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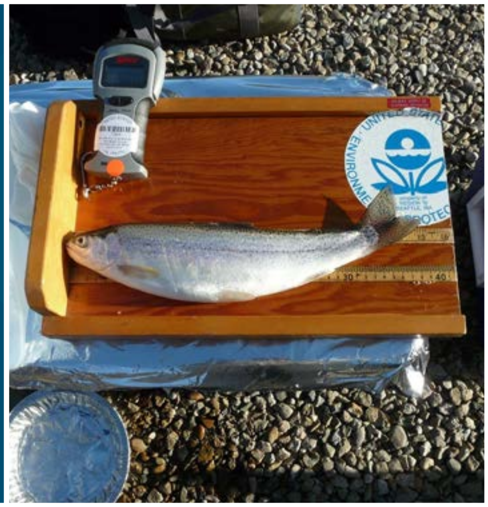

Assessment of Mercury in Fish Tissue from Pacific Northwest Lakes

EPA Region 10 Report

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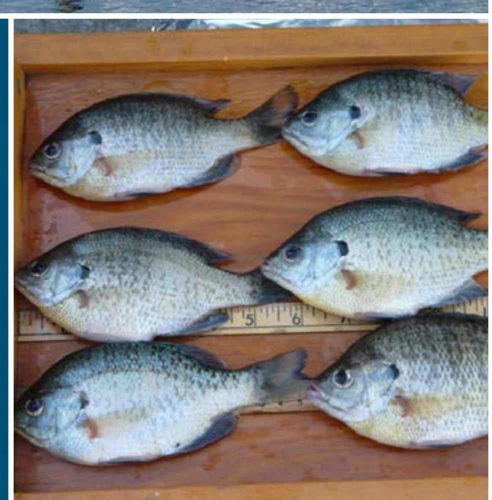
Lillian G. Herger



U.S. Environmental Protection Agency, Region 10
Office of Environmental Assessment

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Abstract

Sportfish collected from 50 lakes in the three Pacific Northwest states of Idaho, Oregon, and Washington during 2012-2014 were analyzed for mercury. A probabilistic design was used to determine the region-wide concentration of fish tissue mercury in lakes that may be used for recreational fishing. Mercury was detected in all fish samples. The EPA tissue-based water quality criterion of 300 $\mu g\ kg^{-1}$ was exceeded in 11% of the 905 lakes represented by the sample lakes. The results are compared to other regional fish tissue mercury studies and the feasibility of adding this indicator into future EPA large-scale lake assessments is discussed.

Introduction

Mercury is one of the most toxic metals found in the environment. Mercury is a naturally occurring metal that cycles among the atmosphere, water, and sediments. Natural releases include rock weathering as well as emissions from geothermal areas and volcanoes. Human activities increase the amount of mercury cycling in the environment. Significant amounts of mercury are emitted from metal smelters, coal-burning power plants, and industrial waste incinerators. Atmospheric deposition is the most significant pathway transporting mercury through the environment (Driscoll et al. 2013). Other pathways include runoff, point discharges, and releases from metals mining. In aquatic systems, the cycling of mercury prolongs the influence of human-caused mercury compounds (Hudson et al. 1995). Biotic processes in both the water column and sediment convert the inorganic form to the toxic methylated form. Methylmercury is the form that accumulates in fish tissue.

Fish have two routes of mercury uptake. Fish concentrate mercury from water (bioconcentration) and through their diet (bioaccumulation). Fish typically accumulate only small amounts of methylmercury through gill tissue and directly from the water column (Spry and Wiener 1991). The majority of the accumulated mercury is acquired through the food web. Fish that have a moderate to high position in the food web accumulate more mercury and mercury concentrations in their tissue increases as they grow. Accordingly, tissue mercury concentrations in upper trophic level fish species best reflect the amount of mercury available to other higher trophic levels (including humans).

Consuming fish that contain mercury can cause toxic effects to humans. Exposures to mercury can affect the human nervous system and harm the brain, heart, kidneys, lungs, and immune system (WHO 2003). The most common way people are exposed to mercury is by eating fish or shellfish that are contaminated with mercury. Because methylmercury affects the developing human nervous system (NRC 2000), fish advisories based on elevated mercury concentrations have lower consumption recommendations for young children, nursing mothers, and women who are or might become pregnant than they have for the rest of the population. North American government agencies have worked to reduce cycling of mercury. An analysis of global emissions inventories by Zhang et al. (2016) estimated a 30% decrease in elemental mercury emissions occurred between 1990 and 2010 with the largest decreases occurring in North America and Europe. They attribute these decreases to local and regional efforts in the form of phasing mercury out of commercial products, controls on coal-burning power plants, and power plant conversion to natural gas.

In the Pacific Northwest (PNW), lakes are an important and diverse aquatic resource. They support complex ecological interactions and provide habitat for fish, birds and wildlife. Lakes of the region are valued by humans as open-space and for recreation and fishing. Fish tissue mercury levels are not broadly understood in the PNW lakes. The only previous region-wide fish tissue toxics assessment in the Pacific Northwest was the 2000-2003 National Lake Fish Tissue Study. This was a nationwide sample of 500 lakes that included 30 lakes in the Pacific Northwest states (Idaho, Oregon, and Washington). Smaller scale studies of lake fish tissue have been conducted by states and EPA, but these studies are not intended to describe the condition of the entire PNW region.

The EPA, in partnership with states and tribes, conducts broad-scale ecological surveys of aquatic resources in order to evaluate their status and to examine associations between ecological condition and natural and anthropogenic influences. The long-term goal of these surveys is to determine if these aquatic resources are in an acceptable or unacceptable condition relative to a set of environmental or ecological values.

