Mercury in Sportfishes of Lake Whatcom, Washington, Including a Review of Potential Impacts to Aquatic Resources and People

by

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April 2001

Acknowledgments

We thank Pete Verhey, Tom Buroker, John Sneva, and Lucinda Morrow of the Washington Department of Fish and Wildlife (WDFW) for their assistance in the field and lab. We also thank Chuck Phillips, Steve Jackson, and Jim Johnston (WDFW) for helpful advice. Ted Thygesen and the staff of the Bellingham Hatchery (WDFW) generously permitted the use of that facility, whereas personnel from Whatcom County Health and Human Services (WCHHS) and Washington Department of Ecology (DOE) Bellingham field office helped transport fish samples. The second author and volunteer staff from Washington Department of Health prepared fish tissue samples for mercury analysis by an independent laboratory. Robin Matthews of Western Washington University graciously provided water quality data. Chris Miller and Ann-Marie Karlberg of WCHHS provided GPS and GIS support, and expertly prepared the original map of Lake Whatcom. Steve Jackson, Jim Johnston, Karen Mueller DVM, Regina Delahunt (WCHHS), and staff from DOH (Glen Patrick and Jim White) provided thoughtful critiques of the original draft of the manuscript. Darrell Pruett and Peggy Ushakoff (WDFW) designed the cover, whereas Lauren Munday, Walt Cooper, and Everett Latch (WDFW) proved indispensable when preparing and printing the final report. This project was partially funded by WDFW's Warmwater Fish Enhancement Program, which is providing greater opportunities to fish for and catch warmwater fish in Washington. DOE's Environmental Assessment Program and WCHHS provided additional funding.

Abstract

Several tissue samples (n = 273) representing seven species of edible sportfish from Lake Whatcom were analyzed for total mercury content in late spring 2000. Predaceous smallmouth bass (*Micropterus dolomieu*) displayed the highest levels of mercury (mean ± SE, range = 0.49 ± 0.03, 0.10 – 1.84 mg/kg), followed by omnivorous yellow perch (*Perca flavescens*) (0.20 ± 0.03, 0.05 – 0.87 mg/kg) and brown bullhead (*Ameiurus nebulosus*) (0.16 ± 0.06, 0.03 – 0.79 mg/kg), planktivorous kokanee (*Oncorhynchus nerka*) (0.12 ± 0.01, 0.07 – 0.25 mg/kg), herbi-detritivorous signal crayfish (*Pacifasticus leniusculus*) (0.11 ± 0.02, 0.03 – 0.54 mg/kg), and benthivorous pumpkinseed (*Lepomis gibbosus*) (0.10 ± 0.01, 0.03 – 0.28 mg/kg). Predaceous cutthroat trout (*Oncorhynchus clarki*) had the lowest levels (0.07 ± 0.01, 0.03 – 0.20 mg/kg), possibly related to the low trophic level of the smaller size classes captured, natal stream residency of wild fish, or hatchery origins of stocked fish. Interbasin differences in mercury concentrations were evident in all species sampled. The mean levels found in Basin 3 (south) were higher than those from Basins 1 or 2 (north). Our results are compared with levels found in other North American fish populations, both near known pollution sources and away from anthropogenic influence. A literature review provides insight into possible population-level consequences (i.e., fish health concerns), trophic links from blue-green algae to higher order vertebrates, and human health concerns. To this end, our results are related to a range of values representing state, federal, and international screening levels for the contaminant.

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Introduction

A recent study by Washington Department of Ecology (Serdar et al. 1999) indicated that several contaminants of concern were detected in water, sediment, and fish tissue samples from Lake Whatcom and its tributaries near the City of Bellingham (Whatcom County) during 1998. Fecal coliform bacteria was the most common contaminant found in creeks surrounding Lake Whatcom, with levels exceeding Washington State water quality standards wherever water was sampled. Other contaminants included a wide variety of carcinogenic and neurotoxic pesticides and metals. For example, levels of polychlorobiphenyl (PCB)-1254, PCB-1260, and dieldrin found in smallmouth bass (*Micropterus dolomieu*), kokanee (*Oncorhynchus nerka*), and longnose sucker (*Catostomus catostomus*) exceeded the edible fish tissue criteria to protect human health established by the U.S. Environmental Protection Agency (EPA) National Toxics Rule. Of particular concern though was the disturbing level of mercury (0.50 mg/kg) detected in a composite sample of smallmouth bass (Serdar et al. 1999).

Extensive laboratory and field studies have shown that fish and wildlife exposed to mercury may result in population-level consequences by altering normal reproductive and behavior patterns, cell and organ function, or immune responses. In humans, mercury poisoning can cause irreversible neurological damage, and thus, EPA classifies the metal as a developmental toxicant. By the latter 20th century, mercury exposure had become so pervasive nationwide, that a review of the problem was mandated by Section 112(n)(1)(B) of the Clean Air Act. In 1997, EPA delivered its eight-volume study, The Mercury Study Report to Congress, to the federal government (EPA 1997). The study serves as a primary information source on methylmercury, the dominant form of the metal found in edible fish tissues.

Because of the elevated levels of mercury found in Lake Whatcom smallmouth bass in 1998, a collaborative effort between the Washington Departments of Fish and Wildlife (WDFW), Ecology (DOE), Health (DOH), and Whatcom County Health and Human Services (WCHHS) was undertaken during late spring 2000. The work extended that of Serdar et al. (1999) by including a wider variety and greater number of edible sportfishes for mercury analysis. WCHHS in conjunction with DOH used these results to implement a fish consumption advisory on April 12, 2001. The baseline information presented here may also be used for future studies concerning mercury processing in the Lake Whatcom watershed, possible sources, and the potential impact of mercury on fish, wildlife, and people.

Materials and Methods

Study Site

Lake Whatcom is a large (surface area = 2,030 ha, volume = 936,651,000 m^3), natural body of water located directly east of the City of Bellingham in Whatcom County (48E 44' 18" N, 122E 19' 32" W). The lake consists of three basins separated by distinct glacial sills. The north and middle basins (Basin 1 and 2, respectively) are relatively small (210 and 160 ha, respectively) and shallow (20 – 25 m maximum depth), whereas the south basin (Basin 3) is considerably larger (1,660 ha) and deeper (85 – 100 m maximum depth) (Figure 1). Silver Beach, Carpenter, Olsen, and Smith Creeks flow into Lake Whatcom from the east, whereas Austin and Beaver Creeks flow into the lake from the west. Anderson, Fir, and Brannian Creeks feed the lake from the south. Several unnamed, intermittent creeks discharge into each basin, whereas water from the middle fork of the Nooksak River is occasionally diverted to Basin 3 via Anderson Creek. Surface water exits the lake from Basin 1, through Whatcom Creek, eventually discharging into Bellingham Bay. Water quality studies have shown a tendency toward increased eutrophication in Basins 1 and 2 in recent years, whereas Basin 3 remains oligotrophic (Matthews et al. 2000).

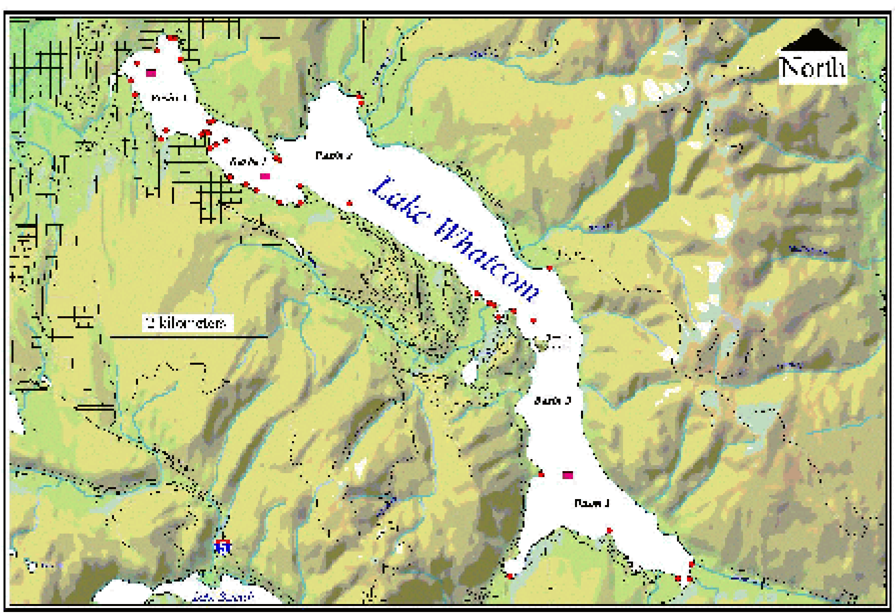

Figure 1. Map of Lake Whatcom (Whatcom County) showing fish sampling locations (circles). Rectangles indicate water quality stations.

The near-shore habitat of Basin 1 is comprised mostly of gravel, sand, and silt. Basin 2 is comprised mostly of gravel, sand, and exposed bedrock. Much of Basin 3 is comprised of exposed bedrock and gravel. Low to moderate amounts of coarse woody debris can be found in the shallows of all three basins. The aquatic plant community consists of a variety of pondweeds (*Potamogeton* sp.), waterweed (*Elodea* sp.), stonewort (*Nitella* sp.), common naiad (*Najas flexilis*), and exotic Eurasian watermilfoil (*Myriophyllum spicatum*). Emergent and submersed aquatic vegetation covers up to one-third of the littoral zone of all three basins (Mueller et al. 1999; Jenifer Parsons, DOE, unpublished data).

Like many large bodies of water, Lake Whatcom exhibits patches of distinct habitat types with associated fish assemblages (Hayes et al. 1996). For example, with few exceptions, brown bullhead (*Ameiurus nebulosus*) and juvenile largemouth bass (*Micropterus salmoides*) occur in Basin 1 only, whereas yellow perch (*Perca flavescens*) and pumpkinseed (*Lepomis gibbosus*) reside in the shallow, vegetated habitats of all three basins. Peamouth (*Mylocheilus caurinus*), cutthroat trout (*Oncorhynchus clarki*), and kokanee (*O. nerka*) are ubiquitous throughout the lake, yet longnose sucker (*Catostomus catostomus*) occur only in the lower half of Basin 3, mostly on the steep, rocky drop-offs of the east shore. Likewise, large numbers of smallmouth bass can be found along rocky outcroppings and points, while marginal habitats (e.g., barren gravel or sandy substrates) are home to a paucity of other species, including sculpin (*Cottus* sp.) and three-spine stickleback (*Gasterosteus aculeatus*) (Mueller et al. 1999).

Lake Whatcom serves as the drinking water source for residents of Bellingham and the surrounding area. Recreational activities at the lake include swimming, water skiing, sailing, and fishing. Land use around Basins 1 and 2 is primarily high-density residential. Up to one-third of the shoreline is bulkheaded within these basins and the mean number of docks ranges from 2 to 3 per 100 m shoreline. Timber and undeveloped lands comprise the dominant uses of Basin 3; however, some high-density residential areas occur as well. Less than five percent of the shoreline in Basin 3 is bulkheaded, with an average of less than 1 dock per 100 m shoreline (Mueller et al. 1999).

Water quality data was collected during midday from three locations on May 2 – 4, 2000 using a Hydrolab® probe and digital recorder (Robin Matthews, Western Washington University, unpublished data). Secchi depth was recorded in meters. Table 1 summarizes the information gathered on dissolved oxygen (mg/l), temperature (EC), pH, and specific conductance (FS).

Table 1. Water quality from the deepest regions of Basins 1, 2, and 3 at Lake Whatcom (Whatcom County). Samples were collected midday on May 2 - 4, 2000 (Robin Matthews, Western Washington University, unpublished data).

	Parameter					
Location	**Secchi depth (m)**	**Depth (m)**	**Dissolved oxygen (mg/l)**	**Temp (EC)**	**pH**	**Specific conductance (FS)**
Basin 1	5.3	1	9.77	11.94	7.58	56.3
		4	9.79	11.94	7.53	56.8
		7	9.69	11.93	7.50	56.8
		10	9.69	11.92	7.48	57.0
		13	8.71	9.38	7.24	56.4
		16	8.26	8.92	7.07	56.6
		19	8.23	8.48	6.95	56.8
Basin 2	4.0	1	10.84	11.46	7.67	55.2
		4	10.75	11.27	7.62	55.3
		7	10.73	10.99	7.60	55.3
		10	10.79	10.27	7.48	55.3
		13	10.47	9.31	7.28	55.2
		16	9.99	8.54	7.19	55.3
		19	9.47	8.27	7.08	55.6
Basin 3	4.0	1	11.08	10.34	7.57	54.9
		4	11.04	10.16	7.51	55.1
		7	10.88	10.03	7.45	54.9
		10	10.82	9.69	7.44	55.0
		20	10.68	8.37	7.28	55.2
		30	10.3	6.86	7.18	55.3
		40	10.17	6.69	7.14	55.1
		50	10.20	6.63	7.08	55.2
		60	10.06	6.60	7.06	55.1
		70	10.07	6.58	7.04	55.5
		80	10.02	6.57	7.02	55.4
		90	9.89	6.55	7.01	55.4

Fish Sampling

Fish were collected during May 15 to June 2, 2000 by a three-person team consisting of two biologists and one scientific technician. Fish were captured using three sampling techniques: electrofishing, gillnetting, and scuba diving. The electrofishing unit consisted of a 4.9 m Smith-Root 5.0 GPP ‘shock boat’ set to 250 volts of 6 amp pulsed DC (120 cycles/sec). Experimental gillnets (45.7 m long × 2.4 m deep) were constructed of four sinking panels (two each at 7.6 m and 15.2 m long) of variable-size (13, 19, 25, and 51 mm stretched) monofilament mesh.

Sample timing was selected to maximize the type and number of fish captured. In Washington, water temperatures during spring and fall generally result in higher electrofishing catch rates compared to winter or summer (optimal electrofishing efficiency occurs at moderate water temperatures between 16 and 22E C). During spring, most warmwater fish species, such as smallmouth bass, move into the shallows for nest-building and spawning purposes increasing their susceptibility to capture. Thus, electrofishing catch rates during this period are generally high (Bonar et al. 2000). Catch rates for anglers targeting the shallows also increase during spring (Ledeboer 2000). Except for diving, sampling occurred during evening hours to take advantage of the cover of darkness as well as the foraging habits of the target species. Diving operations were conducted during daylight hours to take advantage of the resting habits of the nocturnally motile signal crayfish.

