3.3 IMPACT OF MERCURY BIOACCUMULATION ON FISHING AND AQUATIC LIFE IN CALIFORNIA

3.3.1. Introduction

Mercury contamination is common in aquatic food webs in California, with long-term trends indicating little change over the past few decades. Mercury exists in the environment in several different chemical forms, the most problematic of which is methylmercury. Methylmercury accumulates in aquatic food webs, with most of the contaminant being efficiently passed up the food chain at every trophic level. Depuration of methylmercury in vertebrates is very slow.

Mercury is present in California from many different sources. The main source by mass is historical mining operations for mercury and for gold (where mercury was used to extract the precious metal). Combustion emissions result in atmospheric deposition of mercury. Some sources are urban-related, including fluorescent light bulbs, electrical switches, dental fillings, medical instruments, and vaccines.

Mercury becomes a problem when it bioaccumulates in food webs to concentrations that may harm humans or wildlife (Wiener et al. 2003a). Mercury is neurotoxic to vertebrates and other animals, causing deformities, impairing the nervous system, and altering metabolism. The greatest effects occur during early development, and the concentrations at which subtle effects arise are not well understood for many species, including humans. Even less is known concerning the synergistic effects with other contaminants and stressors. The main management actions that affect significant mercury source loading to the environment are currently TMDLs and mine clean-ups. Consumption advisories, when effective, can help protect human populations. This chapter addresses the assessment questions, which are summarized in the Introduction.

The following section (3.3.2) and all the maps in the mercury chapter are geared exclusively toward concentration categories relating to human consumption of sport fish and human health concerns. Section 3.3.3 addresses how mercury may be affecting aquatic life in California, but sufficient small fish data were not available to create the same detailed maps. Maps geared toward impacts on aquatic life would have different species represented (i.e., small fish, such as Mississippi silversides) and would have much lower thresholds (see the TMDL wildlife threshold discussed in section 3.3.3).

3.3.2. Impact of Mercury on Fishing in California

a. Current Status

Consumption Advisories
Consumption advisories issued by OEHHA are one key indicator of the impact of mercury on fishing in California. As of January 2006, consumption advisories due at least partially to mercury were in place for four general groups of water bodies: 1) estuaries near San Francisco (Tomales Bay and San Francisco

Bay-Delta), 2) lakes and reservoirs in the Coastal Range (from Lake Nacimiento in San Louis Obispo County to Black Butte Reservoir in Glenn and Tehama Counties), 3) lakes and rivers in the northern Sierra Nevada foothills and northern Central Valley, and 4) the Trinity River Watershed in the Klamath/Trinity Range (Figure 3.2.1, Table 3.2.1). All of the consumption advisories involving mercury are north of Morro Bay and all but one of the advisories north of Morro Bay include mercury (the Grassland Area advisory for selenium is the exception). Most of these advisories are exclusive for mercury, save for the two in the most urbanized areas: San Francisco Bay-Delta and the Bay Area reservoirs.

Most of the mercury advisories have been issued in the last decade. This pattern reflects a trend toward increasing availability of information on mercury contamination in sport fish and increasing awareness of the mercury problem, not a trend of increasing concentrations. Mercury contamination is extremely persistent, particularly in northern California where substantial loads are still moving down the watersheds toward estuaries, so these advisories are likely to be in place for quite some time. It is possible and even likely that, with increased spatial coverage in monitoring of water bodies in California, other areas may be identified where mercury concentrations persist above the threshold for concern, as happened recently with Bay Area reservoirs. Advisories that will cover a large portion of the state (specifically, much of the Central Valley) are currently being developed as part of the CALFED-funded Fish Mercury Project.

303(d) Listings

The 2002 303(d) List for California indicates that mercury is a major contributor to pollutant impact on the fishing beneficial use in the state (Appendix 3). The 2002 303(d) List included mercury listings for the following general areas:

- Region 1 – Lake Pillsbury, Lake Mendocino, Sonoma Lake (6054 acres);
- Region 2 – San Francisco Bay (276,698 acres), Sacramento-San Joaquin Delta (41,736 acres), Tomales Bay (8545 acres) and Walker Creek (16 miles), Guadalupe water bodies (63 acres and 26 miles), and other Bay Area reservoirs and creeks (1226 acres and 16 miles);
- Region 3 – Clear Creek (10 miles) and Hernandez Reservoir (626 acres);
- Region 4 – A few coastal water bodies (380 acres and 1 mile), creeks (6 miles), and lakes (413 acres);
- Region 5 – Many lakes and reservoirs (79,652 acres), rivers and creeks (421 miles), and the Delta waterways (21,087 acres);
- Region 8 – Big Bear Lake (2865 acres); and
- Region 9 – San Diego Bay shoreline (55 acres).

Most of the impacted areas are in central and northern California, although there are a few in the south. The list includes major estuaries, rivers, and lakes as well as many smaller creeks and reservoirs. Some impacted areas may not yet have been assessed for 303d listing, as discussed in section 3.2.

There is general agreement between areas on the 303(d) List and those with consumption advisories in Regions 1, 2, and 5, with exceptions as follows. In Regions 3, 8, and 9 the water bodies on the 303(d) List do not have consumption advisories. These water bodies may have been listed as impaired due to data, such as sediment or small fish mercury concentrations, which are insufficient to produce a consumption advisory. At least nine sport fish must have been sampled in the defined area for an advisory to be issued. Notable areas with advisories that are not on the 303(d) List include the Trinity River Watershed and Lake Nacimiento. In the former case, this discrepancy is probably due to the advisory being issued after the 2002 303(d) List was finalized.

Recent Monitoring Data

Sport fish monitoring data collected from 1998 – 2003 indicate that mercury concentrations are above thresholds for concern for human health in many areas of the state (Figure 3.3.1, Table 3.3.1). A total of 294 locations were sampled for mercury during this period. Intensive sampling focused on mercury occurred in the Delta region (Davis et al. 2003a), resulting in the aggregation of dots in this area on the map.

Table 3.3.1. Total number of locations sampled for mercury and percentage in each concentration category for three different time intervals from 1978 to 2003.

Time Interval	Total Number of Locations Sampled	Low	Moderate	High	Very High
Recent (1998 – 2003)	294	24%	47%	21%	8%
1988 – 1997	162	38%	47%	12%	3%
1978 – 1987	113	16%	67%	10%	7%

Twenty-three of these locations (8% of the total) had a species with a median concentration above 0.90 ppm, placing these sites in the red very high mercury category. All these locations are north of Morro Bay. These hotspots are clustered in central California: in the Sierra Nevada, Coast Range, Central Valley and surrounding foothills, Sacramento-San Joaquin Delta, and San Francisco Bay. Most of the very high mercury sites are within the Golden Gate watershed, with a few others along the coast near the Golden Gate and Lake Nacimiento notably farther south. The Golden Gate watershed and most of the other hotspots (Tomales Bay and Lake Nacimiento) are areas that have been known or suspected to have mercury contamination for decades.

Around one-fifth (21%) of the locations sampled from 1998 – 2003 had mercury concentrations in the orange high category (> 0.5 – 0.9 ppm), and nearly half (47%) fell in the yellow moderate grouping (0.1 – 0.5 ppm). These moderate and high locations were primarily concentrated in the same central California cluster as the hotspots, with the addition of several yellow and orange sites in the Klamath/Trinity Range, southern Sierra Nevada, southern Central Valley, and in southern California along the urbanized coast, Los Angeles Basin, and Salton Sea.

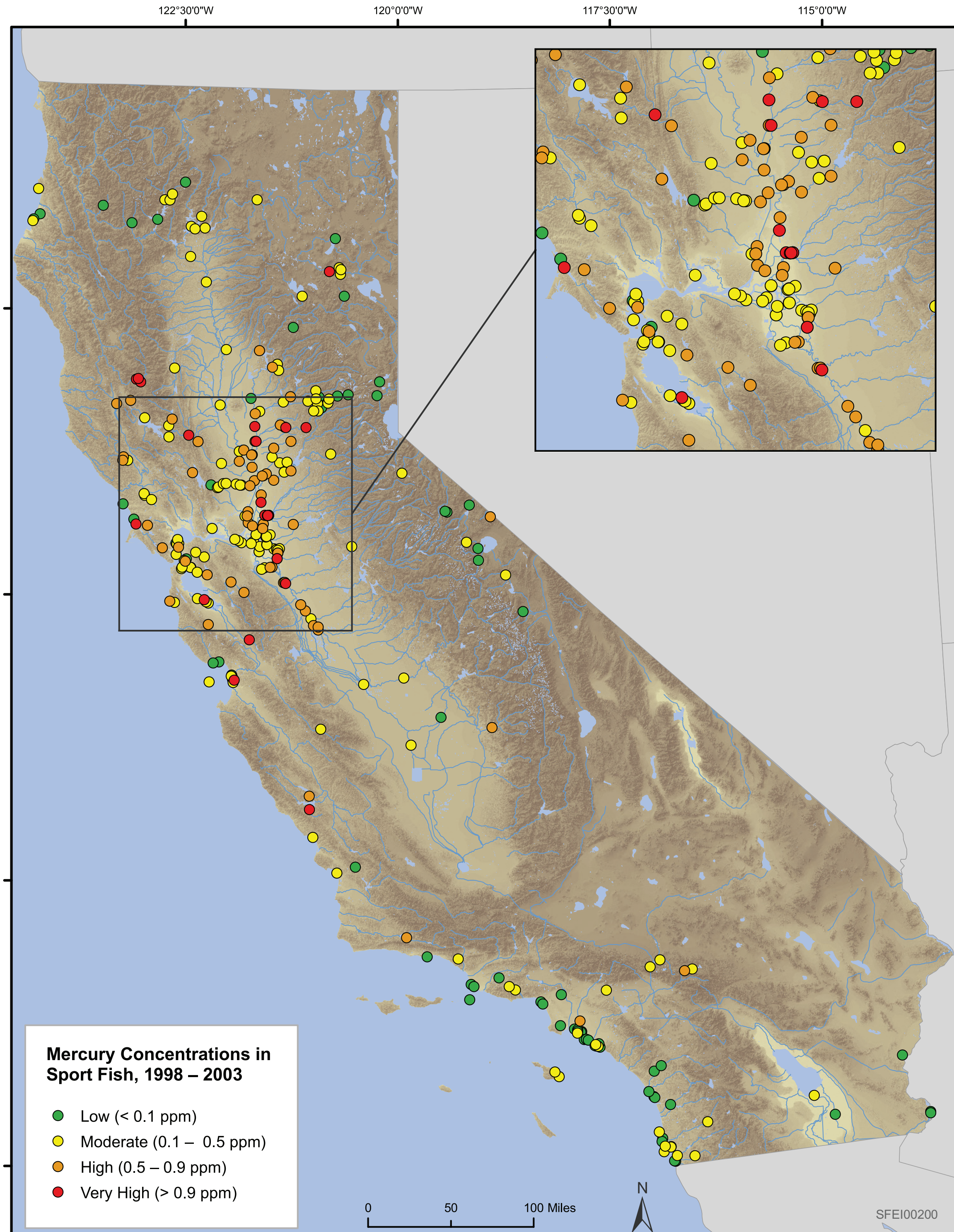

Figure 3.3.1. Mercury concentrations in California sport fish, 1998 – 2003. Based on mercury measurements (ppm wet wt) in muscle tissue from a variety of fish species. Size limits for each species were applied (Appendix 1). Dots represent sampling locations. Dot colors are based on the species with the highest median concentration at a location.

