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Summary of Total Mercury Concentrations in Fillets of Selected Sport Fishes Collected during 2000–2003 from Lake Natoma, Sacramento County, California

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In cooperation with the Bureau of Reclamation and the California Department of Water Resources

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Data Series 103

U.S. Department of the Interior
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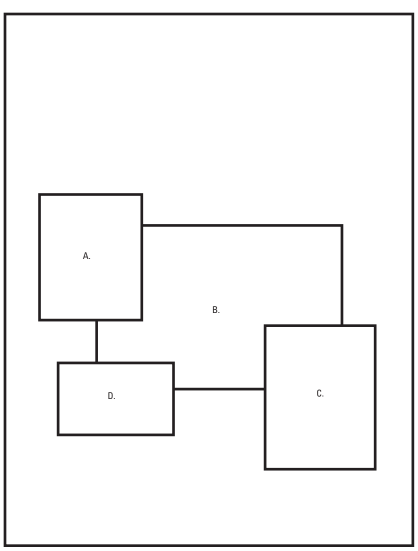

Cover Photographs

A. Darell G. Slotton holding a channel catfish from Lake Natoma, July 2003. (*Photograph by Shaun M. Ayers, University of California at Davis*)
B. Willow Creek arm of Lake Natoma, June 2003. (*Photograph by Charles N. Alpers, U.S. Geological Survey*)
C. Largemouth bass from Davis Creek Reservoir, Yolo County, California, June 2004. (*Photograph by Darell G. Slotton, University of California at Davis*)
D. Bluegill from Camp Far West Reservoir, California, August 2003. (*Photograph by Amy A. Story, U.S. Geological Survey*)

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Conversion Factors, Abbreviations, and Acronyms

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter (m^3)
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
kilometer (km)	0.6214	mile (mi)
milligram (mg)	0.0000353	ounce (oz)
millimeter (mm)	0.03937	inch (in.)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Abbreviations

Hg	mercury
ng	nanogram
µg/g	microgram per gram (equivalent to parts per million)
µg Hg/g	microgram of mercury per gram
>	greater than
≤	less than or equal to
%	percent

Acronyms

CDFG	California Department of Fish and Game
CERC	Columbia Environmental Research Center
CRM	Certified Reference Material
FDA	Food and Drug Administration
LOQ	limit of quantitation
MDL	method detection limit
MQL	method quantitation limit
NIST	National Institute of Standards and Technology
NRCC	National Research Council Canada
OEHHA	Office of Environmental Health Hazard Assessment (State of California)
RPD	Relative Percent Difference
RSD	relative standard deviation
SD	standard deviation
UCD	University of California, Davis
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

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By Michael K. Saiki[1], Darell G. Slotton[2], Thomas W. May[3], Shaun M. Ayers[2], and Charles N. Alpers[4]

Abstract

This report summarizes results of total mercury measurements in skinless fillets of sport fishes collected during August 2000, September–October 2002, and July 2003 from Lake Natoma, a small (8,760 acre-feet) afterbay for Folsom Dam on the lower American River. The primary objective of the study was to determine if mercury concentrations in fillets approached or exceeded guidelines for human consumption. The Food and Drug Administration (FDA) human-health action level for methylmercury in commercially caught fish is 1.0 µg/g (microgram per gram); the U.S. Environmental Protection Agency (USEPA) human-health criterion for methylmercury residue in fish tissue is 0.30 µg/g. Wet weight concentrations of total mercury in skinless fillets were as high as 0.19 µg/g in bluegill (*Lepomis macrochirus*), 0.39 µg/g in redear sunfish (*L. microlophus*), 1.02 µg/g in largemouth bass (*Micropterus salmoides*), and 1.89 µg/g in channel catfish (*Ictalurus punctatus*). Maximum concentrations of mercury in other fish species varied from 0.10 µg/g in rainbow trout (*Oncorhynchus mykiss*) to 0.56 µg/g in white catfish (*Ameiurus catus*). Altogether, 1 of 86 largemouth bass and 11 of 11 channel catfish exceeded the FDA human-health action level. In addition, 1 of 20 redear sunfish, 26 of 86 largemouth bass, 2 of 3 spotted bass (*M. punctulatus*), 1 of 1 brown bullhead (*A. nebulosus*), and 1 of 1 white catfish exceeded the USEPA human-health criterion. These results indicate that some fish species inhabiting Lake Natoma contain undesirably high concentrations of mercury in their skinless fillets.

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Introduction

Background

Mercury contamination from historic gold mining operations is widespread in many rivers, lakes, and reservoirs on the western slopes of the Sierra Nevada (Alpers and Hunerlach, 2000). Miners used mercury (quicksilver) to recover gold from hardrock (lode) mines and from placer (alluvial) mines, where hydraulic, drift, and dredging methods were used. At hydraulic mining operations, placer ores were eroded with monitors (water cannons), and the resulting slurry was directed through sluices and drainage tunnels where gold particles were combined with liquid mercury to form gold-mercury amalgam. Bowie (1905) estimated that 10–30% of the mercury used in this process was lost each season, resulting in highly contaminated sediments downstream from mines. Annual loss of mercury from a typical sluice was likely several hundred kilograms during the operating season (Alpers and Hunerlach, 2000). Churchill (2000) estimated that between 1848 and 1968, about 4.5 million kg of mercury was lost throughout California as a result of placer gold mining operations, including hydraulic, drift, and dredging activities. Operations at hardrock mines caused an additional 1.3 million kg (estimated) of mercury to be lost to the environment during the same period (Churchill, 2000).

A significant event in the history of gold mining in California was the discovery of placer gold by John Marshall in January 1848 in the South Fork American River near Coloma. Extensive hydraulic mining of placer gold deposits took place in the American River watershed between the 1850s and 1884, with more limited hydraulic mining continuing until the 1930s. Hardrock mining of lode gold deposits in the American River watershed occurred from the 1880s until 1942. Dredging of placer gold deposits in the lower American River watershed took place from 1898 to 1956, the year that Folsom Dam and Nimbus Dam (*fig. 1*) were completed. Nimbus Dam forms Lake Natoma, the 8,760-acre-ft reservoir that is an afterbay to Folsom Lake, a large reservoir with total capacity of 975,000 acre-ft. Cobble piles, the stacked waste from large-scale gold dredges, are conspicuous features on both the north and south shores of Lake Natoma. Such areas have elevated concentrations of mercury, and it is fairly easy to find elemental mercury and gold-mercury amalgam in the bed sediments of tributary creeks to Lake Natoma that traverse the mine waste piles.

Figure 1. General locations of sampling sites in the study area, Lake Natoma, California.

Purpose and Scope

This report presents data on fish tissue that were gathered as part of a broader investigation of mercury dynamics and bioaccumulation in the lower American River watershed, specifically in areas near Folsom, California, that were historically subjected to gold dredging activities and are now partially urbanized. One specific objective of the investigation was to determine if total mercury concentrations in skinless fillets of selected sport fishes approach or exceed criteria for human health concerns set by the Food and Drug Administration (FDA) and the U.S. Environmental Protection Agency (USEPA). The FDA action level for methylmercury in fish is 1.0 µg/g wet weight, which is used to regulate the sale of commercially caught fish for human consumption (U.S. Food and Drug Administration, 1994). The USEPA recently established a maximum methylmercury concentration of 0.30 µg/g wet weight as the fish tissue residue criterion for protecting human health (U.S. Environmental Protection Agency, 2001). Any human-health protection offered by the FDA action level and the USEPA residue criterion may be compromised if fish consumption rates or meal frequencies exceed assumed levels.

Acknowledgments

We thank Walter Beers, Michael J. Harris, and Janna Herren (California Department of Fish and Game, CDFG) and Rick Humphreys (California State Water Resources Control Board) for helping to initiate this study by collecting fish during 2000. We also thank Melissa Farhina, Paul Gerrity, and Barbara Martin (U.S. Geological Survey, USGS) and Michael Healy (CDFG) for assisting with fish collections during 2002. Melissa Farhina, Paul Gerrity, Barbara Martin, Jason May, Francine Mejia, and Amy Story (USGS) assisted by processing fish samples or entering data, or providing other technical support. William Brumbaugh (USGS) helped to determine the concentrations of mercury and moisture in fish samples. We especially thank the U.S. Bureau of Reclamation for funding this work through Interagency Agreement No. 5-07-20-X0338, Work Request No. 45 with the USGS, Water Resources Discipline (California District). In addition, we thank the California Department of Water Resources for funding a portion of this work through a grant from its Watershed Program. Matching funds from the USGS Cooperative Water Program also contributed to this study.

Study Area

Lake Natoma (*fig. 1*) is managed by the U.S. Bureau of Reclamation and the California Department of Parks and Recreation for multiple uses that include fishing and other water-based recreation. Lake Natoma is located about 19 km east of Sacramento, near the city of Folsom. Water in Lake Natoma originates primarily from upstream releases at Folsom Dam, with small inflows from Willow and Alder Creeks (*fig. 1*) and other sources.

Fish were collected from Lake Natoma on the American River during August 2000, September–October 2002, and July 2003 from as many as six general locations (roughly from upstream to downstream): (1) the Negro Bar vicinity, (2) Natomas Slough, (3) the mouth of Willow Creek, (4) the Mississippi Bar vicinity, (5) the mouth of Alder Creek, and (6) the Nimbus Dam vicinity (*fig. 1*).

Methods

During August 2000, staff members of the California Department of Fish and Game (CDFG), with assistance from the State Water Resources Control Board, used a boat-mounted electroshocker to collect largemouth bass (*Micropterus salmoides*) and channel catfish (*Ictalurus punctatus*) from Lake Natoma. In September–October 2002, scientists from the U.S. Geological Survey (USGS) used a boat-mounted electroshocker to obtain bluegill (*Lepomis macrochirus*), largemouth bass, green sunfish (*L. cyanellus*), redear sunfish (*L. microlophus*), smallmouth bass (*M. dolomieu*), spotted bass (*M. punctulatus*), white catfish (*Ameiurus catus*), black bullhead (*A. melas*), brown bullhead (*A. nebulosus*), and rainbow trout (*Oncorhynchus mykiss*). In July 2003, scientists from the University of California, Davis (UCD) used a boat-mounted electroshocker and gill nets to capture largemouth bass and channel catfish.

Both catchable and subcatchable sizes of fish were collected as part of this study. Although the designation of a minimum size for catchable fish is often arbitrary, this study adopted either the minimum legal size limit established by the State of California (California Department of Fish and Game, 2002) or the minimum sizes for human consumption suggested by various authors. In Lake Natoma, the largemouth bass fishery is regulated by a minimum size restriction of 305 mm, whereas other fishes have no legal size restrictions (California Department of Fish and Game, 2002). However, Bennett (1971) indicated that anglers generally keep fish of the following minimum sizes: for bluegill and other sunfishes, 152 mm; for bullheads (close relatives of the white catfish), 178 mm; and for channel catfish, 305 mm. According to Leitritz (1970, cited by Edmondson, 2002), a “harvestable trout” is a fish between 178 and 254 mm in length or about 182 g in weight.