As with sample timing, sample locations were selected to maximize the type and number of fish captured. The selective criterion for these sites was higher catch rates relative to those found in other areas of the lake as determined by Mueller et al. (1999) and anecdotal angling reports. Nighttime electrofishing occurred along the entire shoreline of Basins 1 and 2, and about 30% of the available shoreline in Basin 3. While electrofishing, the boat was maneuvered through the shallows (depth range: 0.2 - 1.5 m), adjacent to the shoreline, at a rate of about 18 m/minute. To capture pelagic kokanee, we electrofished offshore foraging aggregations as indicated by fish rising at the surface during the evening crepuscular period. Gillnets were set perpendicular to the shoreline overnight at 8 locations (= 8 'net nights'). The small-mesh end was attached onshore while the large-mesh end was anchored offshore. Signal crayfish were collected from known signal crayfish habitat previously verified by WDFW divers (Mueller and Rothaus *in press*). Divers used standard, open-circuit scuba and stayed within no-decompression limits derived from U.S. Navy dive tables. Table 2 summarizes the fish sampling effort during the study period.

Table 2. Summary of fish sampling effort at Lake Whatcom during late spring 2000. EB = electrofishing boat, GN = gillnetting, and DIVE = scuba diving.					
Sample date	**Gear type**	**Location**	**Duration (hours) electrofishing unit engaged**	**Net nights**	**Bottom time (hours)**
05/15/00	EB	Basin 1	0.43		
05/16/00	GN	Basin 1		1	
05/16/00	GN	Basin 1		1	
05/16/00	GN	Basin 2		1	
05/16/00	GN	Basin 2		1	
05/16/00	EB	Basin 1	1.15		
05/17/00	EB	Basin 2	1.39		
05/18/00	EB	Basin 2	0.71		
05/19/00	GN	Basin 3		1	
05/19/00	GN	Basin 3		1	
05/19/00	GN	Basin 3		1	
05/19/00	GN	Basin 3		1	
05/22/00	EB	Basin 2 and 3	2.11		
05/23/00	EB	Basin 2 and 3	2.12		
05/24/00	EB	Basin 2 and 3	2.50		
05/25/00	EB	Basin 2 and 3	2.13		
05/31/00	DIVE	Basin 1			0.27
05/31/00	DIVE	Basin 1			2.12
05/31/00	DIVE	Basin 1			0.47
06/01/00	DIVE	Basin 3			0.70
06/01/00	DIVE	Basin 3			0.70
06/01/00	DIVE	Basin 3			0.73
06/02/00	DIVE	Basin 2			0.40
06/02/00	DIVE	Basin 2			0.38
06/02/00	DIVE	Basin 2			0.33

The selective criteria for retaining finfish was based on nationally accepted standard length categories (Gabelhouse 1984; Anderson and Neumann 1996), the population characteristics for each species from Lake Whatcom (Mueller et al. 1999), and WDFW fishing rules. To this end, we hoped to attain a sufficient sample size for each species. Essentially, only those fish measuring greater than stock- or quality-length were targeted. Stock- and quality-lengths, which vary by species (Table 3), are based on percentages of certified world-record lengths (i.e., fish of interest to anglers and ultimately human consumers). Stock-length (20-26% of world-record length) refers to the minimum size fish with recreational value, whereas quality-length (36-41% of world-record length) refers to the minimum size fish most anglers like to catch (Gabelhouse 1984; Anderson and Neumann 1996). Because of the uniqueness of each of Lake Whatcom's basins, and the possibility that certain species remain resident within a specific basin, fish from each basin were considered separate population units. In this way, fish could be analyzed individually to obtain estimates of variance for each sub-population. Sample sizes (n = 10) for all species were based on published mean and standard deviation values for mercury in fish tissue (Serdar et al. 2001). Table 4 summarizes the target lengths and number of sportfishes to be collected for mercury analysis based on the work cited above.

Table 3. Standard length categories used to calculate stock density indices (PSD and RSD; Gabelhouse 1984) of sportfishes captured at Lake Whatcom (Whatcom County) during late spring 2000. Measurements are minimum total lengths (mm) for each category (Anderson and Neumann 1996; Bister et al. 2000).

	Size (mm TL)				
Type of Fish	**Stock**	**Quality**	**Preferred**	**Memorable**	**Trophy**
Brown bullhead	130	200	280	360	430
Cutthroat trout	200	350	450	600	750
Kokanee[a]	200	250	300	400	500
Pumpkinseed	80	150	200	250	300
Smallmouth bass	180	280	350	430	510
Yellow perch	130	200	250	300	380

[a] M. W. Hyatt and W. A. Hubert, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, unpublished data.

Table 4. Proposed target lengths and number of sportfishes to be sampled from Lake Whatcom for determination of total mercury concentrations during late spring 2000. Target lengths were based on nationally accepted standard length categories (Gabelhouse 1984; Anderson and Neumann 1996), population characteristics for each species from the lake (Mueller et al. 1999), and WDFW fishing rules.

Species	**Target length**	**Target number from each basin**
Brown bullhead	> 152 mm (6")	10
Cutthroat trout	> 305 mm (12")	10
Kokanee	> 178 mm (7")	10
Pumpkinseed	> 76 mm (3")	10
Signal crayfish	> 82 mm (3.25"), no gravid females	15
Smallmouth bass	254-305 mm (10-12")	10
	305-356 mm (12-14")	10
	> 356 mm (14")	10
Yellow perch	> 152 mm (6")	10

All fish captured were identified to the species level. Each fish was measured to the nearest 1 mm and assigned to a 10-mm size class based on total length (TL). For example, a fish measuring 256 mm TL was assigned to the 250-mm size class for that species, a fish measuring 313 mm TL was assigned to the 310-mm size class, and so on. All specimens were weighed to the nearest 0.5 g. Several scales were removed from each scale-bearing fish for aging purposes (Jearld 1983; Fletcher et al. 1993). A lack of technical resources precluded aging brown bullhead and signal crayfish directly.

Signal crayfish were retained according to Washington Administrative Code (WAC) 220-52-060. This rule states that "the minimum commercial crayfish size is 3-1/4 inches in length from the tip of the rostrum (nose) to the tip of the tail and…all female crayfish with eggs or young attached to the abdomen must be immediately returned unharmed." Furthermore, since signal crayfish are closely associated with sediments, a potential sink for mercury in Lake Whatcom (Serdar et al. 1999; Matthews et al. 2000), and less motile relative to finfish species, we felt they could provide clues about the geographical distribution of mercury in the lake. Accordingly, target sample sizes for signal crayfish were increased to 15 per basin (Table 4) in order to analyze five individuals from three discrete locations within each basin. Signal crayfish lengths, weight, and depth at capture (mm, g, and m, respectively) were recorded by location. Like brown bullhead, a lack of technical resources precluded aging signal crayfish.

Fish and signal crayfish were double-wrapped in aluminum foil (dull-side-in), labeled, and placed in large plastic or zip-lock bags. Unique sample identification numbers were included with each sample and recorded in the field log for that sample. Wrapped samples were stored in ice-filled coolers until being transferred to a secure freezer for temporary storage or for direct transfer to the Washington Department of Ecology headquarters in Olympia for sample preparation. Chain-of-custody tags were affixed to sample coolers to ensure sample integrity.

Fish and Mercury Sampling Data Analysis

Catch per unit effort (CPUE) by gear type was determined for all species (number of fish/hour electrofishing, number of fish/net night, and number of crayfish/hour bottom time). Except for signal crayfish, only stock-length fish and larger were used to determine CPUE. Stock-length refers to the minimum size of fish having recreational value (Table 3). Eighty-percent confidence intervals (CI) were determined for each mean CPUE by species and gear type. CI was calculated as the mean ± $t_{(á,\ N\text{-}1)} \times SE$, where t = Student's t for á confidence level with N-1 degrees of freedom (two-tailed) and SE = standard error of the mean. Since it is standardized, CPUE is a useful index for comparing relative abundance of stocks between lakes. Furthermore, the index will be useful when planning the effort required for similar studies in the future.

Individual fish were filleted on the right side and tissues homogenized according to DOE standards. Signal crayfish tail muscle was extracted and processed similarly. All processing equipment was decontaminated between handling samples, which were stored at -20EC until analysis. Tissues were analyzed for mercury at Manchester Environmental Laboratory using cold vapor atomic absorption EPA method 245.5 (EPA 1986). Method detection limits were 0.005 – 0.010 mg/kg (wet weight). See Serdar et al. (2001) for a full description of laboratory techniques used as well as data quality control and assurance measures.

Mean (± SE) total mercury concentrations (mg/kg) for all species except signal crayfish were calculated for each of three stock density indices. Stock-length, proportional stock density (PSD), and relative stock density (RSD) reflect not only the size structure of a fish population, but also its recreational value. Stock-length, PSD, and RSD vary by species (Table 3) and are based on percentages of certified world-record lengths (i.e., fish of interest to anglers and ultimately human consumers). Thus, reporting mercury concentrations by stock-length, PSD, and RSD for each species is a way to assess the risk to anglers who might consume fish of a certain size.

The PSD of each fish species was determined following procedures outlined in Anderson and Neumann (1996). PSD, which was calculated as the number of fish $\geq$ quality-length divided by the number of fish $\geq$ stock-length × 100, is a numerical descriptor of length frequency data that provides useful information about population dynamics and fish of interest to anglers.

The RSD of each fish species was examined using the five-cell model proposed by Gabelhouse (1984). In addition to stock- and quality-length, Gabelhouse (1984) introduced preferred-, memorable-, and trophy-length categories (Table 3). Preferred-length (45-55% of world-record length) refers to the minimum size fish anglers would prefer to catch when given a choice. Memorable-length (59-64% of world-record length) refers to the minimum size fish most anglers remember catching, whereas trophy-length (74-80% of world-record length) refers to the minimum size fish considered worthy of acknowledgment. Like PSD, RSD provides useful information regarding population dynamics, but is more sensitive to changes in year-class strength. RSD was calculated as the number of fish $\geq$ specified length divided by the number of fish $\geq$ stock-length × 100. For example, RSD P was the percentage of stock-length fish that also were longer than preferred-length, RSD M, the percentage of stock-length fish that also were longer than memorable-length, and so on. Eighty-percent confidence intervals for PSD and RSD were calculated similar to that of CPUE (see above).

Age and growth of scaled fishes from Lake Whatcom were evaluated using two techniques: the direct proportion method (Jearld 1983; Fletcher et al. 1993) and Lee's modification of the direct proportion method (Carlander 1982). Although Lee's modification is more appropriate when aging warmwater fish species such as smallmouth bass, much of WDFW's archived age and growth data is based on the direct proportion method. Thus, results using the direct proportion method are included for comparison with historic information from WDFW management files. Using the direct proportion method, total length at annulus formation, L_n, was back-calculated as $L_n = (A \times TL)/S$, where A is the radius of the fish scale at age n, TL is the total length of the fish captured, and S is the total radius of the scale at capture. Using Lee's modification, L_n was back-calculated as $L_n = a + A \times (TL - a)/S$, where a is the species-specific standard intercept from a scale radius-fish length regression (Carlander 1982). Mean back-calculated lengths at age n for each species were presented in tabular form for easy comparison of growth between year classes, previous work by Mueller et al. (1999), and when available, between Lake Whatcom fish and the state average for the same species (listed in Fletcher et al. 1993). The range of ages for brown bullhead and signal crayfish were inferred from published literature. Except for brown bullhead and signal crayfish, the mean (± SE) concentration of mercury for each year class was included to examine bioaccumulation of the contaminant.

To further examine bioaccumulation in Lake Whatcom sportfishes, the mercury concentration of each specimen of all species was plotted against its total length. Linear regressions were then conducted to determine whether total lengths and $\log_{10}(X+1)$ transformed total mercury concentrations (X) were significantly and positively related. We chose to report the length frequency of each species based on the total catch from combined gear types broken down by the relative contribution each gear type made to each size class (i.e., a stacked length frequency histogram). To this end, the number of fish captured in each size class by gear type was divided by the total number of fish captured by all gear types × 100. It should be noted that length frequencies are generally reported by gear type because selectivity of gear types biases species catch based on body form and behavior, and size classes within species (Willis et al. 1993). Nevertheless, differences in size selectivity of gear types can sometimes result in offsetting biases (Anderson and Neumann 1996). Thus, if concern arises that pooled gear does not represent the least biased assessment of length frequency for a given species, then the shape of the gear type-specific distributions is still represented on the graphs, which can be interpreted independently.

A relative weight (W_r) index was used to evaluate the condition of all species except signal crayfish. A W_r value of 100 generally indicates that a fish is in good condition when compared to the national standard (75th percentile) for that species. Furthermore, W_r is useful for comparing the condition of different size groups within a single population to determine if all sizes are finding adequate forage or food (ODFW 1997). Following Murphy and Willis (1991), the index was calculated as $W_r = W/W_s \times 100$, where W is the weight (g) of an individual fish and W_s is the standard weight of a fish of the same total length (mm). W_s is calculated from a standard $\log_{10}$weight-$\log_{10}$length relationship defined for the species of interest. The parameters of the W_s equations for many cold- and warmwater fish species, including the minimum length recommendations for their application, have been compiled by Anderson and Neumann (1996), Bister et al. (2000), and Mathew W. Hyatt and Wayne A. Hubert (Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, unpublished data). The W_r values from this study were compared to the national standard (75th percentile or $W_r = 100$) for each species. A Fulton condition factor (K) was used to evaluate the condition of signal crayfish. Following Anderson and Neumann (1996), K was calculated as $(W/L^3) \times 10^5$, where W is the weight (g) of an individual signal crayfish and L is its total length in mm (measured from acumen of rostrum to end of telson). As with total length, linear regressions were conducted to determine whether relative weights or condition factor and $\log_{10}(X+1)$ transformed total mercury concentrations (X) were significantly and positively related.

