

MERCURY IN SPORT FISH FROM THE DELTA REGION (TASK 2A)

Final Report Submitted to the CALFED Bay-Delta Program for the Project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed

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EXECUTIVE SUMMARY

In spite of the popularity of the Delta as a fishing location, human health concerns raised beginning in 1971, the existence of a consumption advisory for the Bay, and recent concern over fish tissue contamination in the Sacramento River watershed, very little systematic sampling has been conducted in the Delta to evaluate human health risks associated with chemical contamination of fish tissue. This report documents the most detailed study of mercury contamination in sport fish from the Delta region ever performed.

The objectives of this study were, in order of priority:

- Determine whether mercury occurs in sport fish at concentrations of potential human health concern and provide the information needed to determine whether further consumption advice should be issued;
- Firmly establish present mercury concentrations in sport fish as a basis for assessing long term trends;
- Evaluate spatial patterns in mercury accumulation at high trophic levels in the Bay-Delta; and
- Evaluate important factors influencing mercury concentrations such as age/size and trophic position.

Key features of the sampling design aimed at meeting these objectives were 1) sampling of a wide variety of species and 2) analysis of mercury in individual fish for the primary target species.

Sampling was performed in late summer 1999 and 2000. Primary target species, including largemouth bass, white catfish, striped bass, and Sacramento pikeminnow, were analyzed as individuals. Secondary target species, including channel catfish, black crappie, Sacramento sucker, common carp, bluegill, and redear sunfish, were sampled as multi-individual composites. Measured concentrations were compared to a screening value for mercury, defined as a concentration in fish or shellfish tissue that is of potential public health concern. Exceedance of the screening value should be interpreted as an indication that more intensive site-specific monitoring and/or evaluation of human health risk should be conducted. The screening value used in this report (0.3 ppm wet weight) was published in a recent report by the California Office of Environmental Health Hazard Assessment - the agency responsible for managing health risks due to contaminated sport fish in California.

The principal conclusions of the study are:

- Several species (including largemouth bass, striped bass, Sacramento pikeminnow, channel catfish, and white catfish) had mercury concentrations of high human health concern, exceeding the screening value (0.3 ppm) in a majority of samples and frequently exceeding 1 ppm.
- Two species had mercury concentrations of moderate human health concern (exceeding the screening value in 30-50% of samples): common carp and Sacramento sucker.
- Two species that are abundant and widespread in the Delta region, bluegill and redear sunfish, had methylmercury concentrations that infrequently exceeded the 0.3 ppm threshold for concern (less than 10% of samples). These species are popular for consumption with many anglers throughout the nation and provide excellent sport on ultra-light tackle. Shifting fishing pressure to these species would be one way to immediately reduce human exposure to methylmercury in the region.
- Significant spatial variation exists in the watershed. Mercury concentrations in the Feather River, northern Delta, lower Cosumnes River, and San Joaquin River regions were significantly elevated and in the 1 ppm range. Concentrations in the central Delta region were significantly lower than other locations, and usually below the screening value. These regional patterns were evident among several sport fish species. There was a precipitous drop in concentrations between nearby stations in the Central Delta.
- Mercury concentrations in recent samples of striped bass, which are integrative indicators of mercury in the watershed, were similar to those measured in 1970-71, suggesting the lack of a decline over this 30 year period. Some striped bass samples collected for this study were high even relative to the concentrations measured 30 years ago.

INTRODUCTION

In 1969, as the scope of worldwide environmental contamination due to mercury was first being discovered, two striped bass from the Delta were found to have 0.70 ppm wet weight (all concentrations in this report are presented in wet weight) mercury in their muscle tissue. In 1970, as a result of this finding, an Interagency Committee was created to evaluate mercury contamination in California (California State Department of Public Health 1971). The Committee assembled existing data and initiated further studies of mercury in sport fish, commercial fish, game birds, water, and sediments. In samples collected between April and July 1970, 55 of 102 fish collected in the Delta region were higher than a 0.5 ppm “federal tolerance level” (the report does not provide any further description of this guideline) in place at that time. This included 42 striped bass weighing over 4 pounds that were all higher than 0.5 ppm. In late 1970, based on these studies, a human health advisory was issued for the Delta advising pregnant women and children not to consume striped bass (R. Brodberg, OEHHA, pers. comm.).

In 1993 the advisory for the Delta was revised by the California Environmental Protection Agency’s Office of Environmental Health Hazard Assessment (OEHHA) upon review of more mercury data for striped bass. The revised advisory included size-specific consumption advice for adults, children 6-15 years, and pregnant women and children under age 6.

Recent studies in the Bay-Delta watershed have also found concentrations of mercury and other chemicals that are of potential human health concern in striped bass and other popular sport fish species. Extensive sampling was conducted in San Francisco Bay in 1994 and 1997 (Fairey et al. 1997, Davis et al. 2002). In response to the 1994 results, an interim fish consumption advisory was issued for the Bay-Delta, due to concern over human exposure to methylmercury, PCBs, organochlorine pesticides, and dioxins (OEHHA 1994). This advisory is still in place. The current version of the advisory states that:

- Adults should limit consumption of Bay sport fish, and striped bass and sturgeon from the Delta to, at most, two meals per month.
- Adults should not eat any striped bass over 35 inches (89 cm).
- Pregnant women or women that may become pregnant or are breast-feeding, and children under 6 should not eat more than one meal per month, and should not eat any meals of shark over 24 inches (61 cm) or striped bass over 27 inches (69 cm).

In spite of the popularity of the Delta as a fishing location, the concerns raised in the 1971 report (California State Department of Public Health 1971), the existence of the consumption advisory for the Bay, and recent concern over fish tissue contamination in the Sacramento River watershed, until recently very little sampling had been conducted in the Delta since 1971 to evaluate human health risks associated with chemical contamination of fish tissue. In 1998 a study of concentrations of mercury and other contaminants in sport fish from the Delta region was conducted, focusing on largemouth bass and white catfish and analyzing composite samples from many locations (Davis et al. 2000). This study identified significant regional variation in mercury concentrations, with elevated concentrations in Delta tributaries (including the Feather River, Sacramento River, American River, and San Joaquin River), and low concentrations (below the 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 mercury concentrations.

This report describes one component of the multifaceted CALFED Mercury Project that followed up on the 1998 work by conducting an intensive, focused evaluation of mercury contamination in sport fish from the Delta region. This was the most systematic, comprehensive survey of mercury contamination in Delta sport fish ever performed.

The objectives of this study were, in order of priority:

- Determine whether mercury occurs in sport fish at concentrations of potential human health concern and provide the information needed to whether further consumption advice should be issued;
- Firmly establish present mercury concentrations in sport fish as a basis for assessing long term trends;
- Evaluate spatial patterns in mercury accumulation at high trophic levels in the Bay-Delta; and
- Evaluate important factors influencing mercury concentrations such as age/size and trophic position.

Key features of the sampling design aimed at meeting these objectives were 1) sampling of a wide variety of species and 2) analysis of mercury in individual fish for the primary target species.

METHODS

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 (Figure 1). A shift toward a slightly different array of locations was made in 2000 in an effort to align the sport fish sampling locations with those being sampled by other researchers for lower trophic level biota, water, and sediment. New locations were also sampled in order to obtain more complete coverage of regions with high mercury, such as the Feather River region.

The primary target species (largemouth bass, white catfish, and striped bass) were analyzed as individuals. Secondary target species (bluegill, Sacramento pikeminnow, redear sunfish, channel catfish, Sacramento sucker, brown bullhead, black crappie, and Sacramento blackfish) were analyzed as composites of 5 fish each. Target size ranges were established for all species (Table 1) following USEPA guidance (USEPA 2000) which specifies that the smallest fish in a composite should be no less than 75% of the largest. Each location was sampled for as long as it took to obtain the desired number of the primary target species, and the secondary target species encountered during this time were also kept. In 1999, following the precedents of previous studies and USEPA guidance for composite sampling, the primary target species largemouth bass and white catfish were collected in relatively narrow size ranges. The data obtained provided an inadequate basis for regression analysis of length:mercury relationships. In 2000, the sampling design was modified to include collection of largemouth bass and white catfish from smaller size ranges in order to provide a better basis for regression.

Fish were collected with an electrofisher boat and with fyke nets. Total length (longest length from tip of tail fin to tip of nose/mouth) was measured in the field. Information on bycatch, including species and approximate numbers, was recorded. Fish were wrapped in chemically cleaned Teflon sheeting and frozen whole on dry ice for transportation to the laboratory. Dissection and compositing of muscle tissue samples were performed following USEPA guidance (USEPA 2000). Fish were kept frozen wrapped in Teflon in their original bags until the time of dissection. At the time of dissection, fish were placed in the clean lab in their original bags to thaw. After thawing, fish were cleaned by rinsing with de-ionized (DI) water, and were handled only by personnel wearing polyethylene gloves. Total length and weight for individual fish were taken prior to dissection. All dissection materials were cleaned by scrubbing with Micro® detergent, rinsing with tap water, DI water, and finally ASTM Type II water.

Fish scales were removed from largemouth bass, striped bass, Sacramento pike minnow, Sacramento sucker, blue gill, red ear sunfish, crappie and common carp prior to skin on dissection. Skins were removed from white catfish and channel catfish prior to dissection. Dissections were done on a Teflon cutting board. For composites approximately 40 grams of fillet were taken from each of 5 fish for a total of approximately 200 grams per sample. All 200 grams were taken from a single fish for fish analyzed as individuals. Samples were homogenized with a Büchi Mixer B-400 with a titanium cutter. The cutter was cleaned between samples in the same manner as the dissection materials.

Total mercury in muscle tissue was measured by Moss Landing Marine Lab. 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 rerun. Three blanks, a standard reference material (DORM-2 for total and methylmercury), as well as a method duplicate and a matrix spike pair were run with each set of samples.

The 1999 mercury samples were digested and analyzed in 36 batches (Appendix 1). SRM (DORM-2 from the NRC) recoveries averaged 100%, and all 36 were within the 25% criterion established in the QAPP. The mercury matrix spike recoveries averaged 104%, and all matrix spikes and matrix spike duplicates were within the 25% criterion in the QAPP. All of the mercury matrix spike RPDs and lab duplicate RPDs were below 25% and all method blanks were below the detection limit.

The 2000 mercury samples were digested and analyzed in 16 batches (Appendix 2). SRM (DORM-2 from the NRC) recoveries averaged 99.6 %, and all 16 were within the 25% criterion established in the QAPP. The mercury 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 mercury 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). Out of 40 split samples, only two had RPDs greater than 25%, indicating good agreement between the labs. Details are provided in Appendix 4 of Heim et al. (2003).

Stable isotopes of nitrogen and carbon were measured by the University of Utah in 1999 and by UC Davis in 2000. For stable isotope analysis, samples were dried in a 65 to 70 degree Celsius drying oven for 48 to 72 hours and were ground to a flour-like texture. One mg aliquots were used in stable isotope analysis. In 1999, stable isotope ratios were determined at the Stable Isotope Ratio Facility for Environmental Research, University of Utah, using a Finnigan MAT Delta mass spectrometer. In 2000, stable isotope ratios were determined at the Stable Isotope Facility, University of California, Davis using a Europa Scientific Hydra 20/20 continuous flow isotope ratio mass spectrometer and Europa ANCA-GSL elemental analyzer to convert organic C and N into carbon dioxide and N₂ gas. Isotope results are presented as $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$. For $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$:

$$\delta X = [(R_{\text{sample}}/R_{\text{standard}}) - 1] * 1000$$

where $\delta X = \delta^{15}\text{N}$ or $\delta^{13}\text{C}$ and $R = {}^{15}\text{N} / {}^{14}\text{N}$ or ${}^{13}\text{C} / {}^{12}\text{C}$. The standard for N is atmospheric N₂ and for C it is Peedee Belemnite.

Mercury concentrations were compared to a screening value calculated following U.S. EPA guidance (2000). U.S. EPA (2000) defines screening values as concentrations of target analytes in fish or shellfish tissue that are of potential public health concern. Exceedance of screening values should be taken as an indication that more intensive site-specific monitoring and/or evaluation of human health risk should be conducted. The screening value used in this report (0.3 ppm wet weight) was published in a recent report by OEHHA (1999). OEHHA is the agency responsible for managing health risks due to contaminated sport fish in California. OEHHA (1999) used a consumption rate of 21 g/day in the calculation. The frequency of exceedance of the screening value was used to categorize levels of concern for the different fish species: species with greater than 50% of samples above 0.3 ppm fell in the high concern category; species with 10 – 50% of samples above 0.3 ppm were in the moderate category; and species with less than 10% were in the low concern category. These categories do not have any regulatory significance; they were simply used for descriptive purposes for this report.

Statistical analysis of spatial patterns in mercury concentrations in largemouth bass was performed following the method of Tremblay et al. (1995, 1998). Given the usual strong influence of fish length or age on mercury concentration (e.g., Huckabee et al. 1979, Wiener et al. 2003), analysis of covariance (ANCOVA) is an appropriate tool for detecting significant differences among locations (e.g., Watras et al. 1998). An assumption in conventional ANCOVA is that the slope of the length:mercury regression line is equal among all locations. This assumption is often inappropriate, and would have been inappropriate for the dataset presented in this report. The Tremblay method performs a type of analysis of covariance that does not require equal slopes, and actually allows testing of whether the slopes of different locations are significantly different from each other. The Tremblay method also allows for curvilinear relationships between length and mercury by including a polynomial term in the regression analysis. The method employs dummy variables and backward, stepwise elimination regression to determine differences in means, slopes, and curve shapes among locations.

The following steps were taken in applying the Tremblay method to this dataset. 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 mercury data along with a Box-Cox analysis of the optimal transformation for achieving normality and minimizing 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) mercury data.
- 4) Coefficients with $p < .05$ were retained in the model.
- 5) The resulting regression equation was used to calculate predicted mercury concentrations (mean and 95% confidence interval) at a standard length of 350 mm for each location.

RESULTS AND DISCUSSION

Largemouth Bass

Background. Largemouth bass (*Micropterus salmoides*) were the primary focus of the sampling effort, with a total of 326 individual fish analyzed in the two years of the study. Largemouth bass exhibit several characteristics that make them an excellent indicator species for mercury contamination in the Delta region (Table 2). First, largemouth bass are voracious predators, and, like other predatory fish species, they are susceptible to accumulation of high mercury concentrations. Second, largemouth bass are very abundant and distributed widely throughout the study area. The California Department of Fish and Game (CDFG) performs monitoring of the abundance of resident fishes in the Delta, sampling with an electroshocking boat similar to the one used in this study (Michniuk and Silver 2002). In the most recent sampling (2002), largemouth bass were third in catch per unit effort, behind only bluegill and redear sunfish. The Delta population of largemouth bass is increasing (Nobriga and Chotkowski 2000, Moyle 2002). Given the abundance and wide distribution of largemouth bass, it was possible to obtain, with a reasonable sampling effort, adequate numbers of samples from a large number of locations spread across the study area. Third, largemouth bass have high site fidelity, and are therefore a useful indicator of spatial variation in mercury 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 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, spotted, and redeye bass) fishing tournaments are increasingly popular in the Delta, with 1,681 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. Recent tag-recapture data indicate that 90% of largemouth bass caught in the Delta are released (Schaffter 2000). A recent 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 1,223 bass were reported kept in 2000, compared to 59,704 striped bass and 40,600 catfish. However, it should be noted that anglers targeting “anything” kept 15,866 fish, and likely added to the largemouth bass catch.

Age and trophic position are two important influences on mercury concentrations observed in fish. The largemouth bass collected in this study were primarily between 305 mm (12 in – the legal limit) and 438 mm. Based on growth rates observed in the Delta (Schaffter 1998), this corresponds to about 4 to 7 yr of age (Figures 2 and 3). 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. 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 mercury concentrations.

Screening Value Comparison. Mercury accumulation in largemouth bass in the Delta region is a major concern, with a high percentage of samples collected exceeding the 0.3 ppm screening value, and frequently by a considerable amount (Table 3). In 1999, 141 of 172 largemouth bass (82%) were above the screening value, and 32 of 172 (19%) were above 1 ppm (Figure 2). In 2000, 121 of 154 samples (79%) were above the screening value, and 22 of 154 (14%) were above 1 ppm (Figure 3). Three samples were above 2 ppm: two from the Feather River at Nicolaus (2.35 and 2.08 ppm) and one from the Cosumnes River (2.09 ppm). Other locations with high values were San Joaquin River at Crow’s Landing (1.66 ppm), Feather River above Yuba (1.59 ppm), Mokelumne River downstream of Cosumnes (1.58 ppm), San Joaquin River at Vernalis (1.40 ppm), and Sacramento River at River Mile 44 (1.37 ppm). Regional variation was observed in exceedance of the screening value, with some stations in the central Delta exhibiting average concentrations less than 0.3 ppm (Figures 4 and 5). Outside of the central Delta all locations had average concentrations higher than 0.3 ppm. Outside of the central Delta, 97% of individual largemouth bass exceeded the screening value and 26% were above 1 ppm in 1999 and 2000, compared to 53% above 0.3 ppm and 1% above 1 ppm within the central Delta (Table 4).

Spatial Patterns. Consistent with observations of high site fidelity in tag return studies, largemouth bass showed distinct spatial variation over distances of as little as 4 miles. With the sampling design employed in 2000, targeting 10 or more fish across a broad size range at each location, resolution of many statistically significant differences among locations was possible.

Distinct spatial variation was observed in 1999 (Figure 4), with high average concentrations in the Feather River drainage, the lower Cosumnes River system, the Sacramento River in the north Delta, and the San Joaquin River drainage, and low concentrations in the central Delta. [The term “central Delta” is used in this report to describe the operationally defined area in the Delta where low concentrations have been consistently observed. This area is indicated in Figures 4 and 5 by

the blue and purple bars.] However, evaluation of these data by ANCOVA was not possible. ANCOVA with mercury and length depends on accurately characterizing the length:mercury relationship at each location; this could not be done due to the limited size range and low sample sizes collected in that year (Figures 2 and 6). The same basic spatial pattern in largemouth bass mercury was also observed in a 1998 study (Davis et al. 2000) that examined composite samples at many locations in the Delta region.

The modified design employed in 2000 provided a solid foundation for ANCOVA. Figure 7 shows the regression lines resulting from polynomial regression ANCOVA of the dataset. The regression equation describing the reference condition (arbitrarily set as White Slough) was: $\text{SQRT(Hg)} = 0.449 + 0.00178(\text{LC})$, where LC is the centered length (see **Methods**). Statistically significant coefficients for dummy variables modifying the slope and intercept at each location are indicated in Figures 5 and 6. Differences in the intercept term (Figure 7) are comparable to those examined in conventional ANCOVA, and indicate differences in mean concentration among locations. The ANCOVA technique of Tremblay et al. (1998) also examines differences in slope, and 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) (Figure 7). A polynomial term was also included in the model, but was not significant for any of the locations indicating that a straight line adequately fit the data from each location.

The equations resulting from the ANCOVA were used to estimate mean mercury concentrations of largemouth bass at 350 mm, along with confidence intervals for the means (Figure 8). This size was selected as a round number in the middle of the target range (the median size in 2000 was 359 mm). Significant differences among locations are indicated by non-overlapping confidence intervals. These results clearly delineate significant spatial variation in the watershed, with elevated concentrations in areas around the periphery of the Delta and a sharp drop to low concentrations in the central Delta.

Concentrations within river systems were generally consistent and not significantly different from one another (Figure 8). 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. The slope of the length:mercury regression was also significantly higher at Mokelumne River. Differences in slope could be caused by biological factors such as differences in growth rate (a slow-growing population would have a higher slope) or consumption rate (which might vary due to factors such as the nutritional quality of prey). 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 Feather River, Sacramento River, and San Joaquin River systems formed a group with lower concentrations than the Cosumnes River, but still significantly elevated above central Delta locations. 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 (Figure 6).

In the Sacramento River system, the Sacramento River at River Mile 44 had the third highest 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. 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.

Mercury 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 ppm at Landers Avenue to 0.86 ppm 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 (not at standard length) of 0.95 ppm at San Joaquin River at Bowman Road (Figures 4 and 6). The largemouth bass data from the San Joaquin system collected in this study and in Davis et al. (2000) have firmly established the existence of a regional problem that had not previously been recognized.

Putah Creek, in spite of extensive historic mercury mining in its watershed, 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.

In spite of elevated mercury concentrations on all of its tributaries, the central Delta had concentrations that were low both in comparison to the screening value 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 – 0.27 ppm (the means were identical due to the selection of White Slough as the “default” condition in the regression, and the backward elimination of insignificant 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. 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 and yielded similarly low concentrations, with means (not at standard length) in the 0.2 – 0.4 ppm range (Figures 4 and 6).

Temporal Patterns. Evaluation of interannual variation in sport fish mercury concentrations was not a priority in this study. Consequently, the dataset generated is not well-suited to a rigorous analysis of interannual variation. There are several shortcomings of the dataset from this perspective. One is that there are only two years of detailed data, which do not provide an adequate basis for generalization. Second, the limited size range targeted in 1999 precluded characterization of length:mercury relationships and ANCOVA on those data. Third, in an attempt to coordinate sport fish sampling with sampling of other trophic levels, a largely new set of Delta locations was sampled in 2000.

While a sound quantitative temporal analysis is not possible, a graphical comparison of data from 1999 and 2000 at the 11 locations sampled in both years (Figure 9) suggests that interannual variation was not significant. At each location, data from the two years appear to fit on the same curve describing the length:mercury relationship.

