3.4 THE IMPACT OF PCB BIOACCUMULATION ON FISHING AND AQUATIC LIFE IN CALIFORNIA

3.4.1. Introduction

Polychlorinated biphenyl (PCB) bioaccumulation in aquatic food webs in California has declined significantly since PCB production was banned in the 1970s, but this persistent pollutant continues to have a negative impact on fishing and aquatic life in many parts of the State.

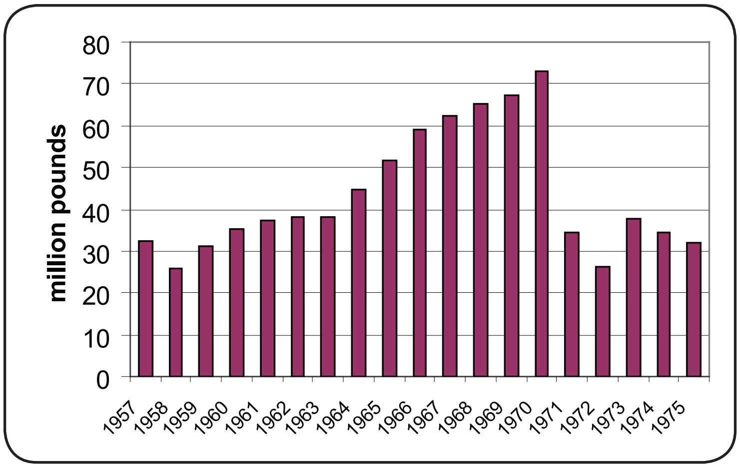

Figure 3.4.1. PCB production in the U.S., 1957 – 1975. From Brinkmann and de Kok (1980).

PCBs are a family of chemicals that were widely used for many decades, are extremely stable in the environment, have a strong tendency to accumulate in living organisms, and continue to pose health risks to humans and wildlife. The term “polychlorinated biphenyl” refers to a family of 209 individual chemicals (called “congeners”). In the U.S., PCBs were sold as mixtures of many congeners known as “Aroclors”. Due to their resistance to electrical, thermal, and chemical processes, PCBs were used in a wide variety of applications from the time of their initial commercial production in 1929 (Brinkmann and de Kok 1980). PCBs were most commonly used as insulators in electrical equipment such as transformers and capacitors. Electrical utilities and industries consuming large quantities of electricity used the greatest quantities of PCBs. PCBs were also used in many other applications, including hydraulic fluids, lubricants, inks, and as a plasticizer. U.S. production peaked in 1970 at 39 million kg (Figure 3.4.1). Trends in PCB release to the environment approximately matched trends in PCB production.

U.S. production of PCB-containing capacitors and transformers ended in January 1979. However, the use of PCBs in some totally enclosed applications remains legal to this day. The life-expectancy of capacitors and transformers is decades. In-place capacitors, transformers, and other PCB-containing equipment may still be significant potential sources of PCBs to the environment. A U.S. EPA voluntary transformer registration database showed significant ongoing use, almost 200,000 kg, in the San Francisco Bay Area (the entries in the database were reported between 1998 and 2001) (USEPA 2004). PCBs are extremely persistent in the environment. Leakage from or improper handling of PCB-containing equipment over many decades has led to contamination that persists today, and stormwater continues to wash tainted soils from contaminated sites into California water bodies.

The 1979 ban resulted from a growing appreciation of the health risks of PCBs. In spite of the fact that their use has been restricted for almost two decades, PCBs remain among the environmental contaminants of greatest concern because they are potent toxicants that are resistant to degradation and have a strong tendency to accumulate in biota. PCBs can cause toxic symptoms including developmental abnormalities and growth suppression, disruption of the endocrine system, impairment of immune function, and cancer. U.S. EPA classifies PCBs as a probable human carcinogen. PCBs and other similar organochlorines reach higher concentrations in higher levels of aquatic food chains in a process known as "biomagnification". Consequently, predatory fish, birds, and mammals (including humans that consume fish) at the top of the food web are particularly vulnerable to the effects of PCB contamination.

The following section (3.4.2) and maps in this chapter are geared exclusively toward impact on fishing, with concentration categories related to human consumption of sport fish and human health concerns. Section 3.4.3 addresses how PCBs may be affecting aquatic life in California, but sufficient data for aquatic life indicators were not available to create the same detailed maps. Maps geared toward impacts on aquatic life would have different species represented (e.g., small fish, such as Mississippi silversides, or bird eggs) and would apply different thresholds.

3.4.2. Impact of PCBs on Fishing in California

a. Current Status

Consumption Advisories

Consumption advisories issued by OEHHA are one key indicator of the impact of PCBs on fishing in California. As of April 2007, consumption advisories due at least partially to PCBs were in place for three general groups of water bodies: 1) San Francisco Bay, 2) reservoirs in the San Francisco Bay Area, and 3) coastal locations in southern California between Point Dume and Dana Point (Figure 3.2.1, Table 3.2.1). In spite of the fact that PCB concentrations in fish in California were probably at their peak in the 1960s and 1970s and have declined gradually since that time, these advisories have all been issued since 1991. This reflects a trend toward increasing availability of information on PCBs in sport fish, not a trend of increasing concentrations. PCBs are extremely persistent and in some cases are well above the threshold for concern, so some of these advisories may be in place for quite some time. In San Francisco Bay, for example, it is expected that it will take 50 to 100 years for PCB concentrations in white croaker and shiner surfperch to fall below the applicable threshold for human health concern (Davis et al. 2007). It is possible that with increased spatial coverage in monitoring of water bodies in California, other areas may be identified where PCB concentrations persist above the threshold for concern, as happened recently with Bay Area reservoirs.

303(d) Listings

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

- Humboldt Bay (16,075 acres);
- San Francisco Bay (318,417 acres);
- Coastal water bodies in the Los Angeles area (many miles and acres, most notably Santa Monica Bay [146,645 acres]);
- Two inland lakes in the Los Angeles area (256 acres);
- 15.5 miles of drainage canal in the Sacramento area;
- 3.3 miles of channel near Stockton;
- 623 acres at Anaheim Bay; and
- 55 acres of San Diego Bay.

Most of the area impacted lies in major bays and estuaries – PCBs are a major contributor to the high degree of impact of pollutants on this class of water body as discussed in Section 3.2.

There is general agreement between areas on the 303(d) List and those with consumption advisories. Major exceptions to this, where water bodies are listed but no consumption advisory including PCBs is in place, are Humboldt Bay, Anaheim Bay and Huntington Harbor, and San Diego Bay. The Bay Area reservoirs are also an exception, where consumption advice is in place but the reservoirs do not appear on the 303(d) List, probably due to the advisories being issued after the 2002 303(d) List was finalized.

Recent Monitoring Data

Sport fish monitoring data collected from 1998 – 2003 indicate that PCB concentrations are elevated in many areas of the state (Figure 3.4.2, Table 3.4.1). A total of 251 locations were sampled for PCBs during this

Table 3.4.1. Total number of locations sampled for PCBs 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)	251	66%	26%	4%	4%
1988 – 1997	237	82%	9%	3%	6%
1978 – 1987	186	66%	14%	8%	12%

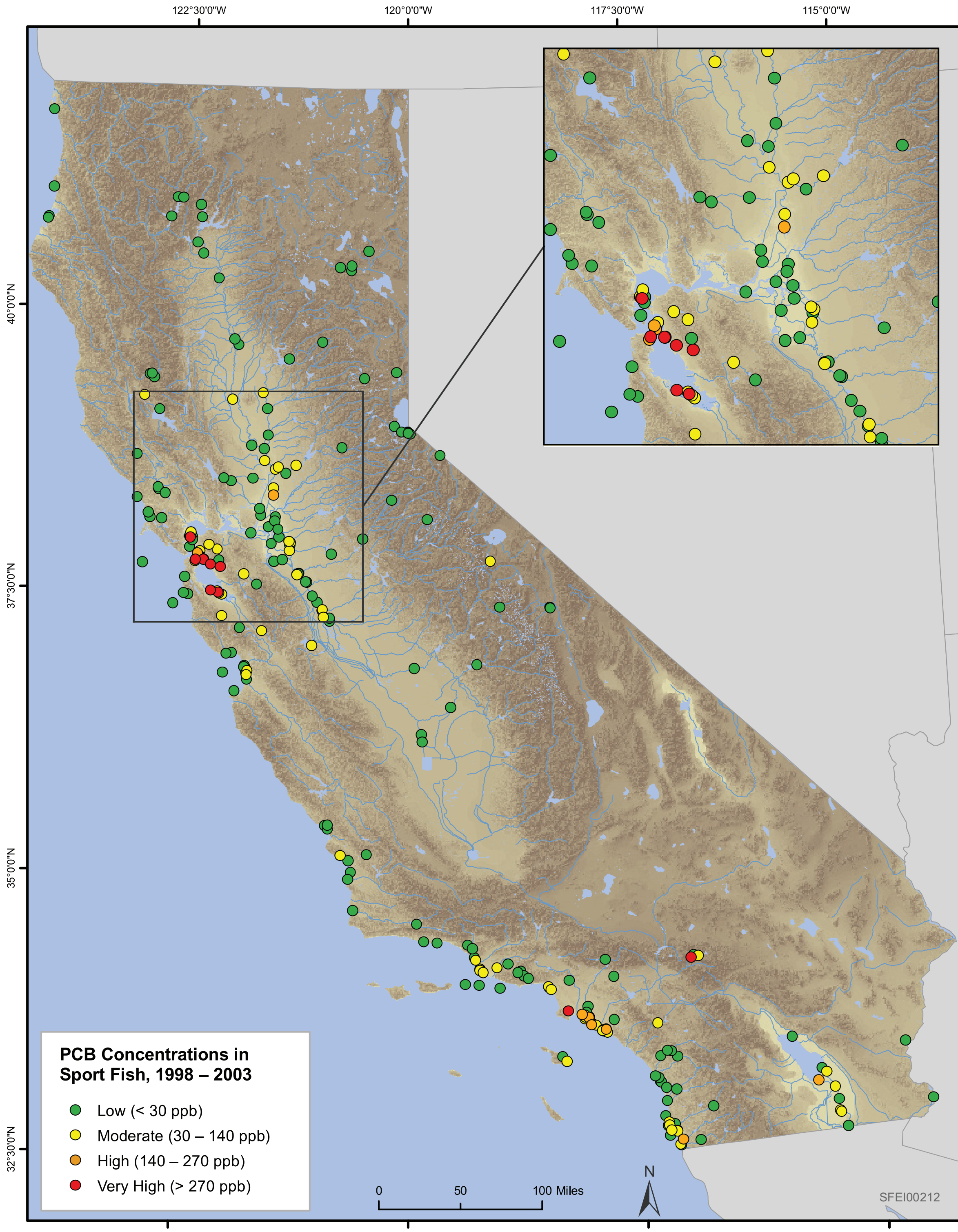

Figure 3.4.2. PCB concentrations in California sport fish, 1998 – 2003. Based on PCB measurements (ppb wet wt) in muscle tissue from a variety of fish species. Dots represent sampling locations. Dot colors indicate the highest median concentration among species at each location.

period. Ten of these locations (4% of the total) had a species with median concentrations above 270 ppb, placing them in the very high concentration category. Seven of these locations were within San Francisco Bay, which has a well-documented, persistent PCB problem. The other three locations in the very high category were Lake Chabot in the Bay Area, Machado Lake (formerly Harbor Park Lake) in Los Angeles County, and Big Bear Lake in San Bernardino County. Very high PCB concentrations in carp from Lake Chabot (up to 406 ppb) were first discovered in 2001. Elevated concentrations in multiple species from Machado Lake (formerly Harbor Park Lake) have been measured repeatedly since 1984. Very high concentrations have been observed in carp from Big Bear Lake since 1988.

