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Contaminant Concentrations in Sport Fish from San Francisco Bay: 2019

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Executive Summary

This technical report presents results from a 2019 survey of contaminants in San Francisco Bay sport fish. This monitoring effort represents the eighth round of sport fish contaminant monitoring in the Bay, with the last seven conducted by the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP). This technical report is intended for water quality managers and scientists charged with managing 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 per- and polyfluoroalkylated substances (PFAS) were analyzed across 5 fish species collected at 13 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 versus pelagic), and have been monitored in the past.

Concentrations were compared to numeric human health thresholds (advisory tissue levels, or ATLs) 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 a 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 health risks due to exposure to mercury and PCBs. The 2019 data show that mercury and PCB concentrations remain above thresholds and are widespread, indicating that these contaminants continue to pose the greatest human and wildlife health risks.

Average mercury concentrations exceeded OEHHA's no consumption ATL of 0.44 ppm wet weight (ww) for the sensitive population (women 18-49 and children 1-17) in striped bass and bat rays, and average concentrations in four additional species exceeded the water quality objective of 0.2 ppm ww. The five-species mean specified in the water quality objective was 0.27 ppm, above the goal of 0.20 ppm. Striped bass from the Coyote Creek area have

consistently had higher mercury concentrations than other parts of the Bay. No trend was evident in a time series of striped bass concentrations that spans 1971-2019.

Average PCB concentrations in shiner surfperch exceeded the no consumption ATL of 120 ppb. Overall, 10 of the 16 species monitored had an average concentration above the Water Board's numeric target of 10 ppb. PCB concentrations vary significantly across the long-term monitoring stations. Oakland Harbor remains the region of highest concern, although San Francisco Waterfront and South Bay also had average concentrations above the no consumption ATL of 120 ppb in this round of sampling. Although PCB concentrations in shiner surfperch (the primary indicator species) were generally higher in 2019 than in the prior round of sampling, there are some possible signs of long-term decline. Concentrations in shiner surfperch at the Berkeley station showed a significant decline on a lipid weight basis, and concentrations in white croaker (a second key indicator species) were distinctly lower in 2019 than in prior years. Overall, the rate of PCB decline in the Bay is slow at best, and continued monitoring is needed for a more definitive assessment.

Dioxin concentrations remain above a Water Board screening level, and are still particularly high in Oakland Harbor. However, there are signs of possible decline in both of the key indicator species: shiner surfperch and white croaker. In white croaker, the concentrations in 2019 were sharply lower than in the last year of comparable data in 2009 and only slightly above the screening level. In shiner surfperch, concentrations appear to be progressively decreasing across all of the monitoring stations, although the decline is not statistically significant. Continued monitoring of these two species is needed to establish whether these possible trends are statistically significant and signs of real long-term declines.

Selenium concentrations remain below levels of human health concern. However, an exceedance of the North Bay TMDL numeric target (11.3 ppm dw) was observed in an individual white sturgeon caught in Suisun Bay, while the 2019 average was below the target. Consistent with past sampling, selenium concentrations in North Bay white sturgeon were significantly higher than concentrations in South Bay white sturgeon. Only two of 30 white sturgeon samples analyzed in South Bay since 1997 have exceeded the North Bay numeric target, and the long-term average concentration (5.7 ppm dw) is well below the target.

The 2019 PBDE data provide further evidence of the decline of PBDEs in Bay sport fish since 2003, and are at levels well below guidelines for the protection of human health. Ongoing monitoring of these chemicals will be of interest to continue to measure the impact of the PBDE phase-outs.

No human health or regulatory thresholds have yet been established for PFAS in San Francisco Bay fish. Concentrations in Bay fish, however, particularly in the South Bay region, are persisting over time at levels that exceed thresholds that have been established by other states for development of consumption advisories. The monitoring conducted to date for PFAS in fish has been limited in scope, hindering evaluation of spatial patterns and long-term trends. More intensive monitoring is warranted to track long-term trends, understand spatial variation

across Bay regions, and more firmly characterize concentrations for comparison to thresholds. The Lower South Bay appears to be a region of particular concern; this could be established more definitively by expanded monitoring.

The 2019 survey addressed some of the data gaps identified by OEHHA relating to developing more extensive consumption advice for the Bay. Mercury and PCBs were analyzed in multiple samples of bat rays, northern anchovy, Pacific herring, brown rockfish, and staghorn sculpin.

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 1997 the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) initiated a long-term monitoring program to follow up on the 1994 pilot study. In 2011, OEHHA published an updated health advisory, based in large part on RMP data collected over the previous decade (Gassel et al. 2011).

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 (Davis et al. 1999, Davis et al. 2002, Greenfield et al. 2003, Greenfield et al. 2005, Davis et al. 2006, Hunt et al. 2008, Davis et al. 2011). 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 inputs to the Bay. This report presents findings from the eighth round of Bay sport fish monitoring conducted by the RMP in 2019. Key analyses in this report include comparisons of concentrations to Advisory Tissue Level (ATL) and water quality 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

Sampling Design

Fish were collected at 13 sampling locations in San Francisco Bay between May and September 2019 (Figure 1). Further details on sampling locations and collections can be found in the 2019 RMP Sport Fish Monitoring Sampling and Analysis Plan (Buzby et al. 2020) as well as the 2019 Sport Fish Cruise Report (Appendix 1). Sport fish have been monitored at five of the 13 2019 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. The South Bay station code used over the years actually includes two areas that are rather far apart: Redwood Creek and Coyote Creek. 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. Additional sampling occurred in several areas as part of the Priority Margin Unit (PMU) Special Study. PMUs are local-scale Bay margin areas (Redwood Creek/Steinberger Slough, San Leandro Bay, Emeryville Crescent, and Richmond Inner Harbor) where actions to reduce watershed loads of PCBs are underway or anticipated and monitoring is being initiated to track the in-Bay response to the load reductions. Findings related to the PMU special study are not specifically addressed in this report, but are further addressed in a separate report (Davis et al. in preparation). Many of the PMU locations were sampled for sport fish for the first time in 2019 with the motivation being monitoring PCB concentrations in shiner surfperch, a crucial indicator species in the PCBs TMDL.

In general, target species were successfully collected; a few exceptions are noted here. Monkeyface prickleback were difficult to collect due to the specialized technique required (poke poling) and limited days fishing at extreme low tides. Shiner surfperch were not caught in Steinberger Slough or Emeryville Crescent, in spite of a concerted effort. Emeryville Crescent is a broad, shallow area without channels or structure to target. Steinberger Slough seems to be an anomaly since the channel and nearby wetlands should support shiner surfperch and other fish species. Shiner surfperch in San Pablo Bay and Loch Lomond had low population numbers and were smaller in size this year. Harbor seals ripped fish out of the nets creating holes and reducing efficiency in catching target species such as jacksmelt and striped bass. Common carp were targeted at the freshwater station at the San Jose Santa Clara outfall in Artesian Slough, but were extremely difficult to catch from the weir even though the crew could see them, and striped bass were not coming into Artesian Slough to feed.

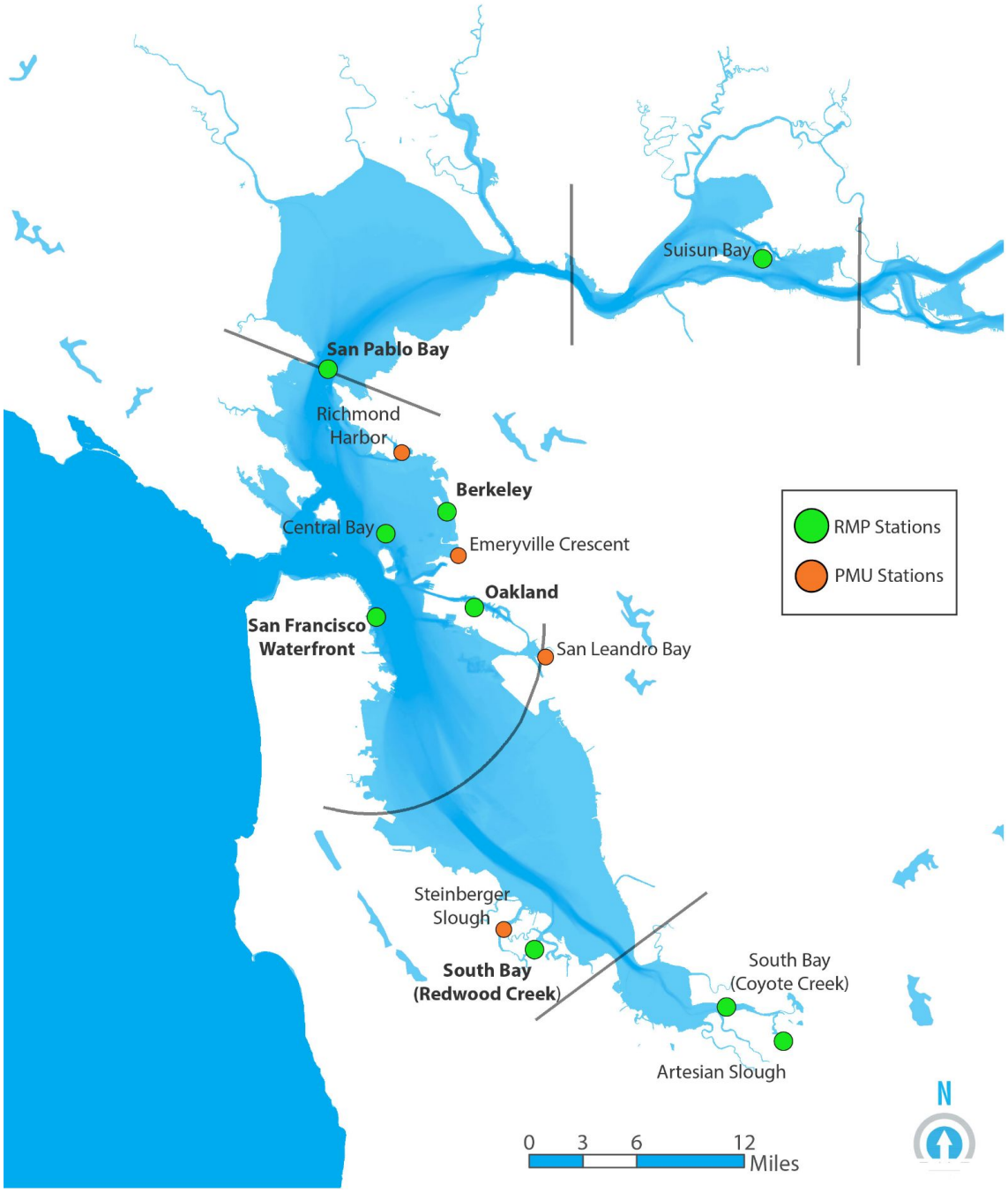

Figure 1. Locations sampled for San Francisco Bay fish, 2019. Green dots indicate historical RMP sampling locations; orange dots denote Priority Margin Unit (PMU) locations that were sampled as a part of a RMP Special Study. Artesian Slough includes a freshwater area above a weir. Berkeley, San Francisco Waterfront, Oakland, San Pablo Bay, and South Bay (Redwood Creek) are historical stations that have been sampled consistently since 1994.

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 additional species were also collected, including Pacific herring, staghorn sculpin, bat ray, monkeyface prickleback, brown rockfish, and largemouth bass. Largemouth bass were collected in freshwater below the San Jose-Santa Clara municipal wastewater outfall and are a widely used indicator species for California freshwater ecosystems.

The contaminants that were measured in fish tissues were mercury, PCBs, dioxins, selenium, polybrominated diphenyl ethers (PBDEs), and per- and polyfluorinated alkyl substances (PFAS). The core monitoring species were analyzed for mercury, PCBs, and selenium, for which regulatory control plans are in place, as well as PFAS, 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, striped bass, 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.

Fish were caught using gill nets, hook and line, and otter trawls. Poke poling was performed to collect monkeyface prickleback in shallow, rocky areas. Additional sampling details, including station coordinates, sampling dates, field methods, and deviations from the original sampling design can be found in the 2019 Sport Fish Cruise Report (Appendix 1).

Laboratory Analysis

Sample Processing

Dissection and compositing of muscle tissue samples were performed following method MPSL-105. 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, Pacific sardine, and Pacific herring) that were too small to be filleted were processed whole but with head, tail, and viscera removed.

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). The length of the smallest fish in each composite was no less than 75% of the length of

the largest fish. Selenium and mercury analysis of select species were conducted on samples of individual fish. Additionally, the digestive tracts of striped bass and shiner surfperch were archived for potential microplastic analysis. Special dissection steps were also taken with each individual white sturgeon collected. Skinless fillets were taken from both epaxial and caudal areas on each fish in order to compare the tissue from these areas and inform future comparisons to the historic time series. 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.

Table 1. Summary of fish samples collected, 2019. 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).

Common Name	Species Name	Total # of Fish Collected	# of Composite Samples	Composites - # of Locations Sampled	# of Individual Fish Samples	Individuals - # of Locations Sampled	Total # of Locations Sampled	Min Length (mm)	Median Length (mm)	Max Length (mm)	# of Gut Samples	Gut Samples - # of Locations Sampled
Bat Ray	*Myliobatis californica*	18	6	3			3	510	615	910		
Brown Rockfish	*Sebastes auriculatus*	15	3	1	15	1	2	233	285	360		
California Halibut	*Paralichthys californicus*	11	4	4			4	111	560	640		
Diamond Turbot	*Hypsopsetta guttulata*	5	1	1			1	230	285	315		
Jacksmelt	*Atherinopsis californiensis*	80	8	6			6	205	278	352		
Largemouth Bass	*Micropterus salmoides*	16	1	1	16	1	2	240	295	430	7	1
Monkeyface Prickleback	*Cebidichthys violaceus*	3	1	1			1	360	470	475		
Northern Anchovy	*Engraulis mordax*	500	8	4			4	37	55	106		
Pacific Herring	*Clupea pallasii*	29	3	1			1	151	172	216		
Pacific Staghorn Sculpin	*Leptocottus armatus*	86	6	4			4	80	109	154		
Shiner Surfperch	*Cymatogaster aggregata*	443	23	7			7	72	115	193	46	5
Starry Flounder	*Platichthys stellatus*	5	1	1			1	238	249	265		
Striped Bass	*Morone saxatilis*	27	9	4	27	4	8	435	524	595	19	2
White Croaker	*Genyonemus lineatus*	54	11	4			4	195	267	315		
White Sturgeon	*Acipenser transmontanus*	9	3	3	18	3	6	1160	1260	1595		
White Surfperch	*Phanerodon furcatus*	5	1	1			1	104	110	110		

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 Dectection Limits	Number of Samples	Frequency of Dectection (%)	Frequency of Reporting (%)
BAL	Selenium	Selenium	0.08	64	100	100
MPSL-DFW	Mercury	Mercury	0.00	134	100	100
SGS AXYS	Dioxin/Furan	TCDD, 2,3,7,8-	0.06	28	57	100
SGS AXYS	Dioxin/Furan	PeCDD, 1,2,3,7,8-	0.07	28	79	100
SGS AXYS	Dioxin/Furan	HxCDD, 1,2,3,4,7,8-	0.06	28	25	100
SGS AXYS	Dioxin/Furan	HxCDD, 1,2,3,6,7,8-	0.06	28	61	100
SGS AXYS	Dioxin/Furan	HxCDD, 1,2,3,7,8,9-	0.05	28	7	100
SGS AXYS	Dioxin/Furan	HpCDD, 1,2,3,4,6,7,8-	0.07	28	54	100
SGS AXYS	Dioxin/Furan	OCDD, 1,2,3,4,6,7,8,9-	0.06	28	79	100
SGS AXYS	Dioxin/Furan	TCDF, 2,3,7,8-	0.05	28	89	100
SGS AXYS	Dioxin/Furan	PeCDF, 1,2,3,7,8-	0.06	28	75	100
SGS AXYS	Dioxin/Furan	PeCDF, 2,3,4,7,8-	0.07	28	82	100
SGS AXYS	Dioxin/Furan	HxCDF, 1,2,3,4,7,8-	0.05	28	18	100
SGS AXYS	Dioxin/Furan	HxCDF, 1,2,3,6,7,8-	0.05	28	18	100
SGS AXYS	Dioxin/Furan	HxCDF, 1,2,3,7,8,9-	0.06	28	29	100
SGS AXYS	Dioxin/Furan	HxCDF, 2,3,4,6,7,8-	0.06	28	14	100
SGS AXYS	Dioxin/Furan	HpCDF, 1,2,3,4,6,7,8-	0.06	28	21	100
SGS AXYS	Dioxin/Furan	HpCDF, 1,2,3,4,7,8,9-	0.05	28	0	100
SGS AXYS	Dioxin/Furan	OCDF, 1,2,3,4,6,7,8,9-	0.06	28	4	100
SGS AXYS	PBDE	PBDE 007	0.00	19	100	100

