CONTAMINANT CONCENTRATIONS IN SPORT FISH FROM SAN FRANCISCO BAY

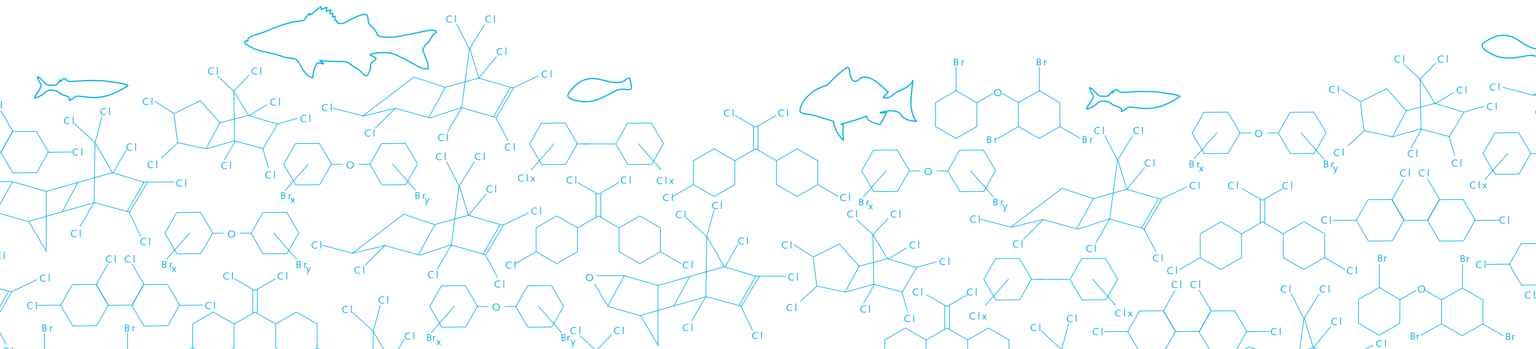
2006

A report by the San Francisco Estuary Institute

and the Regional Monitoring Program for Water Quality in the San Francisco Estuary

www.sfei.org

This report should be cited as:
Contaminant Concentrations in Fish from San Francisco Bay, 2006. J.A. Hunt, J.A. Davis, B.K. Greenfield, A. Melwani, R. Fairey, M. Sigala, D.B. Crane, K. Regalado, and A. Bonnema. 2008. SFEI Contribution #554. San Francisco Estuary Institute, Oakland, CA.



CONTAMINANT CONCENTRATIONS IN SPORT FISH FROM SAN FRANCISCO BAY

2006

Jennifer Hunt

Jay Davis

Ben Greenfield

Aroon Melwani

Rusty Fairey

Marco Sigala

Dave Crane

Kathleen Regalado

Autumn Bonnema

CONTRIBUTION No. 554

AUGUST 2008

A report by the San Francisco Estuary Institute

and the Regional Monitoring Program for Water Quality in the San Francisco Estuary

TABLE OF CONTENTS

5 INTRODUCTION

9 SAMPLING AND ANALYSIS

13 DATA ANALYSIS

15 MERCURY

23 PCBs (POLYCHLORINATED BIPHENYLS)

33 PBDEs (POLYBROMINATED DIPHENYL ETHERS)

37 DIOXINS

41 LEGACY PESTICIDES (DIELDRIN, DDT, AND CHLORDANE)

47 SUMMARY POINTS

49 REFERENCES

51 ACKNOWLEDGMENTS & CREDITS

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. This interim advisory is still in effect.

The advisory states that:

1. women beyond childbearing years and men should limit consumption of Bay sport fish to, at most, two meals per month, including striped bass and sturgeon caught in the Delta

2. women beyond childbearing years and men should not eat any striped bass over 35 inches (89 cm)

3. pregnant women or women that may become pregnant or are breast-feeding, and children should not eat more than one meal of sport fish per month, and should not eat any meals of striped bass over 27 inches (69 cm) or any shark

The advisory does not apply to salmon, anchovies, herring, and smelt caught in the Bay, other ocean-caught sport fish, or commercial fish. The advice was issued due to concern over human exposure to methylmercury and PCBs. Although there has also been concern regarding other contaminants in sport fish, such as dioxins and organochlorine pesticides, the advice is driven by methylmercury and PCBs.

The Clean Water Act requires California and the federal government to adopt and enforce water quality standards to protect the Bay. The Basin Plan and the California Toxics Rule contain these standards. The standards include delineation of beneficial uses of the Bay, numeric and narrative water quality criteria to protect those uses, and provisions to enhance and protect existing water quality. Section 303(d) of the Clean Water Act requires states to compile a list of "impaired" water bodies that do not meet water quality standards (the "303(d) List"). All segments of San Francisco Bay appear on the 303(d) List because the fish consumption advisory represents an impairment of the beneficial use of the Bay for sport fishing. The Clean Water Act also requires that Total Maximum Daily Load (TMDL), 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. A Bay TMDL for mercury has been completed and a Basin Plan Amendment adopted. A TMDL and Basin Plan Amendment for PCBs is awaiting review by the State Water Resources Control Board. In these TMDLs the emphasis is shifting away from enforcement of water quality objectives and toward enforcement of targets that are more directly linked with impairment, particularly methylmercury and PCB concentrations in sport fish and wildlife prey. Concentrations of mercury, PCBs, and other contaminants in sport fish are, therefore, fundamentally important indices of Bay water quality.

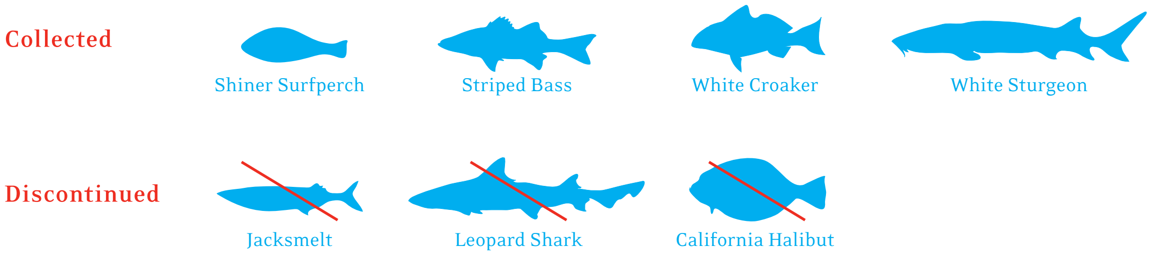
Sport fish monitoring has continued on a three-year cycle since 1994. This report presents findings from the fifth round of RMP sport fish sampling, conducted in 2006. The core of the monitoring program (referred to as "Status and Trends monitoring") targets species that are frequently caught and consumed by Bay anglers at five popular fishing areas in the Bay. This monitoring provides information on long-term trends in mercury, PCBs, legacy pesticides (DDT, dieldrin, and chlordane), PBDEs, and dioxins.

The objectives for the Regional Monitoring Program (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
4. to understand factors that influence contaminant accumulation in sport fish in order to better resolve signals of temporal and spatial trends

SAMPLING AND ANALYSIS

*Fish were collected in the summer of 2006 from the Berkeley and San Francisco waterfronts, Oakland Inner Harbor, San Pablo Bay, and the South Bay (***Figure 1***). These regions were identified as popular fishing areas in 1997 and have been revisited every three years since then for Status and Trends monitoring. The Status and Trends species collected in 2006 included shiner surfperch, striped bass, white croaker, and white sturgeon. Jacksmelt, leopard shark, and California halibut were discontinued from the monitoring program in favor of a greater emphasis on select indicator species for the different contaminants of concern.*



Status and Trends species were analyzed for mercury, PCBs, legacy pesticides, PBDEs, and dioxins (white croaker only). In addition, white sturgeon was analyzed for selenium. In 2006, the RMP analyzed three larger-sized (31-38 cm) white croaker composites in addition to the target size range of 20-30 cm. One larger-sized composite from Oakland and two larger-sized composites from San Pablo Bay were analyzed. A special study was initiated in 2003 to evaluate contaminants in additional Bay species. Continuing this work in 2006, barred surfperch, brown rockfish, black surfperch, Chinook salmon, rubberlip surfperch, walleye surfperch, and northern anchovy were collected and analyzed for PCBs, PBDEs, and mercury.

Fish were caught using gill nets, hook and line, or otter trawls. Each fish was carefully processed using techniques that minimize contact with any potentially contaminated surface. Fish samples were dissected, composited, and analyzed in a manner similar to previous RMP fish sampling. Fillets of muscle tissue were analyzed. For composite samples, equal weight fillets were taken from each fish. Fillets were prepared consistent with typical culinary preparation for each species. All Status and Trends species were prepared without skin except white croaker (with skin) and shiner surfperch (muscle with skin and skeleton). All special study fish were prepared without skin except for walleye surfperch (with skin) and anchovy (whole body). Samples were analyzed using methods established by U.S. EPA and in adherence with the RMP Quality Assurance Project Plan (Lowe et al. 1999). The vast majority of chemical measurements met QA/QC acceptance criteria. Results for a few chemicals - PCB 70, hepta-furan (1,2,3,4,7,8,9-HpCDF), octa-furan (1,2,3,4,6,7,8,9-OCDF), and octa-dioxin (1,2,3,4,6,7,8,9-OCDD) - did not meet QA/QC acceptance criteria, and were not included in any of the graphs, tables, or analyses for this report. There were other contaminants with minor QA issues, but the majority of samples for these contaminants passed QA/QC review (see raw data at www.sfei.org/rmp/data/rmpfishtissue.htm for more information).

