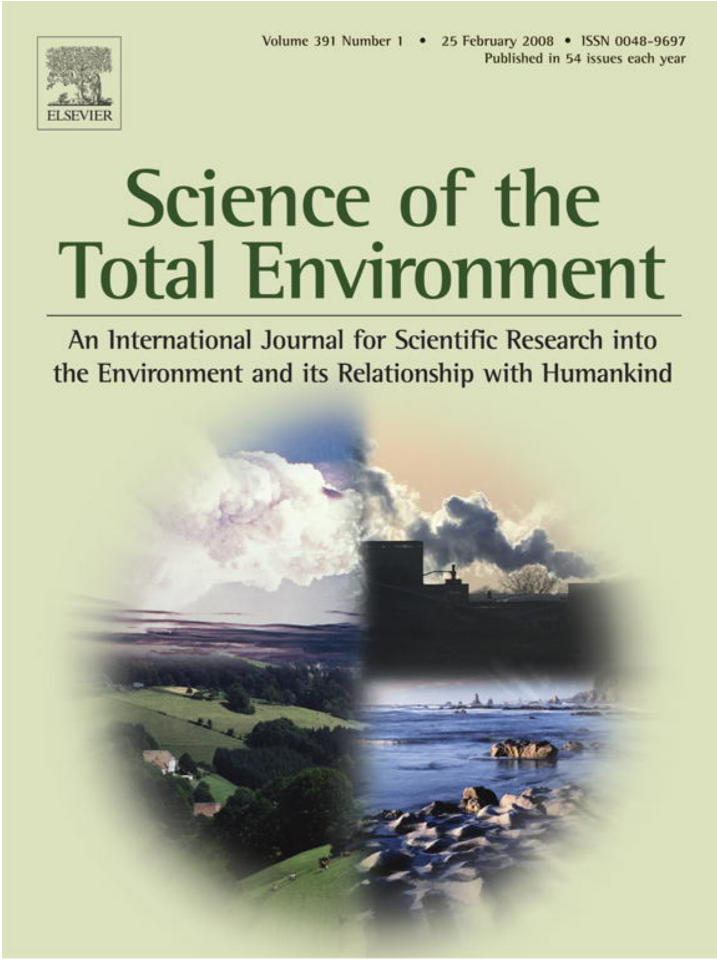
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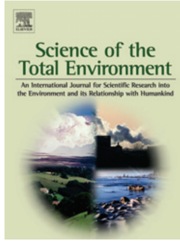


# Mercury in sport fish from the Sacramento–San Joaquin Delta region, California, USA

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ABSTRACT

Total mercury (Hg) concentrations were determined in fillet tissue of sport fish captured in the Sacramento–San Joaquin River Delta and surrounding tributaries, a region particularly impacted by historic gold and mercury mining activity. In 1999 and 2000, mercury concentrations were measured in 767 samples from ten fish species. Largemouth bass (*Micropterus salmoides*), the primary target species, exhibited a median Hg concentration of 0.53 $\mu g\ g^{-1}$ ($N$=406). Only 23 largemouth bass (6%) were below a 0.12 $\mu g\ g^{-1}$ threshold corresponding to a 4 meals per month safe consumption limit. Most of the largemouth bass (222 fish, or 55% of the sample) were above a 0.47 $\mu g\ g^{-1}$ threshold corresponding to a 1 meal per month consumption limit. Striped bass (*Morone saxatilis*), channel catfish (*Ictalurus punctatus*), white catfish (*Ameirus catus*), and Sacramento pikeminnow (*Ptychocheilus grandis*) also had relatively high concentrations, with 31% or more of samples above 0.47 $\mu g\ g^{-1}$. Concentrations were lowest in redear (*Lepomis microlophus*) and bluegill (*Lepomis macrochirus*) sunfish, with most samples below 0.12 $\mu g\ g^{-1}$, suggesting that targeting these species for sport and subsistence fishing may reduce human dietary exposure to Hg in the region. An improved method of analysis of covariance was performed to evaluate spatial variation in Hg in largemouth bass captured in 2000, while accounting for variability in fish length. Using this approach, Hg concentrations were significantly elevated in the Feather River, northern Delta, lower Cosumnes River, and San Joaquin River regions. In spite of elevated Hg concentrations on all of its tributaries, the central Delta had concentrations that were low both in comparison to safe consumption guidelines and to other locations.



## 1. Introduction

In California, extensive gold and mercury (Hg) mining activity caused the historic release of large amounts of mercury into watersheds, rivers, and lakes (Nriagu, 1994; Conaway et al., 2004; Alpers et al., 2005). As a result, elevated concentrations of Hg have been observed in water and sediments in northern and central California (Domagalski, 1998, 2001; Heim et al., 2007). In San Francisco Bay, concentrations of Hg and other bioaccumulative pollutants are elevated in sport fish tissue (Fairey et al., 1997; Davis et al., 2002; Greenfield et al., 2005). A fish consumption advisory was issued for the Bay, due to concern over human exposure to methylmercury, PCBs, organochlorine pesticides, and dioxins (OEHHA, 1997).