Lab	Class	Analyte	MDL	n	Detection (%)	Reporting (%)
SGS AXYS	PBDE	PBDE 008	0.00	19	53	100
SGS AXYS	PBDE	PBDE 010	0.00	19	32	100
SGS AXYS	PBDE	PBDE 011		19	100	100
SGS AXYS	PBDE	PBDE 012	0.00	19	58	100
SGS AXYS	PBDE	PBDE 013		19	100	100
SGS AXYS	PBDE	PBDE 015	0.00	19	100	100
SGS AXYS	PBDE	PBDE 017	0.00	19	100	100
SGS AXYS	PBDE	PBDE 025		19	100	100
SGS AXYS	PBDE	PBDE 028	0.00	19	100	100
SGS AXYS	PBDE	PBDE 030	0.00	19	0	100
SGS AXYS	PBDE	PBDE 032	0.00	19	63	100
SGS AXYS	PBDE	PBDE 033		19	100	100
SGS AXYS	PBDE	PBDE 035	0.01	19	5	100
SGS AXYS	PBDE	PBDE 037	0.00	19	74	100
SGS AXYS	PBDE	PBDE 047	0.00	19	100	100
SGS AXYS	PBDE	PBDE 049	0.00	19	100	100
SGS AXYS	PBDE	PBDE 051	0.00	19	100	100
SGS AXYS	PBDE	PBDE 066	0.00	19	100	100
SGS AXYS	PBDE	PBDE 071	0.00	19	95	100
SGS AXYS	PBDE	PBDE 075	0.00	19	95	100
SGS AXYS	PBDE	PBDE 077	0.00	19	63	100
SGS AXYS	PBDE	PBDE 079	0.00	19	79	100
SGS AXYS	PBDE	PBDE 085	0.00	19	0	100
SGS AXYS	PBDE	PBDE 099	0.00	19	100	100
SGS AXYS	PBDE	PBDE 100	0.00	19	100	100
SGS AXYS	PBDE	PBDE 105	0.00	19	0	100
SGS AXYS	PBDE	PBDE 116	0.00	19	16	100
SGS AXYS	PBDE	PBDE 119	0.00	19	95	100
SGS AXYS	PBDE	PBDE 120		19	100	100
SGS AXYS	PBDE	PBDE 126	0.00	19	100	100
SGS AXYS	PBDE	PBDE 128	0.00	19	26	100

Lab	Class	Analyte	MDL	n	Detection (%)	Reporting (%)
SGS AXYS	PBDE	PBDE 138	0.00	19	16	100
SGS AXYS	PBDE	PBDE 140	0.00	19	84	100
SGS AXYS	PBDE	PBDE 153	0.00	19	100	100
SGS AXYS	PBDE	PBDE 154	0.00	19	100	100
SGS AXYS	PBDE	PBDE 155	0.00	19	100	100
SGS AXYS	PBDE	PBDE 166		19	100	100
SGS AXYS	PBDE	PBDE 181	0.00	19	5	100
SGS AXYS	PBDE	PBDE 183	0.00	19	84	100
SGS AXYS	PBDE	PBDE 184	0.00	19	42	100
SGS AXYS	PBDE	PBDE 190	0.00	19	0	100
SGS AXYS	PBDE	PBDE 197	0.00	15	0	0
SGS AXYS	PBDE	PBDE 203	0.00	19	37	100
SGS AXYS	PBDE	PBDE 204		19	100	100
SGS AXYS	PBDE	PBDE 205	0.00	19	0	100
SGS AXYS	PBDE	PBDE 206	0.00	19	47	100
SGS AXYS	PBDE	PBDE 207	0.00	19	32	100
SGS AXYS	PBDE	PBDE 208	0.00	19	21	100
SGS AXYS	PBDE	PBDE 209	0.01	19	89	100
SGS AXYS	PCB	PCB 001	0.00	82	89	100
SGS AXYS	PCB	PCB 002	0.00	82	80	100
SGS AXYS	PCB	PCB 003	0.00	82	68	100
SGS AXYS	PCB	PCB 004	0.00	82	89	100
SGS AXYS	PCB	PCB 005	0.00	82	5	100
SGS AXYS	PCB	PCB 006	0.00	82	93	100
SGS AXYS	PCB	PCB 007	0.00	82	46	100
SGS AXYS	PCB	PCB 008	0.00	82	98	100
SGS AXYS	PCB	PCB 009	0.00	82	57	100
SGS AXYS	PCB	PCB 010	0.00	82	29	100
SGS AXYS	PCB	PCB 011	0.00	82	99	100
SGS AXYS	PCB	PCB 012		82	100	100
SGS AXYS	PCB	PCB 013	0.00	82	39	100

Lab	Class	Analyte	MDL	n	Detection (%)	Reporting (%)
SGS AXYS	PCB	PCB 014	0.00	82	0	100
SGS AXYS	PCB	PCB 015	0.00	82	85	100
SGS AXYS	PCB	PCB 016	0.00	82	80	100
SGS AXYS	PCB	PCB 017	0.00	82	93	100
SGS AXYS	PCB	PCB 018	0.00	82	100	100
SGS AXYS	PCB	PCB 019	0.00	82	88	100
SGS AXYS	PCB	PCB 020		82	100	100
SGS AXYS	PCB	PCB 021		82	100	100
SGS AXYS	PCB	PCB 022	0.00	82	98	100
SGS AXYS	PCB	PCB 023	0.00	82	7	100
SGS AXYS	PCB	PCB 024	0.00	82	44	100
SGS AXYS	PCB	PCB 025	0.00	82	99	100
SGS AXYS	PCB	PCB 026	0.00	82	100	100
SGS AXYS	PCB	PCB 027	0.00	82	87	100
SGS AXYS	PCB	PCB 028	0.00	82	100	100
SGS AXYS	PCB	PCB 029		82	100	100
SGS AXYS	PCB	PCB 030		82	100	100
SGS AXYS	PCB	PCB 031	0.00	82	100	100
SGS AXYS	PCB	PCB 032	0.00	82	100	100
SGS AXYS	PCB	PCB 033	0.00	82	95	100
SGS AXYS	PCB	PCB 034	0.00	82	80	100
SGS AXYS	PCB	PCB 035	0.00	82	4	100
SGS AXYS	PCB	PCB 036	0.00	82	7	100
SGS AXYS	PCB	PCB 037	0.00	82	99	100
SGS AXYS	PCB	PCB 038	0.00	82	45	100
SGS AXYS	PCB	PCB 039	0.00	82	45	100
SGS AXYS	PCB	PCB 040	0.00	82	100	100
SGS AXYS	PCB	PCB 041		82	100	100
SGS AXYS	PCB	PCB 042	0.00	82	94	100
SGS AXYS	PCB	PCB 043	0.00	82	61	100
SGS AXYS	PCB	PCB 044	0.00	82	100	100

Lab	Class	Analyte	MDL	n	Detection (%)	Reporting (%)
SGS AXYS	PCB	PCB 045	0.00	82	99	100
SGS AXYS	PCB	PCB 046	0.00	82	91	100
SGS AXYS	PCB	PCB 047		82	100	100
SGS AXYS	PCB	PCB 048	0.00	82	99	100
SGS AXYS	PCB	PCB 049	0.00	82	100	100
SGS AXYS	PCB	PCB 050		82	100	100
SGS AXYS	PCB	PCB 051		82	100	100
SGS AXYS	PCB	PCB 052	0.00	82	100	100
SGS AXYS	PCB	PCB 053	0.00	82	99	100
SGS AXYS	PCB	PCB 054	0.00	82	79	100
SGS AXYS	PCB	PCB 055	0.00	82	20	100
SGS AXYS	PCB	PCB 056	0.00	82	98	100
SGS AXYS	PCB	PCB 057	0.00	82	72	100
SGS AXYS	PCB	PCB 058	0.00	82	76	100
SGS AXYS	PCB	PCB 059	0.00	82	100	100
SGS AXYS	PCB	PCB 060	0.00	82	100	100
SGS AXYS	PCB	PCB 061		82	100	100
SGS AXYS	PCB	PCB 062		82	100	100
SGS AXYS	PCB	PCB 063	0.00	82	93	100
SGS AXYS	PCB	PCB 064	0.00	82	100	100
SGS AXYS	PCB	PCB 065		82	100	100
SGS AXYS	PCB	PCB 066	0.00	82	100	100
SGS AXYS	PCB	PCB 067	0.00	82	83	100
SGS AXYS	PCB	PCB 068	0.00	82	93	100
SGS AXYS	PCB	PCB 069		82	100	100
SGS AXYS	PCB	PCB 070	0.00	82	100	100
SGS AXYS	PCB	PCB 071		82	100	100
SGS AXYS	PCB	PCB 072	0.00	82	94	100
SGS AXYS	PCB	PCB 073	0.00	82	65	100
SGS AXYS	PCB	PCB 074		82	100	100
SGS AXYS	PCB	PCB 075		82	100	100

Lab	Class	Analyte	MDL	n	Detection (%)	Reporting (%)
SGS AXYS	PCB	PCB 076		82	100	100
SGS AXYS	PCB	PCB 077	0.00	82	100	100
SGS AXYS	PCB	PCB 078	0.00	82	16	100
SGS AXYS	PCB	PCB 079	0.00	82	98	100
SGS AXYS	PCB	PCB 080	0.00	82	0	100
SGS AXYS	PCB	PCB 081	0.00	82	5	100
SGS AXYS	PCB	PCB 082	0.00	82	98	100
SGS AXYS	PCB	PCB 083		82	100	100
SGS AXYS	PCB	PCB 084	0.00	82	96	100
SGS AXYS	PCB	PCB 085	0.00	82	99	100
SGS AXYS	PCB	PCB 086		82	100	100
SGS AXYS	PCB	PCB 087	0.00	82	100	100
SGS AXYS	PCB	PCB 088		82	100	100
SGS AXYS	PCB	PCB 089	0.00	82	61	100
SGS AXYS	PCB	PCB 090		82	100	100
SGS AXYS	PCB	PCB 091	0.00	82	100	100
SGS AXYS	PCB	PCB 092	0.00	82	99	100
SGS AXYS	PCB	PCB 093		82	100	100
SGS AXYS	PCB	PCB 094	0.00	82	87	100
SGS AXYS	PCB	PCB 095	0.00	82	100	100
SGS AXYS	PCB	PCB 096	0.00	82	82	100
SGS AXYS	PCB	PCB 097		82	100	100
SGS AXYS	PCB	PCB 098		82	100	100
SGS AXYS	PCB	PCB 099	0.00	82	100	100
SGS AXYS	PCB	PCB 100		82	100	100
SGS AXYS	PCB	PCB 101	0.00	82	100	100
SGS AXYS	PCB	PCB 102		82	100	100
SGS AXYS	PCB	PCB 103	0.00	82	99	100
SGS AXYS	PCB	PCB 104	0.00	82	66	100
SGS AXYS	PCB	PCB 105	0.00	82	100	100
SGS AXYS	PCB	PCB 106	0.00	82	0	100

Lab	Class	Analyte	MDL	n	Detection (%)	Reporting (%)
SGS AXYS	PCB	PCB 107		82	100	100
SGS AXYS	PCB	PCB 108		82	100	100
SGS AXYS	PCB	PCB 109	0.00	82	94	100
SGS AXYS	PCB	PCB 110	0.00	82	100	100
SGS AXYS	PCB	PCB 111	0.00	82	85	100
SGS AXYS	PCB	PCB 112	0.00	82	0	100
SGS AXYS	PCB	PCB 113		82	100	100
SGS AXYS	PCB	PCB 114	0.01	82	77	100
SGS AXYS	PCB	PCB 115		82	100	100
SGS AXYS	PCB	PCB 116		82	100	100
SGS AXYS	PCB	PCB 117		82	100	100
SGS AXYS	PCB	PCB 118	0.00	82	100	100
SGS AXYS	PCB	PCB 119		82	100	100
SGS AXYS	PCB	PCB 120	0.00	82	100	100
SGS AXYS	PCB	PCB 121	0.00	82	90	100
SGS AXYS	PCB	PCB 122	0.00	82	57	100
SGS AXYS	PCB	PCB 123	0.04	82	28	100
SGS AXYS	PCB	PCB 124	0.00	82	99	100
SGS AXYS	PCB	PCB 125		82	100	100
SGS AXYS	PCB	PCB 126	0.01	82	13	100
SGS AXYS	PCB	PCB 127	0.00	82	68	100
SGS AXYS	PCB	PCB 128	0.01	82	100	100
SGS AXYS	PCB	PCB 129		82	100	100
SGS AXYS	PCB	PCB 130	0.01	82	93	100
SGS AXYS	PCB	PCB 131	0.01	82	84	100
SGS AXYS	PCB	PCB 132	0.01	82	100	100
SGS AXYS	PCB	PCB 133	0.01	82	100	100
SGS AXYS	PCB	PCB 134	0.01	82	91	100
SGS AXYS	PCB	PCB 135		82	100	100
SGS AXYS	PCB	PCB 136	0.00	82	100	100
SGS AXYS	PCB	PCB 137	0.01	82	100	100

Lab	Class	Analyte	MDL	n	Detection (%)	Reporting (%)
SGS AXYS	PCB	PCB 138	0.01	82	100	100
SGS AXYS	PCB	PCB 139	0.01	82	100	100
SGS AXYS	PCB	PCB 140		82	100	100
SGS AXYS	PCB	PCB 141	0.01	82	93	100
SGS AXYS	PCB	PCB 142	0.01	82	0	100
SGS AXYS	PCB	PCB 143		82	100	100
SGS AXYS	PCB	PCB 144	0.00	82	99	100
SGS AXYS	PCB	PCB 145	0.00	82	40	100
SGS AXYS	PCB	PCB 146	0.01	82	100	100
SGS AXYS	PCB	PCB 147		82	100	100
SGS AXYS	PCB	PCB 148	0.00	82	98	100
SGS AXYS	PCB	PCB 149	0.01	82	100	100
SGS AXYS	PCB	PCB 150	0.00	82	96	100
SGS AXYS	PCB	PCB 151	0.00	82	100	100
SGS AXYS	PCB	PCB 152	0.00	82	79	100
SGS AXYS	PCB	PCB 153	0.00	82	100	100
SGS AXYS	PCB	PCB 154		82	100	100
SGS AXYS	PCB	PCB 155	0.00	82	87	100
SGS AXYS	PCB	PCB 156	0.01	82	100	100
SGS AXYS	PCB	PCB 157		82	100	100
SGS AXYS	PCB	PCB 158	0.00	82	100	100
SGS AXYS	PCB	PCB 159	0.00	82	87	100
SGS AXYS	PCB	PCB 160		82	100	100
SGS AXYS	PCB	PCB 161	0.00	82	0	100
SGS AXYS	PCB	PCB 162	0.00	82	94	100
SGS AXYS	PCB	PCB 163		82	100	100
SGS AXYS	PCB	PCB 164	0.00	82	100	100
SGS AXYS	PCB	PCB 165	0.00	82	96	100
SGS AXYS	PCB	PCB 166		82	100	100
SGS AXYS	PCB	PCB 167	0.00	82	100	100
SGS AXYS	PCB	PCB 168		82	100	100

