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Contaminant Concentrations in Sport Fish from San Francisco Bay: 2014

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Executive Summary

This summary report presents results from a 2014 survey of contaminants in San Francisco Bay sport fish, as well as an additional 2015 sampling of sport fish in Artesian Slough in Lower South Bay. This monitoring effort represents the seventh round of sport fish contaminant monitoring conducted by the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP). This technical report is intended for agency staff charged with managing water quality issues related to bioaccumulation of contaminants in San Francisco Bay.

The RMP began sport fish monitoring in 1997, following a pilot study conducted by the Bay Protection and Toxic Cleanup Program in 1994. Data collected through this monitoring program provides updates on the status and long-term trends of contaminants in Bay sport fish, and are used to update human health consumption advisories and evaluate the effectiveness of regulatory and management efforts to reduce the impacts of contaminants of concern in the Bay. Key analyses in this report include comparisons of concentrations to human health and regulatory thresholds, spatial trend evaluation, and temporal trend evaluation.

Mercury, polychlorinated biphenyls (PCBs), dioxins, selenium, polybrominated diphenyl ethers (PBDEs), and perfluoroalkylated substances (PFASs) were analyzed across sixteen fish species collected at eight locations in San Francisco Bay and Artesian Slough. Fish species were selected based on a number of criteria, including species that are popular for consumption, are sensitive indicators of problems (accumulating relatively high concentrations of contaminants), are widely distributed, represent different exposure pathways (benthic vs. pelagic), and have been monitored in the past. Concentrations were compared to numeric human health thresholds established by the California Office of Environmental Health Hazard Assessment (OEHHA) for mercury, PCBs, selenium, and PBDEs. Results were also compared to regulatory thresholds for mercury, PCBs, and selenium, as well as non-regulatory screening value for dioxins, which have been established in Total Maximum Daily Load (TMDL) regulations by the San Francisco Bay Regional Water Quality Control Board (Water Board).

The OEHHA fish consumption advisory is primarily driven by human exposure risks to mercury and PCBs. The 2014 data show that mercury and PCB concentrations remain high and widespread, indicating that these contaminants continue to pose the greatest human and wildlife health risks. Mercury concentrations exceeded OEHHA’s no consumption threshold for the sensitive population (women 18-45 and children 1-17) in several white sturgeon and striped bass samples, while PCB concentrations exceeded the no consumption threshold in Pacific sardine and white sturgeon samples. The spatial distribution of contamination has remained consistent over time, reflecting current knowledge of contaminated source areas targeted for management activities. Recent data showed no clear evidence of Bay-wide declines in either mercury or PCBs, although progressively lower PCB concentrations have been observed in recent years near Berkeley and in San Pablo Bay.

Selenium and PBDE concentrations remain well below OEHHA thresholds. However, exceedances of the North Bay TMDL selenium target were observed in the two sturgeon caught in Suisun Bay, suggesting a potential concern for selenium impacts to this species. Results from a special study comparing selenium measurements in white sturgeon muscle plugs and muscle

fillet show a strong correlation, supporting the use of muscle plugs as a proxy for muscle fillets in future non-lethal sturgeon monitoring efforts.

Recent data show that PBDE concentrations are continuing to decline in Bay sport fish, and are at levels falling further and further below thresholds for the protection of human health. Higher PBDE concentrations in fish collected from the Artesian Slough point to a wastewater source for these compounds, but concentrations measured in these wastewater effluent-influenced fish still remained well below the OEHHA threshold.

Human health and regulatory thresholds have not yet been established for dioxins and PFASs. However, dioxins concentrations remain well above the Water Board screening level presented in the PCBs TMDL and show no evidence of decline. The spatial distribution of dioxins concentrations is similar to that of PCBs, with particularly high concentrations observed in Oakland Harbor.

PFAS data in San Francisco Bay sport fish are limited, including only one previous round of monitoring in 2009. Analytical methods have improved since 2009, resulting in a higher frequency of detection of a larger number of PFAS congeners. No detectable levels of any PFASs were found in 24% of samples, including multiple species and locations sampled in Central and North Bay. The highest concentrations and numbers of compounds were detected in South Bay and Artesian Slough, suggesting a wastewater source for these compounds. Total PFAS concentrations have remained below a Minnesota PFAS guideline.

Overall, this round of sampling indicated that mercury and PCBs continue to be the contaminants of greatest bioaccumulation concern in fish, and show no clear evidence of declines. Dioxin concentrations also continue to exceed a screening value, and selenium concentrations in white sturgeon occasionally exceed the North Bay Selenium TMDL target. In contrast, PBDE concentrations have continued to decline, demonstrating the effectiveness of PBDE use restrictions. Continued monitoring of PFASs in sport fish is needed to determine whether or not concentrations of these compounds are increasing in the Bay.

Introduction

Fish from San Francisco Bay contain concentrations of mercury, PCBs, and other chemical contaminants that are above thresholds of concern for human health. This problem was first documented in 1994 when the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) performed a pilot study to measure contaminant concentrations in Bay sport fish (Fairey et al. 1997). As a result of this pilot study the California Office of Environmental Health Hazard Assessment (OEHHA) issued an interim health advisory for consumption of fish from San Francisco Bay (OEHHA 1994). In 2011, OEHHA published an updated health advisory, based in large part on RMP data collected over the previous decade (Gassel et al. 2011). The revised guidelines include additional species, provide more detailed guidelines for the recommended servings per week for different species, and takes into account the beneficial levels of omega-3 fatty acids in some species.

The updated advisory states that:

1. women beyond childbearing years and men should limit consumption of Bay fish and shellfish to, at most:
    a. seven servings a week of Chinook salmon, OR
    b. five servings a week of brown rockfish or red rock crab, OR
    c. two servings a week of jacksmelt, California halibut, or striped bass, OR
    d. one serving a week of sharks, white croaker, or white sturgeon, AND
    e. no consumption of shiner perch or other surfperch species
2. pregnant women or women that may become pregnant or are breast-feeding, and children (1-17 years) should limit consumption of Bay fish and shellfish to, at most:
    a. two servings a week of brown rockfish, Chinook salmon, jacksmelt, or red rock crab, OR
    b. one serving a week of California halibut or white croaker, AND
    c. no consumption of sharks, shiner surfperch or other surfperches, striped bass, or white sturgeon
3. only the skinless fillet portion of fish should be consumed, excluding all skin, visible fat, internal organs, and cooked juices
4. consumption advice should not be combined across serving categories. For example, only one fish from the “one serving a week” category should be consumed each week, or two servings of one or two species from the “two serving a week” category.
5. no one should consume fish caught in the Lauritzen Channel in Richmond Inner Harbor

This updated narrative consumption advisory is primarily driven by human exposure risks to methylmercury and polychlorinated biphenyls (PCBs). High concentrations of DDT and dieldrin have caused the no consumption advisory in the Lauritzen Channel.

This report compares new data on fish tissue concentrations to Advisory Tissue Levels, or numeric thresholds for concern for pollutants in sport fish that were developed by OEHHA (Klasing and Brodberg 2008; Klasing and Brodberg 2011). These thresholds are described further in the Data Analysis section of this report. The assessments presented in this report are not intended to represent consumption advice.

All segments of San Francisco Bay appear on the 303(d) List due to impairment of the beneficial use of the Bay for sport fishing. The Clean Water Act also requires that Total Maximum Daily Loads (TMDLs), or cleanup plans based on evaluation and reduction of contaminant loads, be developed in response to inclusion of a water body on the 303(d) List. TMDLs have been completed for mercury and PCBs in the Bay and selenium in North Bay, and amendments to the San Francisco Bay Basin Water Quality Control Plan (Basin Plan) have been adopted (SFBRWQCB 2006; SFBRWQCB 2008; SFBRWQCB 2015). The implementation of these TMDLs focuses on targets that are directly linked with impairment – particularly methylmercury, PCB and selenium concentrations in sport fish and wildlife prey. Concentrations of methylmercury, PCBs, selenium, and other contaminants in sport fish are, therefore, fundamentally important indices of Bay water quality.

Sport fish monitoring in the Bay was conducted on a three-year cycle between 1994 and 2009 (Fairey et al. 1997). This monitoring element was reduced to a five-year cycle after 2009, in response to the high cost of sport fish monitoring and relatively slow response of fish contaminant levels to changes in contaminant sources and pathways. The results from the prior six rounds of sampling are summarized in Davis et al. 1999, Davis et al. 2002, Greenfield et al. 2003, Greenfield et al. 2005, Davis et al. 2006, Hunt et al. 2008, and Davis et al. 2011.

This report presents findings from the seventh round of sport fish sampling conducted in 2014 and 2015 under the Regional Monitoring Program for Water Quality in the San Francisco Bay (RMP). Key analyses in this report include comparisons of concentrations to Advisory Tissue Level (ATL) thresholds, spatial trend evaluation, and temporal trend evaluation. The monitoring program targets species that are frequently caught and consumed by anglers at popular fishing areas in the Bay. This monitoring provides updates on the status of and long-term trends in contaminants of concern in Bay sport fish.

The objectives of the RMP fish contamination monitoring element are:

1. to produce the information needed for updating human health advisories and conducting human health risk assessments;
2. to measure contaminant levels in fish species over time to track temporal trends and to evaluate the effectiveness of management efforts;
3. to evaluate spatial patterns in contamination of sport fish and the Bay food web; and
4. to understand factors that influence contaminant accumulation in sport fish in order to better resolve signals of temporal and spatial trends.

Methods

<u>Sampling Design</u>

Fish were collected at eight sampling locations in San Francisco Bay between April and August 2014 and one additional location in 2015 (Figure 1). Sport fish have been monitored at five of the eight 2014 sampling locations since monitoring began in 1994, focused on popular fishing locations: the Berkeley Waterfront, San Francisco Waterfront, Oakland Inner Harbor, San Pablo Bay, and South Bay. Species that are found primarily in deeper waters are sampled closer to the middle of Central Bay, rather than near-shore locations near Berkeley, San Francisco, or Oakland. Drought conditions in the summer of 2014 leading to increased salinity in North Bay also allowed for sampling in Carquinez Strait and Suisun Bay. In particular, analyses of selenium in white sturgeon caught in Suisun Bay will support implementation of the North Bay Selenium TMDL.

Fish species were selected based on a number of criteria, including species that (1) are popular for consumption, (2) are sensitive indicators of problems (accumulating relatively high concentrations of contaminants), (3) are widely distributed, (4) represent different exposure pathways (benthic vs. pelagic), and (5) have been monitored in the past.

Core Status and Trends monitoring species that were collected, and have been consistently collected since RMP monitoring began, included shiner surfperch, striped bass, white croaker, and white sturgeon. Other Status and Trends species that have been previously collected included jacksmelt, California halibut, staghorn sculpin, and the wildlife indicator prey species, northern anchovy. Several non-target species were also collected, including pacific sardines and various surfperch species (white, pile, barred, black and walleye surfperches).

The contaminants that were measured in fish tissues were mercury, PCBs, dioxins, selenium, polybrominated diphenyl ethers (PBDEs), and perfluorinated alkyl substances (PFASs). The core monitoring species were analyzed for mercury, PCBs, and selenium, for which regulatory control plans are in place, as well as PFASs, which is a contaminant of relatively recent concern. Dioxins and PBDEs, for which additional regulatory control measures are not planned, were analyzed only in key indicator species – shiner surfperch and white croaker (dioxins only). Other species, including non-target species, were primarily analyzed for mercury and PCBs, the two contaminants driving current fish consumption guidelines.

In 2015, an additional study was conducted on several fish species collected in Artesian Slough, near the outfall of the San Jose-Santa Clara Regional Wastewater Facility. The purpose of this study was to assess the influence of wastewater effluent on contaminant bioaccumulation in fish. Striped bass, largemouth bass, and carp were collected from the Artesian Slough in June and July 2015 and subsequently analyzed for mercury, PCBs, PBDEs, and PFASs.

Fish were caught using gill nets, hook and line, and otter trawls in the open Bay, as well as seines and fyke nets in Artesian Slough. Additional sampling details, including station coordinates, sampling dates, field methods, and deviations from the original sampling design can be found in the 2013-2014 RMP Annual Monitoring Results report (SFEI 2015) and the 2014 Sport Fish Cruise Report (CCR 2014).

Laboratory Analysis

Sample Processing

Dissection and compositing of muscle tissue samples were performed following USEPA guidance (USEPA 2000). In general, fish were dissected skin-off, and only the fillet muscle tissue was used for analysis. Several species (shiner surfperch, jacksmelt, staghorn sculpin, northern anchovy, and Pacific sardines) that were too small to be filleted were processed whole but with head, tail, and viscera removed. White croaker samples were improperly processed as whole body composites, instead of skin-off fillets. As a result, measured concentrations could not be accurately compared to risk thresholds, which are intended for comparison to fillets. The results for PCBs and dioxins in whole-body white croaker samples are documented in Appendix B on a lipid weight basis, but wet-weight results for mercury, selenium, PCBs and dioxins were not included in analyses in the main body of this report. Additional white sturgeon muscle plug and ovary samples were analyzed for selenium to assist with the development and implementation of the North Bay Selenium TMDL.

Fish samples were analyzed as either individuals or composites. Composites were created by combining equally weighted aliquots from each fish, typically from the same sampling location and size class, and homogenizing these aliquots into a single composite, using methods established during previous RMP fish sampling events (SFEI 2015; Davis et al. 1999). Further details about the compositing methods, including the number of fish per composite and number of composites analyzed per species, are presented in Table 1.

Chemical Analyses

Analyses were conducted using USEPA methods in accordance with the 2014 RMP Quality Assurance Program Plan (QAPP) for the RMP (Yee et al. 2014), and as described in the 2013-2014 Annual Monitoring Results report (SFEI 2015). The comprehensive analyte list, analytical laboratories, method detection limits, and analyte detection and reporting statistics are shown in Table 2.

Quality Assurance / Quality Control

Samples were analyzed by multiple laboratories in multiple batches. Quality assurance analyses to access precision, accuracy, recovery, completeness, and sensitivity were performed for each batch as required by the 2014 RMP QAPP (Yee et al. 2014).

Data that met all measurement quality objectives (MQOs) as specified in the QAPP are classified as “compliant” and considered useable without further evaluation. Data that failed to meet one or more of the program MQOs specified in the QAPP were classified as “qualified”, but considered usable for the intended purpose. Results that were greater than two times the MQO requirements or outside MQO requirements due to blank contamination were classified as “rejected” and considered unusable. A single result from a PCB analysis of a certified reference material sample was considered “estimated” by the laboratory because the measured concentration exceeded the instrument calibration.

Overall, there were 10,855 sample results for individual constituents including tissue composites and laboratory QA/QC samples. Of these:

- 6,239 (57%) results were classified as “compliant”
- 4,427 (41%) results were classified as “qualified”
- 188 (0.02%) results were classified as “rejected”
- 1 (0%) result was classified as “estimated”

The large number of qualified results is largely because the laboratory did not provide a reporting limit, and in many cases a method detection limit, for dioxin measurements. Results qualified for this reason accounted for nearly a quarter of all results. Although these omissions trigger “qualified” classifications, the results are still considered useable.

Sums of organic contaminant classes were calculated by summing the concentrations of individual congeners within each contaminant class. The validity of these organics sums was assessed by comparing congener percent contributions to the sum in the current sampling round to those calculated over the last three rounds of sampling (2003, 2006, and 2009). For any sum, if congeners that have historically (i.e. over the previous three rounds of sampling) contributed 30% or more of the sum were rejected (i.e. not reported), that sum was classified as “no reportable sum,” and was not used for analysis. Sums for which congeners that add up to 30% or more of the historical sums were either rejected or not detected were qualified. Additional details about the data management process are documented in Appendix A.

Data that were considered useable and reportable (i.e. classified as “compliant,” “qualified,” or “estimated”) are available at cd3.sfei.org and are labeled by the project name “2014 RMP FISH”. Detailed quality assurance/quality control summaries for each analysis can be found in the 2014 RMP Sport Fish Samples Quality Assurance Report (Appendix C).

Data Analysis

Assessment Thresholds

This report compares new data on fish tissue concentrations to numeric thresholds for human health concern for pollutants in sport fish that were developed by OEHHA (Klasing and Brodberg 2008; Smith et al. 2016) – Advisory Tissue Levels (ATLs) – as well as regulatory thresholds established by the SFBRWQCB (Table 3). Klasing and Brodberg described ATLs in their 2008 report, “Development of Fish Contaminant Goals and Advisory Tissue Levels for Common Contaminants in California Sport Fish”:

> Advisory Tissue Levels (ATLs), while still conferring no significant health risk to individuals consuming sport fish in the quantities shown over a lifetime, were developed with the recognition that there are unique health benefits associated with fish consumption and that the advisory process should be expanded beyond a simple risk paradigm in order to best promote the overall health of the fish consumer. ATLs provide numbers of recommended fish servings that correspond to the range of contaminant concentrations found in fish and are used to provide consumption advice to prevent consumers from being exposed to more than the average daily reference dose for non-carcinogens or to a risk level greater than $1x10^{-4}$ for

carcinogens (not more than one additional cancer case in a population of 10,000 people consuming fish at the given consumption rate over a lifetime).

ATLs are designed to encourage consumption of fish that can be eaten in quantities likely to provide significant health benefits, while discouraging consumption of fish that, because of contaminant concentrations, should not be eaten or cannot be eaten in amounts recommended for improving overall health (eight ounces total, prior to cooking, per week). ATLs are but one component of a complex process of data evaluation and interpretation used by OEHHA in the assessment and communication of fish consumption risks. The nature of the contaminant data or omega-3 fatty acid concentrations in a given species in a water body, as well as risk communication needs, may alter strict application of ATLs when developing site-specific advisories. For example, OEHHA may recommend that consumers eat fish containing low levels of omega-3 fatty acids less often than the ATL table would suggest based solely on contaminant concentrations. OEHHA uses ATLs as a framework, along with best professional judgment, to provide fish consumption guidance on an ad hoc basis that best combines the needs for health protection and ease of communication for each site.

Consistent with the description of ATLs above, the assessments presented in this report are not intended to represent consumption advice.

The results were also compared to thresholds developed for the Bay by the SFBRWQCB, including methylmercury, PCB, and selenium TMDL targets for fish tissue and a dioxin screening level. In this report, thresholds reported for methylmercury are specific to the sensitive population (i.e., women 18-45 years and children 1-17 years). The OEHHA thresholds shown in the figures indicate the lower end of the ATL range (Table 4).

Summary Statistics

All data are presented on a wet weight basis, unless otherwise noted, in order to compare values against fish consumption advisory levels and regulatory thresholds. Selenium results are presented on a dry weight basis, for comparison to the North Bay TMDL fish tissue numeric target on a dry weight basis. In other cases, data have also been presented on a lipid weight basis, to adjust the data for variability caused by fish lipid content. Lipid content in fish tissue is an important driver of variation in organic contaminant concentrations in space and time, and lipid weight adjustments can make any temporal and spatial trends clearer. Conversions between wet weight and lipid weight concentrations, and between wet weight and dry weight concentrations, are made using the percent lipid and percent moisture measured in each sample. Estimated conversion factors are not used.

This report uses the arithmetic mean (referred to in this report as the “average”) as a measure of central tendency, which incorporates samples with high contaminant concentrations, and is a more conservative measure for estimating contaminant exposure. OEHHA also uses arithmetic means in developing consumption guidelines (Gassel et al. 2011). Table 4 presents average concentrations for each species and analyte, calculated as arithmetic means.

Statistical Analyses

Except where otherwise noted, analyses were conducted on log-transformed data. Statistical analyses for PBDEs were conducted on untransformed data. Pairwise comparison tests used to analyze spatial distributions and some temporal trends were conducted using a one-way ANOVA followed by Tukey's Honestly Significant Difference post-hoc tests. Long-term trends for data sets in which fewer than six sampling rounds were available were evaluated using pairwise comparison tests between 2014 and previous sampling years; long-term datasets in which more than six sampling rounds were available were evaluated using simple linear regressions, including trends for mercury, PCBs, and selenium, as well as dioxins (reported as PCDD/PCDF toxic equivalents) in white croaker (Appendix B). Long-term trend analyses on Bay-wide data are conducted using all individual data points collected across all segments of the Bay, rather than the average values calculated within each embayment or sampling site. However, samples collected in 1994 at additional locations that were not subsequently monitored by the RMP in future years were excluded from the long-term analyses of PCBs and dioxins. Linear regressions were also used to establish mercury-length relationships in bass and to evaluate muscle fillet-muscle plug relationships in white sturgeon. For all statistical tests, an alpha value of 0.05 was used to determine statistical significance.

Mercury

Mercury exposure is one of the primary concerns driving the sport fish consumption advisory for the Bay. Mercury is a toxic heavy metal that, in the form of methylmercury, can biomagnify in the aquatic food web, leading to high concentrations in upper trophic level fish species that are commonly caught for human consumption. In 2008, USEPA approved the San Francisco Bay TMDL for mercury, which established a numerical target of 0.2 ppm in fish muscle tissue for protection of human health. This TMDL target was subsequently adopted as a water quality objective in the Basin Plan. OEHHA has also established advisory tissue levels that are lower than this water quality objective (one serving/week ATL of >0.15-0.44 and two servings/week ATL of >0.07-0.15 ppm for the sensitive population [women 18 to 45 years and children 1-17 years]). The TMDL also established a wildlife target of 0.03 ppm in small prey fish for the protection of piscivorous species, which has also been adopted as a water quality objective in the Basin Plan.

Mercury contamination of the Bay and its watershed primarily occurred as a result of mining activity during the 1800s, and mercury continues to wash into the Bay from many of these mining regions today. Other pathways of mercury input into the Bay include urban runoff, atmospheric deposition, and wastewater discharges. Recent studies also indicate that the large amount of historically-released mercury currently stored in the sediment of the Bay may be the dominant supply of methylmercury, the toxic form of mercury that bioaccumulates in the food web (Greenfield et al. 2013; Davis et al. 2014). As a result, current mercury load reductions are expected to be reflected gradually in the food web. Substantial efforts are underway to reduce ongoing sources of mercury inputs and methylmercury production in the Bay. Continuing to monitor mercury in sport fish will be crucial to assessing the effectiveness of the TMDL and identifying the additional mercury reductions required to meet the water quality objective.

In this report, total mercury measurements are used as proxies for methylmercury concentrations. Methylmercury is the more toxic form of mercury that is of greatest concern to human and wildlife health, and the majority of mercury accumulated in fish tissue is methylmercury (>95%) (Bloom 1992).

<u>Comparison to Thresholds and Variation Among Species</u>

Mercury concentrations continue to exceed thresholds of concern in Bay sport fish (Figure 2, Tables 4 and 5). The average mercury concentration in white sturgeon (0.52 ppm) and striped bass caught in Artesian Slough (0.56 ppm) exceeded the no consumption ATL (for the sensitive population) of >0.44 ppm, and several individual striped bass caught outside Artesian Slough and largemouth bass exceeded this threshold as well (ranges = 0.12-0.66 ppm and 0.05-0.56 ppm, respectively). Lower concentrations were measured in other popularly consumed sport fish species. California halibut had an average concentration that fell within the one serving/week ATL range for the sensitive population (0.26 ppm; threshold = >0.15-0.44 ppm), while jacksmelt had an average concentration within the four servings per week range for the sensitive population (0.05 ppm; four servings/week range = >0.044-0.055 ppm). Average concentrations in other species were below the no consumption ATL but above the two servings/week ATL range for the sensitive population.

The mercury water quality objective of 0.2 ppm in sport fish is assessed as a grand mean of the five most popular sport fish species consumed in the Bay – striped bass, California halibut, jacksmelt, white sturgeon, and white croaker, listed in order of catch frequency (SFBRWQCB 2006, CDHS & SFEI 2000). White croaker was not analyzed in 2014, preventing a strictly complete calculation of the grand mean for comparison against the objective. However, similar to previously observed mercury concentrations, average concentrations in the highest trophic level species – striped bass, white sturgeon, and California halibut (0.42, 0.52 and 0.26 ppm respectively) – exceeded the objective. The average concentration in jacksmelt (0.05 ppm), a mid-trophic level species, remained below this threshold. Northern anchovy, an important prey fish indicator species for the protection of piscivorous wildlife health, had an average concentration (0.07 ppm) above the objective for prey fish (0.03 ppm).

Mercury in Artesian Slough

In 2014, mercury was analyzed for the first time in two freshwater species collected in Artesian Slough – largemouth bass and common carp. Largemouth bass is a high trophic level species that is confined to the fresh water in Artesian Slough and upstream tributaries in the Coyote Creek watershed. Concentrations observed in largemouth bass (average = 0.23 ppm; range = 0.07-0.48 in 350 mm length-adjusted) were moderately high relative to other Bay species, but lower than the median observed in statewide sampling of this species in lakes in recent years (0.33 ppm, 350 mm length-adjusted; Davis et al. *in prep*.).

Mercury was also analyzed in striped bass caught in Artesian Slough, which will be discussed in the following sections.

Mercury in Striped Bass

Striped bass are perhaps the most important human health indicator of mercury contamination in the Bay-Delta as a result of their abundance, popularity among anglers, and life-history characteristics that cause them to accumulate relatively high mercury levels. Striped bass are high tropic-level predators and therefore highly susceptible to accumulating high concentrations of mercury in their tissues. In this round of sampling, striped bass had the second highest mercury concentrations measured in Bay sport fish, following white sturgeon. Striped bass are also good integrative indicators of mercury contamination in the Bay-Delta Estuary because of their use of the entire ecosystem, including both fresh and saline waters. However, although striped bass spend most of their lives in San Francisco Bay, they also move into freshwater and coastal ocean, and their use of these different habitats can be quite variable. While this extensive movement makes striped bass good integrative indicators of the estuarine ecosystem, it generally makes them poor indicators of small-scale spatial variation within the Bay-Delta and may confound attempts to discern long-term trends.

Length-adjusted mercury concentrations are used to compare striped bass mercury concentrations over time or across locations, in order to correct for variation in the size of fish collected each year (Greenfield et al. 2005). These data are presented as estimated concentrations of each individual striped bass at a length of 60 cm, based on a length-mercury regression calculated for each sampling round. Striped bass generally show a strong positive relationship with size, as observed in 2014 (Figure 3; linear regression: $p=2.0 \times 10^{-5}$, $R^2 = 0.84$). Striped bass caught in Central and San Pablo Bay were analyzed as composites in 2014; therefore, the data used for these locations in the regressions were the average length of the fish in each composite. Composites were created using fish within the same size range (Table 4). Mercury measured in fish caught in Suisun Bay and Artesian Slough was analyzed in individual fish.

Striped bass caught in Artesian Slough showed a distinctly different pattern of mercury accumulation (Figures 2, 4-5), with elevated concentrations relative to those observed in other parts of the Bay. Differences between the average mercury concentrations measured in the Artesian Slough and other regions of the Bay in 2014-2015 were not statistically significant due to the high variability in the Artesian Slough samples and the small number of samples collected in other regions of the Bay; however, these differences were significant when considering all historical data (Figure 6). Additionally, the average mercury concentration was well above the no consumption ATL for the sensitive population in Artesian Slough striped bass (average=0.73 ppm, 60 cm length-adjusted), and a greater proportion of striped bass caught in this region had mercury concentrations above the threshold compared to other regions of the Bay.

These data support the hypothesis that the striped bass caught in Artesian Slough are primarily resident in Lower South Bay, outside the Artesian Slough, and are accumulating their mercury from this region, which has the highest inputs of mercury in the Bay. The lower concentrations observed in largemouth bass in Artesian Slough suggest that the striped bass exposure may primarily occur in other parts of Lower South Bay, such as the area influenced more directly by the Guadalupe River and its legacy contamination. This area receives inputs from the most mercury-contaminated Bay watershed, including the historic New Almaden mercury mining district, which has been linked to some of the highest mercury concentrations measured in forage fish in the Bay (Greenfield et al. 2013).

Spatial Patterns

Shiner surfperch is a species with high site fidelity that can be used as a good indicator of spatial variability. Additionally, the large number of individuals in each composite sample (n=20) and replicates per location (n=3, except San Pablo Bay and Carquinez Strait) provides some statistical power to detect spatial patterns. Although mercury concentrations in this species were relatively low (average=0.08 ppm; all samples had concentrations that measured below the one serving/week ATL range of >0.15-0.44 ppm for the sensitive population), the distinct spatial distribution of mercury concentrations measured in this species provides some insight on areas of particular concern for mercury exposure (Figure 7).