Figure 1. *RMP fish sampling locations in San Francisco Bay in 2006.*

DATA ANALYSIS

In this report, contaminant concentrations in fish are compared to "screening values." Screening values are defined as concentrations of chemicals in fish or shellfish tissue that are of potential public health concern. Exceedance of screening values should be taken as an indication that more intensive monitoring and evaluation of human health risk should be conducted. With the exception of methylmercury, PCBs, and dioxins, screening values in this report were published by OEHHA, the organization that uses these data to produce and update fish consumption advisories. Targets for methylmercury, PCBs, and dioxins were provided by the SFBRWQCB, which has established its own screening values for these contaminants in the TMDLs. This report uses the arithmetic average (previous reports used the median), for all data, as a measure of central tendency. The arithmetic mean incorporates samples with high contaminant concentrations (unlike the median), and is thus more conservative for estimating maximum contaminant exposure. **Table 1** *shows the summary statistics for each analyte.*

All data are presented on a wet weight basis unless otherwise noted in order to allow comparison to screening values. For analysis of long-term trends in organic contaminants, data are presented on a lipid weight basis. Lipid content in fish tissue is an important driver of variation in organic contaminant concentrations in space and time. Presenting data on a lipid weight basis adjusts the data for variation due to lipid and thus temporal and spatial trends, if present, become clearer.

This report uses common names for perch species that are slightly different than American Fisheries Society nomenclature in order to be consistent with previous RMP reports (Nelson et al., 2004).

Table 1

	Number in Composite[1]	Number of Composites Analyzed (Hg-Org)	% Lipid	Length	Sum of Aroclors	Sum of PCBs	Dioxins	Mercury	Sum of PBDEs	Sum of Chlordanes	Sum of DDTs	Dieldrin
				(cm)	ppb ww	ppb ww	ppt ww	ppm ww	ppb ww	ppb ww	ppb ww	ppb ww
Screening Value					10	10	0.14	0.20		30	100	2
Anchovy	3	3-3	1.6	9	93	71	NM	0.06	12	NM	NM	NM
Black Surfperch	3	6-6	0.71	27	16	10	NM	0.14	2.7	NM	NM	NM
Brown Rockfish	3	3-3	0.44	25	5.3	3.2	NM	0.15	0.88	NM	NM	NM
Chinook Salmon	3	3-3	3.8	86	8.7	5.6	NM	0.09	1.9	NM	NM	NM
Rubberlip Surfperch	5	4-4	0.48	38	10	8.7	NM	0.35	1.8	NM	NM	NM
Shiner Surfperch	20	0-15	1.2	11	150	92	NM	NM	13	8.5	22	2.3
Walleye Surperch	3	3-3	0.4	31	9	5	NM	0.12	1	NM	NM	NM
White Croaker	5	0-9	4.8	29	470	329	2	NM	56	16	85	1.7
White Sturgeon	3	4-4	1.5	137	88	66	NM	0.28	20	10	36	1.7

1. Composite number is target–actual number in composite may vary by 1 to 2 fish
2. NM = Not Measured

MERCURY

BACKGROUND

Mercury is a toxic heavy metal that accumulates to concentrations of concern in the Bay food web. Mercury contamination of the Bay and its watershed primarily occurred due to mining activity during the 1800s. Historical releases of mercury from mercury and gold mining districts were substantial, and in many cases mercury continues to wash downstream from these areas today. Mercury also enters the Bay from urban runoff, atmospheric deposition, and wastewater discharges. A large amount of mercury is also stored in the deeper sediments of the Bay, and some of this is being remobilized as the Bay floor erodes.

Mercury

Mercury exposure is one of the primary concerns behind the sport fish consumption advisory for the Bay. Mercury reaches higher concentrations in higher levels of the aquatic food web. Predatory fish, birds, and mammals (including humans that consume fish) at the top of the food web are most vulnerable to mercury exposure. Mercury is a neurotoxicant, and is particularly hazardous for fetuses and children as their nervous systems develop. Mercury can cause serious problems, including mental impairment, impaired coordination, and other developmental abnormalities depending on the level of exposure. However, there is uncertainty regarding the exposure level at which impairment occurs in humans (Davidson et al, 2004). The San Francisco Bay sport fish consumption advisory for mercury is protective of the most vulnerable human life stages. Following this advisory will reduce Bay sport fish consumer exposure to mercury. Similarly, in wildlife species, high mercury exposure can cause damage to nervous, excretory, and reproductive systems, and early life stages are most sensitive.

The San Francisco Bay TMDL for mercury was approved by the U.S. EPA in February 2008. Continuing to monitor mercury in sport fish will be crucial in assessing the effectiveness of the TMDL and highlighting additional reductions in mercury required to meet the recovery target. This report is using a fish tissue target of 0.2 parts per million (ppm). This value has been incorporated in the mercury TMDL as the goal for safe consumption of Bay fish (SFBRWQCB, 2006).

In terms of potential risks to humans and wildlife, the most important form of mercury in the aquatic environment is methylmercury, which is readily accumulated by biota and transferred through the food web. Most of the mercury (about 95%) that accumulates in fish tissue is methylmercury. Methylmercury is also the form of mercury of greatest toxicological concern in the environment. In this study, total mercury (all forms of mercury) is measured and is used to estimate the more bioaccumulative form of this contaminant (methylmercury).

This report does not include a new round of striped bass mercury data. Striped bass are the main sport fish indicator for mercury in the Bay. Striped bass samples collected in 2006 are still undergoing analysis for mercury and other pollutants. This work is taking longer because additional analyses are being performed to investigate the influence of striped bass use of freshwater, Bay, and ocean habitats on their level of contamination. A separate report on striped bass will be released after the analysis is completed. All mercury data are presented in parts per million (ppm).

Additional background information on mercury and the sport fish consumption advisory is available at the OEHHA website: www.oehha.ca.gov/fish/pdf/HGfacts.pdf.

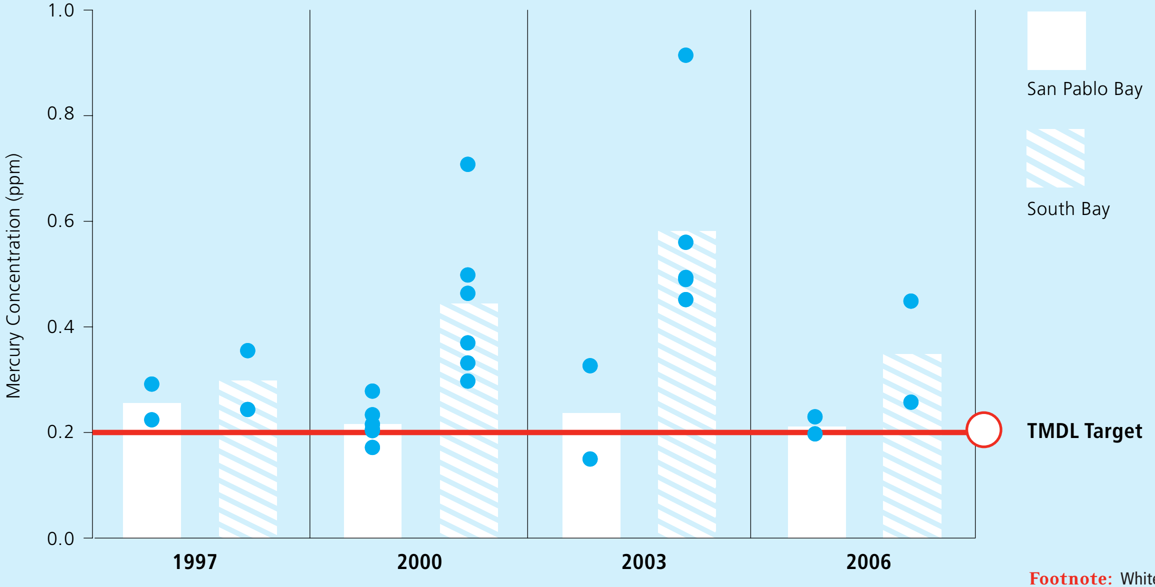
THE LATEST DATA

The RMP is using two species as the main indicators for trends in mercury: striped bass (the primary indicator) and white sturgeon. As explained in the previous section, striped bass data are not included in this report, and will be reported separately.

Sport fish continued to exceed the mercury target of 0.2 ppm. In 2006, three out of the four (75%) white sturgeon samples exceeded the target (**Table 2, Figure 2**). In 2003, 85% of the sturgeon samples exceeded the target. A 30% reduction would be required in 2006 Bay-wide average white sturgeon mercury concentrations in order to meet the target.