Lab	Class	Analyte	MDL	n	Detection (%)	Reporting (%)
SGS AXYS	PCB	PCB 169	0.01	82	0	100
SGS AXYS	PCB	PCB 170	0.00	82	100	100
SGS AXYS	PCB	PCB 171	0.00	82	100	100
SGS AXYS	PCB	PCB 172	0.00	82	100	100
SGS AXYS	PCB	PCB 173		82	100	100
SGS AXYS	PCB	PCB 174	0.00	82	100	100
SGS AXYS	PCB	PCB 175	0.00	82	100	100
SGS AXYS	PCB	PCB 176	0.00	82	100	100
SGS AXYS	PCB	PCB 177	0.00	82	100	100
SGS AXYS	PCB	PCB 178	0.00	82	100	100
SGS AXYS	PCB	PCB 179	0.00	82	100	100
SGS AXYS	PCB	PCB 180	0.00	82	99	100
SGS AXYS	PCB	PCB 181	0.00	82	91	100
SGS AXYS	PCB	PCB 182	0.00	82	95	100
SGS AXYS	PCB	PCB 183	0.00	82	99	100
SGS AXYS	PCB	PCB 184	0.00	82	93	100
SGS AXYS	PCB	PCB 185		82	100	100
SGS AXYS	PCB	PCB 186	0.00	82	0	100
SGS AXYS	PCB	PCB 187	0.00	82	100	100
SGS AXYS	PCB	PCB 188	0.00	82	98	100
SGS AXYS	PCB	PCB 189	0.00	82	98	100
SGS AXYS	PCB	PCB 190	0.00	82	100	100
SGS AXYS	PCB	PCB 191	0.00	82	100	100
SGS AXYS	PCB	PCB 192	0.00	82	4	100
SGS AXYS	PCB	PCB 193		82	100	100
SGS AXYS	PCB	PCB 194	0.00	82	100	100
SGS AXYS	PCB	PCB 195	0.00	82	99	100
SGS AXYS	PCB	PCB 196	0.00	82	100	100
SGS AXYS	PCB	PCB 197		82	100	100
SGS AXYS	PCB	PCB 198		82	100	100
SGS AXYS	PCB	PCB 199	0.00	82	100	100

Lab	Class	Analyte	MDL	n	Detection (%)	Reporting (%)
SGS AXYS	PCB	PCB 200	0.00	82	100	100
SGS AXYS	PCB	PCB 201	0.00	82	100	100
SGS AXYS	PCB	PCB 202	0.00	82	100	100
SGS AXYS	PCB	PCB 203	0.00	82	100	100
SGS AXYS	PCB	PCB 204	0.00	82	68	100
SGS AXYS	PCB	PCB 205	0.00	82	100	100
SGS AXYS	PCB	PCB 206	0.00	82	100	100
SGS AXYS	PCB	PCB 207	0.00	82	100	100
SGS AXYS	PCB	PCB 208	0.00	82	100	100
SGS AXYS	PCB	PCB 209	0.00	82	100	100
SGS AXYS	PFAS	Perfluorobutanoate	0.74	14	7	100
SGS AXYS	PFAS	Perfluoropentanoate	0.37	14	0	100
SGS AXYS	PFAS	Perfluorohexanoate	0.19	14	0	100
SGS AXYS	PFAS	Perfluoroheptanoate	0.19	14	0	100
SGS AXYS	PFAS	Perfluorooctanoate	0.19	14	21	100
SGS AXYS	PFAS	Perfluorononanoate	0.19	14	36	100
SGS AXYS	PFAS	Perfluorodecanoate	0.19	14	64	100
SGS AXYS	PFAS	Perfluoroundecanoate	0.19	14	71	100
SGS AXYS	PFAS	Perfluorododecanoate	0.19	14	64	100
SGS AXYS	PFAS	Perfluorotridecanoate	0.19	14	57	100
SGS AXYS	PFAS	Perfluorotetradecanoate	0.19	14	71	100
SGS AXYS	PFAS	Perfluorobutanesulfonate	0.19	14	0	100
SGS AXYS	PFAS	Perfluoropentanesulfonate	0.19	14	0	100
SGS AXYS	PFAS	Perfluorohexanesulfonate	0.19	14	29	100
SGS AXYS	PFAS	Perfluoroheptanesulfonate	0.19	14	0	100
SGS AXYS	PFAS	Perfluorooctanesulfonate	0.21	14	93	100
SGS AXYS	PFAS	Perfluorononanesulfonate	0.19	14	0	100
SGS AXYS	PFAS	Perfluorodecanesulfonate	0.19	14	43	100
SGS AXYS	PFAS	Perfluorododecanesulfonate	0.19	14	0	7
SGS AXYS	PFAS	Perfluorooctanesulfonamide	0.19	14	86	100
SGS AXYS	PFAS	Methyl-perfluorooctanesulfonamide, N-	0.21	14	0	100

Lab	Class	Analyte	MDL	n	Detection (%)	Reporting (%)
SGS AXYS	PFAS	Ethyl-perfluorooctanesulfonamide, N-	0.46	14	0	100
SGS AXYS	PFAS	Methyl Perfluorooctane Sulfonamido Acetic Acid, N-	0.19	14	7	100
SGS AXYS	PFAS	Ethyl Perfluorooctane Sulfonamido Acetic Acid, N-	0.19	14	29	100
SGS AXYS	PFAS	Methyl-perfluorooctanesulfonamidoethanol, N-	1.86	14	0	7
SGS AXYS	PFAS	Ethyl-perfluorooctanesulfonamidoethanol, N-	1.39	14	0	100
SGS AXYS	PFAS	Fluorotelomer Sulfonate, 4:2-	0.74	14	0	100
SGS AXYS	PFAS	Fluorotelomer Sulfonate, 6:2-	0.67	14	7	100
SGS AXYS	PFAS	Fluorotelomer Sulfonate, 8:2-	0.74	14	0	100
SGS AXYS	PFAS	Dioxa-3H-Perfluorononanoate Acid, 4,8-	0.74	14	0	100
SGS AXYS	PFAS	Chlorohexadecafluoro-3-Oxanonane-1-Sulfonic Acid, 9-	0.74	14	0	100
SGS AXYS	PFAS	Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid, 11-	0.74	14	0	100
SGS AXYS	PFAS	Perfluoro-2-Propoxypropanoic Acid	0.71	14	0	100

Chemical Analyses

Analyses were conducted using USEPA methods in accordance with the 2019 RMP Quality Assurance Program Plan (QAPP) for the RMP (Yee et al. 2019). The comprehensive analyte list, analytical laboratories, method detection limits, and analyte detection and reporting statistics are shown in Table 2. Quality assurance analyses to access precision, accuracy, recovery, completeness, and sensitivity were performed for each batch as required by the 2019 RMP QAPP (Yee et al. 2019).

Data that met all measurement quality objectives (MQOs) as specified in the QAPP are classified as “compliant” and considered usable 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 19220 sample results for individual constituents in tissue composites (Table 2), with over 99.5% of them reportable [classified as “compliant” (23.5%), “qualified” (73.8%), or “estimated” (2.4%)].

Sums of organic contaminant classes were calculated by summing the concentrations of individual congeners or analytes 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 in previous rounds of sampling. For any sum, if congeners or analytes 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 2.

Data that were considered usable and reportable (i.e., classified as “compliant,” “qualified,” or “estimated”) are available at cd3.sfei.org and are labeled by the project name “2019 RMP FISH”. Detailed quality assurance/quality control summaries for each analysis can be found in the 2019 RMP Sport Fish Samples Quality Assurance Report (Appendix 3).

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 the California Office of Environmental Health Hazard Assessment (OEHHA) (Klasing and Brodberg 2008 [updated 2017]) – advisory tissue levels (ATLs) (Table 3) – as well as regulatory thresholds established by the SFBRWQCB. Klasing and Brodberg 2008 [updated 2017] described ATLs as follows.

> "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 this description of ATLs, the assessments presented in this report are not intended to represent consumption advice.

The 2019 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 18-49 years and children 1-17 years). The OEHHA thresholds shown in the figures indicate the lower end of the ATL range (Table 3).

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 servings/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.

			Average Concentrations											
Species	**Tissue Type**	**Approximate # of Fish per Composite [1]**	**Number of Samples [2]**	**% moisture**	**% lipid [3]**	**Sum of 208 PCBs (ppb)[4]**	**Sum of 40 PCBs (ppb)[4]**	**Sum of PBDEs (ppb)**	**Dioxin TEQs (pptr)**	**Sum of PFAS (ppb)**	**PFOS (ppb)**	**Hg (ppm)**	**Se (ppm ww)**	**Se (ppm dw)**
		Screening Values				**10**						**0.2**		
Bat Ray	Muscle fillet	3	7	74.5	0.85	12	11					0.83		
Brown Rockfish	Muscle fillet	1	15											
		5		76.8	0.49	3.6	2.9					0.12		
California Halibut	Muscle fillet	3	4	74.7	0.26	7.5	6.1					0.14	0.45	1.8
Diamond Turbot	Muscle fillet	10	1	75.7	0.33	4.0	3.2					0.24		
Jacksmelt	Muscle fillet	10	8	76.9								0.09	0.30	1.3
Largemouth Bass	Muscle fillet	1	16									0.40		
		5	1	76.7	0.27	81	70	23		15	9.1			
Monkeyface Prickleback	Muscle fillet	5	1	77.4	0.65	0.49	0.40					0.02		
Northern Anchovy	Whole without head, tail, or guts	20	8	78.8	1.5	110	91					0.06		
Pacific Herring	Muscle fillet	20	3	78.5	1.5	3.7	3.0					0.05		
Shiner Surfperch	Whole without head, tail, or guts	20	23	76.7	2.0	180	160	6.2	0.79	7.6	3.7	0.15	0.33	1.5
Staghorn Sculpin	Whole without head, tail, or guts	10	6	77.3	1.7	69	58					0.05		
Starry Flounder	Muscle fillet	5	1	76.2	0.41	3.0	2.4					0.08		
Striped Bass	Muscle fillet	1	25									0.46		
		3	9	76.8	0.57	20	16	1.4		12	7.5		0.44	2.0
White Croaker	Muscle fillet	5	11	75.6	2.0	55	45		0.19	1.9	0.84	0.36	0.46	2.0
White Sturgeon[5]	Muscle fillet	1	9									0.29	1.4[5]	5.9[5]
		3	3	76.8	1.5	21	17			4.1	2.9			
White Surfperch	Muscle fillet	10	1	75.2								0.05	0.33	1.6

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

2 – 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.

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

4 – Average values exclude data from samples taken from Priority Margin Units (PMU)

5 – White Sturgeon individual selenium samples included fillets from the epaxial muscle of the fish

Summary Statistics

All data are presented on a wet weight basis, unless otherwise noted, in order to compare values against ATLs and regulatory thresholds. Selenium results are also presented on a dry weight basis, for comparison to the North Bay TMDL fish tissue numeric target. For some organic contaminants data have also been presented on a lipid weight basis, to adjust 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. 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.

This report uses the arithmetic mean (or “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.

Summary statistics are presented in two ways: 1) based on data for the stations that have been sampled consistently in previous rounds of sampling, and 2) based on data for all stations sampled, including the PMUs. The first approach presents the data in a manner that can be consistently compared to data from prior years, which is best for assessing long-term trends. The second approach including the PMU stations provides a comprehensive summary of the overall 2019 dataset that includes more extensive coverage of the Bay, but includes stations that were specifically selected because of their high PCB concentrations.

Statistical Analyses

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. These ANOVAs were conducted on log-transformed data, except for PBDEs which were not log-transformed due to the data’s normal distribution. Long-term trends for datasets in which fewer than six sampling rounds were available were evaluated using pairwise comparison tests between 2019 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 2). Long-term trend analyses on Bay-wide data were 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. For all statistical tests, an alpha 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. The majority of mercury (> 95%) accumulated in fish tissue is methylmercury (Bloom 1992). In 2008, the USEPA approved the San Francisco Bay TMDL for mercury (SFBRWQCB 2006), 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 (e.g., one serving/week ATL of >0.15-0.44 ppm and two servings/week ATL of >0.07-0.15 ppm for the sensitive population [women 18 to 49 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 occurred largely 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 (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 additional mercury reductions required to meet the water quality objective. In this report, total mercury measurements are used as proxies for methylmercury concentrations.

Comparison to Thresholds and Variation Among Species

Mercury concentrations continue to exceed thresholds of concern in Bay sport fish (Figure 2, Tables 4 and 5). The average mercury concentration in bat rays (0.83 ppm) and striped bass (0.46 ppm [not length-adjusted]) exceeded the no consumption ATL (for the sensitive population) of >0.44 ppm, and a few white croaker composites and individual largemouth bass (not length-adjusted) exceeded this threshold as well (ranges = 0.24-0.62 ppm, and 0.16-1.3 ppm, respectively), as did one individual white sturgeon (white sturgeon range = 0.15-0.52 ppm). Lower concentrations were measured in other popularly consumed sport fish species. White croaker, white sturgeon, and diamond turbot had average concentrations that fell within the one serving/week ATL range (>0.15-0.44 ppm) for the sensitive population (0.36, 0.29, and 0.24 ppm, respectively); shiner surfperch, California halibut, brown rockfish, starry flounder, and jacksmelt averages were in the two serving/week.

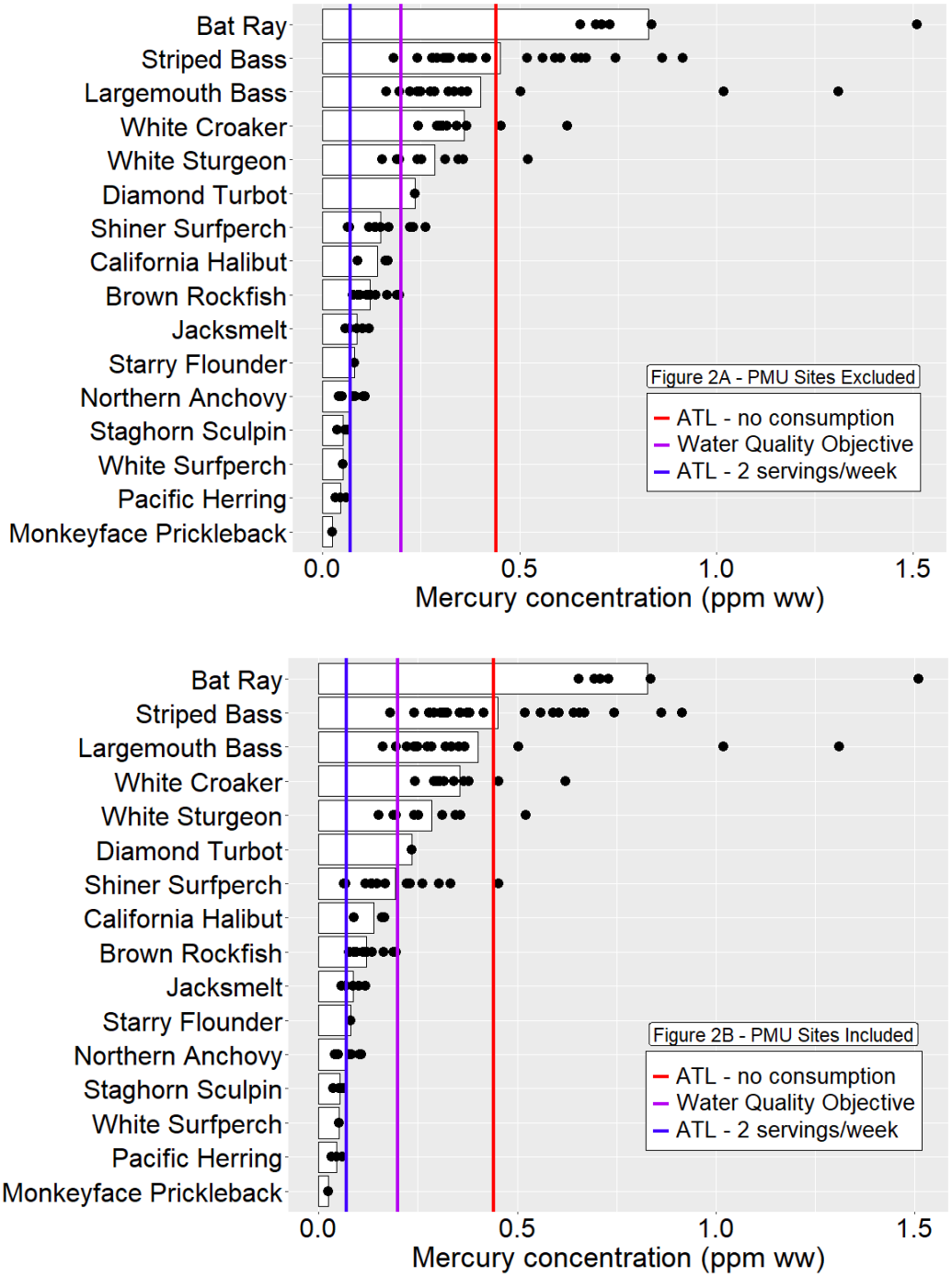

Figure 2. Mercury concentrations (ppm ww) in San Francisco Bay fish species, 2019. A) PMU station (Richmond Harbor and San Leandro Bay) data points excluded, specifically for shiner surfperch. B) PMU station data points included. Bars indicate average concentrations. Points represent individual samples (either composites or individual fish). Concentrations in striped bass and largemouth bass are not length-adjusted. The colored lines indicating ATL thresholds show the lower end of the advisory tissue level ranges (see Table 3 for ranges).