One-quarter (24%) of the locations sampled from 1998 – 2003 had concentrations in the green low mercury category, indicating that median concentrations for all species analyzed at these locations were below 0.1 ppm. Mountainous areas of the state (Sierra Nevada and Klamath/Trinity Range) and southern California had the preponderance of green locations, but there were no regions with sites exclusively in this category.

The geographic patterns of more impacted areas in the state from the recent monitoring data correspond well with the location of consumption advisories and 303(d) listed water bodies.

b. Long-term Trends in Impact of Mercury on Fishing in California

Management Actions

Mercury has proven to be the most pervasive and problematic trace metal pollutant in the aquatic environment of California. Data for assessing trends in mercury over several decades are sparse. The expectation is that mercury is neither increasing nor declining across the state as a whole, because this metal is extremely persistent in the environment and has a long residence time in polluted watersheds. Due to the complex cycling of mercury species in aquatic environments, and the small percentage of total mercury that the toxic form methylmercury represents, even a significant reduction in total mercury may not greatly affect food web contamination by methylmercury. In many cases in California, total mercury currently does not appear to be a limiting factor for food web methylmercury concentrations.

Cessation of mercury and gold mining decades ago was an important change in human activities that reduced the production and use of mercury in California but also left hundreds of mine sites in need of remediation. Current management actions of importance include TMDLs, wetland restoration, mine clean-up activities, and consumption advisories. TMDLs have been established for 16 of the 72 water bodies on the 303(d) List, and more are in development, including a large and complex effort for the San Francisco Bay and another for the Guadalupe River watershed. TMDLs aim to reduce the load of mercury entering a water body. Although current concentrations of total mercury may not be limiting food web bioaccumulation in some areas, improvement over the long run is expected if TMDLs reduce total mercury concentrations significantly to the point where it is limiting.

Another management action that could affect mercury contamination of food webs is wetland restoration. There is concern that wetlands may have the potential to increase bioaccumulation of mercury, due to environmental conditions that promote the activity of sulfur-reducing bacteria that methylate mercury and because wetlands can export dissolved organic matter laden with methylmercury (Davis et al. 2003b, Wiener et al. 2006). Previous studies have shown that on a regional level, watersheds with greater wetland acreage have higher rates of mercury bioaccumulation (Krabbenhoft et al. 1999). Large projects, such as the South Bay Salt Pond Restoration in San Francisco Bay and CalFed-sponsored efforts in the Delta, as well as numerous smaller individual restoration projects, have raised a flag of concern that tidal marshes and other wetlands may return to the San Francisco Bay-Delta on a scale that could affect mercury concentrations in biota throughout the region. More research on this topic is needed to understand the specifics of methylmercury production and bioaccumulation in California's wetlands and adjacent ecosystems, and many such projects are underway.

Mine clean-up projects are a third management action of importance for mercury contamination. Several projects at mine sites have removed mercury-laden sediment and tailings from particular areas and reduced total mercury loads downstream. Examples include the Empire Mine near Grass Valley (clean-ups in 1980s and another effort planned for the future), the Sulphur Bank Mercury Mine near Clear Lake, the Polar Star Mine near Dutch Flat, and the Buena Vista Mercury Mine. Remediation of more mine sites will likely be funded by CalFed. Mine clean-up has proved expensive relative to the scope of the problem, and hundreds of mines, tailing sites, and sediment deposits in streams and rivers have yet to be cleaned up.

Given that even under optimistic scenarios of TMDL implementation and remediation projects, mercury concentrations may not decline significantly in the next ten or twenty years, the most effective short-term management option for human health concerns is to communicate consumption advice. Clearly this approach will not be effective for wildlife, but educating human populations about quantities of fish to eat could prevent harm to those who rely heavily on fish and shellfish in their diet. The CalFed-funded Fish Mercury Project has communication of consumption advice – from target sampling locations to analyzing fish tissue to calculating consumption levels to communicating risk – as one of the project's major goals.

A program designed to address bioaccumulation issues should include provisions for all these management actions. Consumptions advisories should be included as the fastest potential method of reducing mercury bioaccumulation in humans from sport fish in California. TMDLs and clean-up actions would contribute to the longer-term improvement of mercury loading into aquatic habitats. Finally, monitoring and process studies should be undertaken to track whether wetland restoration affects mercury bioaccumulation in the local and regional food webs and whether specific design features or management approaches for wetlands could minimize mercury impacts.

Long-term Trends

Sport Fish

Mercury impairment of the fishing beneficial use has changed little since the 1970s (Table 3.3.1, Figures 3.3.2 and 3.3.3). In each time period, the lowest percentage of sites is in the red category (3 – 8%), while the yellow category contains the largest proportion of sites (47 – 67%). The low green and high orange groupings each contain a significant proportion of sites, with more in the green (16 – 38%) than the orange (10 – 21%). The small changes in percentages in each category among time periods are likely an artifact of changing projects and sampling locations rather than true alteration of mercury bioaccumulation. Spatial patterns in the more and less impacted areas of the state remain very similar over time. Sampling intensity increased over time, which exposed more contaminated areas, but the general location of less and more contaminated areas is remarkably consistent. The New Almaden and Lake Nacimiento sites have been hotspots from the earliest time period through the latest one. The San Francisco Bay-Delta region is

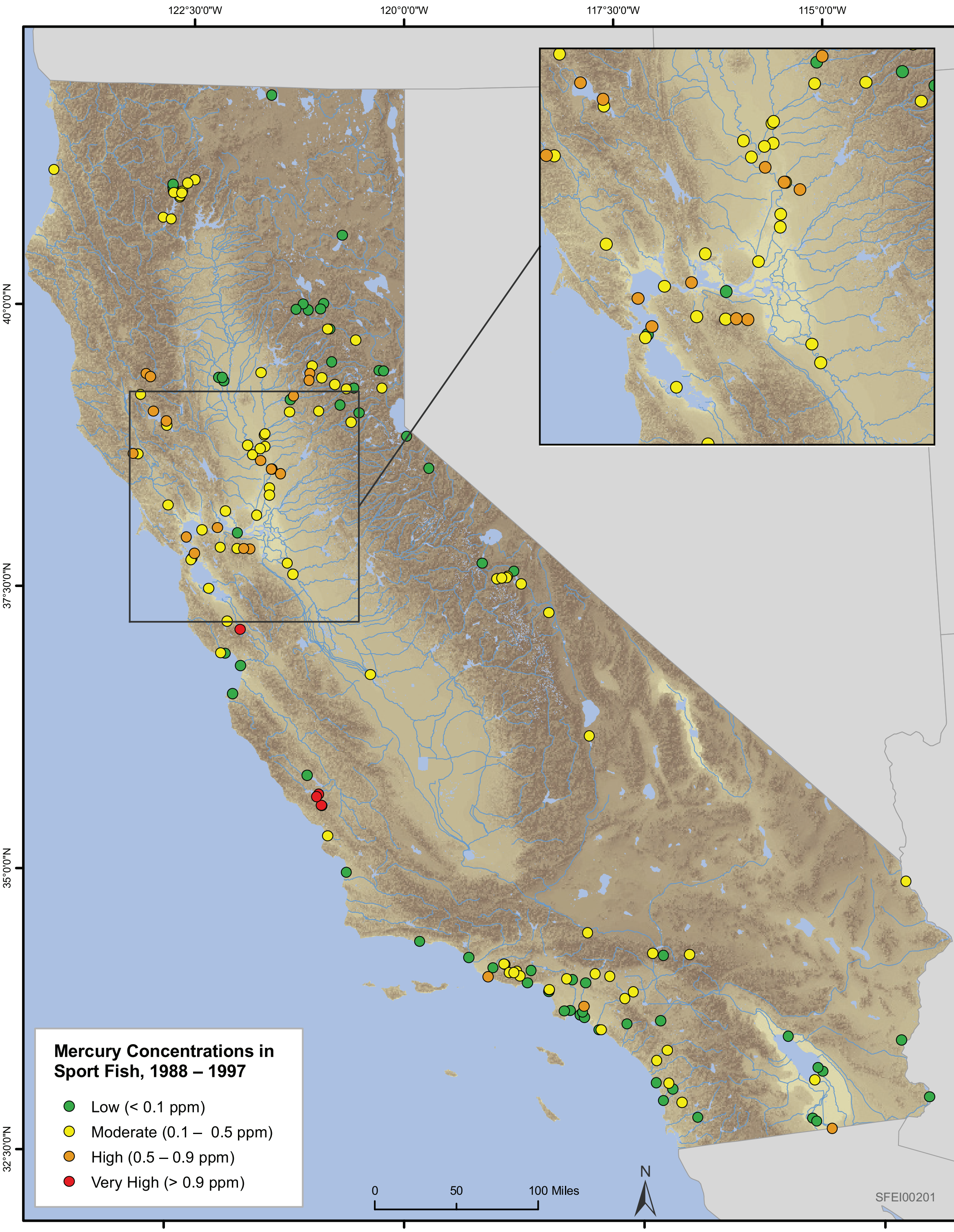

Figure 3.3.2. Mercury concentrations in California sport fish, 1988 – 1997. Based on mercury measurements (ppm wet wt) in muscle tissue from a variety of fish species. Size limits for each species were applied (Appendix 1). Dots represent sampling locations. Dot colors are based on the species with the highest median concentration at a location.