The observed spatial pattern is consistent with observations from previous rounds of sampling. The highest mercury concentrations in shiner surfperch were observed in Oakland and South Bay (average in both locations=0.11 ppm), followed by Berkeley (average=0.09 ppm). Concentrations observed in these regions were significantly higher than concentrations measured in San Pablo Bay (average=0.05 ppm) and the San Francisco Waterfront (average=0.05 ppm) (alpha=0.05; Figure 7).

Similar spatial patterns were observed in white sturgeon and striped bass, the sport fish species with the highest mercury concentrations measured in the Bay. The two exceedances of the no consumption ATL for the sensitive population in white sturgeon occurred in fish collected in

South Bay; white sturgeon were not collected at Oakland and Berkeley. Similarly, a higher average mercury concentration was measured in striped bass caught in Artesian Slough compared to those measured in other regions of the Bay (see discussion in the previous section, "Mercury in Striped Bass").

Temporal Patterns

A relatively extensive historical dataset exists for striped bass in the Bay, allowing for the evaluation of trends over 44 years, between 1971-2014 (Figure 8). These data are presented as 60 cm length-adjusted concentrations. The data were obtained from California Department of Fish and Wildlife (CDFW) historical records (1971-1972), the Bay Protection and Toxic Cleanup Program (1994), a CalFed-funded collaborative study (1999-2000), and the Regional Monitoring Program (1997, 2000, 2003, 2006, 2009, and 2014). Figure 8 does not include fish collected from Artesian Slough, which were collected only in 2015 and reflect a different mercury exposure regime that was not included in the historic sampling.

The lower intra-annual variance observed in 2014 is likely at least partially a result of the inclusion of several composite rather than individual samples. In 2014, the average mercury concentration in length-adjusted bass was not significantly different from those measured in previous years. Overall, no temporal trend is evident in striped bass mercury concentrations (linear regression: $p=0.08$, $R^2=0.01$).

Management Implications and Priorities for Further Assessment

The 2014 data indicate that fish mercury concentrations in the Bay remain high and spatial patterns of contamination have remained similar over time. Spatial patterns are consistent with previous observations and current knowledge of mercury hotspots in upstream watersheds that are being targeted for management actions to reduce loads.

The average concentrations of three out of four sport fish species identified in the mercury TMDL exceeded the water quality objective, and the average concentration of northern anchovy exceeded the wildlife objective as well. The inclusion of all five sport fish species called for in the Basin Plan objective in the next round of RMP monitoring (2019) will allow for a more accurate assessment of current conditions relative to this threshold in the future.

PCBs

PCB exposure is another primary concern behind the sport fish consumption advisory for the Bay. The San Francisco Bay TMDL for PCBs, approved by USEPA in February 2010, established a fish tissue target of 10 ppb as a cleanup goal to protect human health (SFBRWQCB 2008). This concentration falls within the PCB ATL range for six servings per week established by OEHHA (>9-10 ppb ww).

PCBs are extremely persistent synthetic chemicals that were heavily used from the 1930s to the 1970s in electrical equipment and a wide variety of other applications. Awareness of their presence in the environment and their toxicity to humans and wildlife grew in the 1960s and

1970s, leading to a 1979 federal ban on their sale and production. However, some PCBs are currently still legally used in products produced prior to the ban. Since the ban, PCB concentrations in some Bay biota and sediment have gradually declined (Davis et al. 2014), but PCBs in some sport fish species are still more than ten times higher than the water quality objective. Due to their widespread use, PCB sources are diffuse, including both in-Bay sediments and watershed contamination on land, particularly in historically industrialized areas. Continuing to monitor PCBs in Bay sport fish will be crucial to assessing the effectiveness of the TMDL in reducing additional sources of external PCB inputs into the Bay food web. Attaining this target will require a substantial reduction in PCBs in the Bay food web that is anticipated to also result in protection of wildlife from risks due to PCB exposure.

PCBs and other synthetic organic pollutants accumulate in fatty tissue, and have been shown to accumulate in higher concentrations in species with high lipid content. White croaker and shiner surfperch are two key species with high lipid content that have the highest fish PCB concentrations in the Bay, and were identified as indicator species in the PCB TMDL (SFBRWQCB 2008). Previous RMP sampling in 2009 showed that PCB concentrations were significantly lower in white croaker when samples were processed as muscle fillets with the skin off rather than skin on, a preparation that reduces the lipid content of the samples (Klasing et al. 2009; Davis et al. 2011). In 2014, however, white croaker samples were mistakenly processed as whole fish instead of fillets. Because these samples have different lipid contents than either type of fillet, and do not reflect recommended culinary preparation, PCB concentrations in these samples should not be compared to recommended Water Board or OEHHA thresholds. These results are not presented in this section, although further discussion of the lipid-weighted white croaker results is presented in Appendix B.

Shiner surfperch, a smaller species, is typically prepared for consumption with its skin on, and continues to be processed by the RMP with the skin on (but with the head, viscera, and tail removed).

Comparisons to thresholds and analyses of spatial trends were conducted using a total sum of all PCB congeners measured, which included 54 congeners in 2014 (Table 2,4-5). Due to changes in analytical methods, different numbers of congeners are included in this sum of PCBs measured each year. To analyze temporal trends using comparable values, the RMP uses a sum of 40 PCBs (Davis et al. 2014), which in 2014 contributed about 93% of the sum of all PCBs in fish tissue. In 2014, only 38 of these 40 PCBs were analyzed in fish, but the missing congeners (PCB 132 and PCB 183) have historically been only minor contributors to the sum of 40 PCBs. The methods used to process and sum PCB congeners are more comprehensively described in Appendix A.

Comparison to Thresholds and Variation Among Species

PCB concentrations in Bay sport fish remain high and continue to exceed thresholds of concern, including both human consumption thresholds and water quality regulatory thresholds (Figure 9; Tables 4 and 5). The highest species average PCB concentration was based on a single composite sample (n=20) of Pacific sardines, a high-lipid prey species (247 ppb ww; average = 4.6% lipid). Shiner surfperch had the second highest average PCB concentration (95 ppb ww), which falls within the one serving/week ATL category (>42-120 ppb ww; average = 2.3% lipid). Several shiner surfperch composites had concentrations over the no consumption ATL (>120 ppb ww), including some concentrations (maximum concentration = 292 ppb ww) over two times greater than this threshold. Northern anchovy, an indicator species for wildlife exposure, are also a high-lipid species processed as whole body samples (average = 2.0% lipid) and had a relatively high average PCB concentration of 78 ppb ww.

More moderate concentrations were measured in other species, ranging from white sturgeon (average 41 ppb ww) to pile perch (4.6 ppb ww). Eight of the 13 species measured had average concentrations in exceedance of the water quality objective (10 ppb ww). The other five species were less commonly consumed surfperch (white, walleye, black, barred, and pile surfperch) for which only one or two composite samples were analyzed.

In contrast with mercury, relatively low average PCB concentrations were observed in the three species caught in Artesian Slough (largemouth bass, common carp, and striped bass), compared to concentrations measured in other species monitored in the Bay. PCB concentrations in the Artesian Slough species fell within the three servings/week ATL (>16-21 ppb ww) but above the water quality objective (10 ppb ww; mean concentrations: largemouth bass=19 ppb, common carp=19 ppb, striped bass from Artesian Slough=17 ppb; Figure 9, Table 4).

<u>Spatial Trends</u>

Shiner surfperch are excellent indicators of spatial variability in PCB concentrations.
The spatial distribution of PCB contamination observed in shiner surfperch (Figure 10) was consistent with previously observed patterns. PCB concentrations were significantly greater in Oakland Harbor compared to all other regions of the Bay, with an average concentration (231 ppb ww) over nine times the average concentration in the least contaminated region, Carquinez Strait (25 ppb ww). All shiner surfperch composites collected in Oakland had concentrations in exceedance of the no consumption ATL, with a maximum concentration measured 2.4 times higher than the threshold of >120 ppb ww. The only other exceedance of this threshold occurred at the San Francisco Waterfront (155 ppb ww; average= 94 ppb ww). However, variability in the concentrations measured in these highly contaminated regions was also high (coefficient of variation = 24% and 56% in Oakland and San Francisco Waterfront, respectively). As observed in the past, PCB concentrations declined with distance from the historically industrialized regions of Central Bay.

The average concentration of total PCBs measured in Artesian Slough striped bass (17 ppb ww) was not significantly higher than concentrations measured in striped bass collected elsewhere in the Bay (average=11 ppb ww; $p=0.2$, ANOVA by location), indicating that wastewater effluent is not a dominant source of PCBs.

<u>Temporal Trends</u>

Long-term trends in PCBs concentrations are analyzed on both a wet weight and lipid weight basis in order to address different objectives. Examining the time series of wet weight PCB concentrations provides information on trends in human exposure and progress toward achieving the 10 ppb TMDL target (Figures 11-12), while lipid weight concentrations provide a better index of trends in PCB exposure in the Bay food web by normalizing for variation in the lipid content in fish caught in different years (Figures 13-14).

In addition to samples collected by the RMP, shiner surfperch collected in 1994 as part of the Bay Protection Toxic Cleanup Program (BPTCP) study (Fairey et al. 1997) were included in the analysis of PCB trends. The BPTCP study employed a different sampling design than the RMP's subsequent efforts, including different sampling locations; only BPTCP samples collected from regions that were subsequently sampled by the RMP were included in this analysis.

During the past three rounds of sampling, the Bay-wide average wet weight PCB concentration in shiner surfperch has dropped below the no consumption ATL, while average concentrations were above this threshold between 1997 and 2003 (Figure 11). A statistically significant but weak declining trend was observed in PCB concentrations Bay-wide (linear regression: $p=6.0 \times 10^{-4}$, $R^2=0.1$) between 1994 and 2014. A similarly weak declining trend was observed when data from 1994 were excluded (linear regression: $p=2.0 \times 10^{-5}$, $R^2=0.17$).

At each location sampled in 1994 (Berkeley, Oakland, and South Bay), no statistically significant trend was observed between 1994 and 2014. However, statistically significant declines were observed in several regions when data from 1994 were excluded (alpha=0.05; R^2: Oakland = 0.32, Berkeley = 0.77, South Bay=0.57) (Figure 12). Statistically significant declines were also observed at the San Francisco Waterfront and San Pablo Bay locations, which were not sampled in 1994 (alpha=0.05; R^2: San Francisco Waterfront = 0.18, San Pablo Bay = 0.60). The relatively high R^2 values observed at Berkeley and San Pablo between 1997 and 2014 suggest real PCB declines at those locations during this time period.

A comparison of the wet weight and lipid-normalized PCB concentrations shows that variation in fish lipid content is a substantial driver of the interannual variability in PCB concentrations observed in the wet weight results (Figures 11-14). Low lipid content in fish caught in 1994 largely accounts for the discrepancy in the strength of trends observed when including or excluding the 1994 wet weight data, although the use of a different analytical laboratory in 1994 may also have contributed to the comparatively low values observed that year. Evaluating these trends on a lipid weight basis normalizes for this variation, and provides a clearer index of trends in ambient PCB levels.

A very weak but statistically significant declining trend was observed in lipid weight PCB concentrations Bay-wide between 1994 and 2014 (linear regression: $p = 5.5 \times 10^{-3}$, $R^2 = 0.067$), similar to the trends observed in the wet weight data. Within regions, the only statistically significant declining trend over this period was observed in Berkeley ($p=0.02$, adjusted $R^2=0.21$). Although the highest lipid-normalized PCB concentrations, like the wet weight concentrations, were found in Oakland Harbor, the highest concentrations were measured in 2006 rather than 1997. This pattern suggests that PCB concentrations in the food web of this region and in the Bay as a whole have not been progressively declining over the past 20 years. However, the lipid-normalized PCB concentrations suggest that there have been more recent progressive declines since 2003 or 2006 in several regions, including Berkeley, Oakland, and San Pablo Bay.

Together, the wet weight and lipid weight PCB data for shiner surfperch suggest that ambient PCB concentrations in the Bay have not declined substantially Bay-wide between 1994 and 2014, but may be beginning to show evidence of declines in certain regions. Progressively lower PCB concentrations have been observed in recent years in shiner surfperch in Berkeley and San

Pablo Bay. In addition, the Bay-wide average wet weight and lipid weight concentrations measured in 2014 were lower than any previously measured.

RMP assessment of long-term trends in PCBs has historically relied on both shiner surfperch and white croaker data. While shiner surfperch, due to their high site fidelity, represent exposure in specific locations in the Bay, white croaker range more widely and provide a more spatially integrated view of contaminant exposure in the Bay. The different tissue preparation method for white croaker in 2014 described previously prohibits a direct comparison of wet weight PCB concentrations over time. However, lipid-normalizing the PCB concentrations can in part account for differences across years due to different lipid contents. The lipid-normalized PCB data for white croaker do not suggest that PCBs concentrations have changed significantly in white croaker over time. Further discussion of the white croaker PCB results is included in Appendix B.

Management Implications and Priorities for Further Assessment

PCB concentrations remain high and show similar spatial patterns compared to those observed in the past, posing both human and wildlife health risks. Oakland Harbor remains the region of highest concern.

Small fish data collected by the RMP in 2007 and 2010 (Greenfield and Allen 2013) indicated that PCB concentrations are particularly high in prey fish collected in the Bay margins. Future sport fish monitoring efforts could include sampling shiner surfperch at additional Bay margins locations to better monitor impairment and recovery of these areas (Davis et al 2014). An intensive study of PCBs in San Leandro Bay that includes sampling of shiner surfperch is being conducted as part of the RMP's PCB Strategy, with results due in 2017.

Dioxins

Polychlorinated dibenzodioxins and dibenzofurans (in this report the term "dioxins" will be used to refer collectively to all dioxins and furans) are classes of contaminants that are ubiquitous in the environment and are classified as human carcinogens. As part of the PCB TMDL, the SFBRWQCB calculated a fish tissue screening level of 0.14 pptr (parts per trillion) for the assessment of risk to human health due to dioxins (SFBRWQCB 2008), but this has not been established as a regulatory target. OEHHA has not developed ATLs for dioxins.

Dioxin data are presented as toxic equivalents (TEQs). In calculating dioxin TEQs, the measured concentration of the chemical is multiplied by a toxic equivalency factor (TEF), or the relative toxicity of a dioxin-like compound compared to the most toxic dioxin compound, 2,3,7,8-tetrachlorodiobenzo-*p*-dioxin (2,3,7,8-TCDD). For example, 2,3,7,8-tetrachorodibenzofuran (2,3,7,8-TCDF) is one-tenth as potent as 2,3,7,8-TCDD and has a TEF of 0.1. If a sample contains 50 pptr of 2,3,7,8-TCDF, the dioxin TEQ attributable to 2,3,7,8-TCDF in that sample is 5 pptr. Dioxin TEQs for measured dioxin-like compounds with established TEFs can be added together to calculate the total dioxin TEQs in a sample. The TEFs used in this report were established by the World Health Organization in 2005 (WHO 2005; Appendix B, Table 1). The dioxin TEQ sums presented in this report are based on measurements of six dioxins and 10 dibenzofurans but do not include dioxin-like PCBs (Table 2); the notation $TEQ_{PCDD/PCDF}$ is used to clearly indicate this distinction.

It should be noted that many other contaminants also have dioxin-like potency, most prominently PCBs. Specifically, several coplanar PCBs (especially PCB 126) have significant dioxin-like potency that results in PCB TEQs that actually often exceed $TEQ_{PCDD/PCDF}$. The most potent coplanar PCBs are usually not quantified using analytical methods for PCBs (as was the case in this study) because they are present at concentrations that are much lower than the abundant congeners and require a more sensitive method. Past work that did measure the coplanar PCBs in Bay fish found that PCB TEQs were actually about five times greater than $TEQ_{PCDD/PCDF}$ (Davis et al. 1999). The San Francisco Bay Water Board has chosen to regulate PCBs in the Bay on the basis of the sum of PCBs, rather than on the basis of their dioxin-like potency. Achieving the 10 ppb target for sum of PCBs is anticipated to also reduce to dioxin-like PCBs to an acceptable level (SFBRWQCB 2008). It is important to recognize that, even though there are other significant sources of dioxin TEQs that contribute to the overall dioxin-like potency of residues in fish tissue, the TEQs attributable to dioxins and furans on their own exceed the existing threshold for concern by a considerable margin.

Comparison to Thresholds

Dioxin analyses are relatively expensive, and therefore dioxin monitoring was limited in 2014, as in previous monitoring, to the high lipid species that accumulate the greatest concentrations of organic contaminants: shiner surfperch and white croaker. $TEQ_{PCDD/PCDF}$ concentrations in shiner surfperch remained well above the Water Board target of 0.14 pptr (average = 0.78 pptr, range 0.22 - 2.1 pptr; Figure 15). In 2009, the RMP began processing white croaker as fillets without skin in order to provide data that are consistent with OEHHA consumption advice, consistent with data from other parts of the state, and less variable because skin is difficult to homogenize. However, in 2014 white croaker samples were mistakenly processed as whole body composites rather than muscle fillets without skin. This preparation does not reflect a likely culinary preparation of this species, and is inconsistent with samples prepared as muscle fillets, preventing a clear comparison of these results to past data and the Water Board screening level. These data are therefore not presented here. Further discussion of lipid-weighted white dioxins results is presented in Appendix B.

Spatial Trends

Despite an increase in the number of composite samples analyzed at each location compared to the previous round of sampling (n=3 at most locations versus n=2 in 2009), the detection of statistically significant differences between $TEQ_{PCDD/PCDF}$ in shiner surfperch was impeded by high coefficients of variation within each region (23-94%). However, the observed spatial variation resembles previously observed patterns, as well as the pattern observed for mercury and PCBs (Figure 15). The highest average $TEQ_{PCDD/PCDF}$ concentration was observed in Oakland (average = 1.59 pptr), while the lowest concentration was observed in San Pablo Bay (average = 0.37 pptr), a greater than four-fold difference. In contrast with the relatively high mercury and PCB concentrations observed in South Bay, however, the average $TEQ_{PCDD/PCDF}$ concentration measured in South Bay was the second lowest among the regions sampled (average = 0.46 pptr).

Intermediate concentrations were observed in other industrialized locations in Central Bay, including Berkeley (average = 0.82 pptr) and the San Francisco Waterfront (average = 0.65 pptr).

Temporal Trends

Long-term trends in $TEQ_{PCDD/PCDF}$ concentrations can be analyzed on both a wet weight and lipid weight basis. Examination of wet weight concentrations provides information on the temporal variation in human exposure and progress towards achieving the Water Board screening level (0.14 pptr), while lipid weight concentrations provide a better index of trends in ambient contamination by normalizing for variations in the lipid content in fish caught in different years. $TEQ_{PCDD/PCDF}$ concentrations have been measured in shiner surfperch only in 1994, 2000, 2009, and 2014. The wet weight $TEQ_{PCDD/PCDF}$ data indicate that concentrations have declined significantly since 2000, but not 1994 (Figure 16). It is relevant to note that only two composite samples analyzed in 1994 were used in this analysis, so these data may not be fully representative of Bay-wide concentrations at that time. Samples collected in 1994 at locations not subsequently sampled by the RMP were not included in this analysis. The low wet weight $TEQ_{PCDD/PCDF}$ concentrations observed in 1994 were driven in part by low lipid levels in shiner surfperch measured that year, as well as an unusually low concentration measured in a single composite caught in Oakland Harbor (Figure 17).

No statistically significant difference in lipid-normalized $TEQ_{PCDD/PCDF}$ has been observed over time, but a similar temporal pattern is observed, with the average concentrations steadily decreasing in each round of sampling since 2000 (Figures 18-19). Lipid-normalized $TEQ_{PCDD/PCDF}$ concentrations were more variable, driven in large part by particularly high $TEQ_{PCDD/PCDF}$ concentrations in fish caught in Oakland Harbor.

Both the wet weight and lipid-normalized results showed mixed temporal trends in $TEQ_{PCDD/PCDF}$ concentrations across locations (Figures 17 and 19). Oakland Harbor, where concentrations were the highest, had a higher average $TEQ_{PCDD/PCDF}$ concentration in 2014 than in 2009 on a wet weight basis, but not on a lipid weight basis, although these differences were not statistically significant. However, both the wet weight and lipid weight data suggest a decline in $TEQ_{PCDD/PCDF}$ concentrations since 2000 in South Bay, where the average concentration measured in 2014 was significantly lower than those measured in 2000 and 2009 (alpha=0.05). Overall, the wet weight and lipid weight shiner surfperch data suggest that $TEQ_{PCDD/PCDF}$ concentrations may have declined since 2000 in some regions of the Bay, particularly in South Bay.

RMP assessment of long-term trends in dioxins has historically focused on white croaker, for which the long-term time series is more robust, including data from two more rounds of sampling that occurred in 2003 and 2006. In recent years, different tissue preparation methods have prohibited a direct comparison of wet weight $TEQ_{PCDD/PCDF}$ concentrations over time. Prior to 2009, samples were processed as fillets with skin-on. In 2009, samples were analyzed as fillets without skin, an alternative preparation that significantly reduces the lipid content of the samples and the concentration of $TEQ_{PCDD/PCDF}$ present. In 2014, samples were improperly analyzed as whole body composites (with the head, viscera and tail removed), with intermediate lipid content levels. Although these results are not directly comparable across years, lipid-normalizing the $TEQ_{PCDD/PCDF}$ concentrations can in part account for differences across years due to different lipid contents. The long-term trends in lipid-weight $TEQ_{PCDD/PCDF}$ concentrations do not suggest that dioxin concentrations have changed significantly in white croaker over time. Further discussion of the white croaker dioxins results is included in Appendix B.

Management Implications and Priorities for Further Assessment

$TEQ_{PCDD/PCDF}$ concentrations remain well above the Water Board screening level, and remain particularly high in Oakland Harbor. Measurement of dioxins in white croaker muscle fillets will help to confirm the trends, or lack of trends, observed in the more limited shiner surfperch dioxin data set.

Further analysis of these data will be conducted in a comprehensive synthesis of all RMP dioxins data, including concentrations measured in fish, water, sediment, and other tissues. This Dioxin Synthesis report will be available in 2018.

Selenium

Selenium is a naturally occurring element that is an essential nutrient but can be toxic to humans and wildlife at higher concentrations. San Francisco Bay was placed on the 303(d) List in 1998 for selenium impairment as a result of an advisory for consumption of diving ducks. Selenium concentrations in several wildlife species, especially white sturgeon, appear to be high enough in some individuals to potentially cause reproductive toxicity.

Sources and pathways leading to possible impairment in the northern and southern segments of the Bay differ significantly, and therefore separate approaches are being followed to address this issue in each region. In 2016, the Water Board's North San Francisco Bay Selenium TMDL was approved by the USEPA. The TMDL established numerical fish tissue targets for muscle and whole body fish tissue (11.3 and 8.0 ppm dw, respectively), which were subsequently adopted as numeric targets for North Bay in the Basin Plan. The North Bay TMDL and the numeric targets established within it apply to the region extending from Suisun Bay to the Bay Bridge in Central Bay. North Bay receives nearly 90% of the freshwater and sediment inflows to the Bay, including selenium loads from Central Valley agricultural runoff that move through the Delta. Other pathways of selenium loading include oil refinery effluent, and to lesser degrees, wastewater effluent and other tributary inflows (SFBRWQCB 2015). Selenium sources in South Bay primarily include wastewater effluent and tributary inflows from non-agricultural watersheds. Development of a TMDL for South Bay is under consideration by the Water Board.

In June 2016, the USEPA also released draft revised Clean Water Act criteria for selenium in fish tissue in the entire San Francisco Bay-Delta. The criteria proposed for muscle and whole body fish tissue (11.3 and 8.5 ppm dw) for the protection of wildlife are similar to the targets in the North Bay TMDL. These criteria were proposed as instantaneous measurements not to be exceeded. To protect human health, OEHHA has also developed a series of selenium ATLs. For example, no more than two servings/week is recommended when selenium concentrations range from >2.5-4.9 ppm ww (equivalent to 11.4-22.3 ppm dw, assuming an average percent moisture of 78%).

White sturgeon was identified in the North Bay TMDL as the key indicator species to be monitored to measure attainment of the TMDL muscle tissue target. White sturgeon are particularly vulnerable to selenium exposure in the Bay because their diet consists primarily of the selenium-rich overbite clam (*Potamocorbula amurensis*) (Beckon and Maurer 2008; Stewart et al. 2004; Zeug et al. 2015). Although white sturgeon can be found from South San Francisco Bay to the upper reaches of the Sacramento and San Joaquin River systems, where they spawn, the San Francisco Bay white sturgeon population predominantly resides and feeds in North San Francisco Bay, which hosts a large population of overbite clam. White sturgeon have consistently had the highest selenium concentrations of all sport fish monitored by the RMP. Attainment of the TMDL target in white sturgeon is expected to be protective of other species in the Bay as well.

In 2009, the RMP began developing a non-lethal tissue monitoring method using muscle plugs to facilitate the collection of a large number of tissue samples in order to assess attainment of the regulatory thresholds while minimizing impacts to the white sturgeon population. Additional work was conducted during the 2014 Status and Trends monitoring effort to continue evaluating this non-lethal monitoring method. In this report, white sturgeon selenium results refer to concentrations in muscle fillets except when otherwise specified.

Two additional special studies have been conducted over two-year periods to (1) pilot this monitoring method on live white sturgeon in North Bay (2014 and 2015 Sturgeon Muscle Plug studies) and (2) better understand the relationship between selenium in non-lethally collected tissues (muscle plugs, fin rays) and other tissue samples of greater toxicological (ovaries or livers) or regulatory (muscle fillets) significance (2015 and 2016 Sturgeon Derby studies). Results from the first year of monitoring for both studies have been published (Sun et al. 2015; Sun et al. 2016), and results from the second year of monitoring will be available in 2017. Additional results from the 2014 Status and Trends monitoring event, including carbon, nitrogen and sulfur isotope measurements in white sturgeon muscle tissue and selenium concentrations in three white sturgeon ovaries, will be further discussed in the 2016 Sturgeon Derby report, which will be available in 2017.

<u>Comparison to Thresholds and Variations Among Species</u>

Selenium contamination in fish remains a low human health concern in the Bay. Average concentrations in all species were well below the OEHHA two servings/week ATL threshold of >2.5-4.9 ppm ww. Only two of the twelve individual white sturgeon monitored had selenium concentrations above 2.5 ppm ww, but these concentrations were below the one serving/week ATL threshold of >4.9-15 ppm ww (Figure 20).

Average concentrations in all species also remain below the North Bay TMDL target (Figure 21). However, two individual white sturgeon had selenium concentrations exceeding this threshold. High variability in the white sturgeon samples was observed, with a coefficient of variation of 77% in muscle fillets.

Spatial Trends

In spite of small sample sizes, selenium concentrations measured in Suisun Bay, Central Bay, and South Bay sturgeon (n=2, 3 and 6, respectively) were all significantly different from each other (Figure 23). The lowest concentrations were measured in Central Bay (average=2.1ppm dw), while the highest concentrations were measured in Suisun Bay (average=17.0 ppm dw; South Bay average=5.9 ppm dw). Both exceedances of the TMDL muscle tissue target in 2014 occurred in the two fish caught in Suisun Bay. Only one sample was collected in San Pablo Bay (8.3 ppm dw), preventing a statistical evaluation of concentrations in this region.

Historically, sturgeon collected in Suisun Bay and San Pablo Bay were recorded as having been caught at a single North Bay station called San Pablo Bay. Fish caught within these two embayments were not differentiated because selenium sources are similar and it was believed that sturgeon feeding in this region move widely throughout these two embayments. Future analyses will help to evaluate whether selenium concentrations might actually be different between fish that have most recently been feeding in either location, as was observed in a study conducted by Linares-Casenave et al. (2015). Concentrations measured in North Bay (i.e., San Pablo and Suisun Bays) in 2014 were significantly greater than the historical North Bay average concentrations (7.0 ppm dw; p=0.02).

Although not statistically significant, historically, the average selenium concentrations measured in North Bay have been higher than those measured in South Bay (average= 7.0 and 5.8 ppm dw, respectively, 1997-2014) (Figure 24). Fewer exceedances of the TMDL numeric target have been observed in South Bay, and these exceedances have been at lower concentrations than those measured in San Pablo Bay. The most recent exceedance of the draft criteria in South Bay occurred in 2003, while the most recent exceedance in North Bay was 2009.