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 (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-Furan TEQs pptr ww
Threshold		**0.2**	**11.3**	**10**	**0.14**
Bat Ray	Composite	7/7		3/7	
Brown Rockfish	Individual	0/15			
	Composite			0/4	
California Halibut	Composite	0/3	0/3	1/3	
Diamond Turbot	Composite	1/1		0/1	
Jacksmelt	Composite	0/5	0/8	2/3	
Largemouth Bass	Individual	14/16			
	Composite			1/1	
Monkeyface Prickleback	Composite	0/1		0/1	
Northern Anchovy	Composite	0/8		8/8	
Pacific Herring	Composite	0/3		0/3	
Shiner Surfperch	Composite	3/11	0/14	24/24	14/14
Staghorn Sculpin	Composite	0/3		6/6	
Starry Flounder	Composite	0/1		0/1	
Striped Bass	Individual	24/27			
	Composite		0/9	9/10	
White Croaker	Composite	9/11	0/11	12/12	6/11
White Sturgeon	Individual - Epaxial	6/9	1/9		
	Individual - Caudal		1/9		
	Composite			3/12	
White Surfperch	Composite	0/1	0/1	1/1	

range (range = >0.07-0.15; average = 0.15, 0.14, 0.12, 0.08, 0.09 ppm, respectively); northern anchovy (0.06 ppm) were in the three serving/week range (>0.055-0.07); Pacific herring, staghorn sculpin, and white surfperch averages (0.046, 0.052, and 0.050 ppm, respectively) fell below the three serving/week range (<0.055).

According to the Basin Plan, 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). The 2019 results yielded a grand mean of 0.27 ppm, which exceeds the water quality objective. The means discussed here were calculated without PMU data included to maintain consistency with previous years. Striped bass, white croaker, and white sturgeon (averaging 0.46, 0.36, and 0.29 ppm, respectively) – exceeded the objective. Average concentrations in California halibut and jacksmelt (0.14 and 0.09 ppm) were below the objective. Northern anchovy, an important prey fish indicator species for the protection of piscivorous wildlife health, had an average concentration of 0.06 ppm, which is above the water quality objective for mercury in prey fish (0.03 ppm). To put this finding in more detailed context, the wildlife protection objective applies to a size range of 3 - 5 cm (total length) and 2019 anchovy samples had a size range of 3.7 -10 cm with a median length of 5.5 cm (Table 1); none of the composite samples were completely composed of fish below 5 cm.

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 fishers, and life-history characteristics that cause them to accumulate relatively high mercury levels. Striped bass are high trophic-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 bat rays. Striped bass are also good integrative indicators of mercury contamination in the Bay-Delta Estuary because they use the entire ecosystem, including fresh and saline waters. Although some striped bass spend most of their lives in San Francisco Bay, they also move into freshwater and the 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 less valuable as indicators of small-scale spatial variation within the Bay-Delta and may confound attempts to discern long-term trends.

The TMDL established the use of length-adjusted mercury concentrations 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). Length-adjusted data in this report are presented as estimated concentrations for each individual striped bass at a length of 60 cm, based on a length-mercury regression.

The striped bass collected in 2019 (Figure 3) spanned a relatively narrow size range (450-595 mm) making it difficult to establish the length-mercury relationship based only on the 2019 dataset. In addition, variability within the 2019 dataset was high (with concentrations

ranging from 0.18-0.92 ppm), in part due to the targeted sampling effort at South Bay (Coyote Creek). The South Bay (Coyote Creek) sampling station is two miles downstream of the Artesian Slough station at the San José-Santa Clara Regional Wastewater Facility outfall. Striped bass were collected directly near the outfall, in Artesian Slough, in 2015 and found to have unusually high mercury concentrations, and were excluded from the overall length-mercury regression by Sun et al. (2017). The striped bass collected in South Bay (Coyote Creek) in 2019 were likely part of the same subpopulation that spends time in Artesian Slough, and again had relatively high mercury concentrations.

Given these considerations, the length-mercury relationship for length adjustment was based on a combination of data from 2014 (which spanned a wider range of lengths) and 2019, but excluding the 2015 data for fish from Artesian Slough and the 2019 data for fish from South Bay (Coyote Creek) (Figure 4). These data yielded a significant linear regression (R^2 = 0.53, p = $4x10^{-5}$). The resulting regression equation was used to calculate the estimated mercury concentration in each striped bass at a length of 60 cm.

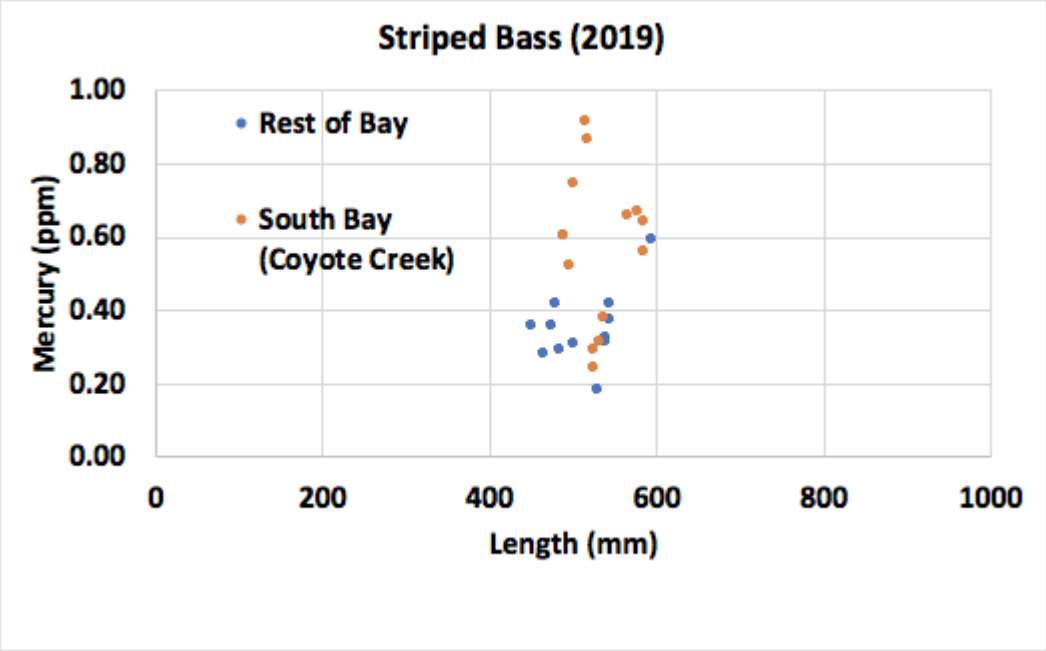

Figure 3. Mercury concentrations (ppm ww) versus total length (mm) in striped bass collected in San Francisco Bay, 2019. Points represent individual samples.

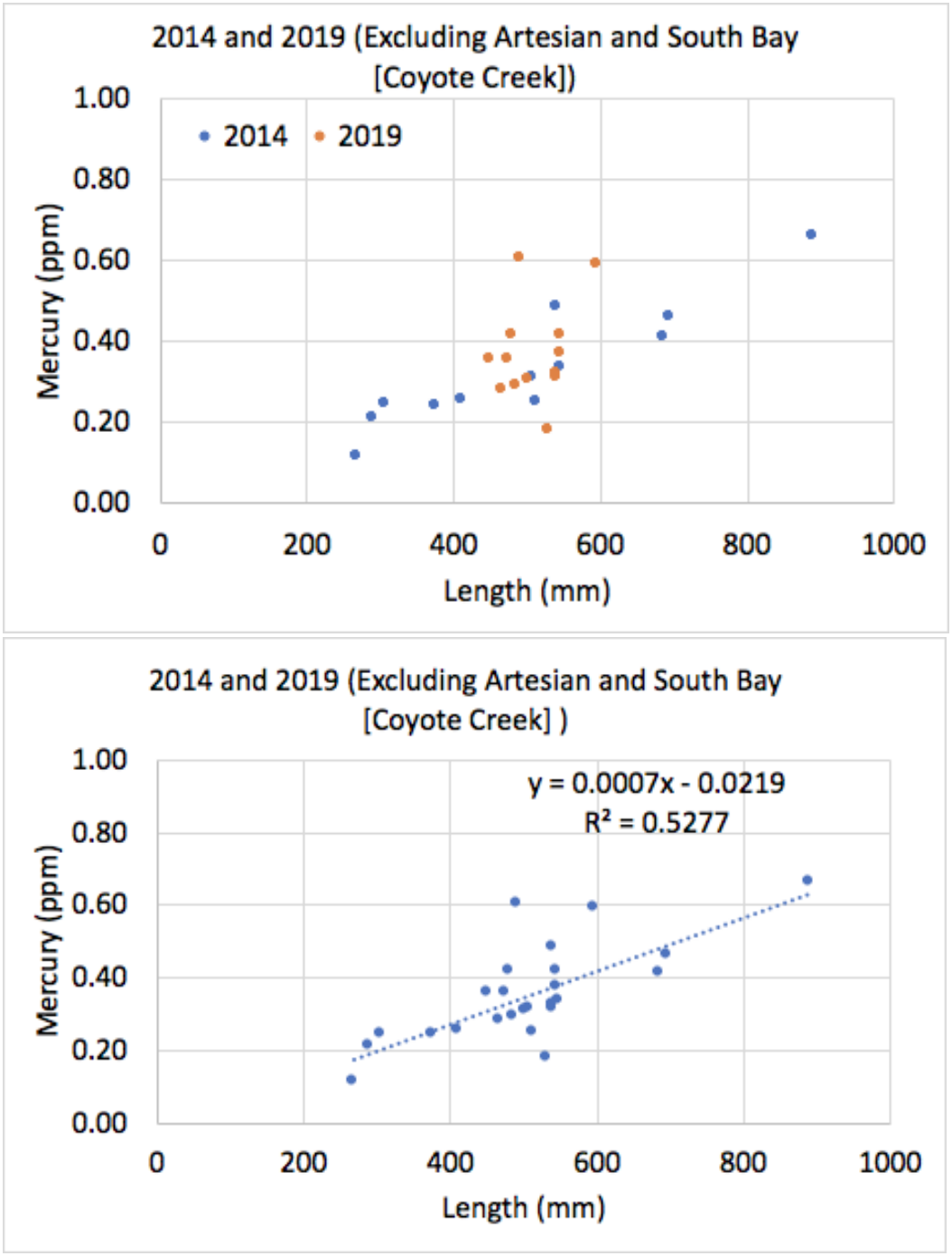

Figure 4. Mercury concentrations (ppm ww) versus total length (mm) in striped bass collected in San Francisco Bay, 2014 and 2019. Points represent individual samples. The relationship between length and mercury concentrations is positive and significant (linear regression, $R^2 = 0.53$, $p = 4x10^{-5}$).

Similar to the findings in 2014-2015, the length-adjusted mercury concentrations in striped bass caught in 2019 in South Bay (including South Bay [Coyote Creek] and South Bay [Redwood Creek]; Figure 1) were statistically distinct (Figures 5 and 6), with elevated concentrations relative to those observed in other parts of the Bay. The “South Bay” station actually consists of samples from two areas in the South Bay: in Coyote Creek at the extreme southern end of the Bay, and further north in the area around Redwood City Harbor (Figure 1). Twelve of the 13 striped bass from South Bay were collected at South Bay (Coyote Creek). Driven by the concentrations in the 12 fish from South Bay (Coyote Creek (one fish was from South Bay [Redwood Creek]), the mean length-adjusted concentration for South Bay (0.61 ppm) was significantly different from the mean for Central Bay (0.40 ppm). Although the San Pablo Bay mean (0.44 ppm) was only slightly higher than the Central Bay mean, the San Pablo Bay mean and the South Bay mean were not significantly different.

The long-term dataset for length-adjusted mercury concentrations in striped bass (Figure 6) provides further evidence of relatively high concentrations in Lower South Bay, along with relatively low and very similar concentrations in Suisun Bay, San Pablo Bay, and Central Bay. The striped bass collected from Artesian Slough in 2015 stand out from the rest of the overall dataset, with a mean (0.73 ppm) that is significantly higher than the means for all other stations except for San Pablo Bay. The lack of a significant difference between Artesian Slough and San Pablo Bay is due to higher variance for San Pablo Bay than for the Central Bay and Berkeley stations, which had higher mean concentrations (0.392 and 0.390 ppm, respectively) than San Pablo Bay (0.38 ppm). The South Bay station (including both South Bay [Redwood Creek] and South Bay [Coyote Creek]) mean (0.41 ppm) was higher (but not statistically significantly higher) than the stations to the north, largely due to the high concentrations measured in the 12 fish from South Bay (Coyote Creek) in 2019 (magenta dots for South Bay in Figure 6).

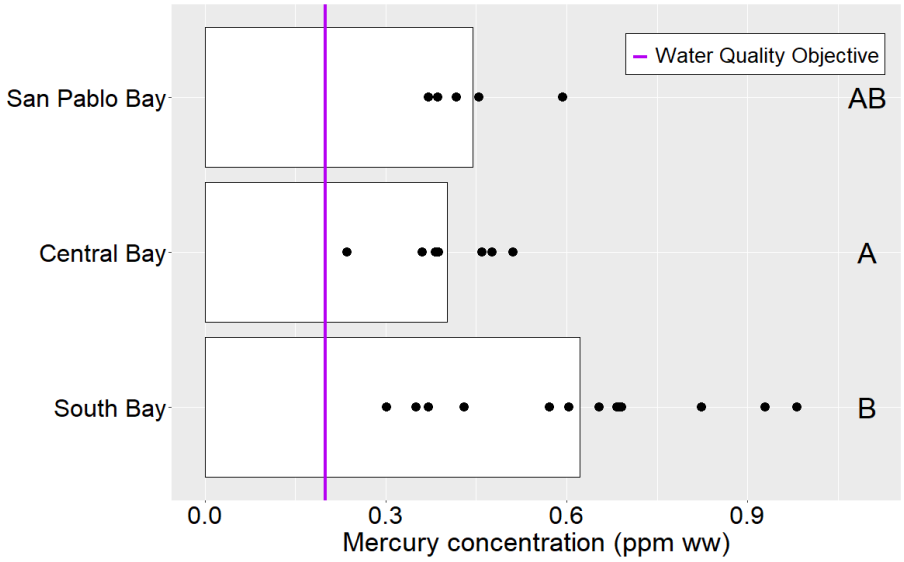

Figure 5. Length-adjusted mercury concentrations (ppm ww) in striped bass in San Francisco Bay, 2019. Bars indicate average concentrations. Points show data for 60-cm length-adjusted individual fish samples. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha = 0.05).