It is also not possible to rigorously evaluate longer term trends in largemouth bass mercury in the region, primarily due to a lack of historic data for comparison. Adequate long term time series do not exist for any locations in the region. Another constraint with regard to statistical evaluation of temporal trends is the sampling designs employed in other studies, which have included small sample sizes, narrower size ranges, and compositing. A sampling design that would allow for rigorous statistical comparisons among years in largemouth bass would include the basic features of the design used for largemouth in this study in 2000: analysis of individual fish, a sufficiently wide size range, and 10 or more fish per location. It would also be desirable to perform annual monitoring of largemouth bass for several years in order to characterize interannual variation. After this initial period it would be appropriate to reduce sampling frequency as indicated by a power analysis.

Factors Influencing Mercury Accumulation. Length, measured as a surrogate for age, had a strong influence on mercury concentrations, and provided the foundation for the ANCOVA presented above. Age data were collected for the 1999 samples, but had weaker correlations with mercury (data not shown) and were not used in statistical analysis. Trophic position is another factor that could conceivably influence mercury accumulation in largemouth bass in this region, particularly given the flexible foraging of this species and potential variability in diet. Stable nitrogen isotopes were measured in all largemouth bass. Significant variation in nitrogen isotope ratios (not baseline corrected) was observed across the region (Figure 10). Based on similar patterns observed in species at lower trophic levels, this appears to be driven by similar spatial variation in baseline nitrogen isotope ratios. Baseline correction of largemouth bass nitrogen data (and sport fish nitrogen data in general) is problematic due to this baseline variation, inconsistencies in sampling locations, and unusual patterns in the top candidate species (*Corbicula* and inland silversides) that might be used for this purpose. Even without baseline correction, the nitrogen data could potentially help explain mercury variation within locations, but graphical analysis of the isotope data from each location did not suggest any clear relationship to mercury accumulation (graphs not shown). The absence of a clear effect of trophic position, and, more importantly, the observation of similar spatial patterns in lower trophic level organisms (*Corbicula* and inland silversides) (Slotton et al. 2003) suggest that variation in prey mercury is the primary cause of the striking spatial variation observed in largemouth bass.

White Catfish

Background. White catfish (*Ameiurus catus*) was another primary target species in this study. White catfish have several characteristics that make them a good indicator species for mercury accumulation in sport fish. White catfish are high trophic level predators and therefore particularly susceptible to mercury accumulation. White catfish are a good complement to largemouth bass in monitoring because they are more dependent on the benthic food web and therefore useful in identifying instances when significant contaminant transfer occurs through the benthic pathway (Moyle 2002, USEPA 2000). White catfish are also widespread and relatively abundant, though

less so than largemouth bass. White catfish were not collected as efficiently as largemouth bass by electroshocking, so additional effort was made to collect them using fyke nets. Even with this additional effort, it was not possible to obtain thorough coverage of the study area. The central Delta and San Joaquin River were two areas where few samples of white catfish were caught in both 1999 and 2000. White catfish have high site fidelity. In the Delta most angler recaptures of tagged fish reported to CDFG take place near the site of release (Moyle 2002).

White catfish is a popular sport fish species, and probably accounts for a large proportion of sport fish consumption in the region. Their popularity is due to their abundance, accessibility, and size. White catfish were first planted in the region in the Delta near Stockton in 1874 (Moyle 2002). The introduction was very successful, leading to a commercial fishery yielding 81,000 – 460,000 kg yr⁻¹ until the fishery was banned in 1953. The fishery is thought to be currently underexploited. Sport fishing catch limits were removed in 1988. Counts of fish kept in the 2000 CDFG creel survey indicate that consumption of white catfish is relatively high: white catfish had the third highest number kept (40,600), after only chinook salmon (70,829) and striped bass (59,704) (Murphy et al. 2001). 80% of the catfish caught by surveyed anglers were kept. Catch per unit effort (fish caught per hr) was relatively high for catfish (0.50, compared to 0.28 for striped bass and 0.22 for black bass). In addition, some anglers were targeting “anything”, and likely added to the white catfish catch.

The Delta white catfish population is one of the slowest growing anywhere. The growth curve shown in Figures 11 and 12 is for the Delta population (Moyle 2002). Fish from other portions of the watershed (e.g., the Sacramento River) may grow much faster (Moyle 2002). Based on the growth curve for the Delta, the white catfish sampled in this study were primarily age 5 or older. White catfish are opportunistic carnivores. Young of the year (40 – 100 mm) feed on amphipods, opossum shrimp, and chironomid midge larvae. The diet of larger fish generally includes fish and large invertebrates. However, in the Delta, amphipods and opossum shrimp remain important prey items for older fish and may explain the slow growth there (Moyle 2002). Based on their opportunistic foraging, white catfish trophic position could vary spatially or over time, and this should be considered in sampling and interpreting mercury data for this species.

Screening Value Comparison. Mercury concentrations in white catfish were not as elevated as in largemouth bass, but, given the apparent importance of this species in angler diets, these concentrations are of high concern. A majority of white catfish samples exceeded the 0.3 ppm screening value. In 1999, 38 of 75 white catfish (51%) were above the screening value, and 3 of 75 (4%) were above 1 ppm. In 2000, 39 of 67 (58%) samples were above the screening value, and 4 of 67 (6%) were above 1 ppm. The highest concentration was 1.27 ppm in a fish from the San Joaquin River at Vernalis. Other high values were measured at Feather River at Nicolaus (1.25 and 1.21 ppm), Sacramento River at River Mile 44 (1.14 and 1.04 ppm), San Joaquin River at Crow’s Landing (1.01 ppm), and Cache Slough (1.00 ppm). Regional variation was observed in exceedance of the screening value, with almost all central Delta locations having average concentrations below, and almost all locations outside the central Delta above. Excluding the central Delta locations, 76% (75 of 99) of the individual white catfish were above the screening value in 1999 and 2000 (Table 4). Within the central Delta, only 5% (2 of 42) of individual white catfish were above the screening value (Table 4). Within the central Delta, mercury in white

catfish is a minor potential human concern, while outside the central Delta it is a significant potential human health concern.

Spatial Patterns. The data for white catfish, though showing a weaker signal of contamination and lower resolution due to fewer locations, suggest the same general regional pattern of mercury accumulation as the largemouth bass. White catfish were not caught in sufficient numbers or across a broad enough size range to support ANCOVA of mercury with length (Figures 13 and 14). Consequently, analysis of spatial patterns did not go beyond graphical analysis and nonstatistical comparison of means.

The regions with elevated mercury concentrations in largemouth bass (Cosumnes River, Feather River, Sacramento River, San Joaquin River) also had relatively high concentrations in white catfish (Figures 15 and 16). The location with the highest average concentration was Feather River at Nicolaus (0.82 ppm in 2000). The next highest location average was 0.76 ppm at Cosumnes River in 2000 (though based on just two fish). Unlike largemouth bass, white catfish at two locations further downstream from the Cosumnes River location (Sycamore Slough and Mokelumne River between Beaver and Hog sloughs) were relatively low. Sacramento River locations in the north Delta (Sacramento River at River Mile 44, Little Holland Tract, Cache Slough, and Sacramento River at Isleton) were intermediate between those in the Feather and Cosumnes and those in the central Delta. Though few locations were adequately sampled, concentrations were also relatively high in the San Joaquin River, ranging from 0.40 to 0.54 ppm. Average concentrations measured for San Joaquin River at Crow's Landing and San Joaquin River at Landers Avenue were relatively high in spite of the small size of the fish sampled.

As observed for largemouth bass, white catfish in the central Delta were relatively low in mercury. More locations were successfully sampled in 1999, and average concentrations ranging from 0.08 ppm (White Slough) to 0.23 ppm (Old River) were measured at four central Delta locations. In 2000, only two central Delta locations were successfully sampled (White Slough and San Joaquin River at Naval Station), and average mercury concentrations were quite low at both (0.06 and 0.08, respectively). Even relatively large fish at San Joaquin River at Naval Station were low in mercury (Figure 14).

Temporal Patterns and Factors Influencing Mercury Accumulation. Delineation of the length:mercury relationship would provide a necessary foundation for an ANCOVA-based analysis of temporal trends or trophic position. The numbers and size ranges of white catfish caught at each location were not sufficient for this type of analysis.

One location in the region, Sacramento River at River Mile 44, has been sampled for white catfish on close to an annual basis since 1978 (specifically 1978-1986, 1991-1993, and 1997-2000), allowing an evaluation of data over this time period. A significant linear relationship of mercury with length was observed (Figure 17A). A temporal pattern was apparent when the residuals of this length:mercury regression was plotted versus year (Figure 17B). These data suggest that mercury concentrations at this location decreased from the late 1970s to the mid-1980s, and remained essentially constant from the mid-1980s to 2000. This pattern of a sharp decline followed by a leveling off is very similar to declines observed in several studies of trends in response to abatement of industrial point sources from the mid-1970s through the 1980s, as summarized in

Wiener et al. (2003). It is not known if such a point source load reduction occurred at this location in the 1970s. Replicate sampling in recent years has provided an indication of within-year variance, information that is valuable in interpreting interannual and long term fluctuations and would be needed for a power analysis. It should be emphasized that this apparent trend was observed for one location, and may not be indicative of a regional trend.

Striped Bass

Background. Striped bass (*Morone saxatilis*) was the third primary target species (along with largemouth bass and white catfish) in this study, and all striped bass that were caught were kept and analyzed. Relatively few striped bass were caught; possible explanations are that the fish collection method (electroshocking boat) may not be efficient for striped bass or perhaps striped bass were not sufficiently abundant in the Delta region during the sampling period.

While not reflected in the numbers analyzed in this study, striped bass are probably the most important indicator of mercury contamination in the region from a human health perspective. Their importance is due to a combination of the high mercury concentrations that are common in their tissue, their abundance, and their great popularity among anglers. Like the other sport fish species of greatest concern with regard to mercury accumulation, striped bass are high trophic level predators and therefore highly susceptible to mercury accumulation. Striped bass are also abundant in the region. The most relevant index of striped bass abundance in the Delta region is the creel survey data of CDFG (Murphy et al. 2001). In the most recent survey year, striped bass ranked number one in total catch (328,316), number two in angler hours (1,155,012, second to chinook salmon), and number two in fish kept (59,704, second to chinook salmon). Catch per unit effort was much higher for striped bass (0.28 fish per angler hr) than chinook salmon (0.07 fish per angler hour). Clearly, striped bass are abundant enough in the region to support a very popular sport fishery and probably account for a large proportion of regional sport fish consumption. Further indications of the importance of this fishery are the many research, monitoring, and management efforts, including manipulation of the hydrology of the Estuary, to enhance the striped bass population. As mentioned in the Introduction, striped bass is one of two species for which consumption advice for the Delta is in place (the other is sturgeon).

Striped bass are also good integrative indicators of mercury contamination in the region, and the Estuary in particular, because of their use of the entire ecosystem, including both fresh and saline waters. Striped bass were introduced to the Estuary in 1879 (Moyle 2002). The introduction was so successful that a commercial fishery began in 1888 and the catch reached 1.2 million pounds by 1899. The population in the Estuary is the main breeding population on the west coast. Striped bass spend most of their lives in San Francisco Bay, but also move into freshwater and the coastal ocean (Calhoun 1952). Striped bass mainly use the freshwater portions of the watershed for spawning, which occurs in the Sacramento and San Joaquin rivers in the Delta and upstream in April, May, and June. There is also a general movement of adult bass into fresh water in fall. Many spend the winter in the Delta and move back into saline water after spawning. Some adult striped bass, however, appear to reside in freshwater areas year round (D. Kohlhorst, CDFG, pers. comm.). After spawning, embryos and larvae are carried downstream into San Francisco Bay, where they reside as juveniles in tidal marshes. Striped bass also sometimes migrate to the ocean,

particularly large striped bass that take advantage of abundant nearshore prey in El Nino years (Moyle 2002).

While all of this extensive movement makes striped bass good integrative indicators of the estuarine ecosystem, it makes them poor indicators of spatial variation in food web mercury (Davis et al. 2002, Greenfield et al. 2002a). Other species, such as largemouth bass, are better spatial indicators than striped bass.

The striped bass collected in this study were primarily 4 to 9 year old fish (Figures 18 and 19). The legal limit for striped bass is 457 mm (18 in). The diet of young striped bass (<100 mm) is primarily shrimp. Larger juveniles (100 to 350 mm) increasingly prey on fish. Subadults (age 2+, 260 – 470 mm) are primarily piscivorous. Adults in the Delta primarily consume threadfin shad and small striped bass, while in the Bay and ocean they eat a variety of pelagic fishes (e.g., anchovies and herring). While primarily piscivores, striped bass are opportunists that will consume almost any fish or invertebrate found in their habitat (Moyle 2002), suggesting that variation in trophic position could influence mercury accumulation in this species.

Screening Value Comparison. Mercury accumulation in striped bass in the Delta region is a major concern, with a very high percentage of samples exceeding the screening value, and many fish greatly exceeding the screening value (Table 3). In 1999, 27 of 30 legal sized striped bass (90%) were above the screening value, and 5 of 30 (17%) were above 1 ppm. In 2000, only six legal sized striped bass were caught; 4 of 6 (67%) were above the screening value, and 1 of 6 (17%) was above 1 ppm. One striped bass from the Feather River at Nicolaus in 1999 measured 3.5 ppm, the highest concentration recorded in this species in the region (including a large number of measurements from the early 1970s – discussed further below). Another high concentration from this location was 1.65 ppm in a sublegal sized (441 mm) fish. Two other fish above 1 ppm were also collected at Feather River at Nicolaus. Other locations with high values included San Joaquin River at Vernalis (1.63 ppm), Mokelumne River (1.2 ppm), Suisun Bay (1.01 ppm), and Cosumnes River (1.00 ppm).

Spatial Patterns. As mentioned above, the extensive movement of striped bass within the watershed renders this species of little use in quantitative evaluation of spatial patterns. Qualitatively, however, some spatial pattern did appear to be present in the data. The highest striped bass mercury concentrations primarily occurred at locations that had statistically elevated concentrations in largemouth bass, such as Feather River at Nicolaus, Mokelumne River, San Joaquin River at Vernalis, and San Joaquin River at Vernalis. However, variance within locations was high, as exemplified by concentrations at Feather River at Nicolaus, which varied over an order of magnitude for similar sized fish. Migration probably contributed to this high within-location variance.

Temporal Patterns. This study, sport fish sampling in the Bay from 1994 to 2000 (Fairey et al. 1997, Davis et al. 2002, Greenfield et al. 2002b), and an extensive dataset on striped bass mercury from the early 1970s (CSDPH 1971) combine to provide the best available dataset on long term trends in food web mercury in the Delta region (Figure 20a,b). The data from the early 1970s were generated in the study described in the Introduction. These samples were analyzed by the California Department of Fish and Game Water Pollution Control Laboratory using the same basic

methodology as the present analyses (sulfuric acid digestion followed by cold vapor atomic absorption spectroscopy). Although standard reference materials were not available at that time, quality assurance measures included duplicates, matrix spikes, reagent blanks, and intercalibration exercises with other laboratories. The 1970s samples were primarily collected in the western Delta, Suisun Bay, and San Pablo Bay. The Bay samples, collected in 1994, 1997, and 2000, were analyzed by the same laboratory performing analyses for this study. Analysis of individual fish in the Bay sampling was not performed in 1994 (all were composite samples), limited to a subset of striped bass in 1997 ($n = 18$), and done for all striped bass in 2000 ($n = 32$).

The length:mercury relationship was poorly described by linear regression for some of these datasets, making the application of ANCOVA to the temporal comparisons inappropriate. It is evident from visual comparison of the datasets, however, that the recent measurements have a strikingly similar distribution to the 1970s data. The bulk of the recent data fall squarely in line with the bulk of the historic data, suggesting that concentrations of methylmercury in the estuarine food web have not declined significantly in the past 30 yr. Some of the recent data, as pointed out above, are high even relative to the historic data. Particularly high were two points from the Feather River at Nicolaus (3.50 ppm/ 817 mm and 1.65 ppm/441 mm), one point from the San Joaquin River at Vernalis (1.63 ppm/627 mm) and three points for small fish from the San Joaquin River at Vernalis (0.68 ppm/106 mm, 0.77 ppm/116 mm, and 0.59 ppm/120 mm). With the invasion of many introduced species in the Estuary over this period (Cohen and Carlton 1998), it is possible that changes in the diet of striped bass have had a role in the observed patterns of methylmercury accumulation.

Another interesting group of striped bass was sampled in the Bay in 1997. In that year, the distribution of mercury appeared to be bimodal, with one group having a higher slope than the other (Figure 20b) (Davis et al. 2002). The occurrence of this high exposure group in 1997 resulted in a considerably increased mean and higher variance in the relatively small dataset for that year. Given the migratory nature of striped bass, a hypothesis that could explain this observation is that the high exposure group represented a cohort of striped bass that spent a larger proportion of their lives in mercury-contaminated habitat, possibly through more time in contaminated freshwater habitats or less time in relatively clean ocean habitat. Another possible explanation for these high concentrations in 1997 is a diet shift by these fish. No data are available to support or refute this hypothesis. Another possible explanation is a shift in prey mercury, but other species sampled failed to show a similar increase in 1997. Whatever the cause, the occurrence of this distribution in 1997 suggests that striped bass can show high interannual variability that may be a function of life history rather than temporal variation in prey mercury.

Factors Influencing Mercury Accumulation. The low sample size obtained in this study and the migratory nature of striped bass interfered with efforts to sort out factors influencing mercury accumulation in this species. The length:mercury relationship could not be established with the data, making it impossible to quantitatively determine the influence of other factors such as location or trophic position. Results obtained for Bay striped bass in 2000 did suggest a relationship with trophic position (Greenfield et al. 2002a). As mentioned above for largemouth bass, application of stable isotope techniques is difficult in situations where the organisms being sampled are mobile and baseline values are spatially variable.

Variable use of freshwater, estuarine, or ocean habitat over the lifespans of different cohorts of striped bass may play an important role in mercury accumulation. Elemental and isotopic composition of otoliths can be examined as an index of habitat use over time (Ingram et al. 1998, Zlokovitz and Secor 1999), and is a tool that may be employed to provide a better understanding of mercury accumulation in striped bass in the Estuary. Otoliths should be preserved when striped bass are collected in order to allow this analysis to occur, if the mercury data suggest that it is warranted.

Sacramento Pikeminnow

Background. Mercury accumulation in Sacramento pikeminnow (*Ptychocheilus grandis*) is potentially of high concern with regard to human health. This is another high trophic level species that accumulates high mercury concentrations. Human consumption of this species, however, appears to be low based on available information.

Sacramento pikeminnow is one of the few native fish species that remains abundant in the watershed. This species is widespread in clear rivers and creeks throughout the watershed. Sacramento pikeminnow is a valuable indicator of spatial pattern in mercury contamination, as it is an abundant member of a fish assemblage found in areas at and beyond the boundary of the largemouth bass distribution (Moyle 2002), and therefore extends the range in which high trophic level sport fish can be used as a mercury indicator. Sacramento pikeminnow are present in small numbers in the Delta itself (Michniuk and Silver 2002).

Catch of Sacramento pikeminnow was not counted in the CDFG creel survey, except perhaps as a contribution to the “anything” category (Murphy et al. 2001). Although available information suggests that this species has a low consumption rate, it was a common food of Native Americans, and Moyle (2002) states that its culinary properties are underappreciated.

Sacramento pikeminnows are predators on large prey. Prior to the introduction of largemouth bass and other predatory fishes, large pikeminnows were at the top of the aquatic food chain throughout the Central Valley (Moyle 2002). Sacramento pikeminnow larger than 200 mm consume almost exclusively fish and crayfish, especially nonsalmonids like sculpins. Like most of the other sport fish species, pikeminnow are opportunistic, taking whatever benthic or pelagic prey is abundant (Moyle 2002). Pikeminnow in the 200 – 300 mm size range are approximately 3 – 5 yr old (Moyle 2002). Most of the fish sampled in this study were more than 5 yr old. Sacramento pikeminnow are variable in their movement, ranging from very sedentary fish residing in the same pool for years to highly mobile fish migrating up to 400 km.

Screening Value Comparison. A large proportion (58%) of Sacramento pikeminnow had mercury concentrations above the screening value, including many (30%) well above the screening value, making mercury accumulation in this species a potentially major human health concern (Table 3, Figure 21). This species was not targeted in 1999, and only six samples were collected. Four of 6 samples (67%) were above the screening value, and 2 of 6 (33%) were above 1 ppm. In 2000, due to high concentrations observed in this study in 1999 and previous years in the Sacramento River Watershed Program (Larry Walker Associates 2000, 2001), collection of Sacramento pikeminnow was made a higher priority, and 37 fish were collected: 21 of 37 (57%)

were above the screening value, and 11 of 37 (30%) were above 1 ppm (Figure 21). Sacramento pikeminnow had the highest frequency of concentrations above 1 ppm (Table 3). Three samples were above 2 ppm, including two from Feather River between Yuba and Bear (2.26 and 2.14 ppm) and one from the north Delta at Sacramento River near Isleton. Other samples above 1 ppm were collected at Sacramento River at Isleton, Feather River above Yuba, and Feather River at Nicolaus. No Sacramento pikeminnow were collected from the central Delta.

Spatial Patterns, Temporal Pattern, and Factors Influencing Mercury Accumulation.

Sacramento pikeminnow were not caught in sufficient numbers or across a broad enough size range to support ANCOVA of mercury with length. Consequently, in general only a qualitative discussion of relationships to other variables is possible. A positive correlation of mercury with length was suggested by the data but was not statistically significant (Figure 21). For one location, the Feather River above Yuba, a significant linear relationship was found ($R^2=0.49$, $p=0.025$). High concentrations were observed at several locations in the Feather River region where other species also had elevated concentrations. Relatively high concentrations in Sacramento pikeminnow at Sacramento River at Isleton, a location bordering the central Delta, highlight the sharp decline observed at the boundary of the central Delta. Available data were generally insufficient to evaluate temporal trends or the influence of trophic position. Regressions of mercury versus nitrogen isotope ratio at the two locations with reasonable sample size (Feather River above Yuba and Sacramento River at Isleton) were not significant. Given the opportunistic nature of Sacramento pikeminnow, however, it is possible that variation in trophic position could be a significant factor in mercury accumulation in the Delta region. The potential for pikeminnow migration and variable use of habitats is another factor that could influence mercury accumulation in this species.