The Sacramento–San Joaquin River Delta (hereafter, Delta), like nearby San Francisco Bay, is a popular location for sport and subsistence fishing, with fishers and their families commonly consuming captured fish (SFEI, 2000; Silver et al., 2007). Concerns about fish tissue contamination in this region date back to 1971 (Interagency Committee on Environmental Mercury, 1971). Until recently, very little fish tissue sampling has been conducted to evaluate human health risks

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associated with chemical contamination in the Delta, and little published scientific literature is available. In 1998 a study of concentrations of Hg and other contaminants in sport fish from the Delta region was conducted. Of particular note were elevated tissue Hg concentrations in largemouth bass (*Micropterus salmoides*), a popular and widely caught sport fish in the region (Davis et al., 2000). This study also identified apparent regional variation in Hg concentrations, with elevated concentrations in Delta tributaries (including the Feather River, Sacramento River, American River, and San Joaquin River), and low concentrations (below a human health screening value) in the central Delta. Because of the compositing strategy employed, it was not possible to perform a rigorous statistical analysis of this spatial variation or to examine other factors that might influence the observed Hg concentrations.

In 1999 and 2000, the "CALFED Mercury Project" was initiated, to characterize the magnitude and extent of the Hg problem in the Delta (Slotton et al., 2002; Davis et al., 2003; Heim et al., 2007). This project was initiated by the CALFED Bay-Delta Program, which is charged with managing aquatic natural resources for the region (Kimmerer et al., 2005). This project included a systematic and comprehensive evaluation of Hg contamination in sport fish from the Delta region. The objectives of this study were: 1. Determine whether Hg occurs in sport fish at concentrations of potential human health concern to provide information needed to update consumption advisories; 2. Establish present Hg concentrations in sport fish as a basis for assessing long-term trends; 3. Evaluate spatial patterns in Hg accumulation at high trophic levels; and 4. Evaluate important factors influencing Hg concentrations such as fish age and size. This paper summarizes results of the sport fish study, and represents the first peer-reviewed journal publication on fish Hg exposure in the Delta region.

## 2. Methods

### 2.1. *Sampling and analysis*

Fish sampling focused on four primary target species: largemouth bass (*M. salmoides*), white catfish (*Ameirus catus*), striped bass (*Morone saxatilis*), and Sacramento pikeminnow (*Ptychocheilus grandis*). Six secondary target species were kept as bycatch: bluegill (*Lepomis macrochirus*), redear sunfish (*Lepomis microlophus*), channel catfish (*Ictalurus punctatus*), Sacramento sucker (*Catostomus occidentalis*), black crappie (*Pomoxis nigromaculatus*), and common carp (*Cyprinus carpio*). Primary target species were analyzed as individuals. Secondary target species were analyzed as single-species 5 fish composites. For largemouth bass and white catfish, stratified size ranges were targeted at each sampling station, to obtain data across a range of expected lengths and ages for adult fish (Schaffter, 1998; Moyle, 2002; Davis et al., 2003). For other species, a single size range was targeted (Table 1). Sampling locations were selected to include known fishing areas and to provide broad geographic coverage. Fish were collected from 26 locations in the Delta region in September and October 1999 and 22 locations in September and October of 2000 (Fig. 1).

All collections were performed with an electrofisher boat and fyke nets. Total length was measured in the field. Fish were wrapped in chemically cleaned Teflon sheeting and frozen whole on dry ice for transportation to the laboratory. After thawing, fish were rinsed with de-ionized (DI) water, and were handled only with polyethylene gloves. Dissection and compositing of muscle tissue samples were performed following U.S. EPA (2000a). Sample preparation materials were cleaned by scrubbing with Micro® detergent, rinsing with tap water, DI water, and finally ASTM Type II water. Two hundred grams of fillet were dissected from each fish for analysis. All fillet samples were skin-on except for white and channel catfish, from which skins were removed. Fish scales were removed from largemouth bass, striped bass, Sacramento pikeminnow, Sacramento sucker, blue gill, redear sunfish, crappie, and common carp prior to skin-on dissection. Fillet tissue was taken from one side of the fish, below the dorsal fin and behind the gill, and rib bones were excluded. Samples were homogenized with a Büchi Mixer B-400 with a titanium cutter.

**Table 1 – Sampling strategy for target species**

| Species | Sample type | Size targeted (mm) | Number targeted |
|---|---|---|---|
| Largemouth bass | Individual | 200–249 | 2 |
| | | 250–304 | 2 |
| | | 305–438 | 7 |
| | | >438 | 3 |
| White catfish | Individual | 130–179 | 2 |
| | | 180–228 | 2 |
| | | 229–330 | 7 |
| | | >330 | 3 |
| Striped bass | Individual | >457 [a] | |
| Sacramento pikeminnow | Individual | 195–400 | 5 |
| Bluegill | Composite | 90–175 | 5 |
| Redear sunfish | Composite | 125–225 | 5 |
| Black crappie | Composite | 150–300 | 5 |
| Common carp | Composite | 400–600 | 5 |
| Channel catfish | Composite | 300–500 | 5 |
| Sacramento sucker | Composite | 340–500 | 5 |

[a] Legal size limit.