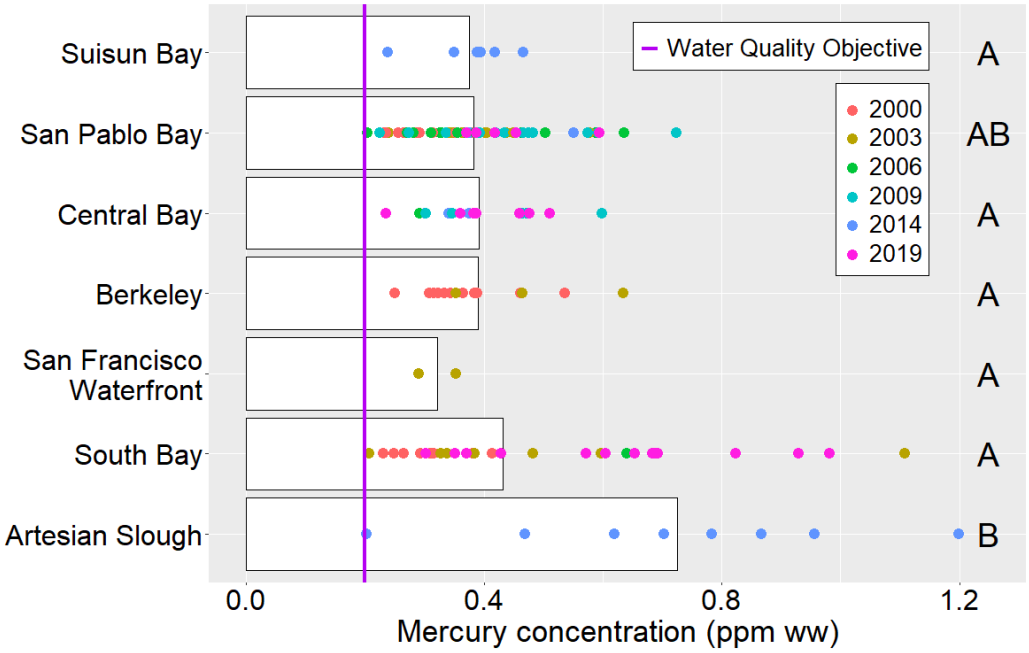

Figure 6. Mercury concentrations in striped bass in San Francisco Bay, 1997-2019. Bars indicate average concentrations. Points represent 60-cm size-standardized composite or individual samples, standardized using the length vs. log(Hg) relationship calculated using fish collected in the Bay proper (not 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 three fish). Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha = 0.05).

Based on mercury concentrations in largemouth bass further upstream in Artesian Slough that were not elevated (350 mm length-adjusted mean of 0.23 ppm), Sun et al. (2017) hypothesized that the Artesian Slough striped bass accumulated their mercury from other areas in Lower South Bay. However, in 2019, 16 largemouth bass from Artesian Slough yielded a 350 mm length-adjusted mean of 0.67 ppm, which is high relative to the extensive statewide dataset for largemouth bass (e.g., a statewide 350 mm length-adjusted mean of 0.35 ppm in largemouth bass from 194 lakes - Davis et al., 2019). Since the Artesian Slough largemouth bass were collected from a non-tidal freshwater area, the 2019 data indicate that this area downstream of the San Jose-Santa Clara municipal wastewater outfall can be a zone of net methylmercury production and accumulation in the food web, and that this area may be a source of mercury in striped bass in tidal waters downstream (i.e., in Artesian Slough and Coyote Creek). It is still possible, however, that these striped bass also accumulate mercury from other areas in Lower South Bay, such as the area influenced more directly by the Guadalupe River and its legacy mercury 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 multiple replicates per location (n = 3, except Berkeley) provides some statistical power to detect spatial patterns. Although the average mercury concentration in this species (0.15 ppm) was lower than several other species, the distinct spatial pattern of mercury concentrations observed 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 (Sun et al., 2017). The highest average mercury concentration in shiner surfperch from historic stations was observed at Oakland (0.24 ppm), which differed significantly from the next highest average concentrations at Berkeley (0.16 ppm) and South Bay (0.13 ppm) (alpha = 0.05; Figure 7). Concentrations observed in all these three regions were also significantly higher than concentrations measured in the San Francisco Waterfront (average = 0.07 ppm) (alpha = 0.05; Figure 7). It should be noted that the shiner surfperch for the South Bay station were collected from Redwood Creek, not the South Bay (Coyote Creek) area where the South Bay striped bass with high concentrations were collected.

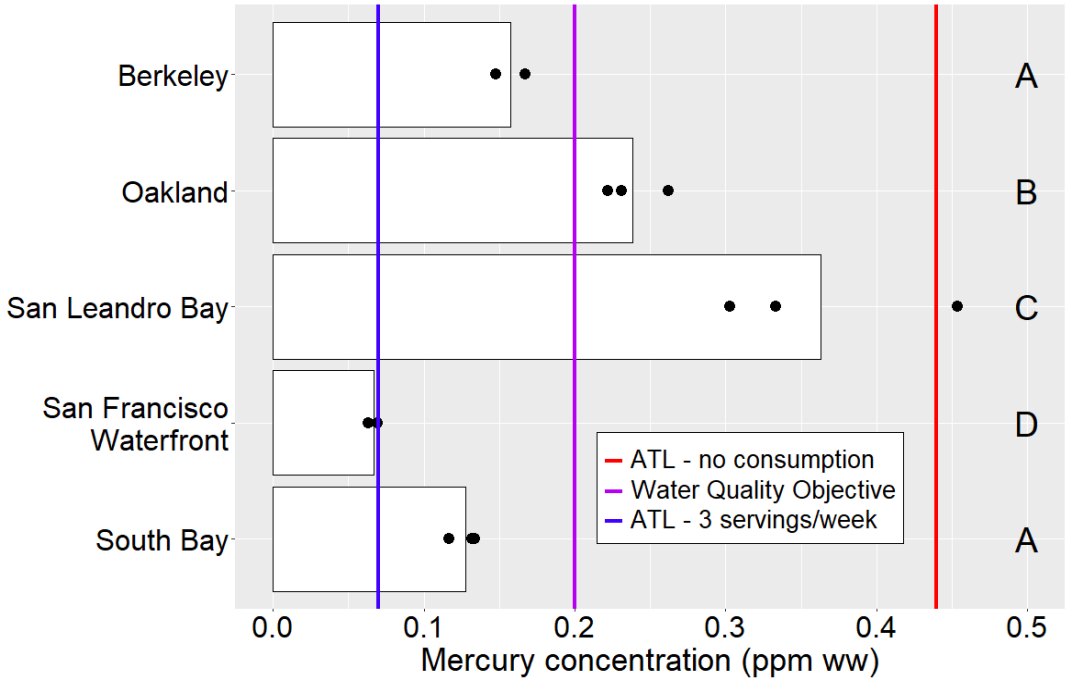

Figure 7. Mercury concentrations (ppm ww) in shiner surfperch in San Francisco Bay, 2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha = 0.05). The colored lines indicating ATL thresholds show the lower end of the advisory tissue level ranges.

Temporal Trends

A relatively extensive historical dataset exists for striped bass in the Bay, allowing for the evaluation of trends over 44 years, between 1971-2019 (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, 2014, and 2019). Figure 8 does not include fish collected from Artesian Slough in 2015 and South Bay (Coyote Creek) in 2019, which reflect a different mercury exposure regime that was not included in the earlier rounds of sampling.

In 2019, the average mercury concentration in 60 cm length-adjusted bass was not significantly different from those measured in 1971. Similar to 2014, no trend was evident in striped bass mercury concentrations (linear regression: $p = 0.29$, $R^2 = 6 \times 10^{-4}$).

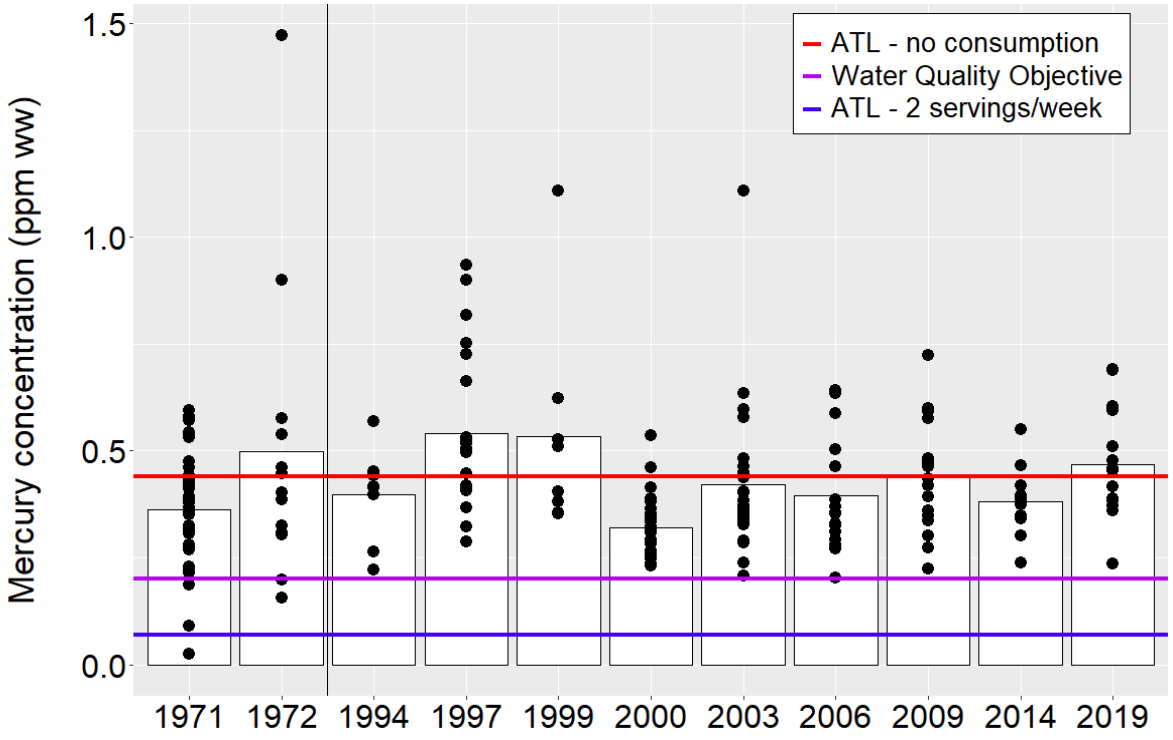

Figure 8. Mercury concentrations (ppm ww) in striped bass in San Francisco Bay, 1971-2019. Bars indicate average concentrations. Points represent individual fish, with the exception of six composite samples (3 fish each) analyzed in 2014. All plotted points are 60 cm length-adjusted The 2014 data do not include fish collected in Artesian Slough, and the 2019 data do not include fish collected in South Bay (Coyote Creek); these areas reflect unique mercury sources and were collected only in 2015 and 2019. 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, 2014, and 2019).

Management Implications and Priorities for Further Assessment

The 2019 data indicate that fish mercury concentrations in the Bay remain high with no evidence of long-term decline and that spatial patterns of contamination have remained similar over time. Spatial patterns are generally consistent with previous observations and current knowledge of mercury hotspots in upstream watersheds (e.g., the Guadalupe River watershed) that are being targeted for management actions to reduce loads. One novel finding in 2019 was the high average mercury concentration in largemouth bass in the freshwater portion of Alviso Slough, which suggests that this habitat below the San Jose-Santa Clara wastewater outfall may sometimes be a zone of net methylmercury production and bioaccumulation, and may contribute to the relatively high mercury bioaccumulation downstream in striped bass in the estuarine Coyote Creek region.

The average concentrations of three out of five sport fish indicator species identified in the mercury TMDL exceeded the water quality objective. The five-species mean specified in the

water quality objective was 0.27 ppm, above the objective of 0.20 ppm. The average concentration (0.06 ppm) for northern anchovy, an important prey fish indicator species for the protection of piscivorous wildlife health, was above the water quality objective for mercury in prey fish (0.03 ppm).

The 2019 survey addressed some of the data gaps identified by OEHHA relating to developing more extensive consumption advice for the Bay. Multiple samples were analyzed for bat rays, northern anchovy, Pacific herring, brown rockfish, and staghorn sculpin. Data gaps remain for diamond turbot, starry flounder, and monkeyface prickleback, where only one sample of each species was analyzed, and other species of interest that were not analyzed (Pacific sardine, cabezon, Pacific sanddab, and petrale sole). These data gaps remain because the additional species were collected opportunistically as bycatch, excluding monkeyface prickleback for which a concerted effort was made.

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 sediment and watershed contamination on land, particularly in historically industrialized areas. Continuing to monitor PCBs in Bay sport fish is crucial to assessing the effectiveness of the TMDL in reducing additional sources of external PCB inputs to 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 thus were identified as indicator species in the PCB TMDL (SFBRWQCB 2008). White croaker tend to have larger and more variable foraging ranges than shiner surfperch, and thus concentrations measured in this species represent a more spatially-integrated assessment of contaminant exposure in the Bay. A long-term time series of PCBs and dioxins in white croaker was established by the Bay Protection Toxic Cleanup Program (BPTCP) (Fairey et al. 1997) and the RMP. In 2009, a comparison of sample processing (skin on versus skin off) was conducted, showing PCB concentrations were significantly lower in white croaker samples prepared with skin off, a method that reduces the lipid content of samples (Klasing et al. 2009; Davis et al. 2011). In 2014, white croaker samples were mistakenly processed as whole fish instead of fillets, which prevented the comparison of PCB concentrations to regulatory thresholds and with long-term, historical data and created a gap in the time series.

Shiner surfperch is a smaller species that has small home ranges and is an excellent indicator of spatial variation. The long-term time series for shiner surfperch also dates back to the BPTCP, and has been uninterrupted and is more complete than the white croaker time series. Shiner surfperch is typically prepared for consumption with its skin on, and is processed by the RMP with the skin on (but with the head, viscera, and tail removed).

Comparisons to thresholds and analyses of spatial patterns in 2019 were conducted using a total sum of all PCB congeners measured, which included 208 congeners in 2019 (Tables 2, 4, and 5). Due to changes in analytical methods, different numbers of congeners have been included in the sum of all PCBs measured each year. To analyze temporal trends using comparable values, the RMP uses a sum of 40 PCB congeners (Davis et al. 2014). The methods used to process and sum PCB congeners are more comprehensively described in Appendix 1.

The 2019 RMP Status and Trends (S&T) sport fish survey was augmented by a RMP Special Study focused on monitoring shiner surfperch in margin areas ("priority margin units," or PMUs) that are not normally included in S&T monitoring. The additional areas included Richmond Harbor, Emeryville Crescent, and San Leandro Bay, as well as more extensive sampling near the S&T station in Redwood Creek (part of the "South Bay" station) (Figure 1). The field team was not able to collect shiner surfperch in Emeryville Crescent, but did collect them in Richmond Harbor and San Leandro Bay. The field team also collected additional species from the PMU stations as bycatch or as substitutes for shiner surfperch. For the sake of consistency with past sampling, this section includes the PMU data but the discussion focuses on the data from the S&T stations, particularly where comparison to past sampling rounds is of interest. A discussion of the results for the PMU Special Study is provided in a separate report (Davis et al. in preparation).