EPA has conducted two studies of the nation's lakes (USEPA 2009, USEPA 2016). These assessments evaluate ecological condition using a large suite of water quality, biological and recreation indicators. Although fish tissue toxics are considered an important indicator for assessing recreational quality of aquatic resources, fish collection has been beyond the scope for the national lakes surveys. Although tissue studies were not included in the national survey, EPA Region 10 collected fish tissue mercury data from the same PNW sampling sites as the 2012 National Lakes Assessment (USEPA 2016). Collection of these data was considered an important opportunity by R10 for several reasons:

1. Characterizing mercury levels in fish, water and sediment is an objective of the Region 10 mercury strategy (USEPA 2008). Determining current mercury levels in fish across the PNW region is considered a key step to defining the geographic extent of elevated mercury concentrations is fish tissue.

2. Although a decade has passed since EPA's last nationwide assessment of contaminants in fish tissue, there are no current plans by EPA to conduct another, or to do follow-up monitoring to toxics in fish tissue on a national scale. This necessitates R10 conducting follow-up monitoring of toxics in fish tissue for trend analysis in the Pacific Northwest.

3. Having fish tissue data from the same lakes that were sampled as part of the 2012 National Lakes Assessment means compatible data were collected for other lake metrics (water quality, landscape characteristics, sediment mercury concentrations). These will be available to complement the fish tissue mercury analysis.

The objective of this Region 10 Lakes Fish Tissue Mercury Assessment is to collect predator fish species from a subset of the lakes that were sampled for ecological condition as part of the National Lakes Assessment 2012 in Idaho, Oregon, and Washington. The fish tissue was analyzed for mercury to determine concentrations in recreational fish species. These data are used to address the following questions:

- What are mercury concentrations in fillet tissue of common sportfish from lakes in the Pacific Northwest states (Idaho, Oregon, and Washington) that are used by the public for fishing?
- What is the estimated percentage of PNW lakes with mercury concentrations in sportfish tissue that are above levels of potential concern for humans?
- What is the trend in fish mercury concentration in these lakes over time?

Study Design

A. Sample Frame

The study area is the EPA Region 10 states of Idaho, Oregon and Washington. Assessing a large area requires a study design that can adequately capture the variation across the landscape and also be descriptive of the entire resource of interest. The following is a description of the survey design of the 2012 National Lakes Assessment (NLA), which serves as the basis for this PNW fish tissue mercury study design (USEPA 2016).

The National Lakes Assessment, as do all of the EPA National Aquatic Resource surveys, uses a probability design, which is similar to a public opinion poll. A subset of lakes are selected for sampling from an explicitly defined set of lakes of interest—the 'target population' (Peck et al 2013). The resulting data are used to make inferences to this greater target population of lakes (Peck et al. 2013). The sample lakes are selected using a probability-based sampling method to ensure that they are representative of the target population of lakes. This design has two advantages: 1) prevents site selection bias and 2) allows for statistically valid inferences to the entire target population of lakes (Stevens and Olsen 1999 and 2004).

The site sample generated for the 2012 NLA is a probability sample of lakes representing a target population of lakes in the PNW (USEPA 2016). The study sample frame (potential sample locations) consisted of all lakes (lakes, reservoirs, and ponds) that are permanent water bodies within Oregon, Idaho, and Washington. The landscape data used to generate this set of lakes was the USGS/EPA National Hydrography Dataset Plus, Version 2 (NHDPlus). For the PNW states, this dataset consisted of 8,317 features that could potentially be lakes included in the NLA survey.

This dataset was screened using the following criteria required for the target population:

- surface area > 1 ha (2.47 acres)
- ≥ 0.1 ha open, unvegetated, water surface area
- ≥ 1 meter depth
- minimum residence time of one week
- excludes 'working' lakes used for tailing disposal, sewage treatment, etc.
- excludes saline coastal water bodies and those under tidal influence

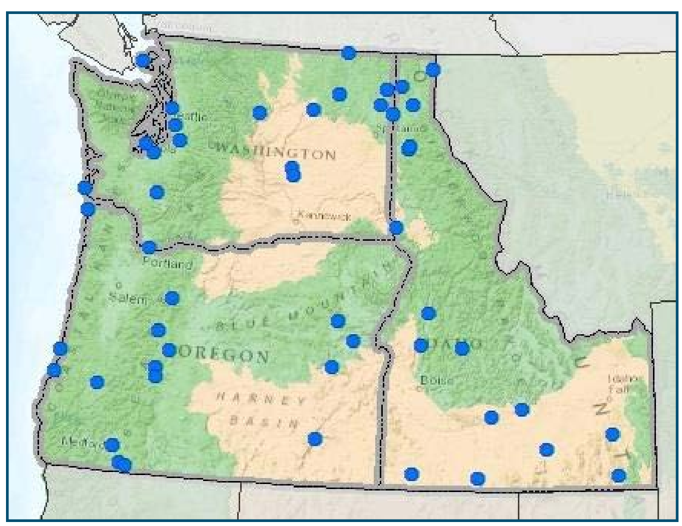
This screening reduced the potential sample locations to a set of 5,013 lakes that represent the target population for the PNW portion of the 2012 National Lakes Assessment.

Sample lakes were selected randomly from this target population in proportion to their occurrence within six size categories (Overton et al. 1990, Stevens and Olsen 2004). Each potential sample lake was evaluated to ensure that it met the target lake screening criteria as well as the following criteria for 'sampleability': 1) no existing safety issues that would prohibit sampling, 2) not excessively remote so sampling with a boat could be conducted in a reasonable timeframe, and 3) permission to access sample sites would be granted by landowners. A final set of 100 lakes were sampled in the Pacific Northwest states (ID, OR, WA), which represented an inference population of 2,479 lakes.

The target population was sampled in a spatially-restricted manner so that the distribution of the sample sites had approximately the same spatial distribution as the target population. This was achieved by using an unequal probability sample method to ensure distribution of samples of sites by size, state, and major ecoregion types (mountainous/humid v. xeric). For example, in this study large lakes were given higher probability of being selected for sampling than small lakes. This effectively increases the probability of having large lakes selected for the sample so that the sample is not dominated by the small lakes, which are much more common across the landscape. This variable selection probability by lake size is accounted for when making the regional estimates by using site weighting factors. Each site is assigned a weight, based on the occurrence of its type (size-class) in the target population. It is important to note that any inferences to the entire target population based simply on the un-weighted site data are inaccurate.