To assess the potential risk to humans of consuming mercury-laden fish from Lake Whatcom, values from this study were related to a range of values representing state, federal, and international screening levels for the contaminant. These are concentrations that when detected in fish tissues usually result in fish consumption advisories by local health authorities. The U.S. Environmental Protection Agency (EPA) recently proposed a screening level of 0.3 mg/kg in fish tissue to protect all exposed human populations (EPA 2001). The World Health Organization (WHO) screening levels for non-predatory and predatory fish are 0.5 and 1.0 mg/kg mercury, respectively (WHO 1991), whereas the U.S. Food and Drug Administration (FDA) screening level is 1.0 mg/kg mercury (Foulke 1994). Screening levels for individual states lie within the range from 0.3 to 1.0 mg/kg.

Results and Discussion

CPUE

Except for brown bullhead, we captured the target number of fish from each basin as originally proposed (Tables 4 and 5). Brown bullhead were not observed in Basin 2, and only three were captured from Basin 3. This was similar to the findings of Mueller et al. (1999) and therefore attributed to basin-specific densities and habitat preferences rather than our ability to capture the species. Target length objectives were satisfied for all species except cutthroat trout and smallmouth bass (Tables 4 and 5). Our ability to land only smaller sizes of cutthroat trout was attributed to the extant population decline of cutthroat trout in the system. This was supported by a lack of older, larger fish observed in tributaries during concurrent spawning surveys by WDFW personnel (Jim Johnston, WDFW, unpublished data). To secure an adequate sample size of smallmouth bass, the primary species of concern, three individuals were retained that measured slightly below the minimum target length of 254 mm TL (size range = 249 – 251 mm TL). Five additional smallmouth bass measuring between 434 and 486 mm TL were collected from Basins 1 and 2. These fish were targeted to examine bioaccumulation of mercury in the largest fish. Furthermore, since smallmouth bass anglers frequently target these basins, we felt the excess might provide useful information concerning those at risk of consuming mercury-laden fish. Except for kokanee, mean electrofishing catch rates (Table 5) were generally lower than those reported by Mueller et al. (1999), reflecting the increased effort to cull out unwanted fish in favor of individuals meeting target length objectives. However, the nine-fold increase in mean electrofishing CPUE for kokanee (1.95 compared to 0.21 fish/hour) can be attributed to the novel method of fishing their offshore foraging aggregations. Gillnetting catch rates for cutthroat trout and smallmouth bass were nearly identical to those reported by Mueller et al. (1999).

Table 5. Size range and mean catch per unit effort (# fish/hour electrofishing and # fish/net night) by gear type, including 80% confidence intervals, of stock-length sportfishes and signal crayfish collected from Lake Whatcom (Whatcom County) for total mercury tissue analysis during late spring 2000.

		Gear Type			
Type of fish	**Size range (mm TL) and number retained (in parentheses)**	**Electrofishing (# fish/hour)**	**Shock nights**	**Gillnetting (# fish/hour)**	**Net nights**
Brown bullhead	186 - 356 (13)	1.82 ± 1.34	8	None	8
Cutthroat trout	173 - 339 (30)	0.51 ± 0.38	8	captured	8
Kokanee	189 - 240 (30)	1.95 ± 1.12	8	1.25 ± 0.58	8
Pumpkinseed	96 - 185 (30)	2.37 ± 1.26	8	None	8
Signal crayfish[a]	83 - 137 (45)	—	—	captured	—
Smallmouth bass	249 - 486 (95)	5.28 ± 1.33	8	None	8
Yellow perch	154 - 333 (30)	2.68 ± 2.57	8	captured	8
				—	
				4.13 ± 2.58	
				1.88 ± 1.12	

[a] Collected by hand while scuba diving (8.94 ± 2.28 crayfish/hour bottom time) at nine locations (three per basin) around the lake.

Mercury Concentrations According to Stock Density Indices

The mean total mercury concentration for stock-length smallmouth bass (0.49 mg/kg) exceeded the screening level of 0.3 mg/kg proposed by EPA (Table 6). The mean total mercury concentrations in quality (PSD), preferred (RSD-P), and memorable-length (RSD-M) smallmouth bass (0.54, 0.66, and 0.96 mg/kg, respectively) were much higher than the national average of weighted means (0.37 mg/kg) reported for the species (EPA 1999a). Brown bullhead and yellow perch of sizes preferred by anglers (RSD-P) displayed mean total mercury concentrations (0.43 and 0.41 mg/kg, respectively) that exceeded the screening level of 0.3 mg/kg proposed by EPA. However, mean total mercury concentrations for stock-length cutthroat trout, kokanee, and pumpkinseed (0.08, 0.12, and 0.10 mg/kg, respectively) were below the screening level of 0.3 mg/kg proposed by EPA. Except for cutthroat trout and kokanee, the PSD and RSD values from this study (Table 6) were consistently higher than those reported by Mueller et al. (1999), which was due to high grading by field staff to retain fish of sizes favorable to anglers and to meet study objectives.

Table 6. Traditional stock density indices, including 80% confidence intervals, and total mercury concentration (mean ± SE, range in parentheses) of stock-length sportfishes collected from Lake Whatcom (Whatcom County) during late spring 2000. PSD = proportional stock density, whereas RSD = relative stock density or preferred length fish (RSD-P), memorable length fish (RSD-M), and trophy length fish (RSD-T), EB = electrofishing boat, GN = gillnetting.

			Stock density index			
Type of fish	**Gear type**	**# Stock-length fish**	**PSD**	**RSD-P**	**RSD-M**	**RSD-T**
Brown bullhead	EB	13	92 ± 9	23 ± 15	0	0
	GN	0	0	0	0	0
Mercury (mg/kg)		0.16 ± 0.06 (0.03-0.79) n = 13	0.17 ± 0.06 (0.03-0.79) n = 12	0.43[b] ± 0.20 (0.09-0.79) n = 3		
Cutthroat trout	EB	5	0	0	0	0
	GN	10	0	0	0	0
Mercury (mg/kg)		0.08 ± 0.01 (0.03-0.20) n = 15				
Kokanee	EB	22	0	0	0	0
	GN	0	0	0	0	0
Mercury (mg/kg)		0.12 ± 0.01 (0.07-0.25) n = 22				
Pumpkinseed	EB	30	27 ± 10	0	0	0
	GN	0	0	0	0	0
Mercury (mg/kg)		0.10 ± 0.01 (0.03-0.28) n = 30	1.12 ± 0.03 (0.05-0.28) n = 8			
Smallmouth bass	EB	62	76 ± 7	32 ± 8	13 ± 5	0
	GN	33	100	85 ± 8	3a	0
Mercury (mg/kg)		0.49[b] ± 0.03 (0.10-1.84) n = 95	0.54[b] ± 0.03 (0.13-1.84) n = 80	0.66[b] ± 0.05 (0.26-1.84) n = 48	0.96[b] ± 0.12 (0.68-1.84) n = 9	
Yellow perch	EB	15	60 ± 16	27 ± 15	7[a]	0
	GN	15	47 ± 16	13 ± 11	13 ± 11	0
Mercury (mg/kg)		0.20 ± 0.03 (0.05-0.87) n = 30	0.28 ± 0.05 (0.08-0.87) n = 16	0.41[b] ± 0.10 (0.16-0.87) n = 6	0.54[b] ± 0.17 (0.37-0.87) n = 3	

[a] Sample size too small or catch rates too variable to permit calculation of reliable confidence intervals.
[b] Mean exceeds EPA proposed screening level of 0.3 mg/kg mercury in fish tissue.

Brown bullhead

Total mercury concentration in Lake Whatcom brown bullhead ranged from 0.03 to 0.79 mg/kg, with a mean (± SE) value of 0.16 ± 0.06 mg/kg (Table 6). Of the 13 brown bullhead sampled at Lake Whatcom, 15% (n = 2) had mercury levels exceeding the proposed EPA screening level of 0.3 mg/kg. These fish measured > 330 mm or 13" TL (Figure 3). The mean and range of values we report are nearly identical to the mean (0.15 mg/kg) and range (0.01 – 0.79 mg/kg) reported for brown bullhead from Massachusetts lakes not likely affected by non-point pollution sources such as landfills, industrial facilities, hazardous waste sites, or wastewater treatment facilities (Rose et al. 1999). The range of mercury concentrations in Lake Whatcom fish is slightly lower than the mean range (0.15 – 0.97 mg/kg) derived from a study of related catfishes (*Ictalurus punctatus*) and (*I. furcatus*) from waters located downstream from a Superfund cleanup site in Tennessee (Bevelhimer and Adams 1996).

Lake Whatcom brown bullhead ranged from 186 to 356 mm TL (Figure 2, Table 5). A linear regression of log-transformed total mercury concentration on total length revealed a significant positive relationship ($r^2 = 0.70$, $P < 0.01$), which is similar to the findings of Scheuhammer and Graham (1999) who examined brown bullhead and other fishes from rural Ontario, Canada. As with total mercury concentration, relative weights of brown bullhead increased with length (Figure 3). Regressing log-transformed mercury on relative weight revealed a significant positive relationship ($r^2 = 0.53$, $P < 0.01$).

At least four age-classes were represented in our sample. We inferred that fish below 290 mm TL were between two and five years old based on age tables for brown bullhead reported by Wydoski and Whitney (1979).

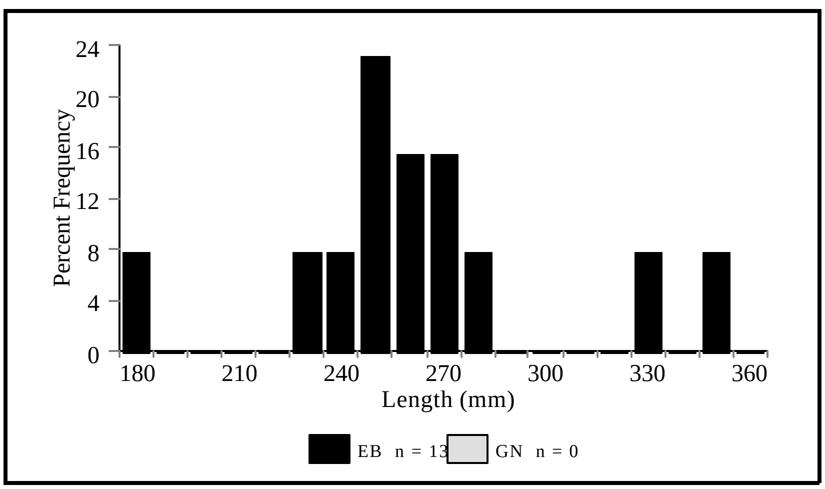

Figure 2. Length frequency histogram of brown bullhead sampled from Lake Whatcom (Whatcom County) during late spring 2000. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type.
EB = electrofishing boat and GN = gillnetting.

Cutthroat trout

Total mercury concentration in Lake Whatcom cutthroat trout ranged from 0.03 to 0.20 mg/kg, with a mean (± SE) value of 0.07 ± 0.01 mg/kg. This was a narrower range and much lower mean total mercury concentration compared to those reported for salmonids (*Salvelinus fontinalis*, *Salmo trutta*, and *Salmo salar*) sampled from several Maine lakes (Stafford and Haines 1997).

The cutthroat trout in our sample ranged from 173 to 339 mm TL (Figure 4, Table 5). Mercury levels increased with length (Figure 5) and a linear regression of log-transformed total mercury concentration on total length revealed a significant and slightly positive relationship (r^2 = 0.20, P < 0.02). Relative weights were low by national standards, but consistent with length (Figure 5). Regressing log-transformed mercury on relative weight revealed no significant relationship (r^2 = 0.11, P > 0.05).

Lake Whatcom cutthroat trout were aged 1+ to 3+ (Table 7). The 1998 year-class was dominant. We were not able to age ten individuals due to scale regeneration, a naturally occurring scale anomaly observed in fishes. There was little or no increase in mean mercury concentration with age (Table 7). A similar pattern was observed by Allen-Gil et al. (1995) for age 1+ to 3+ rainbow trout (*Oncorhynchus mykiss*) from central Oregon, yet the mean total mercury concentration from our study was considerably lower than the range (0.30 – 0.40 mg/kg) reported by these authors. Ostensibly, the difference can be attributed to the close proximity of rainbow trout to mercury deposits in Oregon's Blue Mountains (Allen-Gil et al. 1995).

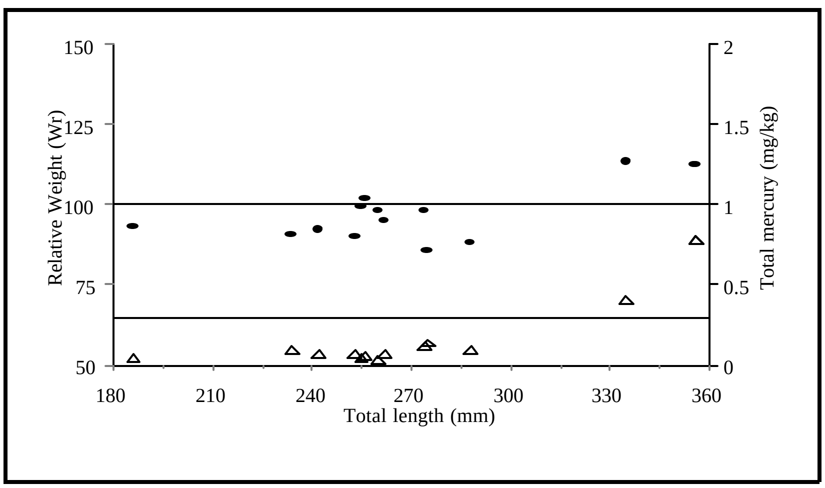

Figure 3. Relationship between total length and relative weight (W_r) of brown bullhead (black ovals) sampled from Lake Whatcom (Whatcom County) during late spring 2000 compared with the national 75th percentile (line at W_r = 100) for the species, and relationship between total length and mercury concentration (mg/kg) of brown bullhead (clear triangles). The range of values for state, federal, and international screening levels of mercury in fish tissues is represented by lines at 0.3 and 1.0 mg/kg.

Table 7. Total mercury concentration [mean ± SE (range)] by year class, and age and growth of cutthroat trout (*Oncorhynchus clarki*) captured at Lake Whatcom (Whatcom County) during late spring 2000. Values are mean back-calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993).