Table 2

	Mercury	Sum of Aroclors	Dioxins	Sum of DDTs	Total Chlordanes	Dieldrin
Screening Value	ppm ww	ppb ww	ppt ww	ppb ww	ppb ww	ppb ww
	0.20	10	0.14	100	30	2.0
Anchovy	0/3	3/3	NM	NM	NM	NM
Barred Surfperch	1/1	1/1	NM	NM	NM	NM
Black Surfperch	0/6	6/6	NM	NM	NM	NM
Brown Rockfish	1/3	1/3	NM	NM	NM	NM
Chinook Salmon	0/3	1/3	NM	NM	NM	NM
Rubberlip Surfperch	3/3	2/3	NM	NM	NM	NM
Shiner Surfperch	NM	15/15	NM	0/15	0/15	4/15
Walleye Surfperch	0/2	0/2	NM	NM	NM	NM
White Croaker	NM	9/9	9/9	3/9	1/9	4/9
White Sturgeon	3/4	4/4	NM	0/4	0/4	1/4
All Species (Including Special Study Species)	8/25	42/49	9/9	3/28	1/28	9/28
% of Samples Above SV	32	86	100	11	4	32



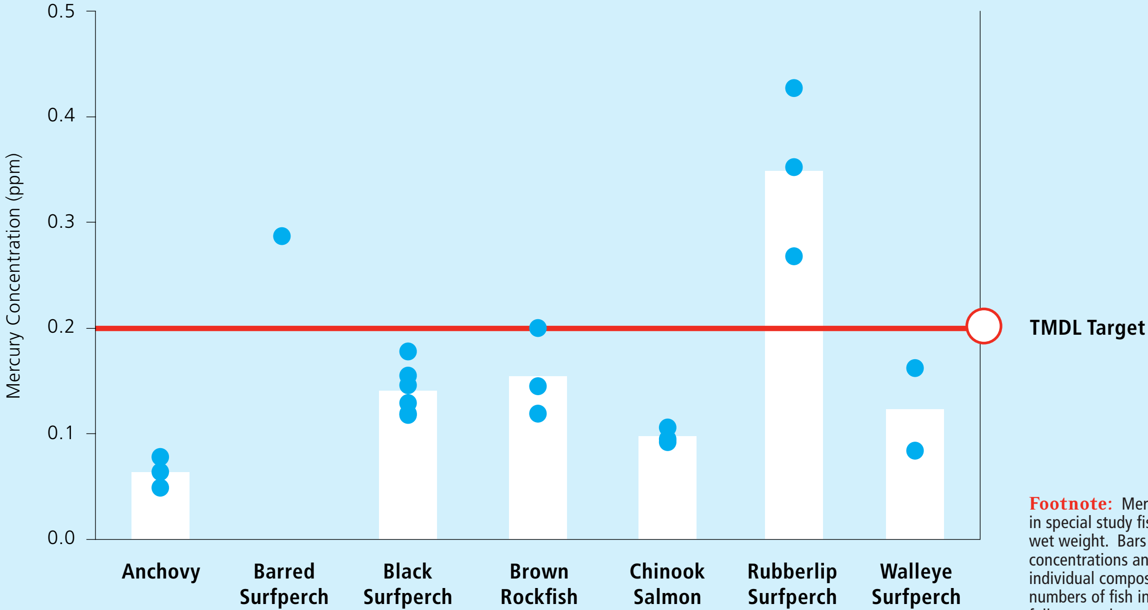
Footnote: White sturgeon mercury concentrations 1997-2006 in ppm wet weight. Bars represent average concentrations and circles represent individual composite samples with three fish in each composite. Red horizontal line — indicates the TMDL target of 0.2 ppm.

Figure 2. *The Bay-wide average concentration for white sturgeon in 2006 was 0.28 ppm. Mercury levels in white sturgeon have varied, but do not suggest an increasing or decreasing long-term trend. Concentrations in the South Bay have been consistently higher than in San Pablo Bay, and have also been more variable.*

In 2006, the RMP analyzed seven other species, in addition to the primary target species, in order to have more comprehensive information on mercury contamination in Bay sport fish. For two of the seven species surveyed, barred surfperch and rubberlip surfperch, mercury concentrations exceeded the 0.2 ppm target in all samples (**Figure 3**). Brown rockfish had no samples above the target (one sample was at the target of 0.2 ppm). All samples for anchovy, black surfperch, Chinook salmon, and walleye surfperch were below the target.

Mercury in Bay sport fish was higher in the South Bay than in other parts of the Bay for some species (based on results from 1997-2006). This finding suggests that mercury in the food web is higher in the South Bay compared to other Bay regions. Higher mercury levels in the South Bay were seen in white sturgeon, jacksmelt, and leopard shark. RMP small fish monitoring also found that mercury levels were high in South Bay in cheekspot goby and Mississippi silverside (Greenfield et al, 2006). Mercury may be higher in South Bay fish due to historic and continued loadings of mercury from the New Almaden mercury mining district, which is located in the San Jose hills and is a known source of mercury to the Bay. In shiner surfperch (1997-2003 data), mercury concentrations were highest in the Oakland area suggesting that this area also has higher amounts of mercury in the food web.

Due to the large quantities of mercury present in the Bay and its watershed, we do not expect to see mercury declines in sport fish in the near-term. None of the sport fish species sampled show any change in mercury levels over the period 1994-2006. Unless significant advances in understanding of mercury cycling and in management occur, it is expected that it will take decades for concentrations in the species that are elevated to reach the TMDL target.



Footnote: Mercury concentrations in special study fish in 2006 in ppm wet weight. Bars represent average concentrations and circles represent individual composite samples, with numbers of fish in each composite as follows: anchovy (30), barred surfperch (3), black surfperch (5), brown rockfish (5), Chinook salmon (3), rubberlip surfperch (5), and walleye surfperch (5). Red horizontal line — indicates the TMDL target of 0.2 ppm.

Figure 3. *In a screening of additional species, several species (including anchovy, black surfperch, Chinook salmon, and walleye surfperch) had concentrations below the TMDL target. All rubberlip and barred surfperch samples exceeded the target and one of three brown rockfish samples was at the target.*

PCBs (POLYCHLORINATED BIPHENYLS)

BACKGROUND

Polychlorinated biphenyls (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. Since the ban, concentrations in the Bay have gradually declined, but PCBs in some sport fish species are still more than ten times higher than the 10 ppb threshold of concern for human health. In response to this problem, the SFBRWQCB has adopted a PCB TMDL report and Basin Plan amendment (to take effect, these documents still need to be approved by the State Water Resources Control Board and U.S. EPA). The TMDL includes an implementation plan to accelerate the recovery of the Bay from PCB contamination. Monitoring long-term trends of PCBs in Bay sport fish is essential to understanding the present rate of decline and the effectiveness of the PCB TMDL in reducing, and eventually eliminating, the impairment of the Bay by PCBs.

It will take decades for the Bay to recover from PCB contamination. In the interim, there are other ways for people to reduce their exposure to these chemicals. Avoiding consumption of fatty tissues in fish can reduce exposure to PCBs and other synthetic organic pollutants (such as legacy pesticides and dioxins). PCBs, like many other synthetic organic pollutants, accumulate in fatty tissue. RMP monitoring has shown that fish species with higher fat content tend to accumulate higher PCB concentrations. Shiner surfperch and white croaker, species with relatively high fat content, had elevated PCB concentrations with all samples exceeding the health threshold in all years of RMP sport fish monitoring. Avoiding fat deposits in fish skin and fatty organs such as the liver are ways to reduce exposure to PCBs and other organic chemicals. Cooking methods such as baking or grilling that allow the juices to drain away and then discarding the juices also reduce exposure. Additional information on PCBs, including their effects on health and ways to minimize exposure, is available at the OEHHA website: www.oehha.ca.gov/fish/general/sfbaydelta.html.

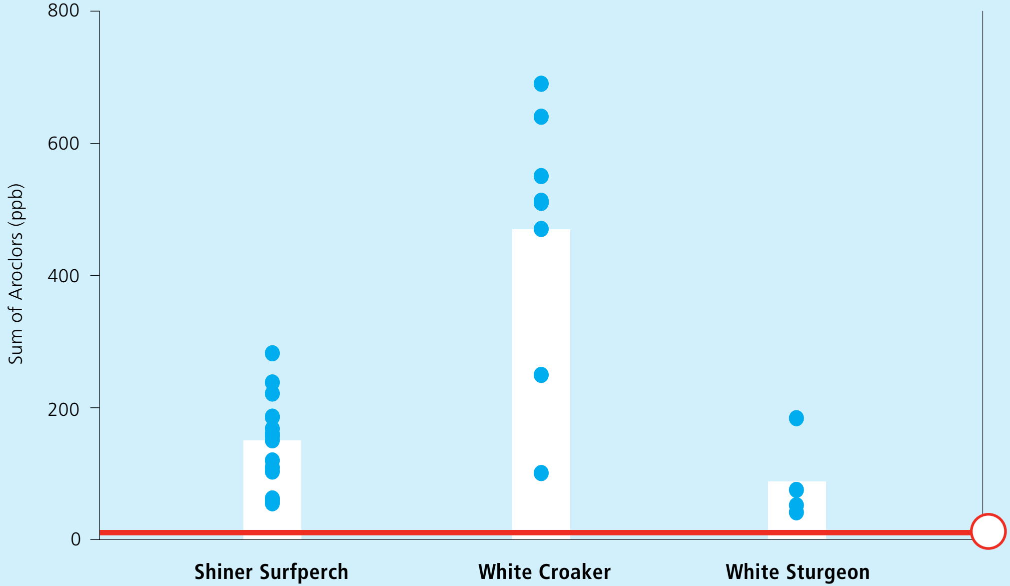
For this report all PCB data are presented on an "Aroclor" basis. Aroclors are mixtures of PCB congeners (individual PCB compounds) that were sold commercially until 1979. The Aroclor concentrations presented in this report are a sum of the most prevalent commercial mixtures: Aroclor 1248, 1254, and 1260. All PCB (as Aroclors) data are presented in parts per billion (ppb).