Thirty percent of the locations sampled in 1998 – 2003 had PCB concentrations in the moderate and high categories. These locations were primarily concentrated near highly urban and industrial areas in the Bay-Delta region, the Los Angeles area, near San Diego, and in the Imperial Valley. However, a few isolated locations in parts of the state removed from dense urbanization had moderate or high concentrations.

Most (66%) of the locations sampled in 1998 – 2003 had concentrations in the low category, indicating that median concentrations for all species analyzed at these locations were below 30 ppb. Areas of the state away from extensive urban and industrial development, such as the northern Sacramento Valley, the Sierra Nevada and foothills, and northern San Diego County, had a preponderance of locations with concentrations below 30 ppb.

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

Management Actions

PCBs have proven to be among the most persistent organic pollutants in the aquatic environment. Concentrations in aquatic food webs across the state have generally shown gradual declines over the past 30 years in response to the use restrictions and federal ban in the 1970s. However, PCBs are declining at a much slower pace than the legacy pesticides, apparently due to their greater resistance to degradation in the environment. Without drastic action, PCB concentrations in highly polluted ecosystems like San Francisco Bay are likely to remain above thresholds for concern for many decades to come.

The most important management actions ever taken to reduce PCB pollution in California and the rest of the country were the phaseout during the 1970s and the 1979 federal ban on sale and production of PCBs (Figure 3.4.1) (Brinkmann and deKok 1980). These actions led to a rapid decline in the open-ended uses of PCBs (e.g., as a pesticide and paint additive, in carbonless copy paper), and a gradual decline in the inventory of PCBs used in electrical equipment and other applications in the watersheds. However, as mentioned above, despite the 1979 ban, a considerable amount of PCBs remains in use today. The PCB ban has had a significant positive long-term impact, but without further action it appears that the general recovery of California water bodies from PCB contamination will take many more decades.

In the 1980s and 1990s, additional management of PCBs in the state was largely driven by regulations pertaining to the cleanup of highly contaminated sites. PCB hotspots have been remediated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or "Superfund". Cleanup of these hotspots undoubtedly has reduced PCB loading to California water bodies, but a review of these actions was beyond the scope of this report.

Long-term Trends

Sport Fish

If the state's sport fish monitoring program applied a consistent sampling design over the years, trends in the impact of PCBs on fishing in California could be evaluated by comparing historic data to the same concentration categories applied to the recent monitoring data in the previous section (Table 3.4.1, Figures 3.4.3 and 3.4.4). While this type of comparison provides a general picture of PCB impact over the long-term, inconsistencies over the years interfere with finer scale comparisons.

Sampling intensity is one factor that varied over the period of record. Sampling intensity was highest in the most recent interval (251 locations sampled) in spite of this interval being shorter than the others. A comparable number of locations (237) was sampled in the 1988 – 1997 interval, but sampling was less intense during the 1978 – 1987 interval (186 locations).

The percentage of locations in the very high concentration category declined from 12% in the 1978 – 1987 interval to 4% in the most recent interval. In contrast, the proportion of locations in the moderate category was highest (26%) in the recent period. The percentage of locations in the low category was highest in the 1988 – 1997 (82%), but still a majority of the samples in the other periods (66% for both).

These changes in percentages of locations in the four categories were influenced by a combination of gradual declines in PCB concentrations over the 26-year period and the shifting geographic emphasis of sampling during the different periods. In the earliest interval, very high locations (red dots) were present in several parts of the state, including clusters of locations in the Sacramento River watershed, the northern Delta, and inland water bodies in the Los Angeles area. In contrast, in the most recent interval the only cluster of red dots was in San Francisco Bay. Declining concentrations are illustrated by trends in the Delta region, which had a cluster of red dots in the earliest period, but no red dots in the recent period in spite of thorough sampling. The influence of changing geographic emphasis is illustrated by the prominent cluster of red locations in San Francisco Bay in the recent interval and the influence of these locations on the overall statistics, compared to the lack of any points in this area in the earliest interval. If the Bay had been sampled in the 1978 – 1987 period there surely would have been more red dots on the map.

A more precise analysis of long-term trends in PCB concentrations in sport fish can be made at locations where sampling was performed consistently over the years. Unfortunately, this type of sampling was performed in very few cases. The best time series generated from the late 1970s to the present are illustrated

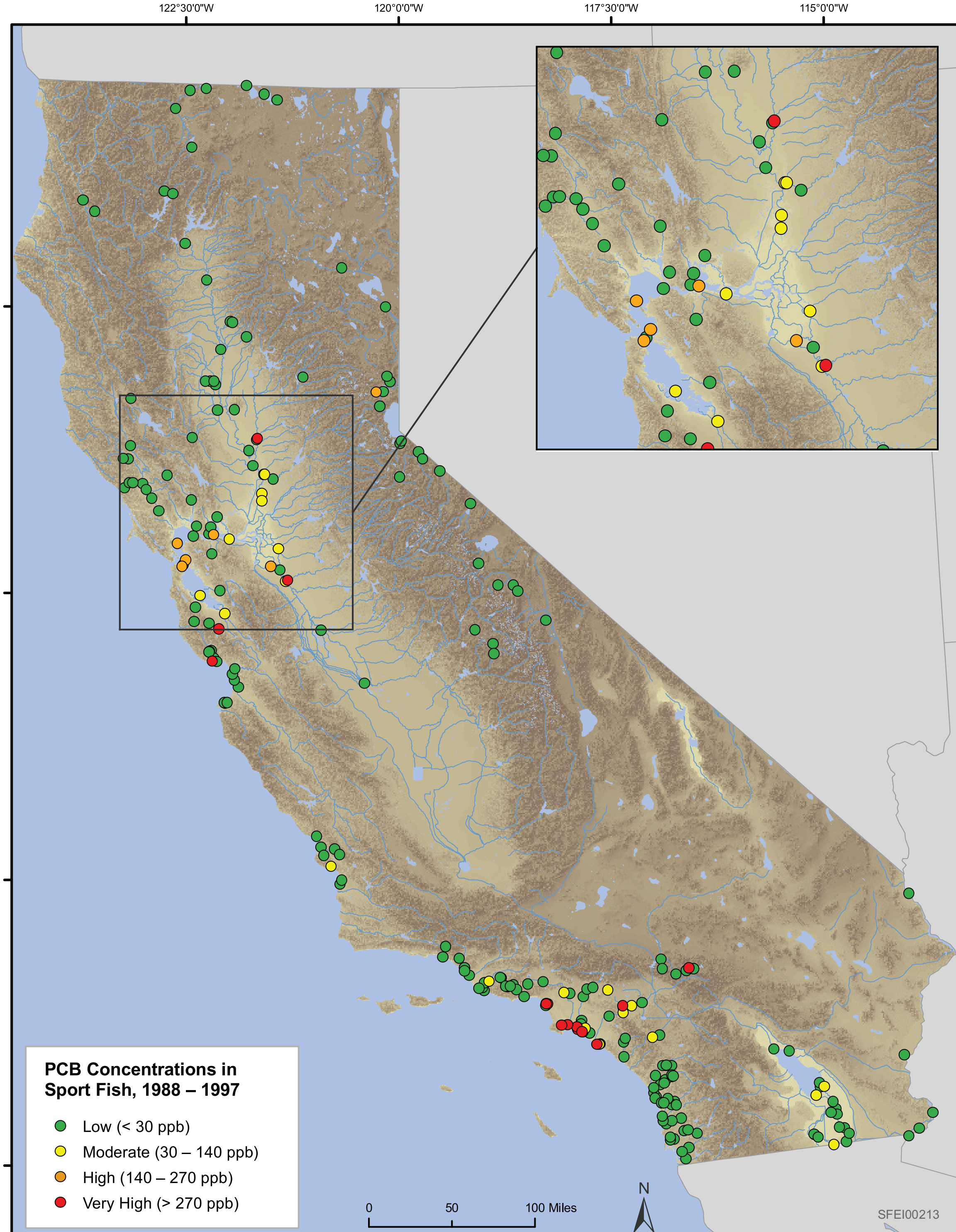

Figure 3.4.3. PCB concentrations in California sport fish, 1988 – 1997. Based on PCB measurements (ppb wet wt) in muscle tissue from a variety of fish species. Dots represent sampling locations. Dot colors indicate the highest median concentration among species at each location.