For total Hg analysis, tissue samples were digested with a 70:30 nitric:sulfuric acid solution. Samples were analyzed using a Perkin Elmer Flow Injection Mercury System (FIMS) with an AS-90 autosampler. Samples, blanks, reductant, and standards were prepared using clean techniques. ASTM Type II water and ultra clean chemicals were used for all standard preparations. A continuing calibration verification (CCV) was performed after every 10 samples and samples run between CCVs that drifted greater than 10% were reanalyzed. Three blanks, a standard reference material (SRM), a method duplicate, and a matrix spike pair were run with each set of samples.

The samples were digested and analyzed in 16 batches. SRM (DORM-2, National Research Council of Canada) recoveries averaged 99.6%, and all 16 were within the 25% criterion established in the QAPP. The Hg matrix spike recoveries averaged 99.7%, and all matrix spikes and matrix spike duplicates were within the 25% criterion in the QAPP. All of the Hg matrix spike RPDs and lab duplicate RPDs were below 25% and all method blanks were below the detection limit. Split samples from 40 fish samples were analyzed by an independent lab (Frontier Geosciences, Seattle, WA). Out of 44

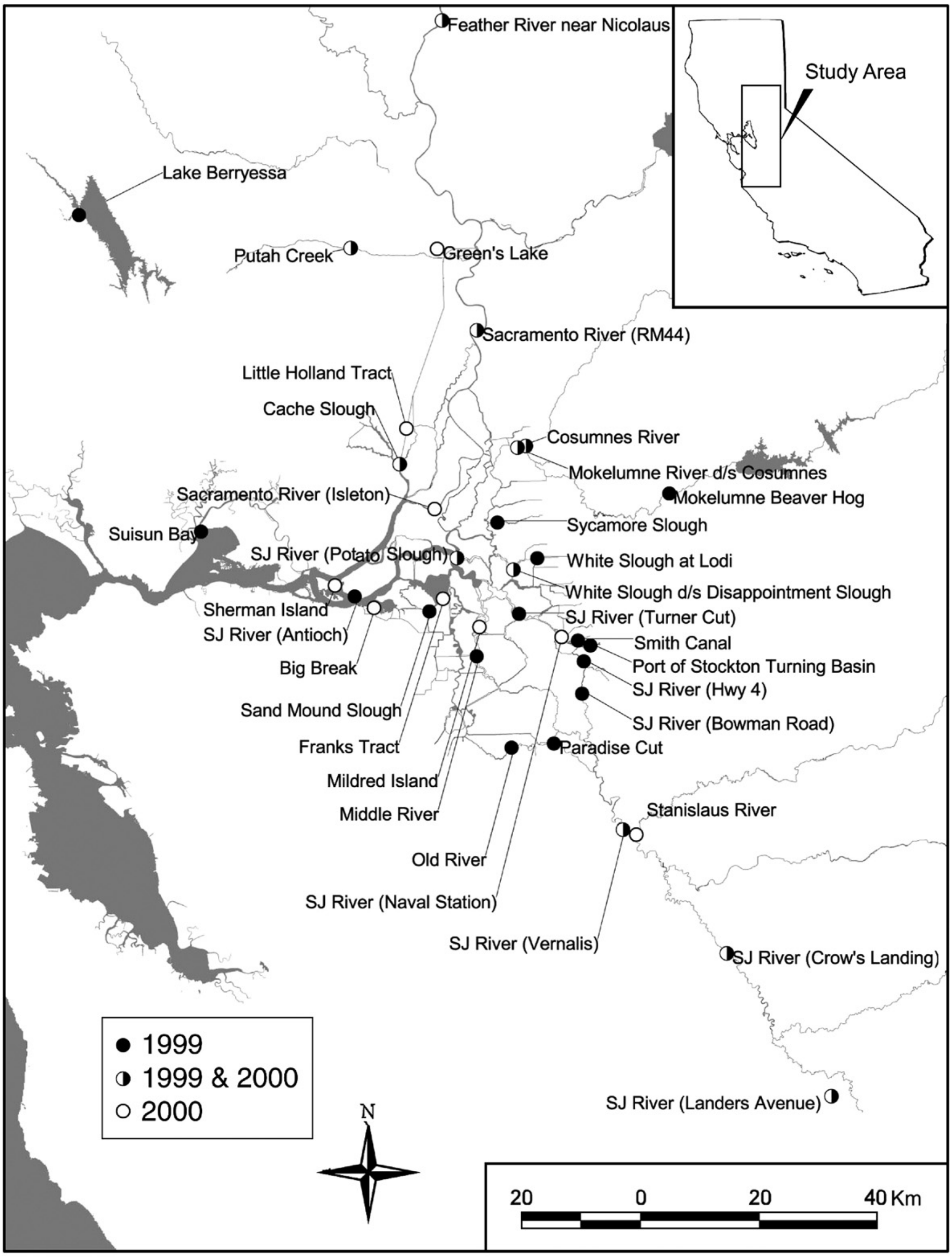


**Fig. 1 – Sampling locations. Note that one station (Feather River above Yuba River) is north of the map.**

split samples, only two had RPDs greater than 25%, indicating good agreement between the labs (Gauthier et al., 2003).