Temporal Trends

White sturgeon selenium data have been collected across multiple studies since the Selenium Verification Study in 1987-1990 (SWRCB 1987; SWRCB 1988; SWRCB 1989; SWRCB 1991), contributing to a long-term data set that can be used to evaluate trends over 28 years (1987-2014) (Figure 25). These data include fish collected by the California Department of Fish and Wildlife (CDFW) and State Water Resources Control Board as part of the Selenium Verification Study (1987-1990); the United States Geological Survey during sturgeon derbies held in North Bay (1999-2001; Stewart et al. 2004); UC Davis, CDFW, and the Bureau of Reclamation (2002-2005; Linares-Casenave et al. 2015), and the RMP as part of Status and Trends monitoring (1997-2014). Intra-annual variability has been high (coefficients of variation by year ranging from 34 to 101%), reducing the power for detection of long-term trends. Recent concentrations have not been as high as those measured in the late 1980s, when concentrations were measured as high as 50 ug/g dw. Although a significant decline in white sturgeon selenium concentrations is observed between 1987 and 2014 (linear regression; 1987-2014: $p=2.4x10^{-4}$), this trend is weak ($R^2=0.08$). When excluding the anomalously high concentrations observed in 1989 and 1990, no distinct temporal trend remains evident (1987-2014, excluding 1989-1990: p=0.054, $R^2=0.02$). Similarly, no significant trend has been observed in white sturgeon caught in North Bay as part of RMP Status and Trends monitoring since 1997 (linear regression; North Bay: p=0.06, $R^2=0.09$; Figure 26).

Muscle Plug Evaluation

In 2009, twelve paired muscle fillets and muscle plugs were collected from individual white sturgeon and analyzed for selenium. This analysis was repeated in 2014 with another twelve paired samples. A significant relationship between muscle plug and fillet samples was observed in both the individual and combined data sets:

2009: Fillet = 0.83*Plugs + 0.22; $p=1.04 \times 10^{-5}$, $R^2=0.85$
2014: Fillet = 0.67*Plug + 1.36; $p=1.08 \times 10^{-6}$, $R^2=0.91$
2009 and 2014: Fillet = 0.73*Plug + 0.91; $p=1.1 \times 10^{-11}$, $R^2=0.88$

These regressions from data collected in 2009 and 2014 support the use of non-lethally sampled muscle plugs as a proxy for muscle fillets (Figure 22).

The regressions on the 2009, 2014, and combined data sets indicate that plug concentrations tend to be lower than fillets, suggesting either that selenium is not homogenously distributed in the sturgeon muscle tissue or that a bias was introduced during laboratory analysis resulting from the sample processing technique. During this study, tissue samples were collected from a section between the dorsal and caudal fins that was cut and prepared in the field. In the lab, the skin was removed from one half of the section, from which the muscle fillet was collected. The muscle plugs were then collected through the skin (i.e., mimicking sampling in the field) on the other side of the section, after which the skin was removed. As a result, the location on the fish from which the muscle plugs and muscle fillet subsamples were collected and the depth of these samples below the skin could not be assessed and may not have remained consistent between samples. Additionally, moisture could not be measured in the muscle plug samples and was estimated from the corresponding fillets collected from the same fish. This may have created additional variability in the wet weight, but not dry weight, measurements.

In contrast, muscle plugs collected from live white sturgeon are consistently sampled from the epaxial muscle (dorsal trunk muscle) through the skin, near or slightly in front of the dorsal fin. All muscle plug samples collected for the RMP special studies were sampled using this technique, including muscle plugs that were collected alongside muscle fillets in fish caught during the 2016 Sturgeon Derby study. Muscle plugs and fillets collected during the Sturgeon Derby were sampled immediately adjacent to each other, and both were sampled through the skin, which was subsequently removed. The muscle plugs collected during the RMP special studies were also smaller (5 mm diameter muscle plugs) than those collected during Status and Trends monitoring (8 mm diameter). These differences in the muscle tissue sampling methods may have contributed to the variability in the muscle plug-muscle fillet regression observed between these studies: in the 2016 Sturgeon Derby study regression, selenium concentrations in plugs did not under-predict concentrations in fillets (unpublished data). Additional discussion of these special studies data will be published in 2018.

Management Implications and Priorities for Further Assessment

The recent Status and Trends data indicate that fish selenium concentrations remain below levels of human health concern. However, exceedances of the North Bay TMDL numeric target and draft USEPA selenium criteria were observed in the two individual white sturgeon caught in Suisun Bay, suggesting a potential concern for impacts to this wildlife species.

The paired white sturgeon muscle plug and muscle fillet analyses show a strong correlation, supporting the use of muscle plugs as a proxy for muscle fillets in future sturgeon monitoring efforts. However, additional analysis of this relationship is needed to determine how muscle plug results should be translated into traditional muscle fillet concentrations for comparison to muscle tissue regulatory thresholds. To clarify this relationship, samples in future Status and Trends monitoring events should be collected to compare between muscle fillets sampled using methods established for the Status and Trends monitoring effort (i.e., representative of all historically-collected RMP data) and muscle plugs sampled from the live sturgeon in the field using methods established for the RMP Special Studies (i.e., representative of future monitoring data collected with this proposed method and data already collected for the Special Studies). A second year of paired muscle plug and fillet sample collection during the 2017 Derby using the modified muscle fillet collection method employed during the 2016 Derby Study (an approximately 5 x 3 x 2 cm fillet collected immediately below the skin surface in the epaxial muscle directly posterior to the location of muscle plug collection) may also help to explain differences observed in the plug-fillet relationship established with Status and Trends samples and 2016 Sturgeon Derby samples (unpublished data).

PBDEs

Polybrominated diphenyl ethers (PBDEs) are a class of bromine-containing flame retardants that has been linked to developmental neurotoxicity, endocrine disruption, liver and thyroid toxicity, and possible carcinogenicity in wildlife (Sutton et al. 2014). In part due to California's strict flammability standards, PBDE concentrations in the Bay food web increased rapidly through the 1990s. However, concerns about its toxicity led to voluntary nation-wide phase-outs of commercial PBDE mixtures, as well as California state bans on certain mixtures. In 2004, a major manufacturer ceased production of two of the three commercial PBDE mixtures, "PentaBDE" and "OctaBDE"; this voluntary phase-out was followed in 2006 by both a California state ban and a USEPA Significant New Use Rule on these mixtures. In 2013, American chemical manufacturers began phasing out the last PBDE mixture, "DecaBDE". Also in 2013, the State of California Department of Consumer Affairs (Bureau of Electronic and Appliance Repair, Home Furnishings and Thermal Insulation) revised the state flammability standard to eliminate the need to incorporate these substances into upholstered furniture and items for infants and young children.

Sutton et al. (2015) documented declines in PBDEs in cormorant eggs, bivalves, and fish as a result of the initial phase-outs. Although declines in DecaBDE congeners were not yet apparent in sediment at that time, the dominant congener, PBDE-209, has a relatively short half-life in tissues and does not accumulate in fish.

In 2011, OEHHA published ATLs for PBDEs (Klasing and Brodberg 2011), but PBDES have not been placed on the 303(d) List. Continued monitoring of these chemicals will help to measure the response of the Bay to the PBDE phase-outs and identify whether further management actions are necessary.

Comparison to Thresholds and Variation Among Species

Previous RMP monitoring showed that PBDE concentrations in San Francisco Bay fish were well below the lowest human health threshold – the OEHHA threshold for seven servings/week (≤45 ppb). As a result, monitoring in 2014 focused primarily on detecting spatial and temporal trends in the key indicator species for PBDEs, shiner surfperch, which had the highest average concentration (8.3 ppm) among all species monitored in 2009 (Davis et al. 2011). The average concentration in shiner surfperch in 2014 was 4.7 ppm. PBDE 47, a major component of the PentaBDE mixture, was detected in 100% of samples and made up about 70% of the total PBDE sums (calculated using the median concentration across samples). The dominant congeners found in the OctaBDE (PBDE 183, 197 and 203) and DecaBDE (PBDE 209) mixtures were either not monitored (PBDE 197, 203) or not detected in any samples (PBDE 183, 209).

PBDEs were also analyzed in the three species of fish caught in Artesian Slough – striped bass, largemouth bass, and common carp. The average concentrations measured in these species were higher than in the other Bay locations (11, 48, and 54 ppb), although sample sizes were small (n=3, 1, and 1, respectively; individual fish samples). Still, all concentrations fell within or below OEHHA's five servings/week ATL (>52-63 ppb)

Spatial Trends

The spatial pattern of PBDE contamination in fish in 2014 was consistent with previous observations in shiner surfperch. As with other contaminants, Oakland had the highest average concentration (7.7 ppb), which was significantly greater than Berkeley (average=3.7 ppb), San Francisco (average=3.4 ppb), and San Pablo Bay (average=2.8 ppb). Concentrations were comparatively high in South Bay (average=5.3 ppb) and Carquinez Strait (7.2 ppb), but not statistically greater than other regions except San Pablo Bay (Figure 28).

Relatively high PBDE concentrations were observed in the three species monitored in Artesian Slough – common carp, largemouth bass, and striped bass. Although these species were not sampled at other locations, the high concentrations observed suggest that wastewater effluent is a pathway for PBDE input to the Bay. The concentrations measured in the individual carp and largemouth bass (48 and 54 ppb ww) were 10.2 and 11.3 times higher than the average concentration measured in shiner surfperch (Figure 27).

Temporal Trends

The most recent RMP data provide further evidence that PBDEs in shiner surfperch declined following the PBDE bans and phase-outs. In 2009, the RMP began using a new PBDE analysis method, switching from an electron capture detection method with external standard calibration and p,p-DDD as a surrogate recovery standard, to a more reliable GC-MS method using isotopically labeled PBDEs as internal standards. PBDE concentrations measured in 2009 were first shown to be significantly lower than those measured in 2003 and 2006, but the impact of the new analytical method was not yet clear. The low concentrations measured in 2014 support the conclusion that PBDE concentrations have been declining following the phase-outs of commercial flame-retardant mixtures in the mid-2000s (68% reduction in PBDEs between 2003 and 2014) (Figure 29).

<u>Management Implications and Priorities for Further Assessment</u>

The 2014 PBDE data indicate that PBDE concentrations are declining in Bay sport fish, and are at levels falling further and further below guidelines for the protection of human health. Ongoing monitoring of these chemicals will continue to measure the impact of the PBDE phase-outs and determine whether further management actions are necessary.

PFAS

Per- and polyfluoroalkyl substances (PFAS; formerly referred to as PFCs or perfluorinated compounds, which make up a subset of PFASs) are class of synthetic chemicals used to resist heat, oil, stains, grease, and water in a wide range of consumer products**,** including surfactants, coatings for food packaging, stain repellants for textiles and furniture, insecticides, refrigerants, and fire-fighting foams. As a result of their chemical stability and widespread use, PFASs such as perfluorooctane sulfonate (PFOS) have been detected in the environment, including in fish, bird eggs, and seals monitored over the past 10 years in San Francisco Bay (Sutton et al. 2015).

<u>Comparison to Thresholds and Variation Among Species</u>

The RMP began monitoring PFASs in sport fish in 2009. The RMP measures 13 perfluorinated compounds, focused on range of short- and long-chained perfluorocarboxylates and perfluorosulfonates, including the commonly detected perfluorooctanesulfonate (PFOS) and its degradate, perfluorooctanesulfonamide (PFOSA). The majority of results measured in 2009 were below detection limits: the only PFAS detected was PFOS, and only four out of 21 samples had detectable PFOS concentrations. For the 2014 sampling, analytical methods improved substantially, lowering detection limits from 2.5 – 5 ppb to 0.5 – 1 ppb across different PFAS congeners. As a result, a greater number of detections across a greater number of congeners were obtained.

PFOS was the dominant congener detected (77% of the total PFAS concentration), followed by PFOSA (12% of the total PFAS concentration). PFOS was also the most commonly detected congener (detected in 76% of samples and in all species monitored), followed by PFOSA (41% of samples and only detected in striped bass and white croaker) (Figures 30-32, Table 6). Several longer chained PFASs were detected for the first time, including PFDA, PFUnA, and PFDoA (perfluorodecanoate, -undecanoate, and -dodecanoate), which are the most commonly detected PFASs following PFOS and PFOSA, according to fish surveys of the nearshore regions of the Great Lakes and urban rivers in the United States (Stahl et al. 2014). One additional congener, perfluoropentanoate (PFPA), was detected in a single composite of white croaker collected near Oakland Harbor. No detectable levels of any PFASs were found in 24% of samples, including multiple species and locations sampled in Central and North Bay (Table 6).

PFOS and other PFASs have been associated with a variety of toxic effects, including carcinogenicity and abnormal development. No human health or regulatory thresholds have yet been established for PFASs in San Francisco Bay fish. However, sampling for PFASs in fish has been more extensive in Minnesota and Michigan, where concentrations have been high enough that the states have established thresholds for issuing consumption guidelines for PFOS, the most commonly detected PFAS (MDH 2008; Delinsky et al. 2010; MDCH & State of Michigan 2014; State of Michigan 2016). All PFOS concentrations measured in the Bay in 2014 were well below the Minnesota one serving/week consumption threshold of 40 ppb ww and the Michigan four meals/month consumption range of >19-38 ppb ww (Figure 31). Concentrations measured in the single largemouth bass sample and several individual striped bass caught in or near the Artesian Slough fell within the Michigan 8 meals/month consumption range (>13-19 ppb). Average concentrations of carp and striped bass fell within the 12 meals/month consumption range (>9-13 ppb ww), while the average concentrations of other species (shiner surfperch and white sturgeon) fell below the lowest Michigan threshold for 16 meals per month (≤ 9 ppb ww).

No consumption guidelines are available for other PFAS congeners.

Spatial Trends

Not enough data are available to provide a statistical analysis of spatial trends. However, both higher concentrations and a greater number of detected congeners were found in fish collected from Artesian Slough and South Bay. Within species, the highest concentrations of total PFASs or any individual congener was almost always highest in fish collected either near the Artesian Slough or in South Bay (with the exception of white croaker, in which PFPA and PFDoA were detected in Oakland Harbor but not South Bay) (Table 6). These fish had higher concentrations of commonly detected congeners (PFOS and PFOSA) and more frequent detections of compounds that were rarely detected at other locations in the Bay, if at all.

Although only five out of 17 samples analyzed were from fish collected in Artesian Slough, four of five detections of PFDA and PFDoA and all three detections of PFUnA were detected in this region. The highest concentrations of these long-chained perfluorocarboxylates were detected in carp and largemouth bass, which are largely confined to the area near the wastewater outfall, pointing to a wastewater source for these compounds.

Temporal Trends

Data on PFAS in sport fish is available for only two sampling events, conducted in 2009 and 2014. Not enough data are available for an analysis of temporal trends.

Management Implications and Priorities for Further Assessment

The limited scope of PFAS sampling in 2009 and 2014 and changes in analytical methods prevents a rigorous analysis of spatial and temporal trends. A more comprehensive synthesis of existing data, remaining data gaps, and future monitoring recommendations is being prepared as part of the synthesis and strategy for perfluorinated and polyfluorinated compounds in San Francisco Bay that will be available in 2018.

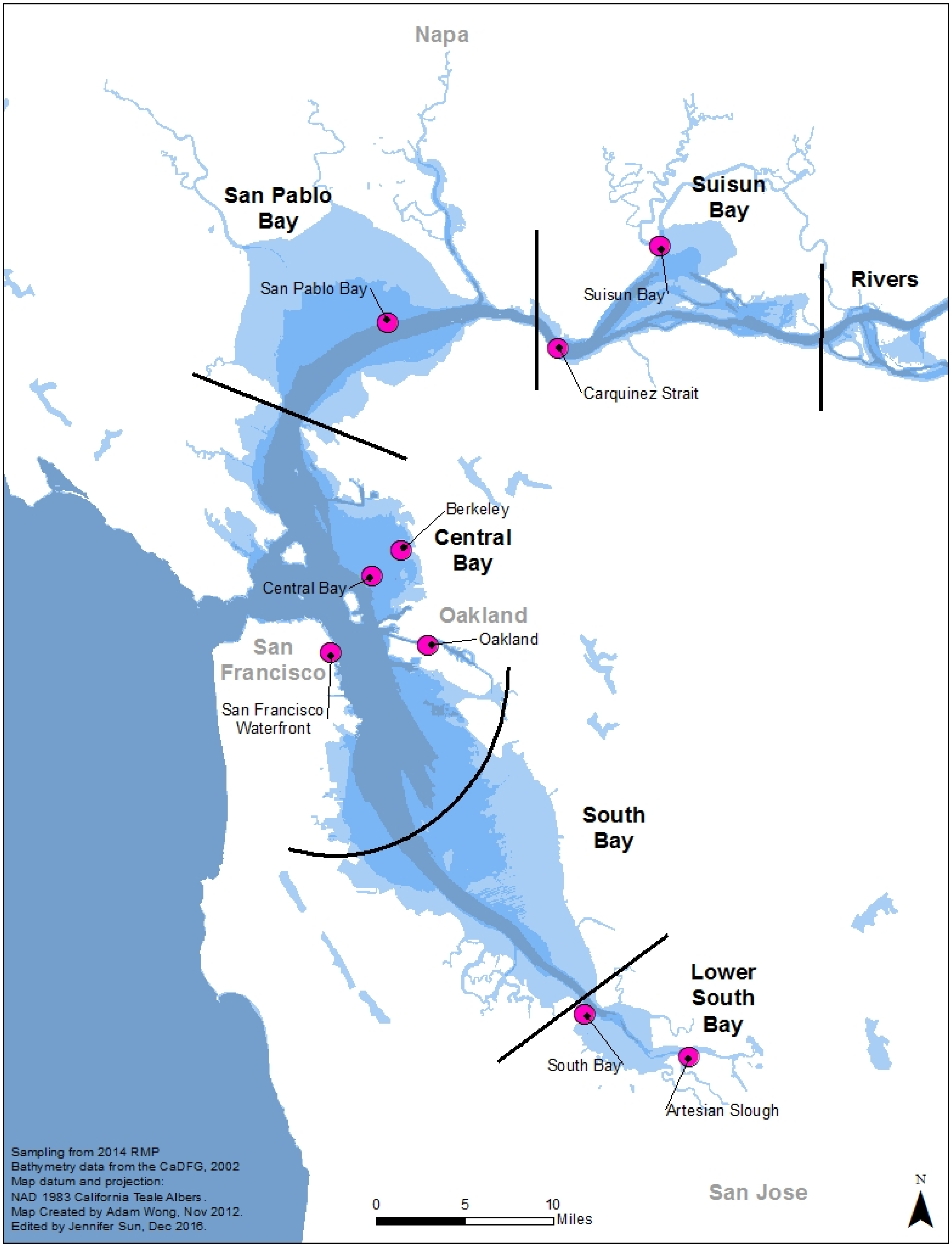

Figure 1. Locations sampled for San Francisco Bay fish, 2014-2015. Artesian Slough fish were caught in 2015; all other locations were sampled in 2014. Exact coordinates of sampling locations vary.

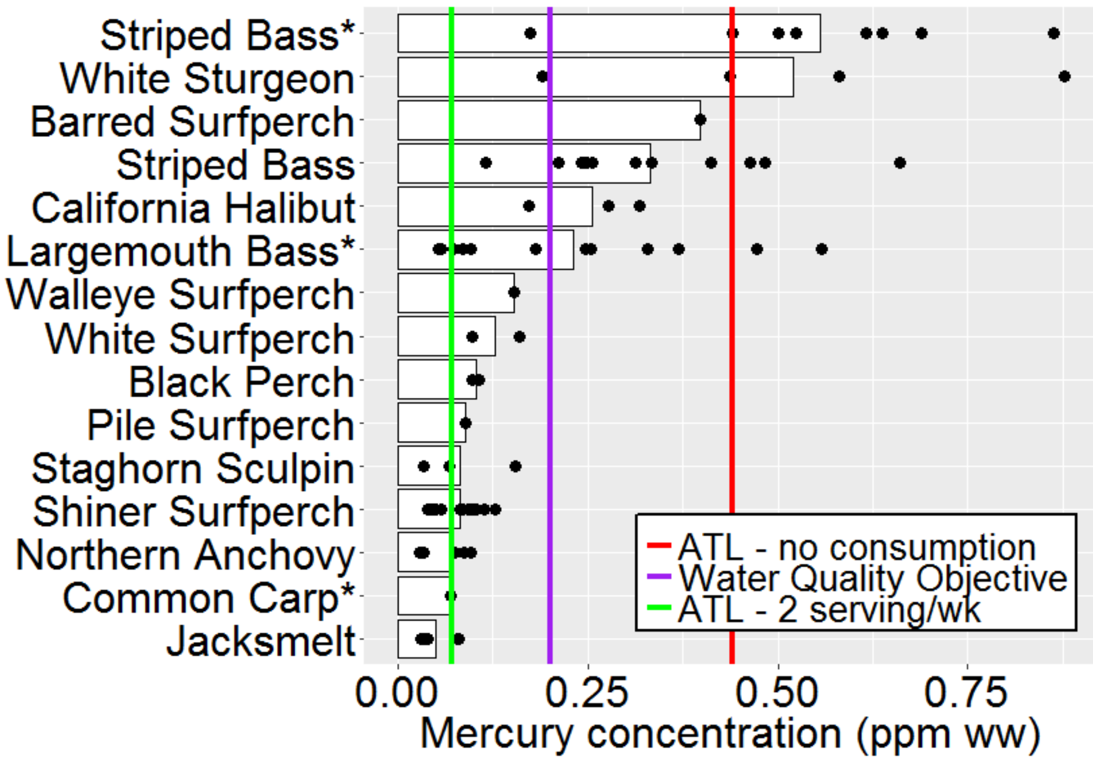

Figure 2. Mercury concentrations (ppm ww) in San Francisco Bay fish, 2014-2015. Bars indicate average concentrations. Points represent individual samples (either composites or individual fish; striped bass samples include both composites and individuals). Concentrations in striped bass and largemouth bass are not size-standardized. The colored lines indicating ATL thresholds show the lower end of the advisory tissue level ranges. Sample groups marked with a star (striped bass, largemouth bass, and common carp) were collected in Artesian Slough.

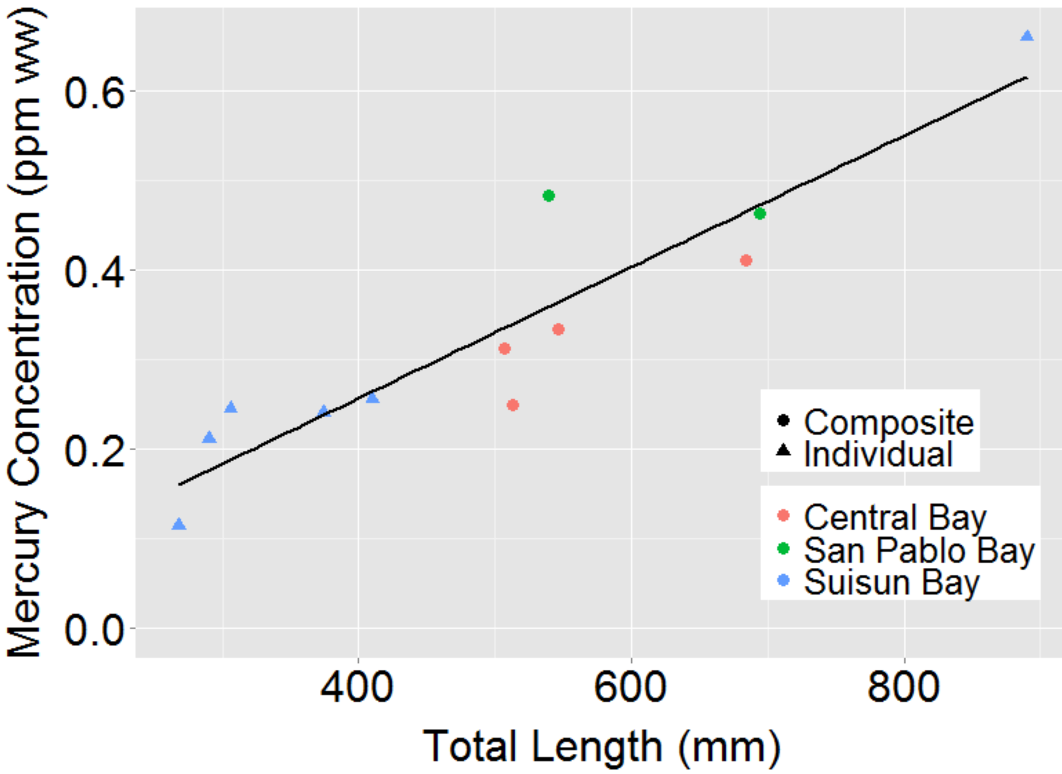

Figure 3. Mercury concentrations (ppm ww) versus total length (mm) in striped bass collected in San Francisco Bay, 2014. Points represent composite (circles) or individual (triangles) samples. Samples from San Pablo Bay and Central Bay were analyzed as composites of 3 fish, while samples from Suisun Bay were analyzed as individuals. Composites include fish of the same size class (Table 4). Total length for composites was calculated as the average total length of the individual fish in each composite. The relationship between length and mercury concentration is strong and statistically significant (linear regression, R^2=0.84, p=2x10^{-5}).

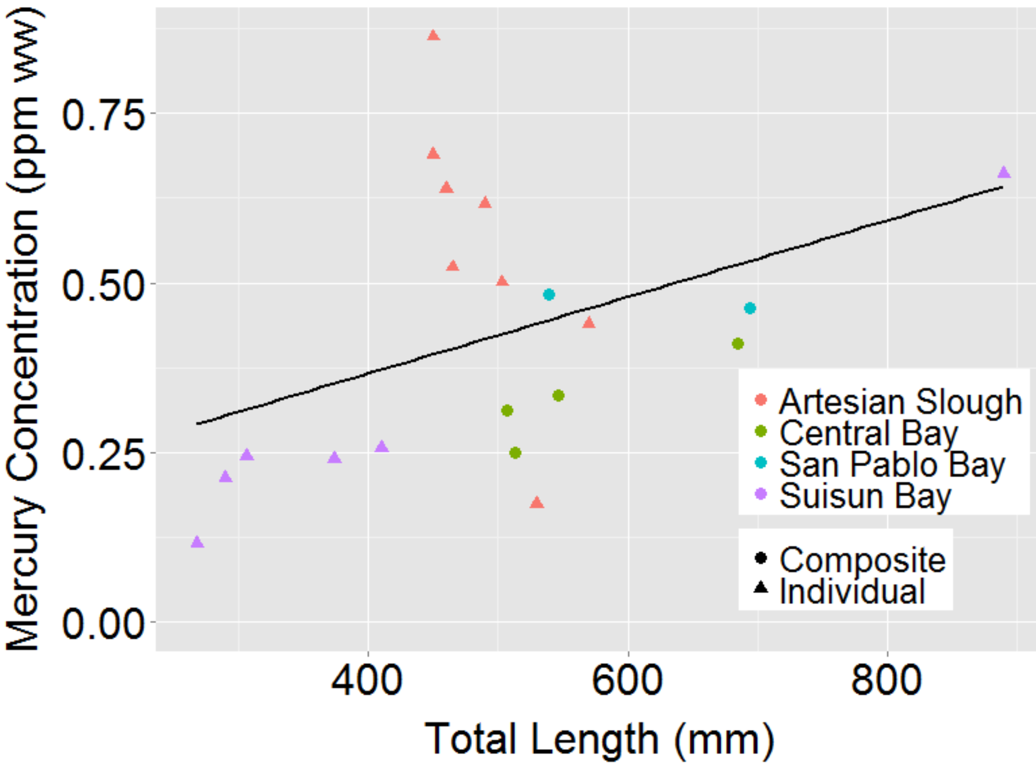

Figure 4. Mercury concentrations (ppm ww) versus total length (mm) in striped bass collected in San Francisco Bay and Artesian Slough, 2014-2015. Points represent composite (circles) or individual (triangles) samples. Samples from San Pablo Bay and Central Bay were analyzed as composites of 3 fish, while samples from Suisun Bay and the Artesian Slough were analyzed as individuals. Composites include fish of the same size class (Table 4). Total length for composites was calculated as the average total length of the individual fish in each composite. The relationship between length and mercury concentrations is positive but not statistically significant (linear regression, $R^2 = 0.12$, $p = 0.075$).