THE LATEST DATA

The RMP, consistent with the PCB TMDL, is using two species as the main indicators for trends in organic contaminants: white croaker and shiner surfperch. These two species have been selected since their PCB concentrations are higher than other Bay species and they are commonly caught in near shore areas by Bay anglers (SFBRWQCB, 2008). To assess human PCB exposure via sport fish consumption, this report uses the fish tissue target established for the PCB TMDL of 10 ppb. Meeting this target requires a 94% reduction in 2006 Bay-wide average concentrations in shiner surfperch and a 98% reduction in white croaker concentrations.

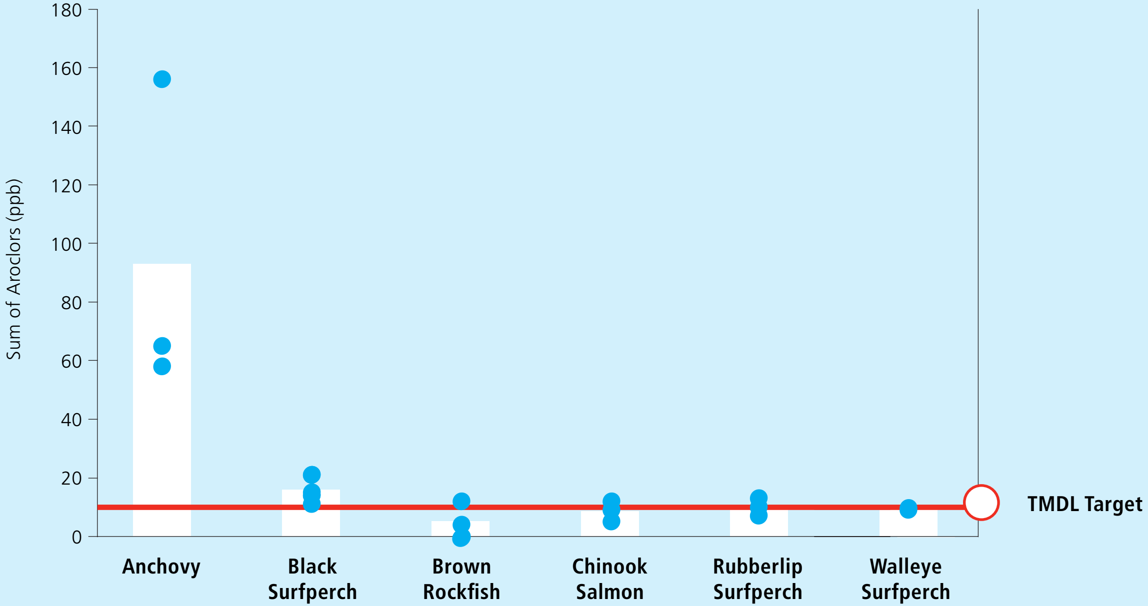
In 2006, as in past years, all of the shiner surfperch, white croaker, and white sturgeon samples exceeded the 10 ppb PCB tissue target (**Figure 4, Table 2**). For white croaker, shiner surfperch and white sturgeon, Bay-wide averages for 2006 were 470 ppb, 150 ppb, and 88 ppb, respectively. Maximum and average PCB concentrations were highest in white croaker.

In the screening survey of additional species, only walleye surfperch had 100% of samples below the tissue target (**Figure 5, Table 2**). Anchovy, barred surfperch, black surfperch, brown surfperch, Chinook salmon, and rubberlip surfperch had at least one sample above the target. All of the anchovy samples exceeded the target and six out of the six 2006 black surfperch (100%) slightly exceeded the target. In 2003, none of the black surfperch exceeded the target.



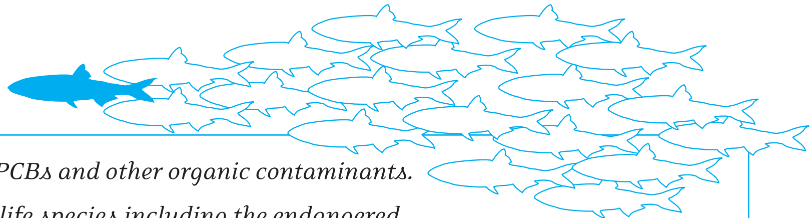
Footnote: PCB concentrations (as Aroclors) for Status &Trends species, 2006, in ppb wet weight. Bars represent the average concentration and circles represent individual composite samples with numbers of fish in each composite as follows: shiner surfperch (20), white croaker (5), and white sturgeon (3). Red horizontal line indicates the TMDL target of 10 ppb wet weight.

Figure 4. *All shiner surfperch, white croaker, and white sturgeon exceeded the TMDL target of 10 ppb. White croaker had the highest average (470 ppb) and maximum (690 ppb) concentrations of all fish species monitored. The average concentration in shiner surfperch was 150 ppb and white sturgeon was 88 ppb*



Footnote: PCB concentrations (as Aroclors), 2006, in ppb wet weight. Bars represent the average concentration and circles represent individual composite samples with numbers of fish in each composite as follows: anchovy (30), black surfperch (5), brown rockfish (5), Chinook salmon (3), rubberlip surfperch (5), and walleye surfperch (5). Red horizontal line indicates the TMDL target of 10 ppb wet weight.

Figure 5. *In a screening of PCB concentrations in additional species, several species (including brown rockfish, Chinook salmon, and rubberlip surfperch) had some samples below the TMDL target. All anchovy and black surfperch exceeded the target.*



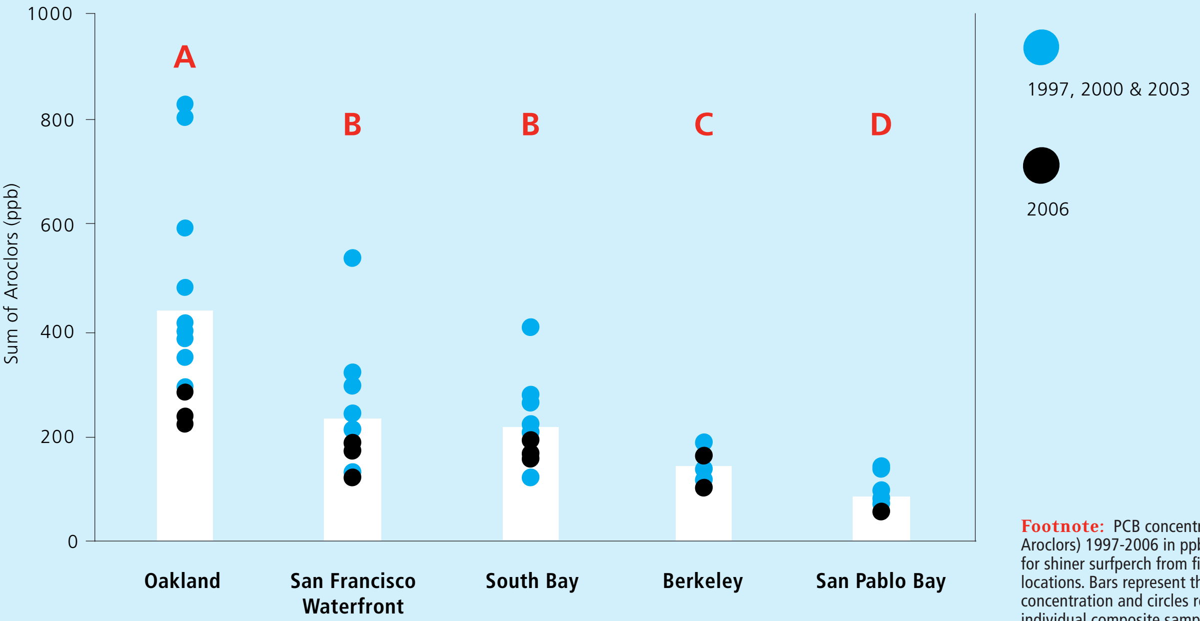
Sidebar : *Bay anchovy are high in PCBs and other organic contaminants.*

Anchovy are prey for many Bay wildlife species including the endangered California least tern, striped bass, and Chinook salmon (Karl et al., 2000). In 2003 and 2006, all of the anchovy samples exceeded the tissue target. Average anchovy PCB concentrations were lower in 2006 (93 ppb) compared to 2003 (360 ppb). Concentrations in 2003 were higher than some of the larger Bay sport fish including sturgeon and croaker. These results indicate that Bay wildlife consuming this species may be highly exposed to PCBs. A more comprehensive look at anchovy contamination will be considered for the next round of sampling in 2009.