Channel Catfish

Background. Although channel catfish (*Ictalurus punctatus*) are not very abundant in the region, their wide distribution and elevated mercury concentrations make mercury accumulation a potentially high concern in this species. Channel catfish are primarily found in the main channels of clear, large, warmwater streams (Moyle 2002). Their abundance is relatively low in the Delta (Michniuk and Silver 2002). Only 11 composite samples were collected in the two years of sampling. With this low level of abundance, channel catfish are not a good candidate as an indicator of spatial or temporal trends.

Channel catfish are popular with anglers in the region because they are easy to raise in hatcheries, have fairly fast growth rates, and are capable of reaching large sizes (Moyle 2002). Large numbers (about 6 million pounds in 1997) are raised in Valley catfish farms and primarily sold in specialty food markets as live fish (Moyle 2002).

Channel catfish in the size range sampled in this study (400 – 500 mm) are usually piscivorous, though they are known to consume a wide variety of organisms, including crayfish, aquatic insects, and any organisms of appropriate size (Moyle 2002). Channel catfish in the 350 – 450 mm size range are about 5 yr in age, so the fish sampled in this study were age 5 or older.

Screening Value Comparison. Although the number of samples analyzed was small, concentrations in channel catfish exceeded the screening value frequently enough to make mercury accumulation in this species a potentially significant human health concern (Table 3, Figure 22). In addition, channel catfish samples were composites of multiple individuals, so the small number of samples actually represented a larger number of fish. In 1999, 5 of 7 samples (71%), representing 22 fish, were above the screening value, and none of these was above 1 ppm. In 2000, 3 of 4 samples (75%), representing 16 fish, were above the screening value, and 1 of 4 (25%) was above 1 ppm. The maximum concentration was 1.07 ppm, measured at Stanislaus River. Two samples were collected from the central Delta (Old River near Paradise Cut and San Joaquin River at Turner's Cut), and both were well below the screening value. Eight of 9 samples (89%) from outside the central Delta were above the screening value (Table 4).

Spatial Patterns, Temporal Patterns, and Factors Influencing Mercury Accumulation. The spatial distribution of concentrations in channel catfish was consistent with that observed for other species, with relatively low concentrations in the central Delta and relatively high concentrations elsewhere. The mercury data suggest that channel catfish have enough site fidelity to indicate spatial pattern. Relatively high concentrations were found in the Feather River and San Joaquin River regions. The maximum value at Stanislaus River, combined with elevated concentrations observed there for largemouth bass, suggest that this tributary is a source of mercury. With composite samples it was not possible to evaluate other potential factors influencing mercury accumulation.

Black Crappie

Background. Black crappie (*Pomoxis nigromaculatus*) are not very abundant in the Delta (Michniuk and Silver 2002), but are widely distributed in the watershed and appear to be prone to mercury accumulation. Black crappie are found anywhere in the watershed where there is warm, quiet water (Moyle 2002). Only 6 composite samples were collected in the two years of sampling. The abundance of black crappie is too low for this species to be a good indicator of spatial or temporal trends in the Delta region.

Black crappie are popular sport fish, especially in lakes and reservoirs (Moyle 2002). Although few of the anglers surveyed by CDFG (Murphy et al. 2001) mentioned sunfish as a target, a significant number were targeting "anything" and black crappie probably accounted for some of this category.

Fish and aquatic insects dominate the diet of adult black crappie. In the Delta, their primary prey are small fish, including threadfin shad, young striped bass, and inland silversides (Moyle 2002). The black crappie sampled in this study were approximately 3 to 4 yr old.

Screening Value Comparison. Although the number of samples analyzed was small, concentrations in black crappie exceeded the screening value frequently, making mercury accumulation in this species a potential human health concern (Figure 23). Black crappie samples were composites of multiple individuals. In 1999, one composite black crappie sample was collected, representing 5 fish from a central Delta location; the concentration in this sample (0.06 ppm) was well below the screening value. In 2000, 4 of 5 samples (80%), representing 22 fish, were above the screening value, and none of these was above 1 ppm. The maximum concentration

was 0.59 ppm, measured at Green's Lake in the north Delta. Three samples were collected from the central Delta (Smith Canal, San Joaquin River at Naval Station, and Sherman Lake), and two of these were below the screening value. All samples from outside the central Delta were above the screening value (Table 4).

Sacramento Sucker

Background. Sacramento sucker (*Catostomus occidentalis*) is one of the few native fish species that still thrives in the region (Moyle 2002). Mercury accumulation in this species is a potential concern, due to moderate levels of contamination and a wide distribution in the watershed. Sacramento sucker are most abundant in clear, cool streams and rivers. Together with Sacramento pikeminnow, they are the most abundant members of a fish assemblage that is found upstream of the assemblage of alien species (largemouth bass, bluegill, etc.) found in the warm, low velocity waters of the Valley floor. They are present, but not very abundant, in the Delta (Michniuk and Silver 2002). The Sacramento sucker samples collected in this study were mainly from the Feather River and Cosumnes River regions, Putah Creek, and the northern Delta. Sacramento sucker and Sacramento pikeminnow are valuable indicators of food web mercury because they extend the range that can be sampled, often into regions that are closer to sources of mercury contamination. However, Sacramento sucker do not draw much interest from anglers (McGinnis 1984), so appear to be of limited value as an indicator of human health concern.

Sacramento sucker occupy a lower position in the food web than the piscivorous species described above, eating algae, detritus, and small bottom invertebrates. The lower mercury concentrations observed in this species are probably related to this lower trophic position. The sucker sampled in this study were approximately 7 – 10 yr old.

Screening Value Comparison. A fairly large number of Sacramento sucker were collected in this study: 17 composite samples comprised of 78 fish. Mercury concentrations exceeded the screening value in less than half of these samples (Figure 24), making mercury accumulation in this species a relatively low potential human health concern. In 1999, 2 of 5 (40%) samples representing 23 fish were above the screening value, and none were above 1 ppm. In 2000, 4 of 12 (33%) samples representing 55 fish were above the screening value, and none were above 1 ppm. Only one central Delta location was sampled (San Joaquin River at Antioch), and it was well below the screening value (Table 4). All of the samples above the screening value were from the Feather River and Cosumnes River regions.

Common Carp

Background. Mercury concentrations in common carp (*Cyprinus carpio*) exceeded the screening value in a low percentage of samples, making accumulation in this species a low potential human health concern. Common carp are distributed throughout the watershed and are moderately abundant. In the Delta they are comparable in abundance to white catfish (Michniuk and Silver 2002). It is unclear how much human consumption of carp occurs in the region. According to Moyle (2002), they were valued as a sport fish in Europe and the period immediately following their introduction in the late 1800s, fell into disfavor by the turn of the century, and their virtue as a food and game fish is being slowly rediscovered. They grow rapidly and reach large sizes in

polluted waters that support few other fish. Carp are highly appreciated by diverse ethnic groups (Moyle 2002).

Carp occupy a lower trophic position than the piscivores discussed above. Carp are omnivorous bottom feeders. Adult carp feed heavily on aquatic plants and associated animals, including insect larvae, crustaceans, mollusks, and annelid worms. The relatively low mercury concentrations observed in carp were consistent with this lower trophic position. The carp sampled in this study were approximately 4 – 5 yr old.

Screening Value Comparison. Even though carp were collected exclusively from locations outside the central Delta, a relatively low percentage of samples exceeded the screening value (Figure 25). In 1999, the only sample collected, representing 5 fish, was below the screening value. In 2000, 3 of 8 (37%) samples representing 36 fish were above the screening value, and none were above 1 ppm. The highest concentration measured was 0.50 ppm at Feather River between Yuba and Bear.

Bluegill

Background. Bluegill (*Lepomis macrochirus*) were sampled extensively in 1999, but only a small proportion of samples exceeded the screening value. From a human health perspective, therefore, bluegill are not a useful mercury indicator in the study area. However, bluegill possess other qualities that suggest that they could be valuable indicators of spatial and temporal trends in mercury. Bluegill are extremely abundant in the region. They are distributed throughout the watershed, and are probably the most widely distributed and abundant game fish in California (Moyle 2002). In the Delta, bluegill had the highest catch per unit effort by large margin (Michniuk and Silver 2002). Bluegill also spend most of their lives in a relatively restricted area. Bluegill also have been observed to accumulate high mercury concentrations in some contaminated California reservoirs (Rasmussen and Blethrow 1990). In spite of these attributes, bluegill also proved to have low value as an indicator of spatial patterns in mercury in the region.

Bluegill are not a primary target of anglers, but due to their high abundance are probably picked up by the anglers fishing for “anything” (Murphy et al. 2001). Bluegill are popular for consumption by anglers in many parts of the county, and provide excellent sport on ultra-light tackle. Bluegill are predators, but at a lower trophic position relative to the piscivorous sport fish species. Bluegill are highly opportunistic, consuming whatever animal food is most abundant, including insect larvae, crustaceans, flying insects, snails, small fish (e.g., threadfin shad), fish eggs, and crayfish when available (Moyle 2002). In the Delta benthic organisms make up a large proportion of the diet, including amphipods (*Corophium*), isopods (*Exosphaeroma*), and chironomid larvae and pupae. When animal food is scarce bluegill will eat plants. The bluegill sampled in this study were probably 4 – 5 yr old (Moyle 2002).

Screening Value Comparison. In 1999, an extensive dataset on bluegill was generated, with a sample collected at every location sampled. In 27 composite samples representing 129 fish and 20 locations (duplicate samples were collected at 7 locations), only 3 (11%) exceeded the screening value, and none were above 1 ppm (Figure 26). In 2000, only 6 composites (representing 30 fish and just two locations) were analyzed, and none exceeded the screening value. The three samples

above the screening value all came from the Cosumnes River region (Cosumnes River, Mokelumne River downstream of Cosumnes, and Mokelumne River between Beaver and Hog Slough). Shifting fishing pressure to this abundant species would be one way to immediately reduce human exposure to methylmercury in the region.

Spatial Patterns. Bluegill generally exhibited low mercury concentrations, and this weak contamination signal was not well suited to resolving spatial patterns. The overall spatial pattern seen in bluegill resembled that observed more clearly in largemouth bass. Bluegill from the central Delta generally had concentrations below 0.1 ppm. The highest concentrations in bluegill were found in the Cosumnes River region, even though two of the samples were of relatively small fish. Largemouth bass also reached their highest concentrations in the Cosumnes River region. The clear elevation of bluegill above bluegill from other locations was yet further evidence of the high degree of mercury accumulation in this area. There were some puzzling inconsistencies with the largemouth bass data, however. For example, the bluegill composite from Smith Canal (one of the lowest sites for largemouth bass and white catfish) had a similar concentration to the sample from Feather River at Nicolaus (one of the highest locations for many species).

Redear Sunfish

Background. Redear sunfish (*Lepomis microlophus*) are another abundant sunfish species that was investigated both for evaluation of human health and as a potential indicator of spatial patterns in food web mercury. Mercury concentrations in redear sunfish were very low, making them a minimal human health concern. Redear sunfish possess two primary qualities that make them potentially useful as indicators of food web mercury in the Delta region. First, they are very abundant in the Delta, second only to bluegill (Michniuk and Silver 2002). They are also widely distributed in the study area, and samples were collected from Feather River at Nicolaus in the north to the San Joaquin River at Crow's Landing in the south. Second, redear sunfish occupy a unique, relatively low, position in the food web, specializing on hard-shelled bottom invertebrates, especially snails and clams. This species therefore provides another angle on mercury in food webs, representing a portion of the food web that may not be represented by sampling piscivores.

Redear sunfish are a much sought after sport fish in other parts of the country, but do not appear to be targeted much in the region. Due to their high abundance, they are probably harvested to some extent by the anglers fishing for "anything" (Murphy et al. 2001). Due to their dietary specialization in shelled invertebrates, a common name for redear sunfish is "shellcracker". In addition to snails and clams, redear sunfish also consume insect larvae and amphipods (Moyle 2002). Adults may feed more heavily on clams. The redear sunfish collected in this study were approximately 3 – 4 yr old (Moyle 2002).

Screening Value Comparison. Only one composite of redear sunfish exceeded the screening value (Figure 27), making mercury accumulation in this species a minimal human health concern. In 1999, 1 of 9 samples (11%) representing 44 fish was above the screening value, and none were above 1 ppm. In 2000, none of the 11 samples, representing 52 fish, analyzed was above the screening value. The highest concentration was 0.33 ppm from the Cosumnes River location. Shifting fishing pressure to this abundant species would be one way to immediately reduce human exposure to methylmercury in the region.

Spatial Patterns. Some spatial pattern was evident in the redear sunfish data, and this was generally consistent with that observed for other species. The one sample to exceed the screening value was from the Cosumnes River, a location with elevated concentrations in multiple species. A group of four locations had concentrations of approximately 0.2 ppm, including Feather River at Nicolaus, San Joaquin River at Vernalis, Stanislaus River, and San Joaquin River at Crow's Landing, each of which also had elevated concentrations for largemouth bass and other species. The lowest concentrations were measured at central Delta locations.

CONCLUSIONS

- Several species (including largemouth bass, striped bass, Sacramento pikeminnow, channel catfish, and white catfish) had mercury concentrations of high human health concern, exceeding the screening value (0.3 ppm) in a majority of samples and frequently exceeding 1 ppm.
- Two species had mercury concentrations of moderate human health concern (exceeding the screening value in 30-50% of samples): common carp and Sacramento sucker.
- Two species that are abundant and widespread in the Delta region, bluegill and redear sunfish, had methylmercury concentrations that infrequently (less than 10% of samples) exceeded the 0.3 ppm threshold for concern. These species are popular for consumption with many anglers throughout the nation and provide excellent sport on ultra-light tackle. Shifting fishing pressure to these species would be one way to immediately reduce human exposure to methylmercury in the region.
- Significant spatial variation exists in the watershed. Mercury concentrations in the Feather River, northern Delta, lower Cosumnes River, and San Joaquin River regions were significantly elevated and in the 1 ppm range. Concentrations in the central Delta region were significantly lower than other locations, and usually below the screening value. These regional patterns were evident among several sport fish species. There was a precipitous drop in concentrations between nearby stations in the Central Delta.
- Mercury concentrations measured in recent samples of striped bass, which are integrative indicators of mercury in the watershed, are similar to those measured in 1970-71, suggesting the lack of a decline in this 30 year period. Some striped bass samples collected for this study were high even relative to the concentrations measured 30 years ago.
- Largemouth bass are an excellent indicator of spatial patterns in food web mercury, and could be monitored in specific areas to evaluate the impacts of management actions.
- Striped bass are an essential mercury indicator species with regard to human health concerns, with high concentrations and high popularity with anglers.
- Mercury concentrations in largemouth bass and other species are greatly influenced by length. This effect can be quantified and removed to reveal other patterns if an appropriate number and range of fish are collected from the units (e.g., locations or times) to be compared.
- Significant regional variation in stable isotope composition impeded the application of stable isotope techniques to determine trophic position of migratory fish species in the system. Trophic position did not appear to be a primary influence on mercury accumulation in largemouth bass.

RECOMMENDATIONS

- OEHHA should be provided with any additional data they need to develop consumption advice for the Delta region. Mercury concentrations observed throughout much of the study area potentially warrant high concern for the health of humans that regularly consume sport fish.
- Future sampling to evaluate mercury in sport fish should place greatest emphasis on striped bass. Striped bass are very popular with anglers and accumulate high concentrations of mercury. Collection of striped bass should employ the collection gear and timing that are optimal for this species.
- Accurate information on the actual consumption of sport fish species is needed to guide future sport fish monitoring. It is unclear, for example, how much largemouth bass is consumed by anglers. Sacramento pikeminnow is another example where high mercury concentrations could pose a human health hazard but consumption may be low.
- The spatial extent of the mercury problem in the watershed should be defined. This study and its precursor (Davis et al. 2000) have provided a thorough assessment of mercury in sport fish in the Delta and the area immediately surrounding the Delta. Major features of the spatial distribution of mercury were not anticipated (i.e., the low concentrations in the central Delta and the high concentrations in the San Joaquin River system). Large portions of the watershed that are downstream of areas with historic mercury and gold mining activity have not been sampled in a manner that allows comparison with other recent data from the region. A thorough spatial survey of mercury in the watershed would help to: 1) minimize human exposure to mercury through creating awareness of the problem, 2) identify sources, and 3) provide insights into mercury biogeochemistry that could reduce the impacts of restoration projects. Reservoirs, streams, and rivers in the mercury impacted area should all be examined.
- Sport fish are an essential indicator of mercury impairment that should be used to evaluate spatial and temporal trends in response to management actions in the watershed. Their use should be tailored to their responsiveness to spatial and temporal variation in food web mercury. Sport fish monitoring should be linked to the study of other mercury indicators, including wildlife, lower trophic level organisms, and cycling in water and sediment in order to develop a conceptual understanding of mercury movement into species of concern.

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Table 1. Size ranges targeted at each location. All data in mm. Background information on abundance and sizes in the Delta from the IEP Resident Fishes Monitoring Program.

Species	Range used in previous work (Larry Walker Associates 2000, 2001, Davis et al. 2000)	RFMP count, Aug 1997	RFMP count, Feb, Apr, Jun, Aug 1997	RFMP Mean (Aug 97)	RFMP Min (Aug 97)	RFMP Max (Aug 97)	Legal Limit	Targets for CalFed Project 2000
Largemouth bass	305-438	493	1806	175	41	560	305	2X(200-249) f 2X(250-304) f 7X(305-438) 3X(>438)
White catfish	229-330	72	498	258	58	545		2X(130-179) g 2X(180-228) g 7X(229-330) 3X(>330)
Striped bass	> 457	24	48	138	33	294	457	> 457
Bluegill	na	616	4455	106	30	177		5X(90-175) (3 larger at 3 locations)
Redear sunfish	na	366	1842	147	37	245		5X(125-225)
Black crappie	na	37	106	187	63	290		5X(150-300)
Common carp	305-438	87	274	507	332	712		5X(400-600)
Sacramento blackfish	na	4	21	329	277	401		5X(230-400) a
Sacramento pikeminnow	229-330	6	53	280	64	513		5X(195-400) b
Splittail	na	2	31	262	214	310		5X(116-154) c
Channel catfish	na	14	36	373	249	504		5X(300-500) d
Brown bullhead	na	36	116	261	128	324		5X(220-325)
Sacramento sucker	229-330	54	158	398	305	530		5X(340-500)

a Used average length from all four 1997 surveys for blackfish: 268 mm

b Used average length from all four 1997 surveys for squawfish: 228 mm

c Used average length from all four 1997 surveys for splittail: 135 mm

d Used average length from all four 1997 surveys for channel catfish: 384 mm

e Size range used by Slotton et al. (2003)

f Based on growth curve in Schaffter (1998). 200-249 are 2-3 year old. 250-304 are 3-4 year old (Schaffter 1998).

g Based on growth curve in Moyle (1976). 130-179 are 2-3 yr old. 180-228 are 3-4 yr old.

Table 2. Summary of attributes of different fish species as mercury indicators.

Species	Habitat	Abundance	Distribution in the Delta region	Trophic position	Site fidelity	Angler harvest	Human consumption	Mercury concentrations	Overall value as a mercury indicator species
Largemouth bass	Low elevation rivers, reservoirs	High	Wide	High	High	High	Low	High	Excellent
White catfish	Low elevation rivers	Moderate	Medium	High, more benthic	High	High	High	Medium	Good
Striped bass	Low elevation rivers, SF Bay, ocean	High	Wide	High	Low	High	High	High	Essential
Sacramento pikeminnow	Foothill streams	High	Wide	High	Variable	Low	Low	High	Good
Channel catfish	Low elevation rivers	Low	Wide	High	?	Low	Low	Medium	Low
Black crappie	Low elevation rivers, reservoirs	Low	Wide	Medium	?	Low	Low	Medium	Low
Sacramento sucker	Foothill streams	High	Wide	Low	?	Low	Low	Medium	Low
Common carp	Low elevation rivers, reservoirs	Moderate	Wide	Low	?	Low	Low	Medium	Low
Bluegill	Low elevation rivers, reservoirs	High	Wide	Medium	High	Low	Low	Low	Low
Redear sunfish	Low elevation rivers, reservoirs	High	Wide	Medium	?	Low	Low	Low	Low

Table 3. Combined statistics from 1999 and 2000 on screening value exceedances.

Species	Sample Type	# Analyzed	# Fish Represented	# over 0.3 ppm	% over 0.3 ppm	# over 1 ppm	% over 1 ppm
Largemouth bass	Individuals	326	326	262	80%	54	17%
White catfish	Individuals	142	142	77	54%	7	5%
Striped bass	Individuals	36	36	31	86%	6	17%
Sacramento pikeminnow	Individuals	43	43	25	58%	13	30%
Channel catfish	Composites	11	38	8	73%	1	9%
Black crappie	Composites	6	27	4	67%	0	0%
Sacramento sucker	Composites	17	78	6	35%	0	0%
Common carp	Composites	9	41	3	33%	0	0%
Bluegill	Composites	33	159	3	9%	0	0%
Redear sunfish	Composites	20	96	1	5%	0	0%
TOTAL		643	986	420	65%	81	13%

Table 4. Comparison of screening value exceedances: A) within the central Delta; and B) outside of the central Delta. Combined statistics from 1999 and 2000 for species caught in both regions.

