. Mercury Concentration versus Fish Length

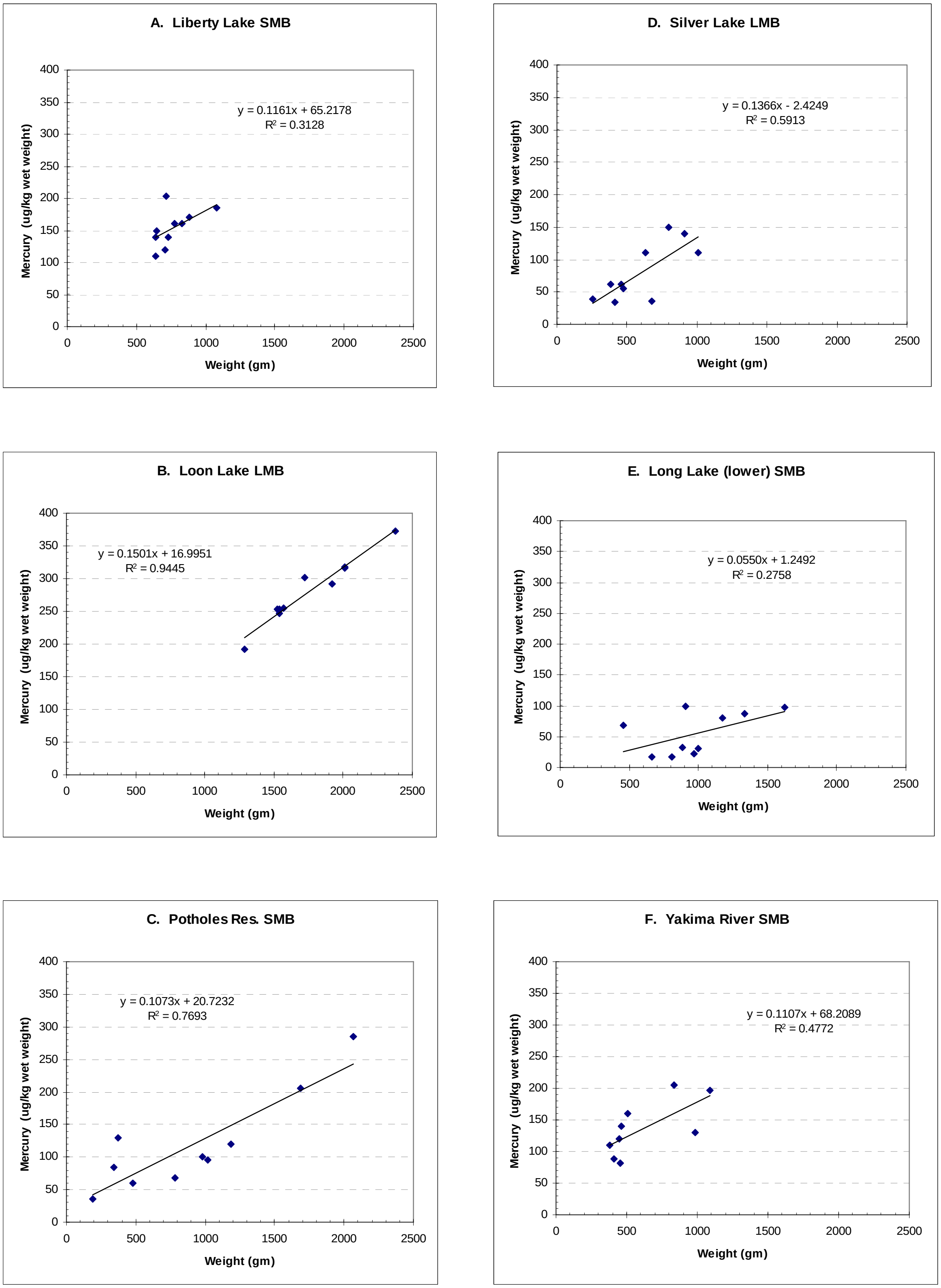

Figure E2. Mercury Concentration versus Fish Weight

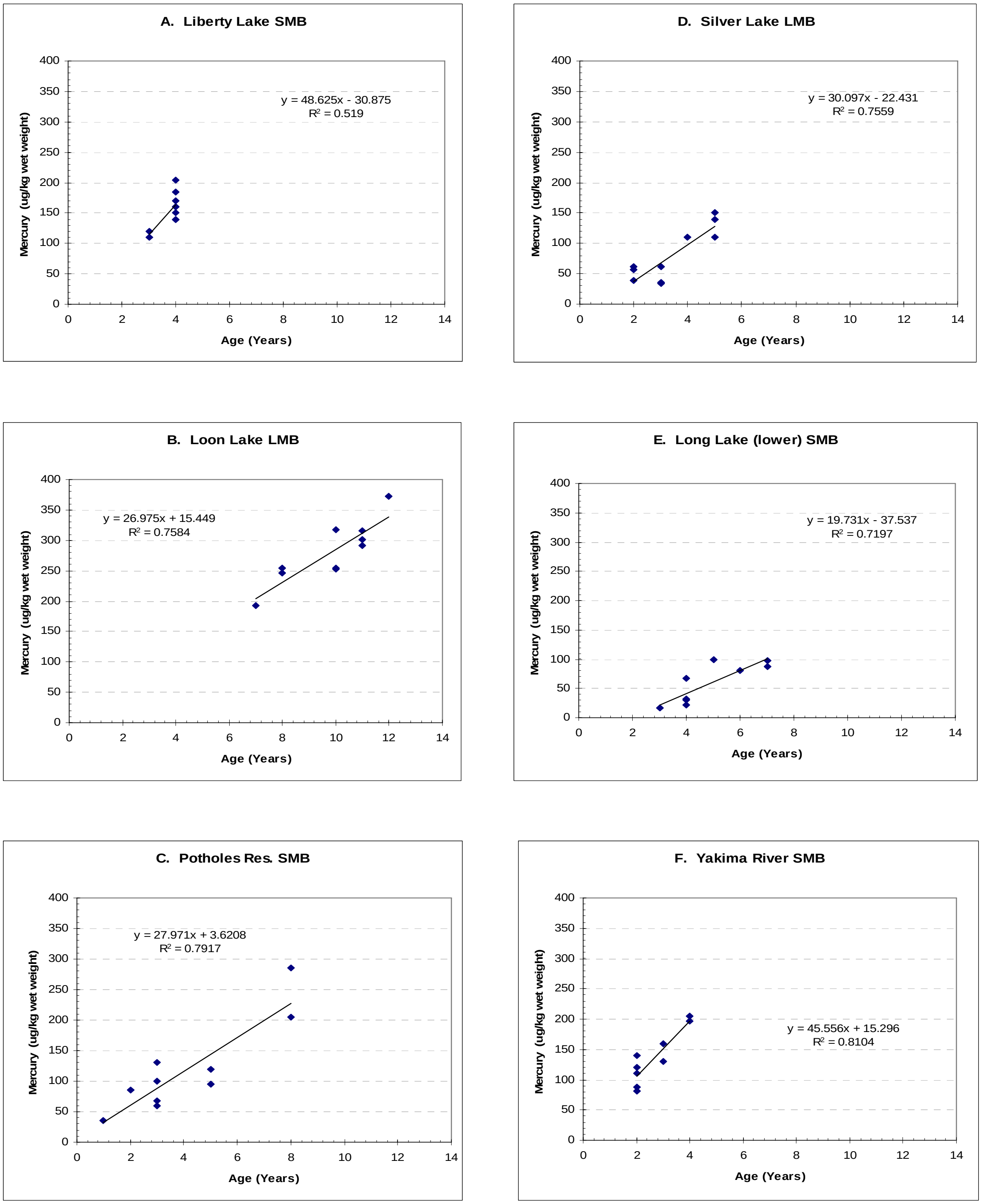

Figure E3. Mercury Concentration versus Fish Age

Table E1. Adjusted Mercury Levels for a Standard 356-mm Fish.

Waterbody	Species	n	Regression Coefficients			Mercury Concentration at 356mm Total Length		r^2*	p
			constant	B1	B2	Log10	µg/kg ww		
Liberty Lake	SMB	10	-41.799	32.24	-5.887	2.132	136	0.069	0.323
Long Lake	SMB	10	177.068	-139.095	27.546	1.506	32	0.212	0.18
Loon Lake^	LMB	10	-	-	-	2.138	137	0.706	0.028
Potholes Reservoir	SMB	10	19.756	-16.15	3.589	1.914	82	0.628	0.013
Silver Lake	LMB	10	127.366	-103.162	21.157	1.889	77	0.539	0.028
Yakima River	SMB	10	-197.42	154.535	29.895	2.242	175	0.054	0.341

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

n – number (sample size)

* adjusted square multiple r

^ Loon Lake fish tissue adjustments were based on log10 transformed data for mercury concentration and total length. The data set did not allow for accurate multiple regression analysis to be performed due to inadequate size ranges. In addition, the r^2 value for Loon Lake is unadjusted.

Appendix F. Fish Tissue Data Evaluation by Ecology and the Washington State Department of Health (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 vary. 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.

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. The 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 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 to bring the waterbody back into compliance with water quality standards.

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 criteria 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 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 criteria 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. The how and when is also dependent on whether the message is targeted toward a sensitive group or a population or the general public. DOH's dual objective is to (1) provide guidance to the public on how to increase consumption of fish low in contaminants to gain the benefits of eating fish, and (2) steer the public away from fish that have high levels of health-damaging contaminants.