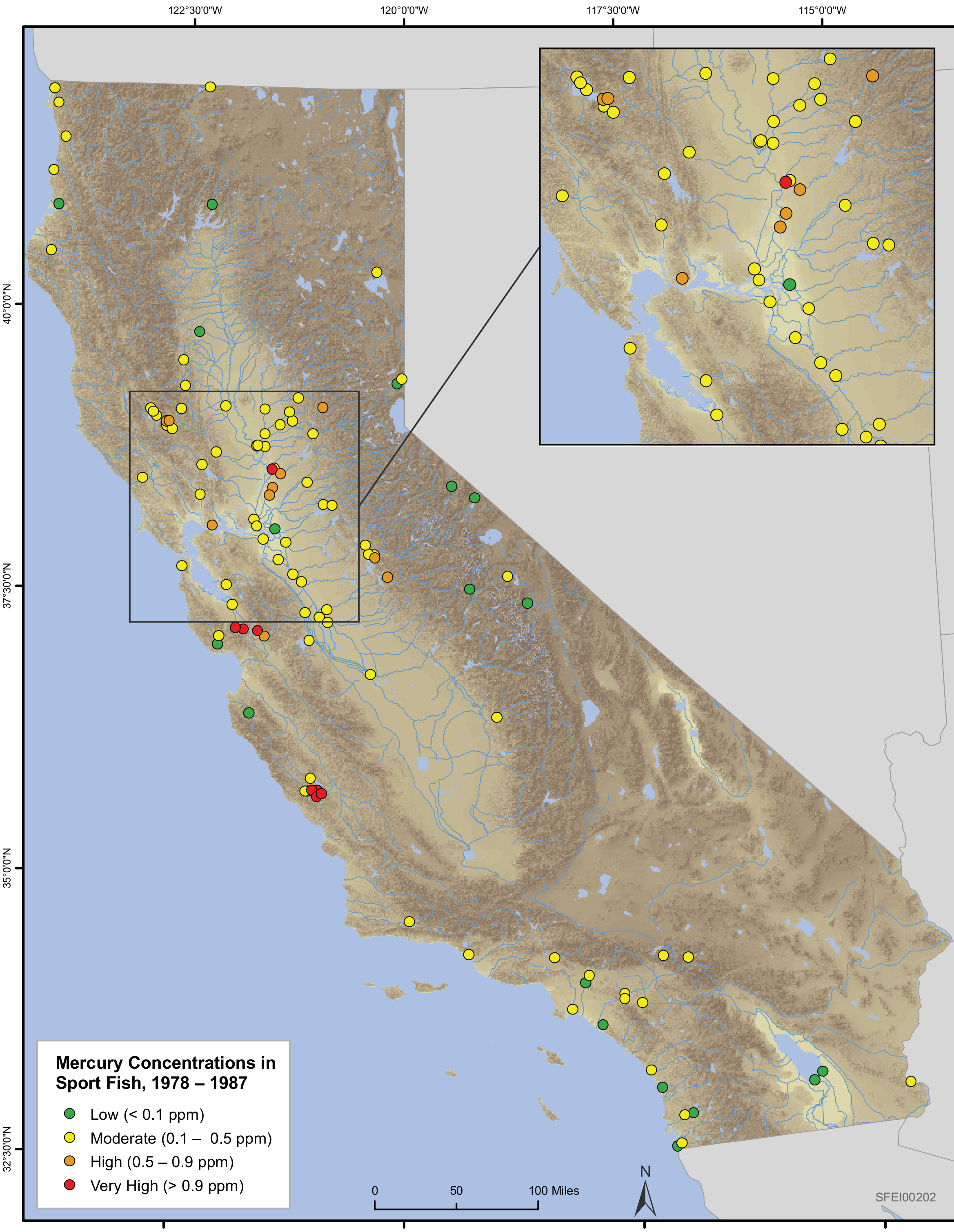

Figure 3.3.3. Mercury concentrations in California sport fish, 1978 – 1987. Based on mercury measurements (ppm wet wt) in muscle tissue from a variety of fish species. Size limits for each species were applied (Appendix 1). Dots represent sampling locations. Dot colors are based on the species with the highest median concentration at a location.

consistently dominated by moderate and high sites with more very high hotspots becoming apparent as sampling increased. Southern California, the Sierra Nevada, and the extreme northwestern part of the state have had a mix of green and yellow sites throughout the 25 years that data were collected. This lack of temporal variability in mercury contamination of food webs is consistent with the expectation of long residence time, as previously discussed.

The data set analyzed in this report is not ideal for the analysis of time trends, because it comprises a variety of studies with differing goals, sampling designs, and methods. These studies form a large body of previous work that advanced our understanding of mercury in the environment, but they were not designed to measure long-term trends. The method detection limits vary over time and between studies, as do the fish species, compositing regimes, and fish-length ranges. Since the data were not designed for this type of analysis, there are few locations that have long time series of comparable data. In general, data from older time periods are sparse. Imperfect as they may be, these time series are nevertheless worth analyzing as the only source of long-term information currently available. Time series of monitoring data that are designed for the purpose of detecting long-term trends should be collected in the future.

The most robust time series were examined, where data from the same species at the same site were available over a span of several years (Figure 3.3.4). Mercury concentration is known to increase with fish size, so the effect of fish length was removed from the analysis (Figure 3.3.5). Fish length was regressed on mercury concentration, and the residuals were analyzed as a time series. The amount of variation in mercury explained by fish length varied from 0.27 to 0.69. Lower correlations may have been partly due to changing study techniques. Despite being the best series available, the Feather, American, and San Joaquin River sites did not have enough data to analyze for trends. Short-term time trends may appear to be decreasing at the Feather and American River sites and increasing at the San Joaquin site in the plots provided, but conclusions should not be drawn from the limited data available. Concentrations in the plots may vary over time due to small sample sizes that do not adequately characterize the population. In general, this data set is weak for analyzing time trends.

At one site on the Sacramento River, data were sufficient to analyze trends over time. These data suggest that mercury in white catfish has declined since 1980, while concentrations in largemouth bass show no significant trend. Davis et al. (2003a) first studied this time series in catfish and noted the same trend. The causes for the decline are unknown. However, the pattern of a steep decrease followed by a leveling off, which is suggested by the data (Figure 3.3.4), is consistent with declines observed in several studies that tracked the response of fish populations following the abatement of an industrial point source (Wiener et al. 2003a, Wiener et al. 2003b). The bass data from the same site are biased toward more recent years and are fewer, so no strong conclusions may be drawn regarding incongruence in the trends between the two species.

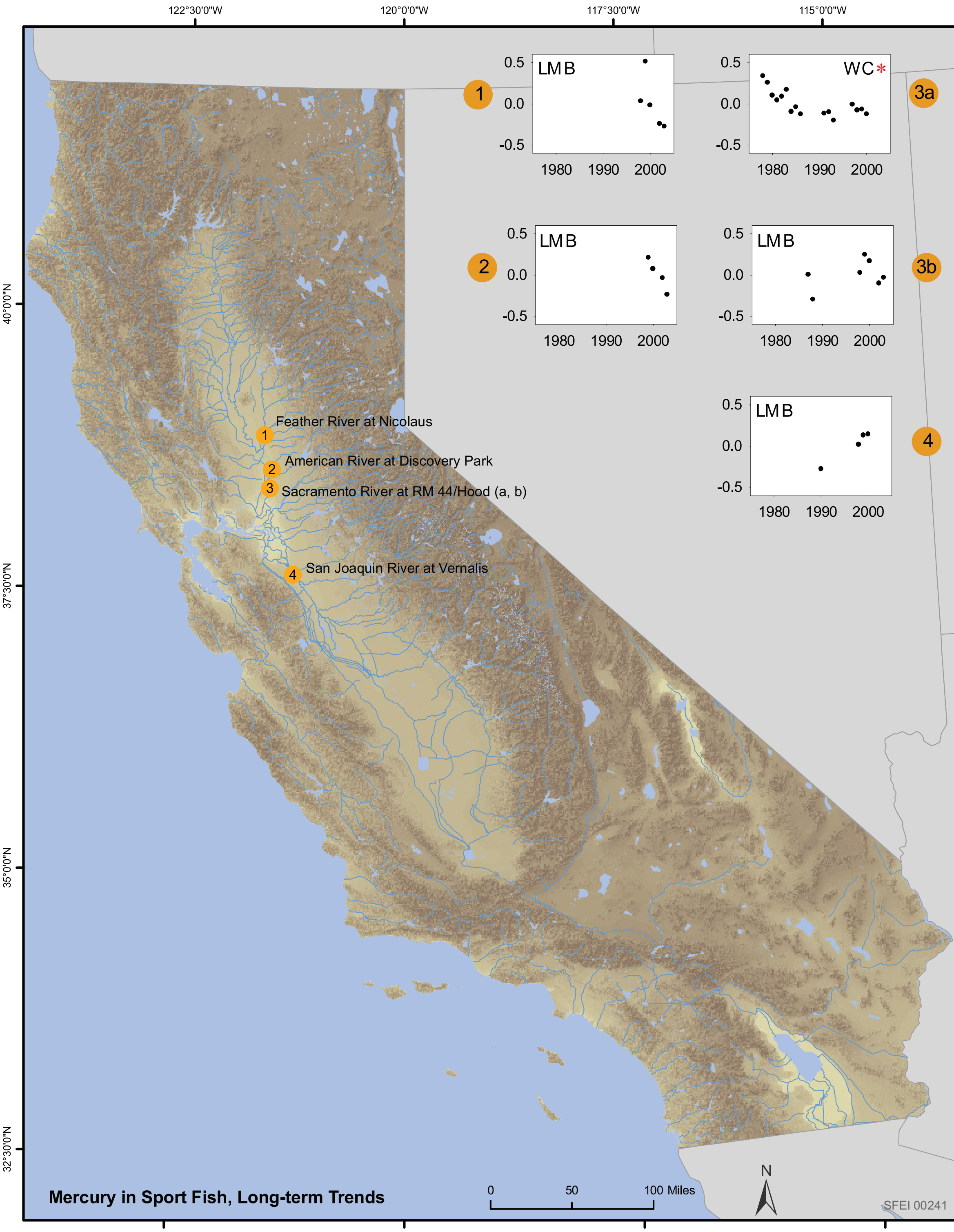

Figure 3.3.4. Long-term trends in mercury concentrations in California sport fish. Locations shown represent the best time series available for different parts of the state. Concentrations (ppm wet wt) presented are the are the residuals of a length versus mercury regression (Figure 3.3.5) for each location to remove the effect of variation in fish size. The red asterisk indicates a significant trend. Species shown are largemouth bass (LMB) and white catfish (WC).