B. Fishable Lake Selection and Extent

The lakes of interest for this mercury study are 'fishable' lakes, where fishable is defined as lakes that are useable and accessible by anglers to capture fish for consumption. These fishable lakes form the target population for this study. The NLA 2012 target population of sample lakes was useable as the base list of sample lakes for this PNW fish tissue mercury study because the fishable lakes target population is more restrictive than the NLA 2012 lakes population. The list of NLA sample lakes described above for the three states was restricted to a 'fishable' target population by applying the following two criteria to validate angler useability and accessibility for the purpose of angling: 1) sites must have public access with ability to harvest fish legally (this would include private water bodies that have an agreement in place with state fisheries agencies so that angler access is allowed) and 2) sites must contain at least one species known to be commonly consumed by anglers of the region (salmonids, centrarchids, etc.) (USEPA 2000a).



Map 1. Locations of the 50 sampled fishable lakes for the PNW states shown in the Western Mountains (green) and Xeric (brown) aggregated level III ecoregions.

The lakes were carefully evaluated for fishability and selected from the lists of NLA sampled lakes of the three states.

The first 16 or 17 lakes that meet the fishable criteria constitute the probability sample of the Fishable Target Population for each of the three states. This process was repeated for each state to generate a 50 lake list. The resulting 50 fish-sampleable lakes were sampled over three field seasons 2012-2014 (Appendix A). Probability design sample weights applied to each lake result in a total inference population of 905 fishable lakes of the PNW. Fishable lakes in the region can be described based on this inference population.

C. Landscape Description of Region 10 Fishable lakes

Descriptive features of the fishable lake inference population based on the 50 lakes sampled are shown in Figure 1. Fishable lakes are predominately in the Western Mountains ecoregion with < 20% in the Xeric ecoregions (USEPA 2003). Most of the fishable lakes are in the Northern Rockies, followed by the Cascades, Coast Range, and Puget Lowlands subecoregions (Level III ecoregions).

The size of most of the fishable lakes was in the 10-50 ha surface area size category and none of the lakes were in the smallest size category (<4 ha). The origin of most of the lakes is either natural or natural with some human influence (e.g., flow alteration or construction) to enhance the size of the lake. The rest of the lakes are either entirely human-made or the result of dam construction.

The biological productivity of the fishable lakes varies from highly productive (hyper-eutrophic) to very low productivity (oligotrophic). About two-thirds of the lakes have medium to low productivity and less than 10% are in the hyper-eutrophic category.

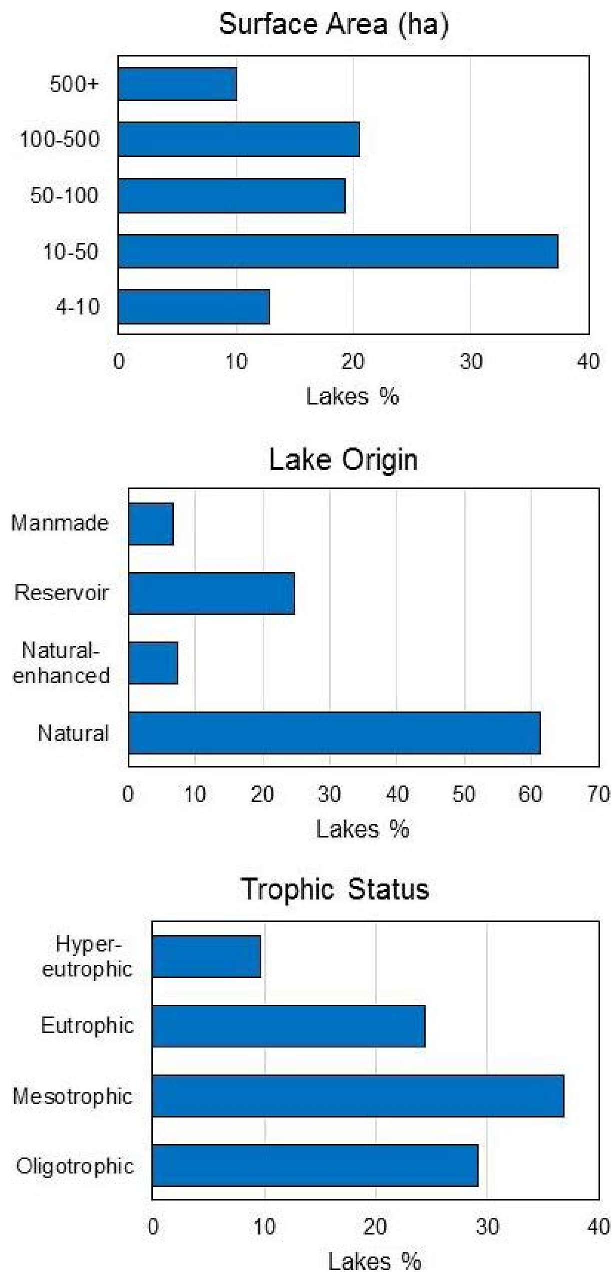


Figure 1. Descriptive features of the fishable lake inference population expressed as percent (N=905).

D. Target Species and Sample Hierarchy

Resident (non-migratory) sportfish species were targeted for sampling, since these are the species that would be captured and consumed by humans. In the PNW lakes, most game species are typically predatory (carnivorous) fish that feed on invertebrates, fish, or both. These can be categorized into two main sportfish groups, salmonids (trout, char, and whitefish) and non-salmonids (centrarchids, percids, and ictalurids).