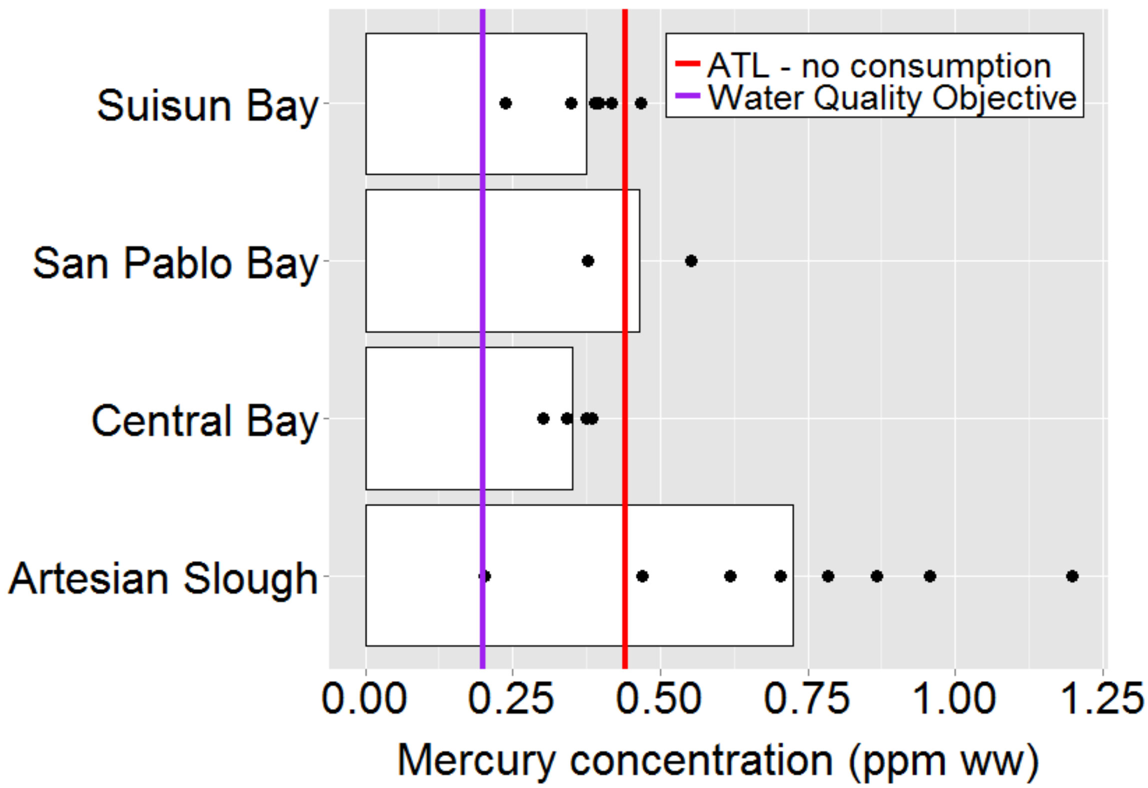

Figure 5. Mercury concentrations (ppm ww) in striped bass in San Francisco Bay, 2014-2015. Bars indicate average concentrations. Data are shown as mercury concentration for 60-cm size-standardized composite or individual fish samples (points), standardized using the length vs. log(Hg) relationship calculated using fish collected in the Bay proper (not including Artesian Slough). Samples from San Pablo Bay and Central Bay were analyzed as composites of 3 fish, while samples from Suisun Bay were analyzed as individuals. No statistically significant differences were observed between regions (Tukey HSD, alpha=0.05), but a greater proportion of fish caught in Artesian Slough had mercury concentrations above the no consumption ATL.

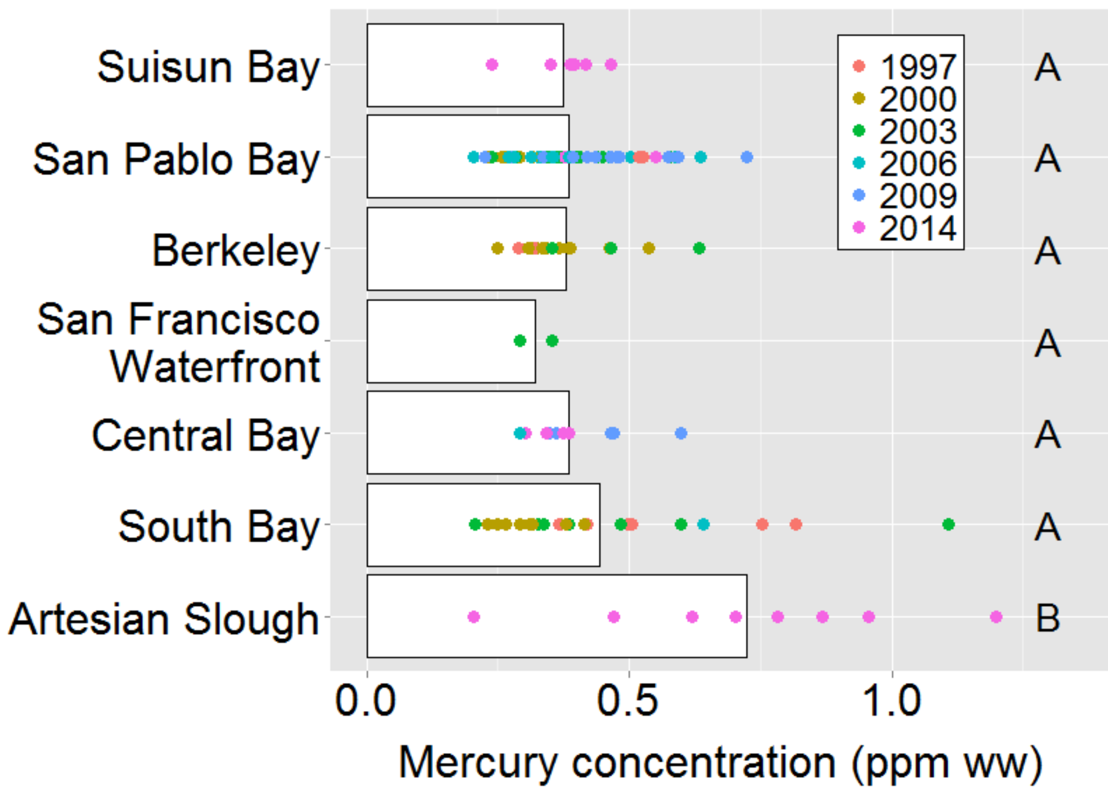

Figure 6. Mercury concentrations (ppm ww) in striped bass in San Francisco Bay, 1997-2015. Bars indicate average concentrations. Points represent 60-cm size-standardized composite or individual samples, standardized using the length vs. log(Hg) relationship calculated using fish collected in the Bay proper (not including Artesian Slough) for each year. All samples represent individual fish with the exception of San Pablo Bay and Central Bay fish caught in 2014 (composites of 3 fish). Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha=0.05).

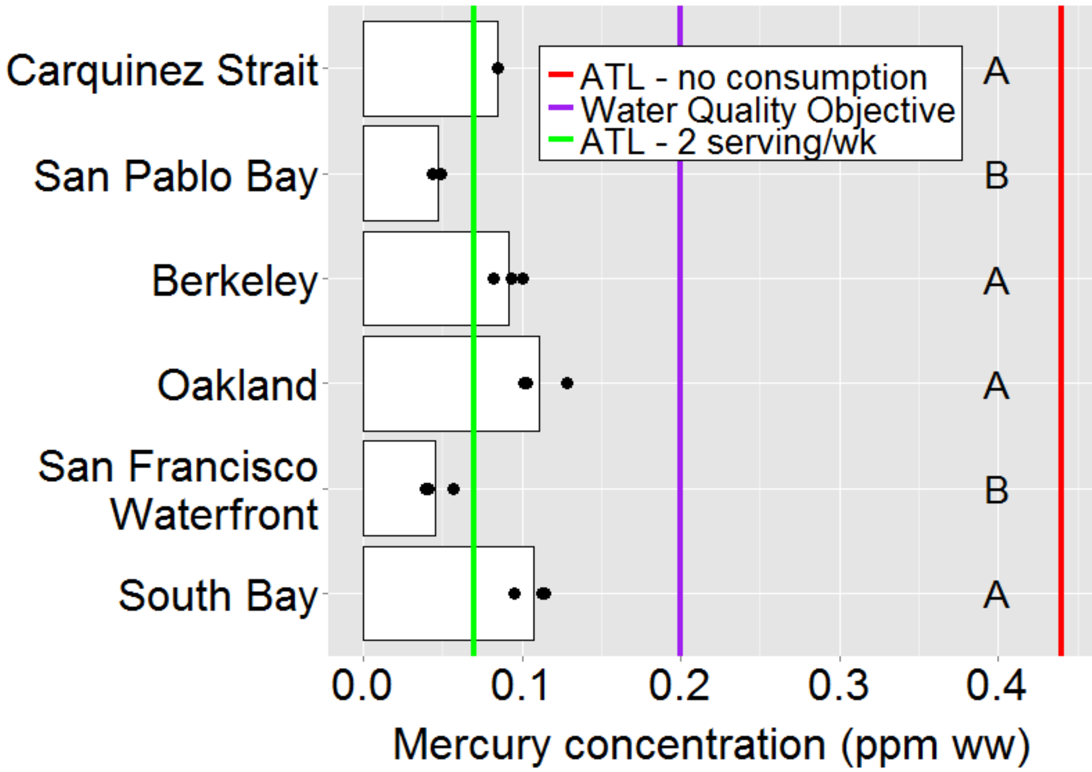

Figure 7. Mercury concentrations (ppm ww) in shiner surfperch in San Francisco Bay, 2014. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha=0.05). The colored lines indicating ATL thresholds show the lower end of the advisory tissue level ranges.

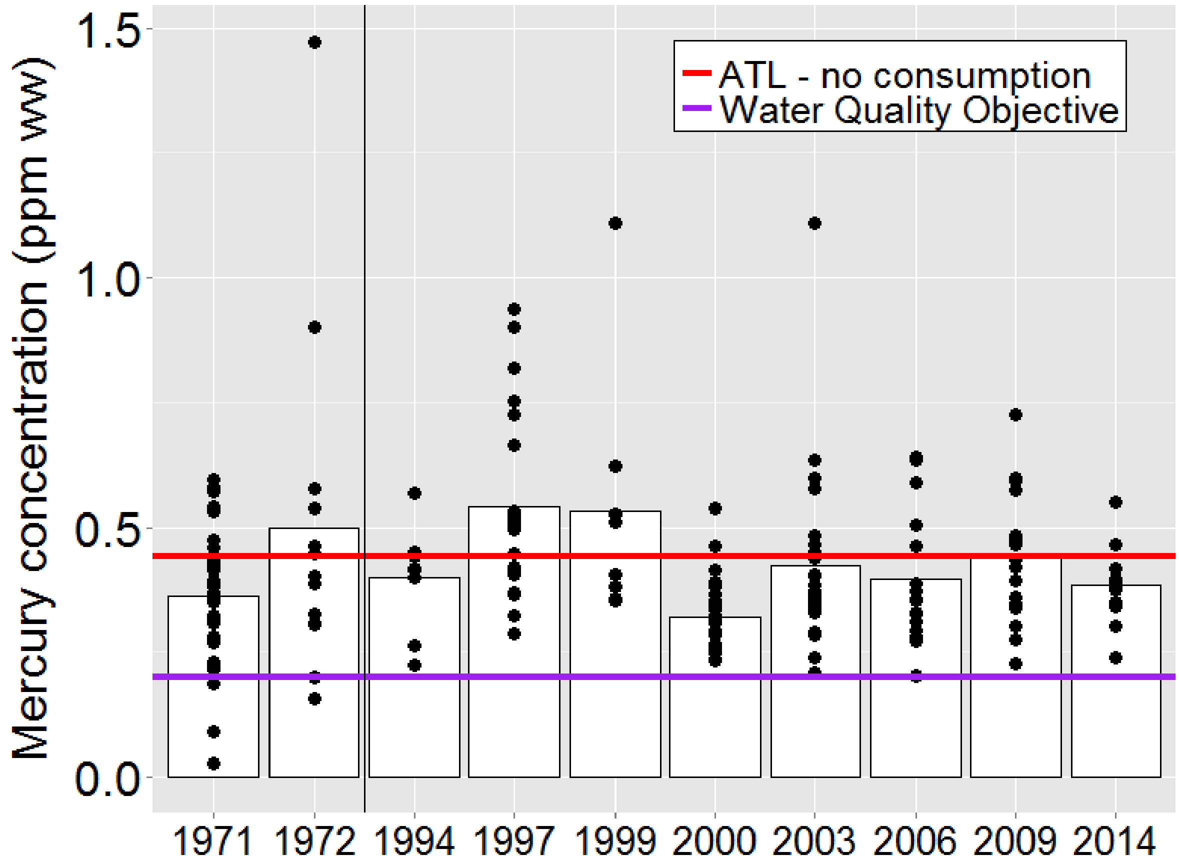

Figure 8. Mercury concentrations (ppm ww) in striped bass in San Francisco Bay, 1971-2014. Bars indicate average concentrations. Points represent individual fish, with the exception of six composite samples (3 fish each) analyzed in 2014. To correct for variation in fish length, all plotted data have been calculated for a 60-cm fish using the residuals of a length vs. log(Hg) relationship calculated for each year. Total length for composites was calculated as the average total length of the individual fish in each composite. The 2014 relationship and data do not include fish collected in Artesian Slough, which reflect unique mercury sources and were collected only in 2015. Data were obtained from CDFW historical records (1971-1972), the Bay Protection and Toxic Cleanup Program (1994), a CalFed-funded collaborative study (1999 and 2000), and the Regional Monitoring Program (1997, 2000, 2003, 2006, 2009, and 2014). No statistically significant long-term trend was observed (linear regression: $p=0.08$, $R^2=0.01$)

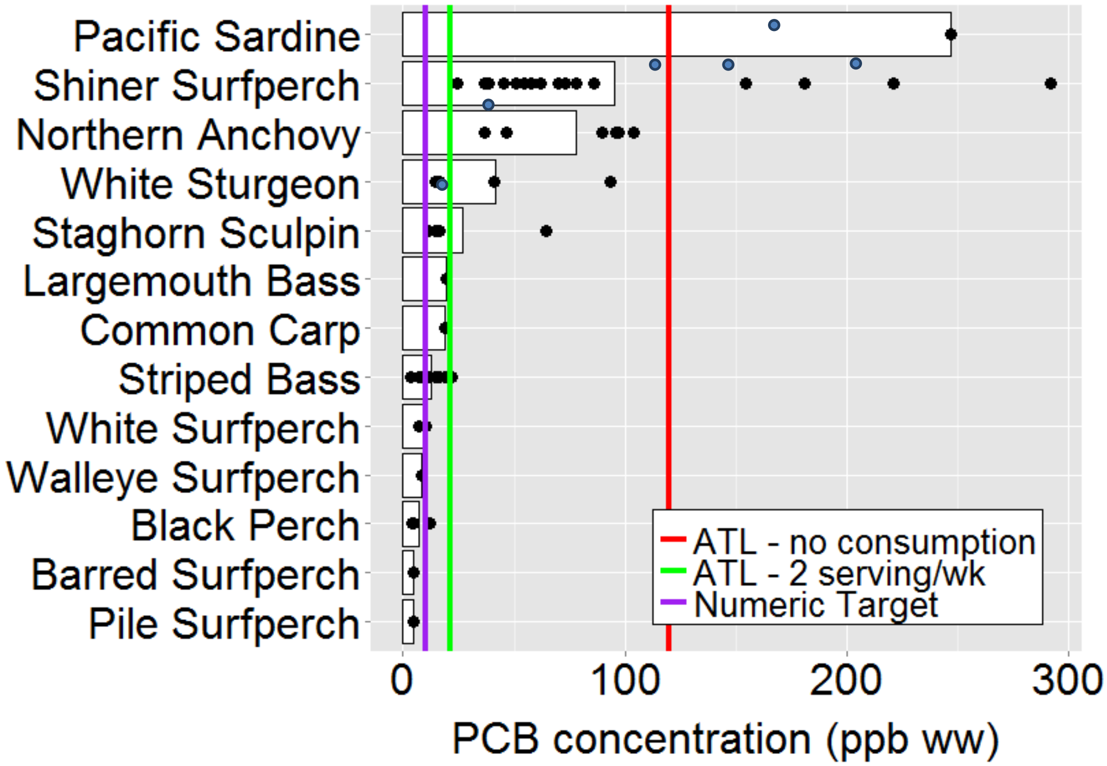

Figure 9. PCB concentrations (ppb ww) in San Francisco Bay fish, 2014-2015. Bars indicate average concentrations. Points represent individual samples (either composites or individual fish; striped bass samples include both composites and individuals). The blue points represent samples collected in Oakland Harbor. The colored lines indicating ATL thresholds show the lower end of the advisory tissue level ranges.

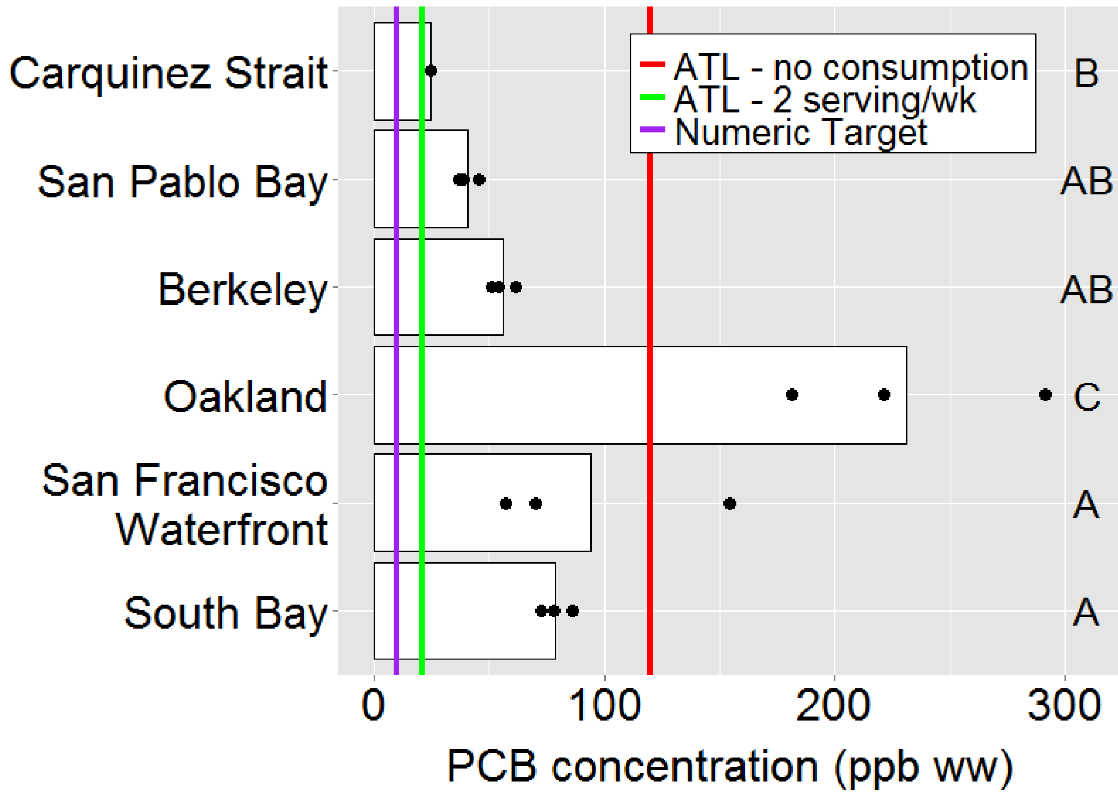

Figure 10. PCB concentrations (ppb ww) in shiner surfperch in San Francisco Bay, 2014. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha=0.05). The colored lines indicating ATL thresholds show the lower end of the advisory tissue level ranges.

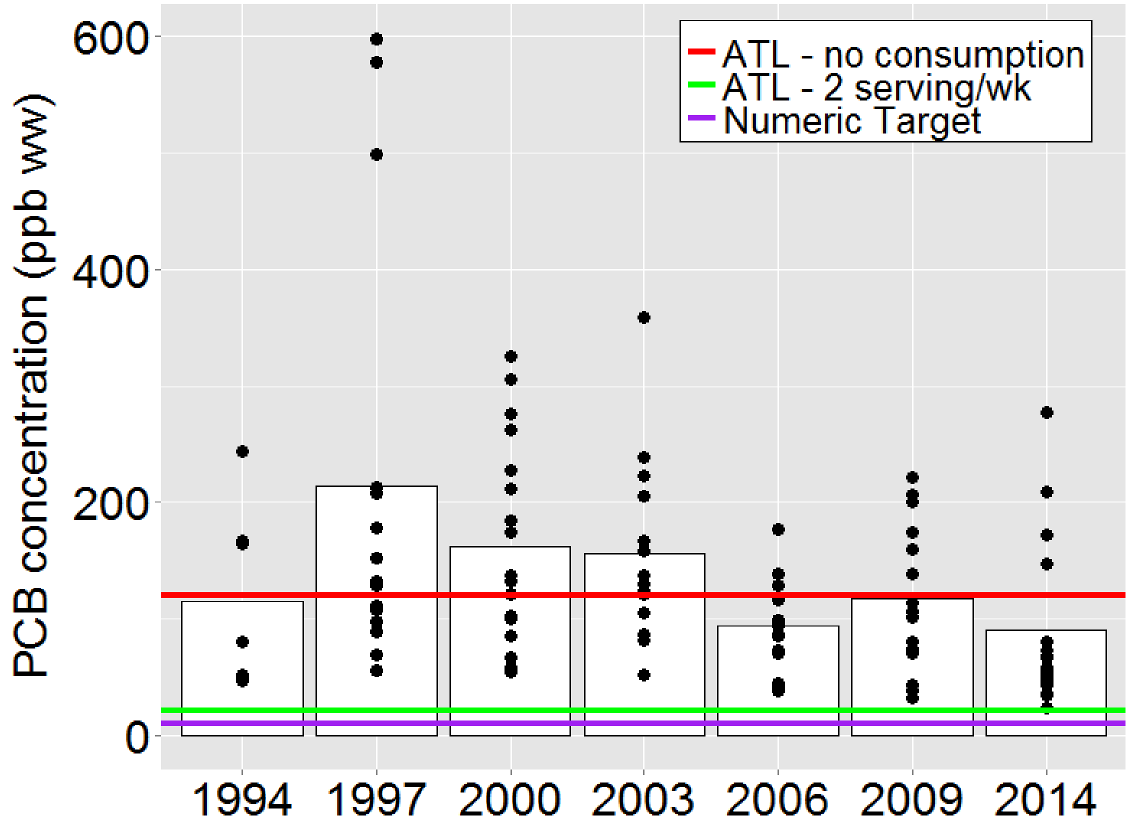

Figure 11. PCB concentrations (ppb ww) in shiner surfperch in San Francisco Bay, 1994-2014. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included. A weak but statistically significant declining trend in PCB concentrations was observed (linear regression, $p=6.0 \times 10^{-4}$, $R^2=0.1$). The colored lines indicating ATL thresholds show the lower end of the advisory tissue level ranges.

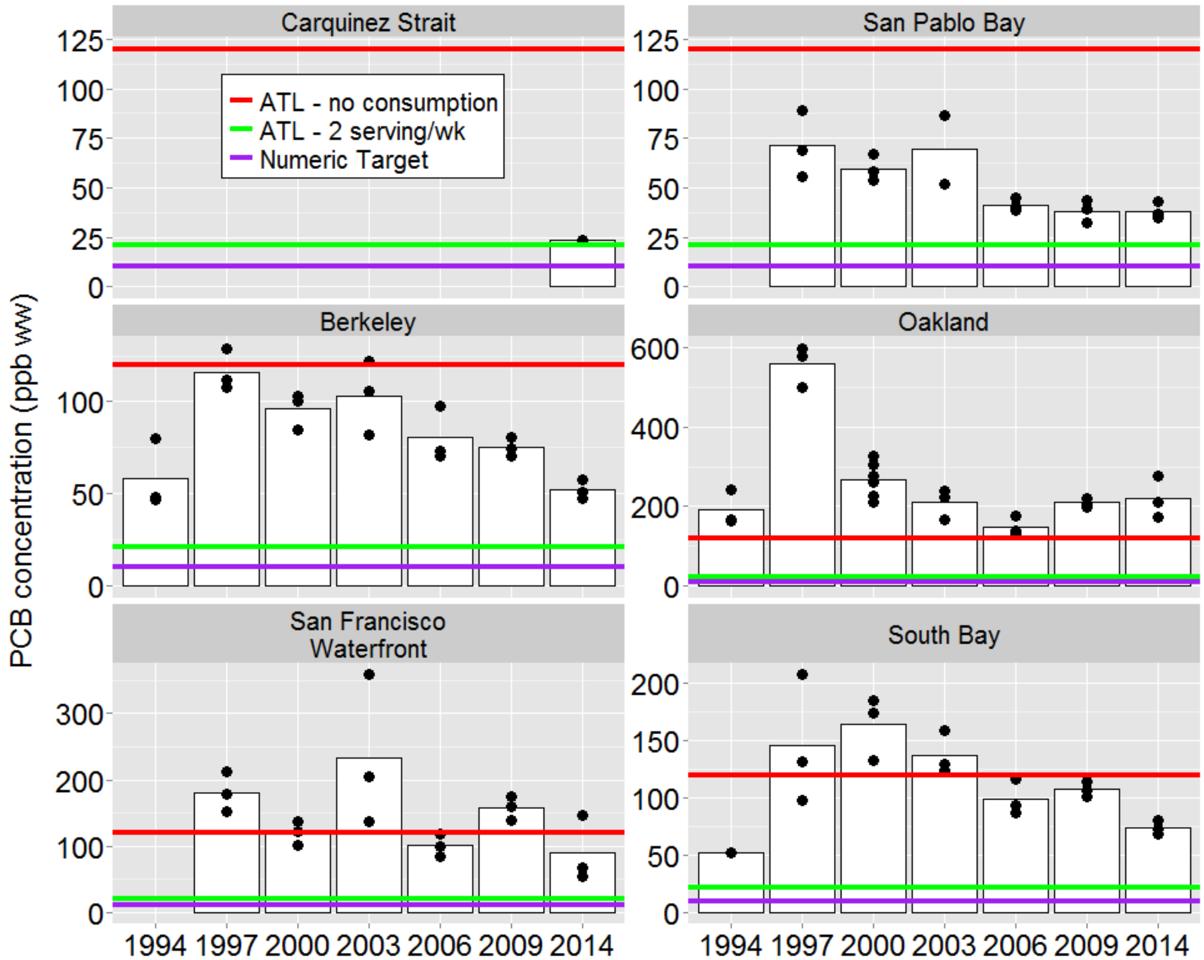

Figure 12. PCB concentrations (ppb ww) in shiner surfperch in each region of San Francisco Bay, 1997-2014. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included. The colored lines indicating ATL thresholds show the lower end of the advisory tissue level ranges.

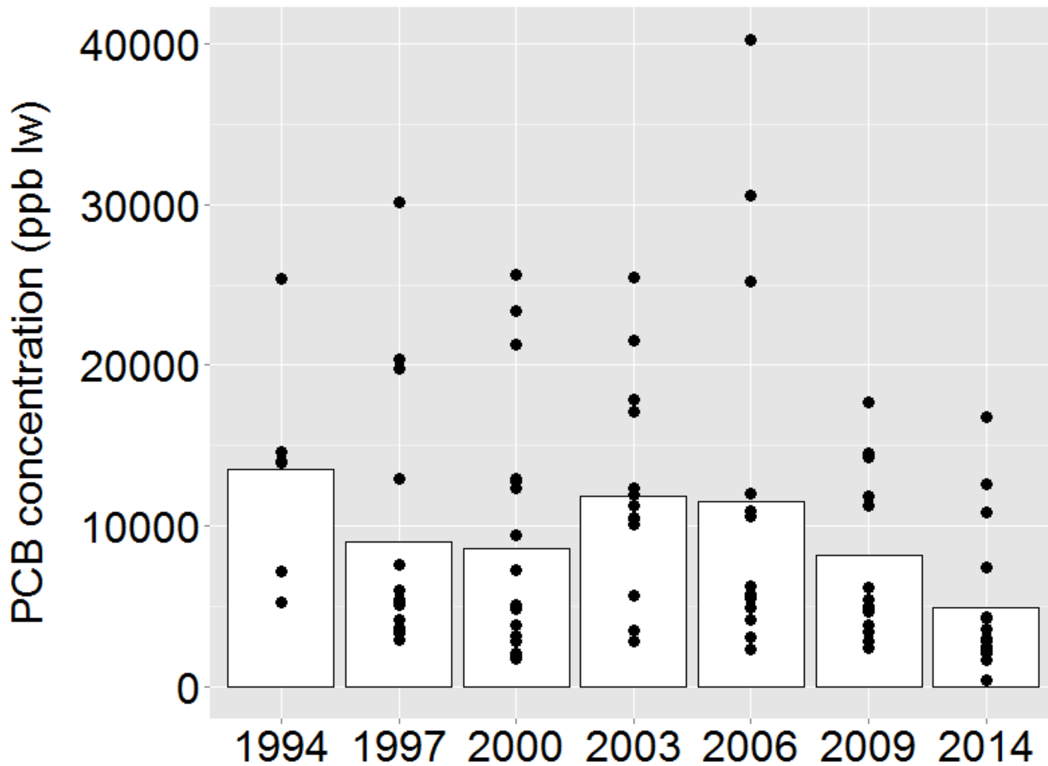

Figure 13. PCB concentrations (ppb lw) in shiner surfperch in San Francisco Bay, 1994-2014. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included. A weak but statistically significant declining trend in PCB concentrations was observed (linear regression, $p=5.5 \times 10^{-2}$, $R^2=0.07$).