Immediately after capture, fish retained for mercury determinations were measured for length, then placed into clean plastic ziplock bags (along with unique code identifiers) and chilled on wet ice. Within 24 hours, fish were weighed, then dissected and skinned to yield skinless fillets from both sides of each fish. The two fillets were weighed and wrapped in clean plastic sheets, double-bagged in clean plastic ziplock bags, and frozen (–10°C). The remaining carcass of each fish was then archived by wrapping and bagging in plastic before freezing. Frozen fish fillets collected during 2002 were stored for 2–3 months in a chest freezer before being shipped overnight with dry ice to the USGS Columbia Environmental Research Center (CERC). At CERC, samples were stored an additional 2–3 months before analysis.

Methods used to homogenize fillets varied according to the biomass of the sample. Large fillets (>500 g) were processed using a Hobart band saw, whereas intermediate-sized fillets (100–500 g) were homogenized using a blender and an attached meat processor unit. Small fillets (20–100 g) were minced with a titanium knife. After homogenization, the samples were lyophilized using a Virtis Genesis 35EL freeze dryer to determine moisture content. Once dried, samples weighing more than 3 g were further homogenized with a Bamix mixer/blender, whereas smaller samples were ground mechanically with a glass rod. Dried samples were stored in glass vials in a desiccator.

Moisture content and total mercury concentration in fillets were determined either at CERC in Columbia, Missouri (fish samples collected in 2002), or at the UCD laboratory in Davis, California (fish samples collected in 2000 and 2003). About 95–99% of the mercury in fish muscle tissues is methylmercury, approximately the same as total mercury; therefore, analyzing for either gives similar results (Grieb and others, 1990; Bloom, 1992; Wiener and Spry, 1996). Total mercury was measured rather than methylmercury because of cost considerations.

At the CERC laboratory, total mercury was determined using a direct mercury analyzer. A dried fish sample (50–100 milligrams) was first combusted in a stream of oxygen. Then the volatilized sample was trapped by amalgamation on a gold substrate and thermally desorbed for quantification by atomic absorption spectrophotometry. A Milestone DMA-80 analyzer equipped with an automated sample carousel was used.

For quality control purposes, the samples of fish fillets analyzed by CERC were placed into 10 groups or blocks for determining mercury concentrations. Quality control procedures included analysis of blanks, replicate samples, pre-combustion spikes, and tissue reference materials. An independent calibration verification standard was analyzed at the beginning and end of each instrumental run to confirm calibration status of the DMA-80 system. Percentage errors varied from –6.3 to 7.8. Results from analyzing three reference fish tissues—CERC whole-body striped bass, 2.29 ± 0.05 µg Hg/g dry weight; National Institute of Standards and Technology (NIST) Research Material 50 albacore tuna fillet, 0.92 ± 0.02 µg Hg/g dry weight; and National Research Council Canada (NRCC) DORM-2 Certified Reference Material (CRM) dogfish muscle, 4.77 ± 0.09 µg Hg/g dry weight—were within certified or recommended ranges. Method precision, determined from triplicate analysis of 18 fish tissue samples, did not exceed 5.8% relative standard deviation [%RSD = standard deviation/(mean × 100)]; the method precision of most triplicate analysis sets was less than 3.0% RSD. Recovery of methylmercury from pre-combustion tissue spikes of methylmercury chloride varied from 102% to 111% (mean, 108%) compared to a control range of 80% to 120%.

The method detection limit (MDL) of an analytical procedure is defined as “the minimum concentration that can be determined with 99% confidence that the true concentration is greater than zero” (U.S. Environmental Protection Agency, 1984, 1997). The CERC laboratory computes its MDL using the formula $MDL = 3(SD_b^2 + SD_s^2)^{1/2}$, where SD_b is the standard deviation of a blank (N = 3) and SD_s is the standard deviation of a low-concentration sample or spiked sample (N = 3), where N is the number of samples. The method quantitation limit (MQL) at the CERC laboratory is computed as 3.3 times the MDL.

Blank equivalent concentrations at the CERC laboratory were consistently less than the MDL (0.0007–0.0059 µg Hg/g dry weight), whereas the MQL values were 0.0023–0.0194 µg Hg/g dry weight. The instrument detection limit was 0.066 ng Hg. In all cases, these quality control results were within acceptable limits as specified by the CERC.

Fish fillets processed by the UCD laboratory were analyzed as fresh (wet) or dry. Fish collected in 2000 were analyzed as dried material because “freezer burn” had occurred in some samples after being stored frozen for more than a year prior to transfer to UCD. Fish collected in 2003 were analyzed as fresh material within 24 hours of collection and, in the case of channel catfish, as both fresh and dried material. Moisture percentage in the 2003 samples was determined by weighing before and after drying at 55°C, enabling dry results to be converted to a fresh weight basis. For samples collected in 2000 that sustained varied freezer desiccation, dry weight concentrations were converted to wet weight concentrations by using the relationship between size and moisture percentage derived from the same species in the samples collected by the USGS in 2002. The UCD fish samples were ground to a fine powder using a modified coffee grinder. Both fresh and dried samples were digested under pressure at 90°C in a mixture of concentrated nitric and sulfuric acids with potassium permanganate, then analyzed for total mercury by standard cold vapor atomic absorption spectrophotometry using a Perkin Elmer Flow-Injection Mercury System with AS-90 autosampler. Sufficient tissue biomass from each sample was archived (frozen) to allow for reanalysis.

The UCD mercury analyses were done with thorough quality control similar to that used by CERC. Quality control procedures for each analytical run included analysis of blanks, seven aqueous mercury standards, laboratory replicate samples, pre-digestion matrix spikes, matrix spike duplicates, and tissue reference materials with certified concentrations of Hg. During instrumental runs, additional quality control procedures consisted of independent aqueous-based calibration verification checks using a standard different from the one used to prepare the basic aqueous calibration series. Recoveries varied from 102.5% to 104.9% compared to a control range of 75% to 125%. Additionally, continuous within-run calibration was tested by repeatedly analyzing tissue-based samples. Recoveries from the within-run calibrations varied from 98.2% to 104.7% compared to a control range of 75% to 125%. Results from multiple analyses of four certified reference tissues—NIST Research Material 2976 CRM mussel tissue, 0.061 ± 0.004 µg Hg/g dry weight; NRCC TORT-2 CRM lobster tissue, 0.27 ± 0.02 µg Hg/g dry weight; NRCC DOLT-3 CRM dogfish liver, 3.37 ± 0.14 µg Hg/g dry weight; and NRCC DORM-2 CRM dogfish muscle, 4.64 ± 0.26 µg Hg/g dry weight—were within certified or recommended means and ranges. Method precision, determined by analyzing 20 duplicate pairs of fish tissue samples, varied from 0.1 Relative Percent Difference {RPD = $(v_1 - v_2)/[(v_1 + v_2)/2]$, where v_1 and v_2 are values being compared} to 5.4 RPD and averaged 2.6 RPD. Recovery of mercury from tissues spiked prior to digestion varied from 86% to 98% (mean, 91%).

At the UCD laboratory, the MDL is computed using a biological tissue sample with very low initial mercury content spiked with 5 times the estimated MDL concentration. The spiked solution is tested seven or more times and a standard deviation (SD) of the data set is determined. The MDL is calculated according to the formula: MDL = Student's t value × SD. The limit of quantitation (LOQ) is defined as the minimum concentration that can be determined using a defined probability value ($P \leq 0.01$). The LOQ for the UCD laboratory is set at a value of ten times the SD of a blank solution (Keith, 1992).

Blank equivalent concentrations were consistently less than the MDL (0.0001 to 0.0022 µg Hg/g dry weight), whereas the LOQ values were 0.0019 to 0.0056 µg Hg/g dry weight. The instrument detection limit was 0.004 µg Hg/g dry weight. Overall, these quality control results were well within acceptable limits as specified by the UCD laboratory.

Mercury measurements by CERC and UCD were compared by using 20 samples of dried fish tissue spanning the full range of mercury concentrations encountered during this study. Dried splits of 10 channel catfish samples that were initially collected and processed by UCD were sent to CERC, and dried splits of 10 largemouth bass samples initially collected by USGS and processed by CERC were sent to UCD. Results of the intercomparison were excellent. The RPD was less than 8 for all 20 samples and was less than 5 for 16 of the 20 samples. Detailed results of the laboratory intercomparison, including a correlation plot of the results and tabulated data, are given in *Appendix figure A1* and *Appendix table A2*.

Computerized databases were created as Excel spreadsheets. Raw data were summarized by using SAS software and Lotus Freelance Graphics for Windows. Many variables measured during this study were not normally distributed. Even subjecting these variables to standard transformations (angular transformation for moisture content; logarithmic transformation for length, weight, and mercury concentration) did not always normalize the data. Consequently, with two exceptions, nonparametric techniques (for example, Spearman rank correlation) were used to describe relations among variables such as total length, weight, moisture content of fillet, and mercury concentration of fillet. The exceptions were computations of predictive equations for length-moisture relationships and length-mercury relationships. Unless specified otherwise, the level of significance for all statistical tests was $P = 0.05$.

Results

A total of 228 fish-fillet samples were analyzed for moisture content and mercury concentrations during this study (*table 1*). Moisture content in various species ranged from 75.8% to 83.6%; total mercury concentrations ranged from 0.02 µg/g to 1.89 µg/g wet weight (henceforth, all refer-

Table 1. Vital statistics for fish species collected from Lake Natoma during 2000 through 2003, and moisture content and total mercury concentrations in their fillets.

[Except for moisture, values are geometric means (ranges in parentheses). For moisture, values are back-transformed angular means (ranges in parentheses). g, gram; mm, millimeter; N, number of samples; %, percent, µg/g, microgram per gram (equivalent to parts per million)]

Fish species	Year	N	Total length, in mm	Weight, in g	Moisture, in %	Mercury, in µg/g wet weight
Green sunfish	2002	4	118 (90–151)	30.8 (12.5–75.5)	81.4 (80.8–81.8)	0.11 (0.06–0.20)
Bluegill	2002	97	116 (72–174)	25.2 (5.0–91.5)	81.8 (80.7–83.2)	0.08 (0.04–0.19)
Redear sunfish	2002	20	127 (80–187)	33.7 (7.5–117.0)	80.8 (80.1–81.8)	0.07 (0.03–0.39)
Smallmouth bass	2002	2	159 (145–174)	46.0 (35.0–60.5)	79.8 (79.0–80.6)	0.13 (0.11–0.16)
Spotted bass	2002	3	228 (118–335)	141.9 (15.5–476.0)	79.3 (77.1–81.9)	0.27 (0.10–0.49)
Largemouth bass	2000	21	251 (128–480)	230.3 (24.0–1655.0)	79.2 (77.5–81.0)	0.36 (0.14–1.02)
Largemouth bass	2002	61	212 (88–490)	126.3 (7.0–1967.5)	79.7 (77.6–83.0)	0.21 (0.06–0.86)
Largemouth bass	2003	4	225 (174–255)	167.4 (68–255)	79.5 (79.2–80.2)	0.30 (0.25–0.36)
White catfish	2002	1	249	229.5	81.8	0.56
Black bullhead	2002	1	214	134.0	83.6	0.15
Brown bullhead	2002	1	317	554.0	82.1	0.35
Channel catfish	2000	1	540	1867.0	77.9	1.02
Channel catfish	2003	10	641 (505–750)	3,366.5 (1270.0–5200.0)	77.9 (76.3–79.6)	1.50 (1.10–1.89)
Rainbow trout	2002	2	239 (177–324)	145.6 (48.0–441.5)	78.9 (75.8–81.9)	0.04 (0.02–0.10)

ences to mercury concentrations will refer to total mercury reported in terms of wet weight unless specified otherwise). The species with highest maximum concentrations of mercury included brown bullhead (0.35 µg/g), redear sunfish (0.39 µg/g), spotted bass (0.49 µg/g), white catfish (0.56 µg/g), largemouth bass (1.02 µg/g), and channel catfish (1.88 µg/g).