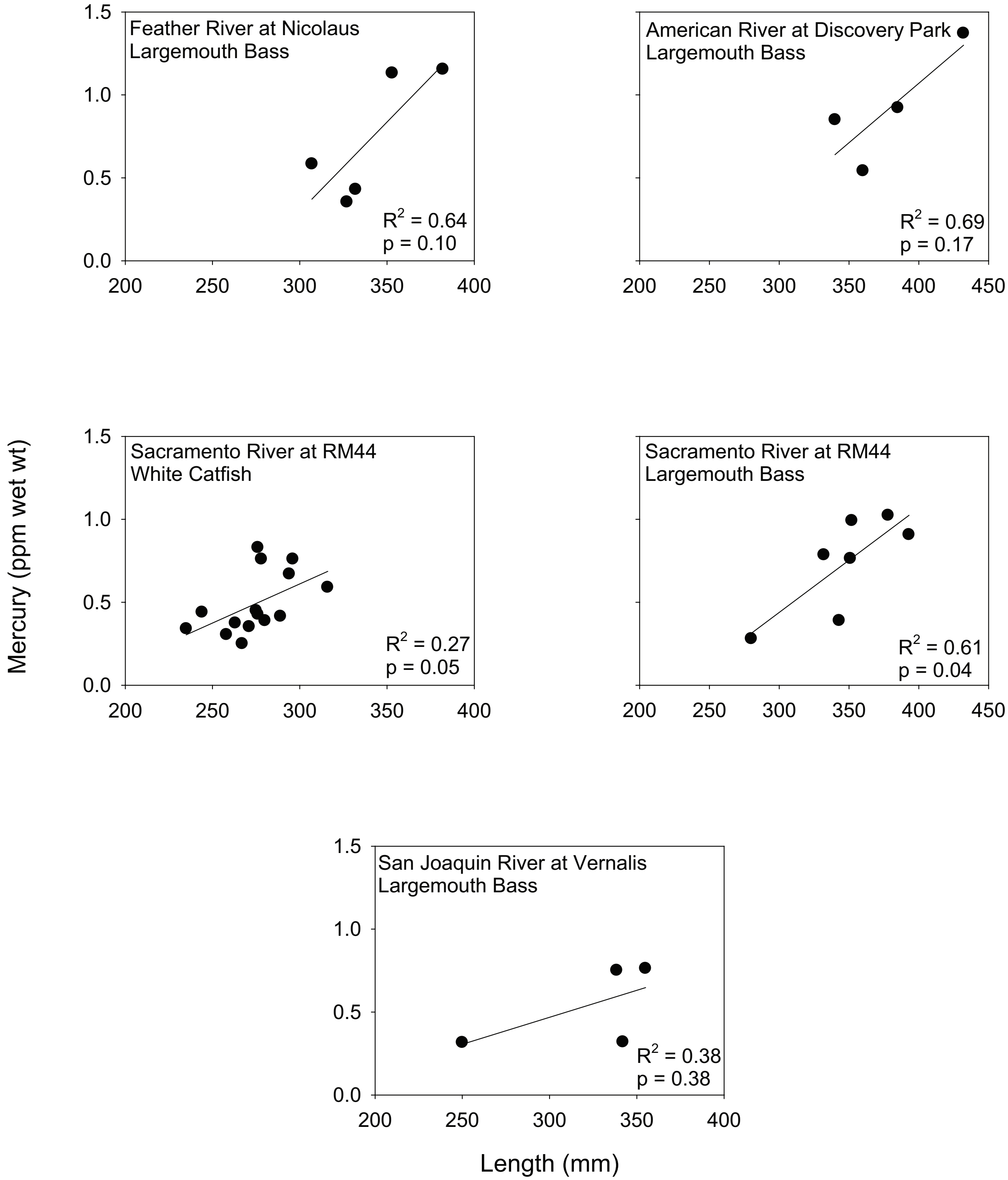

Figure 3.3.5. Regressions of mercury concentration on fish length by site. This analysis was conducted to remove the effect of variation in mercury due to fish size. Residuals were used to assess long-term time trends.

Bivalves

Long-term trends in bivalves cannot be analyzed here, as the necessary data are not in existence. Bivalves are not a good indicator for mercury, unless methylmercury is measured. Methylmercury in bivalves generally has not been a component of the large statewide monitoring programs reviewed in this report.

Case Studies

Sacramento-San Joaquin Delta

The two largest efforts to characterize mercury in sport fish from the Sacramento-San Joaquin Delta were both CalFed-sponsored. The first (Davis et al. 2003a) was completed in 2003, and the other is the Fish Mercury Project which was launched in 2005 and is currently ongoing. The earlier study concluded that concentrations exceeded a 0.3 ppm (wet wt) OEHHA screening value for human health in use at that time (Brodberg and Pollock 1999) in several species (including largemouth bass, striped bass, Sacramento pikeminnow, channel catfish, and white catfish), frequently reaching 1 ppm. The authors identified alternate species, bluegill and redear sunfish, as being safer for consumption with values that rarely exceeded the screening level. This approach of obtaining data on safer species to which anglers may redirect their attention is an important component of sport fish monitoring. Striped bass, an indicator of broad-scale trends in time and space, showed no declines in mercury concentration since the 1970s. Striped bass often have large home ranges, so data from this species represent a large spatial area, such as the Delta and even the adjacent main-stem rivers and Suisun Bay. An important finding was that bioaccumulation in the central Delta was relatively low – a pattern that repeated across several species (Figure 3.3.6). This result – that mercury bioaccumulation in a highly connected ecosystem can vary over short distances – suggested that certain habitats or environments may inhibit methylmercury bioaccumulation relative to adjacent habitats. Current research is pursuing this possibility. The Fish Mercury Project continues and expands upon the earlier study. The Fish Mercury Project has a larger scope and includes components for developing and communicating consumption advisories, as well as a biosentinel component to assess the effects of wetland restoration.

San Francisco Bay

Data from San Francisco Bay sport fish monitoring were reviewed in Greenfield et al. (2005) and updated with the latest round of monitoring by the Regional Monitoring Program for Water Quality in 2003 (RMP 2006). Like the Delta, San Francisco Bay has fish that frequently exceed screening levels in a variety of species. In 2003, 69% of the sampled fish (from species chosen for their value as indicators or popularity for consumption), had concentrations exceeding the screening value of 0.2 ppm, which is the proposed value for the San Francisco Bay Mercury TMDL (RMP 2006). Species with the most frequent exceedances were leopard shark (100%), striped bass (93%), California halibut (100%), and white sturgeon (86%). Slightly more than half (58%) of the white croaker samples exceeded the screening value. These problematic concentrations apparently have neither increased nor declined from 1970 through 2000 (Figure 3.3.7; Greenfield et al. 2005). The time trend analysis by Greenfield et al. (2005) took into account DFG data from the early 1970s, Regional Monitoring Program data, and data from the earlier CalFed study discussed in the paragraph above. The authors found no evidence of any change in mercury values over the 30-year period. These

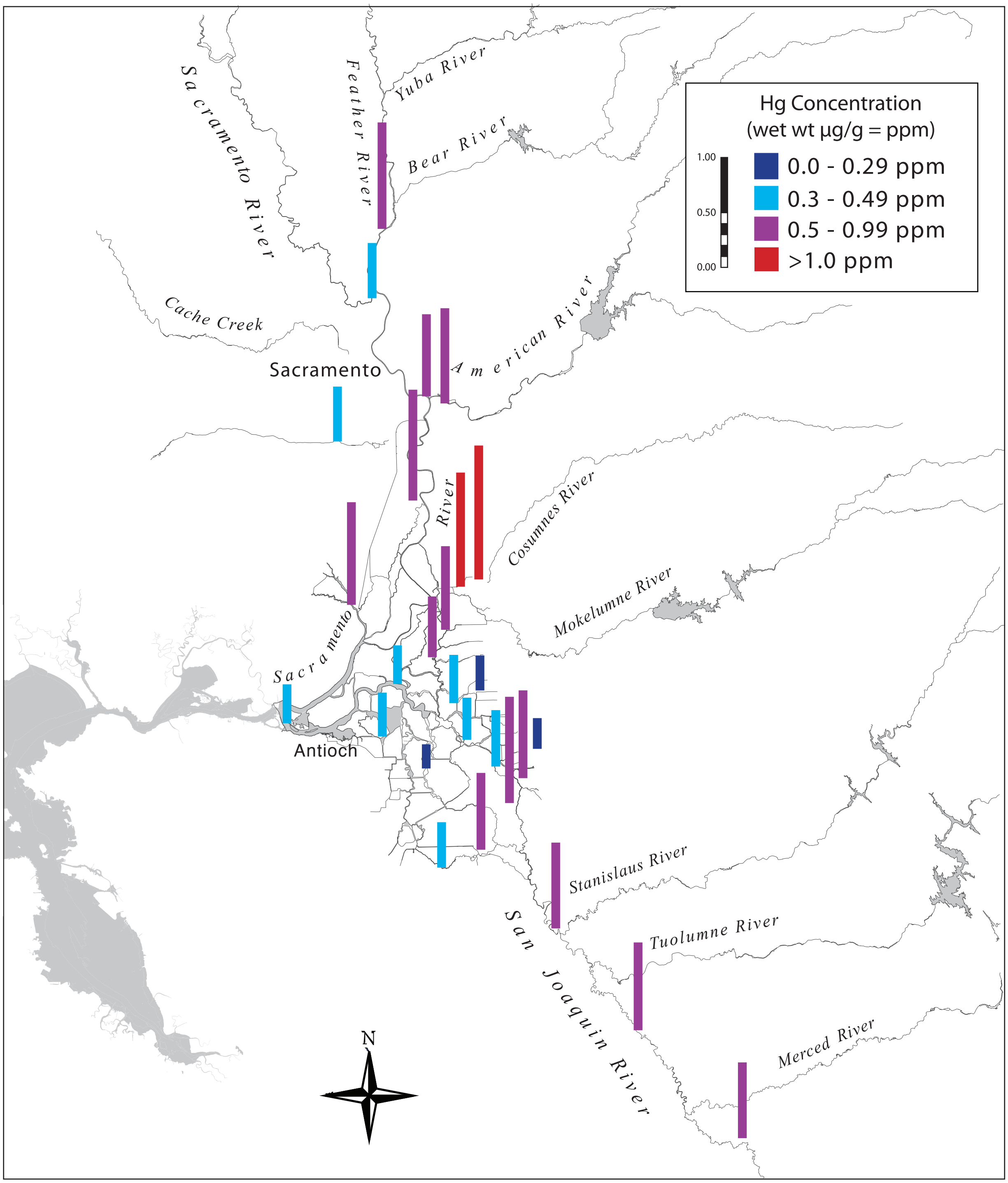

Figure 3.3.6. Average mercury concentrations in largemouth bass from sampling locations in the Sacramento-San Joaquin Delta, 1999. From Davis et al. (2003a). Note the lower concentrations in the central Delta, despite being downstream from two major rivers with high bioaccumulation.

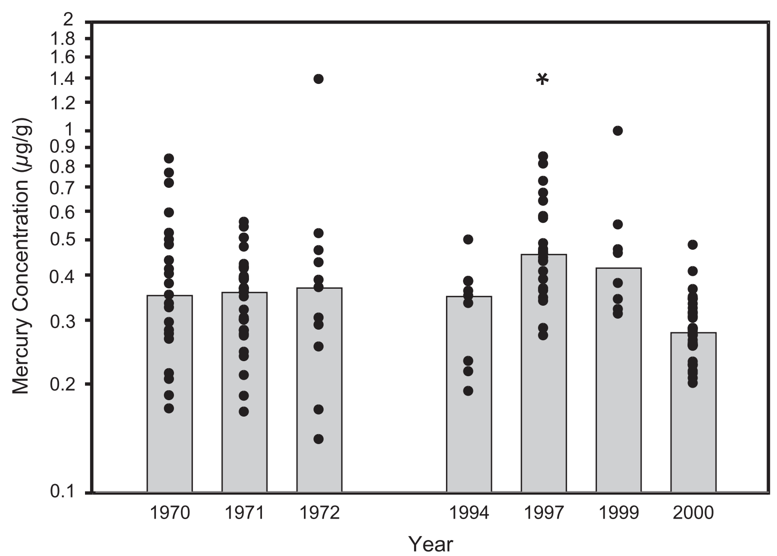

Figure 3.3.7. Mercury concentrations in striped bass in the 1970s and 1990s. From Greenfield et al. (2005). Gray bars indicate annual median concentrations. To correct for variation in fish length, all plotted data were calculated for a 55 cm fish using the residuals of a length vs. log(Hg) relationship. Asterisk above 1997 indicates significant difference from overall length vs. mercury regression. Data were obtained from CDFG historical records (1970 – 1972), a CalFed-funded collaborative study (1999), and the Regional Monitoring Program (1994, 1997, and 2000). Note log scale on the y-axis.