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 (Figures 9a and 9b; Tables 4 and 5). The highest species average PCB concentration (excluding the PMU data) was for shiner surfperch (180 ppb ww) exceeding all thresholds, with concentrations of some composites over two times greater than the no consumption ATL (>120 ppb), and a maximum concentration of 300 ppb ww (Figure 9a). Northern anchovy, an indicator species for wildlife exposure, are also a high lipid species (average = 2.0% lipid) and processed as whole body samples, and had the second highest average concentration (110 ppb).

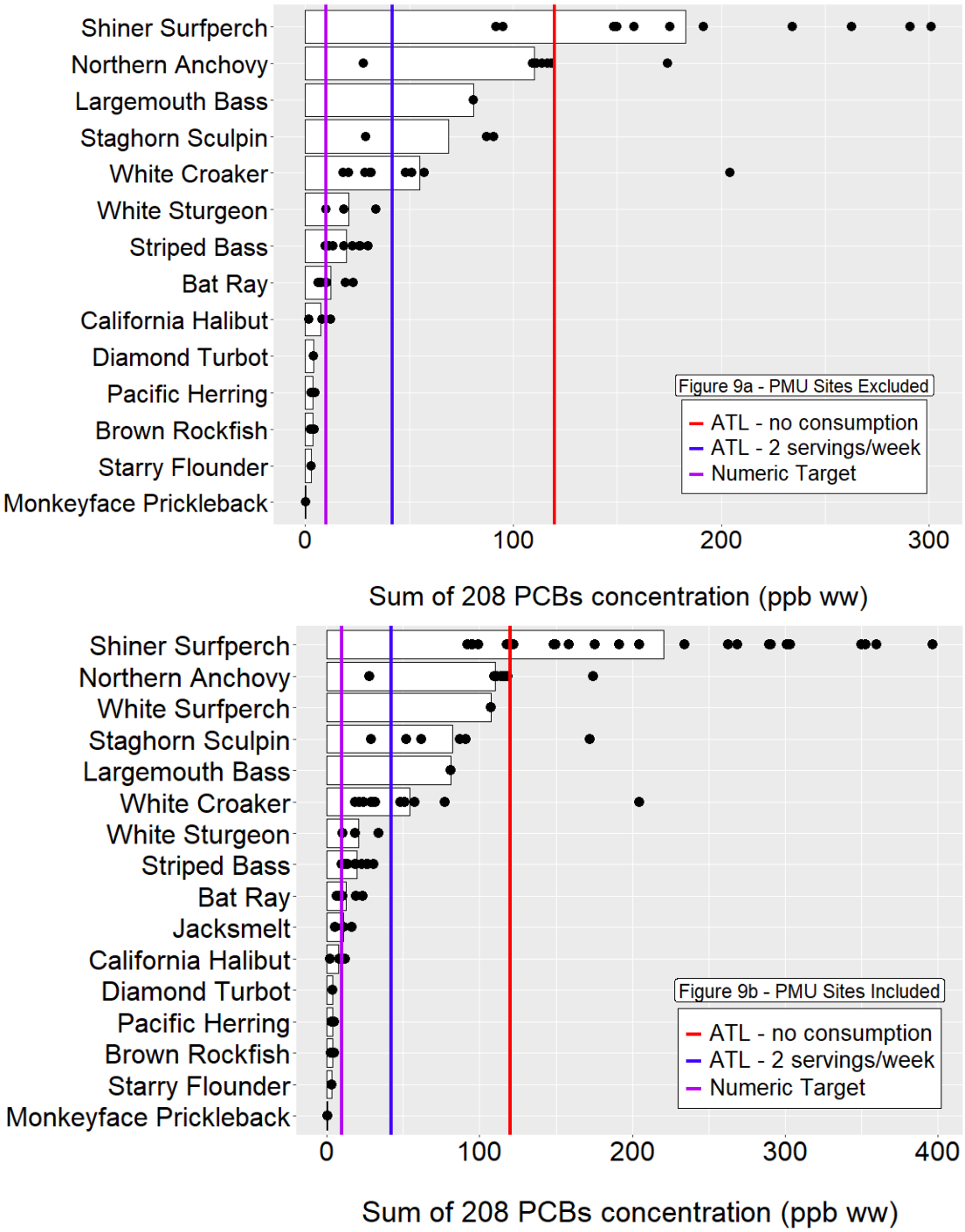

Figure 9. PCB concentrations (ppb ww) in San Francisco Bay fish, 2019. A) PMU station (Richmond Harbor and San Leandro Bay) data points excluded. B) PMU station data points included. Points represent composite samples. Colored lines indicating ATL thresholds show the lower end of the ATL ranges.

More moderate concentrations were measured in other species, ranging from 81 ppb in largemouth bass to 0.5 ppb in monkeyface prickleback. Ten of the 16 species measured had average concentrations in exceedance of the numeric target (10 ppb ww). The other six species below the numeric target included one commonly-consumed species (California halibut), and five other less commonly consumed species (brown rockfish, diamond turbot, monkeyface prickleback, Pacific herring, starry flounder).

Spatial Patterns

Shiner surfperch are excellent indicators of spatial variability in PCB concentrations in the Bay. The spatial distribution of PCB contamination observed in shiner surfperch at the S&T stations (Figure 10) was consistent with patterns observed in earlier rounds of sampling. One difference from prior rounds was that shiner surfperch were not collected from the San Pablo Bay station, which historically has consistently had the lowest average PCB concentrations. As in prior rounds, PCB concentrations were higher in Oakland Harbor (280 ppb) than at the other S&T stations, with a statistically significant difference between Oakland Harbor and the lowest average concentration at Berkeley (94 ppb). Average concentrations were intermediate at South Bay (Redwood Creek) (180 ppb) and at the San Francisco Waterfront (180 ppb) and were not significantly different from any of the other stations.

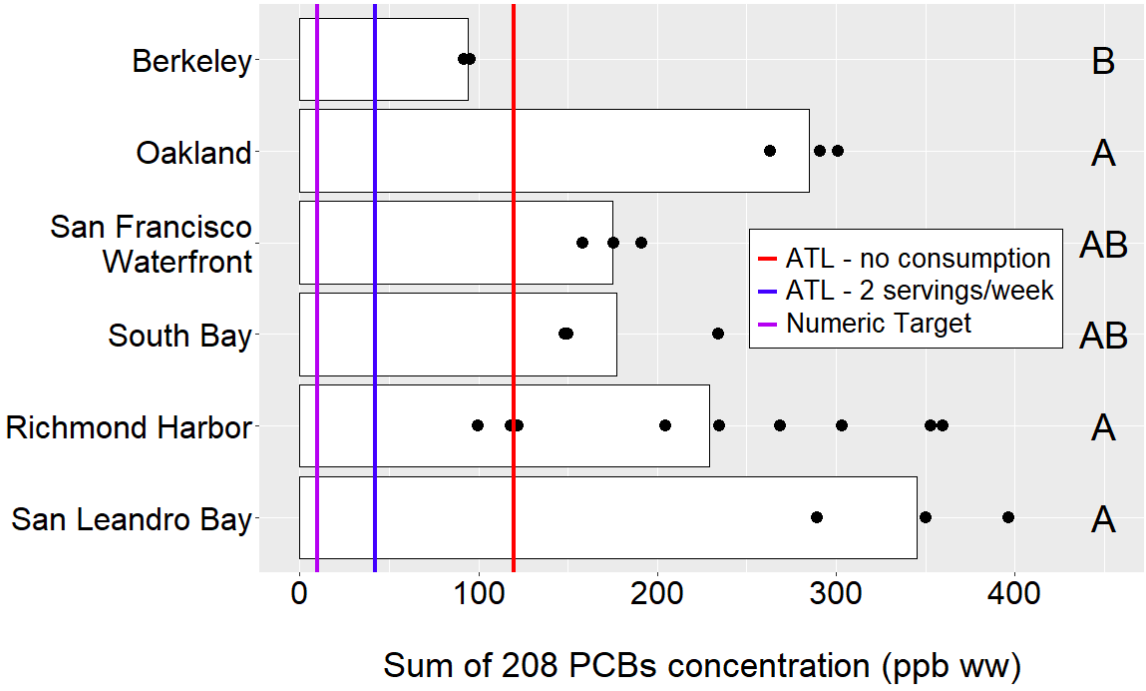

Figure 10. PCB concentrations (ppb ww) in shiner surfperch in San Francisco Bay, 2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha = 0.05). The colored lines indicating ATL thresholds show the lower end of the advisory tissue level ranges.

The two additional areas sampled as part of the PMU special study had relatively high average concentrations that, like Oakland Harbor, were significantly different from Berkeley (the station with the lowest average concentration). The average concentration at San Leandro Bay (350 ppb) was even higher than the average at Oakland Harbor, while the average at Richmond Harbor (180 ppb) was the third highest overall behind San Leandro Bay and Oakland Harbor (Figure 10).

Temporal Trends

Long-term trends in PCB concentrations are assessed on both a wet-weight and lipid-weight basis in order to address different questions. 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 BPTCP study (Fairey et al. 1997) were included in the analysis of PCB trends. The BPTCP study employed a different sampling design than the subsequent RMP 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 previous three rounds of sampling in 2006, 2009, and 2014, the Bay-wide average wet weight PCB concentration in shiner surfperch was below the no consumption ATL (120 ppb), while average concentrations were above this threshold between 1997 and 2003 (Figure 11). Sun et al. (2017) concluded that the long-term time series seemed to suggest a weak, but significant, declining trend between 1994 and 2014. The Bay-wide average concentration in 2019 was back above 120 ppb, however, at 180 ppb. One factor contributing to the higher concentrations reported for 2019 is the longer list of PCB congeners included in the sum of PCBs (208 congeners) in 2019 versus fewer congeners in prior rounds (e.g., 54 congeners in 2014). About 15% of the increase in concentrations in 2019 can be attributed to the longer congener list, as indicated by the 15% difference between the Bay-wide averages for shiner surfperch using the sum of 208 congeners (220 ppb) and the sum of 40 congeners (190 ppb) for the 2019 data (Table 4). Another factor contributing to the higher Bay-wide average in 2019 was the inability to collect shiner surfperch in San Pablo Bay, a station that has consistently been sampled in past rounds and consistently exhibited significantly lower concentrations than the other stations. Given this inconsistency in inclusion of San Pablo Bay (and in lesser inconsistencies in inclusion of other stations over time), as well as significant variation in the contamination profiles of the different stations, examination of trends at individual stations is essential for a rigorous evaluation.

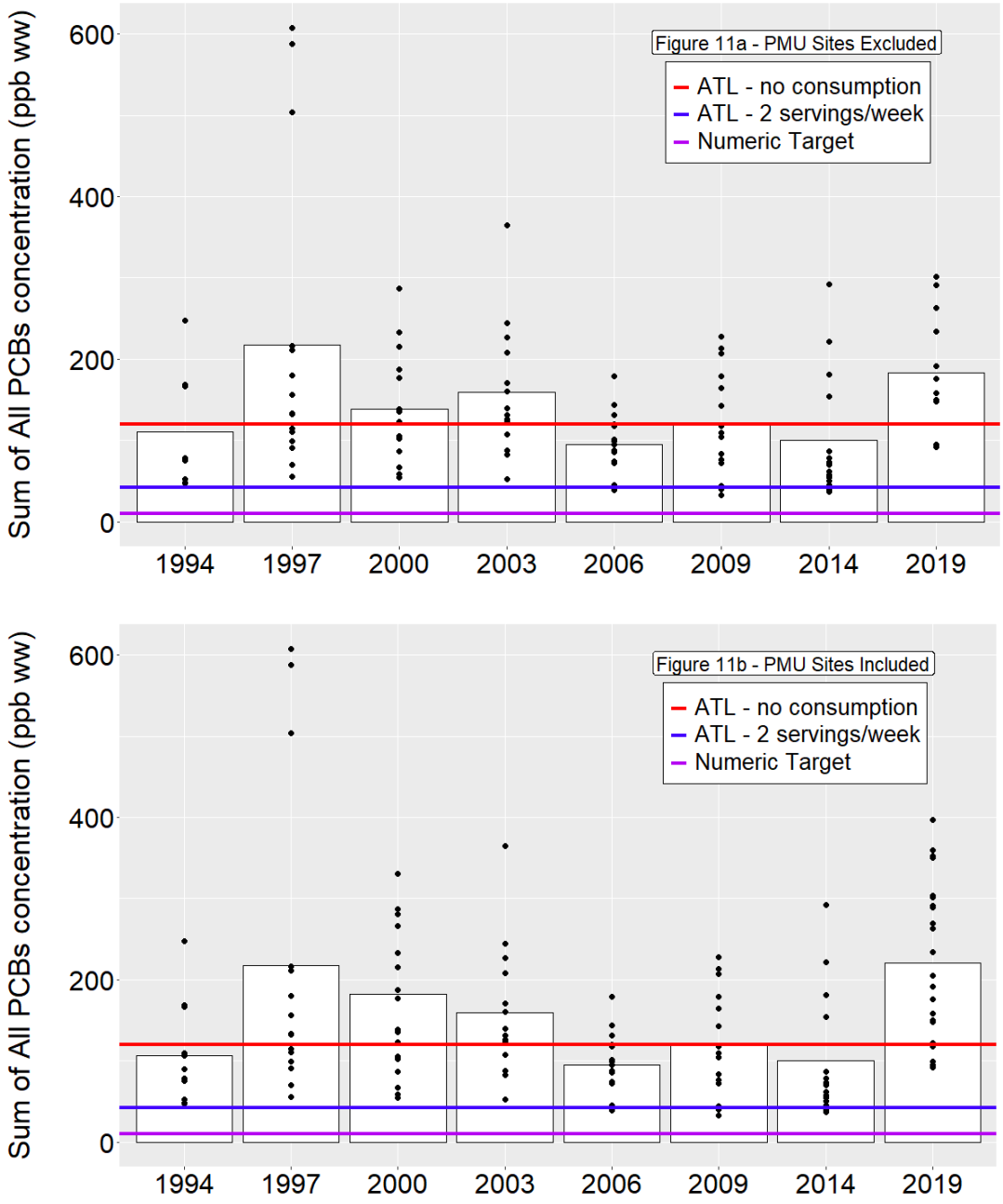

Figure 11. PCB concentrations (ppb ww) in shiner surfperch in San Francisco Bay, 1994 - 2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data shown are the Sum of PCBs for all congeners analyzed; the number analyzed varied from 47 in 1994 to 52 in 2014, and then increased to 209 in 2019. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). The colored lines indicating ATL thresholds show the lower end of the advisory tissue level ranges. A - without PMU station data points (Richmond Harbor and San Leandro Bay). B - with PMU station data (1994 and 2019).

Although the long-term wet weight time series at individual stations through 2014 suggested possible declining trends (Sun et al. 2017), higher concentrations were observed across the stations in 2019 that weakened these patterns (Figure 12). Excluding the 1994 data, which were generated by a different lab and appear anomalous, Sun et al. (2017) found statistically significant declines through 2014 at all of the stations. With the 2019 data added to the time series, however, no significant declines were observed. At each of the long-term stations sampled in 2019, concentrations measured in 2019 were higher than concentrations measured in 2014, and the differences were substantial for Berkeley, San Francisco Waterfront, and South Bay (Figure 12). For San Francisco Waterfront and South Bay, the concentrations went from being well below the 120 ppb no consumption ATL in 2014 to above this threshold in 2019. While the larger number of congeners analyzed contributed to the higher values in 2019, the differences at Berkeley, San Francisco Waterfront, and South Bay were larger than the approximate 15% increase that the added congeners would cause.

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 long-term trends on a lipid weight basis normalizes for this variation, and provides a clearer index of trends in ambient PCB levels.