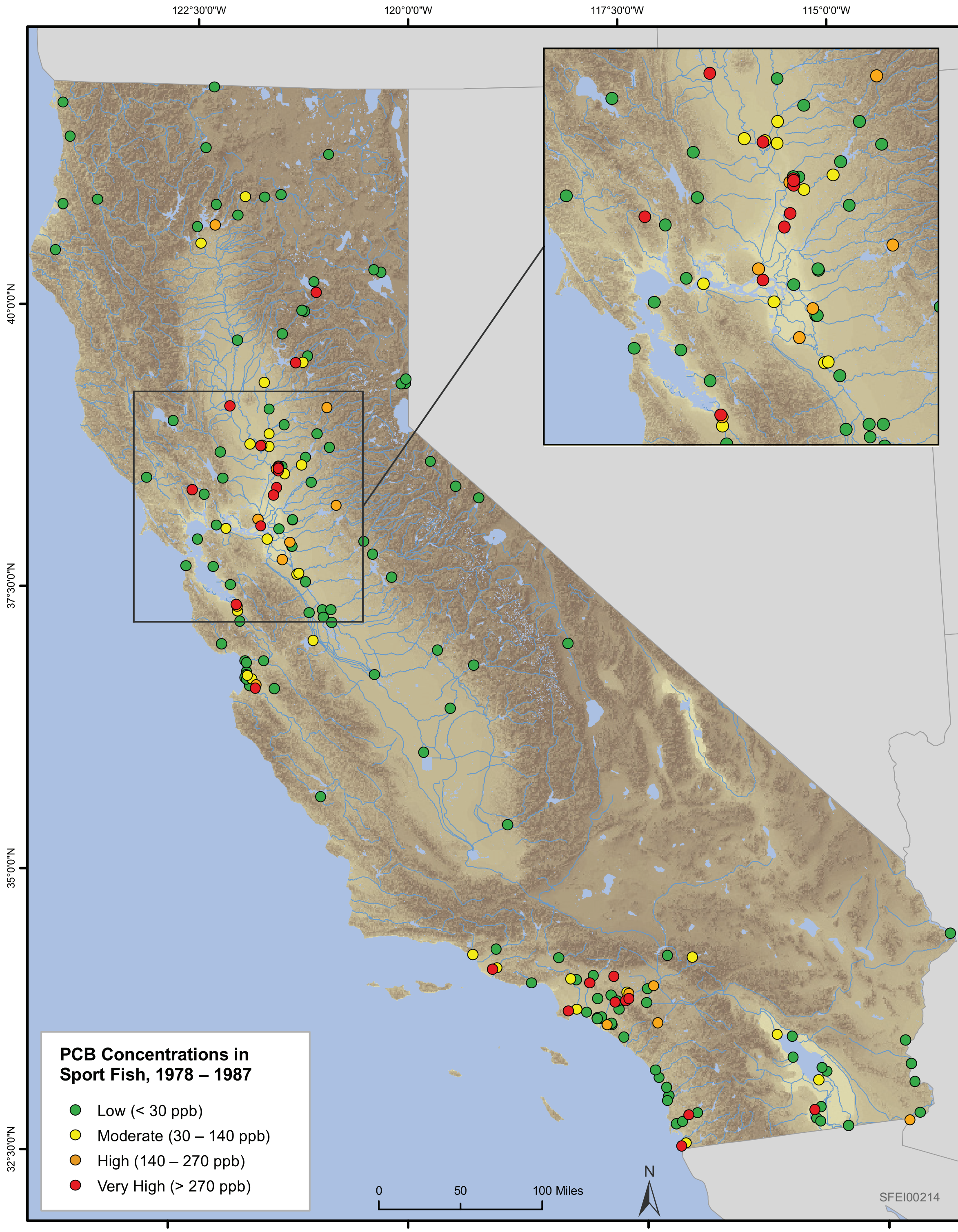

Figure 3.4.4. PCB concentrations in California sport fish, 1978 – 1987. Based on PCB measurements (ppb wet wt) in muscle tissue from a variety of fish species. Dots represent sampling locations. Dot colors indicate the highest median concentration among species at each location.

in Figure 3.4.5. This trend dataset has many shortcomings. First, there are very few decent time series with consistent sampling over the period of record. The best time series are for white catfish at the Sacramento River at RM44/Hood (13 observations), red shiner at San Diego Creek at Michelson Drive (19 observations), and channel catfish at New River at Westmorland (14 observations). The other five locations were not sampled adequately to characterize long-term trends. Other problems plaguing these datasets include high MDLs (causing the many "zero" values shown on the graphs) and inconsistent compositing and size ranges in the samples. The mobility of fish populations is another factor that increases interannual variability and decreases the power of fish monitoring as a trend-detection tool.

In spite of these problems with the dataset, the three locations with reasonable time series illustrate what appear to be common scenarios for PCBs. At some locations, concentrations have declined considerably. San Diego Creek at Michelson Drive is an excellent example of a progressive, statistically significant ($p < 0.05$) decline, with over a ten-fold reduction from 1983 to 2001 (Figure 3.4.5). Sacramento River at RM44/Hood is another time series suggesting a decline, but interannual variability was higher at this location and the relationship was not statistically significant. In contrast, the channel catfish time series from New River at Westmorland is characterized by high variability and persistent high concentrations, with high concentrations in recent years suggesting a possible increase in food web PCBs. This scenario seems to apply in other places such as San Francisco Bay, where concentrations in sport fish persist with no obvious indication of decline (discussed below).

Bivalves

Bioaccumulation monitoring with bivalves conducted by the State Mussel Watch (SMW) Program and other regional programs is another valuable source of information on long-term trends in pollutant concentrations in California water bodies. Bivalves are an indirect indicator of pollutant impact on the fishing beneficial use, but complement fish monitoring by providing a powerful tool for detecting long-term trends in bioavailable pollutants at precise locations. In contrast to the time series for sport fish, the bivalve data include many robust time series that document statistically significant declines from the late 1970s to the present (Figure 3.4.6). Statistically significant ($p < 0.05$) declines were observed at six of the ten locations included in Figure 3.4.6. The Figure shows the best time series available for different parts of the state. PCB concentrations at long-term monitoring locations in the northern part of the state were generally low, and the trends are obscured by a prevalence of below detection limit results. These sites provide a useful indication of conditions in the California water bodies unaffected by local significant PCB sources. Trends within San Francisco Bay are not shown in Figure 3.4.6 because they are discussed in detail below. Many long-term monitoring sites in southern California exhibited a pattern of decline in PCBs. Six of the seven sites included in Figure 3.4.6 had statistically significant declines. One important exception was San Diego Bay at Harbor Island, which had the highest PCB concentrations of any location in the SMW Program. The most recent sample analyzed at this location had the highest concentration (on a lipid weight basis), indicating that PCBs in this water body are persisting at high concentrations. Two sites are shown for Newport Bay, both of which showed a progressive, significant, ten-fold reduction, though the initial concentrations at each location were quite different.

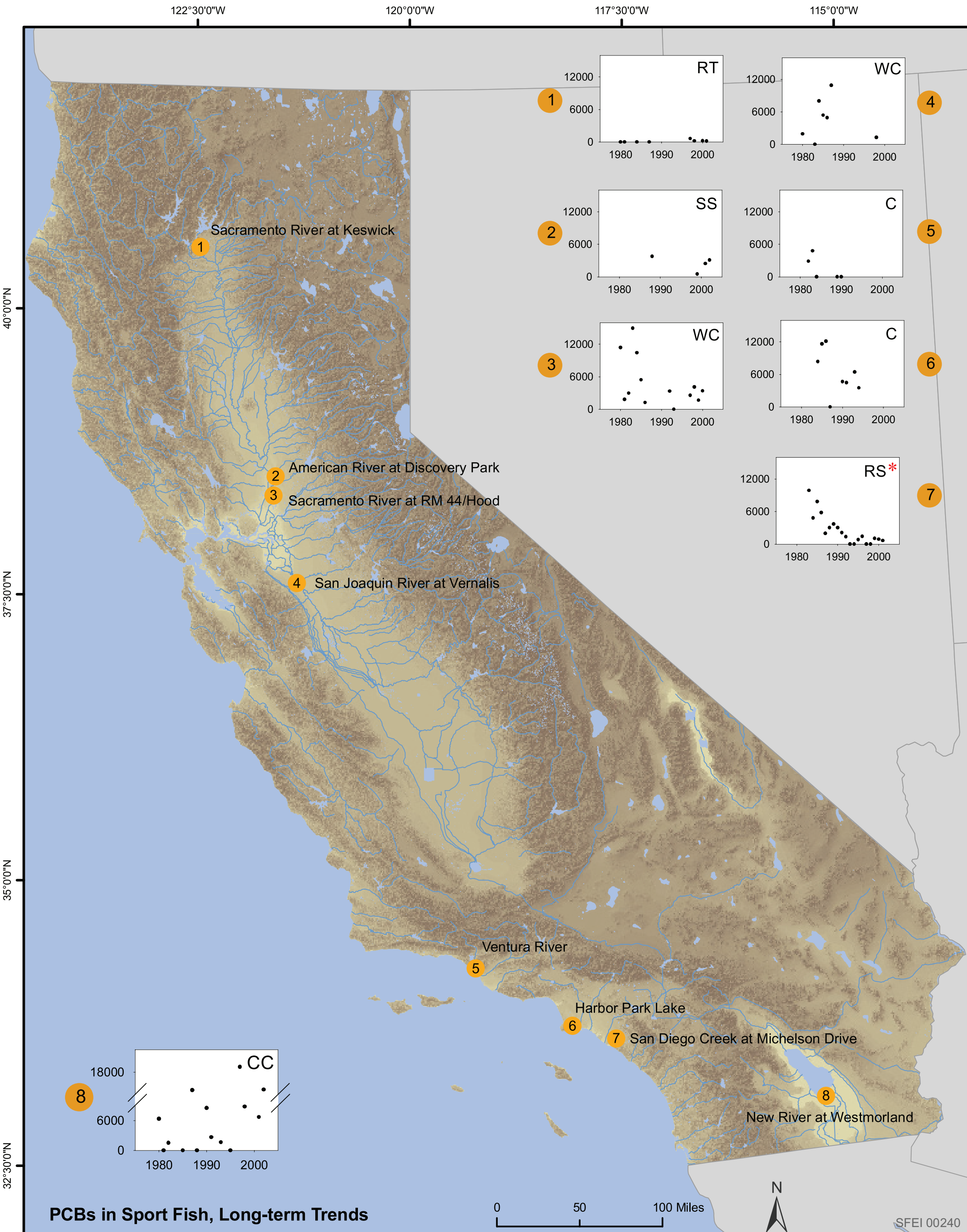

Figure 3.4.5. Long-term trends in PCB concentrations in California sport fish. Locations shown represent the best time series available for different parts of the state. The red asterisk indicates a significant trend. Concentrations are given in ppb lipid weight. Species shown are rainbow trout (RT), Sacramento sucker (SS), white catfish (WC), channel catfish (CC), red shiner (RS), and common carp (C).