Sufficient sample sizes were available for bluegill, redear sunfish, largemouth bass, and channel catfish to determine if moisture content or mercury concentrations in fillets varied with length and weight. Moisture content was inversely correlated with length and weight in redear sunfish and largemouth bass, whereas no correlations were observed for these characteristics in bluegill and channel catfish (*table 2*). Mercury concentrations were directly correlated with length and weight for bluegill and largemouth bass, but not for redear sunfish and channel catfish. Although the Spearman rank correlation coefficients for channel catfish were relatively high (0.487 for the mercury-length relation and 0.573 for the mercury-weight relation), the P values for these relations were >0.05.

One of 86 largemouth bass and 11 of 11 channel catfish from Lake Natoma exceeded the FDA action level of 1.0 µg Hg/g (*figs. 2–6*). In addition, 1 of 20 redear sunfish, 26 of 86 largemouth bass, 1 of 1 brown bullhead, 2 of 3 spotted bass, and 1 of 1 white catfish exceeded the U.S. Environmental Protection Agency fish tissue residue criterion of 0.30 µg Hg/g. These results confirm that some fish species inhabiting Lake Natoma contain undesirably high concentrations of mercury in their skinless fillets.

Table 2. Spearman rank correlation coefficients for total length and weight of bluegill, redear sunfish, largemouth bass, and channel catfish, and moisture content and total mercury concentrations in their fillets.

[N, number of samples; P, probability value; ≤, less than or equal to]

Common name	N		Correlation coefficients: Moisture	Correlation coefficients: Mercury concentration
Bluegill	97	Total length	–0.168	0.232*
		Weight	–0.181	0.236*
Redear sunfish	20	Total length	–0.630**	–0.155
		Weight	–0.595**	–0.190
Largemouth bass	86	Total length	–0.934***	0.889***
		Weight	–0.933***	0.898***
Channel catfish	11	Total length	–0.132	0.487
		Weight	–0.227	0.573

*P ≤ 0.05   ** P ≤ 0.01   ***P ≤ 0.001

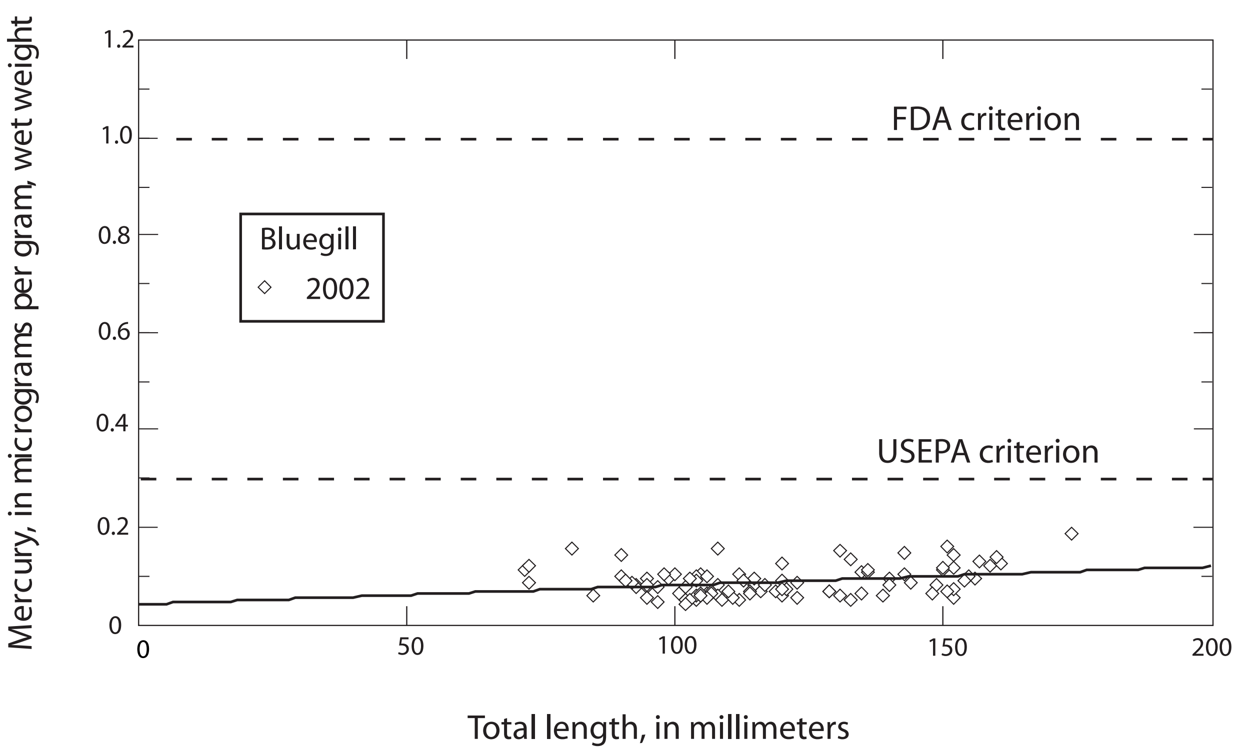

Figure 2. Total length (TL) and total mercury (Hg) concentrations in skinless fillets of 97 bluegill taken from Lake Natoma, 2002. The relation between TL and Hg was described by a "best fit" linear equation as follows: $Hg = 0.0415 + 0.000388 \times TL$, $R^2=0.0874$. FDA, Food and Drug Administration; USEPA, U.S. Environmental Protection Agency.

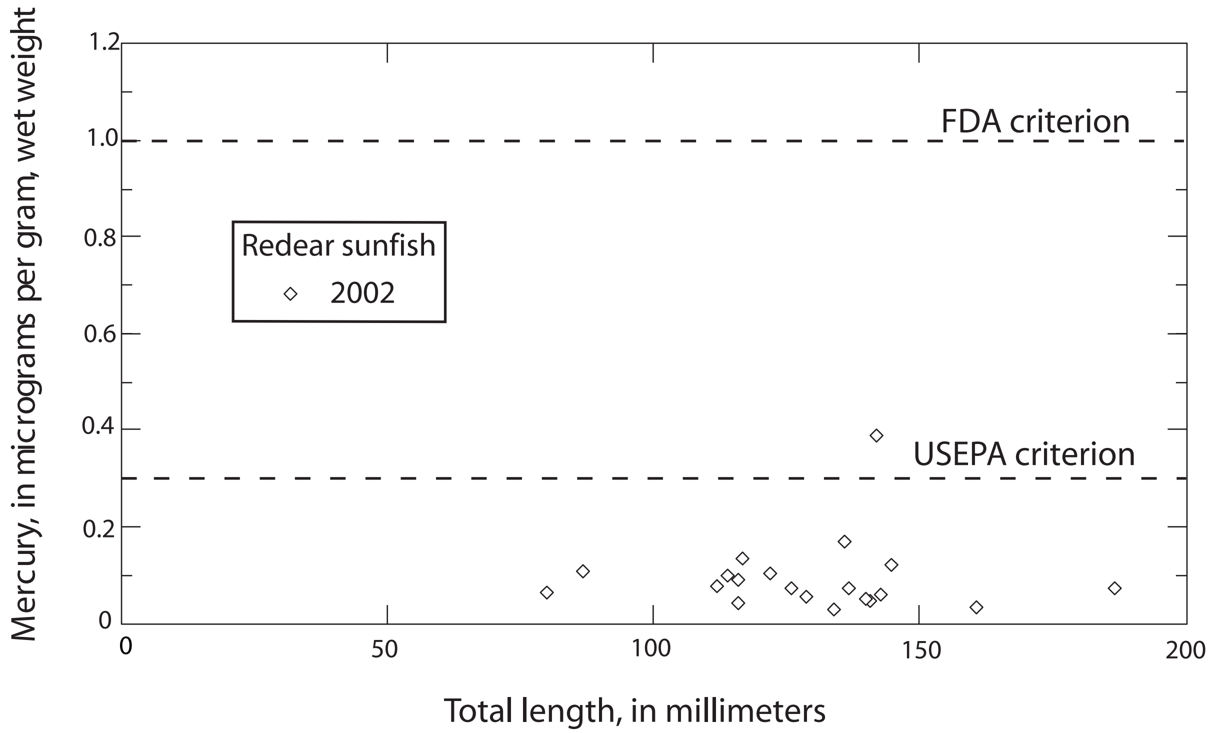

Figure 3. Total length and total mercury (Hg) concentrations in skinless fillets of 20 redear sunfish taken from Lake Natoma, 2002. The relation between total length and Hg was not statistically significant. FDA, Food and Drug Administration; USEPA, U.S. Environmental Protection Agency.