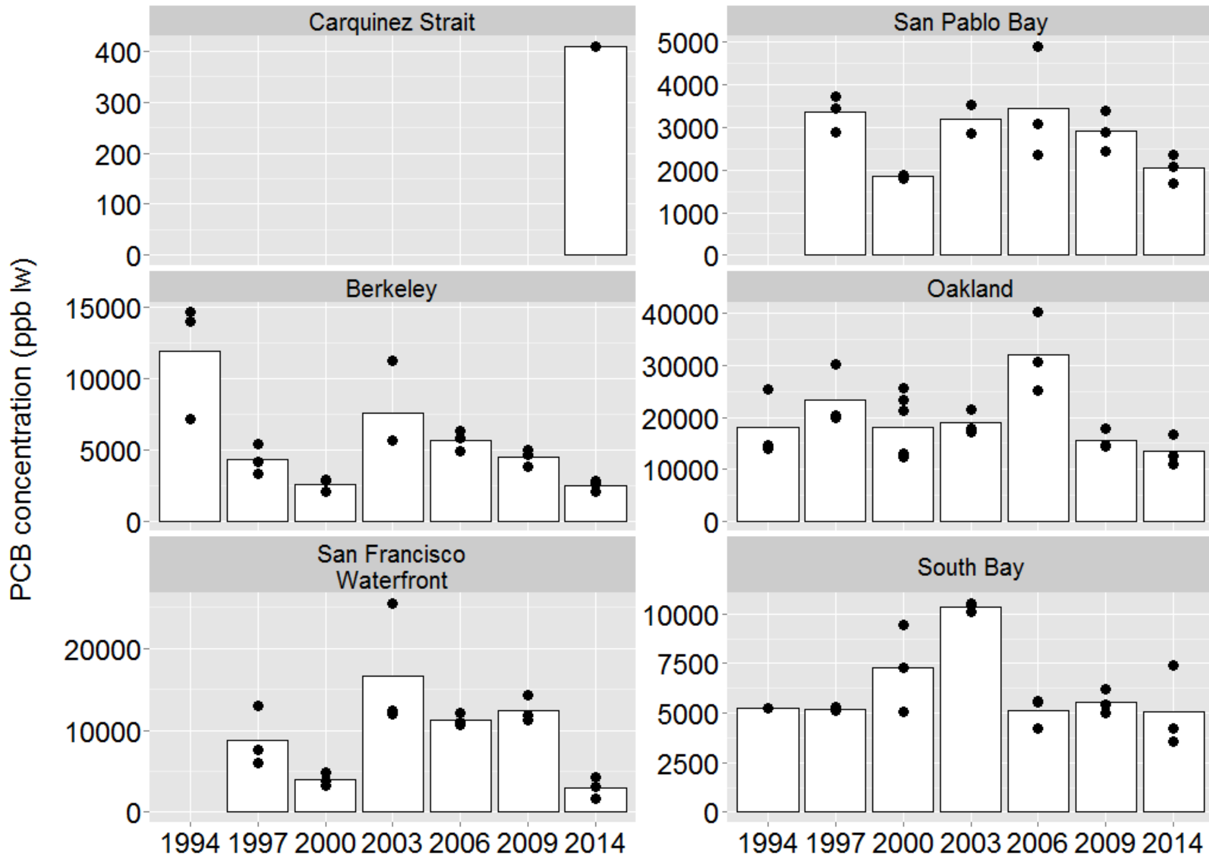

Figure 14. PCB concentrations (ppb lw) in shiner surfperch in each region of San Francisco Bay, 1994-2014. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included.

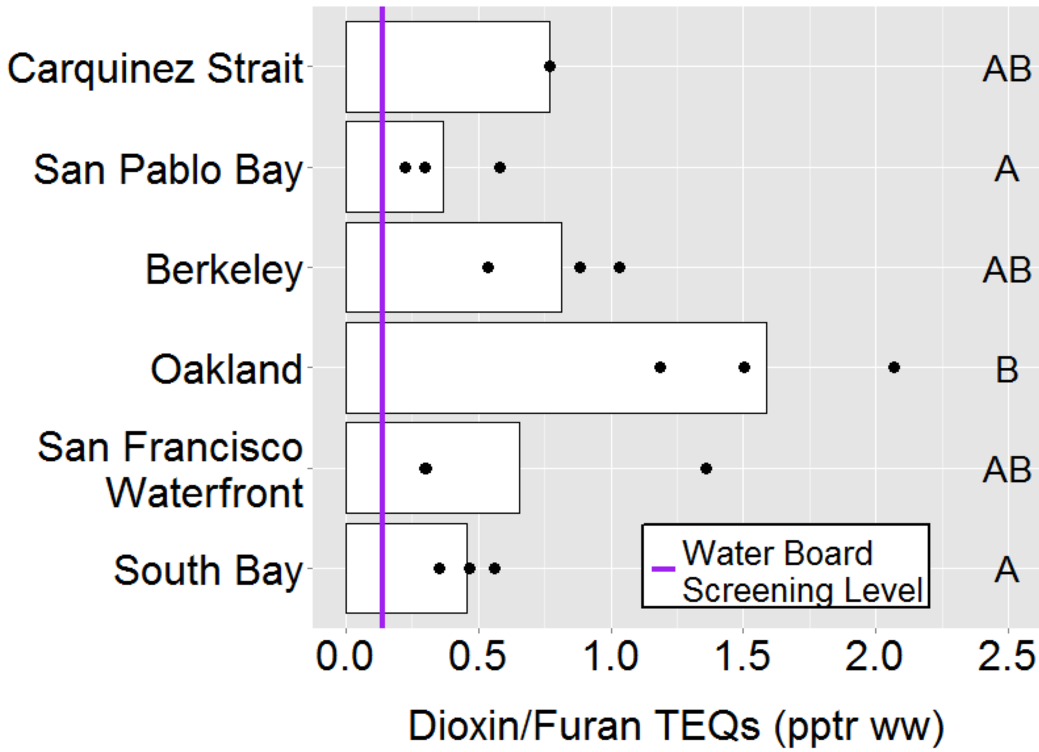

Figure 15. TEQs$_{PCDD/PCDF}$ (pptr ww) in shiner surfperch in San Francisco Bay, 2014. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha=0.05). The Water Board screening level is non-regulatory.

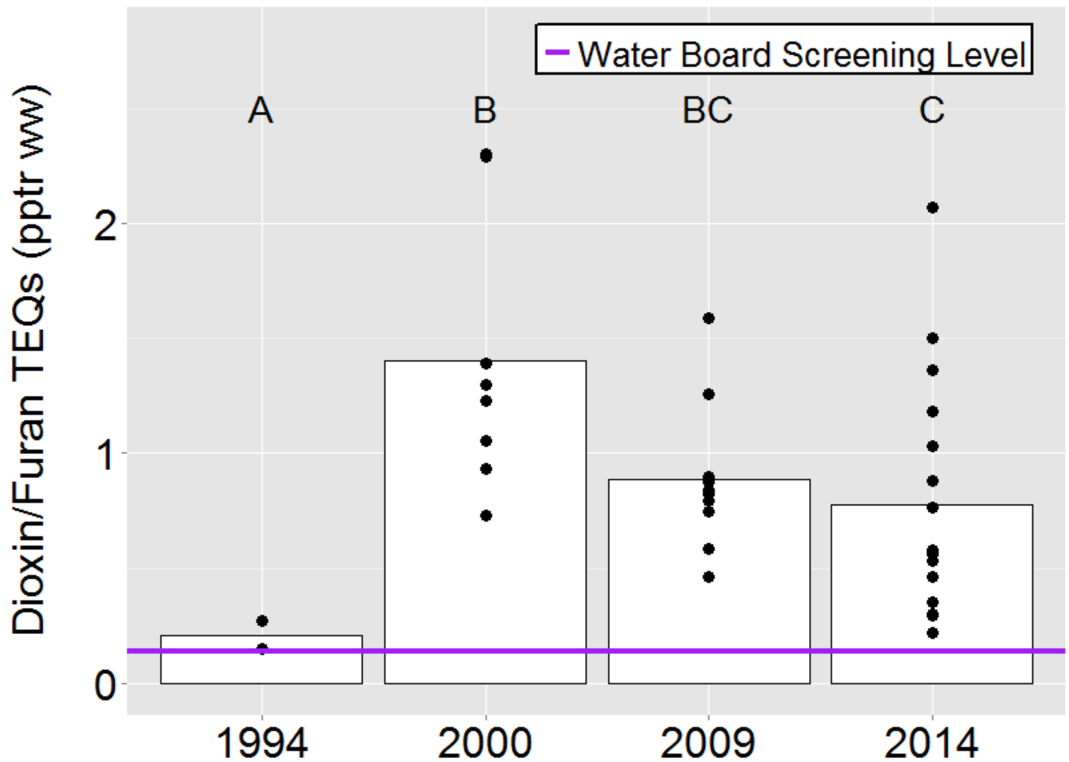

Figure 16. TEQs$_{PCDD/PCDF}$ (pptr ww) in shiner surfperch in San Francisco Bay, 1994-2014. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (2000, 2009, 2014). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included. Years labeled with the same letter did not have significantly different means (Tukey HSD, alpha=0.05).

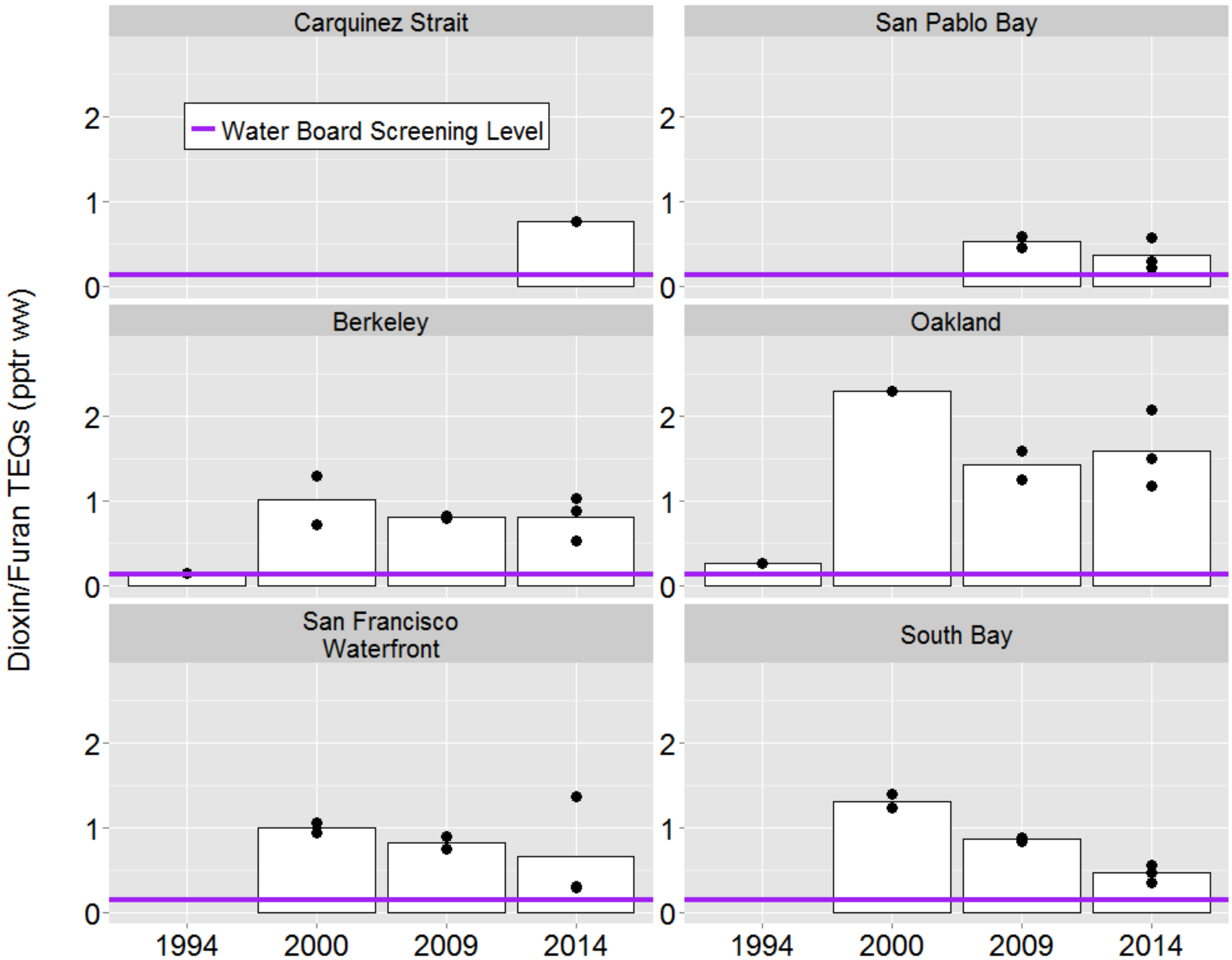

Figure 17. TEQs$_{PCDD/PCDF}$ (pptr ww) in shiner surfperch in each region of San Francisco Bay, 1994-2014. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (2000, 2009, 2014). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included.

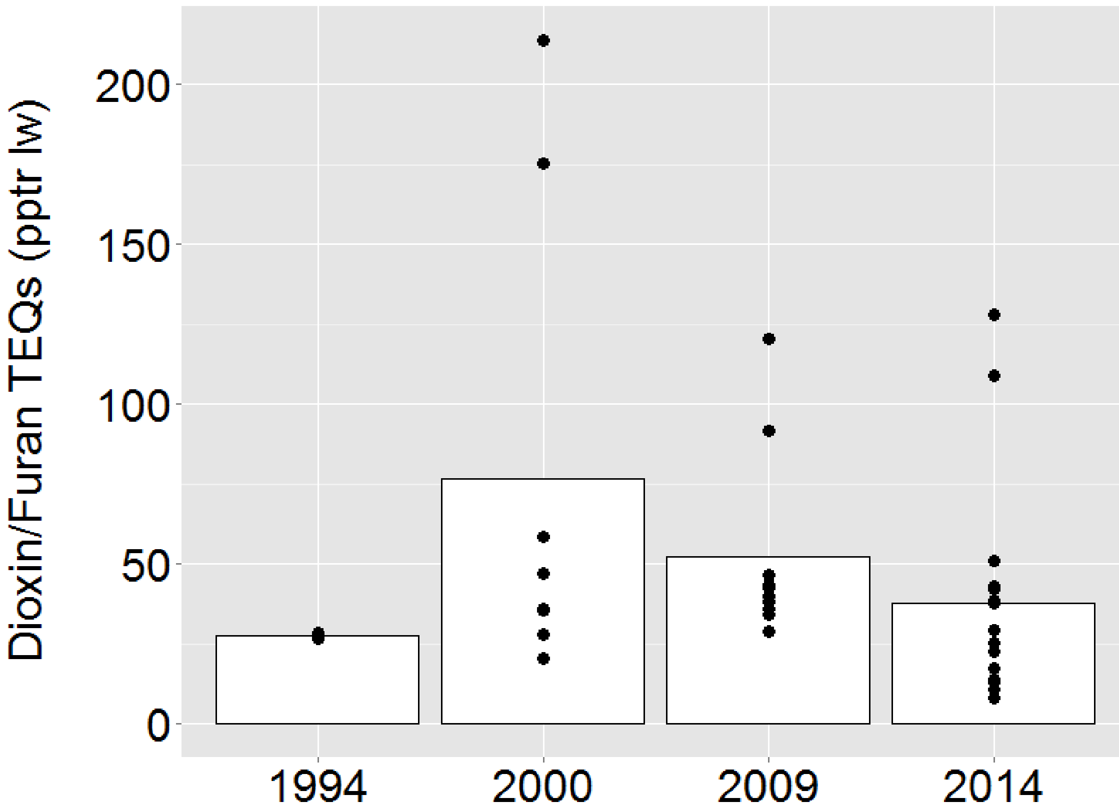

Figure 18. TEQs$_{PCDD/PCDF}$ (pptr lw) in shiner surfperch in San Francisco Bay, 1994-2014. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (2000, 2009, 2014). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included. No statistically significant differences were observed among years (Tukey HSD, alpha=0.05).

Figure 19. TEQs$_{PCDD/PCDF}$ (pptr lw) in shiner surfperch in each region of San Francisco Bay, 1994-2014. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (2000, 2009, 2014). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included.

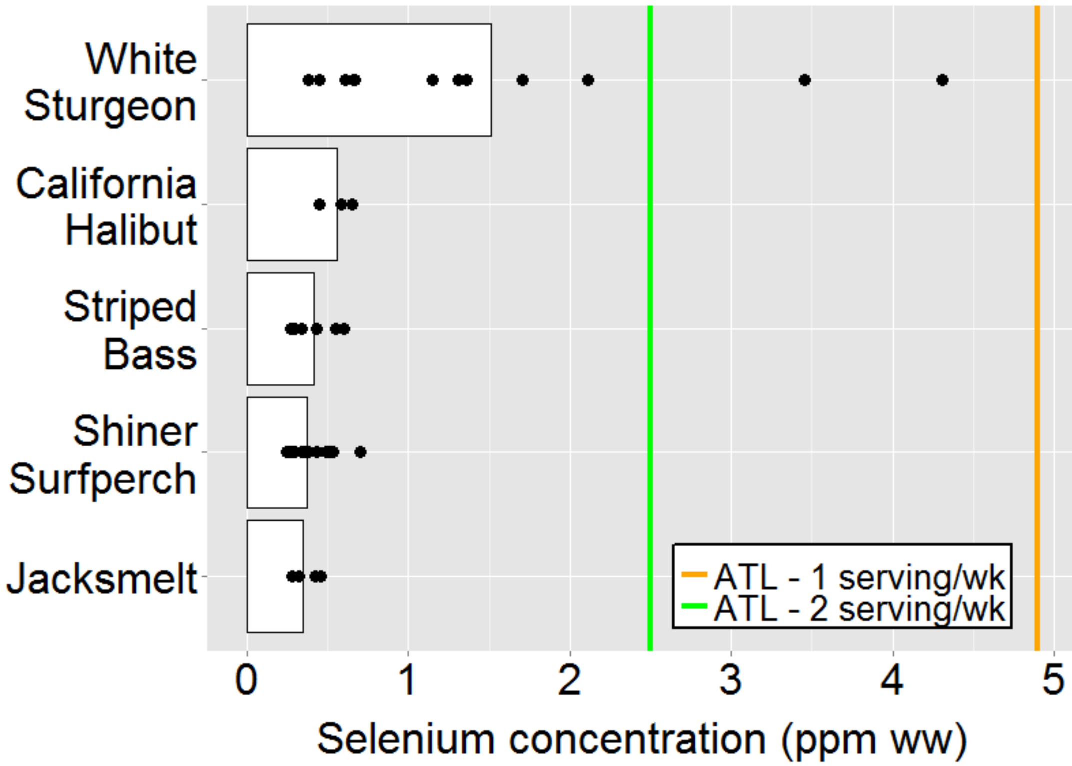

Figure 20. Selenium concentrations (ppm ww) in San Francisco Bay fish, 2014. Bars indicate average concentrations. Points represent individual samples (either composites or individual fish; striped bass samples include both composites and individuals). The colored lines show the lower end of the advisory tissue level ranges.

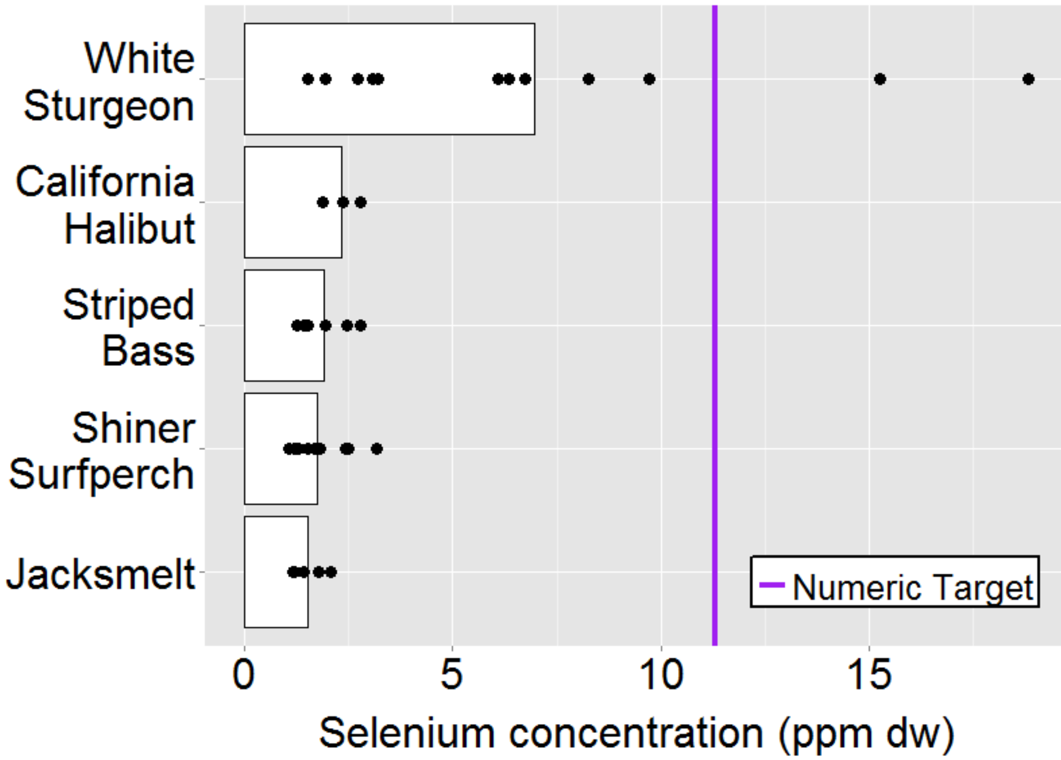

Figure 21. Selenium concentrations (ppm dw) in San Francisco Bay fish, 2014. Bars indicate average concentrations. Points represent individual samples (either composites or individual fish; striped bass samples include both composites and individuals).

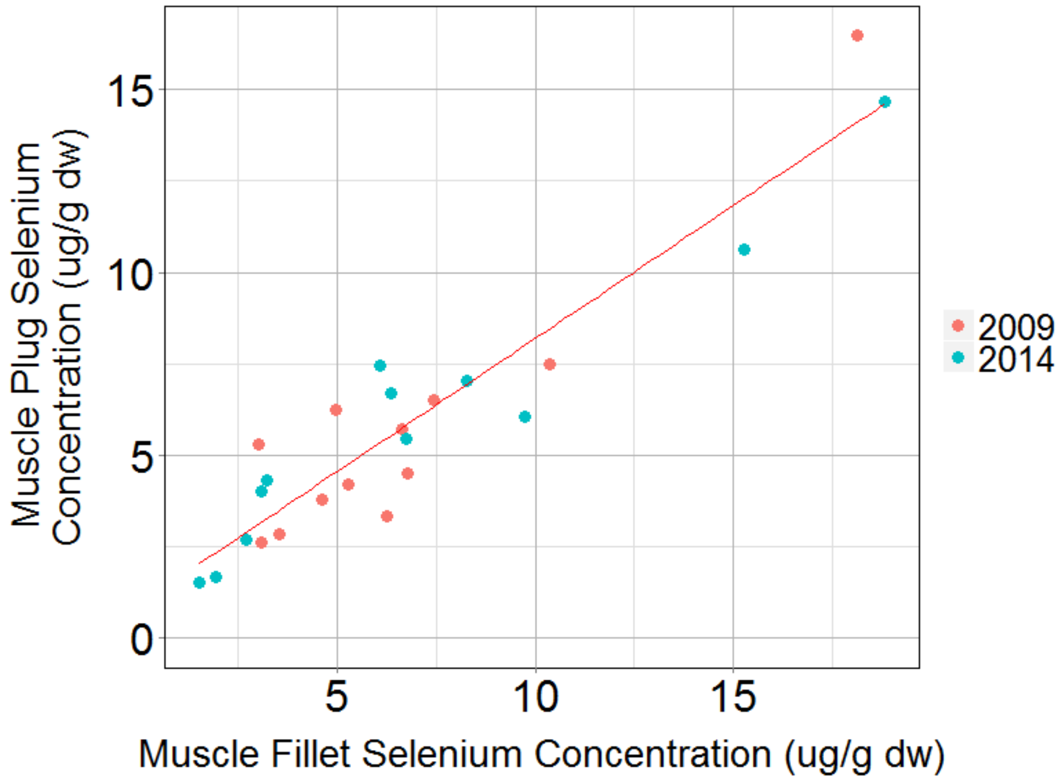

Figure 22. Selenium concentrations (ppm dw) in paired samples of muscle plugs and muscle fillets of white sturgeon in San Francisco Bay, 2009 and 2014. Points represent individual fish. The relationship between selenium concentrations in muscle plugs and muscle fillets was significant in the combined 2009 and 2014 data set (linear regression, $p=1.06 \times 10^{-11}$, $R^2=0.88$, fillet = 0.73* plug + 0.91).

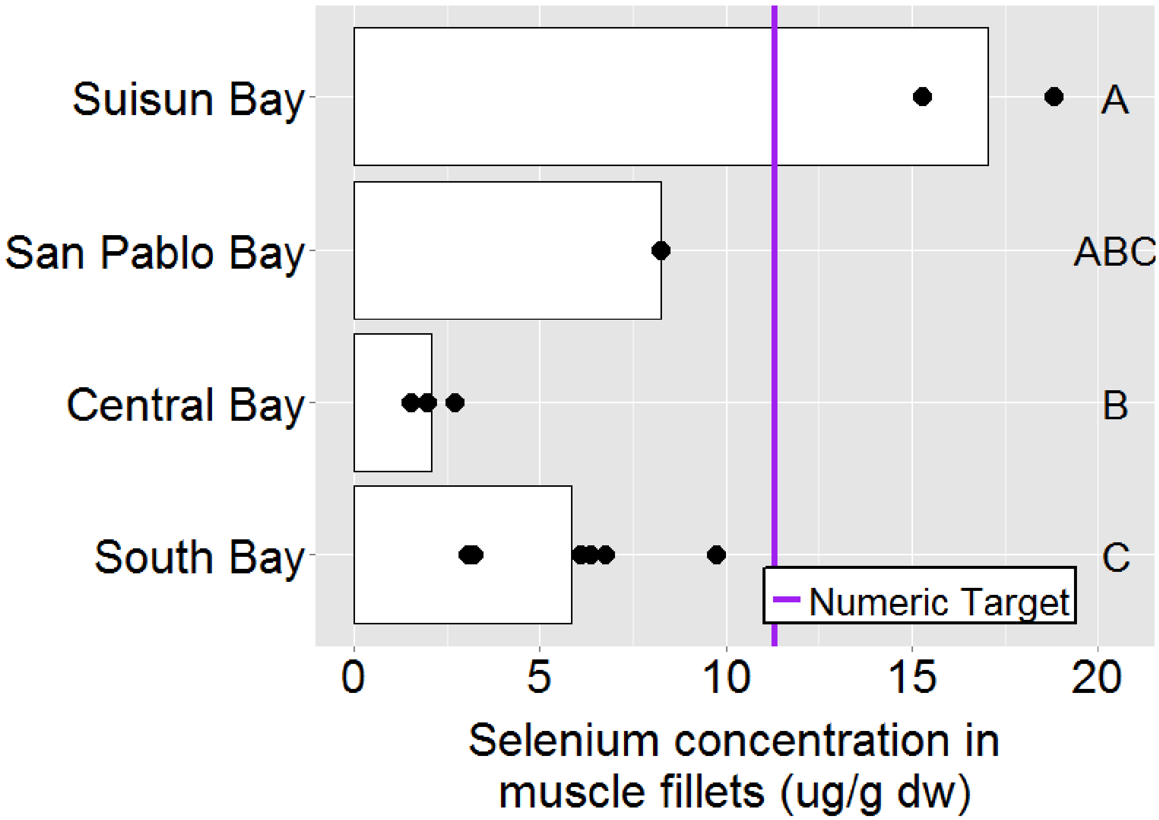

Figure 23. Selenium concentrations (ppm dw) in muscle fillets of white sturgeon in San Francisco Bay, 2014. Bars indicate average concentrations. Points represent individual fish. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha=0.05). The purple line represents the 11.3 ppm dw fish tissue numeric target established in the North Bay Selenium TMDL.