Since species that are predators tend to bioaccumulate mercury, these fish provide more insight into levels of mercury that may be in sportfish and thus have implications for human consumers as compared to bottom-dwelling species, which tend to be detritivores, herbivores, or omnivores. Other game species considered to be bottom-dwellers (e.g., carp and suckers), as well as non-game species (e.g., shiners) were rejected as sample species. Finally, state and federally listed Threatened and Endangered species were avoided. Bull trout was the only T&E species potentially present in these PNW target sample lakes.

The individual fish targeted were adult fish that were within the length ranges typically consumed by anglers for each species and within the legal harvest limits as stated by the regulations published for each of the three states. The fish collection goal at each lake was 3-10 fish from at least one size class of one sportfish species. Additional size classes and species were collected if available. These additional samples also had to meet the size and species criteria for sportfish of the legal collectable/edible size.

The species available for sampling vary by lake thus a variety of species were analyzed for mercury across all of the sample lakes. Many lakes had both salmonids and non-salmonid sportfish species as part of the fish assemblage. At these lakes, we attempted to collect a species representing both types of sportfish. This increased the likelihood of having a more consistent species/trophic level represented across all sites. The list of sportfish species that were likely to be sampled based on the eligible target species and knowledge of PNW lakes is included as Appendix B.

Methods

A. Field Methods

Field sampling was conducted between April and October in the years 2012-2014. Boat electrofishing, angling, and gillnets were the primary gear types. The fish collection method varied to optimize the potential to capture the target species and to minimize sampling effort at each lake. Many lakes in the area are stocked, typically with rainbow trout. We modified sampling approach in these lakes to avoided newly planted fish including collecting larger-sized trout that had likely overwintered and timing our sampling to maximize the time since the last fish planting event. Information from fisheries managers on lake stocking, as well as species presence, lake characteristics, and T&E species, was used to customize sampling to adapt for particular situations.

Captured fish were identified to species and individuals meeting the species and size criteria were retained. These fish were measured, weighed, and grouped by species and similar size (each fish within 75% of the length of the other individuals). Whole fish were packaged, frozen, and delivered to the EPA Region 10 Laboratory in Manchester, Washington where they were stored at -20°C. Sample integrity procedures are detailed in the Quality Assurance Project Plan (QAPP) (USEPA 2012).

B. Laboratory Analysis Methods

Total mercury was the analyte of interest. Total mercury is recommended for screening level monitoring as opposed to methylmercury because this adds a conservative approach when comparing to methylmercury screening criteria. Studies have found that methylmercury can account for over 90% of mercury concentration in predator species (USEPA 2006). Fillet (muscle) was analyzed as this is the portion of the fish commonly consumed by humans.

The chemical analysis was performed by EPA chemists. Fish were partially thawed and approximately one gram of muscle tissue was excised from each fish. All fish tissue samples were analyzed individually using EPA method 7473 (Mercury in solids and solutions by thermal decomposition, amalgamation, and atomic absorption spectrophotometry, USEPA 1998). The method was conducted on a Direct Mercury Analyzer (Milestone Inc.), which uses controlled heating in an oxygen decomposition furnace to liberate mercury from the fish tissue. The analytical parameters and other aspects of the laboratory methods are detailed in the QAPP (USEPA 2012).

C. Data Summary Methods

Fish data were combined for the analysis by calculating the arithmetic mean Hg value for each of the 50 lakes. Although fish species and sizes vary among sites, the unifying feature is that all fish were predators and were part of the fish assemblage that would be targeted and consumed by anglers. Thus, it was reasonable to combine results by lake to evaluate the mercury concentration in sportfish as a whole. Also, we are interested in longer-term exposure (rather than a single meal) and using the mean value is appropriate to reduce within-sample variability. The lake site weights described above in the study design section were applied to generate the probability estimate for the inference lake population. R statistics software (version 3.1.1, R Core Team 2013) and the Spsurvey package (Kincaid and Olsen 2015) were used to estimate the percentiles and the cumulative distribution of tissue mercury concentrations of the predator samples.

Results were compared to USEPA's fish tissue methylmercury criterion of 300 $\mu g\ kg^{-1}$ wet weight (ww) to protect the health of individuals who eat fish (USEPA 2001). This criterion is based on adult consumption rate of 17.5 grams (g) of fish per day. Two other screening values based on higher consumption rates relevant to the PNW were also compared to the mercury tissue results. A 'general population' screening value of 120 $\mu g\ kg^{-1}$ ww is based on a consumption rate of approximately two fish meals per week (59.7 g/day) (Dave McBride, WA Department of Health, Pers. Comm. 1/28/15). This is the amount of fish the American Heart Association recommends eating as part of a healthy diet. Finally, a 'high consumer' screening value of 40 $\mu g\ kg^{-1}$ww based on 175 g/day consumption rate was used for comparison. This is the Oregon State fish tissue standard (ODEQ 2014), which accounts for the portion of the population that eats more fish than average consumers. All screening values are for non-carcinogenic effects of mercury, which are discussed in detail in EPA's guidance on fish advisories (USEPA 2000b).

Results and Discussion

A. Fish Collection Results

Each sample lake had unique constraints for obtaining fish. Practical considerations such as gear type, timing, and fish abundance and conditions on the day of sampling dictated the species and size classes actually captured. Fishing was difficult at some lakes where the optimum sample composite size of five to ten individuals was not obtained. Adequate fish tissue was obtained for analysis from all 50 lakes that were sampled. Washington Department of Ecology supplied tissue samples in the form of processed aliquot for the Moses Lake site.

Over the three year period (2012-2014) 481 fish were collected from the 50 sample lakes. As expected, the numbers of fish, size classes, and species collected varied among lakes. Each lake had a fish sample -- one size class for one species. Two size classes for one species were obtained at 14 sites and three size classes at five sites. Two different species were collected at six sites.