A) WITHIN CENTRAL DELTA

Species	Sample Type	# Analyzed	# over 0.3 ppm	% over 0.3 ppm	# over 1 ppm	% over 1 ppm
Largemouth bass	Individuals	123	65	53%	1	1%
White catfish	Individuals	42	2	5%	0	0%
Channel catfish	Composites	2	0	0%	0	0%
Black crappie	Composites	3	1	33%	0	0%
Sacramento sucker	Composites	1	0	0%	0	0%
Bluegill	Composites	12	0	0%	0	0%
Redear sunfish	Composites	11	0	0%	0	0%

B) OUTSIDE CENTRAL DELTA

Species	Sample Type	# Analyzed	# over 0.3 ppm	% over 0.3 ppm	# over 1 ppm	% over 1 ppm
Largemouth bass	Individuals	203	197	97%	53	26%
White catfish	Individuals	99	75	76%	7	7%
Channel catfish	Composites	9	8	89%	1	11%
Black crappie	Composites	3	3	100%	0	0%
Sacramento sucker	Composites	16	6	38%	0	0%
Bluegill	Composites	21	3	14%	0	0%
Redear sunfish	Composites	9	1	11%	0	0%

Figure 1. Sampling locations.

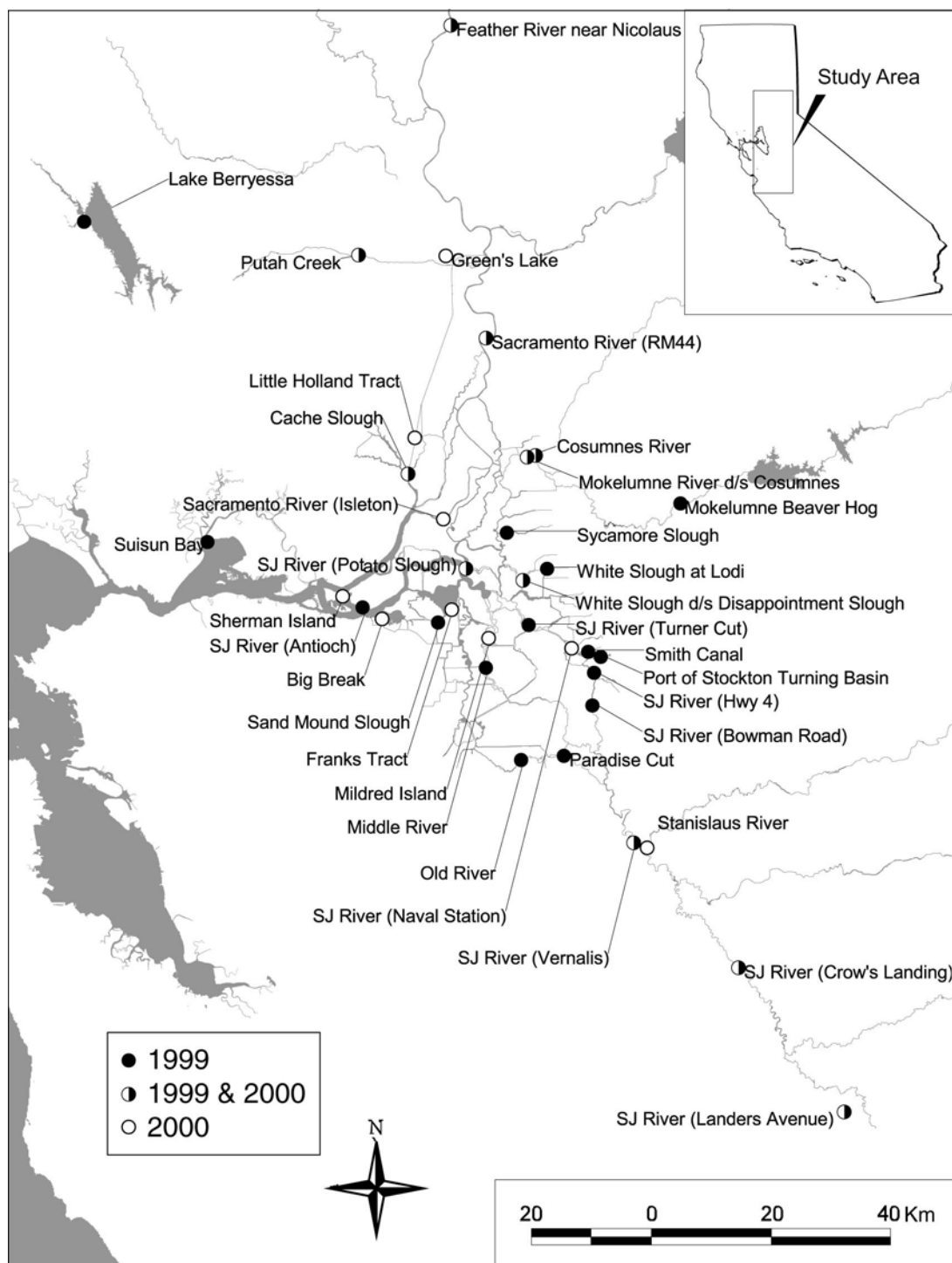


Figure 2. Mercury concentrations versus length in largemouth bass from the Delta region, 1999. 82% (141 of 172) of the legal size (>305 mm) fish analyzed were above the 0.3 ppm screening value. Numbers on top of x-axis show growth curve for largemouth in the Delta (Schaffter 1998).

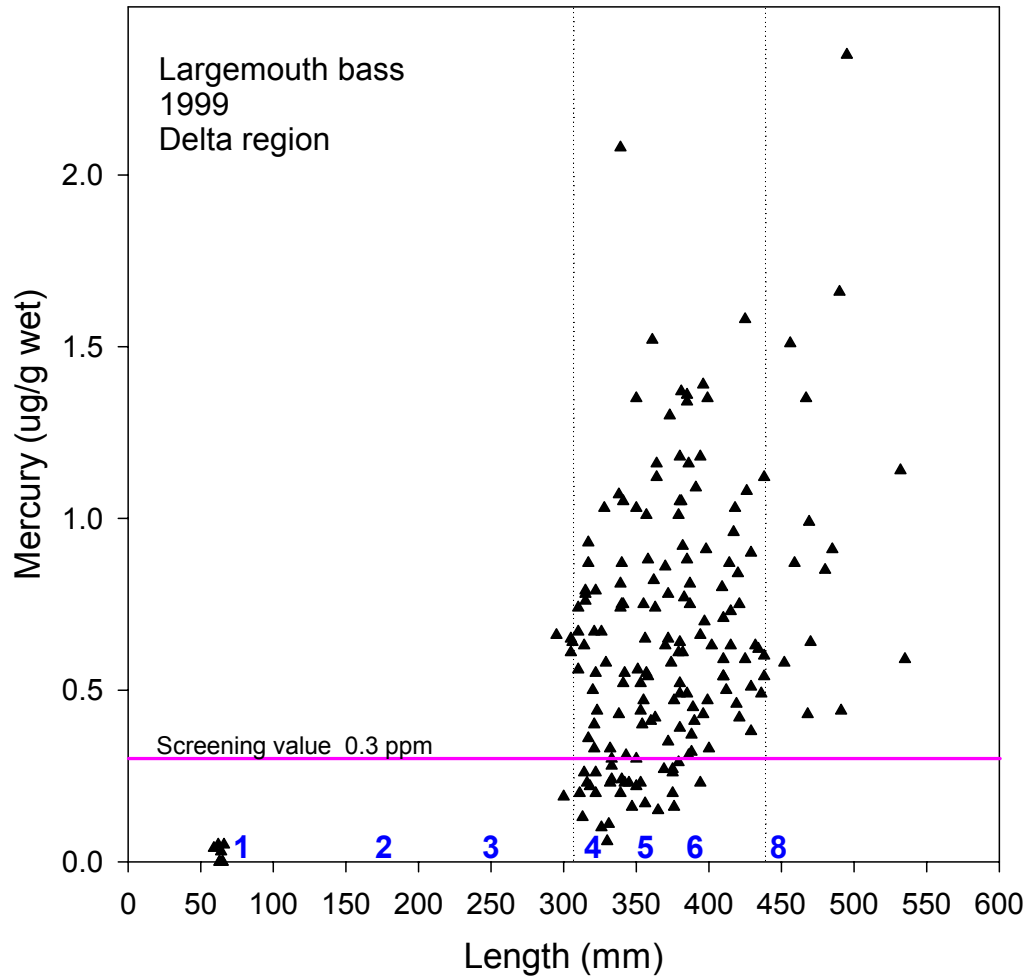


Figure 3. Mercury concentrations versus length in largemouth bass from the Delta region, 2000. 79% (121 of 154) of the legal size (>305 mm) fish analyzed were above the 0.3 ppm screening value. Numbers on top of x-axis show growth curve for largemouth in the Delta (Schaffter 1998).

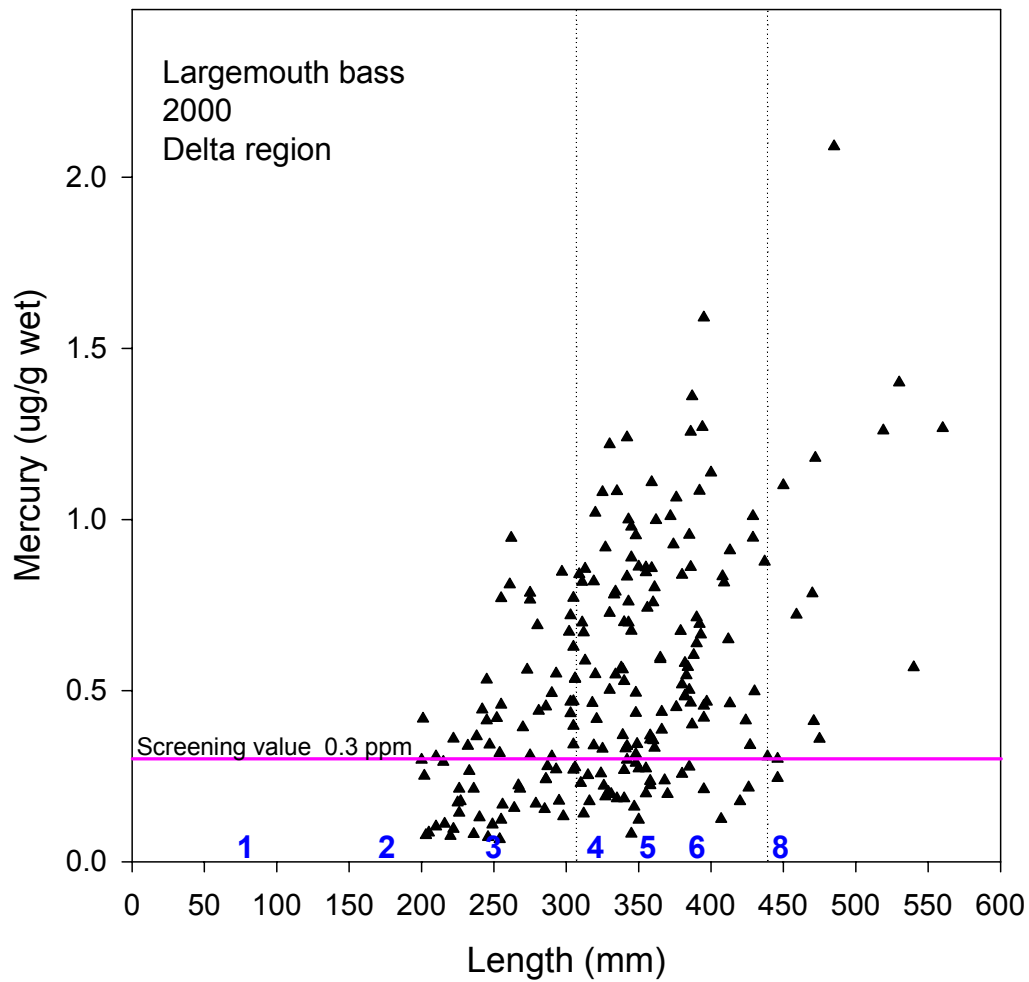


Figure 4. Average mercury concentrations in largemouth bass from each sampling location, 1999. All fish were 305 – 438 mm total length.

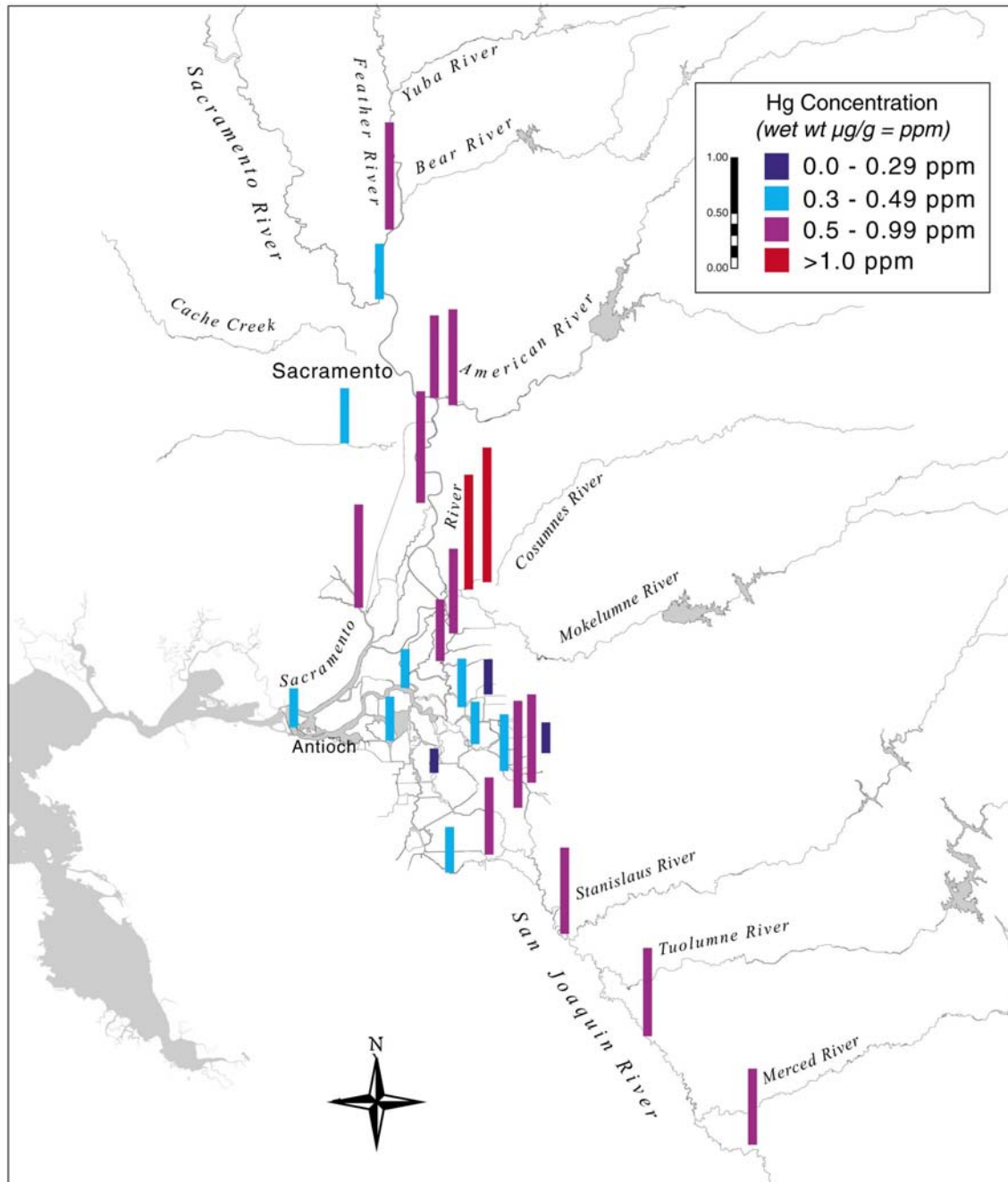


Figure 5. Average mercury concentrations in largemouth bass from each sampling location, 2000. All fish are 305 – 438 mm total length.

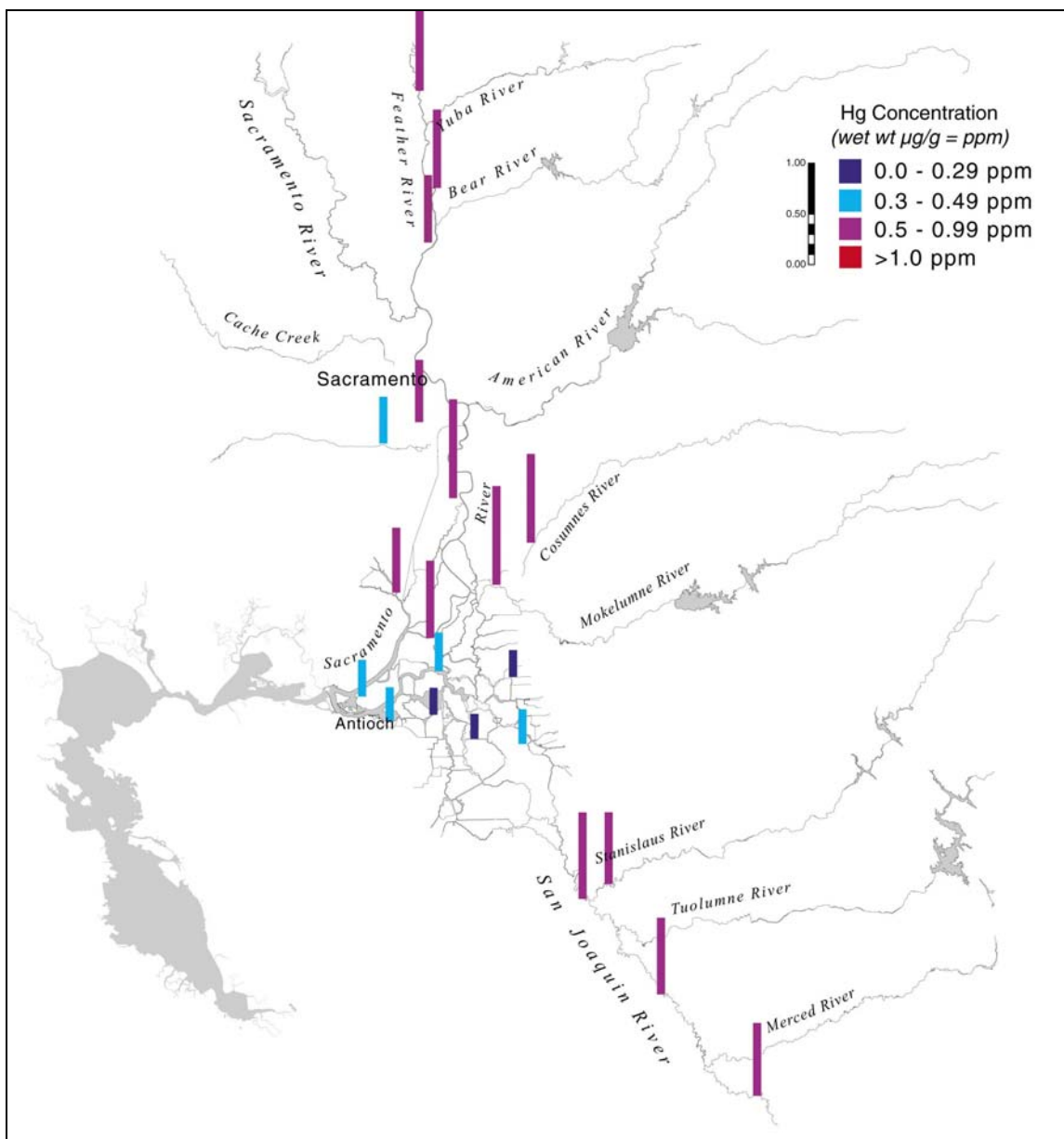


Figure 6. Mercury versus length in largemouth bass at each sampling location in the Delta region, 1999.

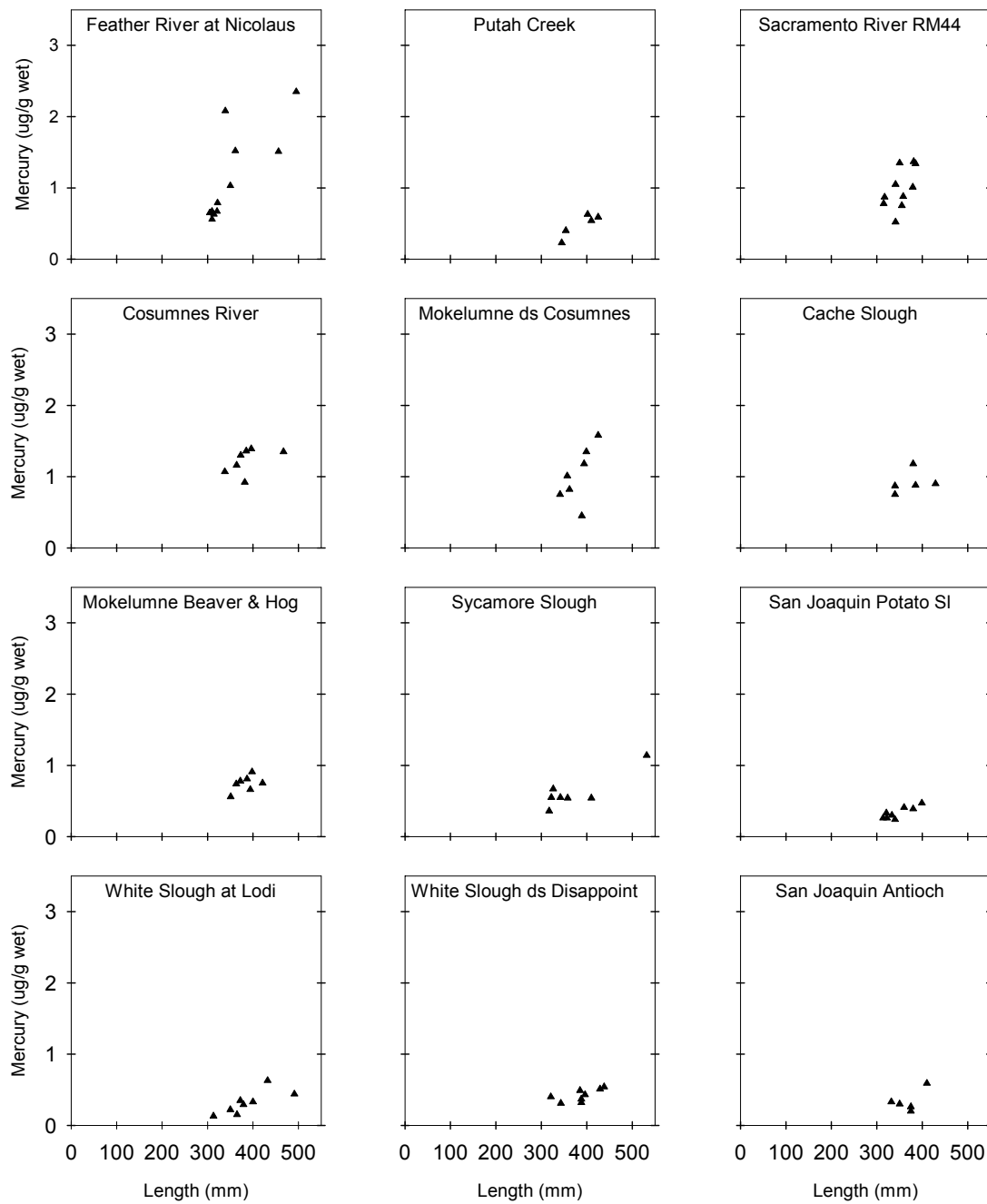


Figure 6. Continued.