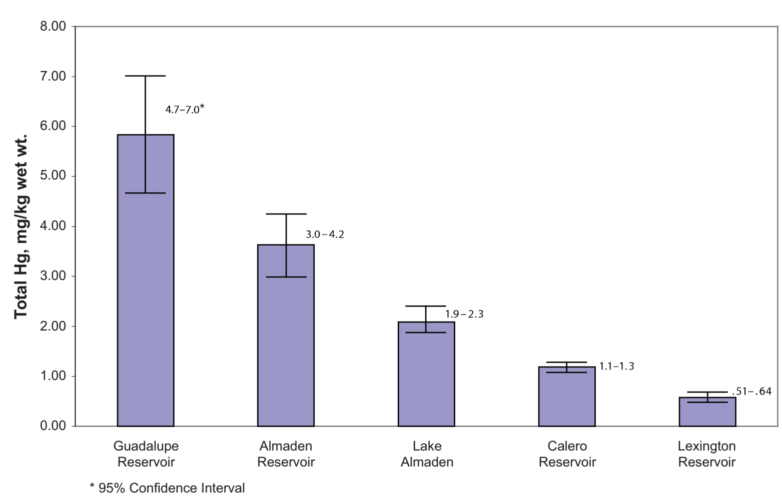

Figure 3.3.8. Mercury concentrations for standardized 40 cm largemouth bass from different reservoirs in the Guadalupe Watershed. From Tetra Tech (2005).

studies indicate that mercury is a significant problem in the San Francisco Bay and the Sacramento-San Joaquin Delta that has neither improved nor worsened appreciably overall during the past few decades.

Guadalupe Watershed

The Guadalupe River Watershed at the south end of San Francisco Bay contains fish with some of the highest mercury concentrations in California, which were studied in depth as preparation for the mercury TMDL in that region (Tetra Tech 2005). Largemouth bass had distinct variation in mercury concentrations between reservoirs, with comparatively little variation within reservoirs (Figure 3.3.8). Differences in mean concentration in each reservoir were related to how closely each site was associated with the New Almaden mining district. Reservoirs close to the historic mining activity (Guadalupe and Almaden) had some of the most contaminated fish in the state, while those farther away (Lexington) had relatively typical concentrations for the larger northern California region. This study identified historic mercury mines as a primary source of mercury in highly contaminated fish in the Guadalupe River basin.

c. Sources and Pathways

The geographic patterns in mercury concentrations are as previously described for mercury impairment and are consistent across the three time periods (Figures 3.3.9, 3.3.10, and 3.3.11). Specifically, the San Francisco Bay-Delta and Central Valley have a cluster of relatively high concentrations, with the Lake Nacimiento area also being quite high, and parts of southern California and the Klamath/Trinity Range showing significant but lower contamination. The concentration-based maps are useful for showing how much greater the concentrations are in the Golden Gate watershed compared to nearly all other sites in the state. Furthermore, Cache Creek in the Coastal Range and Bear Creek to the east can be identified as the most contaminated sites from the recent time period, each having concentrations greater than 2 ppm in sport fish. Few significant changes in the pattern of mercury concentrations are apparent over time.

The predominant geographic correlation between mercury contamination in fish and possible sources in the environment is historical mining. Nearly all the hotspots (red locations in Figures 3.3.1, 3.3.2, and 3.3.3) are associated with a mine nearby or upstream (Figure 3.3.12). Most of these hotspots are in the region of highest mercury concentrations in the Sierra Nevada, Coastal Ranges, and the parts of the Central Valley that they drain into. The central and northern Sierra Nevada and the central Coastal Range were sites of intensive mining for gold and mercury, respectively. Sediment from these operations, particularly placer and hydraulic mining, has moved down through the watersheds, affecting the Sierra Nevada foothills, Central Valley, Delta, and San Francisco Bay. Large amounts of mercury-laden sediment and mine tailings remain in the watersheds, providing current and future sources of contaminated sediment downstream and opportunities for remediation. In addition to those in the Central Valley watershed, most of the other hotspots are also geographically correlated with mining, for example, Lake Nacimiento and the Buena Vista Mercury Mine, south San Francisco Bay and the New Almaden Mine, Tomales Bay and the Gambonini Mercury Mine, Susanville and gold mines in the watershed. The red site in Elkhorn Slough is not as easily attributed to mining. However, historic mines in the Pajaro River watershed could have delivered contaminated sediment to the Slough during episodic periods of hydrologic connectivity. Many sites in the moderate and high range also fall inside the main mining belts, and the mercury consumption advisories are in these areas as well.

Exceptions to the association between the mining areas and high mercury concentrations may include Lake Pillsbury and several Sierra Nevada locations. Lake Pillsbury is a hotspot for mercury in sport fish but has no identified mines in the watershed. Nevertheless, the fact sheet put out by OEHHA regarding mercury in fish from Lake Pillsbury states that "the surrounding area is likely to be rich in mercury, and physical and chemical conditions in the lake may be very suitable for mercury that has settled in the bottom to be converted to methylmercury" (OEHHA 2000, p. 2). Furthermore, a comment letter from the North Coast Regional Water Board to the California State Water Board regarding the 303(d) List indicates that mining in the watershed may have contributed to the concentrations found in fish (Kuhlman 2006). Conversely, the Sierra Nevada region has several low mercury concentration locations, despite the multitude of historic gold mines in that area. The low mercury levels in fish at these locations may occur because the trout in high-mountain streams are at a low trophic level and do not tend to bioaccumulate high concentrations of mercury, and/or the sites are at high elevations above mines.

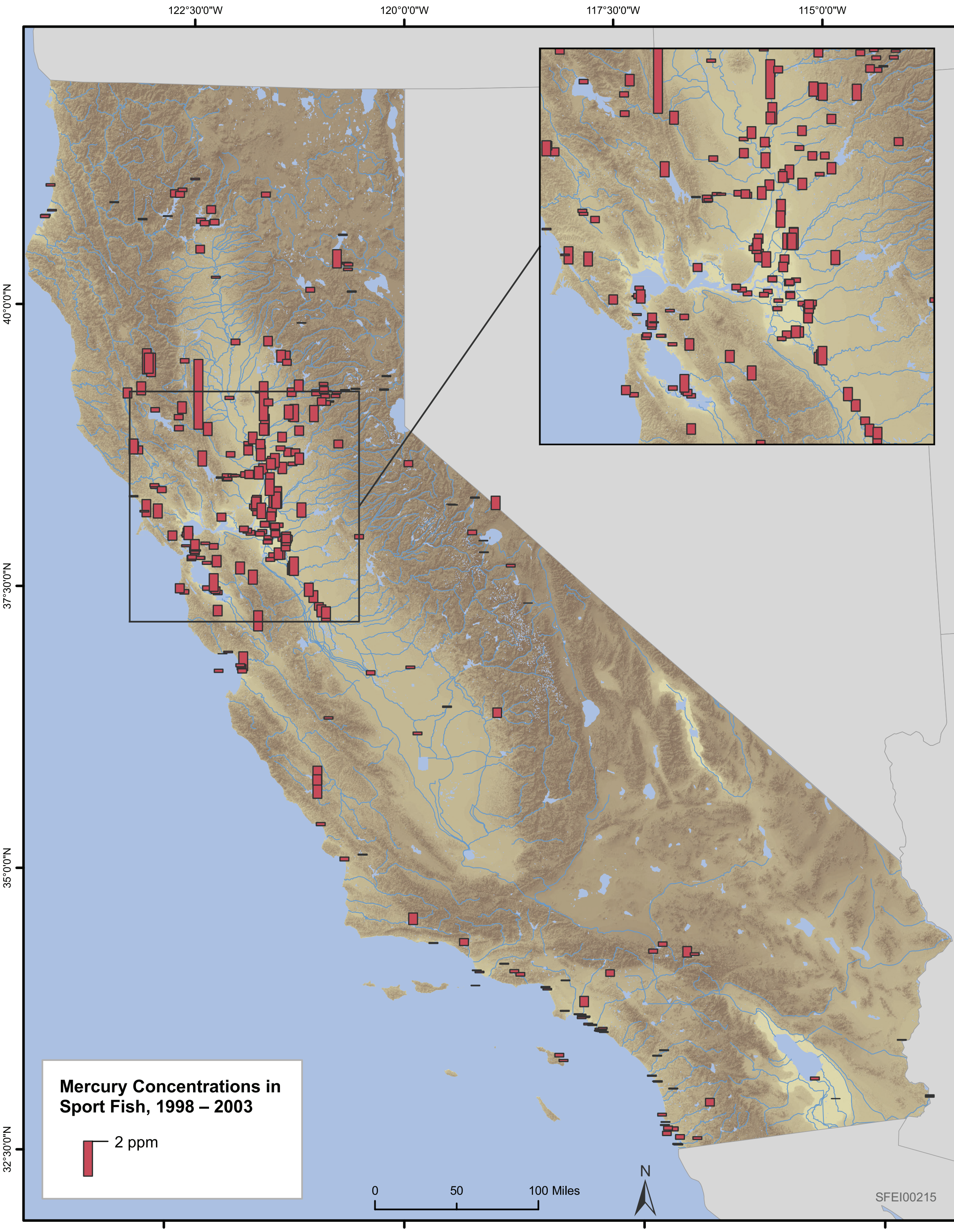

Figure 3.3.9. Mercury concentrations in California sport fish, 1998 – 2003. Bars represent the highest median concentration (ppm wet wt) among species sampled at each location. Size limits for each species were applied (Appendix 1).