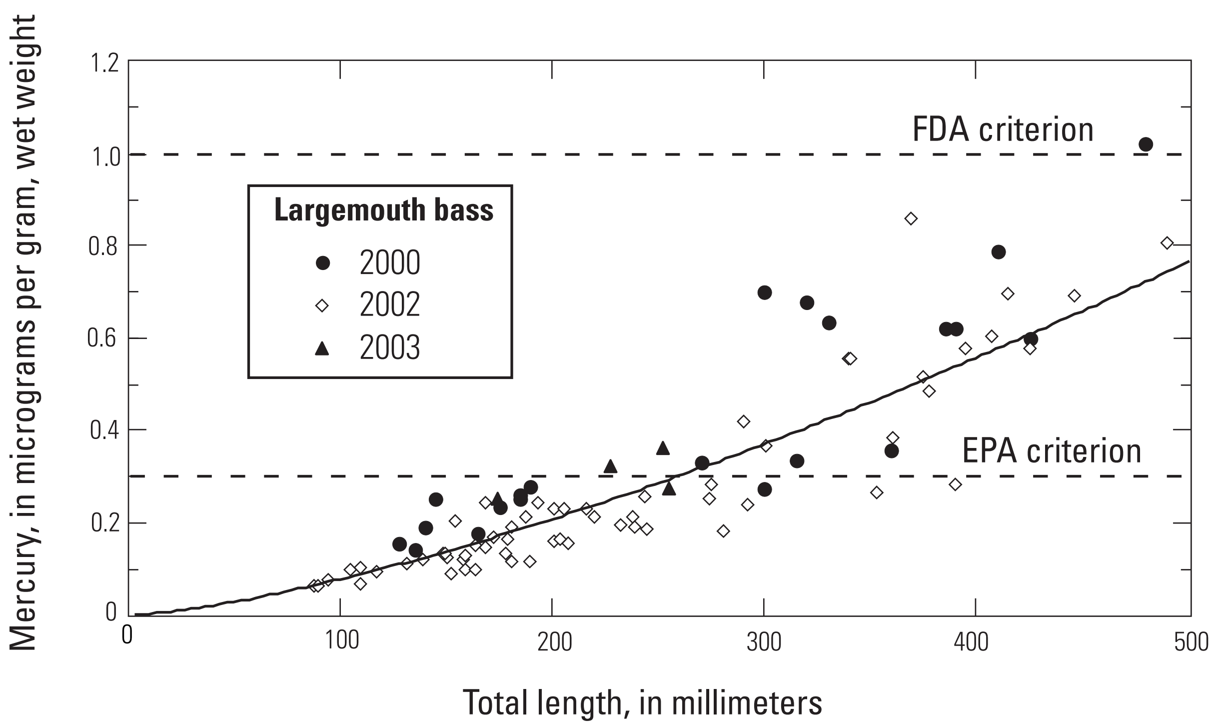

Figure 4. Total length (TL) and total mercury (Hg) concentrations in skinless fillets of 86 largemouth bass taken from Lake Natoma, 2000, 2002, and 2003. The relation between TL and Hg was described by a "best fit" power-curve equation as follows: $Hg = 0.000112 \times TL^{1.42}$, $R^2 = 0.819$. FDA, Food and Drug Administration; USEPA, U.S. Environmental Protection Agency.

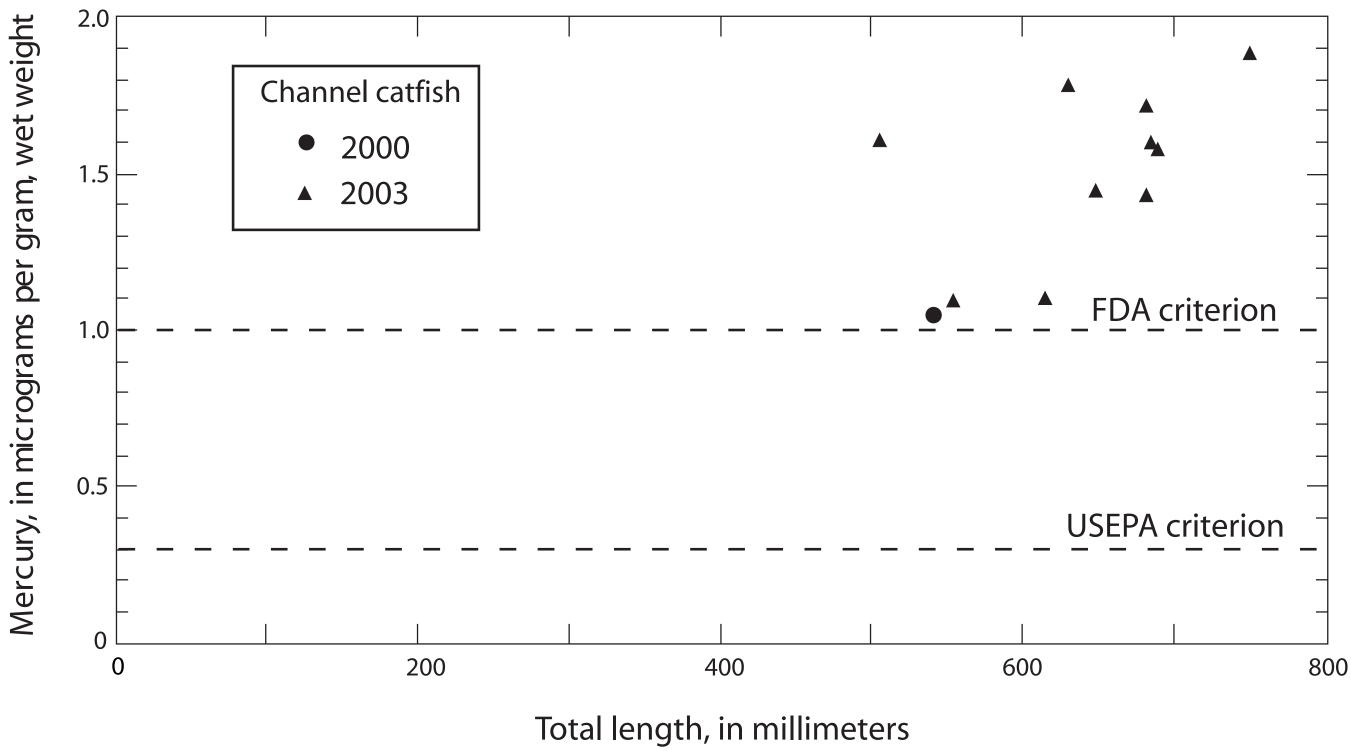

Figure 5. Total length and total mercury (Hg) concentrations in skinless fillets of 11 channel catfish taken from Lake Natoma, 2000 and 2003. The relation between total length and Hg was not statistically significant. FDA, Food and Drug Administration; USEPA, U.S. Environmental Protection Agency.

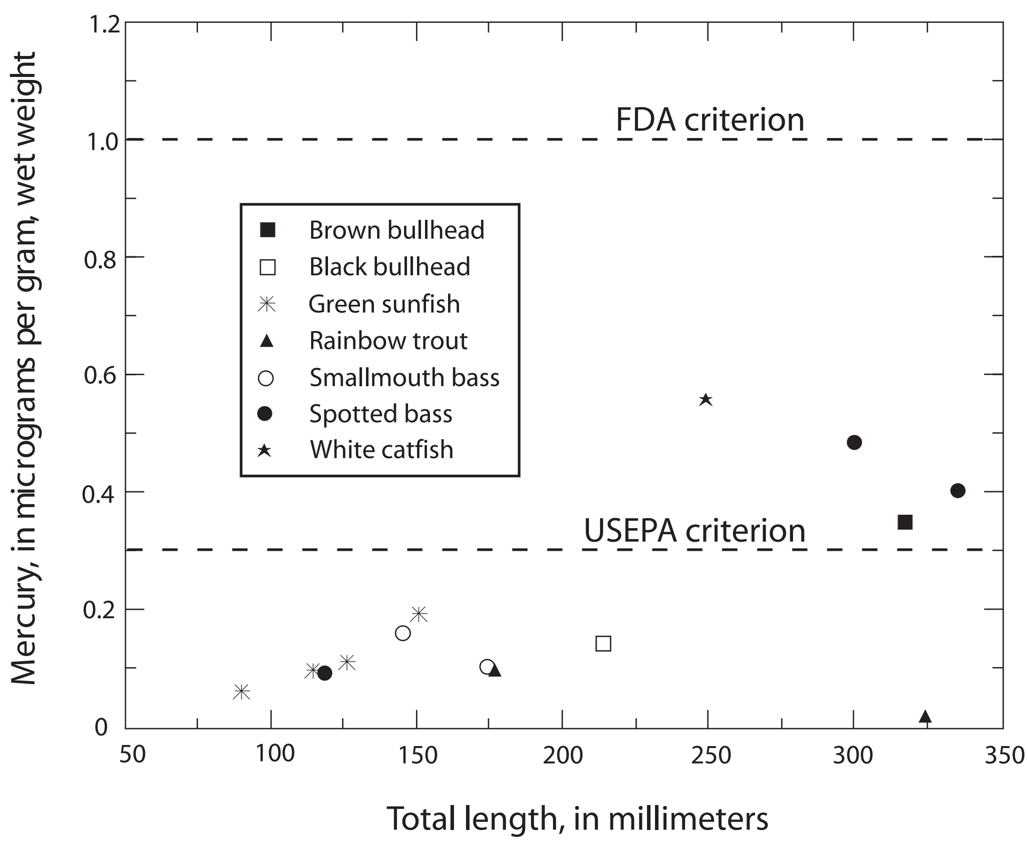

Figure 6. Total length and total mercury (Hg) concentrations in skinless fillets of miscellaneous fish species taken from Lake Natoma, 2002. FDA, Food and Drug Administration; USEPA, U.S. Environmental Protection Agency.

Discussion

A number of field investigations involving a variety of fish species indicate that mercury concentrations typically increase with size and age of fish (Lange and others, 1993, 1994; Wiener and Spry, 1996). In Lake Natoma, the mercury concentrations in fillets of bluegill and largemouth bass, but not redear sunfish and channel catfish, increased as fish increased in total length and weight (*table 2*).

Although fish are exposed to mercury and methylmercury from both water (Olsen and others, 1973) and food (Phillips and Buhler, 1978; Phillips and Gregory, 1979; Turner and Swick, 1983; Rogers and others, 1987), bioaccumulation of methylmercury through the food chain plays a more important role in determining fish methylmercury body burdens (Spry and Wiener, 1991; Watras and Bloom, 1992; Wiener and Spry, 1996). Fish assimilate 15–20% of the methylmercury present in their forage (Phillips and Gregory 1979) and the rate of methylmercury eliminations is slow relative to the rate of uptake (Laarman and others, 1976; McKim and others,1976; Weiner and Spry, 1996), resulting in a net increase in mercury body burdens. MacCrimmon and others (1983) observed increased rates of mercury accumulation in lake trout (*Salvelinus namaycush*) when the young switched from a diet of invertebrates to forage fish. Wren and MacCrimmon (1986) also observed that piscivorous fish had higher concentrations of mercury than prey fish of comparable age.

In Lake Natoma, top-level predators such as spotted bass, largemouth bass, white catfish, and channel catfish had higher concentrations of mercury than did lower trophic level insectivores or planktivores such as bluegill, redear sunfish, and rainbow trout (*table 1*). Moreover, smaller bass, which generally feed on zooplankton and small insects, contained lower concentrations of mercury than did larger bass that feed primarily on large-bodied invertebrates (for example, crayfish) and forage fish (Moyle, 2002). Although size-related increases in mercury body burdens were anticipated in channel catfish, our failure to detect significant correlations may have been due to small sample size (only 11 individuals were captured during our study). Mercury concentrations were weakly correlated with size of bluegill and not correlated with size of redear sunfish, possibly because juveniles and adults of these species tend to forage on similar foods (zooplankton, immature aquatic insects, and other benthic invertebrates, although mollusks are usually less conspicuous in diets of bluegill than redear sunfish; Moyle, 2002). Unlike adult largemouth bass and channel catfish, bluegill and redear sunfish are seldom piscivorous.