PCB concentrations varied, by region, across the Bay for both of the main indicator species. In 2006, white croaker PCB concentrations were highest in South Bay (613 ppb) while San Pablo Bay concentrations were lowest (300 ppb). For shiner surfperch, the Oakland area had the highest average PCB concentration (250 ppb) while San Pablo Bay had the lowest (59 ppb). In 2006, fat content for shiner surfperch in the Oakland area was significantly lower than most other areas (except for Berkeley Waterfront), suggesting that the Oakland fish may have been in poor health. A simple condition index based on the ratio of weight to length indicated lower condition in the Oakland area for shiner in 2006. There are many possible causes of low condition, so this is probably not related to their PCB body burdens.

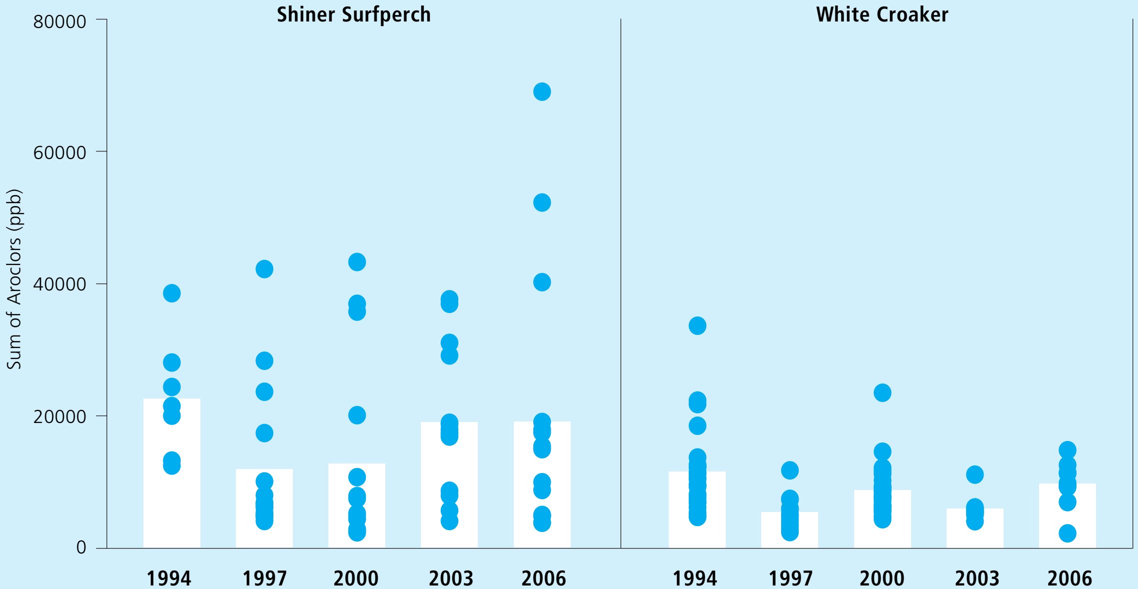
Over the long-term, some areas in the Bay, particularly the Oakland area, have had higher PCB concentrations than others. Shiner surfperch are very good indicators of nearshore PCB concentrations since they spend much of their life in shallow waters near the margins of the Bay (Moyle, 2002). They are also good indicators of spatial differences in PCBs since these fish have smaller home ranges than some of the larger sport fish species. Over the period 1997-2006, PCB concentrations in shiner surfperch were significantly higher in the Oakland area than all the other areas sampled (Figure 6).

There is no clear increasing or decreasing trend in PCBs over the period of record. PCBs have varied substantially over the years in both shiner surfperch and white croaker (Figure 7). PCB concentrations in white croaker in 2006 were relatively high compared to previous years, but there is no indication that this is part of a long-term trend. It appears likely that it will take many decades for PCB concentrations to fall below the TMDL target.



Footnote: PCB concentrations (as Aroclors) 1997-2006 in ppb wet weight for shiner surfperch from five sampling locations. Bars represent the average concentration and circles represent individual composite samples with 20 fish in each composite. Letters indicate statistically significant differences among locations: locations with the same letter are not different, locations with different letters are significantly different.

Figure 6. *PCB concentrations in shiner surfperch have varied by site with Oakland having the highest concentrations of all sites and San Pablo Bay the lowest. This finding suggests that food web contamination by PCBs is higher at some sites in the Bay.*



Footnote: PCB concentrations (as Aroclors) 1994-2006 in ppb lipid weight in shiner surfperch (left) and white croaker (right). Bars represent the average concentration and circles represent individual composites with numbers of fish in each composite as follows: shiner surfperch (20), white croaker (5).

Figure 7. *PCB concentrations have varied over the years 1994-2006. However there is neither an increasing or decreasing trend in PCB levels over the period of record.*

PBDEs (POLYBROMINATED DIPHENYL ETHERS)

BACKGROUND

Polybrominated diphenyl ethers (PBDEs) are a group of persistent environmental contaminants that are used as flame retardants in consumer products such as furniture and electronics. The State of California banned the use of the Penta and Octa mixtures, which have been shown to lead to food web contamination, starting in June 2006. There is one remaining PBDE mixture (Deca) that is still in use in CA. There is, however, some evidence that PBDEs in Deca degrade to more bioaccumulative PBDEs in the environment (La Guardia et al., 2007; Bezares-Cruz et al., 2004) and that Deca PBDEs accumulate in some fish species (Eljarrat et al., 2007).

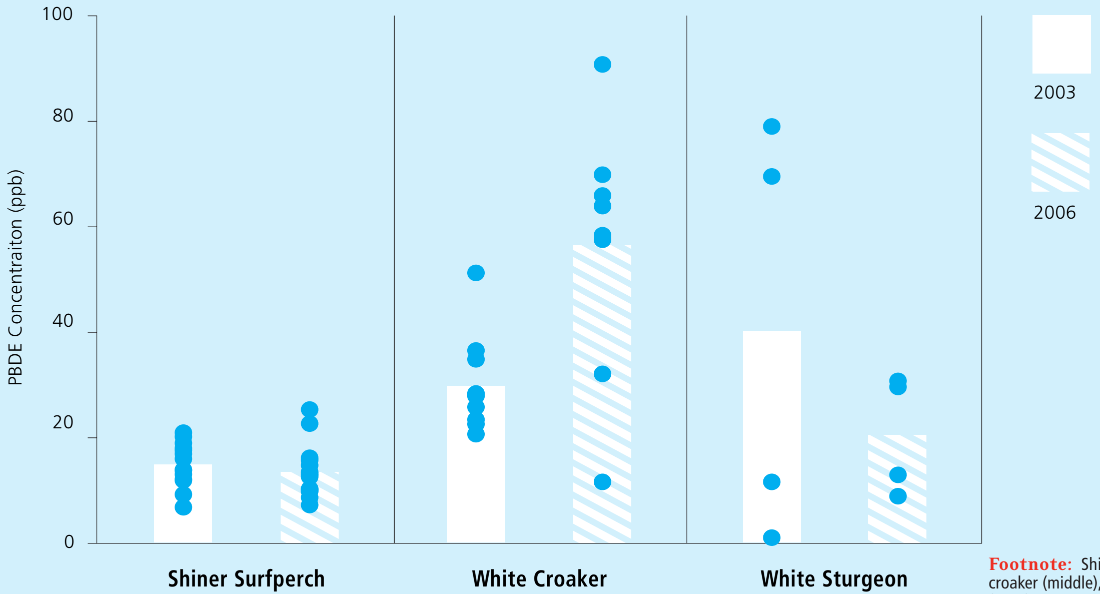
PBDE levels in humans and wildlife increased rapidly through the 1990s. PBDE levels in Americans increased thirty times from 1.5 ppb to 41 ppb in 15 years (Hites 2004). Levels in San Francisco Bay harbor seals were found to be exponentially increasing in the 1990s, and some of the highest PBDE concentrations worldwide have been found in Bay wildlife (She et al., 2004). The most recent monitoring data indicate that PBDE concentrations in the Bay may be leveling off.

The health impacts of PBDEs are not well characterized at present. Potential concerns include thyroid and estrogen hormone disruption, neurobehavioral toxicity, other developmental effects, and possibly cancer. Sensitive populations include pregnant women, developing fetuses, and infants. Screening values for human health assessment of PBDEs have not yet been established. All PBDE data are presented in parts per billion (ppb).