A total of 13 species were included in the analysis representing four fish families (Table 1). The most common species among the 50 sample lakes was rainbow trout followed by largemouth bass, collected in 28% and 24% of the lakes, respectively. Species sampled were fairly evenly split between salmonids and non-salmonids. At least one salmonid was collected at 48% (24) of sites and at least one non-salmonid was collected at 58% (29) of sites.

Table 1. Species included in the lake fish tissue mercury estimates.

Sample type	Family	Species scientific name	Species common name	Adult Feeding type[b]	Number of lakes
salmonids	Salmonidae	*Oncorhynchus mykiss*	rainbow trout	Invert/piscivore	14
		Salvelinus fontinalis	brook trout	Invert/piscivore	5
		Oncorhynchus clarki[a]	cutthroat trout	Invert/piscivore	4
		Oncorhynchus nerka	kokanee	Invertivore	2
Non-salmonids	Centrarchidae	*Micropterus salmoides*	largemouth bass	Piscivore	12
		Micropterus dolomieu	smallmouth bass	Piscivore	3
		Lepomis macrochirus	bluegill	Invert/piscivore	3
		Lepomis gibbosus	pumpkinseed	Invert/piscivore	2
		Pomoxis nigromaculatus	black crappie	Invert/piscivore	2
		Ambloplites rupestris	rock bass	Invert/piscivore	1
	Percidae	*Perca flavescens*	yellow perch	Invert/piscivore	5
		Sander vitreus	walleye	Piscivore	1
	Ictaluridae	*Ameiurus nebulosus*	brown bullhead	Invert/piscivore	2

[a] *Includes all cutthroat trout subspecies.*

[b] *From Zaroban et al. 1999.*

B. Analysis Results

As previously stated, the sample of 50 lakes represents an inference population of 905 lakes. Summary statistics are calculated using site weights to accurately represent this inference population. All of the fish samples had quantifiable levels of Hg that exceeded the Minimum Reporting Level (the smallest measured concentration of a substance that can be reliably measured) of 0.0125 mg kg ww based on standard mass of 80 mg wet tissue. Lake fish tissue Hg concentrations (mean lake value) range from 18.2 to 771.0 µg kg^{-1} ww (Table 2). Mercury concentration versus the cumulative percentage of lakes is shown in Figure 2. The weighted mean Hg concentration for these PNW fishable lakes is 144.8 µg kg^{-1}ww.

Table 2. Percentiles and lake estimates for mercury concentrations (ug/kg ww).

Metric	Min.	10th	25th	50th	75th	90th	95th	Max.
Mean fish Hg conc. (ug/kg ww)	18.2	39.8	50.0	112.3	176.1	318.0	363.2	771.0
Inference lakes (cumulative no.)	13	84	220	451	650	807	853	905

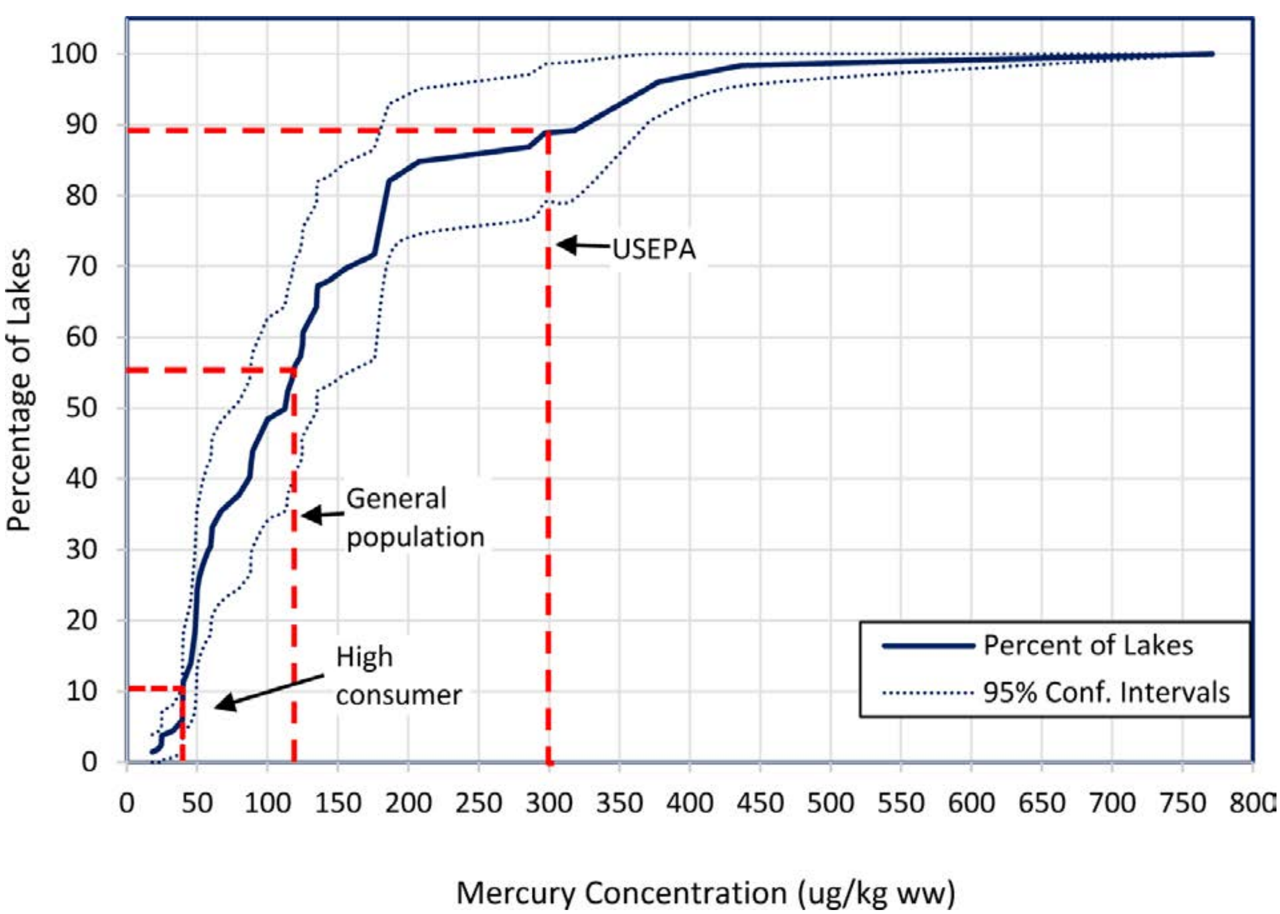


Figure 2. Cumulative distribution frequency plot of fish tissue Hg by percent of lakes. Red dashed lines indicate the lake percentile corresponding to three screening values (inferred population = 905 lakes).