### 2.2. *Statistical analysis and comparison to thresholds*

For all species, mercury concentrations were compared to thresholds that form the basis for the national advisory for mercury in fish that was jointly issued in 2004 by the U.S. Food and Drug Administration and the U.S. Environmental Protection Agency (U.S. EPA, 2000b, 2004a,b). The thresholds used (0.12 $\mu g\ g^{-1}$, 0.31 $\mu g\ g^{-1}$, and 0.47 $\mu g\ g^{-1}$) correspond to risk-based consumption limits of 4, 2, and 1 meals per month. In other words, for fish with concentrations above 0.47 $\mu g\ g^{-1}$, the guidance indicates that no more than 1 meal

**Table 2 – Combined statistics from 1999 and 2000 on human health threshold exceedances**

| Species | N | Length (mm) | Hg (μg g$^{-1}$ wet) | >0.12 μg g$^{-1}$ (%) | >0.31 μg g$^{-1}$ (%) | >0.47 μg g$^{-1}$ (%) |
|---|---|---|---|---|---|---|
| Black crappie | 6 | 238 | 0.33 | 67 | 67 | 17 |
| Bluegill | 37 | 155 | 0.11 | 43 | 11 | 0 |
| Channel catfish | 11 | 444 | 0.50 | 100 | 73 | 64 |
| Common carp | 9 | 450 | 0.26 | 89 | 33 | 11 |
| Largemouth bass | 406 | 350 | 0.53 | 94 | 72 | 55 |
| Redear sunfish | 20 | 177 | 0.10 | 30 | 5 | 0 |
| Sacramento pikeminnow | 43 | 357 | 0.42 | 84 | 58 | 49 |
| Sacramento sucker | 17 | 429 | 0.27 | 94 | 35 | 6 |
| Striped bass | 42 | 565 | 0.49 | 100 | 86 | 52 |
| White catfish | 176 | 276 | 0.33 | 86 | 52 | 31 |

Length and Hg are reported as medians. $N$=number of individual or composite samples (see Table 1).

per month should be consumed to maintain a safe level of mercury exposure.

In 2000, a large sample of largemouth bass ($N$=275) was successfully captured across a broad size range, including between 10 and 16 samples per location. Therefore, largemouth bass collected in 2000 were the focus of statistical analysis of spatial patterns in tissue Hg. Among the 21 locations sampled for largemouth bass in 2000 (Fig. 1), Green's Lake and Little Holland Tract were excluded from the spatial analysis due to lack of sampling success. Given the expected strong influence of fish length on Hg concentration (e.g., Huckabee et al., 1979; Wiener et al., 2002), analysis of covariance (ANCOVA) was used to evaluate differences among locations or sampling events, while accounting for the effect of length. An assumption in conventional ANCOVA is that the slope of the length:Hg regression line is equal among all locations; however, this assumption is often inappropriate. We therefore performed ANCOVA, including dummy variables for both slope and intercept, following the method of Tremblay et al. (1995, 1998). The approach also allows for curvilinear relationships between length and Hg by including a polynomial term in the regression analysis.

The following steps were taken in applying the Tremblay et al. (1995, 1998) method to the 2000 largemouth bass data. The computations were performed using macros developed in SAS (SAS Institute, 1990).

1) The length data were centered by subtracting the mean length.
2) A backward elimination regression analysis with dummy variables for intercept, slope, and a polynomial term for each location was run on the untransformed Hg data along with a Box-Cox analysis (Draper et al., 1998) of the optimal transformation for achieving normality and minimizing

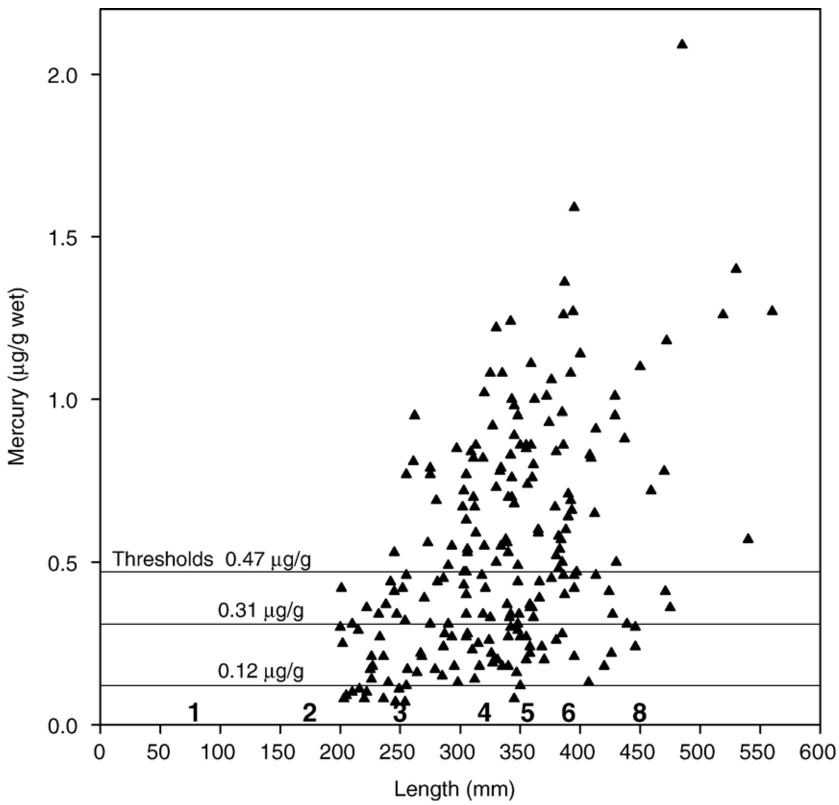


**Fig. 2 – Mercury concentrations versus length in largemouth bass from the Delta region, 2000. Numbers on top of $x$-axis show mean total length at indicated age for largemouth in the Delta (Schaffter 1998).**