THE LATEST DATA

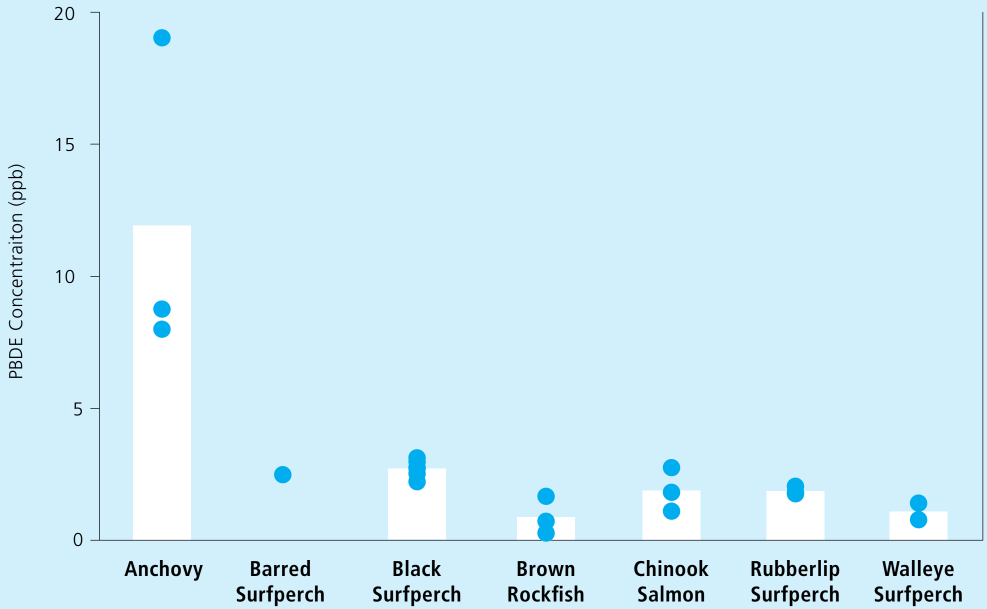
PBDEs were analyzed in primary indicator species (shiner surfperch, white croaker, white sturgeon) as well as additional special study species. Maximum PBDEs were highest in white croaker (91 ppb), followed by white sturgeon (31 ppb), and shiner surfperch (25 ppb) (Figure 8). Other species were generally lower with averages ranging from 0.88 ppb (brown rockfish) to 12 ppb (anchovy) (Figure 9). PBDE concentrations were typically about one-fifth of PCB levels.

For the primary indicator species we have two years of data available across multiple areas in the Bay (Figure 8). However, there are too few data to say if there are spatial or temporal patterns in PBDE levels. White croaker concentrations were higher in 2006 compared to 2003 while white sturgeon PBDE levels were lower in 2006 compared with 2003. Shiner surfperch PBDE levels were similar between the two years. Continued monitoring of PBDEs in sport fish will be important to establish spatial and temporal patterns to gauge the success of the California PBDE ban.



Footnote: Shiner surfperch (left), white croaker (middle), and white sturgeon (right) PBDE concentrations, 2003 and 2006, in pbb wet weight. Bars represent average concentrations and circles represent individual composite samples, with numbers of fish in each composite as follows: shiner surfperch (20), white croaker (5), and white sturgeon (3).

Figure 8. *PBDEs varied between years and by species in 2003 and 2006. There was variation between the two years for all three species with higher concentrations for white croaker in 2006 and lower concentrations for white sturgeon in 2006. Shiner surfperch concentrations were similar between the two years.*



Footnote: PBDE concentrations in special study fish 2006 in ppb wet weight. Bars represent average concentrations and circles individual composite samples, with numbers of fish in each composite as follows: anchovy (30), barred surfperch (3), black surfperch (5), brown rockfish (5), Chinook salmon (3), rubberlip surfperch (5), and walleye surfperch (5).

Figure 9. *In a screening of additional species, anchovy had the highest average PBDE concentration. Maximum anchovy concentrations were 19 ppb while brown rockfish had the lowest concentration at 0.3 ppb. Anchovy PBDE levels were similar to shiner surfperch (a larger sport fish species). There is currently no human health screening value for PBDEs in California.*

DIOXINS

BACKGROUND

Dibenzodioxins and dibenzofurans (for 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 a human carcinogen. Exposure to toxic levels of dioxins has been linked to a variety of responses in humans and other animals, including developmental abnormalities, reproductive effects, and cancer promotion (Ahlborg et al. 1994; Van den Berg et al. 1998). Human exposure to dioxins occurs mostly through diet with consumption of contaminated fish being one source of dioxin intake. As part of the PCB TMDL, the SFBRWQCB has calculated a fish tissue target of 0.14 ppt (parts per trillion) for the assessment of risk to human health due to dioxins (SFBRWQCB, 2008). This dioxin tissue target is not regulatory. An OEHHA screening value of 0.30 ppt was used in previous reports on RMP sport fish monitoring. Past monitoring of Bay sport fish has detected dioxins in some species with levels exceeding the tissue target.

Dioxins

Dioxin contamination is widespread with estimates that storm water runoff is the largest pathway of dioxins to the Bay (Gervason and Tang, 1998). Major sources of these chemicals to the watershed and Bay include burning fuels (diesel fuel in particular) and burning wood (from residential fireplaces and woodstoves) (BAAQMD, 2002). Dioxins therefore have diffuse sources that present a challenge in source control.

Similar to other pollutants such as mercury and PCBs, dioxins increase in concentration at higher levels of the food chain with apex predators such as seals and fish-eating birds accumulating the highest levels. Dioxins also have a very high affinity for fats and fatty tissues, and therefore accumulate to higher concentrations in fish with higher fat content.

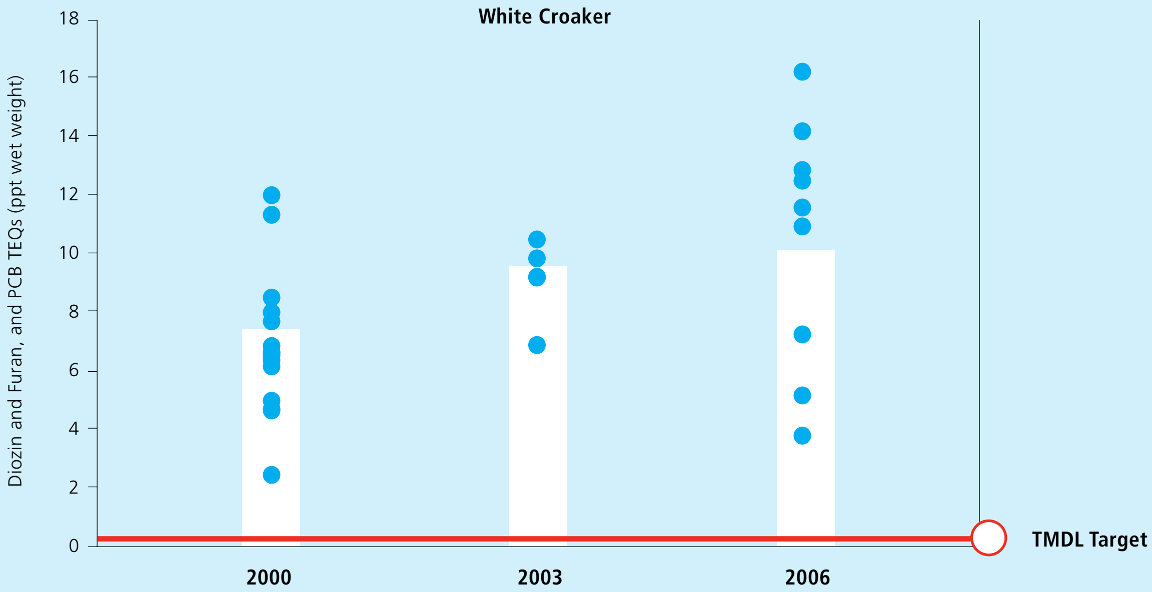
This report includes a summary of new data from 2003 and 2006 and a summary of the past data as well. For 2003 and 2006, dioxins were only analyzed in white croaker. All data are presented as TEQs (toxic equivalents) in parts per trillion (ppt). TEQs are based on the combination of dioxin, furan, and dioxin-like PCBs levels in each sample as well as equivalency factors based on the toxicity of each dioxin or furan relative to the most toxic form of dioxin - 2,3,7,8-TCDD. For example, if a particular dioxin-like chemical is one-tenth as toxic as 2,3,7,8-TCDD, then the measured concentration is multiplied by 0.1 in order to determine its contribution to the TEQ. The products of the result and the equivalency factor for each chemical are then summed to provide an estimate of the overall dioxin toxic equivalents (TEQ) in that sample. In essence, a TEQ is the sum of dioxin-like toxicity where the sum is a function of multiple chemical contaminants.

THE LATEST DATA

There are other contaminants in addition to dioxins and furans that exhibit dioxin-like toxicity. Some PCBs have physical structures similar to dioxins and therefore cause similar toxic responses in sensitive species. Looking at total TEQs derived from the sum of dioxins and dioxin-like PCBs provides a more complete estimate of human exposure to dioxin toxicity. All of the white croaker samples collected exceeded the dioxin tissue target of 0.14 ppt (**Figure 10, Table 2**). Average dioxin total TEQ concentrations need to be reduced by 98% in order for this species to reach the tissue target.