In response to data generated by this study and related investigations, the California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (OEHHA) issued a draft fish-consumption advisory report that offered guidelines for human consumption of fish (Klasing and Brodberg, 2004). The proposed guidelines call for "women of childbearing age and children age 17 and younger [to] eat no channel catfish from Lake Natoma and the lower American River. White catfish, bass, pikeminnow, or sucker should be consumed no more [than] one meal per month from these water bodies. Additionally, these individuals should eat no more than four meals per month of bluegill or sunfish species." Moreover, "[f]or women beyond their childbearing years and men, OEHHA recommends that channel catfish and bass be consumed no more than once per month from Lake Natoma and the lower American River. Additionally, white catfish, pikeminnow, and suckers should be consumed no more than four meals per month." OEHHA also recommends that this subpopulation eat no more than 12 meals per month of bluegill or other sunfish species. The final version of the OEHHA fish-consumption advisory was approved by the State of California in July 2003 and is scheduled for publication in September 2004 (*http://www.oehha.ca.gov/fish/so_cal/fnatoma.html*).

Summary

Mercury contamination from historic gold mining operations is widespread in many rivers, lakes, and reservoirs on the western slopes of the Sierra Nevada. This has lead to concern for the health of those who consume fish from these bodies of water. Fish were collected from Lake Natoma on the American River during August 2000, September–October 2002, and July 2003 from as many as six general locations. Moisture content and total mercury concentration in fillets were determined at two separate laboratories.

One of 86 largemouth bass and 11 of 11 channel catfish from Lake Natoma exceeded the FDA action level of 1.0 μg Hg/g (microgram of mercury per gram). In addition, 1 of 20 redear sunfish, 26 of 86 largemouth bass, 1 of 1 brown bullhead, 2 of 3 spotted bass, and 1 of 1 white catfish exceeded the U.S. Environmental Protection Agency fish tissue residue criterion of 0.30 μg Hg/g. These results confirm that some fish species inhabiting Lake Natoma contain undesirably high concentrations of mercury in their skinless fillets.

In response to data generated by this study and other related investigations, the California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (OEHHA) issued a draft fish-consumption advisory report that offered guidelines for human consumption of fish. The final version of the OEHHA fish-consumption advisory was approved by the State of California in July 2003 and is scheduled for publication in September 2004 (*http://www.oehha.ca.gov/fish/so_cal/fnatoma.html*).

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Appendix

Summary of Total Mercury Concentrations in Fillets of Selected Sport Fishes Collected during 2000–2003 from Lake Natoma

Appendix table A1. Raw data for total mercury in fillets of fish collected from Lake Natoma, California, 2000–2003.

[Wet-weight concentrations of mercury were calculated from dry-weight concentrations and moisture values unless indicated otherwise. SL, standard length; TL, total length; Wt., weight; Moist., moisture content; Hg, mercury. Site abbreviations (see locations in figure 1): AC, Alder Creek arm; DAM, Nimbus Dam; MB, Mississippi Bar; NB, Negro Bar; NS, Natomas Slough; WC, Willow Creek arm. Species abbreviations: BB, brown bullhead; BG, bluegill; BLB, black bullhead; CCF, channel catfish; GS, green sunfish; LMB, largemouth bass, RBT, rainbow trout; RE, redear sunfish; SMB, smallmouth bass; SPB, spotted bass; WCF, white catfish. mm, millimeter; g, gram; µg/g, microgram per gram (equivalent to parts per million); %, percent; —, no data.]

Sample ID	Site	Capture date	Species	SL, in mm	TL, in mm	Wt., in g	Moist., in %	Hg, in µg/g dry wt.	Hg, in µg/g wet wt.
LKNAT-NS-CHCAT-1867g/540TL-0800	NS	Aug 2000	CCF	—	540	1,867	[1]77.2	4.600	[1]1.049
LKNAT-AC-LMB-24g/128TL-0800	AC	Aug 2000	LMB	—	128	24	[2]81.0	0.830	[2]0.158
LKNAT-AC-LMB-56g/165TL-0800	AC	Aug 2000	LMB	—	165	56	[2]80.3	0.910	[2]0.179
LKNAT-AC-LMB-422g/300TL-0800	AC	Aug 2000	LMB	—	300	422	[2]78.7	1.280	[2]0.273
LKNAT-AC-LMB-504g/315TL-0800	AC	Aug 2000	LMB	—	315	504	[2]78.6	1.580	[2]0.338
LKNAT-AC-LMB-709g/360TL-0800	AC	Aug 2000	LMB	—	360	709	[2]78.3	1.650	[2]0.358
LKNAT-AC-LMB-1043g/385TL-0800	AC	Aug 2000	LMB	—	385	1,043	[2]78.1	2.850	[2]0.624
LKNAT-AC-LMB-1655g/480TL-0800	AC	Aug 2000	LMB	—	480	1,655	[2]77.5	4.550	[2]1.024
LKNAT-NS-LMB-31g/135TL-0800	NS	Aug 2000	LMB	—	135	31	[2]80.8	0.740	[2]0.142
LKNAT-NS-LMB-266g/270TL-0800	NS	Aug 2000	LMB	—	270	266	[2]79.0	1.580	[2]0.332
LKNAT-NS-LMB-923g/390TL-0800	NS	Aug 2000	LMB	—	390	923	[2]78.1	2.850	[2]0.624
LKNAT-NS-LMB-1243g/410TL-0800	NS	Aug 2000	LMB	—	410	1,243	[2]77.9	3.570	[2]0.789
LKNAT-WC-LMB-35g/140TL-0800	WC	Aug 2000	LMB	—	140	35	[2]80.8	0.990	[2]0.190
LKNAT-WC-LMB-42g/145TL-0800	WC	Aug 2000	LMB	—	145	42	[2]80.7	1.310	[2]0.253
LKNAT-WC-LMB-72g/175TL-0800	WC	Aug 2000	LMB	—	175	72	[2]80.2	1.190	[2]0.236
LKNAT-WC-LMB-91g/190TL-0800	WC	Aug 2000	LMB	—	190	91	[2]79.9	1.390	[2]0.279
LKNAT-WC-LMB-92g/185TL-0800	WC	Aug 2000	LMB	—	185	92	[2]80.0	1.310	[2]0.262
LKNAT-WC-LMB-94g/185TL-0800	WC	Aug 2000	LMB	—	185	94	[2]80.0	1.260	[2]0.252
LKNAT-WC-LMB-407g/300TL-0800	WC	Aug 2000	LMB	—	300	407	[2]78.7	3.290	[2]0.701
LKNAT-WC-LMB-490g/320TL-0800	WC	Aug 2000	LMB	—	320	490	[2]78.6	3.170	[2]0.678
LKNAT-WC-LMB-590g/330TL-0800	WC	Aug 2000	LMB	—	330	590	[2]78.5	2.950	[2]0.634
LKNAT-WC-LMB-1247g/425TL-0800	WC	Aug 2000	LMB	—	425	1,247	[2]77.8	2.710	[2]0.602
LN-205-F	NB	Sep–Oct 2002	BB	275	317	554	82.1	1.966	0.353
LN-006-F	AC	Sep–Oct 2002	BG	75	95	12.5	81.8	0.420	0.076
LN-007-F	AC	Sep–Oct 2002	BG	76	97	13	81.9	0.261	0.047
LN-021-F	AC	Sep–Oct 2002	BG	74	95	12	81.2	0.505	0.095
LN-066-F	AC	Sep–Oct 2002	BG	88	108	20	82.0	0.463	0.083
LN-068-F	AC	Sep–Oct 2002	BG	77	90	10	81.5	0.529	0.098
LN-084-F	AC	Sep–Oct 2002	BG	82	106	17.5	81.3	0.348	0.065
LN-085-F	AC	Sep–Oct 2002	BG	111	144	50	81.3	0.455	0.085
LN-124-F	AC	Sep–Oct 2002	BG	110	140	44.5	81.5	0.505	0.093
LN-128-F	AC	Sep–Oct 2002	BG	115	135	41.5	81.4	0.336	0.062
LN-139-F	AC	Sep–Oct 2002	BG	96	115	33	80.9	0.438	0.083
LN-206-F	AC	Sep–Oct 2002	BG	80	116	18.5	82.1	0.366	0.066
LN-231-F	AC	Sep–Oct 2002	BG	96	120	28.5	80.9	0.319	0.061
LN-247-F	AC	Sep–Oct 2002	BG	90	112	22	82.7	0.287	0.050
LN-248-F	AC	Sep–Oct 2002	BG	86	107	19	82.0	0.374	0.067

Appendix table A1. Raw data for total mercury in fillets of fish collected from Lake Natoma, California, 2000–2003—Continued.

[Wet-weight concentrations of mercury were calculated from dry-weight concentrations and moisture values unless indicated otherwise. SL, standard length; TL, total length; Wt., weight; Moist., moisture content; Hg, mercury. Site abbreviations (see locations in figure 1): AC, Alder Creek arm; DAM, Nimbus Dam; MB, Mississippi Bar; NB, Negro Bar; NS, Natomas Slough; WC, Willow Creek arm. Species abbreviations: BB, brown bullhead; BG, bluegill; BLB, black bullhead; CCF, channel catfish; GS, green sunfish; LMB, largemouth bass, RBT, rainbow trout; RE, redear sunfish; SMB, smallmouth bass; SPB, spotted bass; WCF, white catfish. mm, millimeter; g, gram; µg/g, microgram per gram (equivalent to parts per million); %, percent; —, no data.]