No statistically significant declining trend was observed in lipid weight PCB concentrations Bay-wide between 1994 and 2019 (Figure 13). However, in spite of not including samples from San Pablo Bay, the lipid weight average for 2019 was still tied (with 2000) for the second lowest for the period of record. The relatively high Bay-wide average in 2019 on a wet weight basis was therefore to a notable degree a function of the generally higher lipid content in fish that year.

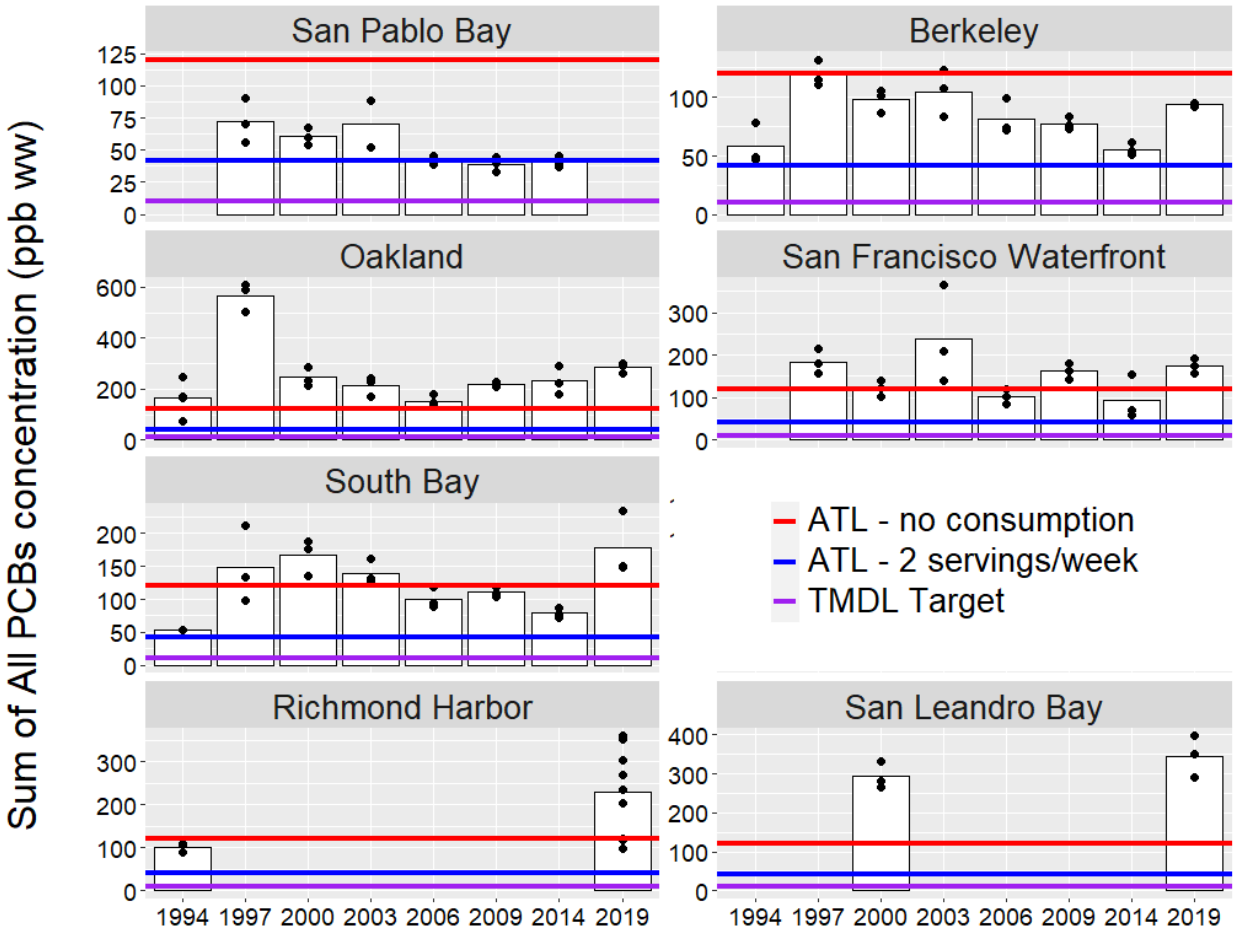

Figure 12. PCB concentrations (ppb ww) in shiner surfperch in each region of San Francisco Bay, 1994-2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data shown are the Sum of PCBs for all congeners analyzed; the number analyzed varied from 47 in 1994 to 52 in 2014, and then increased to 209 in 2019. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). The colored lines indicating ATL thresholds show the lower end of the advisory tissue level ranges.

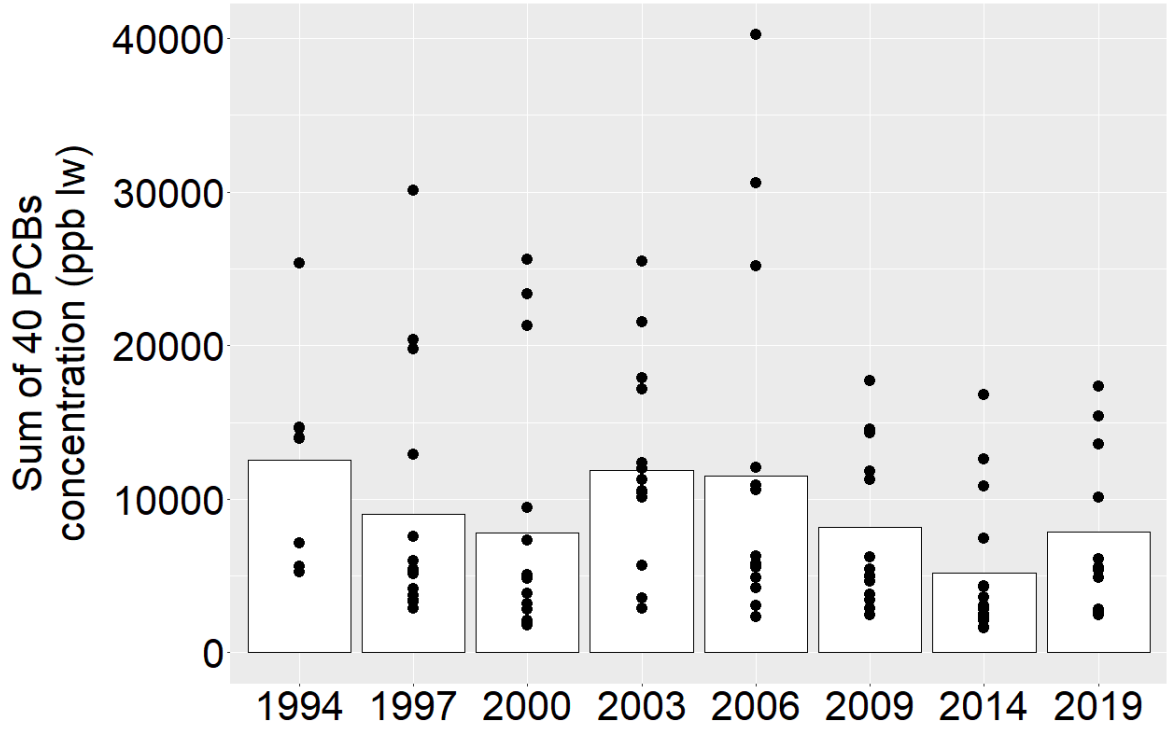

Figure 13. PCB concentrations (Sum of 40 PCBs, ppb lw) in shiner surfperch in San Francisco Bay, 1994-2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). Samples collected at sites that were not monitored by the RMP for an additional two years are not included. No statistically significant trend in PCB concentrations was observed (linear regression, p = 0.08, R2 = 0.02).

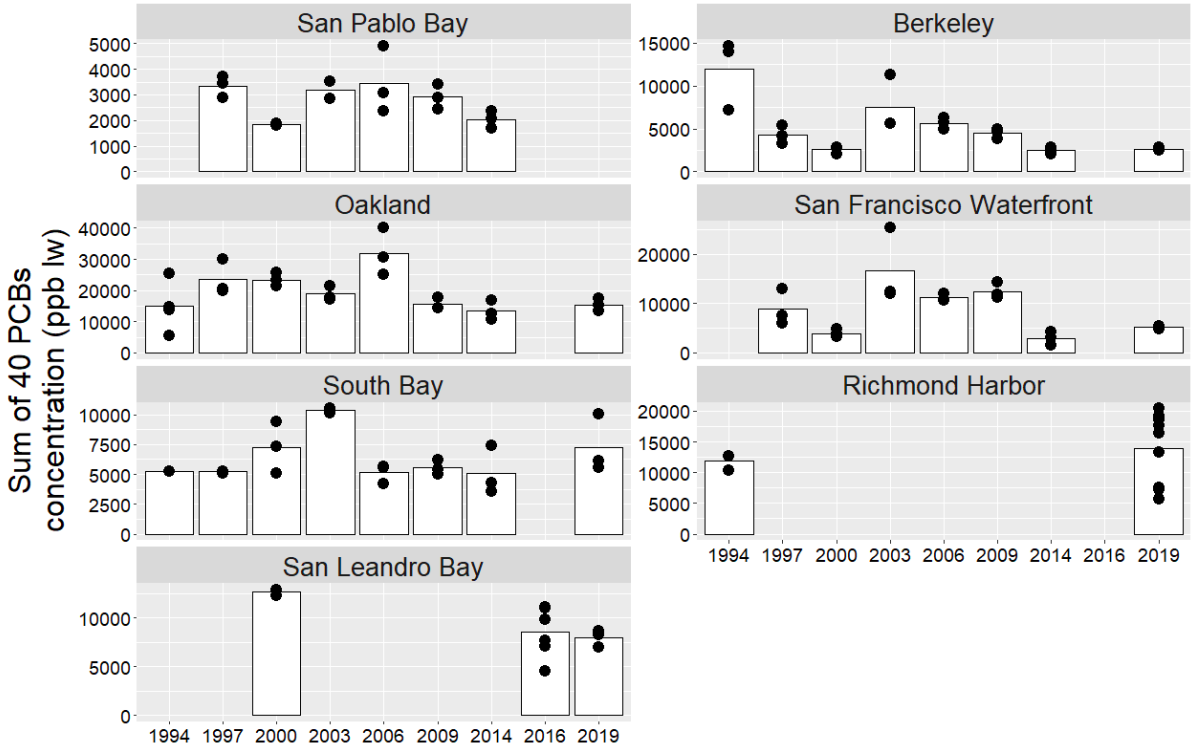

Figure 14. PCB concentrations (Sum of 40 PCBs, ppb lw) in shiner surfperch in each region of San Francisco Bay, 1994-2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) 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.

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 2019, but may be beginning to show evidence of declines on a lipid weight basis, most clearly at the Berkeley station.

The PCB concentrations observed in white croaker in 2019, on the other hand, were the lowest yet observed, suggestive of a possible long-term decline. 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, white croaker range more widely and provide a more spatially integrated view of contaminant exposure in the Bay. Variation in tissue preparation methods for white croaker over the period of record (switching from skin-on fillets through 2006 to skin-off fillets after, and the accidental analysis of whole body fish in 2014) are an impediment to assessment of long-term trends for this species. The Bay-wide average Sum of 40 PCBs concentration for white croaker on a wet weight basis in 2019 was 45 ppb, less than half of the concentration measured in 2009 (Figure 15), and far below the average concentrations measured for skin-on fillets in the rounds before 2009. Much of the variation across the different tissue types is due to variation in the lipid content of the tissues, so the lipid weight concentration time series allows for an assessment of

long-term trends by this species that can include the 2014 whole body data (Figure 16). The 2019 average concentration on a lipid weight basis was also distinctly lower than those observed in previous years. Continued monitoring is needed, however, to determine whether this is indeed signaling a trend rather than high interannual variation.

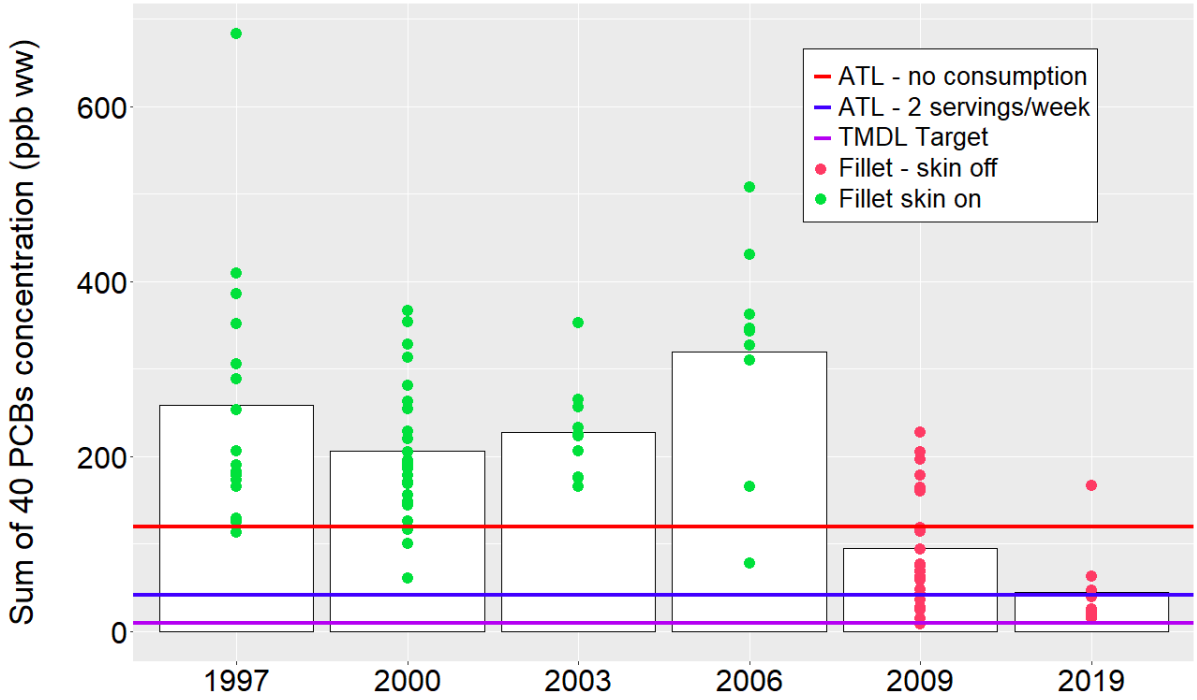

Figure 15. PCB concentrations (Sum of 40 PCBs, ppb ww) in white croaker in San Francisco Bay, 1994-2019, excluding data from 2014. Bars indicate average concentrations. Points represent composite samples with 5 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). Samples collected at sites that were not monitored by the RMP for an additional two years are not included.