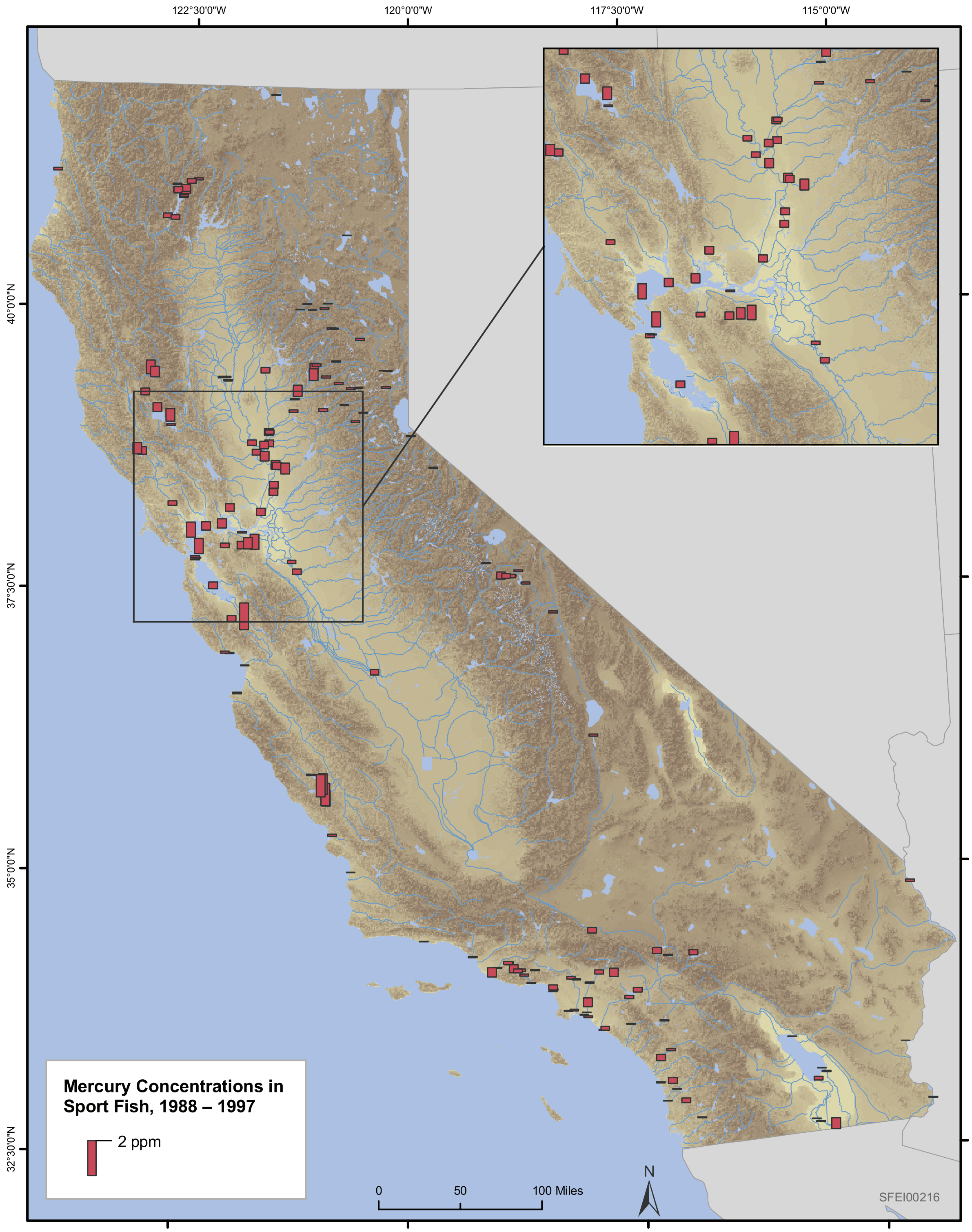

Figure 3.3.10. Mercury concentrations in California sport fish, 1988 – 1997. Bars represent the highest median concentration (ppm wet wt) among species sampled at each location. Size limits for each species were applied (Appendix 1).

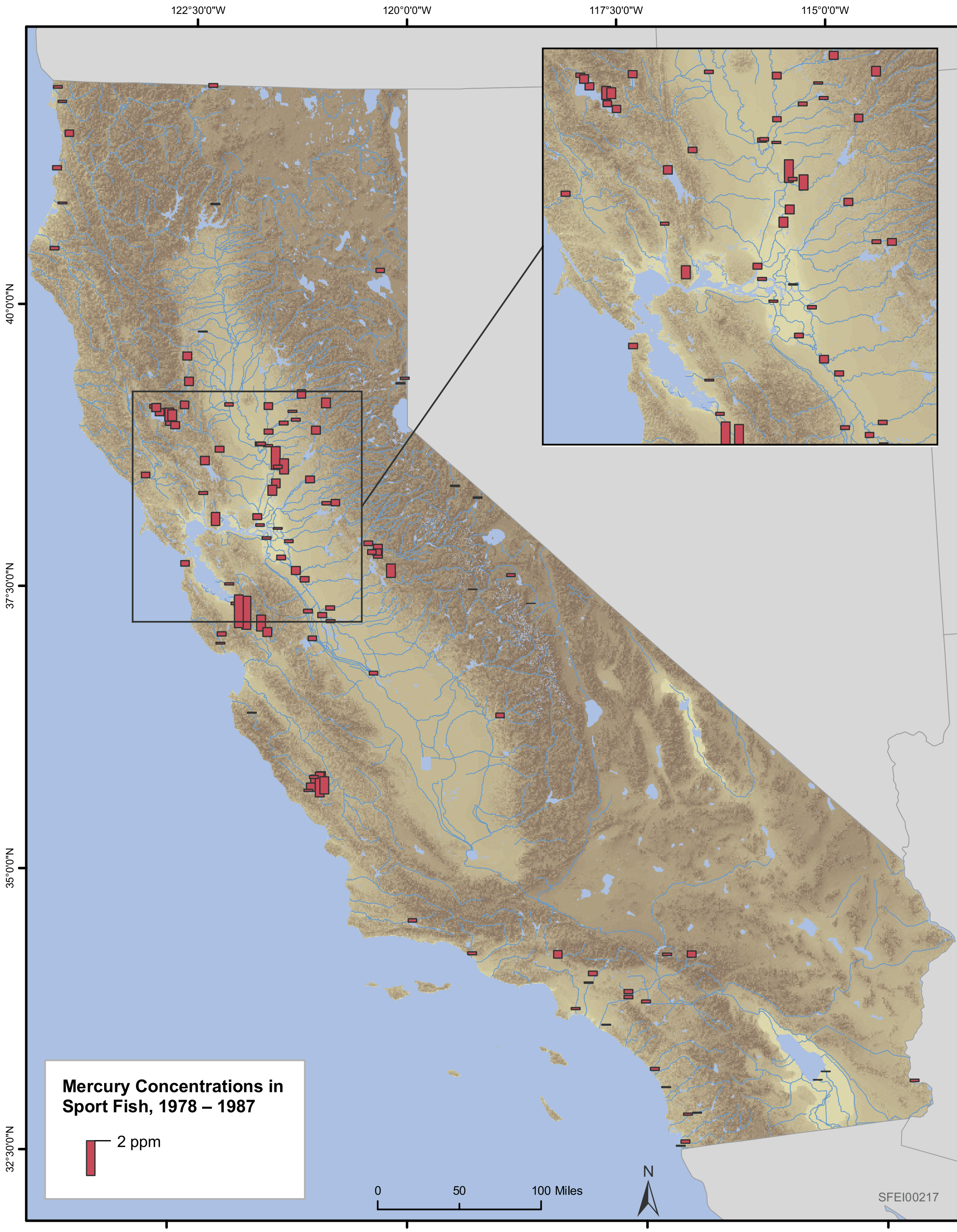

Figure 3.3.11. Mercury concentrations in California sport fish, 1978 – 1987. Bars represent the highest median concentration (ppm wet wt) among species sampled at each location. Size limits for each species were applied (Appendix 1).

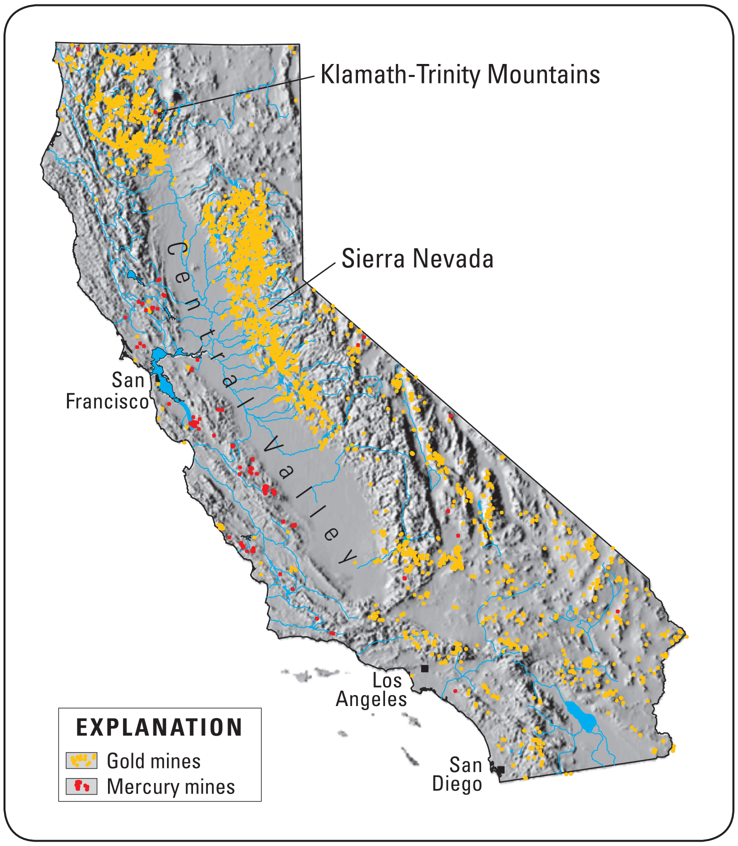

Figure 3.3.12. Locations of past and present gold and mercury mines in California. From Alpers and Hunerlach (2000). Data source: MAS/MILS (Minerals Availability System/Mineral Information Location System) database compiled by the former U.S. Bureau of Mines, now archived by the USGS.

The 303(d) List provides further evidence that mines are an important source. Mining-related potential sources are listed for most of the mercury-impaired water bodies. In the potential sources for the San Francisco Bay-Delta, mining is coupled with urban and industrial sources, as well as atmospheric deposition.

In southern California, mercury concentrations are lower and historic mines are much fewer. Sites in the yellow category are frequent along the highly urbanized coast and around the Los Angeles basin (Figure 3.3.1). This pattern suggests urban and industrial sources may be important in southern California, especially because the moderate (and few high) sites are interspersed with low sites, indicating very local impacts in the small watersheds than run perpendicular to the coast. Agricultural sources are the most likely explanation for the moderate site at the southern edge of the Salton Sea. The Salton Sea is fed by agricultural wastewater that is known to be high in selenium and DDTs. Mining cannot be ruled out as a source for many areas in southern California, however, because some historical mines are present.

Finally, atmospherically deposited mercury may be a significant source (Orihel et al. 2006, Wiener et al. 2006). The 303(d) listing for San Pablo Reservoir cites atmospheric deposition as the sole potential source. Atmospheric deposition is listed as one of several potential sources for the San Francisco Bay-Delta as well. While small in mass relative to other mercury sources in California, atmospheric sources may be sufficient to cause much of the observed bioaccumulation and may be more available for methylation than mercury bound to sediment (Hintelmann et al. 2002).

3.3.3. Impact of Mercury on Aquatic Life in California

a. Overview of the Mercury Issue for Wildlife

Mercury contamination can have essentially the same health and population consequences for wildlife that it has for humans, with an important difference being that some wildlife species are obligate consumers of aquatic prey, meaning their entire diet of fish or invertebrates may be contaminated with mercury from the aquatic or wetland food web. Mercury can impair behavior, reproduction and early development of fish (Latif et al. 2001, Hintelmann et al. 2002, Drevnick and Sandheinrich 2003), mammals (Barron et al. 2003), and birds (Spalding et al. 2000, Kenow et al. 2003), and probably other vertebrate groups as well. At higher concentrations, organic mercury poisoning can result in acute toxicity and death. Comprehensive reviews of the effects of mercury on wildlife are provided in Wolfe et al. (1998) and Scheuhammer et al. (2007), including classic feeding studies, which provide some of the best effects data. The specific studies mentioned above are just a sampling of newer research.