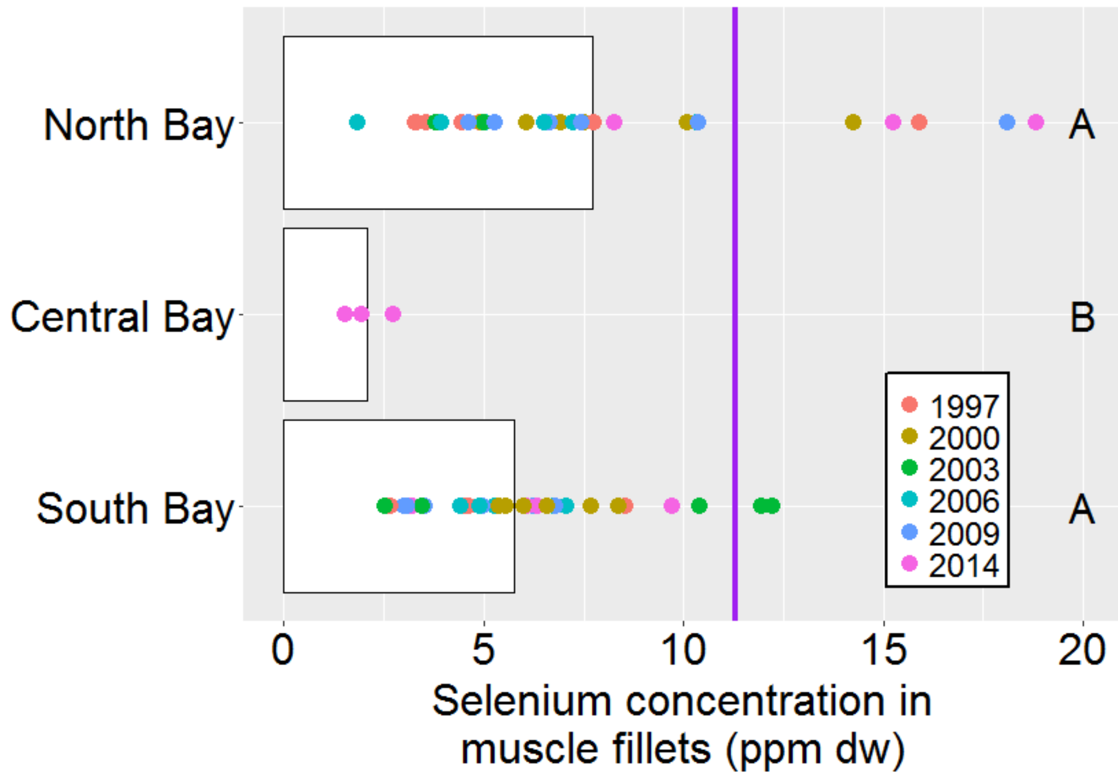

Figure 24. Selenium concentrations (ppm dw) in muscle fillets of white sturgeon sampled by the RMP in San Francisco Bay, 1997-2014. Bars indicate average concentrations. Points represent individual fish. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha=0.05). Historically, sturgeon caught in either Suisun Bay or San Pablo Bay were recorded to have been caught in San Pablo Bay; these sampling stations have been combined in this figure into a single location, North Bay. The purple line represents the 11.3 ppm dw fish tissue numeric target established in the North Bay Selenium TMDL.

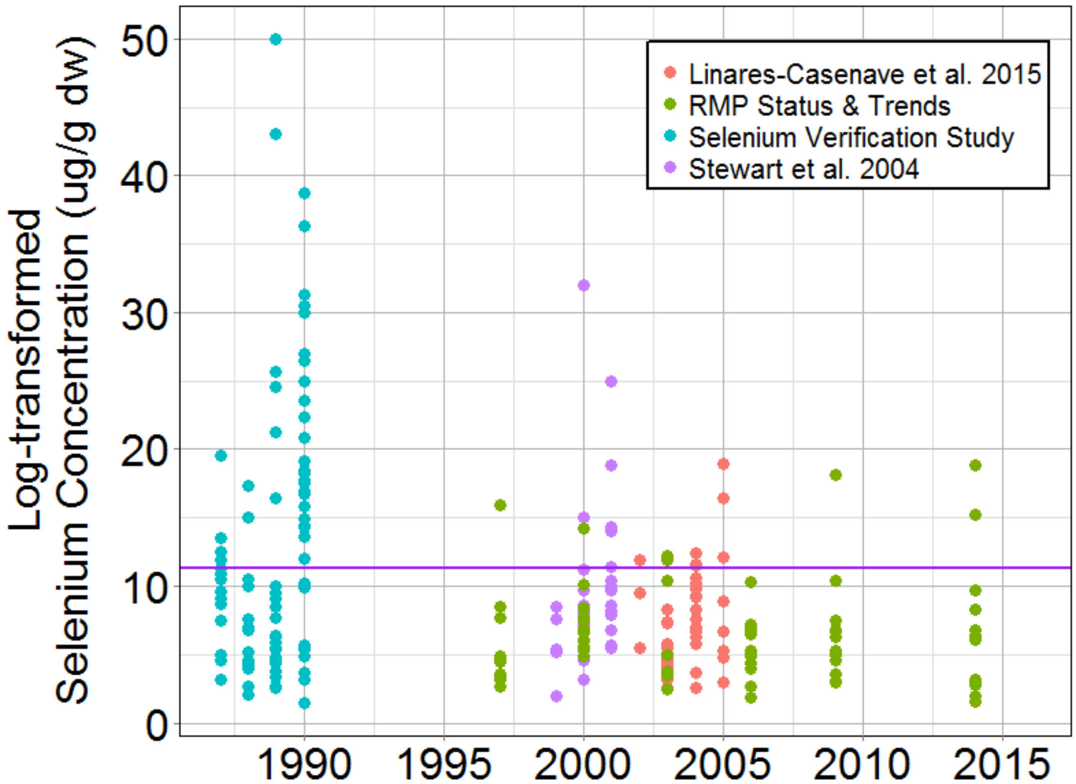

Figure 25. Selenium concentrations (ppm dw) in muscle fillets of white sturgeon in San Francisco Bay, 1987-2014. Bars indicate average concentrations. Points represent individual fish. Data were obtained from the California Department of Fish and Wildlife (CDFW) and State Water Resources Control Board's Selenium Verification Study (1987-1990); a United States Geological Survey study of fish collected during sturgeon derbies held in North Bay (1999-2001; Stewart et al. 2004); UC Davis, CDFW, and the Bureau of Reclamation (2002-2005; Linares-Casenave et al. 2015), and the Regional Monitoring Program's Status and Trends monitoring events (1997-2014). A weak but statistically significant declining trend in selenium concentrations was observed (linear regression, log-transformed data: $p=2.4\times10^{-4}$, $R^2=0.09$), but not when concentrations from 1989 and 1990 are removed ($p=0.054$, $R^2=0.02$). The purple line represents the 11.3 ppm dw fish tissue numeric target established in the North Bay Selenium TMDL.

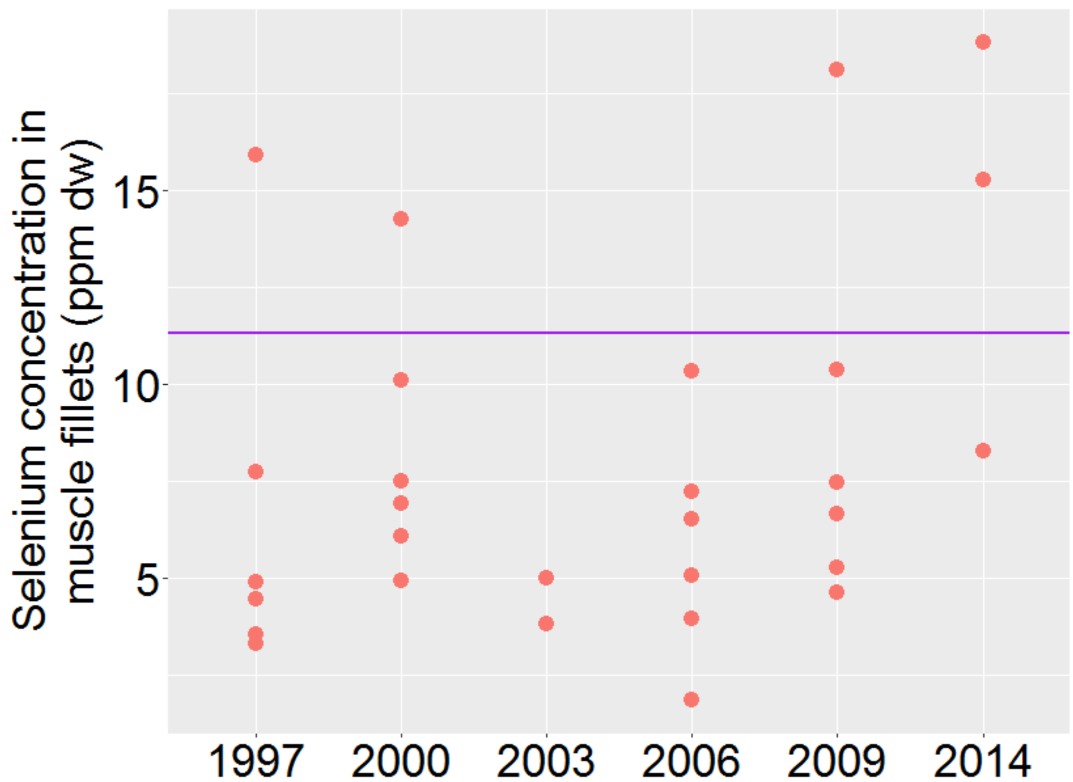

Figure 26. Selenium concentrations (ppm dw) in muscle fillets of white sturgeon sampled by the RMP in North San Francisco Bay, 1997-2014. Points represent individual fish. Selenium concentrations have not changed significantly during this time period (linear regression: $p=0.06$, $R^2=0.09$). The purple line represents the 11.3 ppm dw fish tissue numeric target established in the North Bay Selenium TMDL.

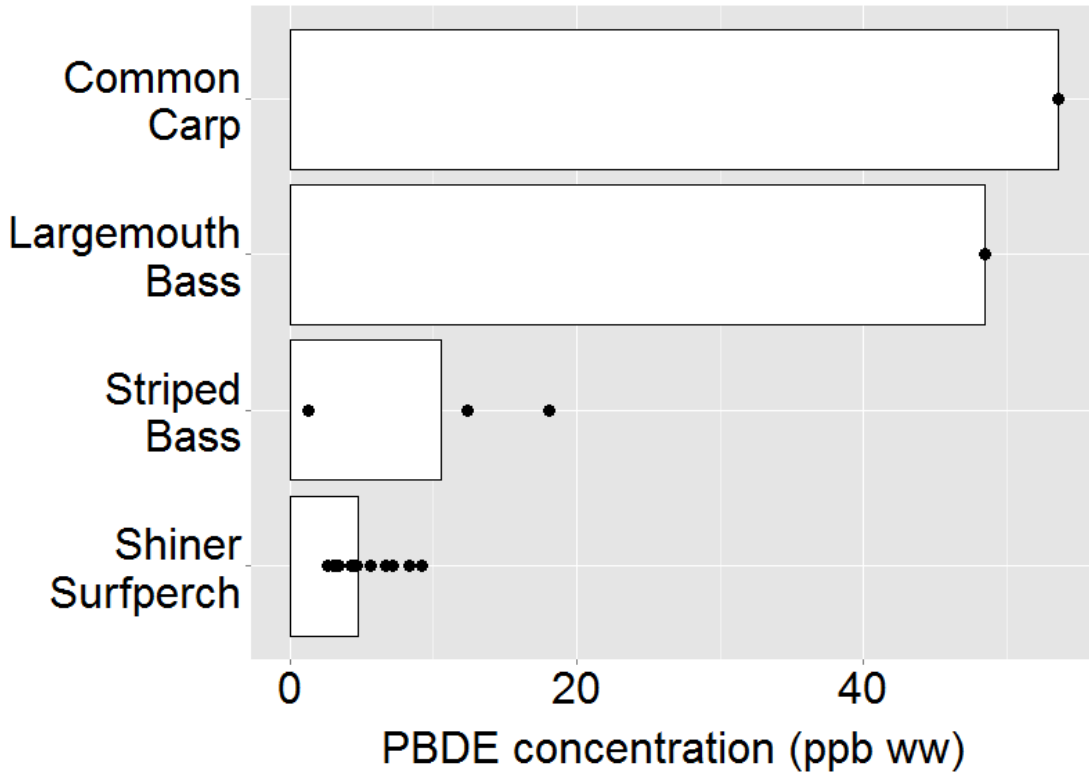

Figure 27. PBDE concentrations (ppm ww) in San Francisco Bay fish, 2014-2015. Bars indicate average concentrations. Points represent individual samples, including composite samples (shiner surfperch) and individual fish (all other species). All samples were well below the lowest OEHHA threshold (2 serving/wk ATL: 100 ppb).

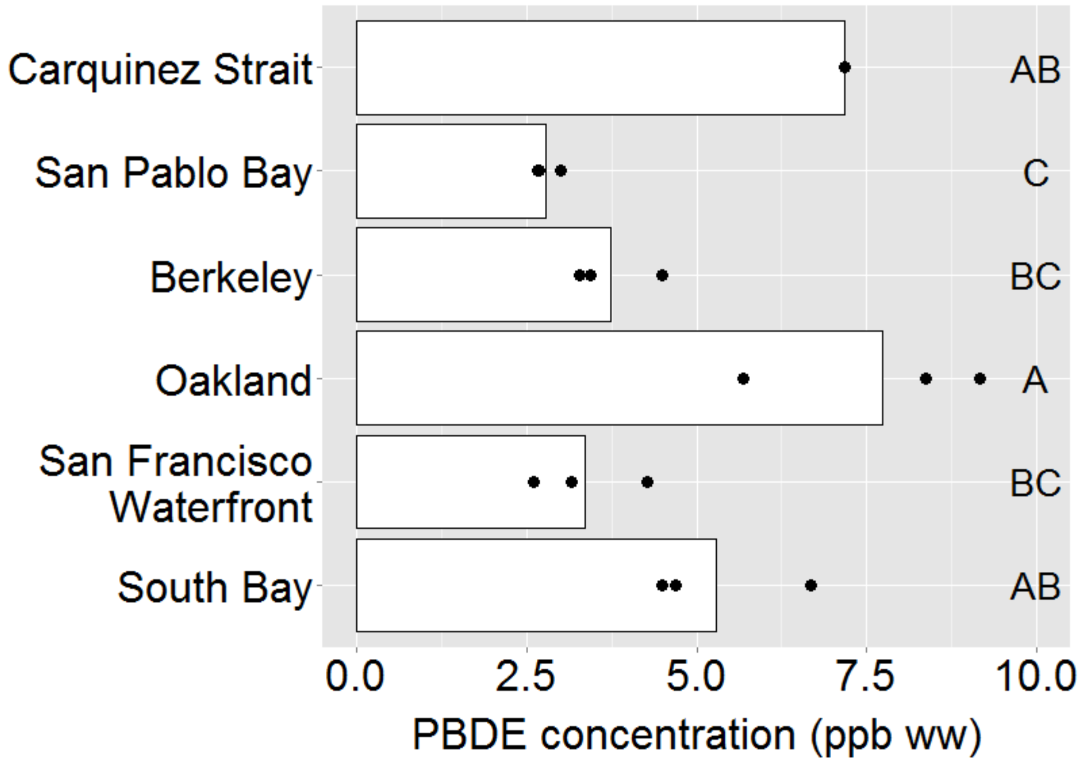

Figure 28. PBDE concentrations (ppm ww) in shiner surfperch in San Francisco Bay, 2014. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha=0.05).

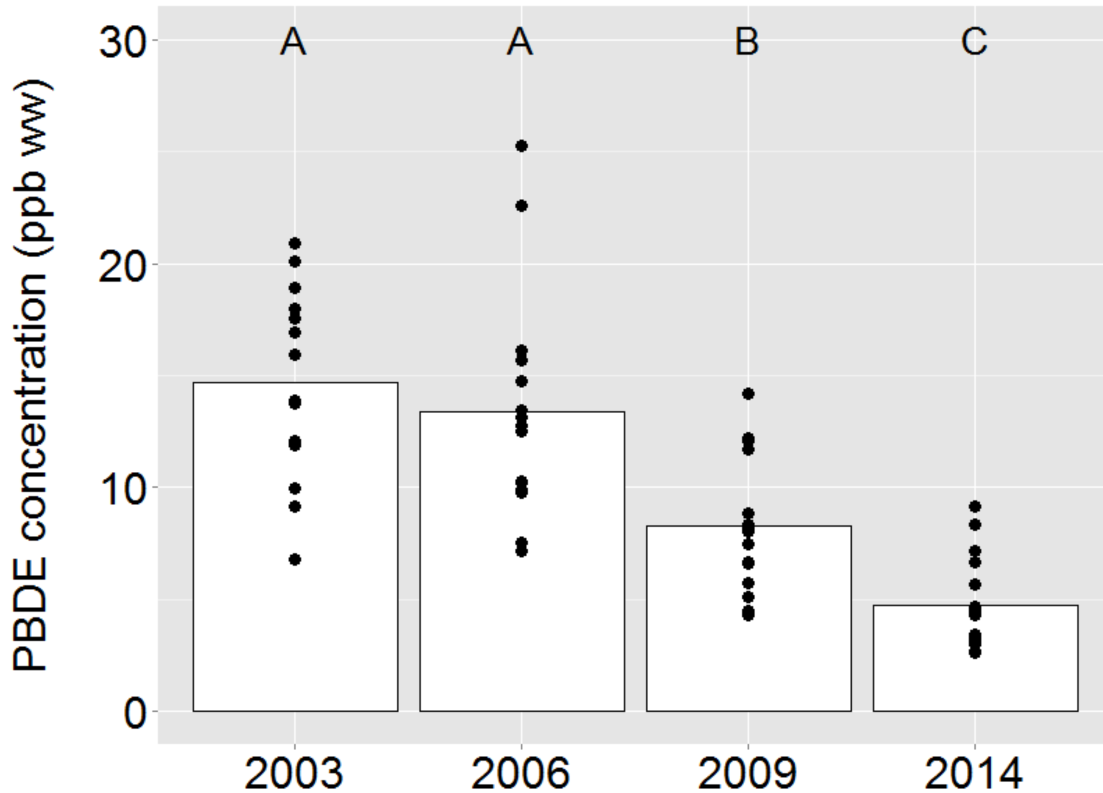

Figure 29. PBDE concentrations (ppm ww) in shiner surfperch in San Francisco Bay, 2003-2014. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Years labeled with the same letter did not have significantly different means (Tukey HSD, alpha=0.05).

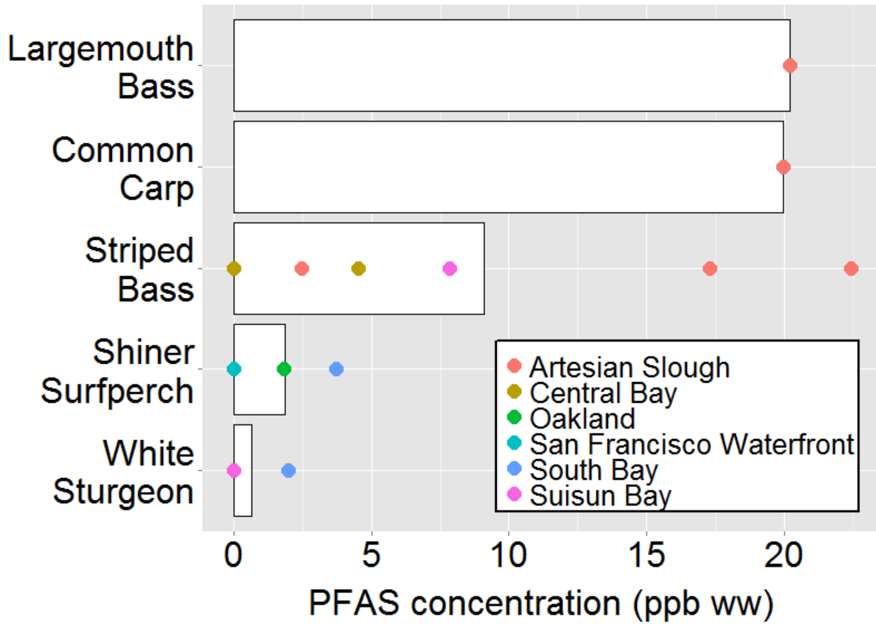

Figure 30. PFAS concentrations (ppb ww) in San Francisco Bay fish, 2014-2015. Bars indicate average concentrations. Points represent individual or composite samples. Points are colored by sampling location. Multiple non-detect samples may be overlapping in this figure. Full results for each sample are presented in Table 6.

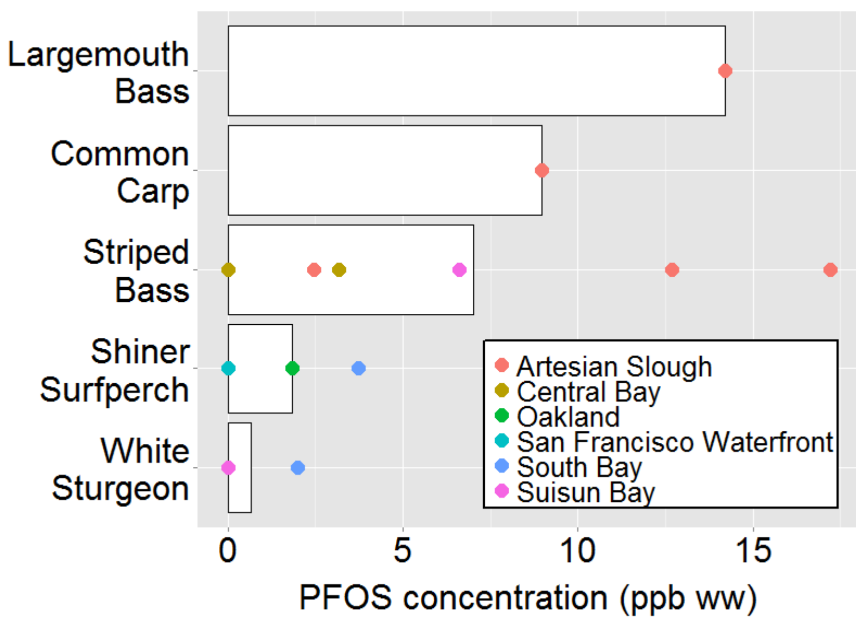

Figure 31. PFOS concentrations (ppb ww) in San Francisco Bay fish, 2014-2015. Bars indicate average concentrations. Points represent individual or composite samples. Points are colored by sampling location. Multiple non-detect samples may be overlapping. Full results for each sample are presented in Table 6.

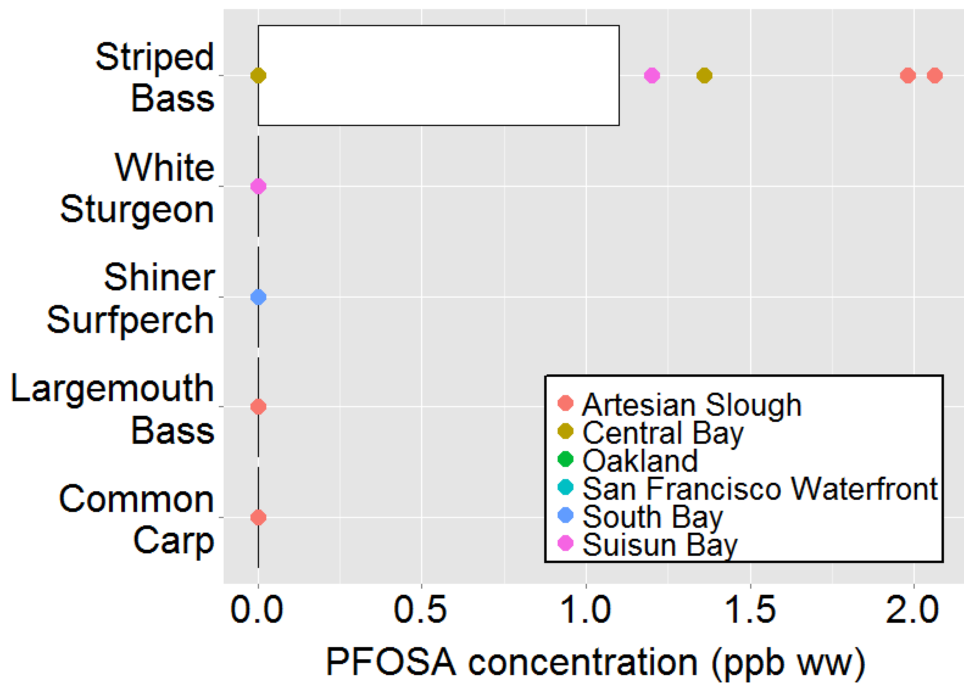

Figure 32. PFOSA concentrations (ppb ww) in San Francisco Bay fish, 2014-2015. Bars indicate average concentrations. Points represent individual or composite samples. Points are colored by sampling location. Many results were non-detect and are overlapping in this figure. Full results for each sample are presented in Table 6.

Table 1. Summary of fish samples collected, 2014. Most contaminants were measured in composite fish samples, although in some cases contaminants were measured in either individual fish, or both composite and individual fish samples (i.e. selenium in sturgeon, mercury in striped and largemouth bass). The number of composites analyzed for a particular species, and the number of unique sampling locations at which fish used in these composites were collected, are indicated in the fields "Number of Composite Samples" and "Composites – Number of Locations Sampled." Similarly, the number of individual fish analyzed for a particular species, and the unique number of sampling locations at which these individual fish were collected, are indicated in the fields "Number of Individual Fish Samples" and "Individuals – Number of Locations Sampled."

Species Name	Common Name	Total Number of Fish Collected	Number of Composite Samples	Composites - Number of Locations Sampled	Number of Individual Fish Samples	Individuals - Number of Locations Sampled	Total Number of Locations Sampled	Min Length (mm)	Median Length (mm)	Max Length (mm)
Acipenser transmontanus	White Sturgeon	12	4	3	12	4	4	1155	1343	1727
Amphistichus argenteus	Barred Surfperch	4	1	1			1	200	256	310
Atherinopsis californiensis	Jacksmelt	49	6	2			2	180	259	342
Cymatogaster aggregata	Shiner Surfperch	319	16	6			6	80	115	1051
Cyprinus carpio	Common Carp	1			1	1	1			
Embiotoca jacksoni	Black Perch	30	3	1			1	128	167	212
Engraulis mordax	Northern Anchovy	140	6	3			3	66	85.5	131
Genyonemus lineatus	White Croaker	59	12	2			2	200	220	314
Hyperprosopon argenteum	Walleye Surfperch	7	1	1			1	204	220	256
Leptocottus armatus	Staghorn Sculpin	63	4	4			4	98	122	156

Species Name	Common Name	Total Number of Fish Collected	Number of Composite Samples	Composites - Number of Locations Sampled	Number of Individual Fish Samples	Individuals - Number of Locations Sampled	Total Number of Locations Sampled	Min Length (mm)	Median Length (mm)	Max Length (mm)
Micropterus salmoides	Largemouth Bass	12	1	1	12	1	1	205	340	450
Morone saxatilis	Striped Bass	32	6	2	14	2	3	268	510	890
Paralichthys californicus	California Halibut	9	3	3			3	550	774	980
Phanerodon furcatus	White Surfperch	20	2	1			1	182	242	290
Rhacochilus vacca	Pile Surfperch	10	1	1			1	176	202	262
Sardinops sagax	Pacific Sardine	10	1	1			1	244	257	276

Table 2. Summary of chemical analyses. Analytes included in this study, method detection limits, number of observations, and frequencies of detection and reporting. Frequency of detection includes all results above detection limits. Frequency of reporting includes all results that were reportable (above the detection limit and passing all quality assurance review). Units for the MDLs are ppm for mercury and selenium, pptr for dioxins and furans, and ppb for all other organics.