Three screening values, based on variable fish consumption rates, are compared to provide perspective on the extent of mercury contamination in fish (Table 3, Figure 2). The EPA human health screening criterion of 300 µg kg^{-1} ww was exceeded in an estimated 11% of the fishable PNW lakes. The most stringent screening value representing high consumers was exceeded in 91% of the inference lakes.

Table 3. Exceedences of three mercury screening values (inferred population = 905 lakes).

Screening value type	Screening value (ug/kg ww)	screening value exceedence (% lakes)	Standard error
USEPA	300	11	4.968
General Population	120	44	7.634
High Consumer	40	91	3.017

C. Comparison to Other Studies

Results are compared to the 2000-2003 nationwide study of contaminants in fish tissue (Stahl et al. 2009). That study's results were based on a probability sample of 500 lakes stratified by lake size. Mercury was analyzed from composite fillets using method USEPA1631 (cold-vapor atomic fluorescence spectrometry). Besides comparing to the nationwide results, comparisons are made to a subset of this 500 lake dataset representing the predator fish sample data for 28 lakes from the PNW states of Idaho, Oregon, and Washington. (Herger et al. 2011). Unweighted summary statistics were calculated for this subset since sample size was small. Summary results for all three datasets are shown in Table 4.

Table 4. Lake predator fish tissue concentrations of Hg (µg kg^{-1} ww). Comparison of results to nationwide and PNW region data from 2000-2003 National Lakes Fish Tissue study.

Study	Mean	Median	Min.	Max.	n	Inference pop.
PNW region-wide 2012-14	144.8	112.3	18.2	771.0	50	905
Nationwide 2000-03[a]	352.0	284.6	23.0	6605	500	36,422
PNW region-wide 2000-03[b]	198.0	133.0	23.0	601.0	28	NA

[a] *Stahl et al. 2009.*

[b] *Herger et al. 2011.*

As with the PNW 2012-14 results, mercury was found to be ubiquitous nationwide, present in all predator samples (Stahl et al. 2009). However, nationwide results had higher mercury concentrations than the PNW study. The EPA criterion was exceeded in 49% of the inference population of lakes versus 11% in the PNW lakes. Results presented in this report are more similar to the PNW subset data from the 2000-2003 study (Table 4). Although not representative of the entire PNW, this small dataset substantiates our PNW region-wide results. We note two differences between this 2012-2014 study and the national lakes fish tissue survey: 1) we used a different tissue mercury analysis method (method 7473 versus method 1631 used in the national tissue survey) and 2) we used a different trophic guild classification to categorize predator species affecting two sites (Zaroban et al. 1999).

The other notable broad-scale study in the PNW is the Idaho state-wide fish tissue toxics study (Essig and Kosterman 2008). Fish samples from fifty lakes were analyzed for mercury (method 7473) using a probabilistic design, stratified by lake size (> 20 ha). They estimated 29% of a 95 lake inference population exceeded the 300 µg kg^{-1} ww screening criteria. The sample was dominated by large lakes, with 40% >120 ha.

D. Feasibility of Fish Tissue as NLA Indicator

The National Lakes Assessment has not included fish tissue toxics because it is an expensive and time consuming indicator, deemed beyond the scope of the survey. Also, many states have tissue monitoring as part of their lakes monitoring program so it is not a high priority indicator for all states. Based on our experience with this study, the following are considerations that may raise the feasibility of this indicator in future NLA surveys, at least at the regional scale.

Site evaluation: As we did in this assessment, the fish tissue indicator can be limited to fishable lakes rather than a more robust study (e.g., all lakes population). If this is done, there is a trade-off in terms of office time versus field time. Sites must be evaluated for fishability to generate the unbiased target sample, however, field time is more efficient as the resulting set of lakes are known to have predators so fish collection success rate is higher.

Collection permits: The process of obtaining scientific collection permits is far less complicated for PNW lakes than for rivers and streams because T&E species are rarely of concern in lakes. We found conventional methods for catching sportfish in lakes were readily approved by the states.

Fish collection: Angling would be the most efficient predator fish collection method that could be integrated into the NLA sample day, similar to the methods in the National Coastal Condition Assessment (USEPA 2015). Angling requires minimal gear and is an effective method during daylight hours. This method is flexible in that can be conducted at various locations during the sample day (e.g., index site and shoreline access sites).

Fish processing: If the fish tissue indicator is restricted to mercury for human health, only small amounts of tissue are required. Field procedures could be simplified by collecting tissue plugs (Peterson et al. 2005), which would reduce field processing time and shipping costs. More analytes would require processing entire fillets or whole fish.

Conclusions

- Results of this mercury assessment show that PNW lakes have generally lower fish tissue mercury concentrations compared to the nation as a whole. However, mercury is ubiquitous in this PNW aquatic resource and a substantial portion of lakes represented by this survey have levels of concern for people that are higher consumers of fish. These data provide insight into the general mercury content in lake fish and represents a baseline condition for the PNW. A trend could be established by repeating this effort in the PNW during future National Lakes Assessments using similar methods to generate compatible information. This is particularly relevant for the Western region of the U.S. which is affected by trans-Pacific atmospheric mercury transport (Huang and Gustin 2012).