The TMDLs in preparation for San Francisco Bay and the Sacramento-San Joaquin Delta will employ 0.03 ppm wet weight from whole body analyses of small fish (less than 5 cm) as the threshold for protection of fish-eating wildlife (USFWS 2003, Johnson and Looker 2004, Wood et al. 2005). This relatively low concentration is likely to be exceeded in many instances (see San Francisco Bay-Delta Case Study). The threshold was calculated to be inclusive of protection for the California least tern, which is on the Federal Endangered Species List. All other wildlife species were deemed to be protected at this threshold.

This TMDL threshold is remarkably similar to the Canadian Tissue Residue Guidelines for the Protection of Wildlife Consumers of Aquatic Biota, which is 0.033 ppm wet weight for methylmercury in prey tissue, such as small fish (CCME 2001). Like the TMDL value above, this Canadian guideline refers to a methylmercury concentration in prey items that is not expected to result in adverse effects in predaceous wildlife.

b. Possible Impairment of Wildlife

San Francisco Bay-Delta Case Study

Open Water Habitats

In the San Francisco Bay-Delta, several lines of evidence from different taxonomic groups indicate that mercury may be adversely impacting wildlife populations. In open water habitats, mercury exposure and effects have been best studied in birds, yet exposure data are not available for all species, and effects thresholds remain largely unknown. The CISNET study (Davis et al. 2004) indicated that concentrations in double-crested cormorant eggs are probably below concentrations of concern, and the same result was found by Schwarzbach and Adelsbach (2003) for a variety of other Bay and Delta species, including herons, egrets, gulls, and cormorants. Forster's and Caspian tern eggs, however, exceeded threshold effects levels, and avocet, stilt and snowy plover exposures were higher than expected for species that mainly consume invertebrates (Figure 3.3.13; Schwarzbach and Adelsbach 2003). The CalFed-sponsored Mercury Effects in San Francisco Bay-Delta Birds Project, a three-year study currently in progress, aims for much more comprehensive understanding of mercury bioaccumulation and effects in three guilds of Bay birds: diving ducks, terns, and recurvirostrids (black-necked stilt and American avocet). This project is likely the most large-scale and in-depth study of the effects of mercury on birds in California ever conducted and should produce a wealth of information. Older studies on diving ducks suggest mercury effects are present in diving ducks in the Bay. Adult male greater scaup, surf scoter, and ruddy ducks from San Francisco and Tomales

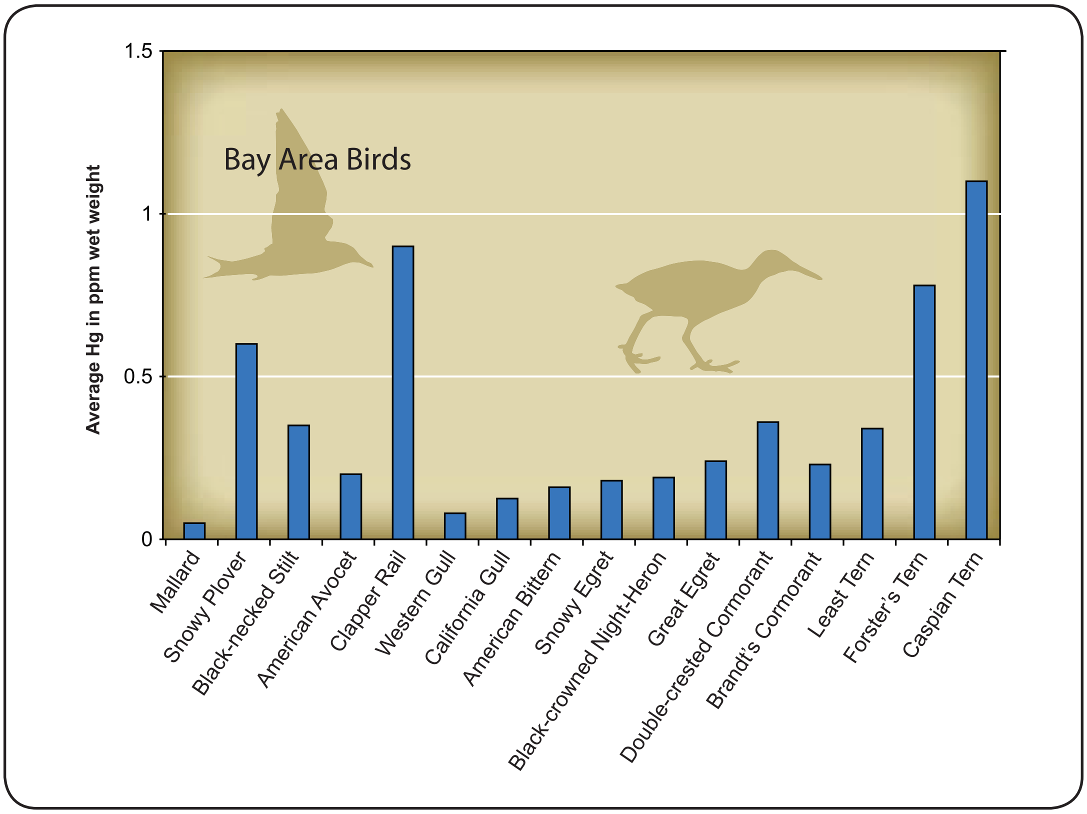

Figure 3.3.13. Mercury concentrations in the eggs of Bay-Delta birds. Mercury concentrations in eggs of the endangered California clapper rail as well as piscivorous Forster's and Caspian terns exceeded the concentration (0.5 – 0.8 ppm) of observed effects in birds. Adapted from Schwarzbach and Adelsbach (2003).

Bays with higher liver mercury had lower body and organ weights (heart, liver) and altered liver metabolism (Ohlendorf et al. 1991, Hoffman et al. 1998). Exceedances of threshold concentrations in small fish, which are important avian prey items for many species in the Bay-Delta, are discussed in the next paragraph.

Less information is available for non-avian wildlife exposure and effects in open-water habitats. Harbor seals in San Francisco Bay have elevated mercury in blood and blubber (Kopec and Harvey 1995). Regarding effects on fish, exposure has been documented in some areas, but effects research is rare. Unpublished data from San Francisco Bay for a study to develop small fish as a monitoring tool for the Regional Monitoring Program show that small gobies and atherinopsids contain mercury at concentrations below effects thresholds for fish (0.2 ppm wet weight, whole body; Beckvar et al. 2006) but above the TMDL target (0.03 ppm) and Canadian guideline (0.033 ppm) for piscivorous wildlife protection (Greenfield, unpubl. data). Extensive studies of small fish in the Delta region by Dr. Darell Slotton (e.g., Slotton et al. 2002) have documented concentrations in inland silversides and other small fish species well above the fish effects screening level of 0.2 ppm, particularly in the north Delta and Suisun. Furthermore, California roach in the Guadalupe watershed exceed the fish effects concentration in some areas and are at or above the 0.03 ppm TMDL target in all locations (Tetra Tech 2005).

Wetlands

Mercury exposure and effects in the wetlands of San Francisco Bay are important for two main reasons. First, these wetlands harbor endangered species, one of which may be inhibited from recovery to some degree by mercury contamination. Second, wetland restoration projects on a large scale are planned for the Bay, and there is concern that restored wetlands will increase mercury bioaccumulation (reviewed in Slotton et al. 2002, Davis et al. 2003b).

California clapper rails are the primary species of concern for mercury effects in Bay wetlands. Clapper rail eggs frequently exceeded the concentrations at which mercury become toxic to avian embryos (Lonzarich et al. 1992), averaging 0.81 ppm wet weight in a recent study of fail-to-hatch eggs (Schwarzbach and Adelsbach 2003). Egg-injections have showed that the clapper rail is more sensitive to mercury than the pheasant and mallard from which the threshold of 0.5 – 0.8 ppm was developed (Heinz 2003). Therefore, negative effects on reproduction seem likely, and this conclusion was supported by a field study indicating repressed fecundity in populations around the Bay (Schwarzbach et al. 2006). This endangered species is a rare case where the evidence points toward population-level effects from mercury contamination.

Other marsh species with poorly known mercury exposure and effects include the endangered salt marsh harvest mouse and three unique subspecies of tidal marsh song sparrow, which are California Species of Special Concern. A small study of egg mercury showed low concentrations in song sparrows (Davis et al. 2004). However, the sensitivity to mercury of this species is unknown, and egg-injection results indicated high sensitivity in other songbirds (Heinz 2003). The only published study of mercury in tidal marsh rodents found a marsh-scale relationship between high mercury concentrations in voles and rats and an absence of salt marsh harvest mice (Clark et al. 1992). More research is needed on the exposure and effects of mercury for wetland species. Two current projects aim to study bioaccumulation from water and sediment through wetland birds: the CalFed Petaluma River Mercury Study and the South Baylands Mercury Project.

Concerns about increased mercury bioaccumulation following wetland restoration have prompted the use of biosentinel species, particularly small fish and birds, as indicators of mercury patterns in space and time. Restoration-oriented mercury monitoring, such as the biosentinel component of the Fish Mercury Project and the South Baylands Mercury Project, will use biosentinel species to test hypotheses about wetland restoration. These studies will also provide important information about wildlife exposure to mercury.

Other Areas

TMDL documents generally include wildlife targets and discuss wildlife impacts. In general, direct studies of wildlife impacts are rare in the watersheds where TMDLs will be implemented, yet tissue concentrations for prey fish and wildlife often exceed screening values. In one of the more contaminated areas, for example, the Clear Lake TMDL states that current concentrations in wildlife are high enough to cause adverse impacts (Cooke 2002), including reduced hatching success and survival of young, as well as behavioral abnormalities (Elbert 1993). Mercury concentrations have been observed to exceed a toxic risk level (20 ppm dry wt; Scheuhammer 1991) for great blue herons, osprey, and double-crested cormorant and may be affecting western grebe nesting success (Elbert and Anderson 1998). Furthermore, river otter and kingfisher may not be protected, even after the TMDL is implemented (Cooke 2002).

Major gaps exist in our understanding of mercury exposure and effects in wildlife, which can only be filled with further research and monitoring. Long-term trends and effectiveness of management actions for wildlife cannot be assessed, because no such data are available. Use of museum skins to document historical patterns of contaminants in wildlife may be useful, and one such study is underway for clapper rails (Schwarzbach, personal communication). It is important to remember that some areas of the state, such as Mud Slough and certain tidal marshes, are not important human fishing areas, but are teeming with wildlife and have high mercury loads. Sites like these will require monitoring that is targeted toward characterizing the status of and trends in wildlife exposure. Top predators in aquatic ecosystems, such as osprey, northern harriers, and otters, are an important wildlife guild that is likely to have high mercury concentrations. However, very few studies have examined mercury exposure and effects for top predators in California.

3.3.4. Mercury Summary

The impact of mercury bioaccumulation on fishing and aquatic life in California waters is significant. Regarding mercury impact on sport fishing, large regions of the state contain fish in high and very high mercury categories ($>$ 0.5 ppm). The impact is generally greatest in the San Francisco Bay-Delta, the Central Valley, and at higher elevations in the watershed, with sites downstream of abandoned mercury mines containing the most highly mercury-contaminated fish. The very few good time series available for mercury in sport fish show no clear trends over the past three decades. Thus, the available evidence supports the hypothesis that the problem may take decades to be resolved. TMDL implementation actions, mine clean-ups, and consumption advisories are important management actions that may improve the situation over different time scales. The effect of large-scale wetland restoration in the San Francisco Bay-Delta on mercury bioaccumulation in this region is unknown. The area with the most data for wildlife, also the San Francisco Bay-Delta, shows that impacts on wildlife populations, including endangered species, from mercury contamination are likely.