Total dioxin TEQ concentrations were highest in South Bay in 2006 (16.3 ppt) and lowest in San Pablo Bay in 2006 (2.1 ppt). This 2006 South Bay value was the highest dioxin TEQ measured in sport fish by the RMP. Spatially, the data indicated that San Pablo Bay generally had lower total dioxin TEQ concentrations than Oakland and South Bay over the period 2000-2006.

Total dioxin TEQ concentrations were higher in white croaker in 2006 compared with 2000 for all areas. As discussed above, fat content has a large influence on how dioxin concentrations vary over space and time. After removing the variation in dioxin TEQs due to fat content, dioxin TEQ concentrations were slightly lower in 2006 compared to 2000. This suggests that much of the variability seen in dioxins is due to varying fat content and that white croaker dioxins are actually neither increasing nor decreasing over time.



Footnote: White croaker dioxin, furan, and PCB TEQ concentrations, 2000-2006, in ppt wet weight (using 1998 WHO TEFs Van den Berg et al., 1998). PCB TEQs make up 75% of the total TEQs in 2003 and 2006. Bars represent average concentrations and circles represent individual composite samples, with numbers of fish in each composite as follows: white croaker (5). Red horizontal line indicates the TMDL target of 0.14 ppt wet weight.

Figure 10. *All white croaker samples exceeded the dioxin TEQ target of 0.14 ppt included in the PCB TMDL. There have been no changes over the period of record in dioxin concentrations in this species. Dioxin concentrations in 2006, were highest in the South Bay with a maximum of 16.3 ppt.*

LEGACY PESTICIDES (DIELDRIN, DDT, AND CHLORDANE)

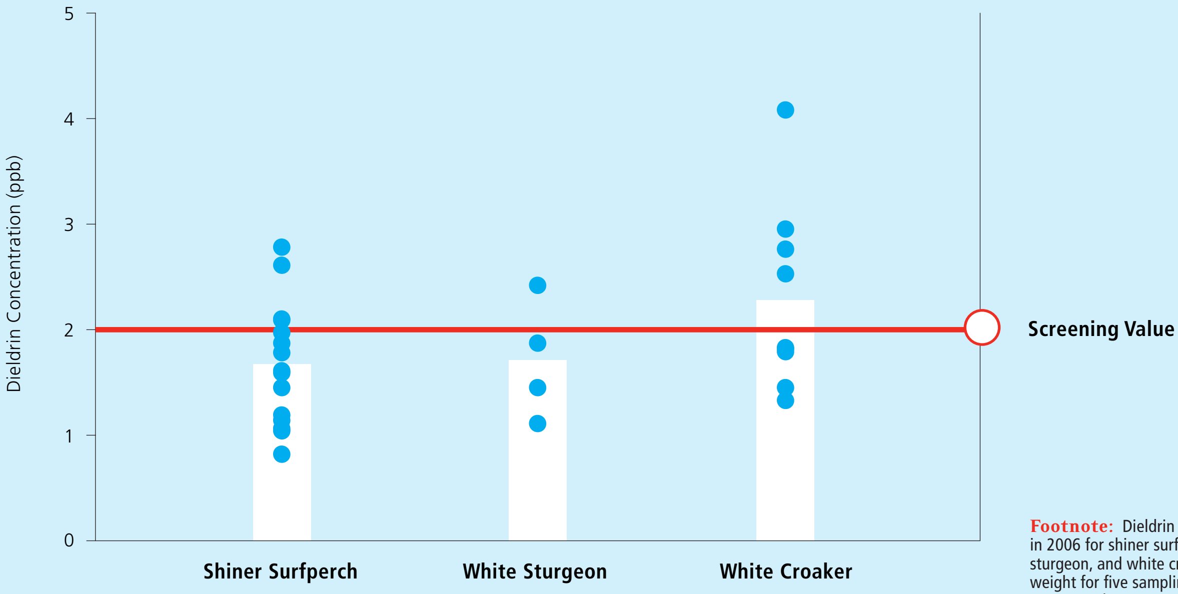
BACKGROUND

Historical use of the legacy pesticides dieldrin, DDT, and chlordane has resulted in contamination of the Bay and its watershed. These insecticides were widely used in both agricultural and domestic applications. Bans on these chemicals were implemented in the 1970s and 1980s. Simple fate models for the Bay (Connor et al. 2007), sport fish monitoring data (Davis et al. 2006), and mussel monitoring (Gunther et al. 1999) have all indicated declining trends in legacy pesticides. Dieldrin is the most toxic legacy pesticide and still poses the most persistent health concern. All pesticide data are given in parts per billion (ppb).

THE LATEST DATA

DIELDRIN

In 2006, dieldrin concentrations exceeded the 2.0 ppb screening value in 9 of 28 (32%) samples (**Figure 11, Table 2**). White croaker (4 of 9), white sturgeon (1 of 4), and shiner surfperch (4 of 15) all had some samples exceeding the dieldrin screening value. Average concentrations were highest in white croaker (2.3 ppb), followed by white sturgeon and shiner surfperch (both 1.7 ppb). All of the fish exceeding the screening value were caught in South Bay and Oakland. Average shiner surfperch dieldrin concentrations (on a lipid weight basis) were two times higher in 2006 than in 2003. Higher levels in shiner surfperch were mostly due to high dieldrin concentrations in fish from Oakland. It is unclear why dieldrin concentrations were higher in shiner surfperch in 2006. White croaker concentrations in 2006 (lipid weight basis) were similar to 2003 levels. Dieldrin in white croaker and shiner surfperch continues to pose a potential health concern, as it has during all five rounds of sampling.



Footnote: Dieldrin concentrations in 2006 for shiner surfperch, white sturgeon, and white croaker in ppb wet weight for five sampling locations. Bars represent the average concentration and circles represent individual composite samples with numbers of fish in each composite as follows: shiner surfperch (20), white croaker (5), and white sturgeon (3). Red horizontal line indicates screening value of 2.0 ppb.

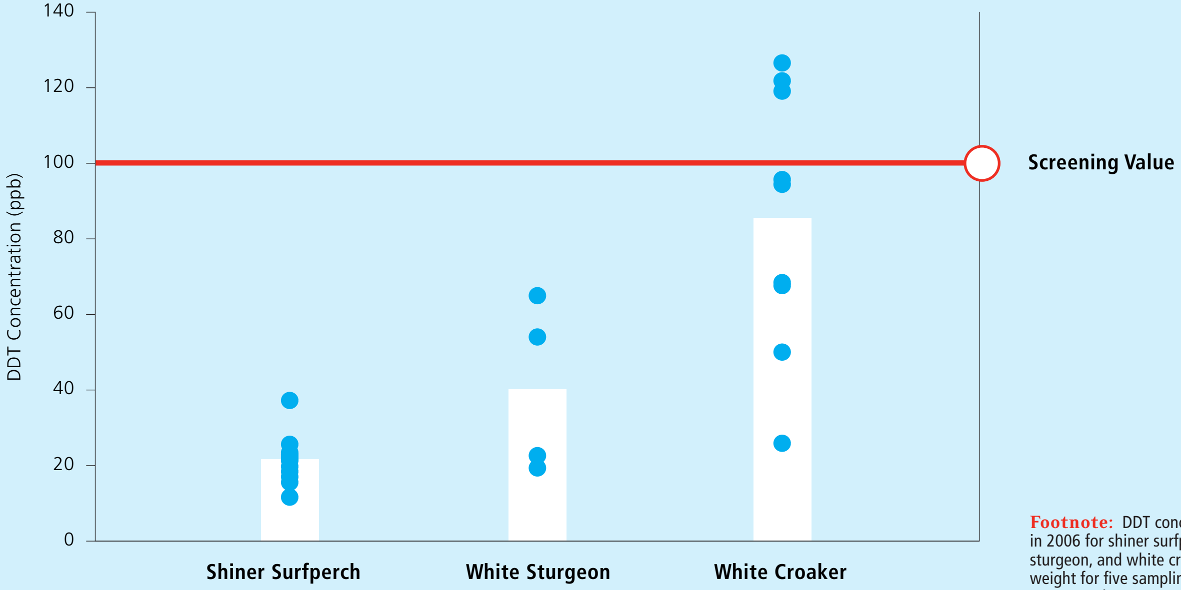
Figure 11. *Each of the Status and Trends species had some exceedance of the dieldrin screening value. Samples above the dieldrin screening value were from Oakland and South Bay.*

DDT

In 2006, 33% of white croaker samples (3 out of 9) exceeded the 100 ppb DDT screening value (**Figure 12, Table 2**). These croaker were collected in South Bay (2) and San Pablo Bay (1). None of the shiner surfperch or white sturgeon samples exceeded the screening value in 2006. In 2003, out of all the species sampled, there was only 1 white sturgeon sample exceeding the DDT screening value. The maximum concentrations in 2006 for white croaker, shiner surfperch, and white sturgeon were 130 ppb, 37 ppb, and 65 ppb, respectively. Bay-wide average DDT concentrations in shiner surfperch decreased from 1994 thru 2003. However, 2006 concentrations were higher compared to the 2000 and 2003 concentrations. This increase in 2006 was largely driven by higher DDT concentrations in the Oakland fish. For white croaker, DDT concentrations in 2003 were lower than all other years sampled, including 2006. However, 2006 concentrations were not different from 1997 or 2000.