			Mean fork length (mm) at age		
Year class	**Mercury (mg/kg)**	**# fish**	**1**	**2**	**3**
1999	0.05 ± 0.01 (0.03-0.07)	4	94.4		
1998	0.06 ± 0.01 (0.03-0.12)	14	75.9	185.3	
1997	0.07 ± 0.03 (0.04-0.10)	2	77.9	130.4	208.9
Weighted mean			79.8	178.4	208.9

The native cutthroat trout spawning population of Lake Whatcom decreased markedly from 1987 to 1999, ostensibly the result of urbanization, less-than-ideal timber practices, and other anthropogenic influences. Given its rate of decline, the Lake Whatcom cutthroat trout population is expected to become extinct by 2005 (Jim Johnston, WDFW, unpublished data). Since 1990, hatchery-origin cutthroat trout fry (~ 75 mm or 3" TL, n > 40,000) from captive Lake Whatcom broodstock have been stocked annually into the lake to supplement the declining population, which may partially explain the low mercury levels detected in the lake's cutthroat trout. Stafford and Haines (1997) concluded that fish populations maintained by frequent introductions of hatchery-produced fish, like those of Lake Whatcom, consisted of younger fish with lower exposure to environmental mercury and thus contained lower concentrations than wild populations. Lake Whatcom's wild cutthroat trout reside in their natal streams until age 1+ or 2+. Early in life, cutthroat trout occupy a low trophic level and feed primarily on aquatic invertebrates. When fully mature (up to 700 mm TL), lake-dwelling cutthroat trout are mostly piscivorous, although larger aquatic invertebrates such as signal crayfish are still consumed (Jim Johnston, WDFW, personal communication). Thus, another possible explanation for the low mercury concentrations in Lake Whatcom cutthroat trout is that we sampled only small, immature fish that were potentially isolated from mercury sources before entering the lake.

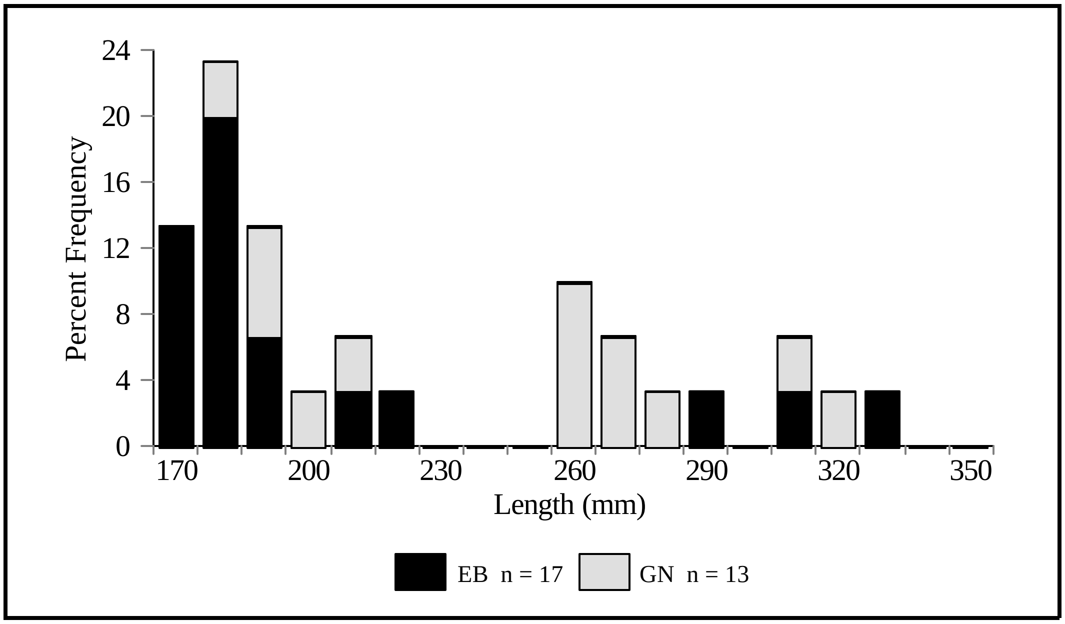

Figure 4. Length frequency histogram of cutthroat trout sampled from Lake Whatcom (Whatcom County) during late spring 2000. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing boat and GN = gillnetting.

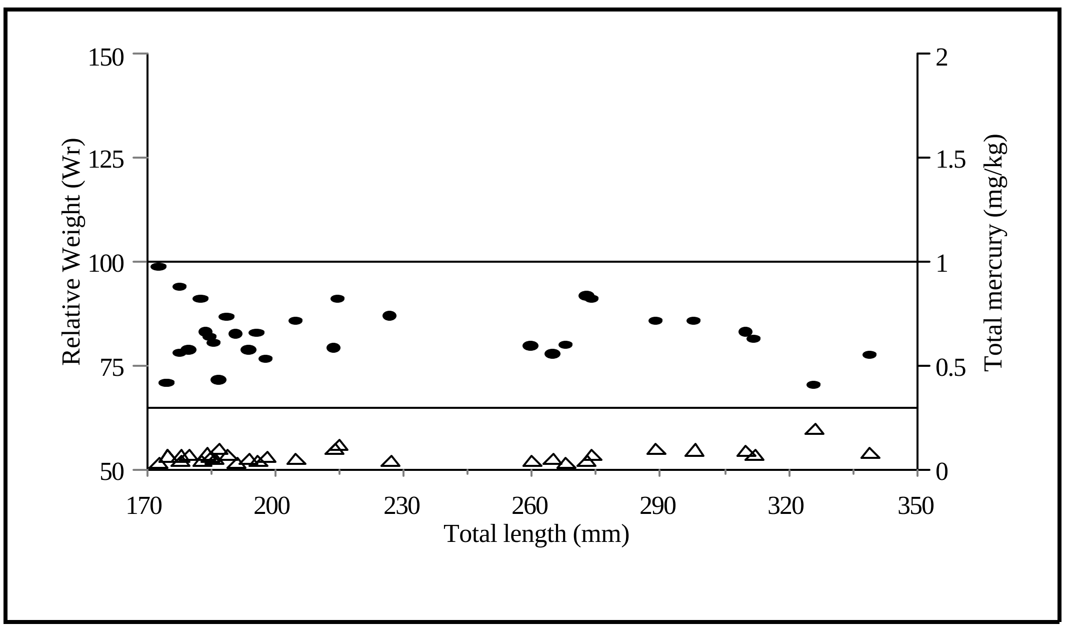

Figure 5. Relationship between total length and relative weight (W_r) of cutthroat trout (black ovals) sampled from Lake Whatcom (Whatcom County) during late spring 2000 compared with the national 75th percentile (line at W_r = 100) for the species, and relationship between total length and mercury concentration (mg/kg) of cutthroat trout (clear triangles). The range of values for state, federal, and international screening levels of mercury in fish tissues is represented by lines at 0.3 and 1.0 mg/kg.

Kokanee

Total mercury concentrations in Lake Whatcom kokanee were higher than cutthroat trout and ranged from 0.07 to 0.25 mg/kg, with a mean (± SE) value of 0.12 ± 0.01 mg/kg. Like cutthroat trout, kokanee displayed a narrower range and much lower mean total mercury concentration compared to those reported for salmonids sampled from several Maine lakes (Stafford and Haines 1997).

Lake Whatcom kokanee ranged from 189 to 240 mm TL (Figure 6, Table 5). Mercury levels did not change significantly with size (Figure 7) as revealed by a linear regression of log-transformed total mercury concentration on total length ($r^2 < 0.01$, $P > 0.50$). Relative weights were low by national standards, but consistent with length (Figure 7). Regressing log-transformed mercury on relative weight revealed no significant relationship ($r^2 < 0.01$, $P > 0.50$).
Fish were aged 2+ to 4+, and there was little or no increase in mean mercury concentration with age (Table 8).

Table 8. Total mercury concentrations [mean ± SE (range)] by year class, and age and growth of kokanee (*Oncorhynchus nerka*) captured at Lake Whatcom (Whatcom County) during late spring 2000. Values are mean back-calculated lengths at annulus formation using the direction proportion method (Fletcher et al. 1993).

			Mean fork length (mm) at age			
Year class	**Mercury (mg/kg)**	**# fish**	**1**	**2**	**3**	**4**
1999		0				
1998	0.104 ± 0.008 (0.069-0.175)	12	42.5	188.7		
1997	0.126 ± 0.014 (0.091-0.248)	11	61.7	171.4	194.5	
1996	0.127 ± 0.011 (0.087-0.167)	7	77.2	148.2	182.8	206.7
Weighted mean			69.6	172.9	190.0	206.7

No known natural spawning of native kokanee occurs in the tributaries of Lake Whatcom and thus, the population is maintained by stocking millions of WDFW hatchery-reared fry into the lake annually (Looff 1994; Stockbridge *undated*; Larry Sisson, WDFW, personal communication). Although it is tempting to relate the work of Stafford and Haines (1997) to Lake Whatcom kokanee (recall the authors concluded that hatchery-produced fish were exposed to lower mercury levels), the probable reason for low mercury levels in Lake Whatcom kokanee is related to diet. Throughout their life, the fish feed primarily on zooplankton and therefore do not bioaccumulate mercury to the same extent as piscivorous fishes.

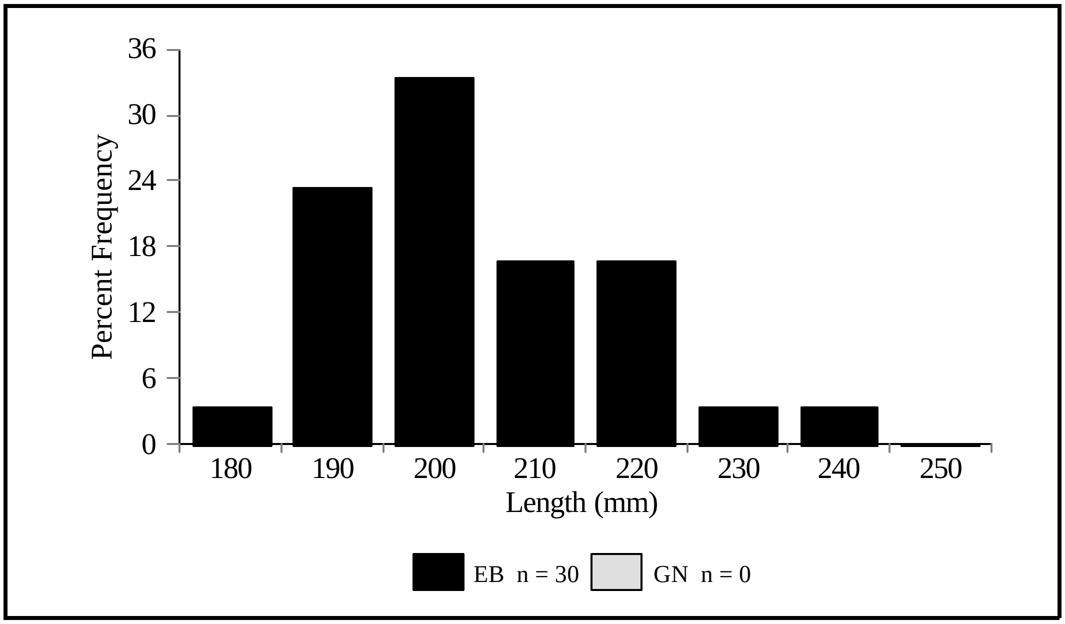

Figure 6. Length frequency histogram of kokanee sampled from lake Whatcom (Whatcom County) during late spring 2000. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing boat and GN = gillnetting.

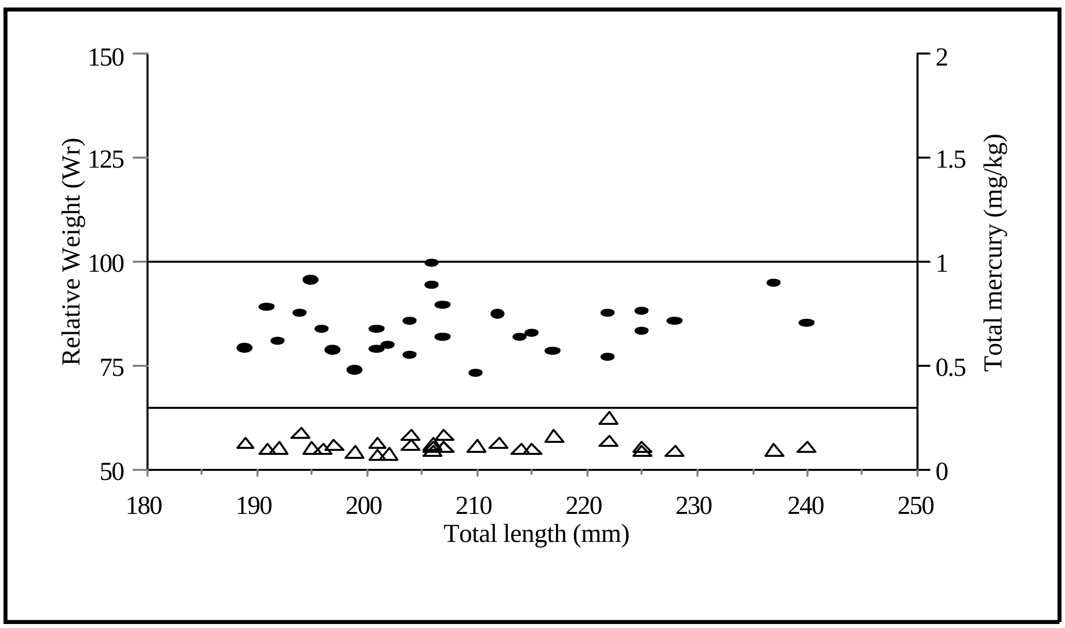

Figure 7. Relationship between total length and relative weight (W_r) of kokanee (black ovals) sampled from Lake Whatcom (Whatcom County) during late spring 2000 compared with the national 75th percentile (line at W_r = 100) for the species, and relationship between total length and mercury concentration (mg/kg) of kokanee (clear triangles). The range of values for state, federal, and international screening levels of mercury in fish tissues is represented by lines at 0.3 and 1.0 mg/kg.