- This project demonstrates the feasibility of adding fish tissue analysis to the Nation Lakes Assessment, at least on a regional scale. The level of effort would be similar to the fish collection effort conducted in the National Coastal Condition Assessment, where angling is conducted for a set amount of time.

- This project was limited to the human endpoint as an indicator of recreation condition of lakes. Wildlife endpoint would be a useful ecological condition indicator at the regional scale. These methods could be modified to include relevant species but this would substantially expand the scope of tissue collection and analysis. Effort to capture a second species and whole fish processing would be required.

- Beyond the overall characterization of the region, these data may be useable as data points for individual lakes of interest. For example, as a contribution to long-term trend analysis for lakes known to be elevated in fish tissue mercury (e.g., Phillips Reservoir, OR). For other lakes in this study, which have never been sampled for fish tissue mercury, these data represent an initial data point. We encourage those interested to access these data via the EPA WQX website.

- Within the US, the impact of reduced emissions on atmospheric mercury concentrations varies regionally. While atmospheric mercury concentrations show a decreasing trend nationally, some Western areas have experienced increasing trends in mercury deposition that may be attributable to trans-Pacific transport of atmospheric mercury (Weiss-Penzias et al. 2016). Changes in atmospheric mercury levels can result in changes in fish mercury concentrations (Harris et al. 2007).The response time can take years and can vary depending on lake and watershed characteristics. For example, results from several lakes in Mid-Western states that have been part of long-term monitoring networks have shown that declines in atmospheric mercury concentrations by ~40% over the last decade can be linked to a similar magnitude of decrease in fish mercury level in some lakes. However, other lakes within the same region have experienced no trend or even increasing fish mercury concentrations over time, suggesting that local-scale watershed and lake differences can be critical in affecting the biotic response to changing atmospheric mercury inputs (Brigham et al. 2014; Hrabik and Watras 2002; Wiener et al. 2006). These results highlight the complex relationship between fish mercury levels and atmospheric inputs and underscore the importance of fish mercury monitoring efforts to document the response to changes in local and global mercury emissions.

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Appendix A. Lake sites sampled for fish in Idaho, Oregon, and Washington, 2012-2014.

Year	Site ID	Site name	Latitude (DD)	Longitude (DD)	St.	County	Area (HA)	Elev. (M)	Species type	Total fish	Design weight
2013	NLA12_ID-102	Chase Lake	48.457702	-116.824065	ID	Bonner	70.5	761	Non-salmonid	10	17.074
2013	NLA12_ID-103	Cave Lake	47.457299	-116.599627	ID	Kootenai	399.6	649	Non-salmonid	6	18.801
2013	NLA12_ID-104	Treasureton Res.	42.234223	-111.852058	ID	Franklin	61.5	1512	Both	12	15.837
2013	NLA12_ID-105	Shepherd Lake	48.184540	-116.527585	ID	Bonner	39.3	695	Non-salmonid	13	46.240
2013	NLA12_ID-108	Killarney Lake	47.517242	-116.565414	ID	Kootenai	201.8	647	Non-salmonid	4	20.890
2013	NLA12_ID-109	Lake Walcott	42.677045	-113.407296	ID	cassia	3395.5	1279	Non-salmonid	9	17.439
2013	NLA12_ID-110	Carey Lake	43.317614	-113.921339	ID	Blaine	81.8	1452	Non-salmonid	10	15.837
2013	NLA12_ID-111	Cedar Creek Res.	42.210602	-114.893838	ID	Twin Falls	393.0	1593	Salmonid	5	17.439
2013	NLA12_ID-112	Perkins Lake	48.756681	-116.092672	ID	Boundary	21.5	803	Non-salmonid	10	3.292
2013	NLA12_ID-113	Otter Pond	44.838471	-116.036701	ID	Valley	9.7	1520	Non-salmonid	10	12.111
2013	NLA12_ID-121	Lake San Souci	48.007041	-117.003441	ID	Bonner	12.7	706	Non-salmonid	11	22.876
2013	NLA12_ID-122	Chesterfield Res.	42.895254	-111.963806	ID	Caribou	504.2	1646	Salmonid	7	5.358
2013	NLA12_ID-141	Sage Hen Res.	44.329039	-116.185324	ID	Gem	71.6	1507	Salmonid	8	5.358
2013	NLA12_ID-143	Shoofly Res.	42.264258	-116.310496	ID	Owyhee	35.5	1690	Salmonid	12	3.292
2013	NLA12_ID-145	Bull Trout Lake	44.299952	-115.254295	ID	Boise	27.9	2117	Salmonid	10	3.292
2013	NLA12_ID-148	Waha Lake	46.201006	-116.834907	ID	Lewis	38.1	1034	Both	25	3.292
2014	NLA12_ID-151	Thorn Creek Res.	43.190822	-114.595021	ID	camas	44.6	1679	Salmonid	1	3.292
2014	NLA12_OR-101	Mann Lake	42.772825	-118.447257	OR	HARNEY	89.8	1272	Salmonid	10	13.532
2014	NLA12_OR-103	Sparks Lake	44.023822	-121.744618	OR	DESCHUTES	128.1	1656	Salmonid	18	39.510
2014	NLA12_OR-105	Phillips Res.	44.681223	-118.047442	OR	BAKER	911.8	1242	Non-salmonid	10	16.065
2014	NLA12_OR-106	Smith Res.	44.313141	-122.045427	OR	LINN	63.7	795	Salmonid	14	14.589
2014	NLA12_OR-109	Waldo Lake	43.731777	-122.039771	OR	LANE	2443.7	1652	Salmonid	10	11.788
2014	NLA12_OR-110	Cooper Creek Res.	43.378746	-123.270434	OR	DOUGLAS	52.7	207	Non-salmonid	5	14.589
2014	NLA12_OR-112	Beulah Res.	43.932778	-118.149981	OR	MALHEUR	716.8	1019	Salmonid	3	16.065
2014	NLA12_OR-113	Emigrant Lake	42.157825	-122.607634	OR	JACKSON	256.5	684	Non-salmonid	10	16.065
2014	NLA12_OR-123	Keen Creek Diversion Pond	42.130013	-122.478277	OR	JACKSON	4.4	1344	Salmonid	5	24.668

Appendix A continued. Lake sites sampled for fish in Idaho, Oregon, and Washington, 2012-2014.