Sample ID	Site	Capture date	Species	SL, in mm	TL, in mm	Wt., in g	Moist., in %	Hg, in µg/g dry wt.	Hg, in µg/g wet wt.
LN-257-F	AC	Sep–Oct 2002	BG	89	111	20.5	81.8	0.296	0.054
LN-271-F	AC	Sep–Oct 2002	BG	80	104	17	82.3	0.285	0.050
LN-278-F	AC	Sep–Oct 2002	BG	110	140	41	81.7	0.454	0.083
LN-285-F	AC	Sep–Oct 2002	BG	84	105	16	82.7	0.596	0.103
LN-287-F	AC	Sep–Oct 2002	BG	95	119	29	82.2	0.369	0.066
LN-026-F	DAM	Sep–Oct 2002	BG	84	105	16.5	82.0	0.338	0.061
LN-044-F	DAM	Sep–Oct 2002	BG	80	104	16.5	81.6	0.551	0.101
LN-047-F	DAM	Sep–Oct 2002	BG	83	104	17	81.7	0.480	0.088
LN-051-F	DAM	Sep–Oct 2002	BG	83	108	19	82.3	0.330	0.058
LN-057-F	DAM	Sep–Oct 2002	BG	93	115	24.5	81.3	0.425	0.080
LN-073-F	DAM	Sep–Oct 2002	BG	79	101	17.5	82.3	0.367	0.065
LN-092-F	DAM	Sep–Oct 2002	BG	73	85	12.5	81.9	0.323	0.058
LN-126-F	DAM	Sep–Oct 2002	BG	100	123	34.5	82.7	0.485	0.084
LN-127-F	DAM	Sep–Oct 2002	BG	73	93	11	81.2	0.436	0.082
LN-148-F	DAM	Sep–Oct 2002	BG	84	104	17	81.8	0.336	0.061
LN-171-F	DAM	Sep–Oct 2002	BG	85	105	18	81.9	0.357	0.065
LN-177-F	DAM	Sep–Oct 2002	BG	112	133	36	82.2	0.286	0.051
LN-182-F	DAM	Sep–Oct 2002	BG	77	99	17	81.4	0.504	0.094
LN-190-F	DAM	Sep–Oct 2002	BG	88	109	19	81.3	0.261	0.049
LN-193-F	DAM	Sep–Oct 2002	BG	90	114	22.5	81.9	0.377	0.068
LN-195-F	DAM	Sep–Oct 2002	BG	90	114	22.5	82.4	0.365	0.064
LN-228-F	DAM	Sep–Oct 2002	BG	102	131	34	81.9	0.830	0.150
LN-232-F	DAM	Sep–Oct 2002	BG	92	115	23.5	81.6	0.509	0.094
LN-252-F	DAM	Sep–Oct 2002	BG	105	131	35	81.2	0.306	0.058
LN-258-F	DAM	Sep–Oct 2002	BG	125	157	69.5	81.9	0.708	0.128
LN-275-F	DAM	Sep–Oct 2002	BG	84	107	21	81.6	0.341	0.063
LN-276-F	DAM	Sep–Oct 2002	BG	71	93	12.5	83.2	0.453	0.076
LN-005-F	MB	Sep–Oct 2002	BG	111	129	33.5	81.7	0.372	0.068
LN-008-F	MB	Sep–Oct 2002	BG	98	121	28.5	81.9	0.408	0.074
LN-009-F	MB	Sep–Oct 2002	BG	70	92	12	81.9	0.465	0.084
LN-012-F	MB	Sep–Oct 2002	BG	95	120	25	82.0	0.510	0.092
LN-013-F	MB	Sep–Oct 2002	BG	84	106	19.5	81.3	0.522	0.098
LN-014-F	MB	Sep–Oct 2002	BG	98	120	29.5	82.4	0.722	0.127
LN-015-F	MB	Sep–Oct 2002	BG	108	139	42	83.0	0.345	0.059
LN-020-F	MB	Sep–Oct 2002	BG	120	150	45.8	81.6	0.613	0.113
LN-030-F	MB	Sep–Oct 2002	BG	84	106	18	82.5	0.304	0.053
LN-054-F	MB	Sep–Oct 2002	BG	89	112	22.5	80.9	0.545	0.104

Appendix table A1. Raw data for total mercury in fillets of fish collected from Lake Natoma, California, 2000–2003—Continued.

[Wet-weight concentrations of mercury were calculated from dry-weight concentrations and moisture values unless indicated otherwise. SL, standard length; TL, total length; Wt., weight; Moist., moisture content; Hg, mercury. Site abbreviations (see locations in figure 1): AC, Alder Creek arm; DAM, Nimbus Dam; MB, Mississippi Bar; NB, Negro Bar; NS, Natomas Slough; WC, Willow Creek arm. Species abbreviations: BB, brown bullhead; BG, bluegill; BLB, black bullhead; CCF, channel catfish; GS, green sunfish; LMB, largemouth bass, RBT, rainbow trout; RE, redear sunfish; SMB, smallmouth bass; SPB, spotted bass; WCF, white catfish. mm, millimeter; g, gram; µg/g, microgram per gram (equivalent to parts per million); %, percent; —, no data.]

Sample ID	Site	Capture date	Species	SL, in mm	TL, in mm	Wt., in g	Moist., in %	Hg, in µg/g dry wt.	Hg, in µg/g wet wt.
LN-056-F	MB	Sep–Oct 2002	BG	107	135	37	81.8	0.585	0.107
LN-060-F	MB	Sep–Oct 2002	BG	111	136	45	81.4	0.570	0.106
LN-082-F	MB	Sep–Oct 2002	BG	75	95	12	82.1	0.467	0.083
LN-097-F	MB	Sep–Oct 2002	BG	104	129	35	81.1	0.350	0.066
LN-164-F	MB	Sep–Oct 2002	BG	126	156	61.5	81.9	0.532	0.096
LN-189-F	MB	Sep–Oct 2002	BG	111	133	36.5	81.6	0.728	0.134
LN-199-F	MB	Sep–Oct 2002	BG	124	152	59	81.6	0.783	0.144
LN-215-F	MB	Sep–Oct 2002	BG	82	103	17.5	81.2	0.495	0.093
LN-218-F	MB	Sep–Oct 2002	BG	83	105	18.5	82.4	0.329	0.058
LN-237-F	MB	Sep–Oct 2002	BG	95	120	24.5	80.9	0.383	0.073
LN-241-F	MB	Sep–Oct 2002	BG	124	152	60	81.2	0.295	0.055
LN-264-F	MB	Sep–Oct 2002	BG	72	90	11	81.7	0.772	0.141
LN-270-F	MB	Sep–Oct 2002	BG	85	113	20.5	82.3	0.499	0.088
LN-289-F	MB	Sep–Oct 2002	BG	116	149	53.5	81.5	0.444	0.082
LN-291-F	MB	Sep–Oct 2002	BG	78	100	14.5	82.7	0.605	0.105
LN-011-F	NB	Sep–Oct 2002	BG	137	174	91.5	82.6	1.064	0.185
LN-027-F	NB	Sep–Oct 2002	BG	119	152	67	81.7	0.399	0.073
LN-031-F	NB	Sep–Oct 2002	BG	73	95	15	82.1	0.313	0.056
LN-039-F	NB	Sep–Oct 2002	BG	111	143	48	81.3	0.782	0.146
LN-045-F	NB	Sep–Oct 2002	BG	127	152	68.5	81.5	0.626	0.116
LN-075-F	NB	Sep–Oct 2002	BG	74	98	15.5	83.1	0.614	0.104
LN-083-F	NB	Sep–Oct 2002	BG	78	102	17.5	82.0	0.276	0.050
LN-103-F	NB	Sep–Oct 2002	BG	124	155	68.5	81.0	0.529	0.100
LN-104-F	NB	Sep–Oct 2002	BG	131	159	81	82.0	0.669	0.121
LN-106-F	NB	Sep–Oct 2002	BG	128	161	69.5	81.7	0.676	0.124
LN-141-F	NB	Sep–Oct 2002	BG	83	108	21	82.1	0.870	0.155
LN-181-F	NB	Sep–Oct 2002	BG	112	143	52.5	81.9	0.566	0.102
LN-194-F	NB	Sep–Oct 2002	BG	119	151	67	81.7	0.883	0.162
LN-211-F	NB	Sep–Oct 2002	BG	120	154	69.5	81.8	0.499	0.091
LN-221-F	NB	Sep–Oct 2002	BG	122	151	67.5	81.1	0.349	0.066
LN-233-F	NB	Sep–Oct 2002	BG	80	102	16.5	81.7	0.412	0.075
LN-259-F	NB	Sep–Oct 2002	BG	74	97	14.5	82.8	0.461	0.079
LN-261-F	NB	Sep–Oct 2002	BG	121	150	65.5	82.8	0.669	0.115
LN-268-F	NB	Sep–Oct 2002	BG	115	148	59.5	82.2	0.356	0.063
LN-283-F	NB	Sep–Oct 2002	BG	93	117	30	81.2	0.437	0.082
LN-292-F	NB	Sep–Oct 2002	BG	69	91	11.5	82.2	0.511	0.091
LN-294-F	NB	Sep–Oct 2002	BG	112	136	50	80.7	0.573	0.110

Appendix table A1. Raw data for total mercury in fillets of fish collected from Lake Natoma, California, 2000–2003—Continued.

[Wet-weight concentrations of mercury were calculated from dry-weight concentrations and moisture values unless indicated otherwise. SL, standard length; TL, total length; Wt., weight; Moist., moisture content; Hg, mercury. Site abbreviations (see locations in figure 1): AC, Alder Creek arm; DAM, Nimbus Dam; MB, Mississippi Bar; NB, Negro Bar; NS, Natomas Slough; WC, Willow Creek arm. Species abbreviations: BB, brown bullhead; BG, bluegill; BLB, black bullhead; CCF, channel catfish; GS, green sunfish; LMB, largemouth bass, RBT, rainbow trout; RE, redear sunfish; SMB, smallmouth bass; SPB, spotted bass; WCF, white catfish. mm, millimeter; g, gram; µg/g, microgram per gram (equivalent to parts per million); %, percent; —, no data.]

Sample ID	Site	Capture date	Species	SL, in mm	TL, in mm	Wt., in g	Moist., in %	Hg, in µg/g dry wt.	Hg, in µg/g wet wt.
LN-022-F	WC	Sep–Oct 2002	BG	56	73	5	81.5	0.455	0.084
LN-049-F	WC	Sep–Oct 2002	BG	58	72	5	80.8	0.593	0.114
LN-088-F	WC	Sep–Oct 2002	BG	85	110	19	81.2	0.362	0.068
LN-111-F	WC	Sep–Oct 2002	BG	61	81	8	82.5	0.900	0.158
LN-114-F	WC	Sep–Oct 2002	BG	80	103	16.5	81.6	0.268	0.049
LN-135-F	WC	Sep–Oct 2002	BG	132	160	75.5	81.4	0.752	0.140
LN-154-F	WC	Sep–Oct 2002	BG	78	102	16	81.4	0.223	0.041
LN-160-F	WC	Sep–Oct 2002	BG	53	73	5	82.0	0.674	0.121
LN-169-F	WC	Sep–Oct 2002	BG	92	123	23.5	81.9	0.311	0.056
LN-210-F	WC	Sep–Oct 2002	BLB	189	214	134	83.6	0.881	0.145
LN-152-F	DAM	Sep–Oct 2002	GS	75	90	12.5	81.4	0.331	0.061
LN-334-F	MB	Sep–Oct 2002	GS	108	126	36.5	81.8	0.611	0.111
LN-390-F	MB	Sep–Oct 2002	GS	97	115	26	81.5	0.529	0.098
LN-227-F	NB	Sep–Oct 2002	GS	130	151	75.5	80.8	1.024	0.196
LN-010-F	AC	Sep–Oct 2002	LMB	260	301	399	77.6	1.639	0.367
LN-029-F	AC	Sep–Oct 2002	LMB	291	340	562	79.4	2.697	0.557
LN-071-F	AC	Sep–Oct 2002	LMB	333	395	941	77.9	2.603	0.576
LN-129-F	AC	Sep–Oct 2002	LMB	200	238	188.5	79.0	1.019	0.214
LN-142-F	AC	Sep–Oct 2002	LMB	305	353	658	78.3	1.232	0.268
LN-143-F	AC	Sep–Oct 2002	LMB	187	220	146	79.5	1.039	0.213
LN-153-F	AC	Sep–Oct 2002	LMB	152	178	72	79.5	0.648	0.133
LN-157-F	AC	Sep–Oct 2002	LMB	327	378	939	79.0	2.309	0.485
LN-180-F	AC	Sep–Oct 2002	LMB	173	201	118	79.1	0.769	0.161
LN-191-F	AC	Sep–Oct 2002	LMB	97	117	15.5	81.1	0.507	0.096
LN-208-F	AC	Sep–Oct 2002	LMB	130	158	38.5	80.7	0.624	0.121
LN-219-F	AC	Sep–Oct 2002	LMB	130	151	43.5	81.2	0.674	0.127
LN-245-F	AC	Sep–Oct 2002	LMB	354	407	1,141	78.1	2.762	0.604
LN-246-F	AC	Sep–Oct 2002	LMB	157	190	92	80.3	0.584	0.115
LN-272-F	AC	Sep–Oct 2002	LMB	360	425	1,285	77.9	2.605	0.577
LN-312-F	AC	Sep–Oct 2002	LMB	154	188	86.5	79.5	1.050	0.215
LN-042-F	DAM	Sep–Oct 2002	LMB	114	139	25	81.4	0.659	0.122
LN-070-F	DAM	Sep–Oct 2002	LMB	253	292	365	78.3	1.104	0.240
LN-121-F	DAM	Sep–Oct 2002	LMB	90	110	14	82.9	0.602	0.103
LN-168-F	DAM	Sep–Oct 2002	LMB	70	88	7	81.2	0.345	0.065
LN-202-F	DAM	Sep–Oct 2002	LMB	129	153	40.5	79.7	0.453	0.092
LN-204-F	DAM	Sep–Oct 2002	LMB	73	90	7	81.7	0.339	0.062
LN-255-F	DAM	Sep–Oct 2002	LMB	76	95	8	83.0	0.453	0.077