Pumpkinseed

Total mercury concentration in Lake Whatcom pumpkinseed ranged from 0.03 to 0.28 mg/kg, with a mean (± SE) value of 0.10 ± 0.01 mg/kg (Table 6). Although none exceeded the proposed EPA screening level of 0.3 mg/kg mercury in fish tissues, one fish (162 mm TL) came very close (Figure 9, Table 6). The range and mean reported here are narrower and lower compared to those of pumpkinseed from several lakes near metal smelters in Ontario, Canada (range and mean total mercury concentration in fish = 0.04 – 0.54 and 0.20 mg/kg, respectively; Wren and MacCrimmon 1983). The values were also lower than those reported for pumpkinseed downstream from mercury sources in Virginia (range of mean total mercury concentration in fish = 0.10 – 0.60 mg/kg; Nicoletto and Hendricks 1987) and from polluted deltaic areas in Greece (range of total mercury concentration in fish = 1.55 – 2.36 mg/kg; Goutner and Furness 1997).

Lake Whatcom pumpkinseed ranged from 96 to 185 mm TL (Figure 8, Table 5). A linear regression of log-transformed total mercury concentration on total length revealed no significant relationship (r^2 = 0.05, $P > 0.20$), which differs from the significant relationship found by Scheuhammer and Graham (1999) for pumpkinseed from rural Ontario, Canada. Relative weights were consistent with the national 75th percentile and increased slightly with length (Figure 9). Regressing log-transformed mercury on relative weight did not reveal a significant relationship ($r^2 < 0.01$, $P > 0.50$).

Fish were aged 2+ to 6+. There was little or no increase in mean mercury concentration with age; the highest concentrations were in younger fish (Table 9). The 1997 year-class dominated our sample, followed by the 1996 year-class. Growth of Lake Whatcom fish, as indicated by length at age, was similar to that reported by Mueller et al. (1999) and above average when compared to pumpkinseed statewide (Table 9).

Table 9. Total mercury concentration [mean ± SE (range)] by year class, and age and growth of pumpkinseed (*Lepomis gibbosus*) captured at Lake Whatcom (Whatcom County) during late spring 2000. Unshaded values are mean back-calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993). Shaded values are mean back-calculated lengths using Lee's modification of the direct proportion method (Carlander 1982).

			Mean total length (mm) at age					
Year class	**Mercury (mg/kg)**	**# fish**	**1**	**2**	**3**	**4**	**5**	**6**
1999		0						
1998	0.11 ± 0.04	5	44.2	111.4				
	(0.03-0.25)		59.6	111.8				
1997	0.09 ± 0.01	13	26.0	94.9	133.2			
	(0.05-0.23)		46.1	102.3	133.5			
1996	0.12 ± 0.04	6	21.4	91.7	125.5	145.7		
	(0.04-0.28)		42.7	101.0	129.1	145.8		
1995	0.11 ± 0.02	3	34.7	92.4	129.3	152.5	170.0	
	(0.07-0.15)		54.6	103.9	135.4	155.1	170.1	
1994	0.12 ± 0.02	3	17.2	54.3	87.8	123.3	137.6	151.9
	(0.09-0.14)		39.4	70.5	98.5	128.3	140.2	152.1
Overall mean			28.7	89.0	119.0	140.5	153.8	151.9
Weighted mean			47.8	100.6	128.5	143.7	155.2	152.1
Date from Mueller et al. (1999)	Overall mean		25.7	79.4	94.9	126.7	—	—
	Weighted mean		42.3	95.8	113.0	130.7	—	—
State average (unweighted)			23.6	72.1	101.6	122.7	139.4	—

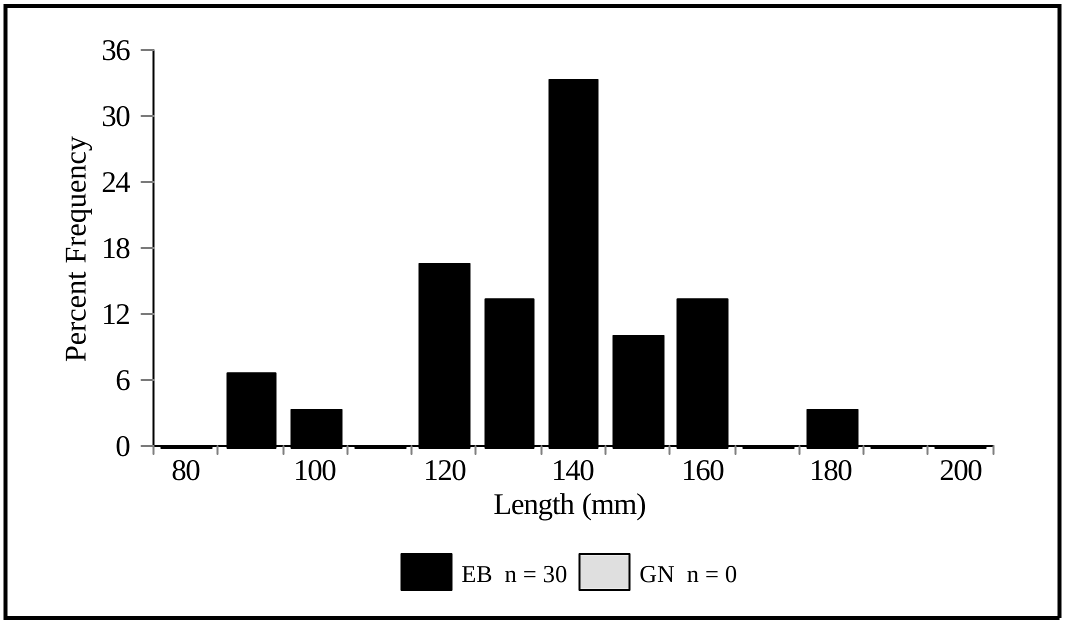

Figure 8. Length frequency histogram of pumpkinseed sampled from Lake Whatcom (Whatcom County) during late spring 2000. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing boat and GN = gillnetting.

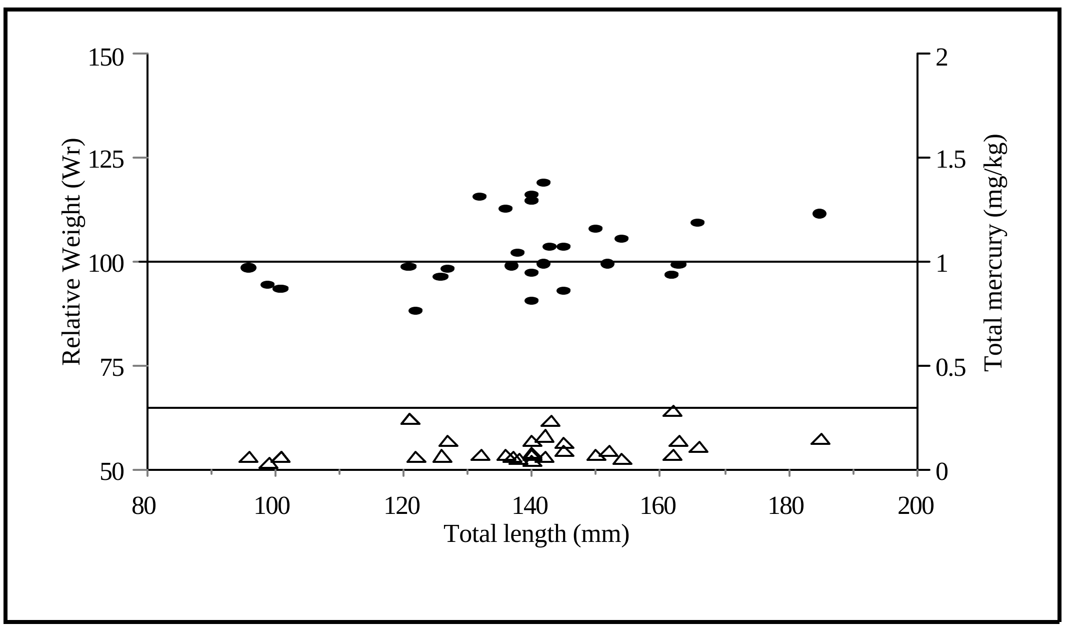

Figure 9. Relationship between total length and relative weight (W_r) of pumpkinseed (black ovals) sampled from Lake Whatcom (Whatcom County) during late spring 2000 compared with the national 75th percentile (line at W_r = 100) for the species, and relationship between total length and mercury concentration (mg/kg) of pumpkinseed (clear triangles). The range of values for state, federal, and international screening levels of mercury in fish tissues is represented by lines at 0.3 and 1.0 mg/kg.

Signal crayfish

Total mercury concentration in Lake Whatcom signal crayfish ranged from 0.03 to 0.54 mg/kg, with a mean (± SE) value of 0.11 ± 0.02 mg/kg. Of the 45 signal crayfish sampled, 4% (n = 2) had mercury levels exceeding the proposed EPA screening level of 0.3 mg/kg. These measured > 125 mm or 5" TL (Figure 11). The range of mercury concentrations from our study are similar to those reported for crayfish (*Cambarus* sp.) downstream of smelters in Ontario, Canada (range of mean total mercury concentration in crayfish = 0.02 – 0.19 mg/kg; Wren and Stokes 1988) and crayfish (*Orconectes* sp.) downstream of paper, pulp, and chloro-alkali industries in Wisconsin (range of mean total mercury concentration in crayfish = 0.07 – 0.56 mg/kg; Sheffy 1978). Similarities also exist between our work and that reported for crayfish (*Orconectes virilis*) collected from a dredge site in Saskatchewan (range of mean total mercury concentration in crayfish = 0.06 – 0.35 mg/kg; Munro and Gummer 1980). However, the range of mercury concentrations in Lake Whatcom signal crayfish is lower than the range reported for *O. virilis* downstream of an historic chloro-alkali plant associated with a large, Ontario pulp and paper complex (range of total mercury concentration in crayfish = 0.06 – 1.60 mg/kg; Parks 1988). Furthermore, our results are consistent with mercury levels found in crayfish (*Cambarus* sp. and *Orconectes* sp.) from several Ontario lakes that receive no known direct discharge of mercury (range of total mercury concentration in crayfish = 0.02 – 0.61 mg/kg; Allard and Stokes 1989).

Total length of signal crayfish ranged from 83 to 137 mm (Figure 10, Table 5). A linear regression of log-transformed total mercury concentration on total length revealed a slightly positive yet significant relationship ($r^2 = 0.32$, $P < 0.01$), which differs from the findings of Scheuhammer and Graham (1999), who found no relationship between mercury concentration and length in crayfish (*O. virilis*) from rural Ontario. The condition of signal crayfish decreased slightly with length (Figure 11). Regressing log-transformed mercury on condition factor revealed no significant relationship ($r^2 = 0.01$, $P > 0.50$).

At least three age-classes were represented in our sample (Figure 10). We inferred that signal crayfish below 120 mm TL were two to three years old, whereas those above 120 mm TL were four years or older, based on age tables for signal crayfish reported by McGriff (1983).

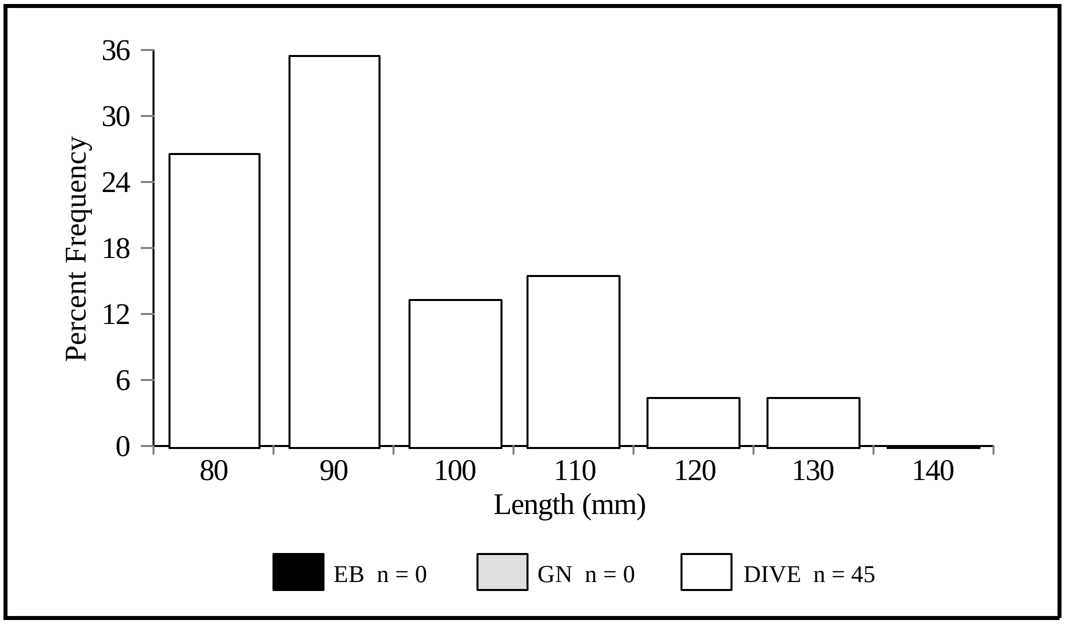

Figure 10. Length frequency histogram of signal crayfish sampled from Lake Whatcom (Whatcom County) during late spring 2000. Length was measured from the acumen of the rostrum to the end of the telson. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing boat, GN = gillnetting, and DIVE = scuba diving.

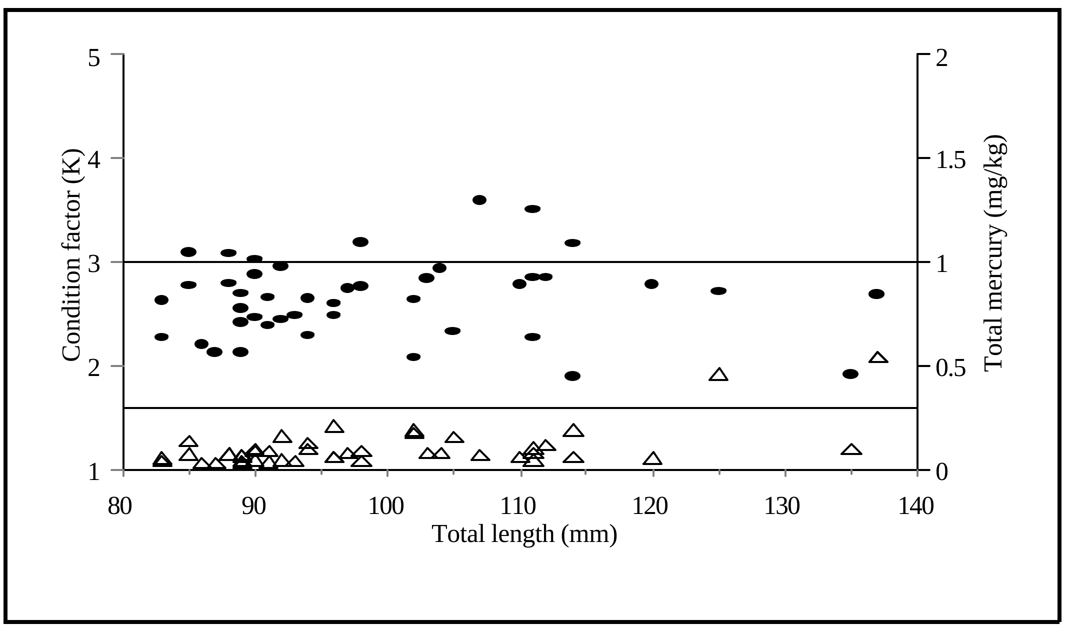

Figure 11. Relationship between total length and Fulton condition factor (*K*) of signal crayfish (black ovals) sampled from Lake Whatcom (Whatcom County) during late spring 2000, and relationship between total length and mercury concentration (mg/kg) of signal crayfish (clear triangles). The range of values for state, federal, and international screening levels of mercury in fish tissues is represented by lines at 0.3 and 1.0 mg/kg.