CHLORDANE

There was only 1 exceedance of the 30 ppb screening value for chlordane. One white croaker sample from the South Bay had a concentration of 31 ppb. None of the shiner surfperch or white sturgeon samples exceeded the screening value in 2006. The South Bay white croaker sample represented the first chlordane screening value exceedance since 1997. Average chlordane concentrations were highest in white croaker (16 ppb), followed by white sturgeon (10 ppb) and shiner surfperch (8.5 ppb). Chlordane concentrations in white croaker appeared to be decreasing over the period 1994-2003 (Davis et al., 2006). White croaker chlordane levels in 2006 were two times higher than 2003, yet most samples remained below the screening value. Chlordane concentrations in Bay sport fish appear to be of lower concern for human health.



Footnote: DDT concentrations in 2006 for shiner surfperch, white sturgeon, and white croaker in ppb wet weight for five sampling locations. Bars represent the average concentration and circles represent individual composite samples with numbers of fish in each composite as follows: shiner surfperch (20), white croaker (5), and white sturgeon (3). Red horizontal line indicates screening value of 100 ppb.

Figure 12. *White croaker was the only species with samples that exceeded the DDT screening value (3 of 9 samples). The samples that exceeded the DDT screening value were from South Bay (2) and San Pablo Bay (1).*

SUMMARY POINTS

MERCURY

- Some Bay species are continuing to exceed the TMDL mercury target of 0.2 ppm
- Some special study (black surfperch, brown rockfish, and Chinook Salmon) species are below the tissue target
- No indication of declining trends

PCBs

- White croaker and shiner were well above the target, some other species also
- No indication of increasing or decreasing trends
- Shiner surfperch PCB concentrations are highest in the Oakland area over the period 1997-2006

PBDEs

- PBDEs were highest in white croaker
- PBDE concentrations in Bay fish were generally one-fifth of PCB concentrations

LEGACY PESTICIDES

- Some Bay fish continue to have DDT and dieldrin levels above the OEHHA screening value

DIOXINS

- All white croaker over the period of record (2000-2006) exceeded the dioxin tissue target
- Total TEQ croaker concentrations are highest in Oakland and South Bay and lowest in San Pablo Bay

REFERENCES

Ahlborg, U. G., G. C. Becking, L. S. Birnbaum, A. Brouwer, H. J. G. M. Derks, M. Feeley, G. Golor, A. Hanberg, J. C. Larsen, A. K. D. Liem, S. H. Safe, C. Schlatter, F. Waern, M. Younes, and E. Yrjanheikki. 1994. Toxic equivalency factors for dioxinlike PCBs: Report on a WHO-ECEH and IPCS consultation. Chemosphere 28:1049-1067.

BAAQMD, 2002. Memorandum from Ellen Garvey, BAAQMD, to Supervisor Scott Haggerty. ABAG Legislative & Governmental Operations Committee. April 2, 2002.

Bezares-Cruz, J., C. T. Jafvert, and I. Hua. 2004. Solar Photodecomposition of Decabromodiphenyl Ether: Products and Quantum Yield. Enviornmental Science and Technology 38:4149-4156.

Connor, M. S., J. A. Davis, J. Leatherbarrow, B. K. Greenfield, A. Gunther, D. Hardin, T. Mumley, J. J. Oram, and C. Werme. 2007. The slow recovery of San Francisco Bay from the legacy of organochlorine pesticides. Environmental Research 105:87-100.

Davis, J. A., J. A. Hunt, B. K. Greenfield, R. Fairey, M. Sigala, D. B. Crane, K. Regalado, and A. Bonnema. 2006. Contaminant concentrations in fish from San Francisco Bay, 2003. San Francisco Estuary Institute, Oakland CA.

Eljarrata, E., A. Labandeiraa, G. Marsha, D. Raldúab, and D. Barceló. 2007. Decabrominated diphenyl ether in river fish and sediment samples collected downstream an industrial park. Chemosphere 69:1278-1286.

Fairey, R., K. Taberski, S. Lamerdin, E. Johnson, R. P. Clark, J. W. Downing, J. Newman, and M. Petreas. 1997. Organochlorines and other environmental contaminants in muscle tissues of sportfish collected from San Francisco Bay. Marine Pollution Bulletin 34:1058-1071.

Gervason, R., and L. Tang. 1998. Dioxin in the Bay Environment -- A review of the environmental concerns, regulatory history, current Status, and possible regulatory options. San Francisco Bay Regional Water Quality Control Board.

Greenfield, B. K., A. Jahn, J. L. Grenier, S. Shonkoff, and M. B. Sandheinrich. 2006. Mercury in biosentinel fish in San Francisco Bay: First-year project report. SFEI, Oakland.

Gunther, A. J., J. A. Davis, D. Hardin, J. Gold, D. Bell, J. Crick, G. Scelfo, J. Sericano, and M. Stephenson. 1999. Long term bioaccumulation monitoring with transplanted bivalves in San Francisco Estuary. Mar. Pollut. Bull. 38:170-181.

Hites, R. A. 2004. Polybrominated diphenyl ethers in the environment and in people: A meta-analysis of concentrations. Environmental Science and Technology 38:945-956.

Karl, H. A., J. L. Chin, E. Ueber, P. H. Stauffer, and J. W. Hendley II. 2001. Beyond the Golden Gate– Oceanography, Geology, Biology, and Environmental Issues in the Gulf of the Farallones Pages 240 in. US Department of the Interior US Geological Survey.

La Guardia, M. J., R. C. Hale, and E. Harvey. 2007. Evidence of Debromination of Decabromodiphenyl Ether (BDE-209) in Biota from a Wastewater Receiving Stream. Enviornmental Science and Technology 41:6663-6670.

Lowe, S., R. Hoenicke, and J. Davis. 1999. 1999 Quality Assurance Project Plan Regional Monitoring Program for Trace Substances. 23, SFEI, Oakland.

Moyle, P. B. 2002. Inland Fishes of California. University of California Press, Berkeley, California.

SFBRWQCB. 2006. Mercury in San Francisco Bay: Proposed basin plan amendment and staff report for revised Total Maximum Daily Load (TMDL) and proposed mercury water quality objectives. Pages 116 in.

SFBRWQCB. 2008. Total Maximum Daily Load for PCBs in San Francisco Bay: Staff report for proposed Basin Plan Amendment. San Francisco Regional Water Quality Control Board, Oakland.

She, J., M. Petreas, J. Winkler, P. Visita, M. McKinney, and D. Kopec. 2002. PBDEs in the San Francisco Bay Area: measurements in harbor seal blubber and human breast adipose tissue. Chemosphere 46:697-707.

Van den Berg, L., L. Birnbaum, and A. T. C. a. o. Bosveld. 1998. Toxic Equivalency Factors (TEFs) for PCBs, PCDDs, PCDFs for humans and wildlife. Environmental Health Perspectives 106:775-792.

ACKNOWLEDGMENTS & CREDITS

Many people in addition to the listed authors made substantial contributions to this report. We wish to thank Andrew Hanson, Billy Cochran, Ashleigh Lyman, Brian Stewart, Berkeley Kauffman, Hannah Eisloeffel, Mark Gleason, Kathy Hieb, and Tom Grenier for help with field collection and for laboratory personnel at Moss Landing Marine Laboratories for fish processing.

Linda Wanczyk designed the report and did all graphical layout.

Constructive reviews provided by Margy Gassel (OEHHA), Karen Taberski (Regional Board), Marco Sigala (MLML), Jon Konnan (EOA, Inc.), and Arlene Fang (Alameda County Clean water Agency) improved this report.

We would also like to thank all members of the RMP Fish Contamination Committee for providing technical guidance in all phases of program development and for reviewing the report.

Page 2

Photograph by Linda Wanczyk
San Francisco Pier, 2006

Page 4

Photograph by Jay Davis
Fishing in San Leandro Bay, 2007

Page 12

Photograph by Dept. of Fish and Game
Fish in net, 2007

Page 22

Photograph by Linda Wanczyk
San Francisco Pier, 2008

Page 32

Photograph by John Gregory
San Francisco Pier, 2006

Page 46

Photograph by Linda Wanczyk
San Francisco Pier, 2006

San Francisco Estuary Institute and the Regional Monitoring Program for Water Quality in the San Francisco Estuary
7770 Pardee Lane, 2nd Floor, Oakland, California 94621, p: 510-746-7334 (SFEI), f: 510-746-7300, w: www.sfei.org

This report is set in Eidetic and Frutiger and printed on recycled paper. Printed and bound in Hayward, California by Alonzo Printing, www.alonzoprinting.com

www.sfei.org