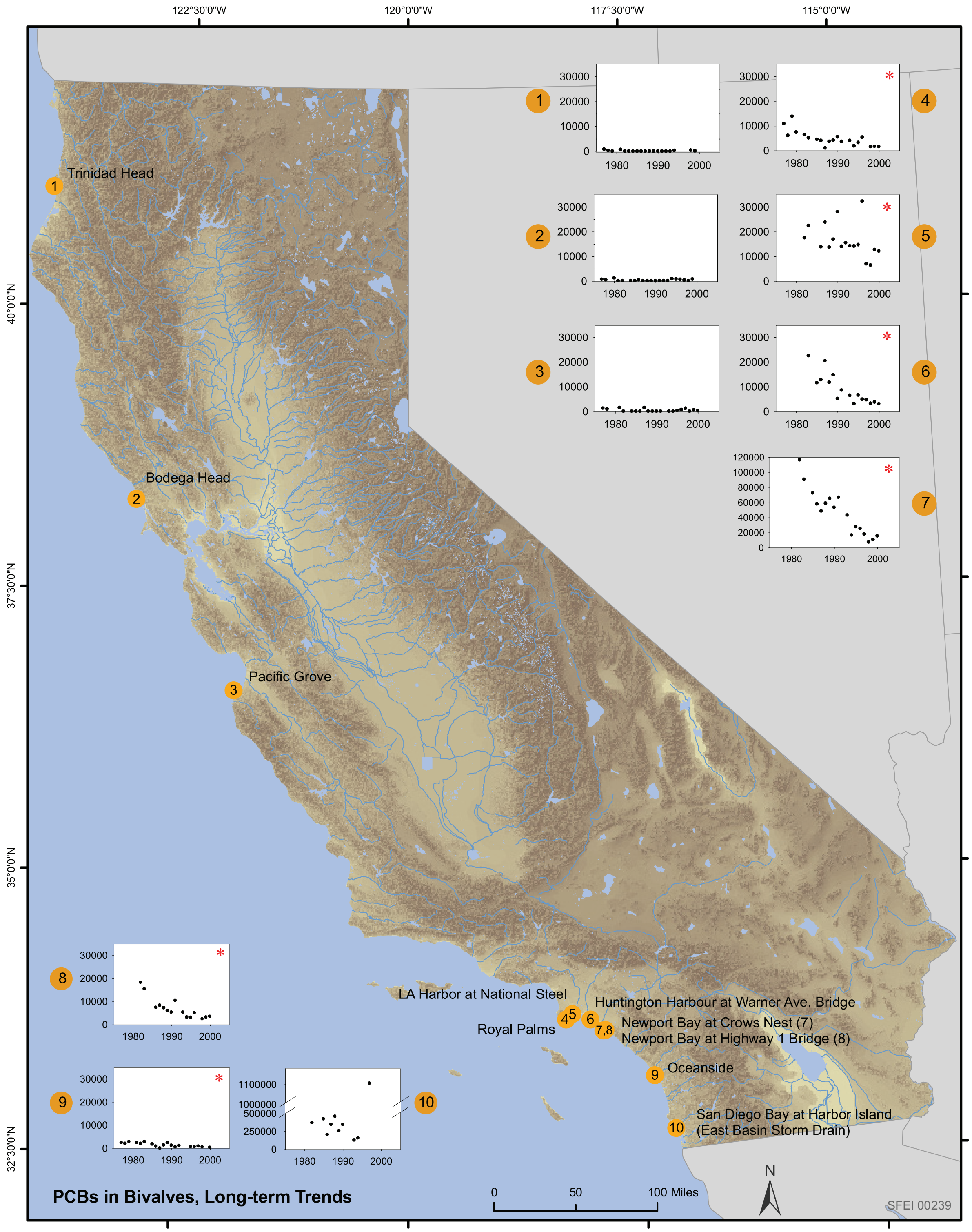

Figure 3.4.6. Long-term trends in PCB concentrations in California mussels measured by the State Mussel Watch Program. Locations shown represent the best time series available for different parts of the state. The red asterisk indicates a significant trend. Concentrations are given in ppb lipid weight.

Case Studies

San Francisco Bay

Long-term trends in the impact of PCBs on fishing are of particular interest in San Francisco Bay due to the persistence of relatively high concentrations in this ecosystem and the relatively thorough monitoring that has been performed over the past decade by the Regional Monitoring Program. The phaseout of PCBs during the 1970s and the 1979 federal ban on sale and production appear to have led to relatively rapid declines in Bay PCBs during the 1970s and early 1980s, followed by a slower trajectory of decline from 1982 to the present. Without further management action it appears that the general recovery of the Bay from PCB contamination will take many more decades. In response to this persistent problem, water quality managers are currently developing a PCB Total Maximum Daily Load (TMDL) and implementation plan to accelerate the recovery of the Bay.

In San Francisco Bay, seven locations sampled by the SMW Program were continued by the Regional Monitoring Program (Davis et al. 2007), and represent the best dataset available on trends in the Bay over the past 20 years (Figure 3.4.7) (Stephenson et al. 1995, Gunther et al. 1999, SFEI 2005b). The trend signals are obscured to some extent by the use of different analytical laboratories and methods. Two distinct general patterns are evident in these data. For the northern Estuary locations (Pinole Point, Richmond Bridge/Red Rock, and Fort Baker/Horseshoe Bay), concentrations declined from approximately 4000 ng/g lipid in 1982 to 1000 ng/g lipid in 2003. For the southern Estuary locations (Treasure Island/Yerba Buena Island, Hunter's Point/Alameda, Redwood Creek, and Dumbarton Bridge), concentrations declined from approximately 6000 ng/g lipid in 1982 to 2000 ng/g lipid in 2003.

Extrapolating these regression lines into the future for southern Estuary locations indicates that a twenty-fold reduction in concentration (the magnitude of reduction needed to bring fish concentrations down below the threshold for concern) will take approximately another 40 years at Yerba Buena Island and Alameda, 80 years at Redwood Creek, and 70 years at Dumbarton Bridge. For the northern Estuary locations, where present concentrations are lower, it will take approximately 45 years at Pinole Point, 40 years at Richmond Bridge/Red Rock, and 25 years at Fort Baker/ Horseshoe Bay to reach 100 ng/g lipid. These are uncertain estimates, based on extrapolation of noisy datasets far into the future.

These estimates are also likely to be lower-bound estimates of time to recovery (in other words, actual recovery is likely to take longer). Food web monitoring data from the Great Lakes indicate that exponential declines with half-lives of a few years are usually good descriptors of PCB trends immediately after active sources have ceased. However, over the long term, processes such as runoff from the watershed, remobilization from sediments, and atmospheric deposition (local urban sources as well as global) begin to dominate the mass budget. This results in a tendency for losses to become balanced with inputs, and the initial rate of decline begins to slow at some point (Devault et al. 1996, Stow et al. 2004). Such processes are likely to reduce the long-term rate of recovery in San Francisco Bay. In addition, as described below, sport fish have not shown similar declines.

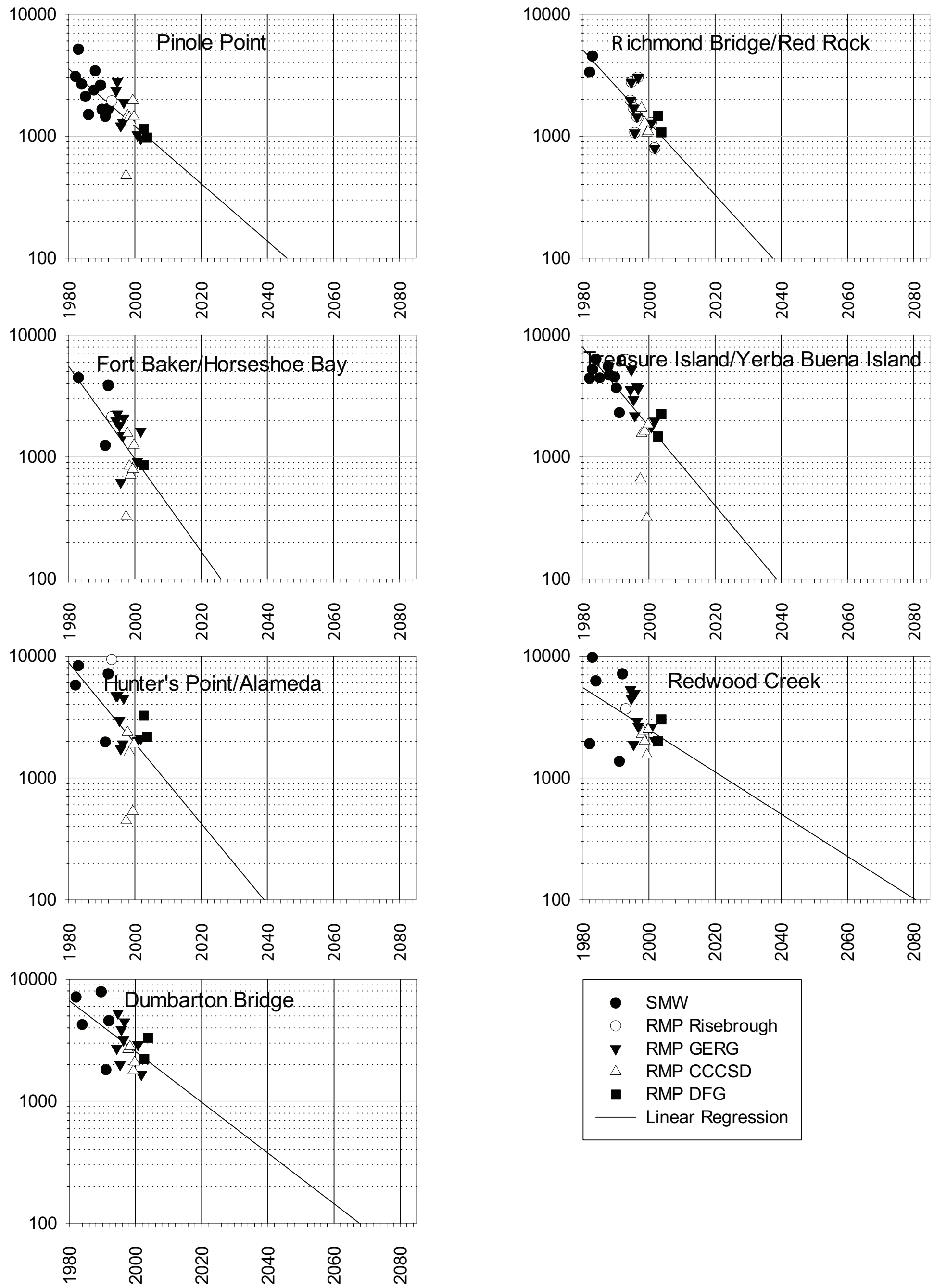

Figure 3.4.7. PCB concentrations in transplanted mussels, 1982 – 2003 (ppb lipid weight). Data from the State Mussel Watch Program as sum of Aroclors and the RMP as sum of congeners. The RMP has used four different analytical labs: Bodega Bay Institute (BBI), Geochemical and Environmental Research Group at Texas A&M (GERG), Central Contra Costa Sanitation District (CCCSD), and Department of Fish and Game (DFG).