Smallmouth bass

Total mercury concentration in Lake Whatcom smallmouth bass ranged from 0.10 to 1.84 mg/kg, with a mean (± SE) value of 0.49 ± 0.03 mg/kg (Table 6), which was higher than the national average of weighted means (0.37 mg/kg) reported for the species (EPA 1999a). Of the 95 fish sampled, 64% (n = 61) had mercury levels exceeding the proposed EPA screening level of 0.3 mg/kg. These measured > 275 mm or 11" TL (Figure 13). The range of values for Lake Whatcom fish overlapped the range of mean values for smallmouth bass (0.31 – 1.12 mg/kg) from 125 randomly selected lakes in Maine (Stafford and Haines 1997). The range of values for preferred-length smallmouth bass (0.26 – 1.84 mg/kg; Table 6) was twice as high as that predicted for similar-size fish from Ontario lakes not adjacent to known point sources of mercury (total mercury concentration in fish = 0.11 – 0.94 mg/kg; McMurtry et al. 1989). Likewise, the range (0.13 – 1.84 mg/kg) and mean (0.54 mg/kg) for quality-length fish (Table 6) were considerably higher than those reported for similar-size fish from a remote lake in Michigan not directly impacted by anthropogenic activities (range and mean total mercury concentration in fish = 0.10 – 0.26 and 0.16 mg/kg, respectively; Henry et al. 1998).

The smallmouth bass sampled ranged from 249 to 486 mm TL (Figure 12, Table 5). Mercury levels changed significantly with size (Figure 13) as revealed by a linear regression of log-transformed total mercury concentration on total length ($r^2 = 0.62$, $P < 0.01$), which is consistent with the findings of Neumann and Ward (1999) for Connecticut smallmouth bass. Relative weights were somewhat low by national standards, but consistent with length. Still, regressing log-transformed mercury on relative weight revealed no significant relationship ($r^2 = 0.01$, $P > 0.20$).

Lake Whatcom smallmouth bass were aged 3+ to 10+ with mercury concentrations increasing with age (Table 10). The range of mercury concentrations in fish aged 3+ to 5+ (0.11 – 0.92 mg/kg; Table 10) was lower than the range reported for similar-age smallmouth bass collected downstream of historic gold and silver mining operations in southeast Oregon (range of mean total mercury concentration in fish = 0.60 – 1.40 mg/kg; Allen-Gil et al. 1995). The 1995 year-class clearly dominated our sample. We were not able to age three individuals due to scale regeneration. Growth of Lake Whatcom fish, as indicated by length at age, was similar to that reported by Mueller et al. (1999) and, after age 3+, consistent with or above the state average for the species (Table 10).

Table 10. Total mercury concentration [mean ± SE (range)] by year class, and age and growth of smallmouth bass (*Micropterus dolomieu*) captured at Lake Whatcom (Whatcom County) during late spring 2000. Unshaded values are mean back-calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993). Shaded values are mean back-calculated lengths using Lee's modification of the direct proportion method (Carlander 1982).

Year class	Mercury (mg/kg)	# fish	Mean total length (mm) at age 1	2	3	4	5	6	7	8	9	10
1999		0										
1998		0										
1997	0.19±0.02	12	74.9	173.4	260.1							
	(0.11-0.29)		99.8	185.1	260.1							
1996	0.28±0.04	12	46.1	139.4	227.7	284.9						
	(0.10-0.45)		75.4	157.3	234.9	285.0						
1995	0.44±0.03	37	54.9	124.3	211.2	292.5	339.9					
	(0.22-0.92)		84.3	146.5	224.5	297.4	339.9					
1994	0.48±0.04	12	50.2	132.6	202.4	274.1	333.2	370.5				
	(0.29-0.68		80.4	155.0	218.2	283.2	336.7	370.5				
1993	0.90±0.13	6	53.5	140.0	216.0	290.0	335.4	377.0	394.1			
	(0.55-1.30)		83.8	162.6	231.8	299.4	340.7	378.5	394.1			
1992	0.85±0.06	8	59.1	128.2	203.0	282.3	333.2	380.1	414.7	431.5		
	(0.68-1.23)		89.3	152.8	221.6	294.5	341.2	384.3	416.1	431.5		
1991	0.98±0.10	2	43.9	141.0	207.3	279.7	340.0	378.4	406.1	433.3	449.0	
	(0.88-1.08)		75.5	165.0	226.1	292.9	348.5	383.9	409.5	434.5	449.0	
1990	1.17±0.34	3	60.1	138.0	241.3	302.4	358.8	386.7	405.6	425.4	441.1	451.3
	(0.75-1.84)		90.4	162.4	257.6	314.0	366.0	391.8	409.2	427.4	441.9	451.3
Overall mean			55.3	139.6	221.1	286.6	340.1	378.5	405.1	430.0	445.0	451.3
Weighted mean			85.1	156.6	231.0	293.8	341.0	378.5	407.4	431.0	444.7	451.3
Date from Mueller et al. 1999	Overall mean		57.4	137.3	213.7	295.3	347.9	393.2	425.0	459.4	—	—
	Weighted mean		89.0	156.5	226.6	299.1	346.3	386.3	410.8	461.1	—	—
State average (unweighted)			70.4	146.3	211.8	268.0	334.0	356.1	392.7	—	—	—

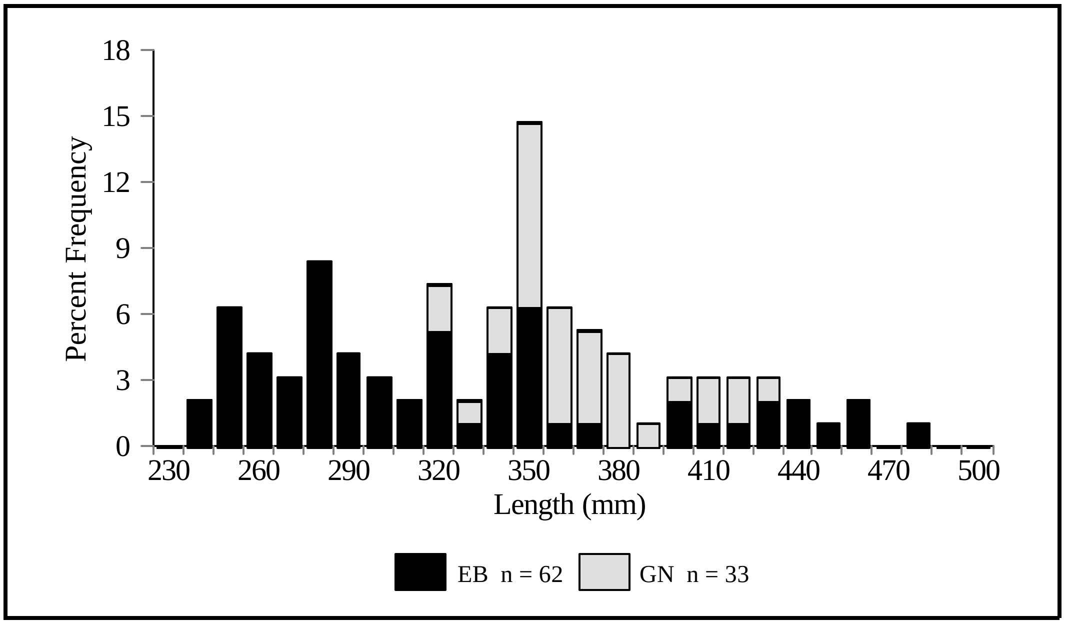

Figure 12. Length frequency histogram of smallmouth bass sampled from Lake Whatcom (Whatcom County) during late spring 2000. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing boat and GN = gillnetting.

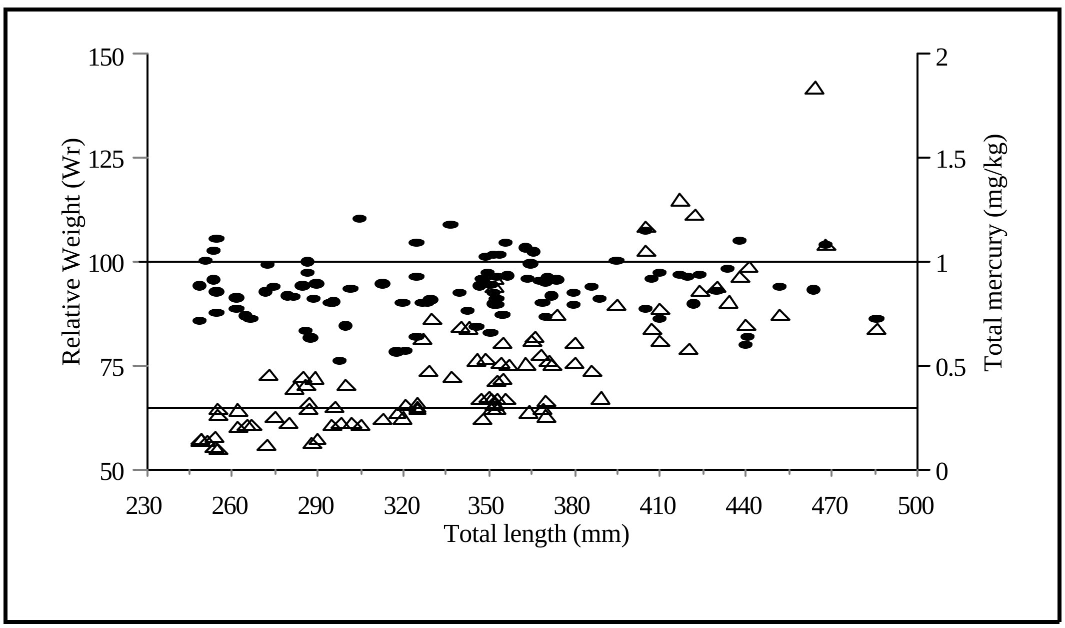

Figure 13. Relationship between total length and relative weight (W_r) of smallmouth bass (black ovals) sampled from Lake Whatcom (Whatcom County) during late spring 2000 compared with the national 75[th] percentile (line at W_r = 100) for the species, and relationship between total length and mercury concentration (mg/kg) of smallmouth bass (clear triangles). The range of values for state, federal, and international screening levels of mercury in fish tissues is represented by lines at 0.3 and 1.0 mg/kg.

Yellow perch

Total mercury concentration in Lake Whatcom yellow perch ranged from 0.05 to 0.87 mg/kg, with a mean (± SE) value of 0.20 ± 0.03 mg/kg (Table 6). Of the 30 fish sampled, 20% (n = 6) had mercury levels exceeding the proposed EPA screening level of 0.3 mg/kg. These measured > 240 mm or 9.5" TL (Figure 15). The mean mercury level found in Lake Whatcom fish was generally lower than the mean values reported for the northeastern USA (Cope et al. 1990; Grieb et al. 1990; Stafford and Haines 1997; Rose et al. 1999) but there were exceptions. For example, although the range for preferred-length yellow perch (0.16 – 0.87 mg/kg; Table 6) was nearly identical to similar-size fish from Maine (total mercury concentration in fish = 0.18 – 0.81 mg/kg; Stafford and Haines 1997), the Lake Whatcom mean was higher (0.41 vs. 0.28 mg/kg). Furthermore, the range reported for Lake Whatcom yellow perch was higher compared to the range found in Massachusetts (mean total mercury concentration and range = 0.31 and 0.01 – 0.75 mg/kg, respectively; Rose et al. 1999).

Total length of yellow perch ranged from 154 to 333 mm TL (Figure 14, Table 5). Mercury levels increased with length (Figure 15) and a linear regression of log-transformed total mercury concentration on total length revealed a significant positive relationship ($r^2 = 0.63$, $P < 0.01$). Like brown bullhead, this is similar to the findings of Scheuhammer and Graham (1999) who examined yellow perch and other fishes from rural Ontario, Canada. Except for the largest yellow perch, relative weights were low by national standards, but consistent with length. Furthermore, regressing log-transformed mercury on relative weight revealed a significant and slightly positive relationship ($r^2 = 0.16$, $P = 0.03$).

Lake Whatcom yellow perch were aged 2+ to 8+. In general, mercury concentrations increased with age. However, the 1992 and 1996 year-classes exhibited levels that did not follow the trend of the other year-classes (Table 11). The range of mercury concentrations for two year old fish (0.07 – 0.15 mg/kg) was lower than that reported for similar-age fish from Wisconsin (range of total mercury concentration = 0.03 – 0.29 mg/kg; Cope et al. 1990). The 1997 and 1998 year-classes dominated our sample. Growth of Lake Whatcom fish, as indicated by length at age, was similar to that reported by Mueller et al. (1999) and, after age 1+, above the state average for the species (Table 11).

Table 11. Total mercury concentration [mean ± SE (range)] by year class, and age and growth of yellow perch (*Perca flavescens*) captured at Lake Whatcom (Whatcom County) during late spring 2000. Unshaded values are mean back-calculated lengths at annulus formation using the direct proportion method (Fletcher et al. 1993). Shaded values are mean back-calculated lengths using Lee's modification of the direct proportion method (Carlander 1982).