Appendix table A1. Raw data for total mercury in fillets of fish collected from Lake Natoma, California, 2000–2003—Continued.

[Wet-weight concentrations of mercury were calculated from dry-weight concentrations and moisture values unless indicated otherwise. SL, standard length; TL, total length; Wt., weight; Moist., moisture content; Hg, mercury. Site abbreviations (see locations in figure 1): AC, Alder Creek arm; DAM, Nimbus Dam; MB, Mississippi Bar; NB, Negro Bar; NS, Natomas Slough; WC, Willow Creek arm. Species abbreviations: BB, brown bullhead; BG, bluegill; BLB, black bullhead; CCF, channel catfish; GS, green sunfish; LMB, largemouth bass, RBT, rainbow trout; RE, redear sunfish; SMB, smallmouth bass; SPB, spotted bass; WCF, white catfish. mm, millimeter; g, gram; µg/g, microgram per gram (equivalent to parts per million); %, percent; —, no data.]

Sample ID	Site	Capture date	Species	SL, in mm	TL, in mm	Wt., in g	Moist., in %	Hg, in µg/g dry wt.	Hg, in µg/g wet wt.
LN-002-F	MB	Sep–Oct 2002	LMB	335	390	837	78.4	1.308	0.282
LN-023-F	MB	Sep–Oct 2002	LMB	432	490	1,967.5	78.0	3.661	0.807
LN-134-F	MB	Sep–Oct 2002	LMB	132	154	44	79.5	0.996	0.204
LN-136-F	MB	Sep–Oct 2002	LMB	87	105	12	81.8	0.538	0.098
LN-159-F	MB	Sep–Oct 2002	LMB	124	159	39	81.0	0.530	0.101
LN-240-F	MB	Sep–Oct 2002	LMB	90	110	13.5	82.1	0.387	0.069
LN-040-F	NB	Sep–Oct 2002	LMB	179	208	130	79.0	0.738	0.155
LN-091-F	NB	Sep–Oct 2002	LMB	209	244	260	79.1	1.228	0.256
LN-098-F	NB	Sep–Oct 2002	LMB	198	232	161	79.0	0.930	0.196
LN-099-F	NB	Sep–Oct 2002	LMB	169	201	110.5	79.9	1.148	0.231
LN-100-F	NB	Sep–Oct 2002	LMB	110	132	30	82.5	0.632	0.111
LN-117-F	NB	Sep–Oct 2002	LMB	146	181	81.5	79.5	0.934	0.192
LN-144-F	NB	Sep–Oct 2002	LMB	135	164	52	80.1	0.495	0.099
LN-150-F	NB	Sep–Oct 2002	LMB	172	206	133.5	79.4	1.125	0.232
LN-165-F	NB	Sep–Oct 2002	LMB	124	149	40.5	80.6	0.689	0.133
LN-172-F	NB	Sep–Oct 2002	LMB	158	181	98	80.6	0.610	0.118
LN-220-F	NB	Sep–Oct 2002	LMB	135	159	58	80.4	0.663	0.130
LN-224-F	NB	Sep–Oct 2002	LMB	354	415	1,197.5	78.6	3.241	0.695
LN-253-F	NB	Sep–Oct 2002	LMB	139	169	67.5	80.3	0.755	0.149
LN-254-F	NB	Sep–Oct 2002	LMB	146	179	64.5	79.4	0.809	0.167
LN-281-F	NB	Sep–Oct 2002	LMB	168	281	121.5	79.5	0.894	0.183
LN-282-F	NB	Sep–Oct 2002	LMB	244	290	370	78.9	1.998	0.421
LN-048-F	WC	Sep–Oct 2002	LMB	166	193	96.5	79.4	1.178	0.243
LN-052-F	WC	Sep–Oct 2002	LMB	145	173	66	80.4	0.865	0.169
LN-076-F	WC	Sep–Oct 2002	LMB	289	341	572	78.7	2.607	0.555
LN-078-F	WC	Sep–Oct 2002	LMB	175	204	110	79.9	0.824	0.165
LN-086-F	WC	Sep–Oct 2002	LMB	316	361	913.5	78.2	1.751	0.383
LN-101-F	WC	Sep–Oct 2002	LMB	125	150	38.5	80.0	0.673	0.135
LN-112-F	WC	Sep–Oct 2002	LMB	386	446	1,448.5	78.3	3.186	0.692
LN-185-F	WC	Sep–Oct 2002	LMB	239	274	299	78.6	1.172	0.251
LN-213-F	WC	Sep–Oct 2002	LMB	184	216	129.5	79.7	1.130	0.230
LN-222-F	WC	Sep–Oct 2002	LMB	215	245	206	78.8	0.880	0.186
LN-229-F	WC	Sep–Oct 2002	LMB	317	369	858	77.7	3.853	0.859
LN-235-F	WC	Sep–Oct 2002	LMB	323	375	921	78.4	2.392	0.516
LN-250-F	WC	Sep–Oct 2002	LMB	236	275	355.5	77.6	1.265	0.283
LN-273-F	WC	Sep–Oct 2002	LMB	140	169	60.5	79.4	1.191	0.246
LN-280-F	WC	Sep–Oct 2002	LMB	139	164	61	79.9	0.756	0.152

Appendix table A1. Raw data for total mercury in fillets of fish collected from Lake Natoma, California, 2000–2003—Continued.

[Wet-weight concentrations of mercury were calculated from dry-weight concentrations and moisture values unless indicated otherwise. SL, standard length; TL, total length; Wt., weight; Moist., moisture content; Hg, mercury. Site abbreviations (see locations in figure 1): AC, Alder Creek arm; DAM, Nimbus Dam; MB, Mississippi Bar; NB, Negro Bar; NS, Natomas Slough; WC, Willow Creek arm. Species abbreviations: BB, brown bullhead; BG, bluegill; BLB, black bullhead; CCF, channel catfish; GS, green sunfish; LMB, largemouth bass, RBT, rainbow trout; RE, redear sunfish; SMB, smallmouth bass; SPB, spotted bass; WCF, white catfish. mm, millimeter; g, gram; µg/g, microgram per gram (equivalent to parts per million); %, percent; —, no data.]

Sample ID	Site	Capture date	Species	SL, in mm	TL, in mm	Wt., in g	Moist., in %	Hg, in µg/g dry wt.	Hg, in µg/g wet wt.
LN-284-F	WC	Sep–Oct 2002	LMB	204	239	196.5	79.3	0.932	0.193
LN-132-F	DAM	Sep–Oct 2002	RBT	282	324	441.5	75.8	0.082	0.020
LN-300-F	NB	Sep–Oct 2002	RBT	146	177	48	81.9	0.537	0.097
LN-368-F	MB	Sep–Oct 2002	RE	71	87	10	80.9	0.553	0.106
LN-380-F	MB	Sep–Oct 2002	RE	110	134	38	80.7	0.146	0.028
LN-034-F	NB	Sep–Oct 2002	RE	94	116	25	80.7	0.211	0.041
LN-225-F	NB	Sep–Oct 2002	RE	115	141	44.5	80.5	0.235	0.046
LN-315-F	NB	Sep–Oct 2002	RE	119	145	51.5	80.1	0.602	0.120
LN-328-F	NB	Sep–Oct 2002	RE	116	142	47	80.6	1.995	0.388
LN-381-F	NB	Sep–Oct 2002	RE	110	137	43.5	80.3	0.371	0.073
LN-087-F	WC	Sep–Oct 2002	RE	—	80	7.5	81.8	0.360	0.065
LN-302-F	WC	Sep–Oct 2002	RE	132	161	69.5	80.6	0.159	0.031
LN-306-F	WC	Sep–Oct 2002	RE	103	126	31.5	81.2	0.378	0.071
LN-308-F	WC	Sep–Oct 2002	RE	96	116	29.5	80.7	0.478	0.092
LN-318-F	WC	Sep–Oct 2002	RE	96	122	29.5	80.6	0.538	0.104
LN-323-F	WC	Sep–Oct 2002	RE	113	129	35.5	80.6	0.294	0.057
LN-324-F	WC	Sep–Oct 2002	RE	110	136	40.5	81.0	0.886	0.168
LN-329-F	WC	Sep–Oct 2002	RE	117	143	49.5	80.8	0.319	0.061
LN-338-F	WC	Sep–Oct 2002	RE	96	117	26	80.4	0.685	0.135
LN-344-F	WC	Sep–Oct 2002	RE	115	140	51.5	80.7	0.268	0.052
LN-355-F	WC	Sep–Oct 2002	RE	—	187	117	80.4	0.368	0.072
LN-358-F	WC	Sep–Oct 2002	RE	87	112	21.5	81.3	0.417	0.078
LN-382-F	WC	Sep–Oct 2002	RE	—	114	23.5	81.2	0.538	0.101
LN-295-F	AC	Sep–Oct 2002	SMB	142	174	60.5	79.0	0.511	0.107
LN-077-F	MB	Sep–Oct 2002	SMB	117	145	35	80.6	0.842	0.163
LN-032-F	AC	Sep–Oct 2002	SPB	249	300	387.5	78.7	2.291	0.488
LN-335-F	DAM	Sep–Oct 2002	SPB	281	335	476	77.1	1.778	0.407
LN-036-F	MB	Sep–Oct 2002	SPB	95	118	15.5	81.9	0.527	0.096
LN-019-F	NB	Sep–Oct 2002	WCF	221	249	229.5	81.8	3.069	0.560
LKNATWILLCHCAT-3450g/630TL-070103	WC	Jul 2003	CCF	—	630	3,450	77.4	8.339	[3]1.785
LKNATWILLCHCAT-1270g/505TL-070103	WC	Jul 2003	CCF	—	505	1,270	80.1	7.880	[3]1.610
LKNATWILLCHCAT-4950g/682TL-070103	WC	Jul 2003	CCF	—	682	4,950	76.4	7.714	[3]1.716
LKNATWILLCHCAT-2250g/555TL-070103	WC	Jul 2003	CCF	—	555	2,250	74.5	4.882	[3]1.098
LKNATWILLCHCAT-4120g/682TL-070103	WC	Jul 2003	CCF	—	682	4,120	75.6	6.224	[3]1.434
LKNATWILLCHCAT-2790g/615TL-070103	WC	Jul 2003	CCF	—	615	2,790	77.7	4.846	[3]1.103
LKNATWILLCHCAT-5200g/750TL-070103	WC	Jul 2003	CCF	—	750	5,200	77.6	7.977	[3]1.887
LKNATWILLCHCAT-4110g/685TL-070103	WC	Jul 2003	CCF	—	685	4,110	77.0	7.146	[3]1.601