Literature Cited

Barron, M. G., R. Heintz, and M. M. Krahn. 2003. Contaminant exposure and effects in pinnipeds: implications for Steller sea lion declines in Alaska. Sci. Tot. Environ. 311:111-133.

Beckvar, N., T. M. Dillon, and L. B. Read. 2006. Approaches for linking whole-body fish tissue residues of mercury or DDT to biological effects threhsolds. Environ. Toxicol. Chem. 24:2094-2105.

Brodberg, R. K., and G. A. Pollock. 1999. Prevalence of selected target chemical contaminants in sport fish from two California lakes: Public health designed screening study. Final project report CX 825856-01-0. Office of Environmental Health Hazard Assessment, Sacramento, California. 24 pp. http://www.oehha.ca.gov/fish/

nor_cal/CX825.html.

CCME. 2001. Canadian tissue residue guidelines for the protection of wildlife consumers of aquatic biota: Summary table. Updated. Canadian environmental quality guidelines, 1999. Canadian Council of Ministers of the Environment, Winnipeg.

Clark, D. R., Jr., K. S. Foerster, C. M. Marn, and R. L. Hothem. 1992. Uptake of environmental contaminants by small mammals in pickleweed habitats at San Francisco Bay, California. Arch. Environ. Contam. Toxicol. 22:389-396.

Cooke, J. 2002. Clear Lake TMDL for mercury, Staff Report, Final Report. Regional Water Quality Control Board, Central Valley Region, Rancho Cordova, CA.

Davis, J. A., B. K. Greenfield, G. Ichikawa, and M. Stephenson. 2003a. Mercury in sport fish from the Delta region (Task 2A). An assessment of the ecological and human health impacts of mercury in the Bay-Delta watershed. CALFED Bay-Delta Mercury Project, Sacramento, CA. 63 pp.

Davis, J. A., J. Ross, R. Fairey, C. Roberts, G. Ichikawa, J. Negrey, and D. Crane. 2004. CISNET technical report: Contaminant accumulation in forage fish. SFEI Contribution 413, San Francisco Estuary Institute, Oakland, CA.

Davis, J. A., D. Yee, J. N. Collins, E. S. Schwarzbach, and S. N. Luoma. 2003b. Potential for increased mercury accumulation in the estuary food web. San Francisco Estuary and Watershed Science 1:36.

Drevnick, P. E., and M. B. Sandheinrich. 2003. Effects of dietary methylmercury on reproductive endocrinology of fathead minnows. Environ. Sci. Technol. 37:4390-4396.

Elbert, R. A. 1993. Ecological assessment of the sulphur bank mercury mine superfund site wildlife study report: heavy metal hazards to wildlife of Clear Lake, Lake County, CA. Remedial Investigation/Feasibility Study, sulphur bank mercury mine superfund site, Clearlake Oaks, CA. US EPA Region 9. August 1994 Report. Department of Wildlife, Fish and Conservation Biology, UC Davis., Clearlake Oaks, CA.

Elbert, R. A., and D. W. Anderson. 1998. Mercury levels, reproduction and hematology in western grebes from three California lakes, USA. Environ. Toxicol. Chem. 17:210-213.

Greenfield, B. K., J. A. Davis, R. Fairey, C. Roberts, D. Crane, and G. Ichikawa. 2005. Seasonal, interannual, and long-term variation in sport fish contamination, San Francisco Bay. Sci. Tot. Environ. 336:25-43.

Heinz, G. 2003. The use of egg injections to rank the sensitivities of avian embryos to methylmercury (final progress report). CALFED Bay-Delta Mercury Project California Bay Delta Authority, Sacramento, CA. 29 pp.
Hintelmann, H., R. Harris, A. Heyes, J. P. Hurley, C. A. Kelly, D. P. Krabbenhoft, S. Lindberg, J. W. M. Rudd, K. J. Scott, and V. L. S. Louis. 2002. Reactivity and mobility of new and old mercury deposition in a boreal forest ecosystem during the first year of the METAALICUS study. Environ. Sci. Technol. 36:5034-5040.

Hoffman, D. J., H. M. Ohlendorf, C. M. Marn, and G. W. Pendleton. 1998. Association of mercury and selenium with altered glutathione metabolism and oxidative stress in diving ducks from the San Francisco Bay Region, USA. Environ. Toxicol. Chem. 17:167-172.

Johnson, B., and R. Looker. 2004. Mercury in San Francisco Bay total maximum daily load (TMDL) proposed basin plan amendment and staff report. California Regional Water Quality Control Board San Francisco Bay Region, Oakland, CA. 173 pp. http://www.swrcb.ca.gov/rwqcb2/TMDL/SFBayMercury/staff_report_043004.pdf.

Kenow, K. P., S. Gutreuter, R. K. Hines, M. W. Meyer, F. Fournier, and W. H. Karasov. 2003. Effects of methyl mercury exposure on the growth of juvenile common loons. Ecotoxicol. 12:171-182.

Kopec, A. D., and J. T. Harvey. 1995. Toxic pollutants, health indices, and population dynamics of harbor seals in San Francisco Bay, 1989-1992. Final Report. 96-4, Moss Landing, CA. 172 pp.

Krabbenhoft, D. P., J. G. Wiener, W. G. Brumbaugh, M. L. Olson, J. F. DeWild, and T. J. Sabin. 1999. A national pilot study of mercury contamination of aquatic ecosystems along multiple gradients. U.S. Geological Survey Toxic Substances Hydrology Program Proceedings of Technical Meeting 2:147-160.

Kuhlman, C. E. 2006. Comment Letter -- 2006 Federal Clean Water Act Section 303(d) List California Regional Water Quality Control Board, North Coast Region, Santa Rosa, California. 4 pp. http://www.swrcb.ca.gov/tmdl/docs/303dlists2006/comments/catherine_kuhlman.pdf.

Latif, M. A., R. A. Bodaly, T. A. Johnston, and R. J. P. Fudge. 2001. Effects of environmental and maternally derived methylmercury on the embryonic and larval stages of walleye (Stizostedion vitreum). Environ. Poll. 111:139-148.

Lonzarich, D. G., T. E. Harvey, and J. E. Takekawa. 1992. Trace element and organochlorine concentrations in California clapper rail (Rallus longirostris obsoletus) eggs. Arch. Environ. Contam. Toxicol. 23:147-153.

OEHHA. 2000. Mercury in Fish from Lake Pillsbury. Fact Sheet. California Environmental Protective Agency, Office of Environmental Health Hazard Assessment, Oakland, California. 4 pp. http://www.oehha.ca.gov/fish/pdf/lpfacts.pdf.

Ohlendorf, H. M., K. C. Marois, R. W. Lowe, T. E. Harvey, and P. R. Kelly. 1991. Trace elements and organochlorines in surf scoters from San Francisco Bay, 1985. Environ. Mon. Assess. 18:105-122.

Orihel, D. M., M. J. Paterson, C. C. Gilmour, R. A. Bodaly, P. J. Blanchfield, H. Hintelmann, R. C. Harris, and J. W. M. Rudd. 2006. Effect of loading rate on the fate of mercury in littoral mesocosms. Environ. Sci. Technol. 40:5992-6000.

RMP. 2006. Contaminant concentrations in sport fish from San Francisco Bay, 2003. Regional Monitoring Program for Traces Substances, San Francisco Estuary Institute, Oakland, CA.

Scheuhammer, A. M. 1991. Effects of acidification on the availability of toxic metals and calcium to wild birds and mammals. Environ. Pollut. 71:329-275.

Scheuhammer, A. M., M. W. Meyer, M. B. Sandheinrich, and M. W. Murray. 2007. Effects of environmental methylmercury on the health of wild birds, mammals, and fish. Ambio 36:12-19.

Schwarzbach, S., and T. Adelsbach. 2003. Field Assessment of avian mercury exposure in the Bay-Delta ecosystem (Subtask 3B). CALFED Bay-Delta Mercury Project, Sacramento, CA. 30 pp. http://loer.tamug.tamu.edu/calfed/FinalReports.htm.

Schwarzbach, S. E., J. D. Albertson, and C. M. Thomas. 2006. Effects of predation, flooding, and contamination on reproductive success of California Clapper Rails (Rallus longirostris obsoletus) in San Francisco Bay. Auk 123:45-60.

Slotton, D. G., S. M. Ayers, T. H. Suchanek, R. D. Weyand, A. M. Liston, C. Asher, D. C. Nelson, and B. Johnson. 2002. Effects of wetland restoration on the production and bioaccumulation of methylmercury in the Sacramento-San Joaquin Delta, California. Draft Final Report. California Bay Delta Authority, Sacramento, CA. 49 pp.

Spalding, M., P. Frederick, H. McGill, S. Bouton, and L. McDowell. 2000. Methylmercury accumulation in tissues and its effects on growth and appetite in captive great egrets. J. Wildl. Dis. 36:411-422.

Tetra Tech. 2005. Technical Memorandum 5.3.2 Data Collection Report. Guadalupe River Watershed Mercury TMDL Project. Santa Clara Valley Water District, San Jose, CA.

USFWS. 2003. Evaluation of the Clean Water Act Section 304(a) human health criterion for methylmercury: protectiveness for threatened and endangered wildlife in California. U.S. Fish and Wildlife Service, Environmental Contaminants Division, Sacramento, CA. 96 + appendix pp.

Wiener, J., B. Knights, M. Sandheinrich, J. Jeremiason, M. Brigham, D. Engstrom, L. Woodruff, W. Cannon, and S. Balogh. 2006. Mercury in soils, lakes, and fish in Voyageurs National Park: importance of atmospheric deposition and ecosystem factors. Environ. Sci. Technol. 40:6261-6268.

Wiener, J. G., C. C. Gilmour, and D. P. Krabbenhoft. 2003a. Mercury strategy for the Bay-Delta ecosystem: unifying framework for science, adaptive management, and ecological restoration. CALFED Bay-Delta Mercury Project, Sacramento, CA.

Wiener, J. G., D. P. Krabbenhoft, G. H. Heinz, and A. M. Scheuhammer. 2003b. Ecotoxicology of mercury. Pages 409-463 in, D. J. Hoffman, B. A. Rattner, G. A. Burton, Jr., and J. Cairns, Jr. , editors. Handbook of Ecotoxicology. CRC Press, Boca Raton, Florida.

Wolfe, M. F., S. Schwarzbach, and R. A. Sulaiman. 1998. Effects of mercury on wildlife: A comprehensive review. Environ. Toxicol. Chem. 17:146-160.

Wood, M., C. Foe, G. Marquis, and J. Cooke. 2005. Sacramento-San Joaquin Delta Estuary TMDL for methyl and total mercury, Staff Report, Draft Report. Regional Water Quality Control Board, Central Valley Region, Rancho Cordova, CA.