variance in the residuals of the regression. For this data set, the square-root transformation was optimal.
3) The backward elimination regression was then run again with the optimally transformed (square-root) Hg data.
4) Coefficients with $p<0.05$ were retained in the model.
5) The resulting regression equation was used to calculate predicted Hg concentrations (mean and 95% confidence interval) at a standard length of 350 mm for each location. The 350 mm value was selected to represent the middle of the typical size distribution above the legal limit of 305 mm (12 in) for largemouth bass in California.

## 3. Results and discussion

### 3.1. *Tissue concentrations and comparisons to risk categories*

All species exhibited some exceedances of the 0.12 μg $g^{-1}$ threshold corresponding to a 4 meals per month safe consumption limit. Only bluegill and redear sunfish had a majority (>50%) of samples below this threshold (Table 2). Over 90% of the samples of channel catfish, largemouth bass, Sacramento sucker, and striped bass were above this threshold. Over 50% of the channel catfish, largemouth bass, and striped bass were above the 0.47 μg $g^{-1}$ threshold corresponding to a 1 meal per month consumption limit. Shifting fishing pressure to the relatively small "panfish" of *Lepomis* genus (bluegill and redear sunfish) would be one way to achieve a near-term reduction of human exposure to methylmercury in the region.

Of the two species captured in greatest abundance, median concentrations were higher in largemouth bass (0.53 μg $g^{-1}$) than in white catfish (0.33 μg $g^{-1}$) (Table 2). Of 406 largemouth bass captured, only 23 (6%) were below the 0.12 μg $g^{-1}$ threshold, and most of these were below the 305 mm legal size limit for largemouth bass in California (as shown for the 2000 samples in Fig. 2). Most of the largemouth bass (222 fish, or 55% of the sample) were above the 0.47 μg $g^{-1}$ threshold, and 294 fish (72%) were above the 0.31 μg $g^{-1}$ threshold corresponding to a 2 meals per month safe consumption limit.

For largemouth bass across all sites, Hg was weakly but significantly correlated with length in 1999 (linear regression $R^2=0.33$; $p<0.0001$; $N=188$) and in 2000 (Fig. 2; $R^2=0.23$; $p<0.0001$; $N=218$). The regression $R^2$ was greater in 1999 because nine composite samples of young-of-year fish were analyzed in 1999, whereas the smallest fish sampled in 2000 was 200 mm. These nine samples ranged in average length from 59–66 mm, and had a median Hg concentration of 0.031 μg $g^{-1}$, anchoring the regression.

The frequent tissue exceedance of safe consumption guidelines, as well as evidence that low income and minority women consume local sport fish (Silver et al., 2007), suggest that mercury accumulation in sport fish in the Delta region is a human health concern. As a result of these findings and other recent studies, the State of California has developed site-specific fish consumption advisories for the Delta and some surrounding tributaries (Gassel et al., 2006a; Gassel et al., 2006b; Klasing et al., 2006).

### 3.2. *Spatial patterns in largemouth bass Hg*

The regression equation describing the reference condition (arbitrarily set as White Slough) was: square-root (Hg) = 0.449 + 0.00178(LC), where LC is the centered length. Two locations (Sacramento River at RM44 and Mokelumne River downstream of Cosumnes) were found to have significantly higher slopes than the other locations ($p=0.005$ and 0.03, respectively) (Fig. 3). Differences in slope could be caused by differences in prey mercury or biological factors such as differences in growth rate (a slow-growing population would have a higher