Appendix table A1. Raw data for total mercury in fillets of fish collected from Lake Natoma, California, 2000–2003—Continued.

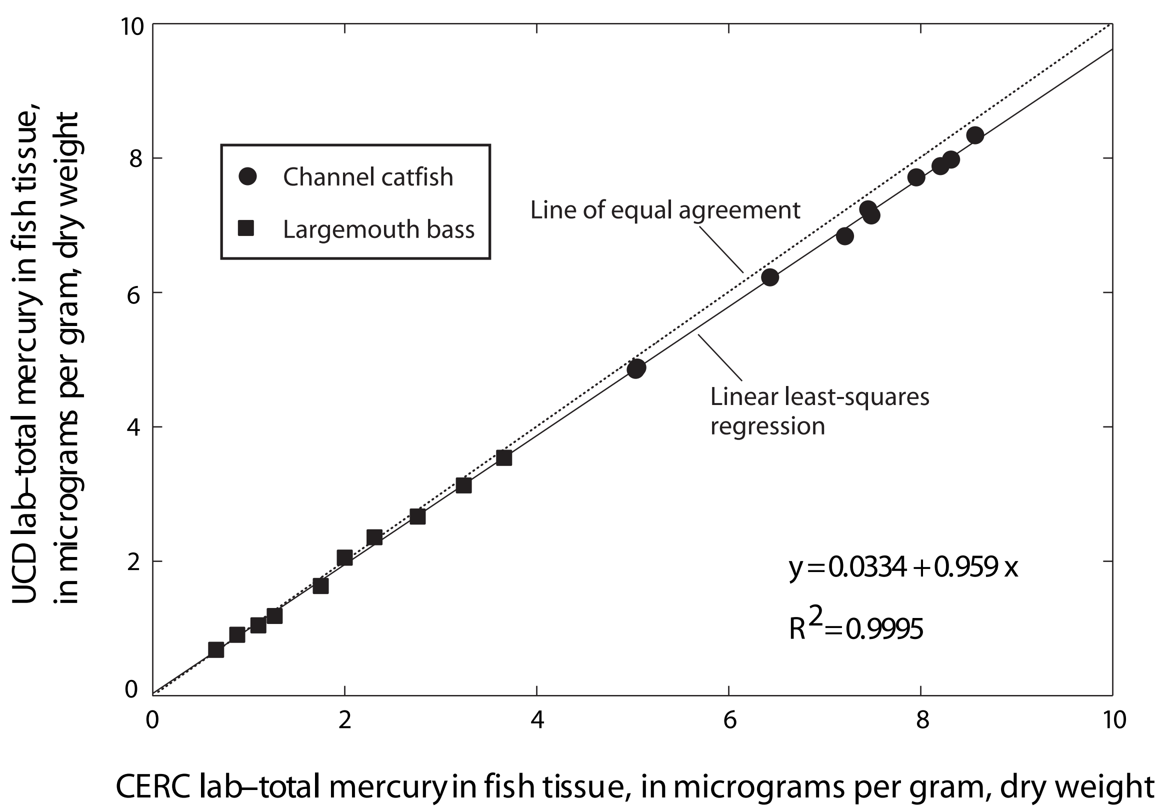
[Wet-weight concentrations of mercury were calculated from dry-weight concentrations and moisture values unless indicated otherwise. SL, standard length; TL, total length; Wt., weight; Moist., moisture content; Hg, mercury. Site abbreviations (see locations in figure 1): AC, Alder Creek arm; DAM, Nimbus Dam; MB, Mississippi Bar; NB, Negro Bar; NS, Natomas Slough; WC, Willow Creek arm. Species abbreviations: BB, brown bullhead; BG, bluegill; BLB, black bullhead; CCF, channel catfish; GS, green sunfish; LMB, largemouth bass, RBT, rainbow trout; RE, redear sunfish; SMB, smallmouth bass; SPB, spotted bass; WCF, white catfish. mm, millimeter; g, gram; µg/g, microgram per gram (equivalent to parts per million); %, percent; —, no data.]

Sample ID	Site	Capture date	Species	SL, in mm	TL, in mm	Wt., in g	Moist., in %	Hg, in µg/g dry wt.	Hg, in µg/g wet wt.
LKNATWILLCHCAT-4560g/690TL-070103	WC	Jul 2003	CCF	—	690	4,560	77.5	7.234	[3]1.576
LKNATWILLCHCAT-3420g/649TL-070103	WC	Jul 2003	CCF	—	649	3,420	77.8	6.837	[3]1.444
WILLKNAT-LMB-68g/174TL-070203	WC	Jul 2003	LMB	—	174	68	[2]80.2	[2]1.278	0.253
WILLKNAT-LMB-195g/228TL-070203	WC	Jul 2003	LMB	—	228	195	[2]79.5	[2]1.585	0.325
WILLKNAT-LMB-232g/252TL-070203	WC	Jul 2003	LMB	—	252	232	[2]79.2	[2]1.736	0.361
WILLKNAT-LMB-255g/255TL-070203	WC	Jul 2003	LMB	—	255	255	[2]79.2	[2]1.312	0.273

[1]Moisture content (estimated as the arcsine-transformed mean for the 2003 CCF data) was used to convert Hg dry-weight concentration to wet-weight concentration.

[2]Moisture content (estimated from the total length-moisture relation for 2002 LMB data, $\%Moist = 95.1 \times TL^{-0.0331}$, $R^2 = 0.780$, $N = 61$, where N is the number of samples) was used either to convert Hg dry-weight concentrations to wet-weight concentrations (samples collected in 2000) or to convert Hg wet-weight concentrations to dry-weight concentrations (samples collected in 2003).

[3]Wet-weight concentrations of Hg in channel catfish samples collected in 2003 were measured directly from fresh (wet) samples and not estimated from dry-weight concentrations and moisture content.



Appendix figure A1. Interlaboratory comparison for mercury in fish tissue from fish taken from Lake Natoma, 2000–2003. UCD lab, University of California at Davis laboratory; CERC lab, Columbia Environmental Research Center laboratory; Hg, mercury.

Appendix table A2. Results of laboratory intercomparison for total mercury in fish tissue.

[CERC, Columbia Environmental Research Center; USGS, U.S. Geological Survey; UC Davis, University of California, Davis; Hg, mercury. Relative percent difference (RPD) computed as RPD = $(v_1 - v_2)/[(v_1 + v_2)/2]$, where v_1 and v_2 are values under comparison. µg/g, microgram per gram (equivalent to parts per million); wt., weight; —, not available]

CERC ID	USGS field ID	UC Davis ID	Species	CERC Hg (µg/g dry wt.)	UC Davis Hg (µg/g dry wt.)	Relative Percent Difference
28612	LN-245-F	CERC, Columbia, MO-A	Largemouth bass	2.76	2.67	3.48
28610	LN-157-F	CERC, Columbia, MO-B	Largemouth bass	2.31	2.35	–1.92
28594	LN-086-F	CERC, Columbia, MO-C	Largemouth bass	1.75	1.63	7.03
28592	LN-250-F	CERC, Columbia, MO-D	Largemouth bass	1.27	1.19	6.90
28619	LN-023-F	CERC, Columbia, MO-E	Largemouth bass	3.66	3.54	3.33
28590	LN-222-F	CERC, Columbia, MO-F	Largemouth bass	0.88	0.91	–2.85
28581	LN-070-F	CERC, Columbia, MO-G	Largemouth bass	1.10	1.04	5.21
28561	LN-220-F	CERC, Columbia, MO-H	Largemouth bass	0.66	0.68	–3.34
28573	LN-282-F	CERC, Columbia, MO-I	Largemouth bass	2.00	2.05	–2.59
28574	LN-224-F	CERC, Columbia, MO-J	Largemouth bass	3.24	3.13	3.57
31531	—	LKNATWILLCHCAT-1270G/505TL-070103	Channel catfish	8.21	7.88	4.07
31533	—	LKNATWILLCHCAT-2250G/555TL-070103	Channel catfish	5.05	4.88	3.35
31535	—	LKNATWILLCHCAT-2790G/615TL-070103	Channel catfish	5.03	4.85	3.74
31539	—	LKNATWILLCHCAT-3420G/649TL-070103	Channel catfish	7.21	6.84	5.34
31530	—	LKNATWILLCHCAT-3450G/630TL-070103	Channel catfish	8.57	8.34	2.71
31537	—	LKNATWILLCHCAT-4110G/685TL-070103	Channel catfish	7.49	7.15	4.65
31534	—	LKNATWILLCHCAT-4120G/682TL-070103	Channel catfish	6.43	6.22	3.28
31538	—	LKNATWILLCHCAT-4560G/690TL-070103	Channel catfish	7.45	7.23	2.98
31532	—	LKNATWILLCHCAT-4950G/682TL-070103	Channel catfish	7.95	7.71	3.08
31536	—	LKNATWILLCHCAT-5200G/750TL-070103	Channel catfish	8.32	7.98	4.16
						Mean RPD 2.81
						Standard deviation 3.06

USGS

Saiki, Slotton, May, Ayers, and Alpers—**Summary of Total Mercury Concentrations in Fillets of Selected Sport Fishes Collected during 2000–2003 from Lake Natoma, Sacramento County, California**—Data Report 103

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