Laboratory	Class	Analyte	Method Detection Limit	Number of Samples	Frequency of Detection (%)	Frequency of Reporting (%)
MPSL-DFG	MERCURY	Mercury	0	92	100	100
MPSL-DFG	SELENIUM	Selenium	0.15	70	100	100
DFG-WPCL	PCB	PCB 008	0.22	62	2	2
DFG-WPCL	PCB	PCB 018	0.22	62	18	18
DFG-WPCL	PCB	PCB 027	0.22	62	3	3
DFG-WPCL	PCB	PCB 028/31	0.25	62	60	44
DFG-WPCL	PCB	PCB 029	0.22	62	2	2
DFG-WPCL	PCB	PCB 033	0.22	62	2	2
DFG-WPCL	PCB	PCB 044	0.22	62	63	45
DFG-WPCL	PCB	PCB 049	0.22	62	63	63
DFG-WPCL	PCB	PCB 052	0.22	62	89	84
DFG-WPCL	PCB	PCB 056/60	0.25	62	53	6
DFG-WPCL	PCB	PCB 064	0.22	62	45	45
DFG-WPCL	PCB	PCB 066	0.22	62	66	50
DFG-WPCL	PCB	PCB 070	0.33	62	61	40
DFG-WPCL	PCB	PCB 074	0.22	62	58	58
DFG-WPCL	PCB	PCB 077	0.22	62	3	3
DFG-WPCL	PCB	PCB 087	0.33	62	63	44
DFG-WPCL	PCB	PCB 095	0.33	62	77	73
DFG-WPCL	PCB	PCB 097	0.22	62	66	53
DFG-WPCL	PCB	PCB 099	0.25	62	100	98
DFG-WPCL	PCB	PCB 101	0.41	62	100	95
DFG-WPCL	PCB	PCB 105	0.22	62	69	60
DFG-WPCL	PCB	PCB 110	0.38	62	89	81
DFG-WPCL	PCB	PCB 114	0.22	62	11	11
DFG-WPCL	PCB	PCB 118	0.39	62	97	90
DFG-WPCL	PCB	PCB 126	0.22	62	3	3

Laboratory	Class	Analyte	Method Detection Limit	Number of Samples	Frequency of Detection (%)	Frequency of Reporting (%)
DFG-WPCL	PCB	PCB 128	0.22	62	76	76
DFG-WPCL	PCB	PCB 137	0.22	62	47	47
DFG-WPCL	PCB	PCB 138/158	0.25	62	100	100
DFG-WPCL	PCB	PCB 141	0.22	62	71	71
DFG-WPCL	PCB	PCB 146	0.22	62	100	100
DFG-WPCL	PCB	PCB 149	0.25	62	97	97
DFG-WPCL	PCB	PCB 151	0.22	62	90	90
DFG-WPCL	PCB	PCB 153	0.44	62	100	100
DFG-WPCL	PCB	PCB 156	0.22	62	56	56
DFG-WPCL	PCB	PCB 157	0.22	62	21	21
DFG-WPCL	PCB	PCB 169	0.22	62	2	2
DFG-WPCL	PCB	PCB 170	0.22	62	98	98
DFG-WPCL	PCB	PCB 174	0.22	62	71	71
DFG-WPCL	PCB	PCB 177	0.22	62	82	82
DFG-WPCL	PCB	PCB 180	0.25	62	100	100
DFG-WPCL	PCB	PCB 187	0.25	62	100	100
DFG-WPCL	PCB	PCB 189	0.22	62	5	5
DFG-WPCL	PCB	PCB 194	0.22	62	68	68
DFG-WPCL	PCB	PCB 195	0.22	62	44	44
DFG-WPCL	PCB	PCB 198	0.22	62	3	3
DFG-WPCL	PCB	PCB 199	0.22	62	77	77
DFG-WPCL	PCB	PCB 200	0.22	62	6	6
DFG-WPCL	PCB	PCB 201	0.22	62	42	42
DFG-WPCL	PCB	PCB 203	0.22	62	76	76
DFG-WPCL	PCB	PCB 206	0.22	62	48	48
DFG-WPCL	PCB	PCB 209	0.22	62	32	32
AXYS	DIOXIN	HpCDD, 1,2,3,4,6,7,8-	0.09	28	79	50
AXYS	DIOXIN	HpCDF, 1,2,3,4,6,7,8-	0.06	28	32	32
AXYS	DIOXIN	HpCDF, 1,2,3,4,7,8,9-	0.06	28	0	0
AXYS	DIOXIN	HxCDD, 1,2,3,4,7,8-	0.07	28	25	25
AXYS	DIOXIN	HxCDD, 1,2,3,6,7,8-	0.07	28	82	82
AXYS	DIOXIN	HxCDD, 1,2,3,7,8,9-	0.06	28	29	29
AXYS	DIOXIN	HxCDF, 1,2,3,4,7,8-	0.06	28	25	25
AXYS	DIOXIN	HxCDF, 1,2,3,6,7,8-	0.06	28	36	36

Laboratory	Class	Analyte	Method Detection Limit	Number of Samples	Frequency of Detection (%)	Frequency of Reporting (%)
AXYS	DIOXIN	HxCDF, 1,2,3,7,8,9-	0.06	28	0	0
AXYS	DIOXIN	HxCDF, 2,3,4,6,7,8-	0.06	28	21	21
AXYS	DIOXIN	OCDD, 1,2,3,4,6,7,8,9-	0.1	28	82	0
AXYS	DIOXIN	OCDF, 1,2,3,4,6,7,8,9-	0.06	28	7	7
AXYS	DIOXIN	PeCDD, 1,2,3,7,8-	0.11	28	86	86
AXYS	DIOXIN	PeCDF, 1,2,3,7,8-	0.07	28	93	93
AXYS	DIOXIN	PeCDF, 2,3,4,7,8-	0.08	28	96	96
AXYS	DIOXIN	TCDD, 2,3,7,8-	0.11	28	61	61
AXYS	DIOXIN	TCDF, 2,3,7,8-	0.09	28	100	100
DFG-WPCL	PBDE	PBDE 030	0.06	21	0	0
DFG-WPCL	PBDE	PBDE 047	0.08	21	100	100
DFG-WPCL	PBDE	PBDE 049	0.06	21	100	100
DFG-WPCL	PBDE	PBDE 066	0.06	21	48	48
DFG-WPCL	PBDE	PBDE 085	0.12	21	0	0
DFG-WPCL	PBDE	PBDE 099	0.12	21	67	67
DFG-WPCL	PBDE	PBDE 100	0.12	21	100	100
DFG-WPCL	PBDE	PBDE 138	0.12	21	0	0
DFG-WPCL	PBDE	PBDE 153	0.12	21	10	10
DFG-WPCL	PBDE	PBDE 154	0.12	21	57	57
DFG-WPCL	PBDE	PBDE 179	0.24	21	0	0
DFG-WPCL	PBDE	PBDE 183	0.24	21	0	0
DFG-WPCL	PBDE	PBDE 184	0.24	21	0	0
DFG-WPCL	PBDE	PBDE 188	0.24	21	0	0
DFG-WPCL	PBDE	PBDE 190	0.24	21	0	0
DFG-WPCL	PBDE	PBDE 201	0.24	21	0	0
DFG-WPCL	PBDE	PBDE 202	0.24	21	0	0
DFG-WPCL	PBDE	PBDE 206	0.59	21	0	0
DFG-WPCL	PBDE	PBDE 207	0.59	21	0	0
DFG-WPCL	PBDE	PBDE 208	0.59	21	0	0
DFG-WPCL	PBDE	PBDE 209	2.35	21	0	0
AXYS	PFAS	Perfluorobutanesulfonate	1	17	0	0
AXYS	PFAS	Perfluorobutanoate	0.56	17	0	0
AXYS	PFAS	Perfluorodecanoate	0.51	17	29	29

Laboratory	Class	Analyte	Method Detection Limit	Number of Samples	Frequency of Detection (%)	Frequency of Reporting (%)
AXYS	PFAS	Perfluorododecanoate	0.5	17	29	29
AXYS	PFAS	Perfluoroheptanoate	0.5	17	0	0
AXYS	PFAS	Perfluorohexanesulfonate	1	17	0	0
AXYS	PFAS	Perfluorohexanoate	0.5	17	0	0
AXYS	PFAS	Perfluorononanoate	0.5	17	0	0
AXYS	PFAS	Perfluorooctanesulfonamide	0.6	17	41	41
AXYS	PFAS	Perfluorooctanesulfonate	1	17	76	76
AXYS	PFAS	Perfluorooctanoate	0.5	17	0	0
AXYS	PFAS	Perfluoropentanoate	0.5	17	6	6
AXYS	PFAS	Perfluoroundecanoate	0.5	17	18	18

Table 3. Human Consumption Risk Thresholds. These thresholds for concern were established in an assessment of human health risk from these pollutants by OEHHA (Klasing and Brodberg, 2008; Smith et al. 2016). All values are presented in ppb wet weight. One serving is defined as 8 ounces (227 g) prior to serving. The fish contaminant goals and advisory tissue levels for mercury are for the most sensitive population (i.e. women aged 18 to 45 years and children aged 1 to 17 years).

Pollutant	**Advisory Tissue Level (7 servings/week)**	**Advisory Tissue Level (6 servings/week)**	**Advisory Tissue Level (5 servings/week)**	**Advisory Tissue Level (4 servings/week)**	**Advisory Tissue Level (3 servings/week)**	**Advisory Tissue Level (2 servings/week)**	**Advisory Tissue Level (1 serving/week)**	**Advisory Tissue Level (No Consumption)**
Mercury	≤31	>31-36	>36-44	>44-55	>55-70	>70-150	>150-440	>440
PCBs	≤9	>9-10	>10-13	>13-16	>16-21	>21-42	>42-120	>120
Selenium	≤1000	>1000-1200	>1200-1400	>1400-1800	>1800-2500	>2500-4900	>4900-15000	>15000
PBDEs	≤45	>45-52	>52-63	>63-78	>78-100	>100-210	>210-630	>630

Table 4. Summary Statistics by Species.

Species	Tissue Type	Approximate Number of Fish per Composite[2]	Number of Samples[3] Analyzed	Average Concentrations									
				% moisture	% lipid[4]	Sum of PCBs	PCB-40	PBDE	PFC	Dioxin	Hg	Se (ww)	Se (dw)
Screening values						**10**					**0.2**		
Barred Surfperch	Muscle fillet	4	1	78.2	0.45	4.7	4.4				0.4		
Black perch	Muscle fillet	10	3	78.7	0.51	7.0	6.7				0.1		
California halibut	Muscle fillet	3	3	76.1							0.3	0.6	2.3
Jacksmelt	Whole without head, tail or guts	10	6	75.4							0.0	0.3	1.2
Northern anchovy	Whole without head, tail or guts	20-30	6	80.1	2.00	78.3	73.5				0.1		
Pacific sardine	Whole without head, tail or guts	10	1	72.0	4.57	247.0	232.4						
Pile Surfperch	Muscle fillet	10	1	78.6	0.47	4.6	4.4				0.1		
Shiner surfperch	Whole without head, tail or guts	20	16 (3 for PFCs)	77.8	2.31	95.4	90.1	4.7	1.9	0.8	0.1	0.4	1.7

Species	Tissue Type	Approximate Number of Fish per Composite[2]	Number of Samples[3] Analyzed	Average Concentrations									
				% moisture	% lipid[4]	Sum of PCBs	PCB-40	PBDE	PFC	Dioxin	Hg	Se (ww)	Se (dw)
Screening values						**10**					**0.2**		
Staghorn sculpin	Whole without head, tail or guts	> 10	4	79.9	0.62	26.6	28.3				0.1		
Striped bass[1]	Muscle fillet	3 (Central & San Pablo Bay)	6 (4 for PCBs; 2 for PFCs)	78.3	0.52	10.8	10.7		9.1		0.3	0.4	1.9
Striped bass[1]	Muscle fillet	1 (Suisun Bay)	6 (2 for PCBs; 1 for PFCs)										
Striped bass[1]	Muscle fillet	3 (Artesian Slough)	3	76.7	1.2	17.3	16.7	10.6	14.0				
Striped bass[1]	Muscle fillet	1 (Artesian Slough)	8								0.6		
Walleye Surfperch	Muscle fillet	7	1	78.6	0.43	8.2	7.8				0.2		
White sturgeon	Muscle fillet	3	4 (3 for PFCs)	78.6	1.11	41.4	46.5		0.7		0.5		
White Sturgeon	Muscle fillet	1	12									1.5	7.0
White sturgeon	Muscle plug	1	12	77.6								1.3	6.0
White sturgeon	Ovary	1	3	67.0								2.1	6.3
White Surfperch	Muscle fillet	10	2	77.5	0.51	8.7	8.3				0.1		

Species	Tissue Type	Approximate Number of Fish per Composite[2]	Number of Samples[3] Analyzed	Average Concentrations									
				% moisture	% lipid[4]	Sum of PCBs	PCB-40	PBDE	PFC	Dioxin	Hg	Se (ww)	Se (dw)
Screening values						**10**					**0.2**		
Largemouth Bass	Muscle fillet	5	1	77.8	0.76	19.4	18.2	48.4	20.2				
Largemouth Bass	Muscle fillet	1	12								0.2		
Carp	Muscle fillet	1	1	76.6	1.3	18.9	18.1	53.5	19.9		0.1		
White croaker[5]	Whole body, skin on	1	12	73.9	4.29	153.6	143.7		7.2	1.4	0.2	0.6	2.2

1 – PCBs in striped bass were analyzed in 4 composites caught in Central Bay, 2 individuals caught in Suisun Bay, and 3 individuals caught in Artesian Slough. PBDEs in striped bass were analyzed in 3 fish caught in the Artesian Slough. PFAS in striped bass were analyzed in 2 composites caught in Central Bay, 2 individuals caught in Suisun Bay, and 3 individuals caught in Artesian Slough. Mercury was measured in all striped bass samples. Size-standardized mercury concentrations are not reported here. Selenium was measured in all striped bass composites.

2 – In cases in which the number of fish per composite is 1, contaminants were analyzed in individual fish.

3 – Samples refer to composite or individual fish samples. The number of samples included in the average concentration may vary slightly, in cases in which analytical results have not met all QA/QC criteria and have been excluded from data analysis.

4 – Lipid measurements were only conducted on samples that were analyzed for organic parameters.

5 – White croaker samples were processed as whole body composites, rather than skin-off (or skin-on) fillets. Results are provided in this table for reference, but should not be used for comparison against regulatory or human consumption thresholds, and should not be directly compared to historical results measured in skin-on or skin-off white croaker fillets.

Table 5. Exceedances of water quality thresholds. Counts of samples exceeding water quality objectives (mercury and PCBs), numeric targets (selenium), and screening levels (dioxins) established by the San Francisco Bay Regional Water Quality Control Board in TMDL control plans (number of samples above the threshold / number of total samples analyzed).

Common Name	Sample Type	Mercury ppm ww	Selenium ppm dw	Sum of PCBs ppb ww	Sum of Dioxin TEQs pptr ww
TMDL Targets or Screening Levels		**0.2**	**11.3**	**10**	**0.14**
Shiner surfperch	Composite	0/16	0/16	0/16	16/16
Striped bass	Composite/Individual	18/20	0/6	6/9	
White sturgeon (Muscle Fillet)	Composite	3/4		4/4	
White sturgeon (Muscle Fillet)	Individual		2/12		
White sturgeon (Muscle Plug)	Individual		1/12		
Northern anchovy	Composite	0/6		6/6	
Staghorn sculpin	Individual	0/4		4/4	
Black perch	Composite	0/3		1/3	
California halibut	Composite	2/3	0/3		
Jacksmelt	Composite	0/6	0/6		
Pacific sardine	Composite			1/1	
Barred Surfperch	Composite	1/1		0/1	
Walleye Surfperch	Composite	0/1		0/1	
White Surfperch	Composite	0/2		2/2	
Pile Surfperch	Composite	0/1		0/1	
Common Carp	Individual	0/1		1/1	
Largemouth Bass	Individual	6/12		1/1	

Table 6. Perfluorinated compounds in San Francisco Bay fish, 2014.

Location	Species	Analyte Name (ppb ww)													
		PFUnA	PFPA	PFOA	PFOS	PFOSA	PFNA	PFHxA	PFHxS	PFHA	PFDoA	PFDA	PFBA	PFBS	Sum of PFASs
Suisun Bay	Striped Bass				6.63	1.20									7.83
San Pablo Bay	White Sturgeon														
San Francisco Waterfront	Shiner Perch														
Oakland	Shiner Perch				1.85										1.85
Oakland	White Croaker				4.68	1.81					0.67				7.16
Oakland	White Croaker		0.72		1.98	1.29									3.99
Central Bay	Striped Bass														
Central Bay	Striped Bass				3.16	1.36									4.52
Central Bay	White Sturgeon														
South Bay	Shiner Perch				3.72										3.72
South Bay	White Croaker				6.96	2.88						0.64			10.48
South Bay	White Sturgeon				2.00										2.00
Artesian Slough	Common Carp	2.23			8.98						4.17	4.56			19.94
Artesian Slough	Largemouth Bass	1.41			14.20						2.08	2.50			20.19
Artesian Slough	Striped Bass	0.62			17.20	1.98					0.60	1.98			22.38
Artesian Slough	Striped Bass				12.70	2.06					0.95	1.55			17.26
Artesian Slough	Striped Bass				2.47										2.47

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Appendix A – Data Management

1. Data Management and Reporting

Data received from the analytical laboratories are formatted, summed (see Section 2 below), QA/QC reviewed, and uploaded to the local Regional Data Center. These data are not publicly published to CD3 or CEDEN until the report is published. Data used for statistical analysis, figure development, and reporting are obtained only through Regional Data Center queries. Standard data query requests, rules, and additional data processing steps that were used in the current report are detailed below.

Standard Data Query Rules

1. Non-detect results are reported as half the method detection limit for inorganic compounds (mercury, selenium) and as zero for organic compounds (PCBs, dioxins, PBDEs, and PFASs). Organic sums are calculated by assuming non-detect results are equal to zero.
2. Rejected results are not reported (i.e., censored). Organic sums that are classified as "no reportable sum," are not reported, but results for the individual congeners for those samples are reported if they are not themselves rejected. For PCBs and dioxins, other sums calculated for those samples and also are not reported. Qualified results are reported, along with the QACode field.
3. Laboratory replicates are not reported in this report. Replicates are not averaged, but are used only for evaluation of analytical precision. If the analytical precision meets data quality objectives in the RMP QAPP, results will not be qualified and only the first laboratory replicate (i.e. LabReplicate field = 1) is reported. If results from the first laboratory replicate are rejected, results from the second laboratory replicate should be reported, if they are not also rejected.
4. QA/QC results are not reported. Staff can review QA/QC results separately from data queries that are used for statistical analysis and figure development.

Standard Data Query Requests

Two standard data queries are produced – one with all data from the current year of sampling, and one with all historical data for species used in trend analysis. Data query requests should include the project codes, analyte names and/or groups (typically all individual congeners and the sums described in Section 2 are reported), and fish species to be reported. Any deviations from the query rules above or fields listed in Table A-1 should be specified.

Beginning in 2014, long-term trend analyses of PCBs and dioxins have included RMP data as well as data collected during the 1994 Bay Protection Toxic Cleanup Program study (ProjectCode = 1994 BPTCP; RMP studies follow the convention: ProjectCode = [XXXX Year] RMP FISH). However, some data collected during the BPTCP study are excluded from trend analyses at locations that were not subsequently monitored by the RMP. A lookup table is used to categorize 1994 sampling locations based on current RMP locations used (Table A-2).

Historical mercury in striped bass and selenium in white sturgeon data are maintained in separate spreadsheets, which include historical data from non-RMP projects. Striped bass mercury data are also length-standardized before trend analyses.

Additional Data Processing Steps

Several additional standard data processing steps are needed to ensure data are properly compared. Selenium results for white sturgeon have historically been reported in multiple tissues collected from the sample fish. The TissueCode and TissueName fields are FIL, MUSC, NADS or fillet, muscle, and gonads for muscle fillet, muscle plugs, and ovary samples, respectively. Samples collected in tissues not relevant to a particular analysis (i.e. comparison to OEHHA or Water Board thresholds) should be excluded.

Additionally, multiple sample processing methods have been used for white croaker samples, which are described in detail in the main report and Appendix B. Careful review and discussion of the sample processing type should be used before reporting historical results on a wet weight basis. In 1997 and 2009, both skin-on and skin-off fillets were measured for certain organic contaminants. To prevent analyses using results from multiple samples of the same fish, samples measured using one of these processing methods should be excluded. Both the TissueCode and PrepPreservationName fields are needed to fully describe the sample processing method (Table A-3).

In some cases, a replicate result exists for a sample for which a result was rejected and not reported. In these cases, the replicate result is reported in place of the rejected result.

2. Organic Contaminant Sums

Sums of organic contaminant classes are calculated by summing the concentrations of individual congeners within each contaminant class. Although some sums are provided by the laboratories, all organic sums are recalculated by the RMP using the rules described below. Six organics sums are calculated:

- Sum of 40 PCBs
- Sum of PCBs
- Sum of Dioxins-Furans TEQs (WHO 2005; ND=0)
- Sum of Dioxins-Furans TEQs (WHO 2005; ND=MDL)
- Sum of PBDEs
- Sum of PFCs

Congeners that are included in the sum of 40 PCBs are in Table A-4 (Davis et al. 2014). Due to changes in analytical methods, different numbers of congeners are included in this sum of PCBs measured each year. To analyze temporal trends using comparable values, the RMP uses a sum of 40 PCBs (Davis et al. 2014). The “Sum of PCBs” is a sum of all congeners reported, and is used for comparisons with thresholds and analyses of spatial trends.

Congeners included in all other sums are listed in Table 2 of the main report. These sums are calculated using a Summing Table saved in an Access Database that includes all current and historically reported congeners. Dioxins-Furans TEQs sums are calculated using the analyte list and toxic equivalency factors in Table A-5 (WHO 2005). The number of individual and co-eluted congeners reported by different analytical laboratories may vary from year to year, and this Summing Table should be reviewed prior to calculating any sums for analysis.

Organic sums are calculated by assuming non-detect results are equivalent to zero. Because at current method detection limits, many dioxins-furans results are reported as non-detect, the effect of this assumption is qualitatively assessed by comparing sums calculated using two methods: one assuming non-detect results are equal to zero, and one assuming non-detect results are equal to the method detection limit. Only sums calculated using the ND = 0 assumption are reported.

The validity of these organic sums is assessed by comparing congener percent contributions to the sum in the current sampling round to those calculated over the last three rounds of sampling (2003, 2006, and 2009). This method of qualifying or rejecting organic sums is not used if fewer than three previous rounds of sampling have occurred (i.e., PFASs in sport fish). Expected percent contributions tables based on historical data are calculated after each sampling round by (1) calculating the percent contribution of each congener to the sum in all individual samples in the previous three sampling rounds for which the result or sum is not rejected, and (2) calculating the mean percent contribution across these samples. When calculating sums for current samples, if congeners that have historically contributed 30% or more of the sum are rejected (i.e. calculated by summing the expected percent contributions for congeners that are rejected in a current sample), that sum is classified as “no reportable sum,” and is not used for analysis. Sums for which congeners that add up to 30% or more of the historical sums are either rejected or not detected are qualified.

3. Lipid Percent Measurements

Fish lipid content can vary substantially by species, year, and sample preparation method (skin-on, skin-off, whole body, etc.). Lipid-normalized results can provide a better index of trends in contaminant exposure in the Bay food web over time, compared to wet weight results.

Percent lipid measurements are typically measured by each laboratory that measures organic contaminants. However, historically, percent lipid measurements were not reported by some laboratories, and instead were estimated using the percent lipid measured for that same fish or composite by another analytical laboratory. A small number of results (36 dioxins results from a single white croaker composite collected in 1997) could not be matched to percent lipid values using these methods and were excluded from lipid weight analyses.

Data queries are provided as cross-tab tables with a field for percent moisture and percent lipid measurements for each sample and analytical result. In most cases, the percent moisture and lipid are matched with a particular analytical result using the CompositeID and the analytical agency name. When one of these measurements is estimated using values from another analytical agency, results are matched based only on the CompositeID field. A spreadsheet with the matched percent lipid data is saved in the 2014 Sport Fish project folder in a subfolder titled “Final Project Files.”

Table A-1. Standard Fields in RMP Sport Fish Data Query

Field	Descriptor / Notes
ProjectName	Equivalent to ProjectCode for Sport Fish as of 2014.
ProjectCode	1994 BPTCP or [Year] RMP FISH
StationCode	
StationName	
SampleDateMax	
CommonName	
TissueCode	WNHTG or FIL; white sturgeon samples also include MUSC and NADS
TissueName	Whole, no head tail or guts; or fillets; white sturgeon samples also include muscle (muscle plugs) or gonads (ovaries)
PrepPreservationName	
NumberInComposite	
TotalLengthAvg	
UnitLengthFish	
CompositeRowID	
CompositeID	
CompositeReplicate	
CompositeType	
ExportData	
ComplianceCode	
SampleTypeCode	
TissueResultRowID	
MatrixName	
MethodName	
AnalyteName	
AnalyteGroup	
UnitName	
LabReplicate	
Result	
ResQualCode	
MDL	
QACode	
LabBatch	
SumGroup	
SumFlag	
LipidPct	Crosstab field
LipidConc	Calculated field based on Result and LipidPct
PctMoisture	Crosstab field

Table A-2. RMP Sport Fish Historical Location Lookup Table. Crosswalk between StationCode and StationName used in the 1994 BPTCP and 1997-2014 RMP FISH project databases and the Location used in RMP reports.

StationCode	StationName	Location
2RMPBERP	Berkeley Pier-2RMPBERP	Berkeley
2RMPDMB	Dumbarton Bridge-2RMPDMB	South Bay
2RMPDRCP	Double Rock (Candlestick)-2RMPDRCP	Other
2RMPIC	Islais Creek-2RMPIC	Other
2RMPOIHF	Oakland Inner Harbor (Fruitvale)-2RMPOIHF	Oakland
2RMPOIHP	Oakland Middle Harbor Pier-2RMPOIHP	Other
2RMPPM	Point Molate-2RMPPM	Other
2RMPRH	Richmond Harbor-2RMPRH	Other
2RMPROD	Rodeo-2RMPROD	San Pablo Bay
2RMPSFP7	San Francisco Waterfront (Pier 7)-2RMPSFP7	San Francisco Waterfront
2RMPSMB	San Mateo Bridge-2RMPSMB	Other
2RMPVMI	Vallejo-Mare Island-2RMPVMI	Other
2RMPBERKI	Berkeley-2RMPBERKI	Berkeley
2RMPOAK	Oakland-2RMPOAK	Oakland
2RMPSFW	San Francisco Waterfront-2RMPSFW	San Francisco Waterfront
2RMPSOB	South Bay-2RMPSOB	South Bay
2RMPSPB	San Pablo Bay-2RMPSPB	San Pablo Bay
2RMPBERK	Berkeley-2RMPBERK	Berkeley
2RMPOAKI	Oakland-2RMPOAKI	Oakland
2RMPSFWI	San Francisco Waterfront I-2RMPSFWI	San Francisco Waterfront
2RMPSLB	San Leandro Bay-2RMPSLB	Oakland
2RMPSOBI	South Bay-2RMPSOBI	South Bay
2RMPSPBI	San Pablo Bay-2RMPSPBI	San Pablo Bay
2RMPBERK3	Berkeley-2RMPBERK3	Berkeley
2RMPOIH	Oakland Inner Harbor - 2RMPOIH	Oakland
2RMPSFW3	San Francisco Waterfront-2RMPSFW3	San Francisco Waterfront
2RMPSOB3	South Bay-2RMPSOB3	South Bay
2RMPSPB3	San Pablo Bay-2RMPSPB3	San Pablo Bay
207SUISUN		Suisun Bay
206CARQNZ		Carquinez Strait
206SNPBLO		San Pablo Bay
203BRKLEY		Berkeley
203OAKLND		Oakland
203SANFRN		San Francisco Waterfront
203CENTRL		Central Bay
204STHBAY		South Bay
ARTSLGH		Artesian Slough

Table A-3. White croaker sample processing method lookup table. The TissueCode, TissueName, and PrepPreservationCode are database fields provided by the analytical laboratory and saved in the Regional Data Center. The Processing Method is a simplified field used to categorize samples that are comparable on a wet weight basis.