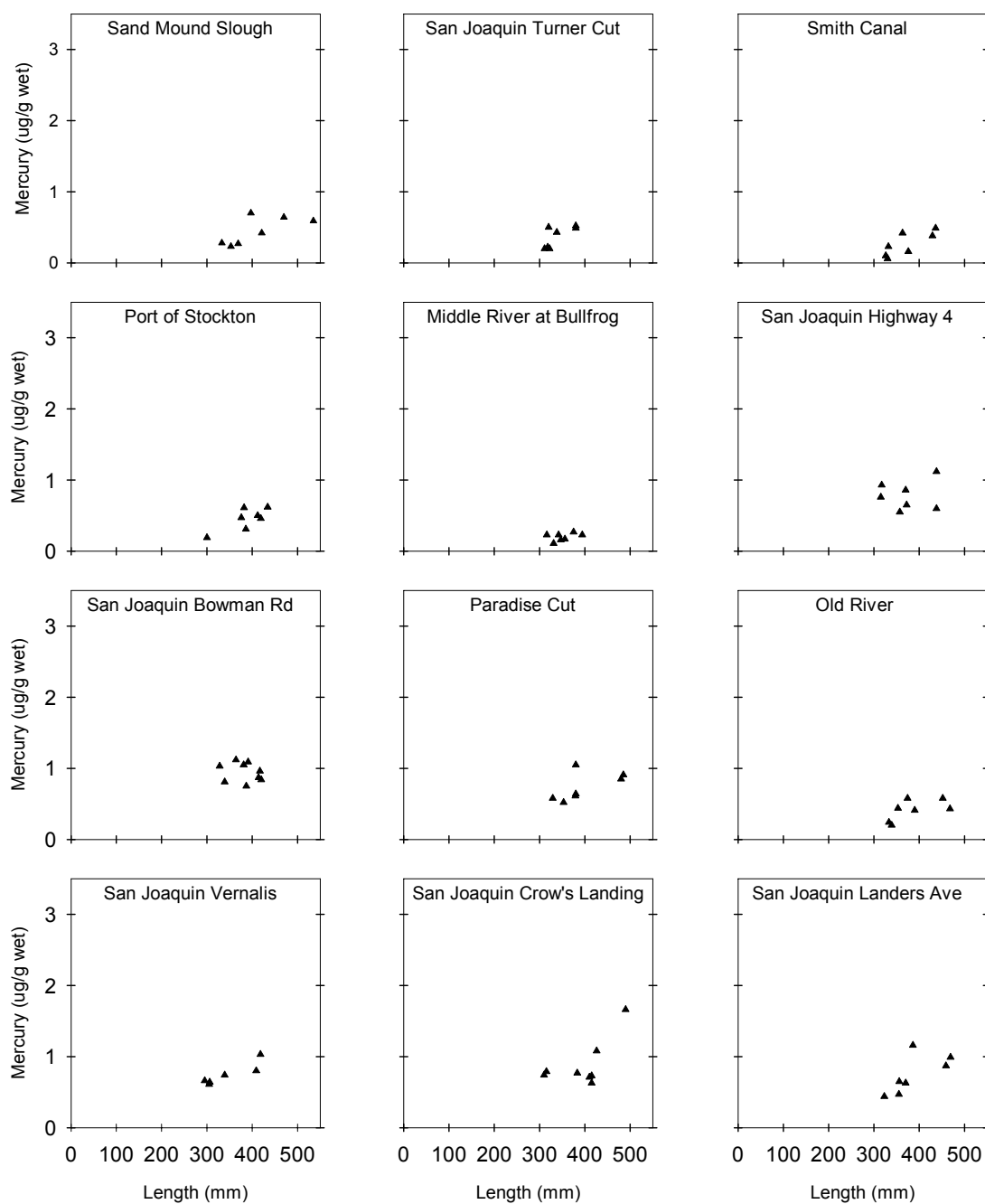


Figure 7. Mercury vs length in largemouth bass at each sampling location, 2000. Regression lines shown are results from polynomial regression ANCOVA (see Methods for details). The regression equation describing the reference condition was: $\text{SQRT}(\text{Hg}) = 0.449 + 0.00178(\text{LC})$. Additional terms describing each location are shown in each graph. The slopes of the curves (coefficients for the LC term) for Sacramento River RM44 and Mokelumne ds Cosumnes were significantly greater than the other locations. No significant coefficients were found for the LC^2 term. LC=centered length

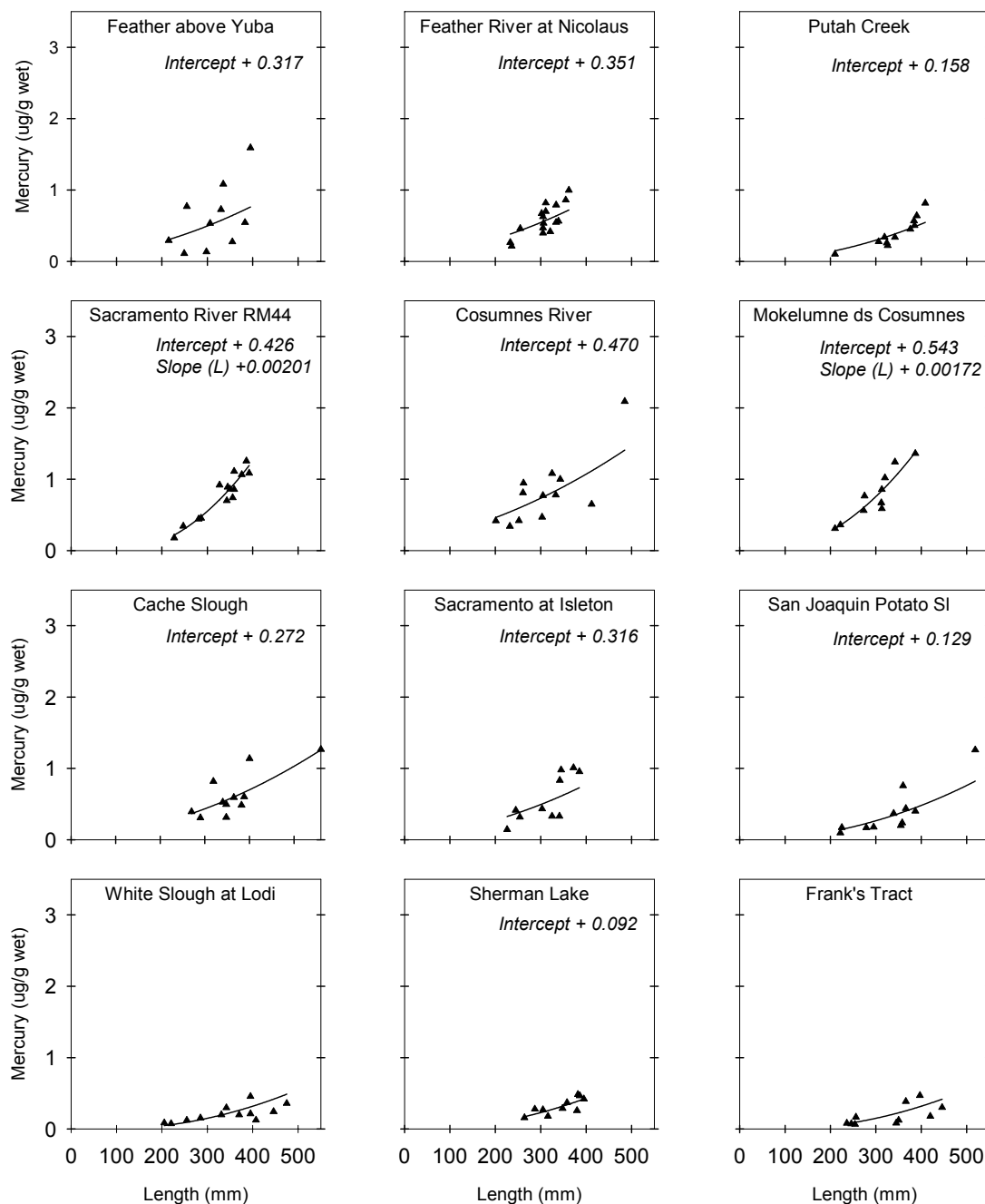


Figure 7. Continued.

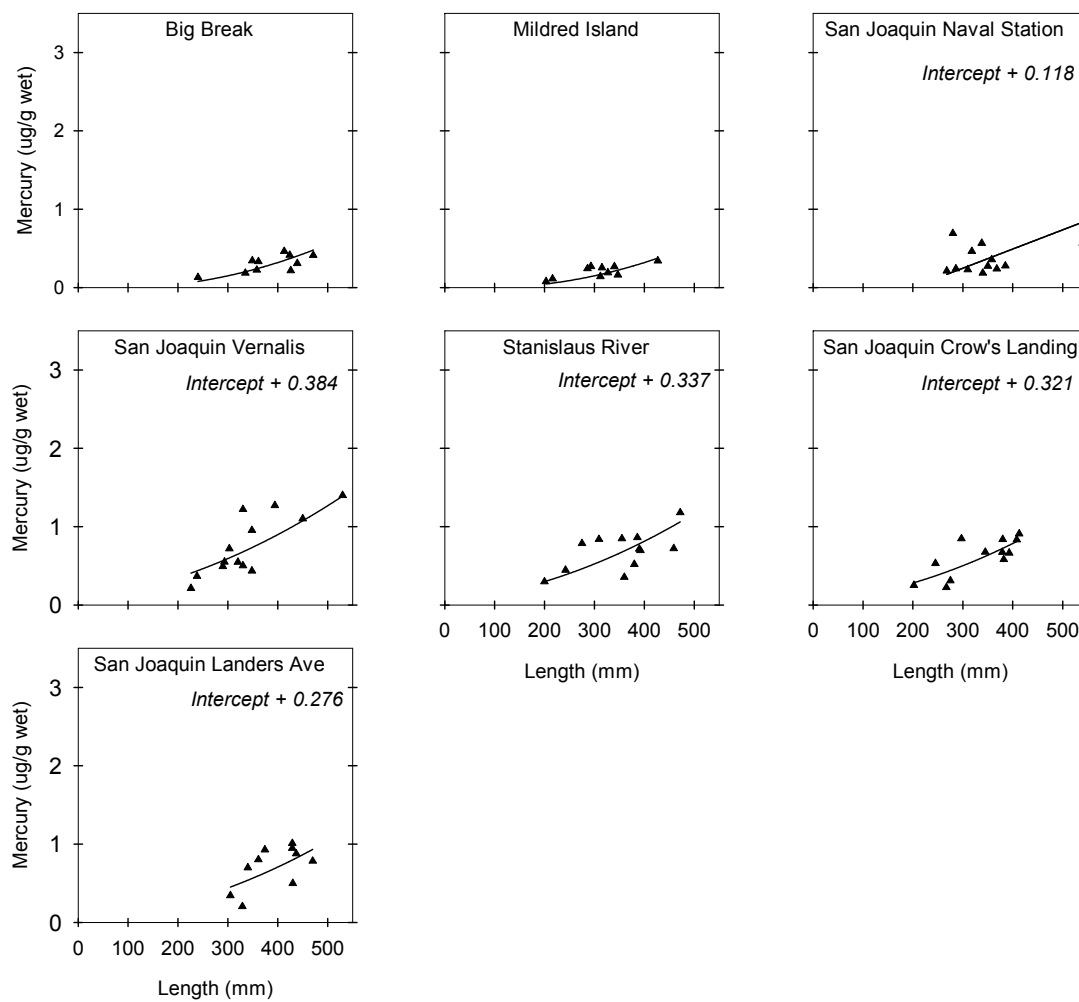


Figure 8. Spatial comparison of largemouth bass mercury concentrations estimated at standard length of 350 mm (mean and 95% confidence interval) by the polynomial regression ANCOVA method of Tremblay et al. (1998). Locations are listed in north (top) to south (bottom) order. Locations with non-overlapping intervals are considered significantly different.

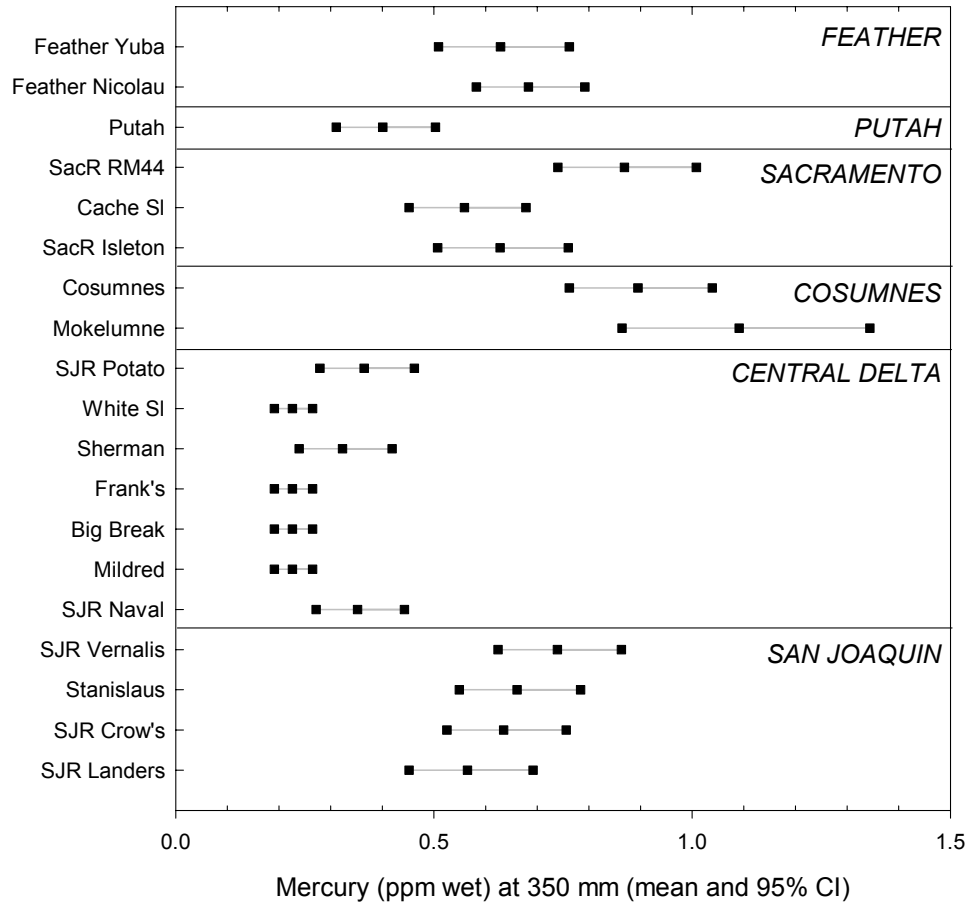


Figure 9. Graphical comparison of mercury concentrations in largemouth bass from 1999 and 2000 at sites sampled in both years.

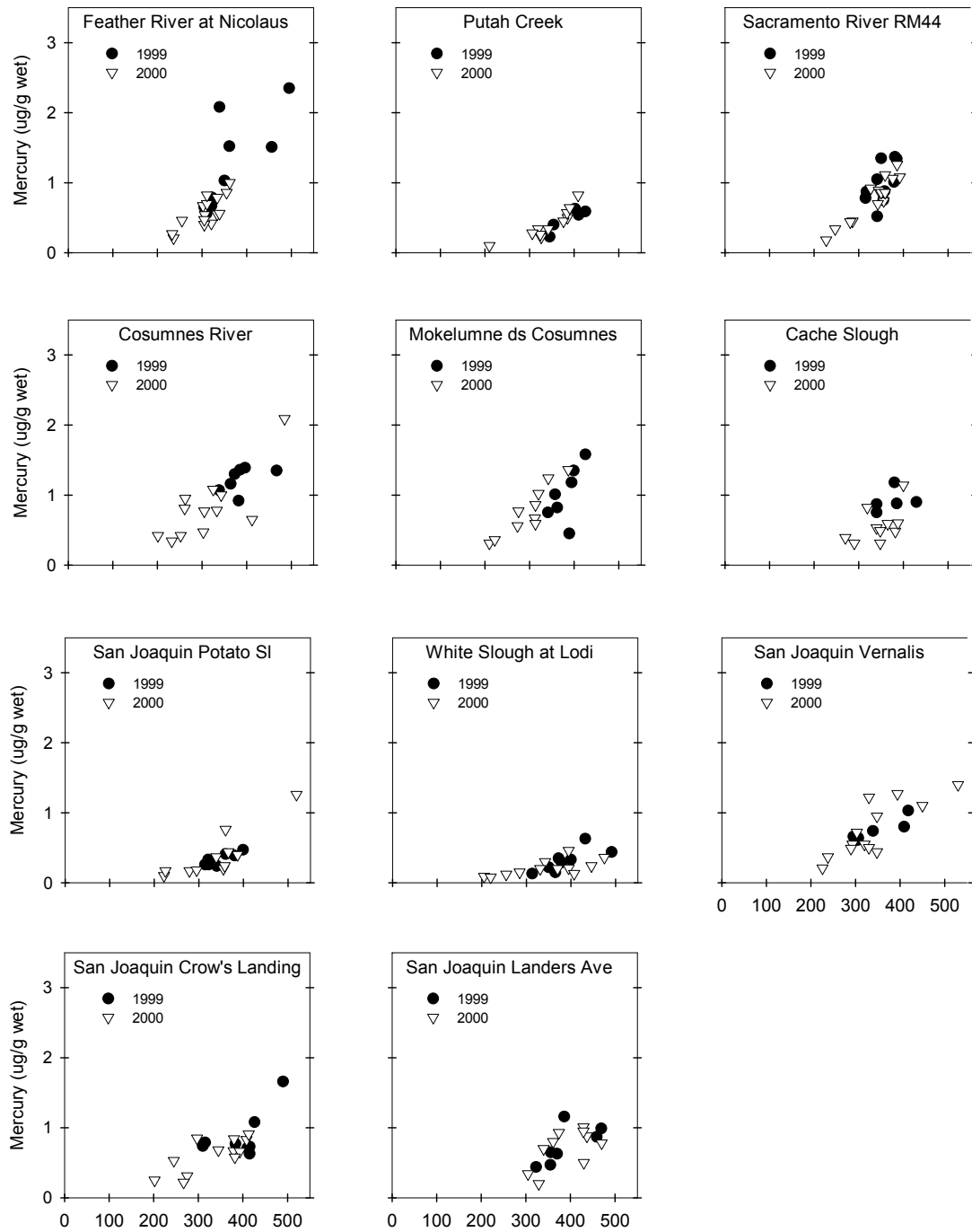


Figure 10. $\delta^{15}\text{N}$ in largemouth bass in 1999.