Year	Site ID	Site name	Latitude (DD)	Longitude (DD)	St.	County	Area (HA)	Elev. (M)	Species types	Total fish	Design weight
2014	NLA12_OR-126	Fish Lake	44.833708	-121.813775	OR	Marion	14.7	1300	Salmonid	6	13.167
2014	NLA12_OR-128	Odell Lake	43.574485	-122.006858	OR	KLAMATH	1389.8	1460	Salmonid	11	17.032
2014	NLA12_OR-129	Carter Lake	43.854166	-124.146755	OR	DOUGLAS	13.4	19	Salmonid	10	13.167
2014	NLA12_OR-145	Beale Lake	43.506883	-124.234262	OR	COOS	45.0	12	Non-salmonid	7	10.553
2014	NLA12_OR-154	Malheur Res.	44.362642	-117.693932	OR	MALHEUR	202.4	1027	Salmonid	13	17.032
2014	NLA12_OR-155	Agate Res.	42.407265	-122.767691	OR	JACKSON	70.6	461	Non-salmonid	6	17.032
2014	NLA12_OR-167	Sunset Lake	46.097165	-123.928461	OR	Clatsop	15.0	8	Non-salmonid	9	13.167
2012	NLA12_WA-101	Island Lake	46.427311	-124.035559	WA	Pacific	17.6	7	Non-salmonid	3	92.239
2012	NLA12_WA-103	American Lake	47.126413	-122.562583	WA	Pierce	441.5	73	Non-salmonid	10	6.623
2012	NLA12_WA-104	Moses Lake	47.076941	-119.324822	WA	Grant	2575.6	320	Non-salmonid	18	6.623
2012	NLA12_WA-106	Swofford Pond	46.497536	-122.405060	WA	Lewis	84.0	239	Non-salmonid	9	22.496
2012	NLA12_WA-107	Lacamas Lake	45.616388	-122.425707	WA	Clark	101.3	56	Non-salmonid	5	24.771
2012	NLA12_WA-108	Sacheen Lake	48.153953	-117.318529	WA	Pend Oreille	120.4	682	Non-salmonid	10	24.771
2012	NLA12_WA-111	Wapato Lake	47.918921	-120.165112	WA	Chelan	76.7	376	Non-salmonid	11	20.866
2012	NLA12_WA-115	Summit Lake	48.959237	-118.127192	WA	Stevens	4.1	774	Salmonid	6	39.673
2012	NLA12_WA-116	Upper Goose Lake	46.941005	-119.279312	WA	Grant	53.1	264	Both	13	16.402
2012	NLA12_WA-118	Ravensdale Lake	47.350898	-121.992564	WA	King	6.4	181	Salmonid	2	39.673
2012	NLA12_WA-120	Round Lake	48.292275	-118.322820	WA	Ferry	20.6	692	Salmonid	24	15.386
2012	NLA12_WA-121	Martha Lake	47.852997	-122.242745	WA	Snohomish	22.6	140	Non-salmonid	9	15.386
2012	NLA12_WA-124	McGinnis Lake	48.036518	-118.891997	WA	Okanogan	48.1	730	Salmonid	22	15.386
2012	NLA12_WA-126	North Skookum Lake	48.405734	-117.178410	WA	Pend Oreille	16.2	1092	Salmonid	6	18.321
2012	NLA12_WA-133	Sportsmans Lake	48.568425	-123.073521	WA	San Juan	26.4	48	Non-salmonid	9	15.386
2012	NLA12_WA-138	Phantom Lake	47.593387	-122.124337	WA	King	24.0	78	Non-salmonid	4	15.386
2012	NLA12_WA-141	Bay Lake	47.243816	-122.757955	WA	Pierce	49.7	10	Non-salmonid	10	15.386

Appendix B. List of species targeted for lake fish tissue sampling based on likely sportfish species present in sample lakes.

Family	Scientific name	Common name	Adult feeding strategy[b]	General lgth range (in)
Centrarchidae	*Micropterus dolomieu*	smallmouth bass	Piscivore	6-15
	Micropterus salmoides	largemouth bass	Piscivore	8-20
	Pomoxis nigromaculatus	black crappie	Invert/piscivore	6-14
	Pomoxis annularis	white crappie	Invert/piscivore	6-14
	Ambloplites rupestris	rock bass	Invert/piscivore	6-10
	Lepomis macrochirus	bluegill	Invert/piscivore	4-8
	Lepomis gibbosus	pumpkin seed	Invert/piscivore	4-8
	Lepomis cyanellus	green sunfish	Invert/piscivore	4-8
Ictaluridae	*Ameiurus nebulosus*	brown bullhead	Invert/piscivore	6-10
Percidae	*Perca flavescens*	yellow perch	Invert/piscivore	6-11
	Sander vitreus	walleye	Piscivore	10-24
Salmonidae	*Oncorhynchus nerka*	kokanee	Invertivore	8-15
	Salvelinus namaycush	lake trout	Piscivore	14-28
	Oncorhynchus mykiss	rainbow trout	Invert/piscivore	8-14
	Oncorhynchus clarki[a]	cutthroat trout	Invert/piscivore	8-14
	Salvelinus fontinalis	brook trout	Invert/piscivore	6-14
	Salmo trutta	brown trout	Invert/piscivore	10-16
	Prosopium williamsoni	mountain whitefish	Invertivore	8-14

[a] *Includes subspecies that occur in the PNW.*

[b] *Based on Zaroban et al. 1999.*

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