Year class	Mercury (mg/kg)	# fish	Mean total length (mm) at age 1	2	3	4	5	6	7	8
1999		0								
1998	0.10±0.01	10	75.0	161.7						
	(0.07-0.15)		91.6	162.7						
1997	0.12±0.01	10	59.9	140.6	200.5					
	(0.05-0.17)		80.9	149.6	200.6					
1996	0.11	1	48.7	135.5	176.6	207.0				
			71.6	145.8	181.0	207.0				
1995	0.22±0.08	3	44.9	109.4	166.2	218.7	248.3			
	(0.12-0.39)		69.4	126.1	175.9	222.3	248.3			
1994	0.38±0.08	2	44.3	131.0	182.0	212.3	235.4	251.0		
	(0.31-0.46)		69.0	145.3	190.3	216.9	237.3	251.0		
1993	0.69±0.18	2	46.7	126.0	197.8	229.7	253.4	272.6	284.5	
	(0.51-0.87)		71.8	142.7	206.9	235.4	256.7	273.9	284.5	
1992	0.37±0.00	2	54.6	135.1	195.9	248.2	280.3	300.5	317.7	332.5
	(0.37-0.37)		79.7	152.9	208.2	255.8	285.0	303.4	319.0	332.5
Overall mean			53.5	134.2	186.5	223.2	254.4	274.7	301.1	332.5
Weighted mean			81.5	150.9	196.3	229.0	255.9	276.1	301.8	332.5
Date from Mueller et al. (1999)	Overall mean		54.6	128.1	184.3	215.9	260.9	—	—	—
	Weighted mean		74.7	124.0	177.5	205.6	262.2	—	—	—
State average (unweighted)			59.7	119.9	152.1	192.5	206.0	—	—	—

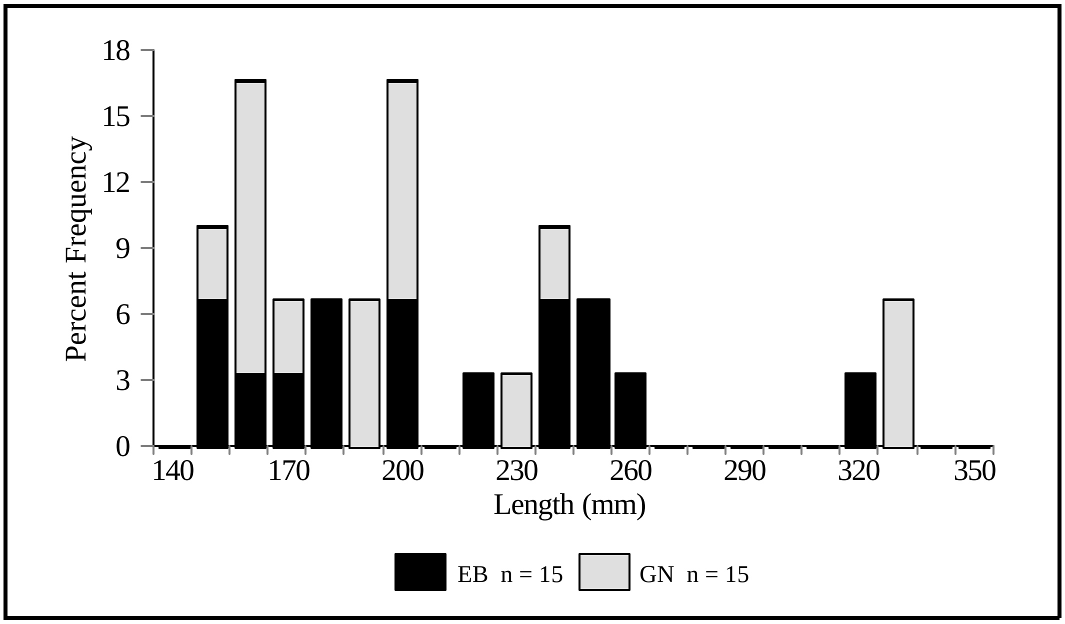

Figure 14. Length frequency histogram of yellow perch sampled from Lake Whatcom (Whatcom County) during late spring 2000. Stacked bars show relative contribution of each gear type to size classes. Length frequencies can be viewed collectively or by gear type. EB = electrofishing boat and GN = gillnetting.

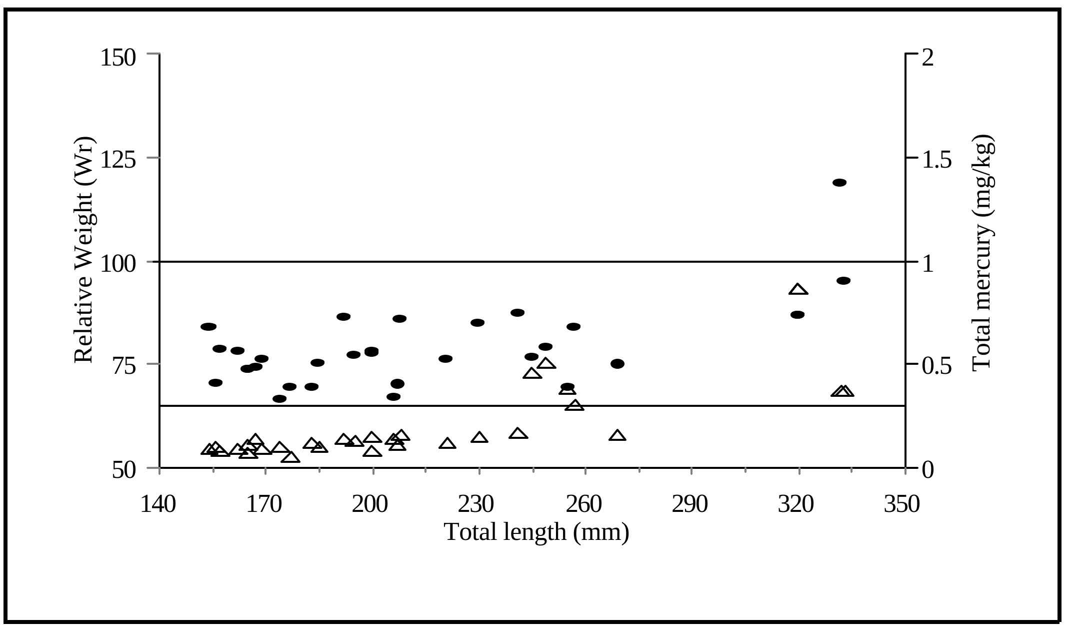

Figure 15. Relationship between total length and relative weight (W_r) of yellow perch (black ovals) sampled from Lake Whatcom (Whatcom County) during late spring 2000 compared with the national 75th percentile (line at $W_r = 100$) for the species, and relationship between total length and mercury concentration (mg/kg) of yellow perch (clear triangles). The range of values for state, federal, and international screening levels of mercury in fish tissues is represented by lines at 0.3 and 1.0 mg/kg.

Spatial Differences in Mercury Concentrations

Spatial differences in the total mercury concentrations of Lake Whatcom's sportfishes were evident during late spring 2000 [refer to Serdar et al. (2001) for a full description]. With few exceptions, mean total mercury concentrations increased from Basin 1 (north) to Basin 3 (south) (Table 12). The same pattern was observed by Serdar et al. (1999) when evaluating total mercury concentrations of waters entering the three basins (i.e., from storm drains and creeks); Basin 1 and 2 levels were less than levels found in Basin 3. However, when evaluating a limited number of bottom sediments, Serdar et al. (1999) found that mercury levels were higher in Basin 1 compared to Basins 2 or 3. Total mercury concentrations for Lake Whatcom and various waters entering the system range from about 0.004 to 0.010 Fg/l, whereas lake sediment concentrations range from 0.08 to 0.46 mg/kg, dry weight (Serdar et al. 1999; Matthews et al. 2000).

The distribution of mercury in a given system is affected by many biotic and abiotic components (Parks 1988; Jackson 1991). At various times throughout the year, the three basins of Lake Whatcom are limnologically distinct from one another (Matthews et al. 2000). Thus, inter-basin differences in mercury concentrations of fishes in Lake Whatcom are inevitable and probably influenced by site-specific foraging and spawning habits of fishes (Munn and Short 1997), proximity to mercury source(s), or the lake's chemical and physical characteristics. For example, some researchers reported a positive correlation between concentrations of mercury in fishes and sediments. Others described a negative correlation between mercury concentrations in fishes and distance from known mercury sources (Sheffy 1978; Munro and Gummer 1980; Cope et al. 1990; Allen-Gil et al. 1995; Bevelhimer and Adams 1996). Many authors reported a negative correlation between mercury concentrations in fishes and pH (Wren and MacCrimmon 1983; Cope et al. 1990; Grieb et al. 1990; Suns and Hitchin 1990; Lange et al. 1993; Allen-Gil et al. 1995; Rose et al. 1999). Negative relationships also exist between mercury concentration in fishes and levels of calcium and dissolved organic carbon (Wren and MacCrimmon 1983; McMurtry et al. 1988; Grieb et al. 1990; Snodgrass et al. 2000). Water temperature plays an important role in mercury dynamics as shown by Ward and Neumann (1999), who found that mercury concentrations in Florida largemouth bass decreased with increasing water temperature from spring to fall. Lake level fluctuations are positively correlated with mercury concentrations in fishes, ostensibly related to terrestrial inputs when water levels are high (Hanten, Jr. et al. 1998; Snodgrass et al. 2000). Furthermore, the flushing ability of a given system appears to influence mercury uptake in fishes. For example, Suns and Hitchin (1990) reported a positive correlation between drainage size/lake volume ratios and mercury levels in yellow perch from Ontario, Canada, and Rose et al. (1999) reported a positive correlation between lake size and mercury content in fishes from Massachusetts.

Table 12. Mean [± SE (range), *n* size] total mercury concentration (mg/kg) of sportfishes by basin at Lake Whatcom (Whatcom County) during late spring 2000.

	Basin		
Species	**1**	**2**	**3**
Brown bullhead	0.07 ± 0.01 (0.03-0.12) n = 10	None captured	0.44 ± 0.19 (0.14-0.79) n = 3
Cutthroat trout	0.06 ± 0.00 (0.03-0.07) n = 10	0.07 ± 0.01 (0.03-0.12) n = 10	0.08 ± 0.02 (0.03-0.20) n = 10
Kokanee	0.12 ± 0.02 (0.09-0.25) n = 10	0.11 ± 0.01 (0.07-0.13) n = 10	0.13 ± 0.01 (0.07-0.18) n = 10
Pumpkinseed	0.11 ± 0.02 (0.05-0.23) n = 10	0.07 ± 0.01 (0.04-0.09) n = 10	0.12 ± 0.03 (0.03-0.28) n = 10
Signal crayfish	0.07 ± 0.01 (0.03-0.18) n = 15	0.12 ± 0.03 (0.04-0.54) n = 15	0.13 ± 0.03 (0.04-0.46) n = 15
Smallmouth bass	0.49 ± 0.06 (0.10-1.84) n = 34	0.40 ± 0.04 (0.11-1.05) n = 31	0.58 ± 0.06 (0.22-1.30) n = 30
Yellow perch	0.12 ± 0.02 (0.05-0.31) n = 10	0.17 ± 0.03 (0.07-0.37) n = 10	0.29 ± 0.08 (0.09-0.87) n = 10

Fish Population Concerns

Fish are exposed to mercury through their environment (e.g., a water-born or sediment-laden insult or during embryogenesis) and ingestion of contaminated food. Signs of toxicity include inability to school, jerking, tilting, or rolling movements, lethargy, or increased aggression and flight response (Al-Akel and Shamsi 1988). Laboratory and field studies have shown that exposing fish to mercury may result in population-level consequences such as altered reproductive and behavior patterns, cell and organ function, or immune responses.

Mercury interferes with fish reproduction and behavior in a number of ways. The accumulation of low levels of mercury in tissues of cutthroat trout and other fishes may disrupt normal reproduction and sexual development (Matta 1999). Although naturally occurring levels of mercury (muscle content ~ 0.3 mg/kg) have little effect on gonad function of northern pike (*Esox lucius*), dietary mercury (0.1 –

1.0 mg/kg in food) significantly impairs growth and gonadal development in male walleye (*Stizostedion vitreum*) (Friedmann et al. 1996a, 1996b). Ovarian maturation in red swamp crayfish (*Procambarus clarkii*) is significantly inhibited by mercury (Reddy et al. 1997), and long-term (> 30 days) survival of male shield crayfish (*Faxonella clypeata*) is compromised when ambient mercury concentrations exceed the modest level of 0.002 Fg/l (Heit and Fingerman 1977). At the onset of sexual maturity, female pumpkinseed accumulate more mercury than males (0.84 compared to 0.60 mg/kg), a phenomenon attributed to increased consumption of food by the former to meet the increased demands of reproduction (Nicolletto and Hendricks 1988). McKim et al. (1976) found that considerable amounts of mercury were passed from parents through eggs to successive generations of brook trout (*Salvelinus fontinalis*), however no toxic symptoms were observed in the third generation after exposures to 0.03 – 0.29 Fg/l. Exposure of developing yellow perch embryos to mercury is also strongly related to maternal bioaccumulation (Hammerschmidt et al. 1999).

Larval and juvenile fish exposed to mercury during embryogenesis (2.0 – 20.0 Fg/l) are subject to developmental instability (Vøllestad et al. 1998), reduced foraging efficiency (Weis and Weis 1995), increased predation (Zhou and Weis 1998), and altered shoaling behavior (Ososkov and Weis 1996). Similarly, adult fish from environments polluted with mercury (up to 11.5 mg/kg in sediments) suffer decreased prey capturing ability and increased susceptibility to predation compared with those from less contaminated or unpolluted environments (Weis and Kahn 1991; Smith and Weis 1997). Kania and O'hara (1974) reported mean mercury concentrations of 0.67 mg/kg in tissues of adult prey fish with significant behavioral alterations.