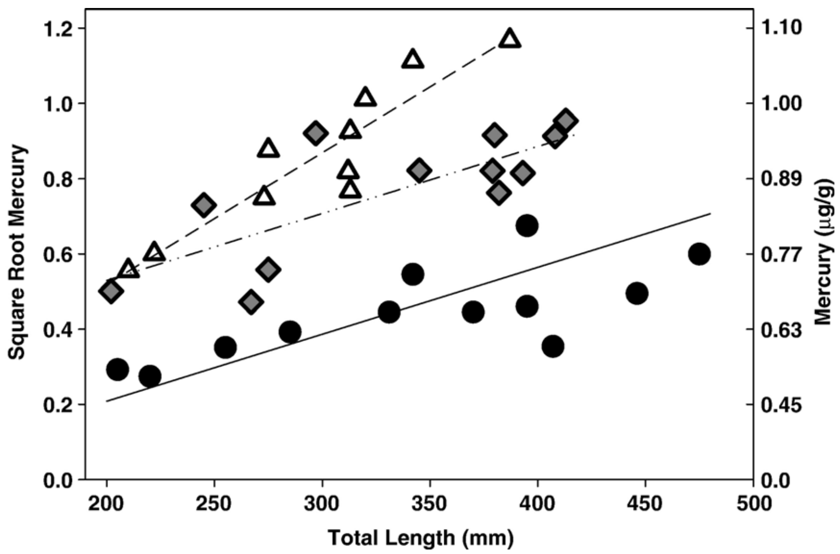


**Fig. 3 – Mercury versus length in largemouth bass at three sampling locations, 2000. Regression lines shown are results from polynomial regression ANCOVA (see Methods for details). ● (solid line) = White Slough at Lodi (reference condition). ◆ (dot and dash line) = San Joaquin River at Crows Landing. Δ (dotted line) = Mokelumne River downstream of Cosumnes River. Mercury concentrations are presented on a square-root scale, to observe results of linear model fit. The left axis units are square-root concentrations and the right axis units are corresponding untransformed concentrations.**

slope) or consumption rate (which might vary due to factors such as the nutritional quality of prey). A polynomial term was not significant for any of the locations, indicating that a straight line adequately fit square-root transformed data from each location. Of the 19 locations included in the analysis, 15 had significantly ($p<0.05$) higher intercepts than the reference condition, and 4 were not significantly different from the reference condition. For locations with similar slopes (which was the case for 17 of the 19 locations), differences in the intercept term indicate differences in mean concentration among locations.

Fig. 3 shows regression lines resulting from the analysis, for three representative locations in the dataset. Fig. 3 includes a location representing the baseline condition (White Slough at Lodi), a location with significantly higher slope and intercept (Mokelumne River) and a location with significantly higher intercept only (San Joaquin River at Crow's Landing). The entire data set and graphical analysis for individual stations are available in Davis et al. (2003), or by contacting the authors.

In interpreting the differences in intercept and slope among groups of fish from different locations, it should be borne in mind that these regressions provide a tool for describing and comparing size:Hg relationships for populations within a limited portion of the overall size range for largemouth bass. The lines with constant slopes and varying intercepts for the square-root transformed data describe these limited portions of the size:Hg curve well, but should not be considered good descriptors of the entire curve. In reality, the intercepts at all locations are near zero because concentrations in fish eggs are a small fraction of those in maternal muscle tissue (Johnston et al., 2001). In addition, mercury concentrations increase with age/size in a manner that varies as the diet (species and size of prey) and physiology change over the lifespan of the fish, and as similar changes occur in prey species. Therefore a line with a constant slope is only a crude approximation of a more complex pattern that is likely to exist in reality.

The equations resulting from the ANCOVA were used to estimate mean Hg concentrations of largemouth bass at 350 mm, along with 95% upper and lower confidence intervals for the means (Fig. 4). Significant differences among locations are indicated by non-overlapping confidence intervals. These results indicate that the significant spatial variation is organized by watershed, with elevated concentrations in areas around the periphery of the Delta and reduced concentrations in the central Delta.

Concentrations within river systems were generally consistent and not significantly different from one another (Fig. 4). The highest concentrations were observed in the Cosumnes River system, including the Cosumnes River and Mokelumne River (downstream of Cosumnes) locations. The Mokelumne River location had the highest standardized mean concentration, and was significantly higher than all other locations except Sacramento River at River Mile 44, Cosumnes River, and San Joaquin River at Vernalis (Fig. 4). Cosumnes River had the second highest estimated mean, and was significantly higher than Putah Creek, Cache Slough, San Joaquin River at Landers Avenue, and all of the central Delta locations. The highly elevated tissue concentrations