Relatively thorough sampling of sport fish has also been conducted in the Bay, primarily over the past decade. The first measurements of PCBs in samples from the Bay were made by Risebrough in shiner surfperch collected in 1965 (Risebrough 1997). Regular sampling of this species on a three-year cycle has been conducted in recent years by the RMP. The mean concentration measured in three composite samples (10 – 15 fish in each) in 1965 was 832 ng/g wet (as Aroclors). In comparison, the Bay-wide median concentration measured in 2003 was 217 ng/g wet (as Aroclors), suggesting a reduction of approximately 74% over this 38 year span. Concentrations in shiner surfperch over the past nine years have shown no clear pattern of decline (Figure 3.4.8 – expressed as sums of congeners). Expressed as sums of congeners on a wet weight basis – most appropriate as an indicator of the status of impairment – Bay-wide medians were nearly identical in 1997, 2000, and 2003 (Figure 3.4.8). Expressed on a lipid weight basis – providing a better index of trends in PCB concentrations in the Bay – Bay-wide medians were highest in 1994 and 2003 (12600 and 10900 ng/g lipid, respectively), and exhibited considerable interannual variation with much lower concentrations in 1997 and 2000 (5200 and 5000 ng/g lipid, respectively). A relatively long time series (data not shown) also exists for white sturgeon in the Bay (1986 – 2003), but sample sizes have been small and relatively high concentrations were observed in the 2003 sampling. Time series for other sport fish species are limited to the 1994 – 2003 period. Concentrations in white croaker, another key indicator species, have also shown no clear pattern of decline from 1994 to 2003. On a wet weight basis, concentrations in white croaker have been quite consistent since 1994, ranging from 191 ng/g wet to 225 ng/g wet (sum of congeners), with the highest median observed in 2003 (Figure 3.4.8). Lipid weight medians have been more variable, ranging from 3800 ng/g lipid in 2003 to 6700 ng/g lipid in 1994 (Figure 3.4.8). Trends in sport fish are a crucial indicator of trends in impairment, but seasonal and interannual variation in fish physiology make them a somewhat unreliable indicator of general trends in Bay contamination, as suggested by the high interannual variance in the lipid-normalized data.

Newport Bay

Newport Bay provides an interesting contrast to San Francisco Bay. Like San Francisco Bay, Newport Bay is a highly urbanized water body that supports a substantial amount of fishing activity and had elevated concentrations of PCBs in the late 1970s (Allen et al. 2004). However, as discussed above, SMW data for bivalves and a recent study of PCBs in Newport Bay fish (Allen et al. 2004) both suggest that concentrations in Newport Bay biota have declined significantly. Of 50 composite samples of sport fish collected in 2000 and 2001, only two samples had concentrations above the 30 ppb threshold used in this report. The maximum concentration observed for any species was 58 ppb. This is much lower than concentrations typically found in white croaker from San Francisco Bay, most of which were above 200 ppb in 2003. In the late 1970s, six species of sport fish had average concentrations above the 30 ppb threshold. It should be noted, however, that in spite of these apparent general declines, recent TSMP sampling in Newport Bay has still found some fish samples with high PCBs – including one with 172 ppb from Upper Newport Bay in 2002. In the TMDL for Newport Bay (USEPA 2002), it is hypothesized that PCB spills at Air Stations and hazardous waste sites in the watershed were the historic sources of PCBs to Newport Bay. The long-term trend data suggest that the PCB ban and the regulations that have resulted in the reduction or elimination of spills have been sufficient to allow a relatively rapid rate of recovery of Newport Bay.

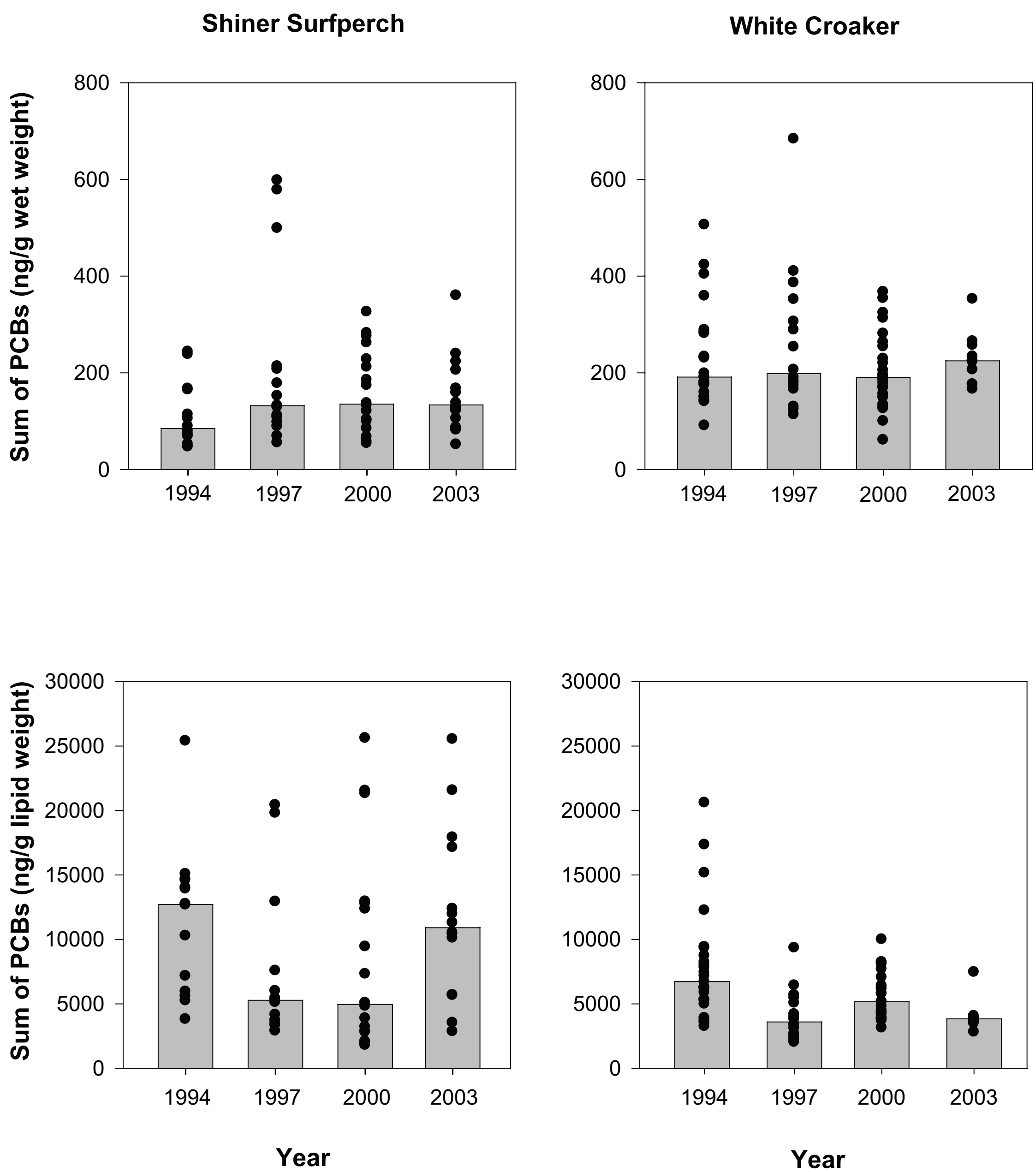

Figure 3.4.8. PCB trends in shiner surfperch and white croaker, 1994 – 2003. Expressed as sum of congeners on a wet weight basis (upper plots) and a lipid weight basis (lower plots). From Davis et al. (2006).

c. Sources and Pathways

The geographic distribution of PCBs measured in California sport fish provides an indication of the location and nature of the principal sources of these chemicals (Figures 3.4.9, 3.4.10, 3.4.11). High concentrations of PCBs are typically found in areas where historic use or maintenance of electrical equipment that contained PCBs occurred. These areas tend to be concentrated in urban centers with high amounts of industrial activity, but also occur in scattered areas across the landscape where electrical equipment or other PCB-containing equipment was used. PCBs were also used as a vehicle in pesticide mixtures, so in some cases their appearance in agricultural areas may be related to that practice. PCBs are additionally transported around the globe through atmospheric processes, leading to a low level background of contamination even in remote areas.

In the earliest time period (1978 – 1987), high concentrations of PCBs occurred primarily near urban areas (e.g., Sacramento, Los Angeles, and San Diego) but there were also elevated concentrations observed in rural areas. Most prominent in Figure 3.4.11 was an extremely high concentration (7,700 ppb wet wt) measured on the south fork of the Feather River at Forbestown, where a PCB spill from a hydroelectric facility (Forbestown Powerhouse) occurred (CVRWQCB 1987). Sampling at this location was only conducted in 1980, so the recovery of this area has not been documented. PCBs were commonly used in electrical equipment, so the many hydroelectric facilities in the state are potential sites of past or even present PCB contamination. Notably absent in this time period are any data from San Francisco Bay, so the lack of an urban signal in this period is partially due to incomplete sampling. The low concentrations of PCBs observed in many parts of the state away from urban centers indicate the weak influence of global atmospheric transport on PCBs in California fish.