At the cellular level, mercury stresses the endocrine system of fish (Bleau et al. 1996) and leads to immune suppression (Roales and Perlmutter 1980; Friedmann et al. 1996b; Sanchez-Dardon et al. 1999). Overexposure to mercury (0.04 – 0.59 mg/l) has been shown to alter blood chemistry and cause decreased levels of red blood cells in mullet (*Liza macrolepis*) (Helmy et al. 1978). In crayfishes, mercury exposure (0.10 – 0.25 mg/l) may adversely affect molting through changes in the hepatopancreas (Torreblanca et al. 1993) or lead to heart failure (Styrishave and Depledge 1996). Adams et al. (1999) reported anomalies of the liver, kidney, and spleen of largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*) associated with mercury-laden sediments. Likewise, Studnicka (1983) reported degenerative changes in the livers and kidneys of brown bullhead exposed to solutions containing mercuric compounds. The amount of DNA damage incurred by largemouth bass living in polluted waters is strongly correlated with mercury concentrations in tissues (range = 0.89 – 6.12 mg/kg; Sugg et al. 1995). Jagoe et al. (1996) provided evidence that high mercury concentrations (2.20 mg/kg in tissues) cause gill pathologies and interfere with ion and osmoregulation in largemouth bass. Furthermore, in rainbow trout fry and fingerlings, acute toxic action of mercury compounds (0.02 – 0.90 mg/l) is exerted on the gills as indicated by swelling, hyperplasia, and necrosis of epithelial cells (Wobeser 1975).

Epidermal mucus secretions and scales are generally the first lines of defense of fish against external mercury exposure (Coello and Khan 1996). Both have been shown to remove mercury from water, and the former can actually process most mercury once the fish is placed in a clean environment (Varanasi et al. 1975; Coello and Khan 1996). The mineral selenium plays an important role in the ability of fish and crayfish to process mercury (Rudd et al. 1980; Pedersen et al. 1998), and zinc affords protection against mercury-induced immunotoxicity (Sanchez-Dardon et al. 1999). However, the elimination of mercury from aquatic animals is extremely slow (McKim et al. 1976), with a reported half-life ranging from 130 to 1,030 days in long-term (> 90 days) experiments on fish (Trudel and Rasmussen 1997).

Trophic Links

Fish and other aquatic organisms obtain mercury mostly through feeding. One study demonstrated that food pathways were responsible for 90% or more of mercury uptake in yellow perch and walleye (*Stizostedion vitreum*) (Harris and Snodgrass 1993). Primary producers (blue-green algae or diatoms) and primary consumers (grazing or omnivorous fish) are critical intermediaries in the movement and biomagnification of mercury from water to upper trophic levels (Hill et al. 1996). Westcott and Kalff (1996) found that mercury levels in filter-feeding zooplankton (*Daphnia* spp.) were strongly correlated with concentrations found in smallmouth bass from 11 of 24 study lakes in south-central Ontario, Canada. The authors concluded that zooplankton were good indicators of the relative bioavailability of mercury at the base of the food chain. Gorski et al. (1999) suggested that planktivorous fish might be useful sentinels for monitoring short-term changes in the availability of mercury in lakes. Hence, future studies may be designed to examine the roles of planktivorous early life stages of fishes and fishes utilizing zooplankton as adults, such as pumpkinseed and kokanee, in mercury cycling at Lake Whatcom.

Aquatic insects are also part of the food web system that transfers mercury from the physical environment to fish. When exposed to a mercury insult, predaceous aquatic insects accumulate more of the contaminant than herbivores or detritivores (Hall et al. 1998). A fish community with a high population of benthic insectivores can lead to higher rates of mercury cycling from benthos to fishes, and ultimately higher mercury concentrations in fishes (Wong et al. 1997).

The rate of mercury accumulation in piscivorous fishes is typically faster than that of omnivores, planktivores, or benthivores (Phillips et al. 1980; Olivero et al. 1998; Neumann and Ward 1999). This was evident in the sportfishes captured at Lake Whatcom during late spring 2000 (Figure 16). For example, predaceous smallmouth bass displayed the highest levels of mercury, followed by omnivorous yellow perch and brown bullhead, planktivorous kokanee, benthivorous pumpkinseed, and herbi-detritivorous signal crayfish. Lake Whatcom smallmouth bass prey largely on signal crayfish and a variety of finfish, including kokanee and yellow perch (Downen 1999). Our results indicate that signal crayfish and yellow perch have the potential for considerable mercury accumulation, which if eaten by smallmouth bass is magnified in the predator.

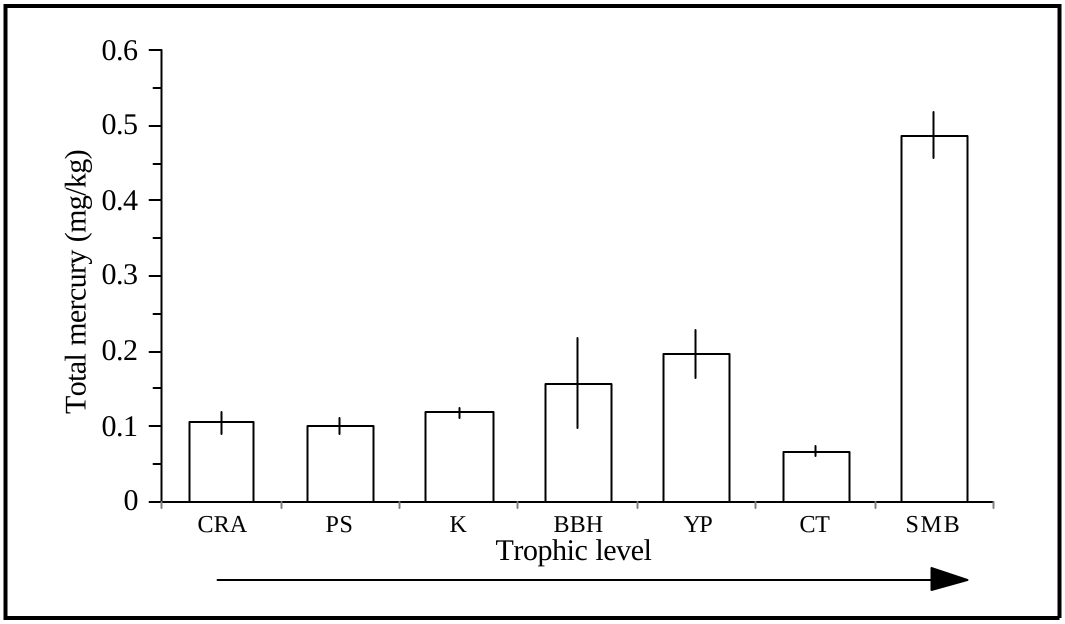

Figure 16. Distribution of total mercury (mg/kg) in sportfishes from different trophic levels in Lake Whatcom (Whatcom County) during late spring 2000. Values are means (± SE). CRA = signal crayfish, PS = pumpkinseed, K = kokanee, BBH = brown bullhead, YP = yellow perch, CT = cutthroat trout, and SMB = smallmouth bass.

After feeding, mercury is rapidly transferred from the fish gut to the rest of the body via the bloodstream (Oliveira-Ribeiro et al. 1999). Top-level fish predators such as northern pike (*Esox lucius*) or channel catfish (*Ictalurus punctatus*) may retain up to one-third of the mercury ingested (Phillips and Gregory 1979; McCloskey et al. 1998). This affects not only human consumers, but fish-eating birds and mammals as well. For example, an ecological hazard assessment by Henry et al. (1998) revealed that concentrations of mercury in smallmouth bass (0.10 – 0.49 mg/kg) from a remote lake in Michigan were sufficiently great to be of concern regarding their consumption by bald eagles (*Haliaeetus leucocephalus*) and mink (*Mustella vison*). Furthermore, an assessment by Sample and Suter II (1999) showed that piscivorous river otter (*Lutra canadensis*) were at significant risk from mercury exposure near a Superfund cleanup site in Tennessee.

As in fish, mercury in birds is passed from parents through eggs to successive generations (Hughes et al. 1997). Much of the mercury in chicks accumulates in their feathers while they grow (Bouton et al. 1999). Goutner and Furness (1997) suggested the negative correlation between mercury content of feathers and size of night heron (*Nycticorax nycticorax*) chicks was from inhibition of growth after feeding on prey that included mercury-tainted pumpkinseed. Indeed, post-fledgling great egrets (*Ardea albus*) became less active, spent more time in the shade, and were less motivated to hunt prey when fed a diet containing concentrations of mercury at the 0.5 mg/kg level (Bouton et al. 1999).

Implications for People Consuming Lake Whatcom Fish

The fisheries of Lake Whatcom are well known among Northwest anglers, especially those targeting smallmouth bass (Hawley 2000; Ledeboer 2000; Shangle 2000). Several fishing tournaments are held annually (Zook 1993; Strahle 1999). In the past, WDFW permitted the commercial harvest of signal crayfish at the lake. A recent pilot study by Washington Department of Health (Patrick *in review*) demonstrated that nearshore residents and boat and shore anglers at Lake Whatcom consume all of the target species from this study in varying degrees. During late spring 2000, specimens from four of the seven edible species evaluated contained total mercury concentrations that exceeded EPA's proposed screening level of 0.30 mg/kg. These were smallmouth bass, yellow perch, brown bullhead, and signal crayfish (maximum total mercury concentration detected in each species = 1.84, 0.87, 0.79, and 0.54 mg/kg, respectively).

Individuals exposed to higher than average levels of methylmercury include recreational and subsistence anglers who routinely consume large quantities of locally caught fish (EPA 1999). For example, in Brazil, as gold mining activities increased mercury concentrations in fishes, the background human exposure increased (Castilhos et al. 1998). In a study of fish-consuming anglers in Montreal, Canada, those who ate their catch from polluted waters more often than others displayed significantly higher levels of mercury in their tissues (Kosatsky et al. 1999). In a related study, ethnicity and cultural origins significantly influenced fish consumption by anglers in the same area (Shatenstein et al. 1999).

Mercury poisoning can cause irreversible neurological damage in humans. Less well known are its effects on reproductive, immunological, and cardiovascular systems. The U.S. EPA classifies methylmercury, the dominant form of the metal found in edible fish tissues, as a developmental toxicant. Prenatal life and developing children are especially sensitive to its effects (EPA 1999). The most severe effects reported in humans include mental retardation, cerebral palsy, deafness, and blindness in individuals exposed in utero, and sensory and motor impairment in exposed adults. Low-level mercury exposure in developing children may result in poor performance on tests of attention, fine-motor function, language, visual-spatial abilities, and verbal memory (NRC 2000).

Recently, several federal government agencies presented data indicating that women of childbearing age who consume fish may be potentially overexposed to mercury. In 1999, the U.S. Congress tasked the National Academy of Science (NAS), National Research Council (NRC) to develop appropriate exposure limits for methylmercury. The NAS concludes that children of women who consume large amounts of fish and seafood during pregnancy might be at special risk for neurological problems. The NRC report estimated that each year about 7% of women in the U.S. exceed the EPA recommended limit for methylmercury exposure (tolerable daily intake = 0.10 microgram per kilogram per day). If that estimate is extrapolated to newborn infants an estimated 60,000 babies born each year are at risk for toxic exposure. Potential effects might result in neurological problems that could lead to learning difficulties due to exposure to mercury in utero. The NRC concluded that the EPA's mercury guideline is justifiable, it went further to say that a pregnant women's consumption of fish and seafood may adversely affect their fetus. The chair of the NRC committee commented that "trends in methylmercury exposure, including regional differences, should be analyzed, as should subpopulations whose diets are high in fish and seafood. And we need to better understand how this chemical affects brain development in fetuses and children."

The Center for Disease Control and Prevention (CDC) analyzed preliminary estimates of blood and hair mercury levels from the 1999 National Health and Nutrition Examination Survey, and compared them with findings from the NRC report. Estimates from this analysis show that approximately 10% of women have mercury levels within one tenth of potentially hazardous levels. This indicates a narrow margin of safety for some women, and supports efforts to reduce methylmercury exposure.

When mercury levels in edible fish tissues exceed state, federal, or international screening levels (range = 0.30 – 1.0 mg/kg), local health organizations typically issue fish consumption advisories. In the U.S.A., fish consumption advisories vary from state to state, and include warnings for single species or entire fish communities. Some states issue blanket warnings covering all waters within their borders, others issue warnings for impaired waters only. Based on the NAS review, CDC analysis, and Washington Department of Health’s (DOH) review and evaluation of methylmercury, DOH developed consumption guidelines for individuals who eat fish caught at Lake Whatcom. The guidelines are based on the DOH tolerable daily intake (TDI) of 0.08 micrograms per kilogram per day, which is 20% lower, and thus more protective, than EPA’s guidelines based on a TDI of 0.10 micrograms per kilogram per day. In addition, DOH conducted a preliminary fish consumption survey for Lake Whatcom to assess the local population’s potential exposure to mercury (Patrick *in review*).

Based on this information, Whatcom County Health and Human Services (WCHHS), in conjunction with DOH, issued a fish consumption advisory for Lake Whatcom on April 12, 2001. Pregnant women, women of childbearing age, and parents or guardians of developing children should pay particular attention to the advisory, which is briefly summarized below. People are advised to limit consumption of smallmouth bass and yellow perch caught in Lake Whatcom due to unhealthy levels of mercury in the fish.

WCHHS advises that:

- Women of childbearing age and children under age six should not eat smallmouth bass caught in Lake Whatcom

- Women of childbearing age and children under age six should also limit the amount of Lake Whatcom yellow perch they eat. Recommended weekly limits for yellow perch are based on bodyweight. More information about consumption limits for yellow perch, based on a person’s bodyweight, is available from WCHHS.

The long-term effects of the advisory on the fisheries of Lake Whatcom are unclear. In his preliminary study, Patrick (*in review*) reported that nearly one-half of adult anglers interviewed would not follow the recommendations of an advisory issued for Lake Whatcom. Similarly, MacDonald and Boyle (1997) found that less than 25% of all anglers who knew about Maine's 1994 statewide fish consumption advisory changed their fishing behavior. Furthermore, over half of the at-risk female anglers from Maine may have been in noncompliance with the guidelines (MacDonald and Boyle 1997). Still, increased concern over the hazards of eating mercury-laden fish may contribute to a decline in intake of caught fish irrespective of the actual risk to consumers (Reinert et al. 1996; Chan et al. 1999). To learn more about the Lake Whatcom fish advisory for mercury, contact Whatcom County Health and Human Services at (360) 676-6724, or check out the DOH "Fish Facts for Healthy Nutrition" website at www.doh.wa.gov/fish. Additional information is available on the U.S. FDA food safety website at www.cfsan.fda.gov or EPA's mercury website at www.epa.gov/mercury/index.html.

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