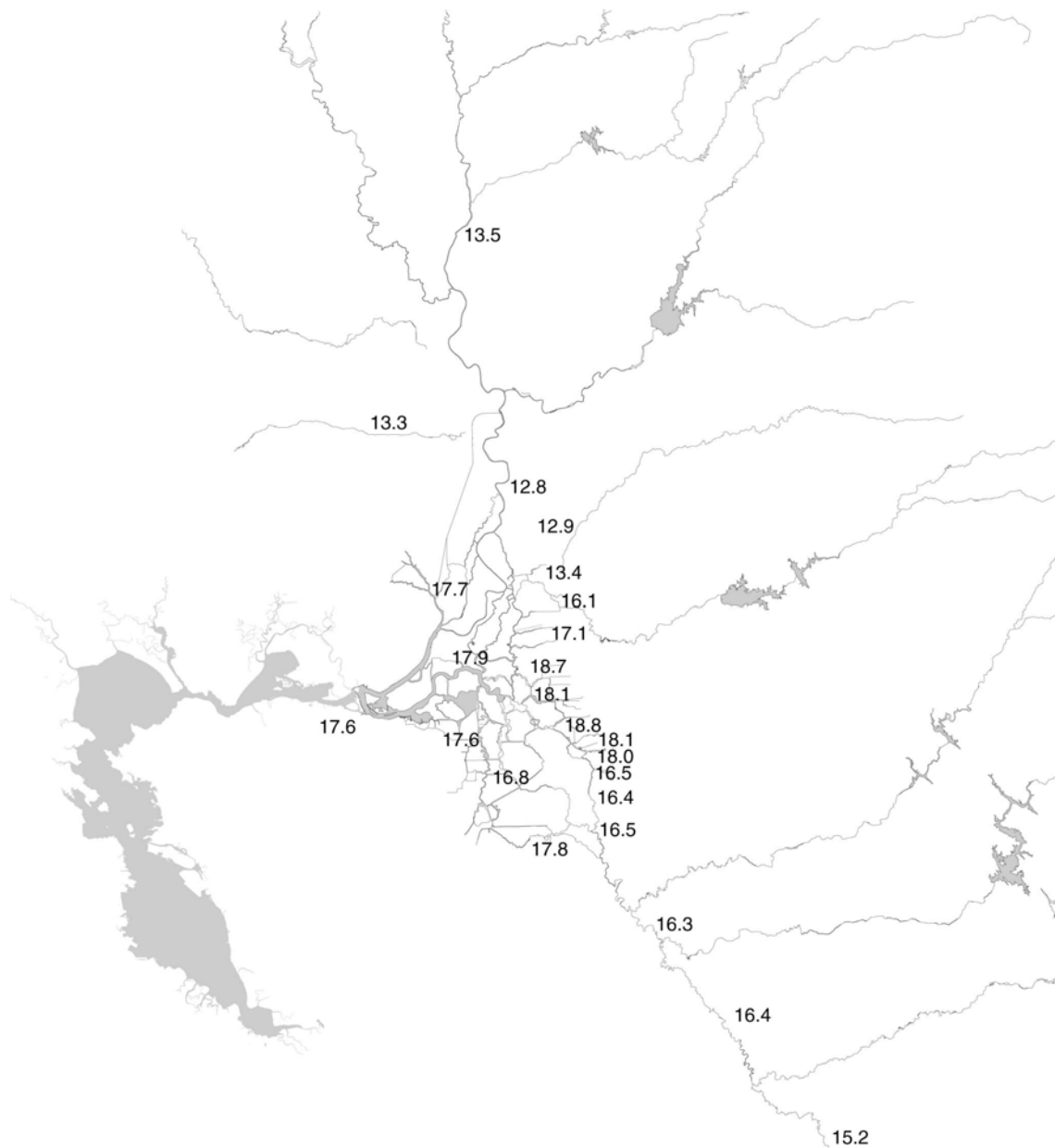


Figure 11. Mercury concentrations versus length in white catfish from the Delta region, 1999. 51% (38 of 75) of fish in the target size range (> 229 mm) analyzed were above the 0.3 ppm screening value. Numbers on top of x-axis show growth curve for white catfish in the south and central Delta (Moyle 2002). Growth is faster in the Sacramento River and other areas (Moyle 2002).

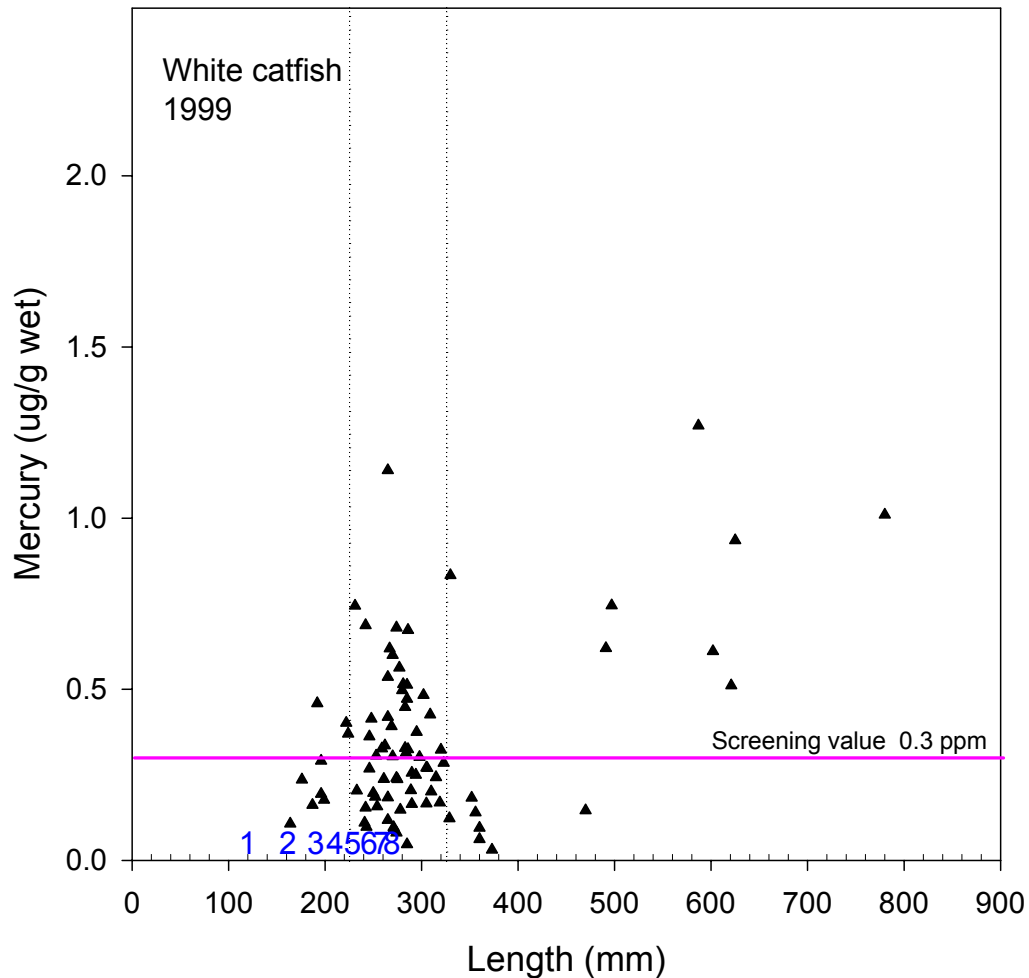


Figure 12. Mercury concentrations versus length in white catfish from the Delta region, 2000. 60% (54 of 90) of fish in the target size range (> 229 mm) analyzed were above the 0.3 ppm screening value. Numbers on top of x-axis show growth curve for white catfish in the south and central Delta (Moyle 2002). Growth is faster in the Sacramento River and other areas (Moyle 2002).

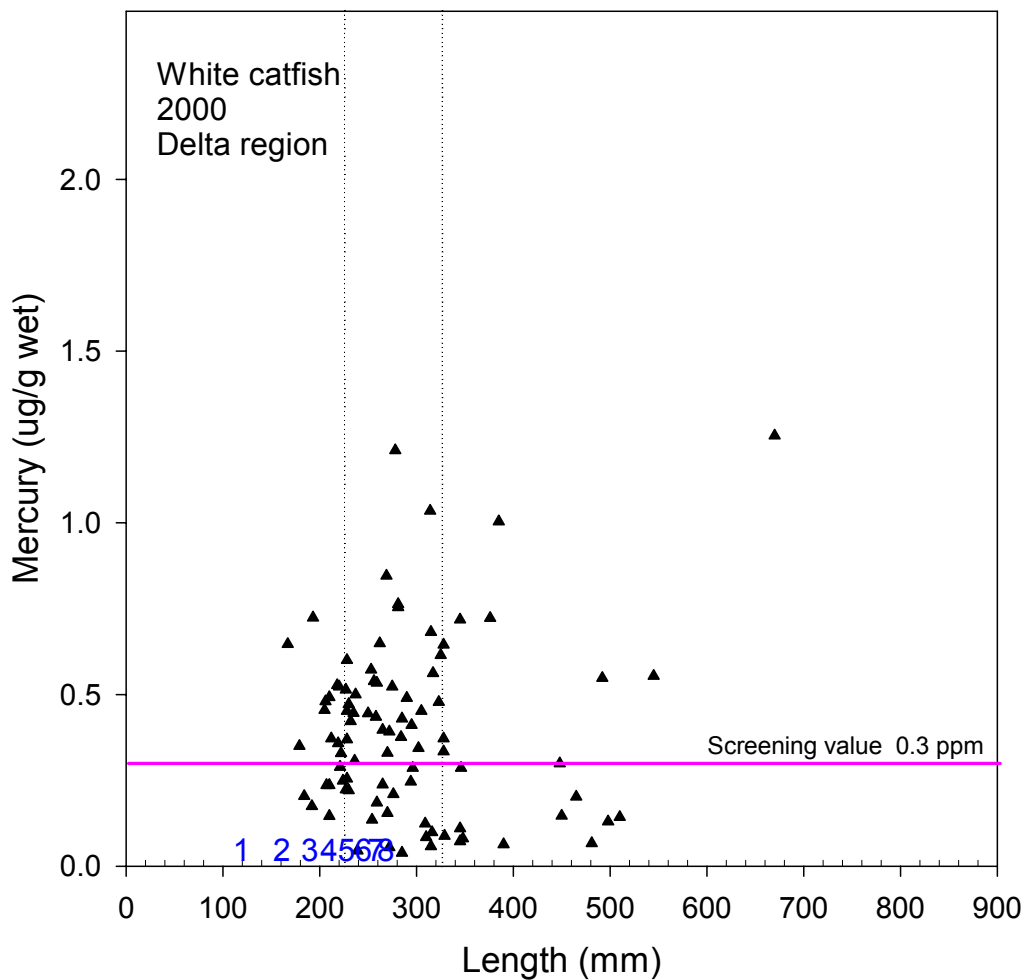


Figure 13. Mercury versus length in white catfish at each sampling location in the Delta region, 1999.

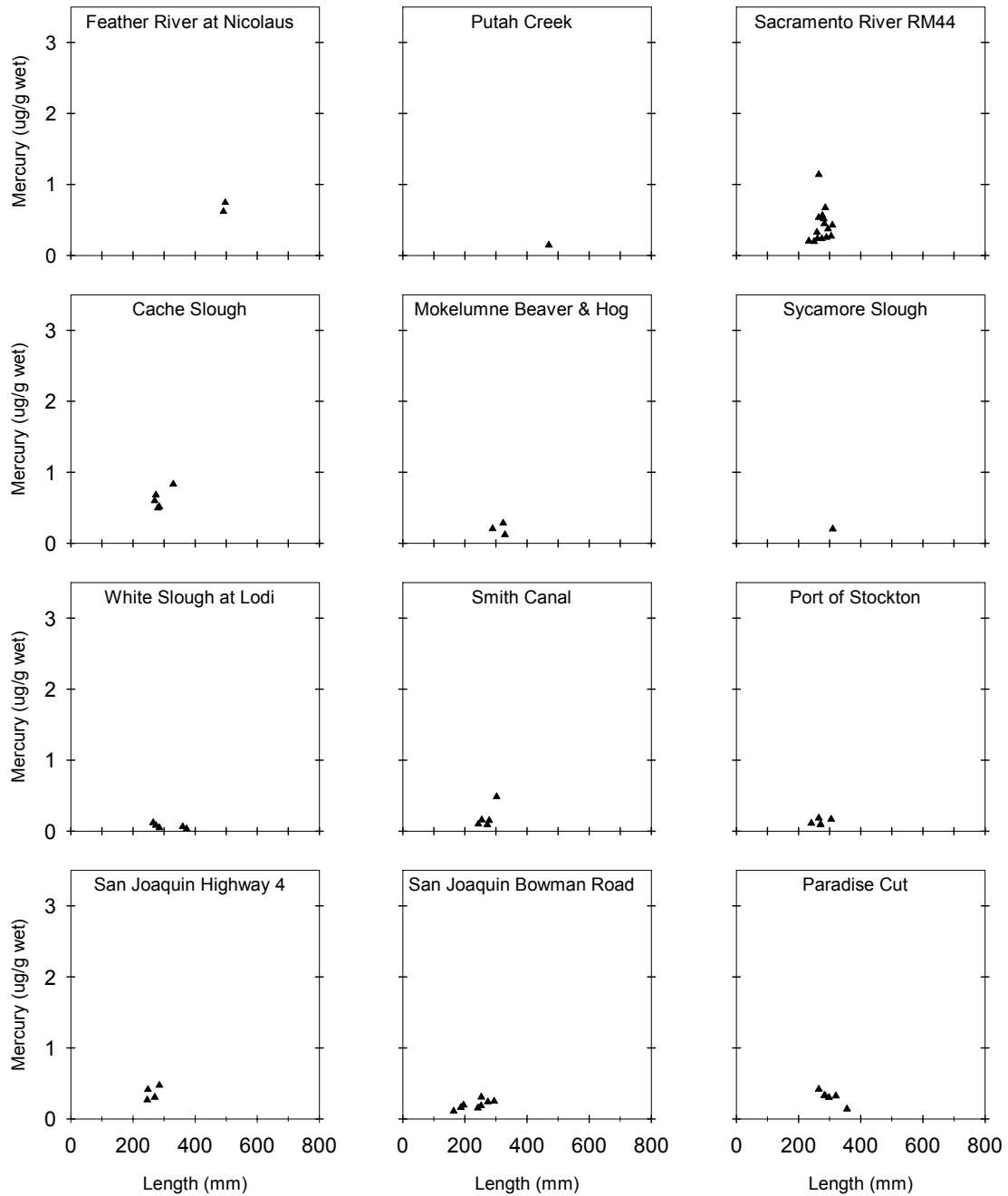


Figure 13. Continued

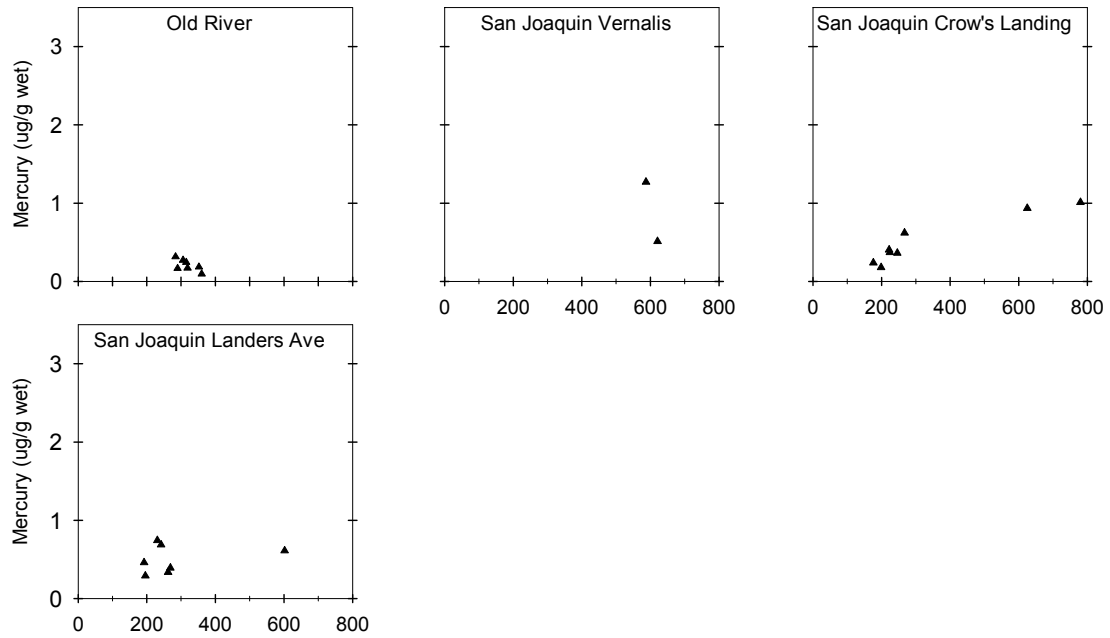


Figure 14. Mercury versus length in white catfish at each sampling location in the Delta region, 2000.

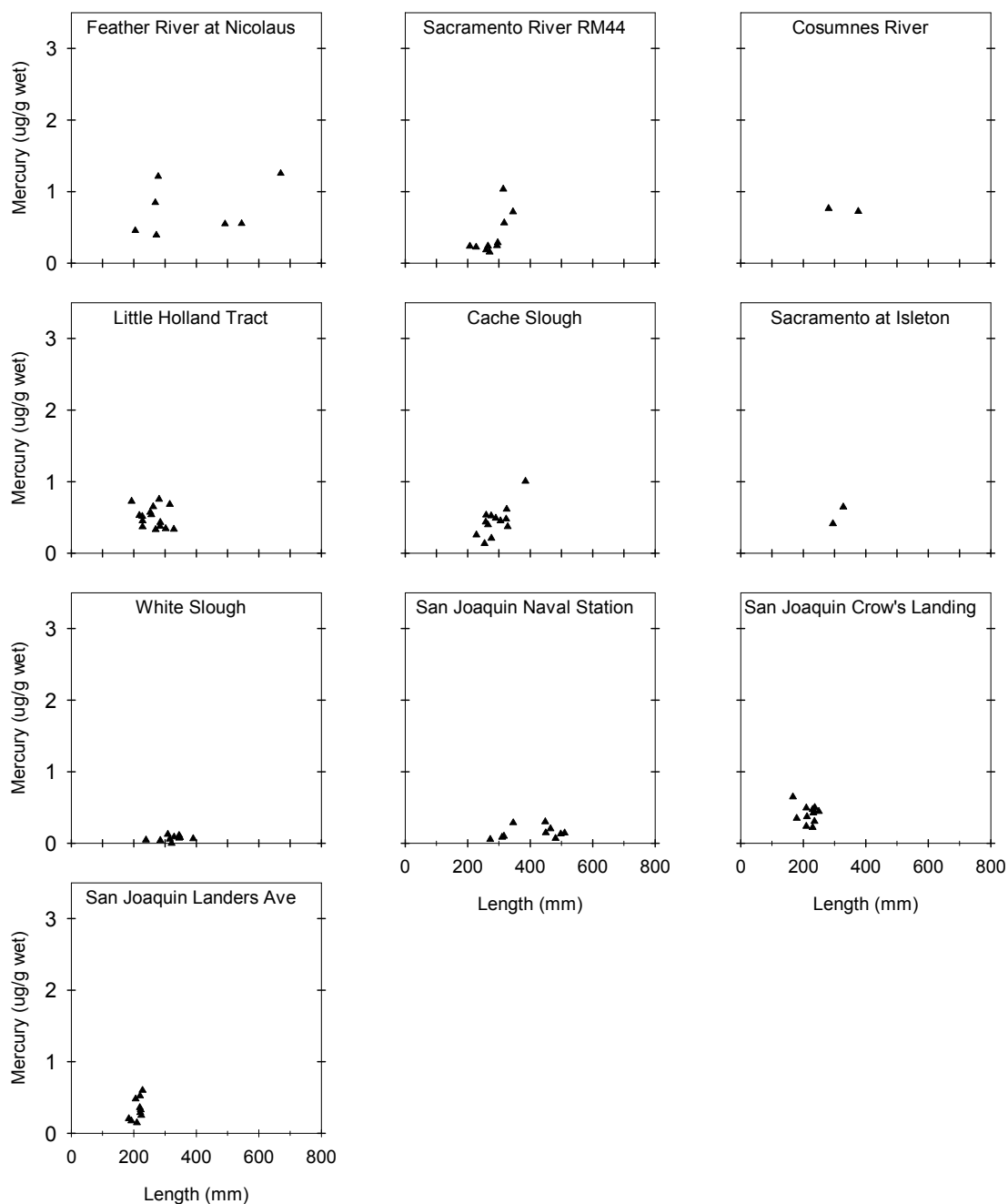


Figure 16. Average mercury concentrations in white catfish from each sampling location, 2000. All fish were 229 - 330 mm total length.

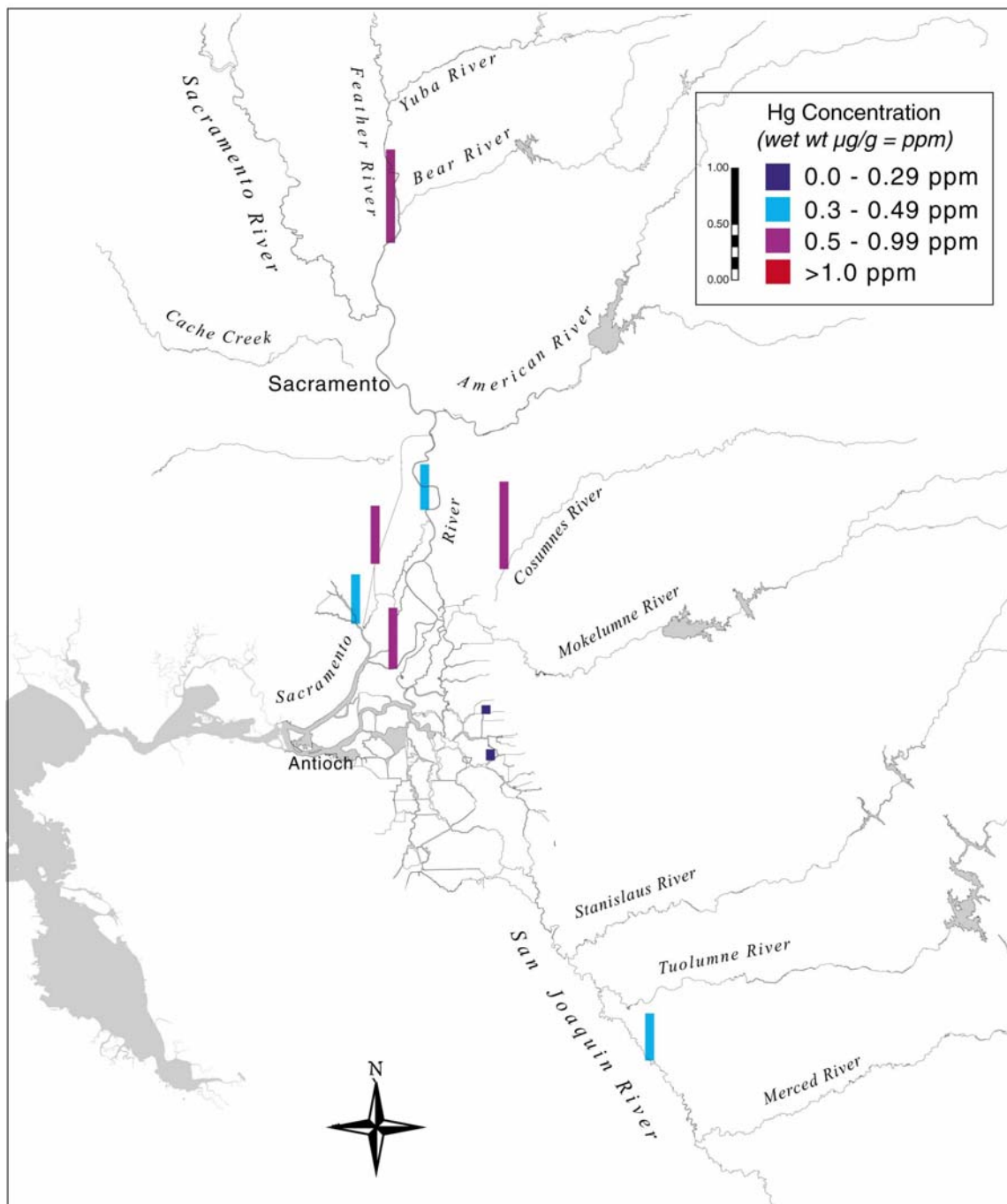


Figure 17. A) Composite and average mercury concentrations in white catfish from the Sacramento River at Hood/RM44, 1978-2000. Data from the TSMP (Rasmussen and Blethrow 1990), SRWP (Larry Walker Associates 2000, 2001), Davis et al. (2000), and this study. B) Residuals from the regression in Figure A versus year.