TissueCode	TissueName	PrepPreservationCode	Processing Method
FIL	Fillet	Skin on, Scales Off	Fillet – skin on
FIL	Fillet	Skin on, Scales on	Fillet – skin on
FIL	Fillet	Skin off	Fillet – skin off
FIL	Fillet	Skin on	Fillet – skin on
WNHTG	Whole, no head tail or guts	Skin on, Scales Off	Whole body – skin on

Table A-4. Sum of 40 PCBs analyte list. IUPAC numbers are listed. Congeners that are starred are included in the standard Sum of 40 PCBs (SFEI) list but were not analyzed in sport fish in 2014.

Polychlorinated Biphenyls (PCBs)			
PCB 008	PCB 066	PCB 118	PCB 170
PCB 018	PCB 070	PCB 128	PCB 174
PCB 028	PCB 074	PCB 132*	PCB 177
PCB 031	PCB 087	PCB 138	PCB 180
PCB 033	PCB 095	PCB 141	PCB 183*
PCB 044	PCB 097	PCB 149	PCB 187
PCB 049	PCB 099	PCB 151	PCB 194
PCB 052	PCB 101	PCB 153	PCB 195
PCB 056	PCB 105	PCB 156	PCB 201
PCB 060	PCB 110	PCB 158	PCB 203

Table A-5. Sum of Dioxins-Furans TEQs analyte list. Congeners and toxic equivalency factors used to calculate toxic equivalency quotients and the Sum of Dioxins-Furans TEQs (WHO 2005).

Compound	**WHO 2005 TEF**
Chlorinated dibenzo-p-dioxins	
TCDD, 2,3,7,8-	1
PeCDD, 1,2,3,7,8-	1
HxCDD, 1,2,3,4,7,8-	0.1
HxCDD, 1,2,3,6,7,8-	0.1
HxCDD, 1,2,3,7,8,9-	0.1
HpCDD, 1,2,3,4,6,7,8-	0.01
OCDD, 1,2,3,4,6,7,8,9-	0.0003
Chlorinated dibenzofuran	
TCDF, 2,3,7,8-	0.1
PeCDF, 1,2,3,7,8-	0.03
PeCDF, 2,3,4,7,8-	0.3
HxCDF, 1,2,3,4,7,8-	0.1
HxCDF, 1,2,3,6,7,8-	0.1
HxCDF, 1,2,3,7,8,9-	0.1
HxCDF, 2,3,4,6,7,8-	0.1
HpCDF, 1,2,3,4,6,7,8-	0.01
HpCDF, 1,2,3,4,7,8,9-	0.01
OCDF, 1,2,3,4,6,7,8,9-	0.0003

Appendix B – White Croaker PCB and Dioxin Trends

White croaker and shiner surfperch, high-lipid benthic species with the highest concentrations of PCBs and dioxins of all species monitored in San Francisco Bay, have been established in the PCBs TMDL as key indicator species for evaluating current levels and trends in PCBs and dioxins exposure in San Francisco Bay sport fish. White croaker tend to have larger and more variable ranges than shiner surfperch, and thus concentrations measured in this species represent a more spatially integrated assessment of contaminant exposure in the Bay. Additionally, long-term time series of PCBs and dioxins in white croaker have been established by the Bay Protection Toxic Cleanup Program (BPTCP) (Fairey et al. 1997) and RMP.

Recent variation in the white croaker sample processing method prevents an evaluation of long-term trends based on white croaker wet weight data. Between 1994 and 2006, white croaker samples were processed as skin-on fillets. In 2009, a comparison of samples processed as fillets with the skin-on and skin-off showed that PCB concentrations were significantly lower in white croaker when samples were processed as muscle fillets with the skin off rather, a preparation that reduces the lipid content of the samples. Subsequent analyses of white croaker samples were planned using muscle fillets with the skin-off. However, in 2014, white croaker samples were mistakenly processed as whole fish instead of fillets, a sample preparation that would have lower lipid content than skin-on fillets and higher lipid content than skin-off fillets. Because whole-body samples do not reflect recommendations for culinary preparation, PCB concentrations in these samples should not be compared to recommended Water Board or OEHHA thresholds.

Additionally, because PCB and dioxin concentrations are strongly influenced by lipid content and the different sample preparation methods substantially affect the lipid content of the samples, historical results cannot be compared to those collected in 2014 on a wet weight basis. Lipid-normalized results, on the other hand, can be better compared between different sample preparation methods, and can provide an index of trends in contaminant exposure in the Bay food web. Different study designs and analytical laboratories were used during the 1994 BPTCP study, so results from 1994 may not be entirely comparable to data subsequently collected by the RMP.

Lipid-weight PCB and dioxin results in white croaker are presented in this Appendix. Results are presented for the entire Bay as well as by region, but statistical analyses of trends were not conducted within each region because of the mobility of this species and the variability in collection locations each year. Results measured in skin-on fillets, but not skin-off fillets, were used when both samples types were available.

In 2014, 12 white croaker composite samples were analyzed, including five fish in each composite (with the exception of one composite that included only four fish). Ten of the 12 samples were collected from Oakland Harbor, while the remaining two samples were collected in South Bay. No samples were collected from other regions of Central Bay or North Bay.

PCBs – Temporal Trend

The lipid-weight PCB concentrations in white croaker support the conclusion, based on the shiner surfperch data, that ambient PCB concentrations do not appear to be declining in the Bay as a whole. A statistically significant but weak decline was observed in the lipid-normalized PCB concentrations between 1994 and 2014 (linear regression: $p=1.0x10^{-3}$; $R^2=0.09$), driven by the relatively high concentrations observed in South Bay and the San Francisco Waterfront in 1994. When 1994 was excluded, no statistically significant trend was observed (linear regression: $p=0.38$; $R^2=-0.003$; Figures B-1 & B-2). White croaker were not collected during the past two or three sampling rounds in San Pablo Bay or Berkeley, respectively, and as a result cannot be used to evaluate the conclusion based on shiner surfperch data that PCB concentrations have been progressively declining in recent years in those areas.

Dioxins – Temporal Trend

In contrast with the shiner surfperch results, the lipid weight dioxin data for white croaker suggest the dioxin concentrations have not changed over time (linear regression, 1994-2014: $p=0.15$; $R^2=-0.02$; Figures B-3 & B-4). The lipid-normalized time series supports the observation that ambient concentrations were higher in 2000 than in years previous or in years since, as was seen in the shiner surfperch data. However, the white croaker data indicate that lipid-normalized dioxins concentrations measured in 2014 are similar to those measured in previous years, in contrast with the lower levels observed in some regions in 2014 in shiner surfperch.

Additional Contaminants

Mercury and selenium were also analyzed in whole-body white croaker composite samples in 2014, but these data are not comparable to established Water Board or OEHHA thresholds and are not presented here. Results for PFAS in white croaker are presented in the main body of the report.

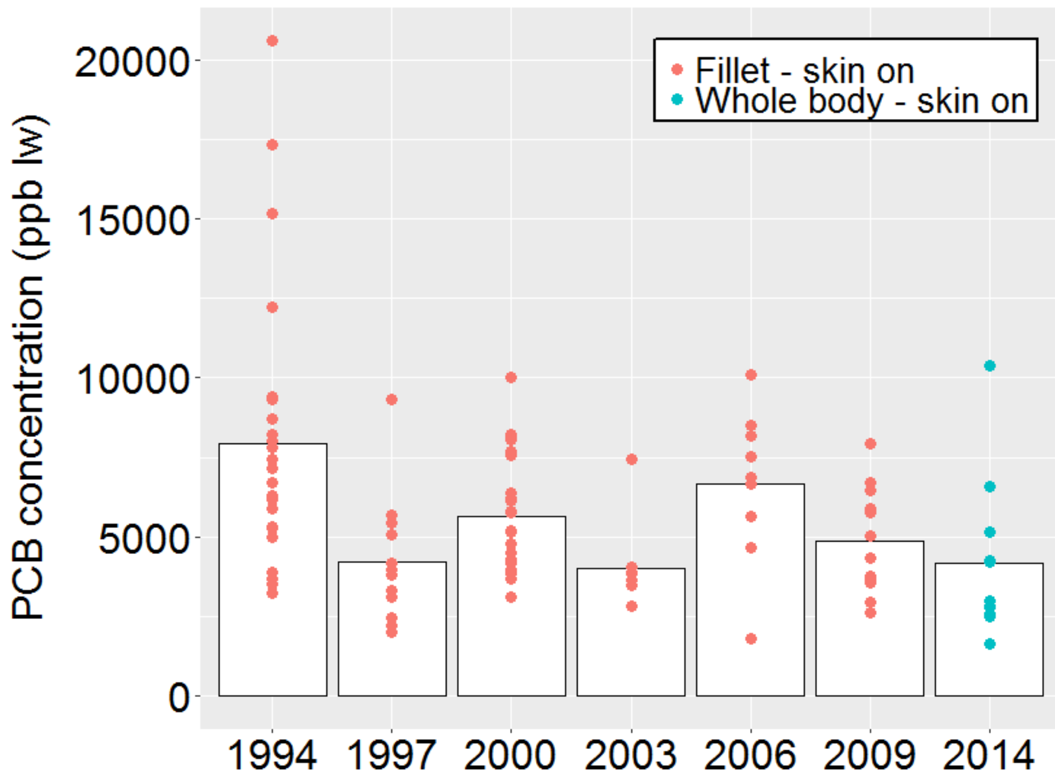

Figure B-1. PCB concentrations (ppb lw) in white croaker in San Francisco Bay, 1994-2014. Bars indicate average concentrations. Points represent composite samples. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included. A weak but statistically significant declining trend in PCB concentrations was observed between 1994 and 2014 (linear regression: $p=1.0 \times 10^{-3}$; $R^2=0.09$), but not when 1994 was excluded (linear regression: $p=0.38$; $R^2=-0.003$).

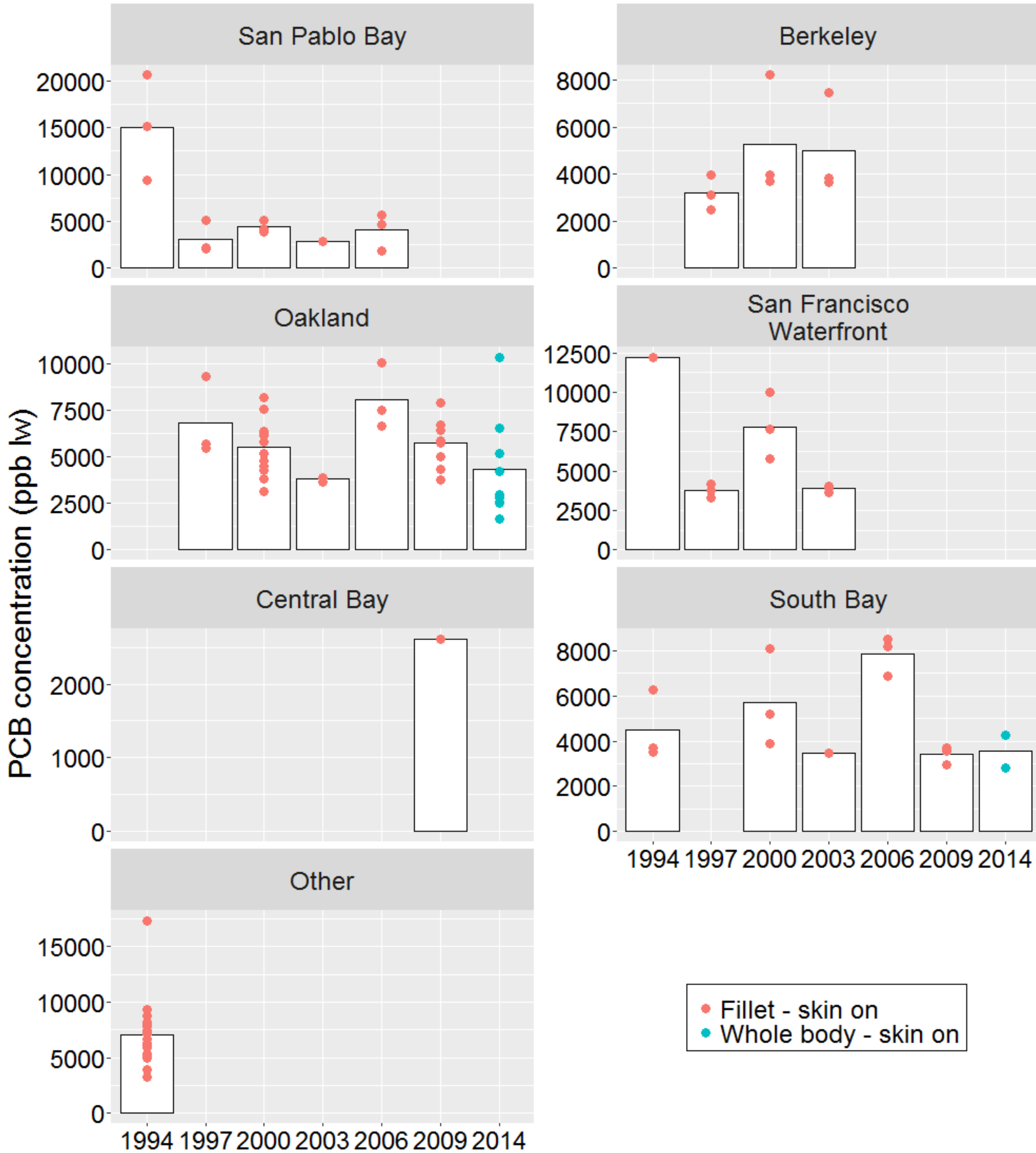

Figure B-2. PCB concentrations (ppb lw) in white croaker in each region of San Francisco Bay, 1994-2014. Bars indicate average concentrations. Points represent composite samples. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years).

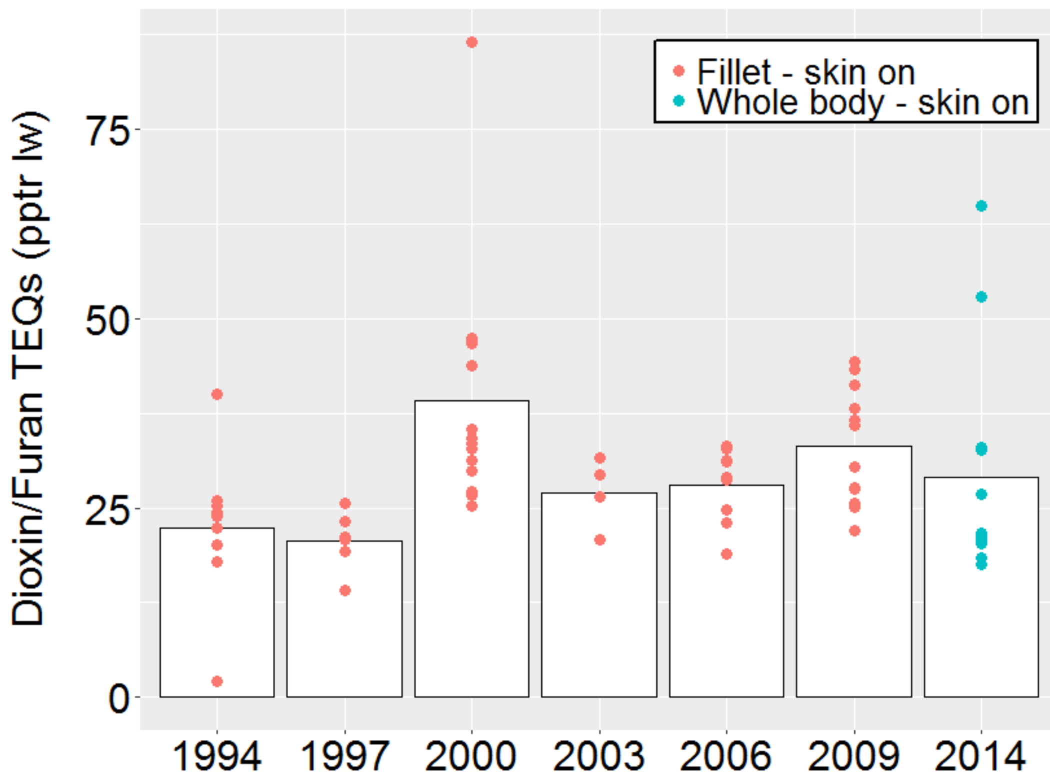

Figure B-3. TEQs$_{PCDD/PCDF}$ (pptr lw) in white croaker in San Francisco Bay, 1994-2014. Bars indicate average concentrations. Points represent composite samples. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included. No statistically significant long-term trend was observed (linear regression: p=0.15; R^2=-0.02)

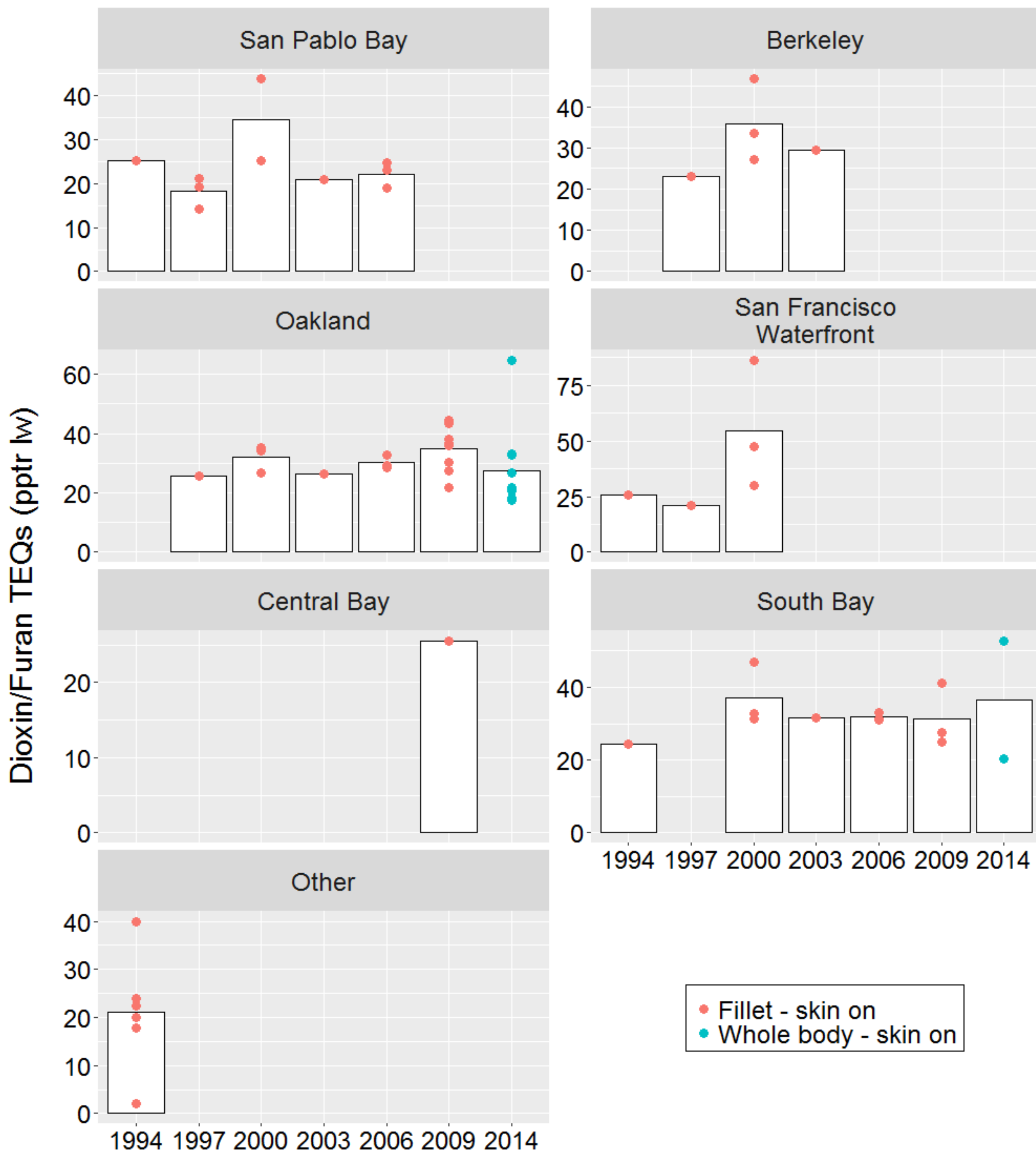

Figure B-4. TEQs$_{PCDD/PCDF}$ (pptr lw) in white croaker in each region of San Francisco Bay, 1994-2014. Bars indicate average concentrations. Points represent composite samples. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included.

Appendix C – Quality Assurance Report

Introduction

In 2014, sport fish samples were collected from 7 areas for the Regional Monitoring Program for Water Quality in San Francisco Bay. Areas targeted included Lower South Bay, South Bay, San Francisco, Oakland, and Berkeley in Central Bay, San Pablo, and Suisun. The details of the sampling collection methods are described in the 2014 Cruise Report for the RMP prepared by Coastal Conservation & Research.

The tissue samples were homogenized by Moss Landing Marine Lab and analyzed for the following compounds by the laboratories indicated:

- *DFG-WPCL – PCBs and PBDEs*
- *Axys – PCDD/Fs, PFCs*
- *MPSL-MLML – Hg and Se*
- *Medallion – C, N, and S isotopes*

The SFEI Data Services Team checked the laboratory results using the methods and data quality objectives in the RMP Quality Assurance Project Plan (QAPP). Overall, 97-100% of the results for each were approved for use in RMP reports and calculations (i.e., not rejected/censored).

This memo provides a high-level summary of the quality assurance assessment for each dataset. Non-conformances with the QAPP were generally minor and of the types seen before, e.g. blank contamination, or high RSDs (low precision) for minor compounds at low concentrations. No special modifications to field or lab procedures appear necessary. The details of the quality assurance assessment of each dataset are provided in Appendix A.

Once approved by the RMP Manager and Lead Scientist, all uncensored results are uploaded to the San Francisco Regional Data Center and CEDEN.

Quality Assurance Summary for 2014 RMP Sport Fish Samples

DFG-WPCL PCBs

PCB data reported by DFG were acceptable, with 97% of field sample results reportable. The most abundant congeners were detected in all samples, but there were extensive NDs for the about half the congeners in many species. A handful of PCBs were found in blanks, with PCB 056/60 detected most often, at concentrations over ⅓ those in field samples, with those results flagged and censored. PCB 070 was also found in one batch at concentrations >⅓ the concentration in some samples and censored. Recoveries were generally good, with PCBs 044, 049, 066, and 126 with recoveries averaging over 35% (but <40%), flagged but not censored. Precision determined from lab and matrix spike replicates were good, with no flags added. Composites within one species at a site occasionally varied greatly, but no flags were added given such variation is often expected. Concentrations were generally in the range seen in previous years.

DFG-WPCL PBDEs

PBDE data reported by DFG were acceptable, with 99% of field sample results reportable. . The most abundant congeners were detected in all samples, but there were extensive NDs for the about ⅔ the congeners in many species. A handful of PBDEs were found in blanks, with BDE 047 detected most often, flagged but not censored. BDE 066 was also found, at concentrations >⅓ the concentration in some samples, which were censored. Recoveries were generally good, with only BDE 047 averaging 37% error (slightly outside the 35% target and flagged but not censored). Precision determined from lab and matrix spike or CRM replicates were mostly good, with only BDE 066 showing a 43% RSD in CRM replicates and flagged VIL but not censored. Concentrations were generally in the range seen in previous years.

Axys PCDD/Fs

PCDD/F data reported by Axys were acceptable with 97% of the field sample results reportable. MDLs were sufficient with <50% non-detects for most analytes, although Hepta-Furans (1,2,3,7,8,9-HxCDF and 1,2,3,4,7,8,9-HpCDF) were 100% NDs. Lipid and moisture had no NDs reported. 1,2,3,4,6,7,8-HpCDD was found in one blank, with 13 field sample results in that batch censored (VRIP flag) for being <3x the blank. Accuracy was evaluated using the CRM [CIL EDF-2525 (2006)], or matrix spikes for analytes not certified in the CRM. Recoveries were generally good, with <35% error, except for 1,2,3,4,6,7,8,9-OCDD and 2,3,4,6,7,8-HxCDF with average errors of 100% and 53%, respectively. All OCDD results were censored for poor recovery (VRIU flag), and 2,3,4,6,7,8-HxCDF results were flagged (VIU) but not censored. OCDD account for very little of total TEQ so its censoring has minor consequences. Precision RSDs for lab and matrix spike replicates were good, ranging from 0% to 11%, all well below the 35% target MQO. Average PCDD/Fs were similar to previous years, ranging from 7% to 101% of 2000-2009 RMP results.

Axys RMP Sport Fish PFCs

PFC data by Axys for RMP sport fish were acceptable, with 97% of the field sample results reportable. Samples were 100% NDs for the majority of analytes, with only the octanesulfonate and octanesulfonamide detected in more than 50% of samples for some species. White croaker was the species with the most analytes detected. None of the target PFCs were detected in blanks. Accuracy was evaluated using the LCS, with recovery within ~15% of the target or better for all analytes in the simple LCS matrix. Precision was evaluated using the lab and matrix spike replicate. Only octanesulfonate and octanesulfonamide were quantifiable in the lab replicate, so RSDs for all other analytes were determined in the MS/MSD instead. RSD's were <10% in all cases for MS/MSDs. Results were similar to 2009 fish results, with many of the analytes ND in 100% of the samples

Axys Artesian Slough PFCs

Axys Artesian Slough fish PFCs were acceptable with 100% of the field samples results reportable. MDLs yielded >50% NDs for 10 of 13 PFCs; with 8 of these being 100% non-detects. No PFCs detected in the method blank. Recoveries in spiked laboratory control samples were generally good, with average %error ranging from 0.50% to 17.5% (within the target 35% MQO). Precision in a lab replicate sample were good detected PFCs (Perfluorodecanoate, Perfluorooctanesulfonamide, and Perfluorooctanesulfonate) with average RSD ranging from 1.65% to 15.6%, all below the 35% target MQO. No additional qualifiers were needed. Average Perfluorooctanesulfonamide and Perfluorooctanesulfonate concentrations were 379% and 642%

of the average 2009 RMP sport fish sample results, respectively, so concentrations here may be generally higher than in the open bay.

MPSL-MLML Hg and Se

Overall the Hg and Se data reported by MPSL-MLML were acceptable, with all results usable for the reported samples. Results were blank subtracted, but the noise in blanks was <MDL. Hg and Se were detected in all field samples. Recoveries on CRMs and MS/MSDs were 15% or better, all well within the <35% error target. Precision on lab replicates was also good, averaging <15% RSDs (well within 35% target). No added flags were needed for recovery or precision. Concentrations of Hg and Se were pretty similar to 2009 results (within 50-150% for both Hg and Se) where the same species were reported across years.

Medallion C N & S Isotopes

The 2014 fish C N isotopes reported by Medallion were acceptable, with all results reportable. No results were reported as non-detects. Isotopes generally do not have blank samples, only quantitation relative to standards. The lab indicated a target of within ~1 per mil of the reference value for the primary standard, which was met. Lab replicates on the CRM were a bit larger than 1 per mil but James Sickman lab PI noted that spread is typical for his instrumentation (rather than the 0.1stdev on the certificate from NIST using much more precise instruments). For isotopes since the numbers are often small/near 0/negative our usual measures of % recovery or %RPD or RSD are probably not appropriate since the divisor may be small or near 0, although the RSDs were all <5%. Recovery on CRMs was within 5% of target values.

Similarly S isotope results were acceptable. We had no prior data for fish S isotopes, but the lab indicated a target of within 0.4 per mil of the reference value for the primary standard, which was met. For S isotopes since the numbers were often small/near 0/negative our usual measures of % recovery or %RPD or RSD are probably not appropriate since the divisor may be small or near 0. Nontetheless, S isotope precision was good, within 15% RSD for laboratory control material (LCMs), and 4% on S mass for replicate field samples (composites with the same site).