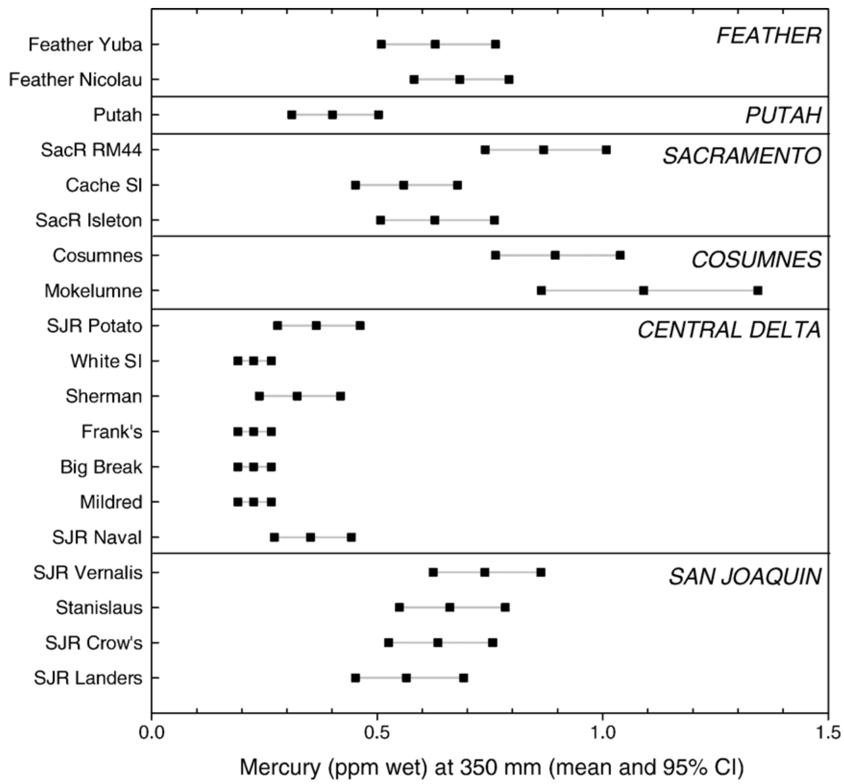


**Fig. 4 – Spatial comparison of largemouth bass mercury concentrations estimated at standard length of 350 mm (mean and 95% confidence interval) by the polynomial regression ANCOVA method. Locations are listed in north (top) to south (bottom) order. Locations with non-overlapping intervals are significantly different.**

in the Cosumnes and Mokelumne Rivers have resulted in development of draft recommendations to consume less fish than in other water bodies in the Delta region (Gassel et al., 2006a; Gassel et al., 2006b; Klasing et al., 2006). For example, women of childbearing age, pregnant and breastfeeding women, and children less than 17 years old are advised not to consume largemouth or smallmouth bass, or Sacramento pikeminnow (Klasing et al., 2006).

The Feather River, Sacramento River, and San Joaquin River systems formed a group with lower length-standardized mean concentrations than the Cosumnes and Mokelumne rivers, but still significantly elevated above central Delta locations (Figs. 3, 4). The two Feather River locations were significantly higher than all central Delta sites and Putah Creek. This region yielded even higher concentrations in 1999 when some larger fish were caught (Davis et al., 2003).

In the Sacramento River system, the Sacramento River at River Mile 44 had the third highest length-standardized mean concentration of all locations, and was significantly higher than Putah Creek, Cache Slough, San Joaquin River at Landers Avenue, in addition to all of the central Delta locations. Sacramento River at River Mile 44 also had a significantly elevated slope. Elevated concentrations in the Sacramento River are consistent with elevated water Hg concentrations, resulting from the influence of upstream historic gold and Hg mining activity (Domagalski, 1998, 2001). Lower concentrations were measured at Sacramento River locations closer to the central Delta (Cache Slough and Sacramento River at Isleton), with Cache Slough significantly lower than Sacramento River at River Mile 44. Putah Creek, in spite of extensive historic Hg mining in its watershed (reviewed in Gassel et al., 2006a), had a significantly lower average concentration than several locations in the Cosumnes, Feather, Sacramento, and San Joaquin rivers, and was significantly higher than only the lowest central Delta sites.

Length-standardized mean Hg concentrations in largemouth bass from the four locations in the San Joaquin River system were comparable to those in the Feather and Sacramento Rivers. Mean concentrations were consistent among the locations, ranging from 0.69 $\mu g\ g^{-1}$ at Landers Avenue to 0.86 $\mu g\ g^{-1}$ at Vernalis, even though the locations were spread over approximately 25 miles. In 1999, largemouth bass with elevated concentrations were also collected at San Joaquin River locations further into the Delta, including an average concentration of 0.95 $\mu g\ g^{-1}$ at San Joaquin River at Bowman Road. The largemouth bass data from the San Joaquin system collected in this study and in Davis et al. (2000) established the existence of a regional problem that had not previously been recognized.

In spite of elevated Hg concentrations on all of its tributaries, the central Delta had length-standardized mean Hg concentrations that were low both in comparison to safe consumption guidelines and to other locations. In the ANCOVA, central Delta locations fell into two groups. Four stations (White Slough, Frank's Tract, Big Break, and Mildred Island) had identical estimated mean concentrations of 0.27 $\mu g\ g^{-1}$. These means were identical due to the selection of White Slough as the "default" condition in the regression, and lack of significant coefficients for dummy variables for the other three stations. The means for these four stations were significantly lower than those of every other location except Sherman Island (Fig. 4). Three stations (San Joaquin River at Potato Slough, Sherman Island, and San Joaquin River at Naval Station) formed a group with concentrations that were significantly higher than the four lowest locations, but significantly lower than most other locations. In 1999, a largely different array of central Delta locations was sampled (Fig. 1) and yielded similarly low concentrations, with means (not at standard length) in the 0.2–0.4 $\mu g\ g^{-1}$ range (Davis et al., 2003).

### 3.3. *The use of largemouth bass as primary target species*

Largemouth bass, the primary focus of the sampling effort, exhibit several useful characteristics as an indicator species for Hg contamination in the Delta region. First, largemouth bass are voracious predators, and, like other predatory fish species, they are susceptible to accumulation of high Hg concentrations. Second, they are abundant and distributed widely throughout the study area. In the most recent abundance sampling performed by California Department of Fish and Game (CDFG), largemouth bass were third in catch per unit effort, behind only bluegill and redear sunfish (Michniuk and Silver, 2002). The Delta population of largemouth bass is increasing (Nobriga et al., 2000; Moyle, 2002). This allows for adequate numbers of samples from multiple widespread locations, with reasonable sampling effort. Finally, largemouth bass have high site fidelity, and are therefore a useful indicator of spatial variation in Hg accumulation. Of 1206 tag returns recorded by CDFG, 65% of the fish were found within 1 mile of the site of release, 83% were within 5 miles, and the median distance between release and recapture was 0 miles (Ray Schaffter, CDFG, unpublished data).