In the 1988 – 1997 and 1998 – 2003 periods, concentrations away from urban centers were reduced relative to the earliest interval, suggesting a decline in sources in these areas. In 1988-1997, the largest cluster of locations with relatively high concentrations was in the Los Angeles/Orange County area. In 1998 – 2003, sampling in San Francisco Bay identified this water body as the broadest area in the state with relatively high PCB concentrations.

In general, these data suggest that PCB sources to California water bodies have diminished considerably over the past 25 years. Regions that were highly contaminated in the 1970s and early 1980s generally now have much lower concentrations. A prominent exception is San Francisco Bay, where concentrations remain elevated. Possible hypotheses for the unique behavior of San Francisco Bay include the erosional sediment regime in the Bay that is uncovering contaminated layers of buried sediment, the long residence time of sediment particles in the Bay, continuing inputs from local watersheds into the Bay, or perhaps a combination of two or more of these factors.

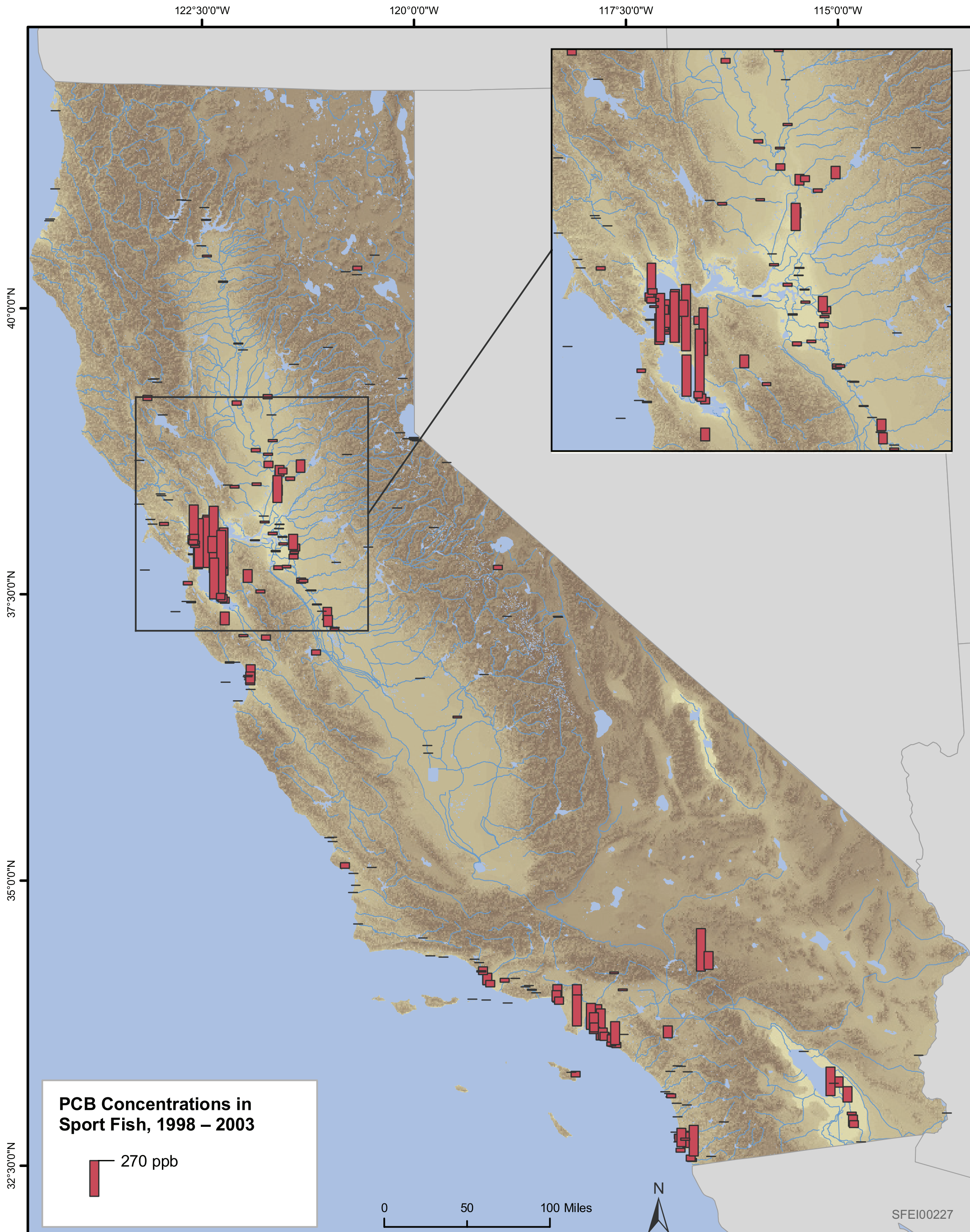

Figure 3.4.9. PCB concentrations (as sums of Aroclors or congeners, depending on the data source) in California sport fish, 1998 – 2003. Bars represent the highest median concentration (ppb wet wt) among species sampled at each location.

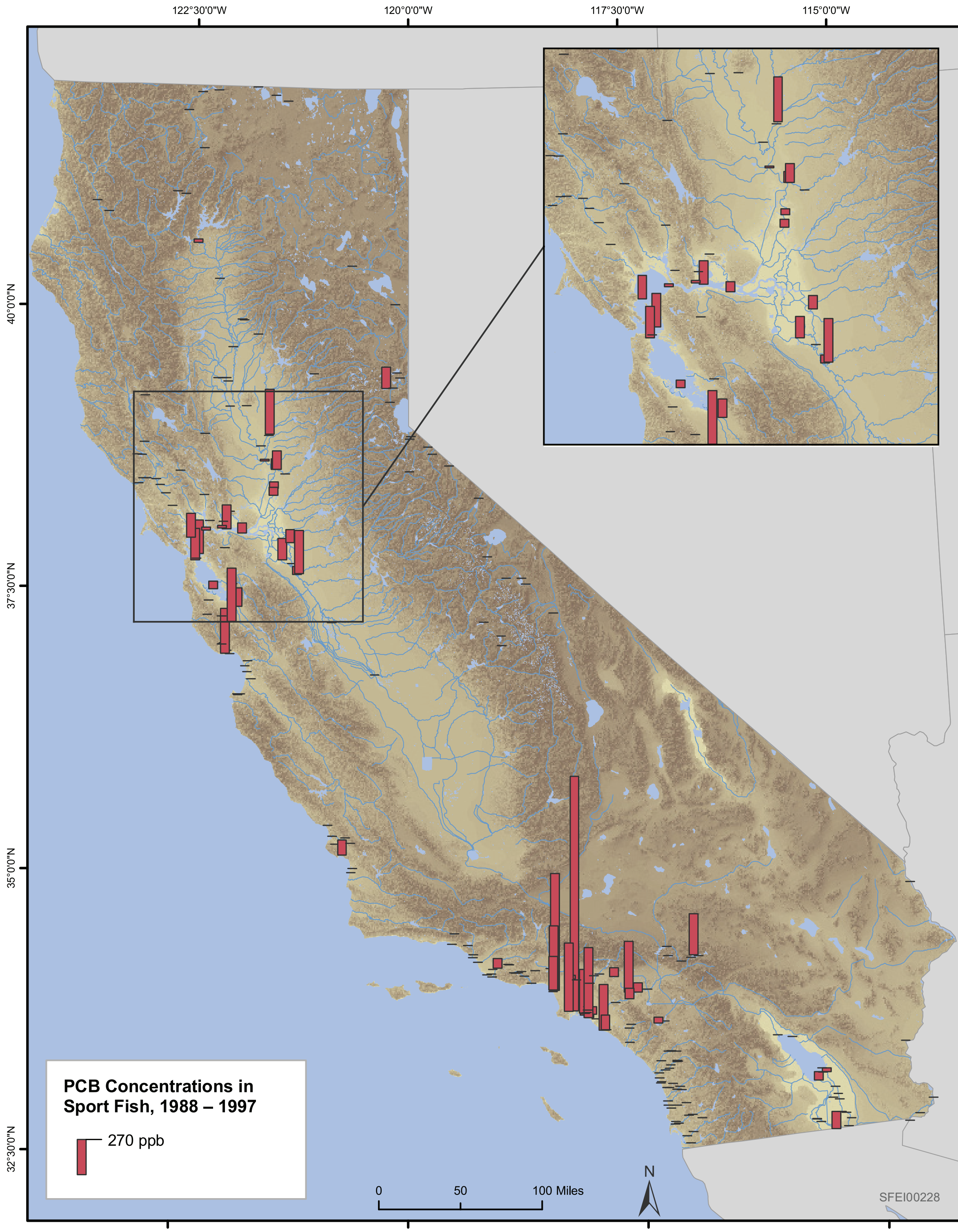

Figure 3.4.10. PCB concentrations (as sums of Aroclors or congeners, depending on the data source) in California sport fish, 1988 – 1997. Bars represent the highest median concentration (ppb wet wt) among species sampled at each location.