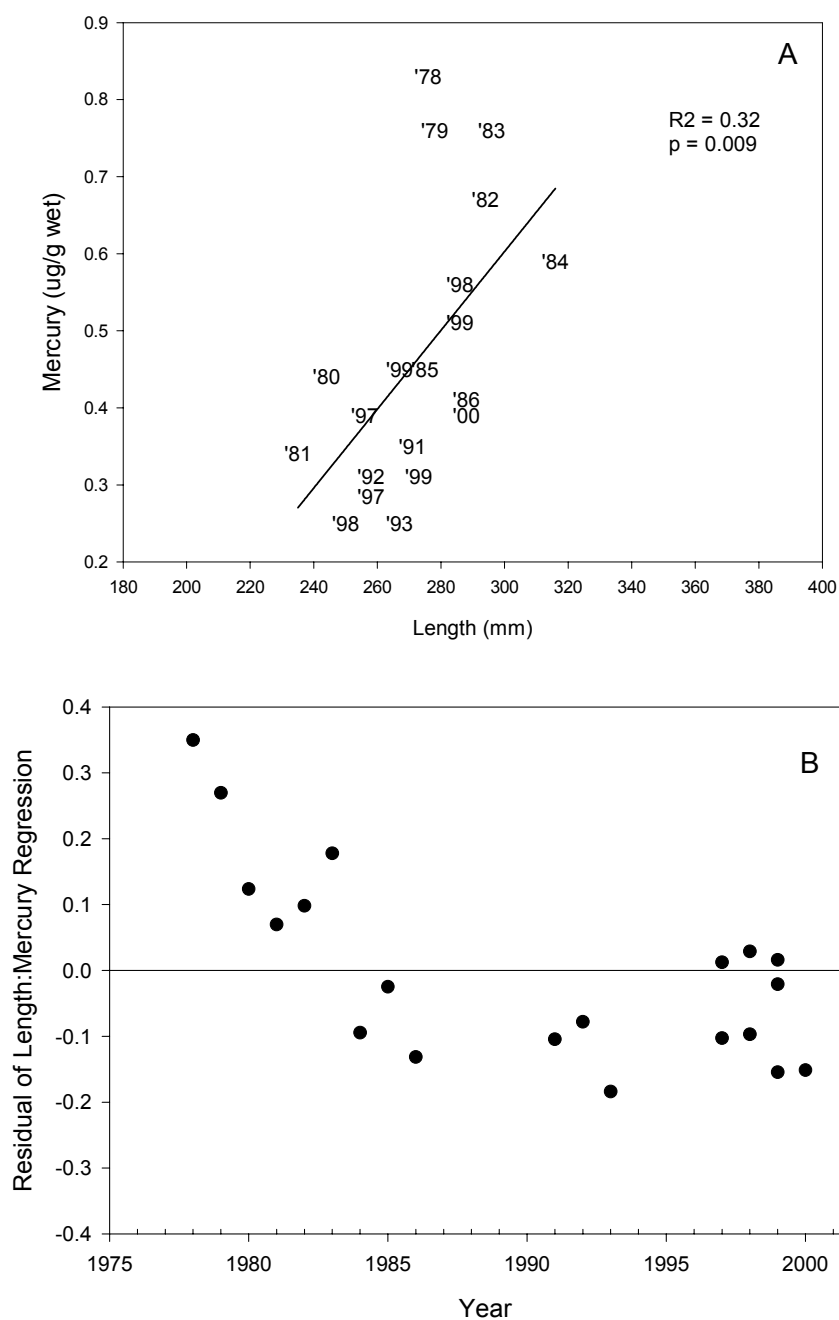


Figure 18. Mercury concentrations versus length in striped bass from the Delta region, 1999. 90% (27 of 30) of legal size fish (> 457 mm) analyzed were above the 0.3 ppm screening value. Numbers on top of x-axis show typical growth curve for striped bass in the Estuary (Moyle 2002). Three-letter codes indicate locations: CRO – San Joaquin River at Crow's Landing; COS – Cosumnes River; FEA – Feather River at Nicolaus; MBH – Mokelumne River between Beaver and Hog Slough; MDC – Mokelumne River downstream of Cosumnes; PAR – Paradise Cut; PRT – Port of Stockton; BOW – San Joaquin River at Bowman Road; VRN – San Joaquin River at Vernalis; HW4 – San Joaquin River at Highway 4; SUI – Suisun Bay.

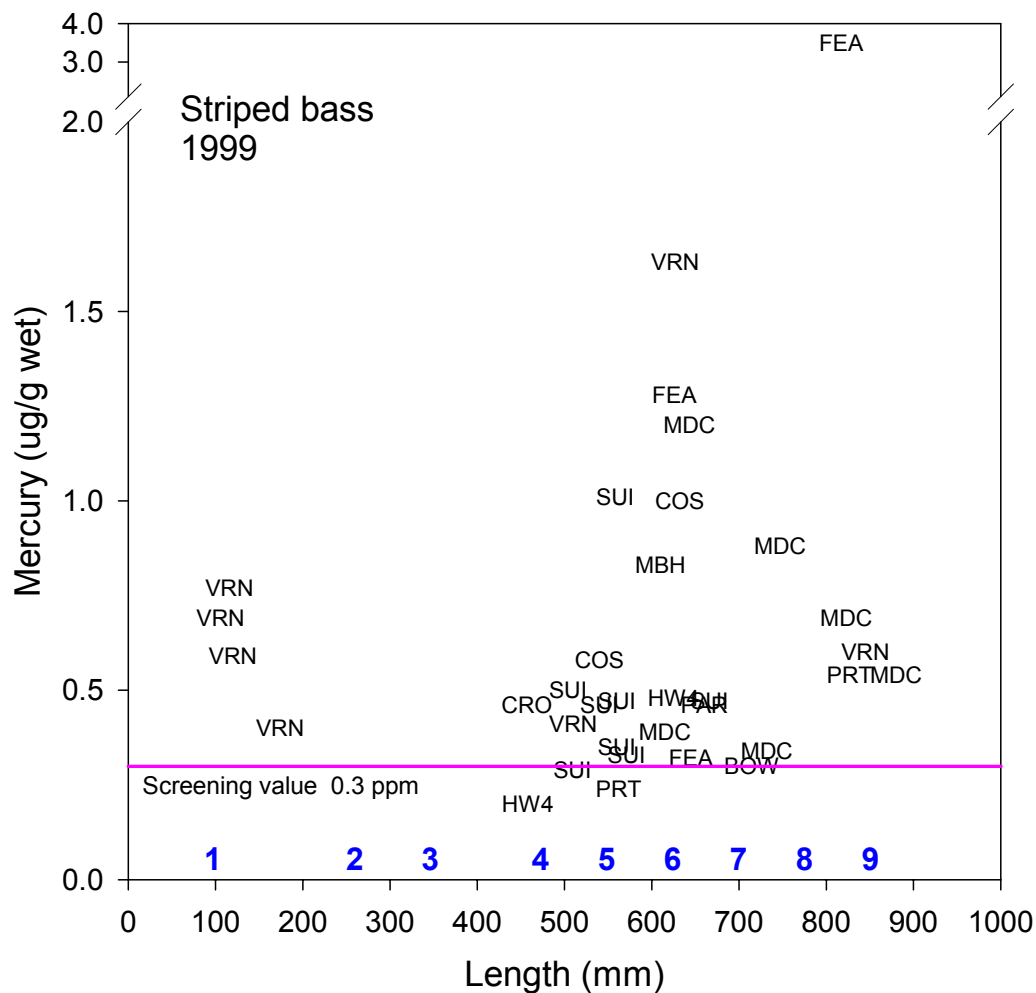


Figure 19. Mercury concentrations versus length in striped bass from the Delta region, 2000. 67% (4 of 6) of legal size fish (> 457 mm) analyzed were above the 0.3 ppm screening value. Numbers on top of x-axis show typical growth curve for striped bass in the Estuary (Moyle 2002). Three-letter codes indicate locations: FEA – Feather River at Nicolaus; FYB – Feather River between Yuba and Bear; RM44 – Sacramento River at River Mile 44; POT – San Joaquin River at Potato Slough; NAV – San Joaquin River at Naval Station; LAN – San Joaquin River at Landers Avenue.

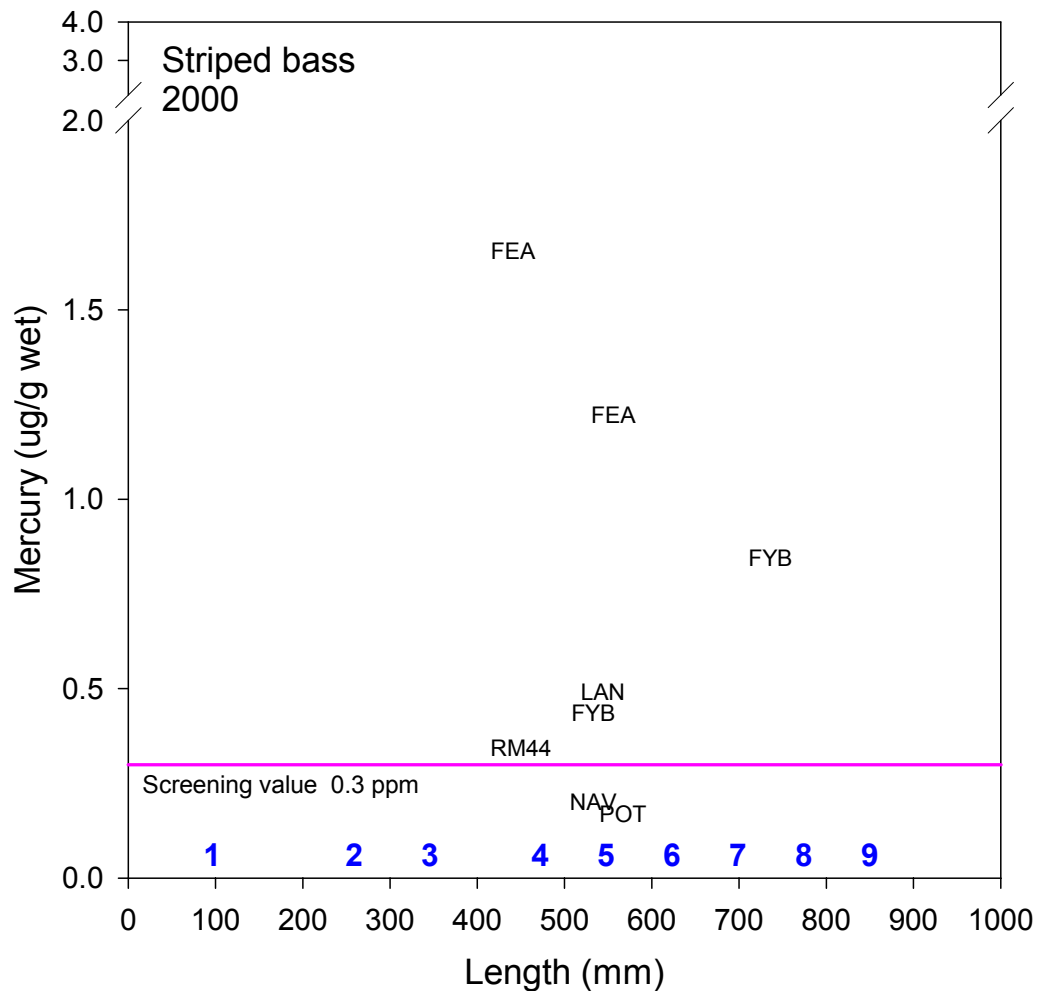


Figure 20. a) Mercury concentrations in striped bass from the Estuary in studies from 1970 to 2000. Data from CSDPH (1971), Fairey et al. (1997), Davis et al. (2002), Greenfield et al. (2002), and this study.

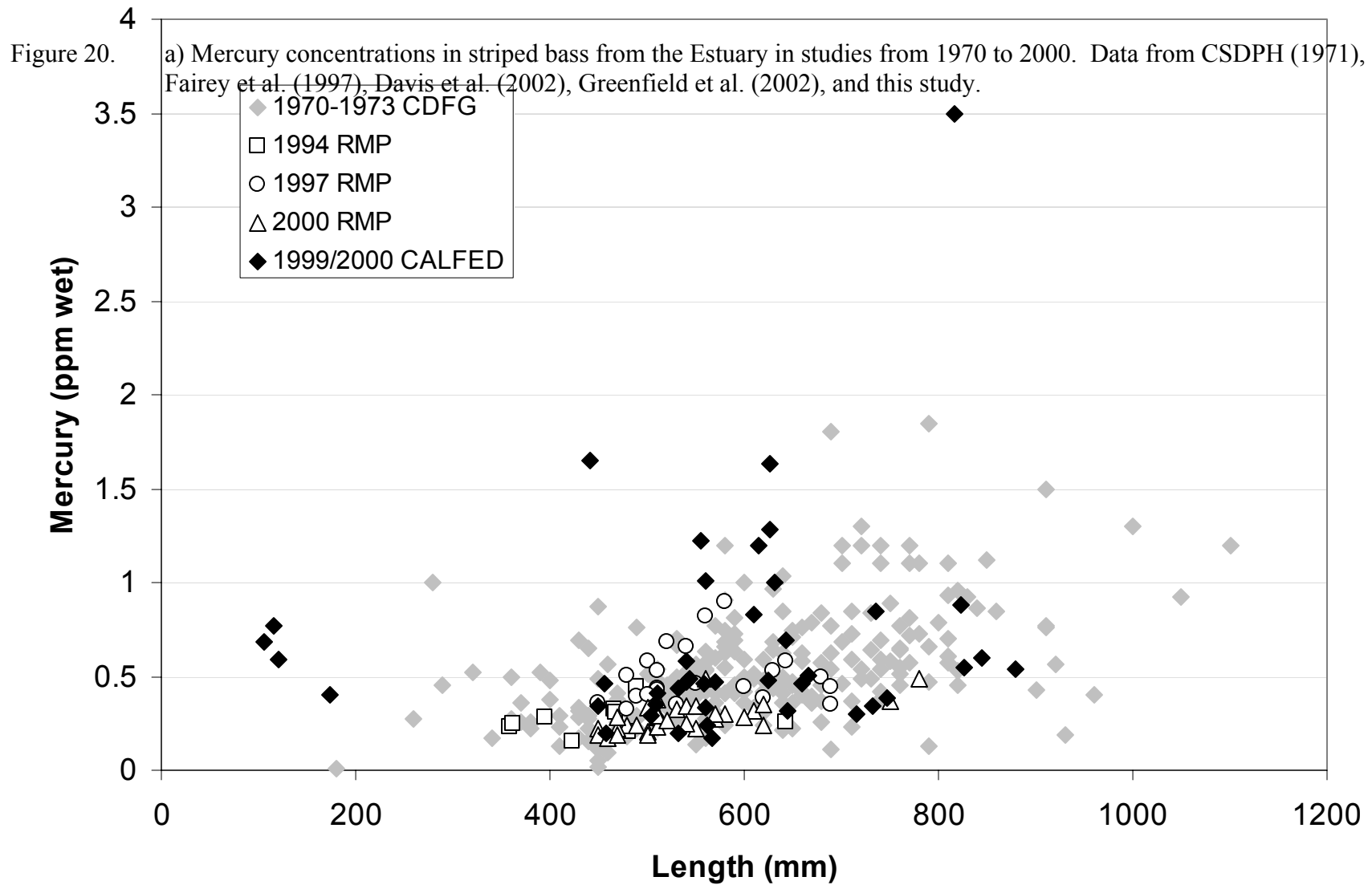


Figure 20. b) Mercury concentrations in striped bass from the Estuary in studies from 1970 to 2000. One high point excluded. Data from CSDPH (1971), Fairey et al. (1997), Davis et al. (2002), Greenfield et al. (2002), and this study.

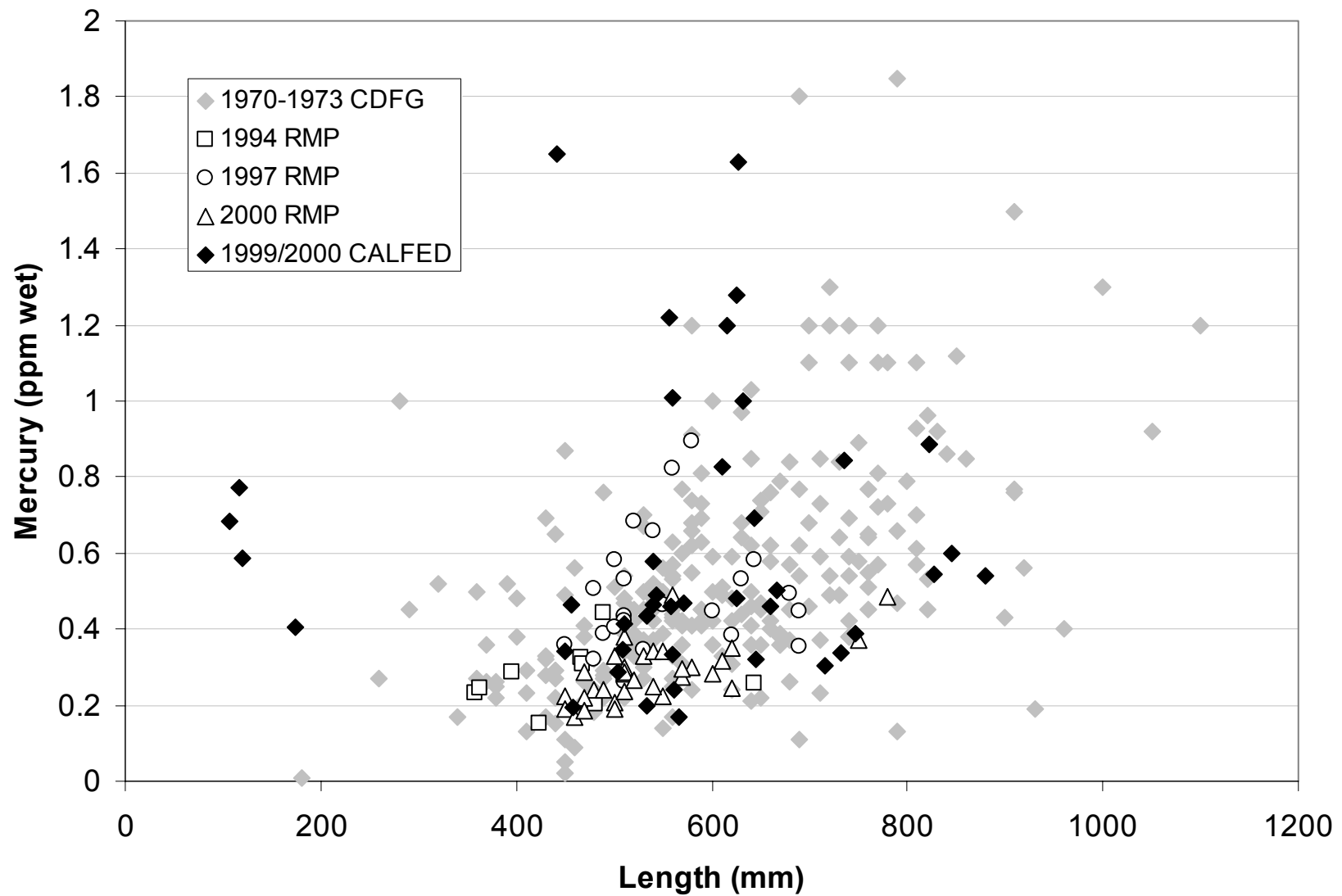


Figure 21. Mercury concentrations versus length in Sacramento pikeminnow from the Delta region, 2000. 57% (21 of 37) fish analyzed were above the 0.3 ppm screening value. Letters indicate locations: Y – Feather River above Yuba; B – Feather River between Yuba and Bear; F – Feather River at Nicolaus; R – Sacramento River at RM44; I – Sacramento River at Isleton; L – San Joaquin River at Landers Avenue.