A large portion of California anglers target largemouth bass, and largemouth bass support a popular sport fishery in the Delta (Lee, 2000). "Black bass" (black bass include largemouth, smallmouth [*Micropterus dolomieu*], spotted [*Micropterus punctulatus*], and redeye bass [*Micropterus coosae*]) fishing tournaments are increasingly popular in the Delta, with 1681 permits issued for tournaments in this region from 1985–1999, representing 845,036 angler hours and 171,240 black bass captured. Most of the fish caught in these tournaments are released alive. CDFG and others have taken many steps to enhance largemouth bass fishing, including widespread introduction, establishing legal size limits, the introduction of a Florida strain of largemouth into the Delta in the 1980s (Lee, 2000), and regulating the bass tournaments.

It is unclear, however, how much human consumption of largemouth bass occurs. Tag-recapture data indicate that 90% of largemouth bass caught in the Delta are released (Schaffter, 2000). A CDFG creel survey in the Delta region (Murphy et al., 2001) found relatively few angler hours spent fishing for black bass, and a low proportion of fish kept: only 1223 bass were reported kept in 2000, compared to 59,704 striped bass and 40,600 catfish. However, anglers that reported targeting "anything" kept 15,866 fish, and likely added to the largemouth bass catch.

### 3.4. *Factors influencing Hg accumulation*

Length influenced Hg concentrations, and provided the foundation for the ANCOVA presented above. Age data were collected for the 1999 samples, but had weaker correlations with Hg (data not shown) and were not used in statistical analysis. Age and trophic position are two important influences on Hg concentrations observed in fish. The largemouth bass collected in this study were primarily between the 305 mm legal limit and 438 mm. Based on growth rates observed in the Delta (Schaffter, 1998), this corresponds to about 4 to 7 years of age (Fig. 2). However, growth rates in the Delta are slow relative to other areas (Schaffter, 1998), so this size range may represent younger fish in other parts of the watershed. Young-of-the-year largemouth bass feed on aquatic insects and fish fry. Older fish (age one and older) feed primarily on fish (Moyle, 2002; Olson and Young, 2003). Largemouth bass are flexible in their foraging, however, and occasionally target crayfish and tadpoles. Individual largemouth bass are also known to develop preferences for particular species (Moyle, 2002). It is conceivable, therefore, that trophic position in largemouth bass could vary across the watershed or over time, and that this could influence observed Hg concentrations. Additionally, as bass get larger, they will be able to consume larger prey, and Slotton et al. (2002) indicate a significant correlation between body size and Hg for prey organisms captured in the region.

Lower tissue Hg concentrations in the central Delta have also been observed for Asiatic (also known as Asian) clams (*Corbicula fluminea*), Mississippi silverside (*Menidia audens*), and other small fish species (Slotton et al., 2002). The similar spatial patterns in lower trophic level organisms suggest that variation in prey Hg is the primary cause of the striking spatial variation observed in largemouth bass.

Studies of methylmercury concentrations in water in the Delta in the same time period covered by the present study found similar spatial patterns in unfiltered water samples to those observed in largemouth bass and lower trophic level species (Foe, 2003). A TMDL for methylmercury in the Delta is being established (Wood et al., 2006) with the relationship between methylmercury in sport fish and in unfiltered water samples providing a foundation for the implementation goal for the TMDL — 0.06 ng/L methylmercury in unfiltered water. Wood et al. (2006) presented a regression analysis for the largemouth bass data reported in this article and the unfiltered aqueous methylmercury data of Foe (2003), which was statistically significant ($p<0.05$) with $R^2=0.91$.

In contrast, concentrations of methylmercury in sediments measured in this same time period did not correlate with concentrations in fish. Methylmercury concentrations in sediment were actually higher in the Delta than the upstream tributaries, Prospect Slough and the Cosumnes River (Heim et al., 2007). Net rates of sediment methylmercury production were also higher in a Delta site (Frank's Tract) than an upstream site in the Sacramento River drainage system (Prospect Slough) (Marvin-DiPasquale and Agee, 2003). This spatial disparity between biota Hg and sediment methylmercury observations is surprising because correlations between these parameters have been observed in other systems — e.g., Gilmour et al. (1998).

The CALFED Program has recently funded studies aimed at determining the mechanisms behind the unusual spatial patterns in biota Hg and sediment methylmercury (Marvin-DiPasquale et al., 2005). Pickhardt et al. (2006) found that dietary uptake rates in fish were far greater than uptake rates from aqueous exposure, and were similar in water collected from a Delta site (Frank's Tract) versus water from the Cosumnes River. These findings and preliminary stable isotope evidence (Davis et al., 2003; Marvin-DiPasquale et al., 2005) do not support hypotheses of different rates of methylmercury dietary uptake or trophic transfer. Other potential mechanisms for reduced concentrations in central Delta fish include reduced rates of methylmercury flux from sediments to the overlying water column, regional differences in plant–Hg interactions, or higher rates of photodegradation (Byington et al., 2005; Marvin-DiPasquale et al., 2005).

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