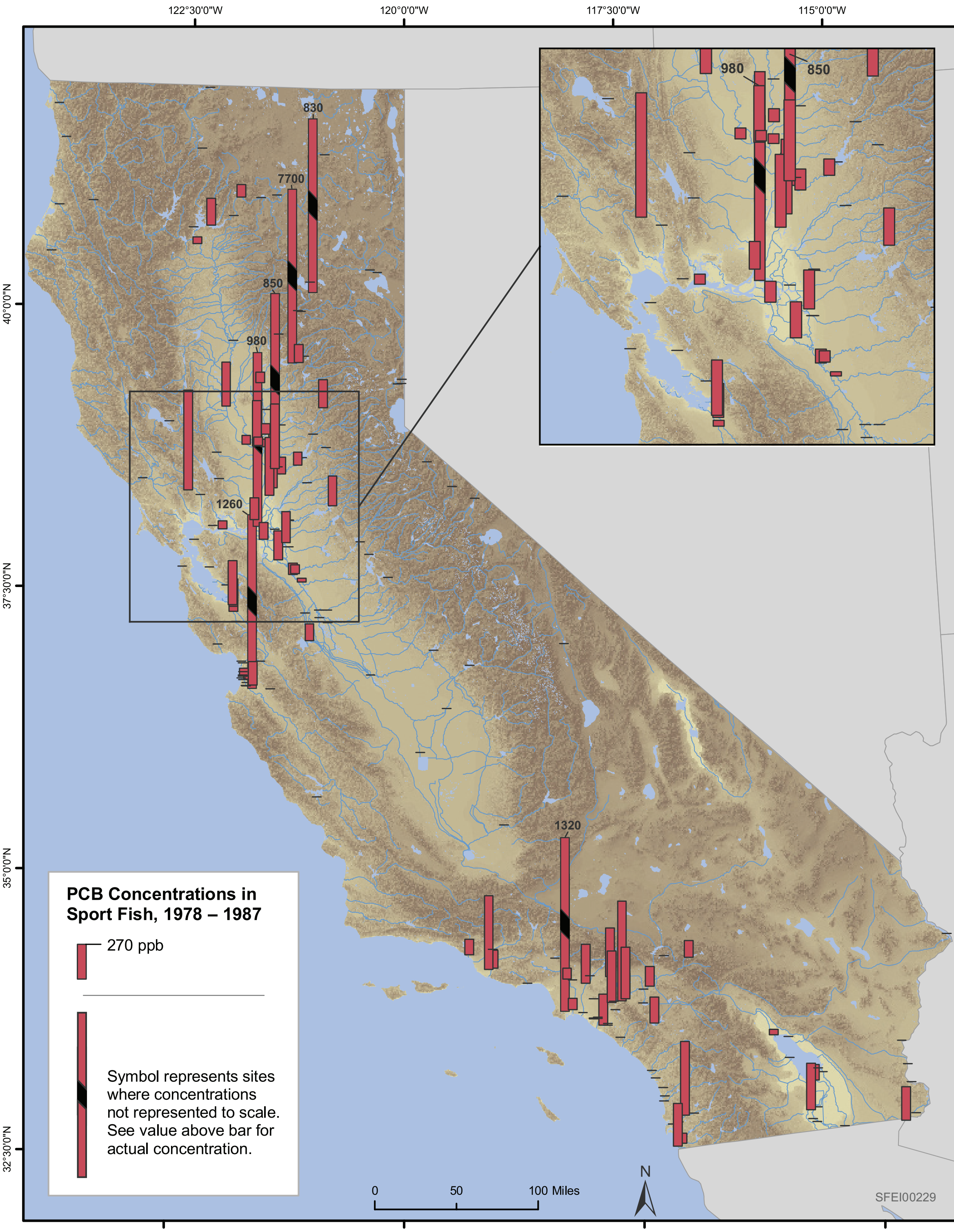

Figure 3.4.11. PCB concentrations (as sums of Aroclors or congeners, depending on the data source) in California sport fish, 1978 – 1987. Bars represent the highest median concentration (ppb wet wt) among species sampled at each location.

3.4.3. Impact of PCBs on Aquatic Life in California

The limited information available on the effects of PCB bioaccumulation on aquatic life in California water bodies suggests that present concentrations may approach thresholds for concern. Considered against the backdrop of steadily declining concentrations across the state, this suggests that impacts were likely in the past when PCB concentrations were substantially higher. Currently, San Francisco Bay appears to be the ecosystem in California with the most severe and persistent PCB contamination – a detailed review of evidence for impacts on aquatic life in the Bay is therefore presented below.

Statewide Assessment

The impacts of pollutant bioaccumulation on the aquatic life beneficial use are best evaluated using a different set of indicators than the sport fish that are used to assess impacts on the fishing beneficial use. The best bioaccumulation indicators for aquatic life assessment are linked as directly as possible to exposure and effects in sensitive species. Since exposure and the potential for effects are often greatest in predators at the top of the food web, indices of exposure of piscivorous wildlife are commonly employed. In piscivorous birds, pollutant concentrations in eggs and in prey fish (analyzed as whole fish) are often measured to assess risks. In piscivorous marine mammals, risks are often assessed through analysis of blubber, blood, and prey fish. Since sport fish are typically larger than the prey fish consumed by wildlife and since only sport fish muscle is analyzed, sport fish data are not very well suited to assessment of wildlife risks.

Unfortunately, no sufficiently systematic monitoring has been conducted to support a statewide analysis of the impact of PCBs on aquatic life in California. Although the sport fish data are not appropriate for a rigorous assessment of aquatic life impacts, they can be used to provide a gross evaluation of potential risks. Birds are the most common fish predators in water bodies across the state, and therefore are the focus of the following discussion of risks to predators.

Studies of PCB movement through food chains have shown that eggs of piscivorous birds generally have total PCB concentrations that are 10 to 30 times higher than their prey. This ratio of concentration in predator and prey is known as a biomagnification factor (BMF). Glaser and Connolly (2002) compiled egg:prey ratios for several piscivorous species that ranged from 10 to 20, with variation among species and among different populations of the same species. For herring gulls in Lake Ontario, data from Braune and Norstrom (1989) indicated a ratio of 32 between eggs and prey (alewife). In order to use sport fish concentration data to evaluate risks to piscivorous birds, BMFs comparing sport fish to bird eggs are needed. These BMFs are not commonly reported in the literature. Data from San Pablo Bay (a sub-embayment of San Francisco Bay) indicate BMFs between cormorant eggs and sport fish ranging from 19 to 44 for seven sport fish species (Davis et al. 1999, 2004). Considering all of this information, a BMF of 30 seems appropriate as a protective ratio to use for converting sport fish concentrations to bird egg concentrations as part of a preliminary screening of potential risks to birds.

Ten locations in the recent sampling period (1998 – 2003) were found to have sport fish with concentrations above 270 ppb (or 0.27 ppm). Seven of these locations were within San Francisco Bay, where evaluations of bird eggs have concluded that PCB concentrations are near thresholds for effects (Davis et al. 2007). The remaining three locations were in Lake Chabot (Bay Area), Machado Lake (Los Angeles area), and Big Bear Lake (San Bernardino County). Using a BMF of 30, eggs of birds from these water bodies might be expected to have concentrations of 8 ppm or higher. A review by Hoffman et al. (1986) concluded that concentrations in the range of 8 to 25 ppm in eggs can lead to decreased hatching success for cormorants, terns, doves, and eagles. A study of cormorants (Yamashita et al. 1993) found an increased incidence of deformities beginning at 3.6 ppm. Water bodies assigned to the "very high" category for sport fish contamination therefore might also be expected to be at or slightly above the threshold for effects on piscivorous birds. Another 11 water bodies were assigned to the "high" category for sport fish (with PCB concentrations between 140 and 270 ppb) and would be predicted to have concentrations of approximately 4 to 8 ppm in bird eggs, which is still in a range where concerns exist for avian reproduction. Most (66%) of the locations sampled fell into the "low" category for sport fish (less than 30 ppb), which would correspond to egg concentrations of less than 0.9 ppm and low concern for risks to birds.

San Francisco Bay

Davis et al. (2007) and Thompson et al. (2007) recently reviewed the evidence for effects of PCB bioaccumulation on wildlife in San Francisco Bay. Several sources of information indicate that PCB concentrations in the Bay may be high enough to adversely affect wildlife, including rare and endangered species. Fish-eating species at the top of the food web generally face the greatest risks. Populations residing in PCB hotspots also face relatively high risks.

Birds

Studies of PCBs in eggs of the endangered California clapper rail, the endangered California Least Tern, and Double-crested Cormorants have found concentrations that are near the threshold for embryo mortality.

One study in the 1980s suggested that PCBs were adversely affecting Bay birds. Hoffman et al. (1986) found a negative correlation between PCB concentrations in eggs and embryo weights in Black-crowned Night Herons collected from Bair Island in 1983. PCB concentrations in these eggs ranged from 0.75 to 52 ppm wet weight. In the South Bay in 1982, three species, Caspian Tern (Sterna caspia), Forster's Tern (Sterna fosteri), and Snowy Egret (Egretta thula), showed organic contaminant concentrations similar to those of the night herons (Ohlendorf et al. 1988).

Several more recent studies of PCBs in Bay birds have found concentrations that were at or near the threshold for embryo mortality. Davis (1997) and Davis et al. (2004) studied Double-crested Cormorants as an indicator of PCB accumulation and effects in the open waters of San Pablo Bay. In samples collected in 1995, PCB concentrations in embryo yolk sacs from this colony were correlated with reduced egg mass, reduced embryo spleen mass, and induced cytochrome P450 in embryo livers (Davis 1997). The degree of cytochrome P450 induction in these embryos appeared to be just above the threshold for causing embryo mortality (Davis et al. 1997). Davis et al. (2004) measured PCB concentrations in freshly laid eggs. Concentrations observed in this study overlapped the lower end of the effects range for this species, with a maximum of 3800 ppb fresh wet weight observed in a composite sample from 2001. These studies indicated that PCB concentrations in the 1990s were still high enough to elicit measurable effects, but probably not high enough to have a significant impact on the viability of the Bay cormorant population.

Recent work on Caspian Terns (Sterna caspia), Forster's Terns (Sterna forsteri), and the endangered California Least Tern (Sterna antillarum browni) have found concentrations that approach thresholds for effects in these species (Adelsbach et al. 2003). Average PCB concentrations in eggs collected in 2001 from colonies distributed throughout the Bay were 1.6 ppm fresh wet weight (fww) in Caspian Terns, 2.0 ppm fww in Forster's Terns, and 2.7 ppm fww in Least Terns. The Least Terns forage in an area near one of the Bay's PCB hotspots, and probably represent a worst case scenario (high concentrations in the local habitat, high trophic level, threatened population) for possible PCB impacts on an avian population in the Bay.

Schwarzbach et al. (2001) examined organochlorines and eggshell thickness in California Clapper Rail eggs collected from South Bay marshes in 1992. PCBs, while elevated in one egg, were generally below effects thresholds, but the mean concentration observed in 1992 (1.30 ppm fww) had not declined from the mean concentration observed in 1986 (0.82 ppm fww). The authors concluded that PCBs in 1992 may still have been high enough in some rail eggs to produce embryotoxic effects.

Seals

PCB concentrations in Bay harbor seals (Phoca vitulina) are elevated in comparison to other parts of the world and a cause for concern for seal health. Risebrough et al. (1980) were the first to investigate the potential impacts of contaminants on Bay seals. PCB concentrations in some of the seals they analyzed were considerably elevated (up to 500 ug/g lipid in blubber) and comparable to concentrations that were later observed to cause reproductive problems in controlled feeding studies (Reijnders 1986).