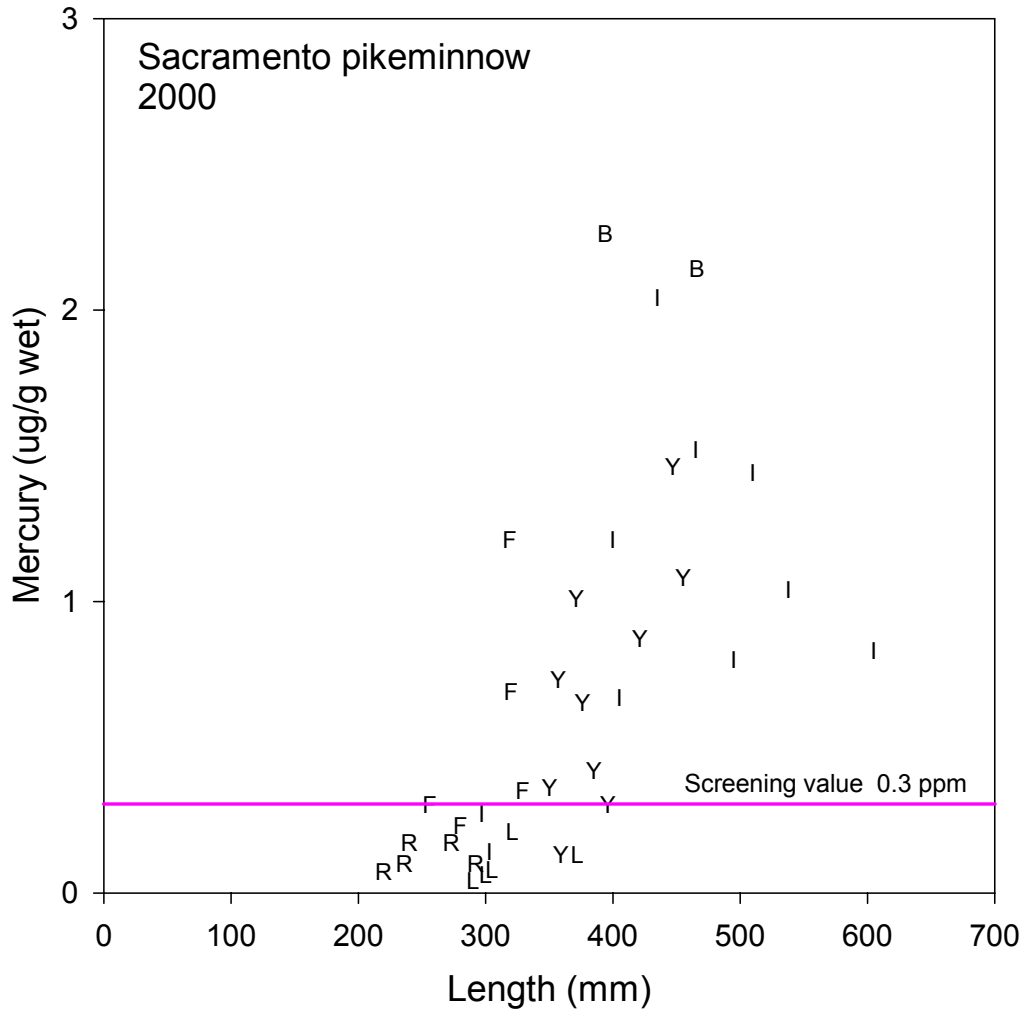


Figure 22. Mercury concentrations versus length in channel catfish from the Delta region, 1999 and 2000. Most samples were composites of 4 or 5 fish. 73% (8 of 11) samples analyzed were above the 0.3 ppm screening value. Letters indicate locations and year (upper case are 1999, lower case are 2000): b – Feather River between Yuba and Bear; F,f – Feather River at Nicolaus; c – Cache Slough; O – Old River near Paradise Cut; T – San Joaquin River at Turner's Cut; V – San Joaquin River at Vernalis; s – Stanislaus River; L – San Joaquin River at Landers Avenue.

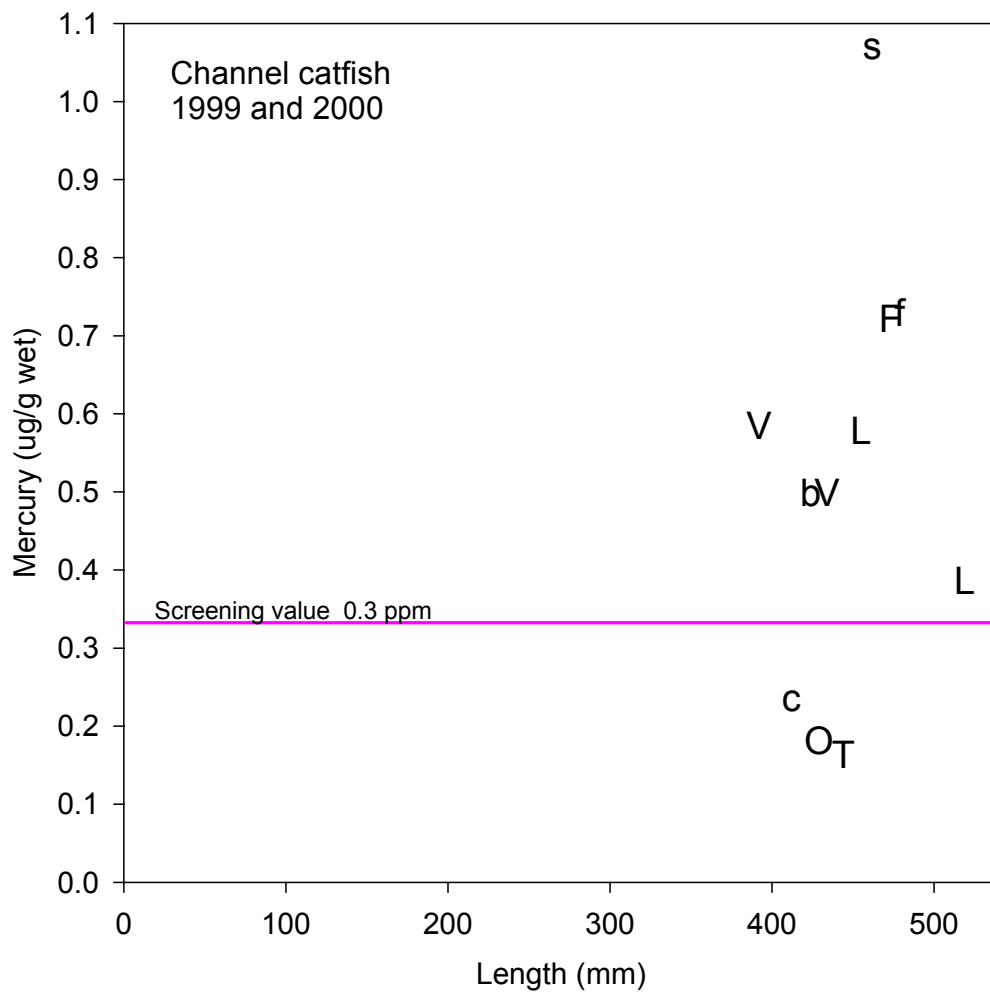


Figure 23. Mercury concentrations versus length in black crappie from the Delta region, 1999 and 2000. Samples were composites of 3 to 5 fish. 67% (4 of 6) samples analyzed were above the 0.3 ppm screening value. Letters indicate locations and year (upper case are 1999, lower case are 2000): g – Green's Lake; c– Cache Slough; sh – Sherman Lake; SM – Smith Canal; n – San Joaquin River at Naval Station.

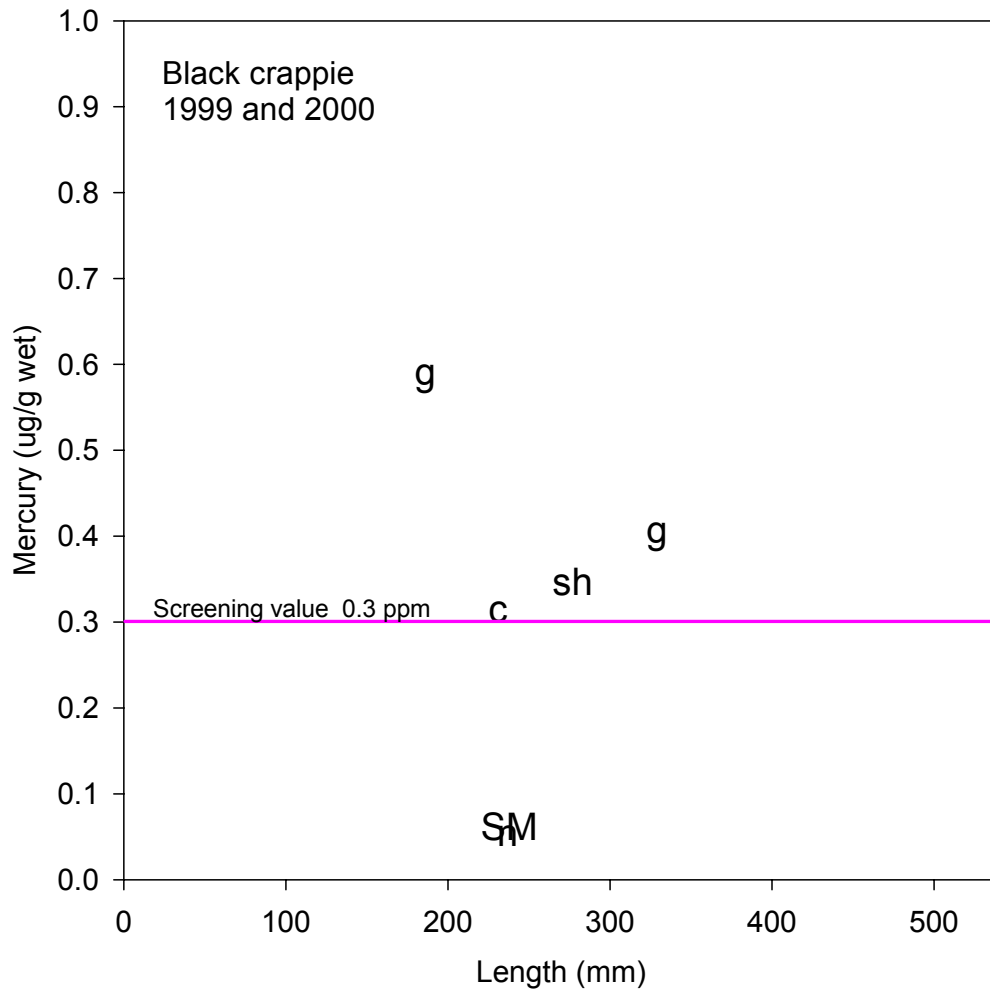


Figure 24. Mercury concentrations versus length in Sacramento sucker from the Delta region, 1999 and 2000. Samples were composites of 3 to 5 fish. 35% (6 of 17) samples analyzed were above the 0.3 ppm screening value. Three-letter codes indicate location and year (upper case are 1999, lower case are 2000): YUB – Yuba River above Feather; fyu – Feather River above Yuba; fyb – Feather River between Yuba and Bear; fea – Feather River at Nicolaus; PUT/put – Putah Creek; rm44 – Sacramento River at River Mile 44; COS/cos – Cosumnes River; MOK/mok – Mokelumne River downstream of Cosumnes; cac – Cache Slough near Ryer Island ferry; isl – Sacramento River near Isleton; ANT – San Joaquin River at Antioch.

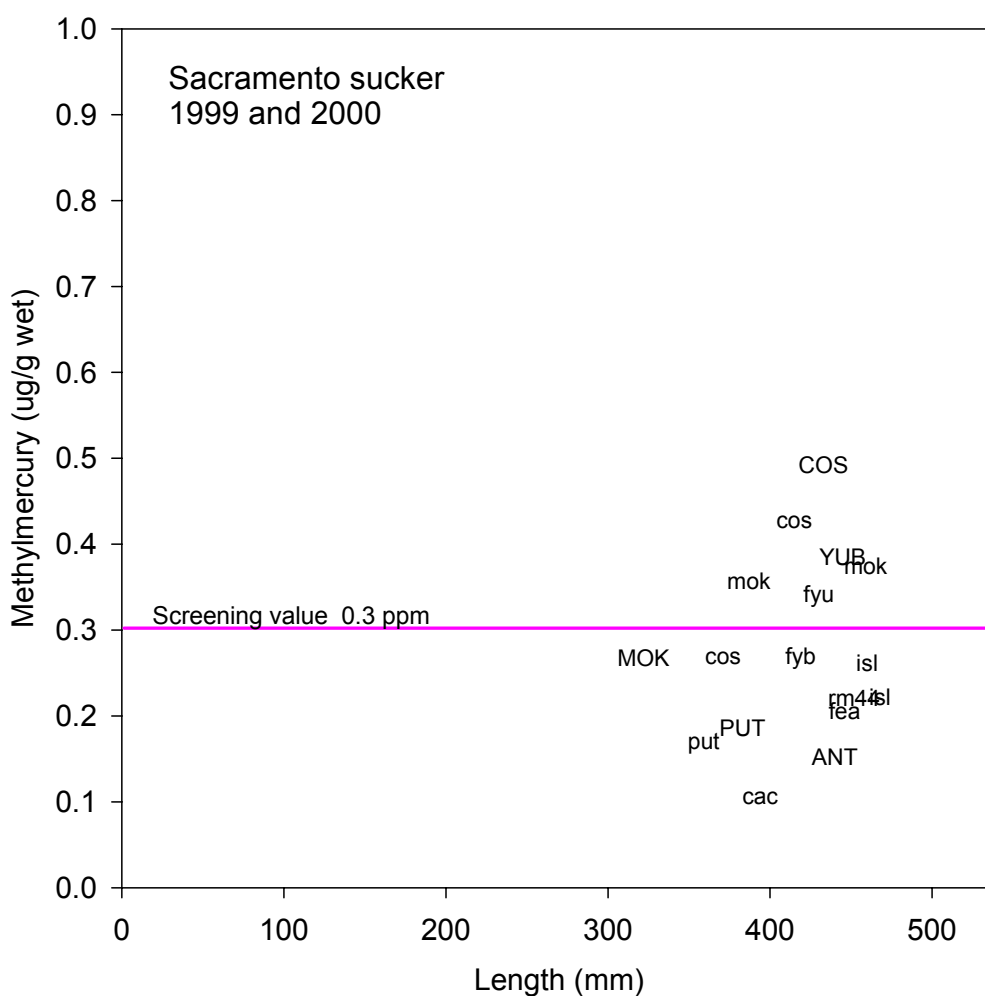


Figure 25. Mercury concentrations versus length in common carp from the Delta region, 1999 and 2000. Samples were composites of 3 to 5 fish. 35% (6 of 17) samples analyzed were above the 0.3 ppm screening value. Three-letter codes indicate location and year (upper case are 1999, lower case are 2000): fyb – Feather River between Yuba and Bear; rm44 – Sacramento River at River Mile 44; grn – Green's Lake; hol – Little Holland tract; CAC/cac – Cache Slough near Ryer Island ferry; lan – San Joaquin River at Landers Avenue.

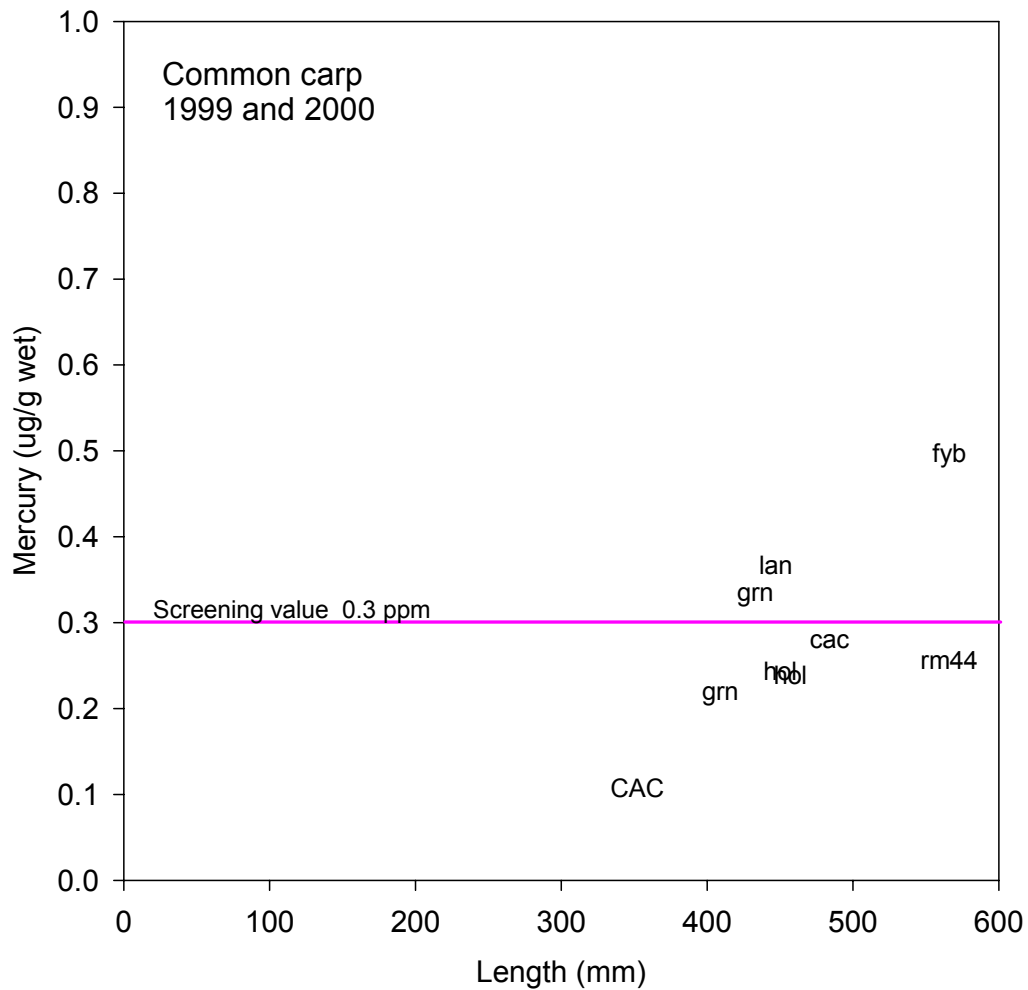


Figure 26. Mercury concentrations versus length in bluegill from the Delta region, 1999. Samples were composites of 5 fish, except for 3 samples with fewer fish. 11% (3 of 27) samples analyzed were above the 0.3 ppm screening value.

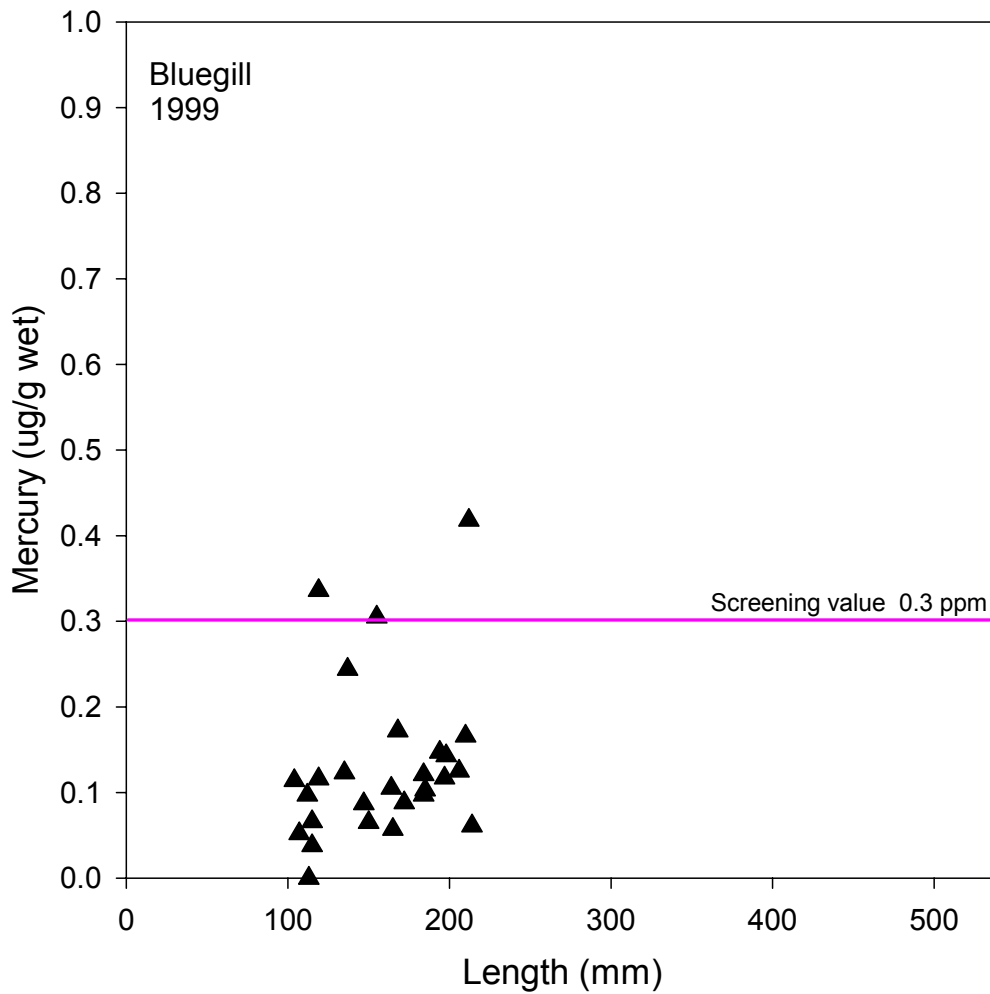


Figure 27. Mercury concentrations versus length in redear sunfish from the Delta region, 1999 (black) and 2000 (white). Samples were composites of 5 fish, except for 3 samples with fewer fish (3 or 4). 5% (1 of 20) of samples analyzed were above the 0.3 ppm screening value.