In response to the slow recovery of the Bay harbor seal population, Kopec and co-workers (Kopec and Harvey 1995, Young et al. 1998) reexamined the potential influence of pollutants on this species. PCB concentrations (sum of congeners) in whole blood of 14 seals sampled in South Bay in 1991 – 1992 (averaging 50.5 ppb wet wt) were higher than the concentrations observed in the feeding studies of Reijnders (1986) and high relative to concentrations observed in harbor seals in other locations around the world. Data from this research suggested the possibility of contaminant-induced anemia, leukocytosis, and disruption of vitamin A metabolism in the Bay seal population.

To further explore the possibility of contaminant-induced health alterations in this population, Neale and co-workers (Neale 2004, Neale et al. 2005) measured blood concentrations of PCBs and other pollutants in Bay seals, examined relationships between pollutant exposure and several key natural blood parameters, and compared PCB concentrations in 2001 – 2002 with concentrations determined in Bay seals in the early 1990s. PCBs in harbor seal blood (defined as the sum of six congeners measured in both studies) declined significantly between the early 1990s and 2001–2002 (from 27 ppb wet to 18 ppb wet), but remained high enough that reproductive and immunological effects were considered possible. PCB concentrations in the Bay were higher than concentrations in Alaska and Monterey Bay. A positive association was found between leukocyte counts and PBDEs, PCBs, and DDE. The authors concluded from these studies that individual seals with high contaminant burdens could experience increased rates of infection and anemia.

Another recent study examined PCB exposure and health risks in harbor seals through modeling PCB movement through the Bay food web (Gobas and Arnot 2005). The authors concluded that there is a substantial probability that risk thresholds for seals are currently exceeded in the Bay. Based on current PCB concentrations in the sediments of the Bay, the probability that PCB concentrations exceed the threshold effects concentration in harbor seals was estimated to be 70 to 73% for male harbor seals and 56% for female harbor seals.

Fish

The most intensive study of PCB effects in Bay fish to date was performed in the 1980s (Spies and Rice 1988), and showed a negative correlation between PCB concentrations and survival of starry flounder embryos based on specimens collected in 1983 – 1985. No additional significant work was conducted on the possible effects of PCBs on Bay fish until the late 1990s, when a study by Ostrach and co-workers (SFEI 2005a) found developmental abnormalities in striped bass larvae that appeared to be associated with elevated concentrations of PCBs and other pollutants in eggs.

Summary

PCB concentrations in some Bay wildlife species appear to be above or near thresholds for effects. Given the long-term general trend of slow decline in PCBs in the Bay, concentrations should gradually fall below these thresholds. However, a major uncertainty with regard to PCB effects on wildlife is the extent to which PCBs combine with other stressors, such as other contaminants, diseases, or food shortage, to impair sensitive life-history processes such as reproduction, development, sexual differentiation, and growth. It is possible that the effects of PCBs on wildlife, in combination with other stressors, may be significantly greater than currently realized.

Other Locations

Southern California Bight

An extensive study was conducted in 1998 to examine concentrations of PCBs and other pollutants in fish that are potential wildlife prey in the Southern California Bight (Allen et al. 2002). This study focused on potential impacts on wildlife, and conducted whole-body analysis of fish in the sanddab guild. A total of 225 locations on the southern California shelf were sampled (Figure 3.4.12). The study found that PCB concentrations exceeded published risk guidelines for mammals in 8% of the area sampled and for birds in 5% of the area. The study also provided valuable recent data on the spatial distribution of PCBs in the region. Relatively high concentrations were observed in ports (median of 156 ppb wet weight for three

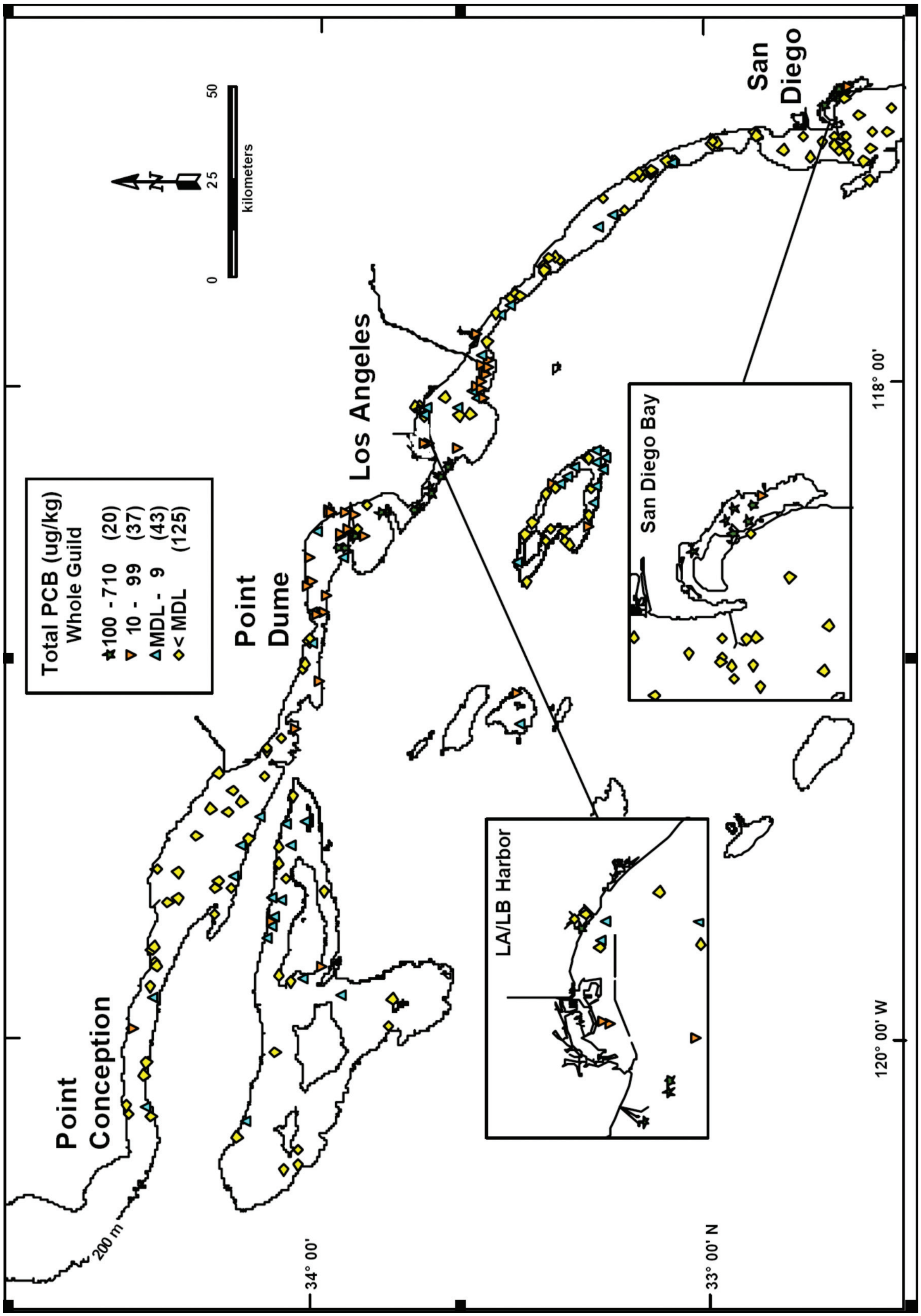

Figure 3.4.12. Distribution of total PCB concentrations in sanddab guild fishes on the southern California shelf at depths of 2-202 m, July-September 1998. From Allen et al. (2002).

samples), other parts of bays and harbors, and near outfalls of large POTWs on the continental shelf (median of 28 ppb for 32 samples). Similar to the studies in San Francisco Bay, this study indicated that PCB concentrations in the Bight in 1998 continued to pose some risk to wildlife predators.

Central Coast

Several studies of marine mammals along the Central Coast have found that PCBs are elevated in some individuals and may be high enough to have adverse impacts. Bacon et al. (1999) reported concentrations of PCBs in livers of stranded sea otters from the California coast from 1988 to 1991. Concentrations in these animals (n = 9) averaged 190 ppm PCBs on a wet weight basis and approximately 300 pg/g TEQ on a lipid weight basis. Concentrations in California were much higher than a location in southeast Alaska. Kannan et al. (2004) also measured PCBs in stranded sea otters collected from coastal locations between Half Moon Bay and Morro Bay from 1992 to 1996. PCB concentrations in the livers of some of these otters were higher than those observed by Bacon et al. (1999) and at or above a reported threshold for toxic effects in aquatic mammals (520 pg TEQ/g lipid). The average concentration for all of the otters analyzed was double the effects threshold. In related work, Nakata et al. (1998) provided additional data on PCBs in livers from stranded sea otters from the central California coast for 1992 to 1996. Though sample sizes were small, they found that Monterey Harbor had the highest concentrations, and that some of the otters they examined had concentrations above a threshold for effects in mink. Kajiwara et al. (2001) measured PCBs and other chemicals in California sea lions, elephant seals, and harbor seals stranded on the northern and central California coast from 1991 – 1997. Concentrations of PCBs in blubber or livers of some individuals of all three species were greater than estimated effects threshold concentrations (Kannan et al. 2000).

3.4.4. PCB Summary

The present impact of PCB bioaccumulation on fishing and aquatic life in California water bodies is moderately significant. In the most recent sport fish monitoring (from 1998 – 2003), 34% of the locations sampled had moderate, high, or very high PCB concentrations. The highest PCB concentrations are in a range where OEHHA discourages consumption for women of childbearing age and children 17 and younger (Klasing and Brodberg 2006). PCB concentrations in some areas also appear to be high enough to cause adverse impacts in wildlife. Concentrations are highest in water bodies near major urban centers, including the Bay Area, Sacramento, Los Angeles, and San Diego. PCB concentrations in San Francisco Bay are particularly high and appear to be unusually persistent. In general, PCB concentrations appear to be steadily declining across the state. The 1979 ban on PCB sale and production and other regulations relating to disposal of PCBs appear to have generally been effective at reducing the impact of PCBs in California water bodies. In some locations, however, particularly San Francisco Bay, recovery from PCB contamination appears likely to take many decades unless significant actions are taken to reduce continuing inputs. A PCB TMDL for San Francisco Bay is under development to identify appropriate management actions.

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