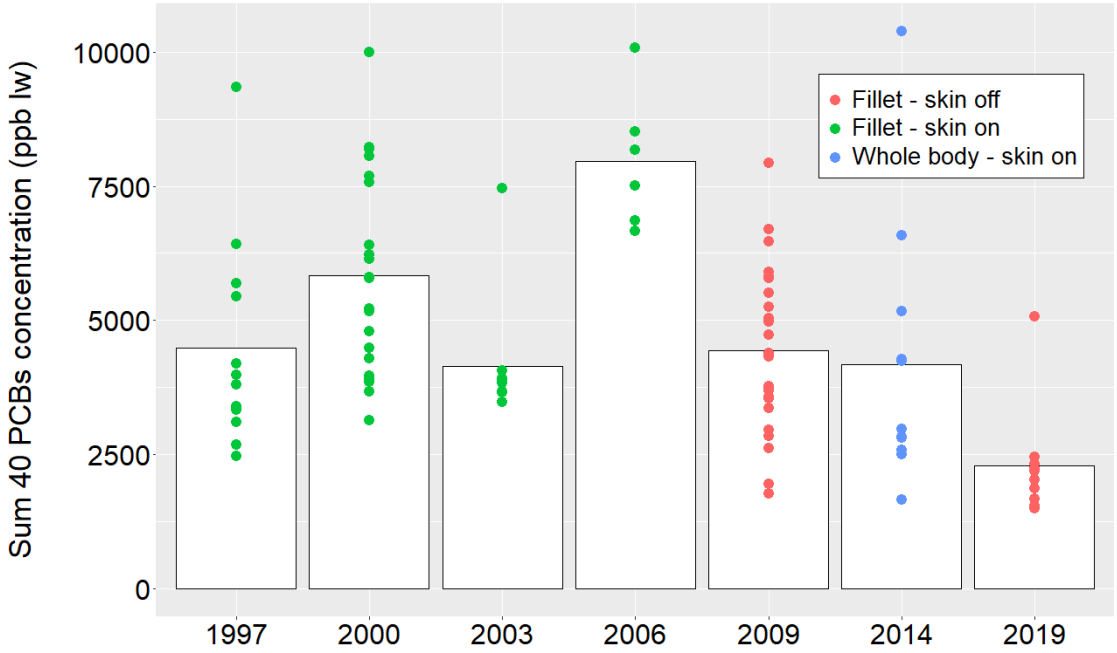

Figure 16. PCB concentrations (Sum of 40 PCBs, ppb lw) in white croaker in San Francisco Bay, 1994- 2019. Bars indicate average concentrations. Points represent composite samples with 5 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). Samples collected at sites that were not monitored by the RMP for an additional two years are not included.

Management Implications and Priorities for Further Assessment

PCB concentrations in Bay sport fish remain high and continue to exceed thresholds of concern. The Bay-wide average concentration in shiner surfperch (180 ppb) exceeded the no consumption ATL of 120 ppb and greatly exceeded the Water Board's numeric target of 10 ppb. Overall, 10 of the 16 species monitored had an average concentration above the numeric target.

PCB concentrations varied significantly across the long-term monitoring stations. Oakland Harbor remains the region of highest concern, although San Francisco Waterfront and South Bay also had average concentrations above the no consumption ATL of 120 ppb in this round of sampling. Two areas sampled as part of the PMU Special Study (Richmond Harbor and San Leandro Bay) also had high concentrations, well above the no consumption ATL.

Although PCB concentrations in shiner surfperch (the primary indicator species) were generally higher in 2019 than in the prior round of sampling, there are some possible signs of long-term decline. Concentrations in shiner surfperch at the Berkeley station showed a significant decline on a lipid weight basis, and concentrations in white croaker (a second key indicator species) were distinctly lower in 2019 than in prior years. The rate of PCB decline in the Bay is slow at best, and continued monitoring is needed for a more definitive assessment.

Dioxins

Polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs) (in this report the term “dioxins” is 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 1, 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 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.

In the 2019 sampling, leveraging sample collection for the PCB PMU Special Study, dioxins in shiner surfperch were measured at San Leandro Bay, a station that has not been monitored for dioxins in previous years.

Comparison to Thresholds

Dioxin analyses are relatively expensive, and therefore dioxin monitoring was limited in 2019, 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 = 1.0 pptr, range 0.28-1.8 pptr; Figure 17). All of the station averages and all of the samples analyzed exceeded the target. Among the RMP S&T stations, Oakland had the highest average concentration (1.6 pptr ww, over 10 times higher than the target) and Berkeley had the lowest (0.39 pptr ww, almost 3 times higher than the target). Dioxins were also analyzed in shiner surfperch from the PMU station in San Leandro Bay, which had the highest average concentration among all stations (1.8 pptr ww), slightly higher than Oakland.

$TEQ_{PCDD/PCDF}$ concentrations in white croaker in 2019 were lower than in prior years (average = 0.20 pptr, range 0.28-1.8 pptr; Figure 18) and much closer to the Water Board target than shiner surfperch. The average was only slightly above the target, and 6 of the 11 samples analyzed were below the target. This was the first round of sampling in which some of the white croaker samples were below the target.

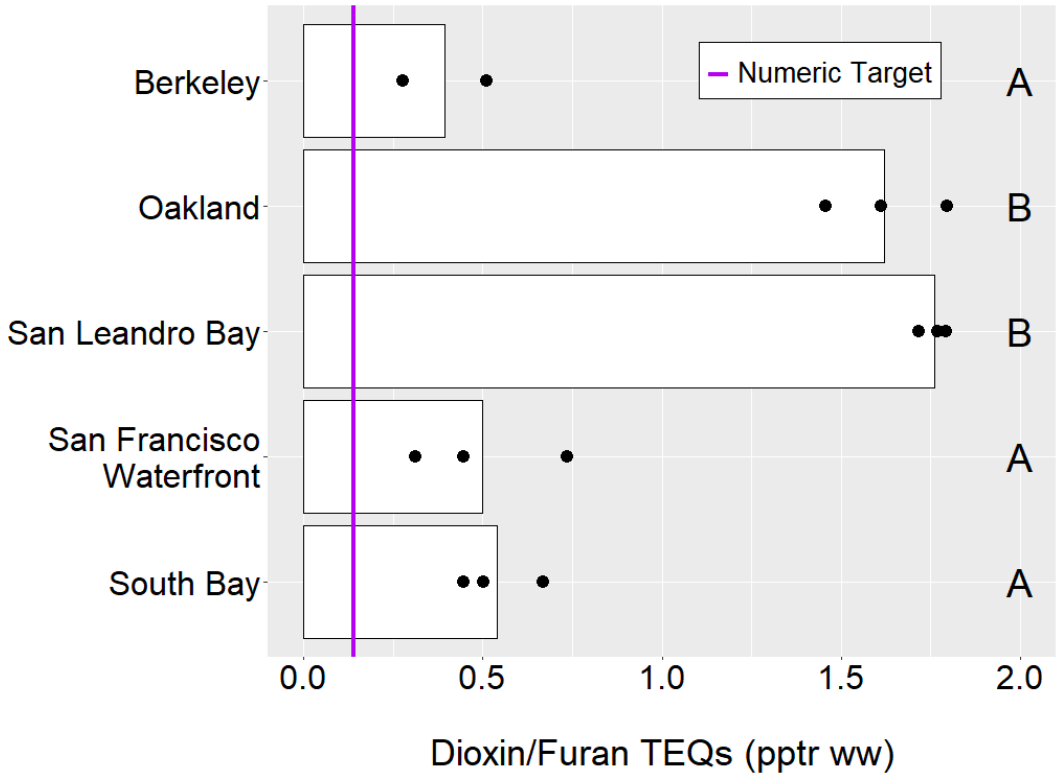

Figure 17. $TEQs_{PCDD/PCDF}$ (pptr ww) in shiner surfperch in San Francisco Bay, 2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. The Water Board screening level (0.14 pptr) is non-regulatory.

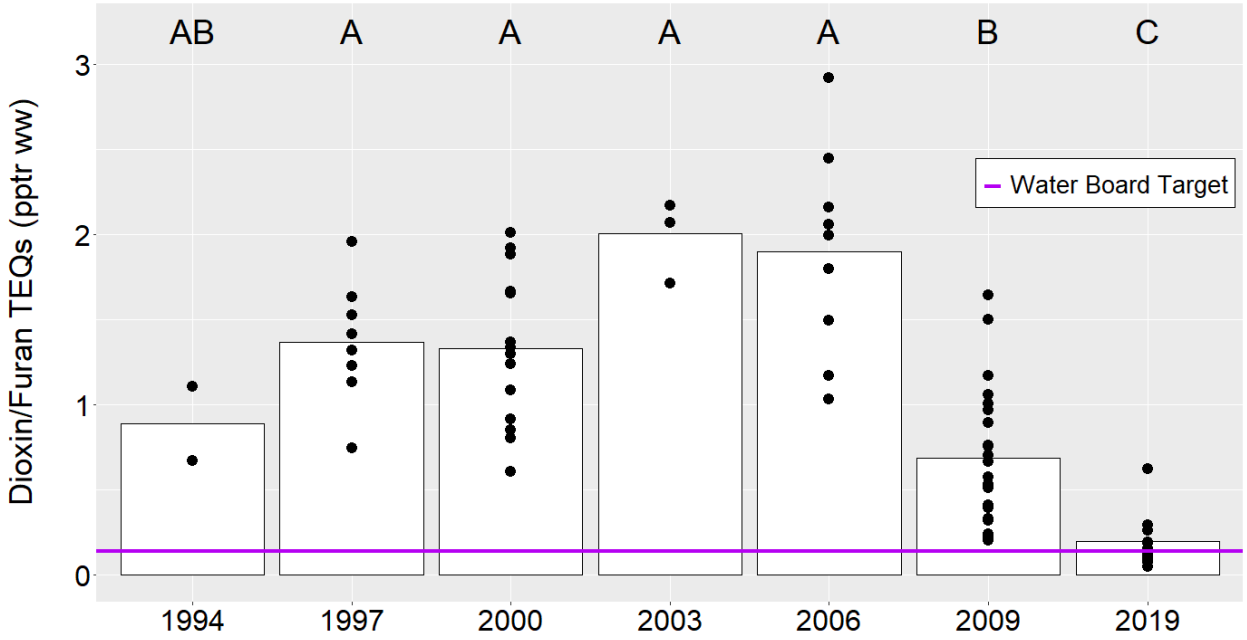

Figure 18. $TEQs_{PCDD/PCDF}$ (pptr ww) in white croaker in San Francisco Bay, 1994-2019. Bars indicate average concentrations. Points represent composite samples with 5 fish in each composite. The Water Board screening level (0.14 pptr) is non-regulatory. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (2000, 2003, 2006, 2009, 2014, 2019). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included along with samples from 2014 that were mistakenly processed as whole fish. Years labeled with the same letter did not have significantly different means (Tukey HSD, alpha = 0.05).

Spatial Patterns

Average $TEQ_{PCDD/PCDF}$ concentrations in shiner surfperch at Oakland and San Leandro were very similar (over 1.5 pptr ww), and significantly higher than the averages at the other three stations, which ranged from 0.40 pptr at Berkeley to 0.54 pptr at South Bay (Figure 17). The difference between Oakland and the other S&T stations was a little more distinct in 2019 than it was in 2014, when Oakland was higher than the other stations but only significantly higher than South Bay and San Pablo Bay (the latter was not sampled in 2019).

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 variation in the lipid content in fish caught in different years.

The Bay-wide wet weight $TEQ_{PCDD/PCDF}$ data indicate that concentrations have declined significantly since 2000, but not 1994 (Figure 19). 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. 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. As for PCBs, the 1994 data were also generated by a different laboratory than in later years. In short, the 1994 data appear anomalous, so it seems appropriate to focus trend analysis on the shiner surfperch data from 2000 to present. The Bay-wide average measured in 2019 (0.79 pptr) was tied with the 2014 as the lowest observed since 2000, and significantly lower than the averages observed in 2000 (1.4 pptr) and 2009 (0.89 pptr) (Figure 16). The 2019 average was relatively low in spite of San Pablo Bay, which has had the lowest concentrations in past sampling, not being included because shiner surfperch were not caught there. Wet weight $TEQ_{PCDD/PCDF}$ concentrations in shiner surfperch also were lower in 2019 than in all prior years (excluding 1994) at each of the long-term monitoring stations except Oakland (Figure 20).

The lipid weight long-term time series for $TEQ_{PCDD/PCDF}$ in shiner surfperch Bay-wide are similar to the wet weight time series and appear to point to declining concentrations, although differences among years are not statistically significant. The Bay-wide average for 2019 was identical to the average for 2014, and lower than the averages in 2000 and 2009 (Figure 21). The average for 2019 was relatively low, in spite of San Pablo Bay not being included in this round of sampling. Lipid weight $TEQ_{PCDD/PCDF}$ at the individual stations (Figure 22) were lowest in 2019 at Berkeley and San Francisco Waterfront, and near the lowest annual averages at Oakland and South Bay.

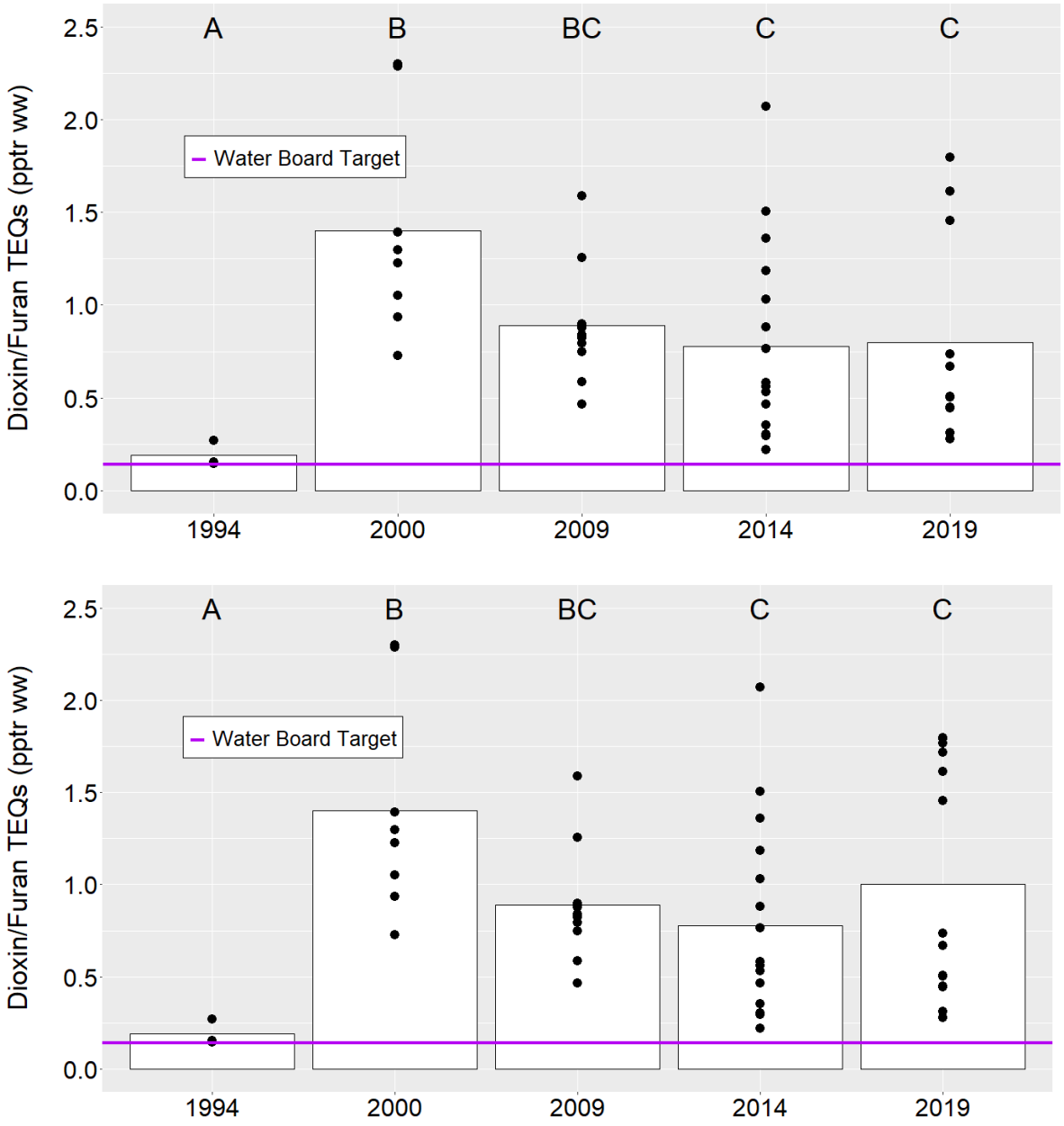

Figure 19. $TEQs_{PCDD/PCDF}$ (pptr ww) in shiner surfperch in San Francisco Bay, 1994-2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. The Water Board screening level (0.14 pptr) is non-regulatory. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (2000, 2009, 2014, 2019). 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). A - without PMU station data; B - with PMU station data (San Leandro Bay in 2019).

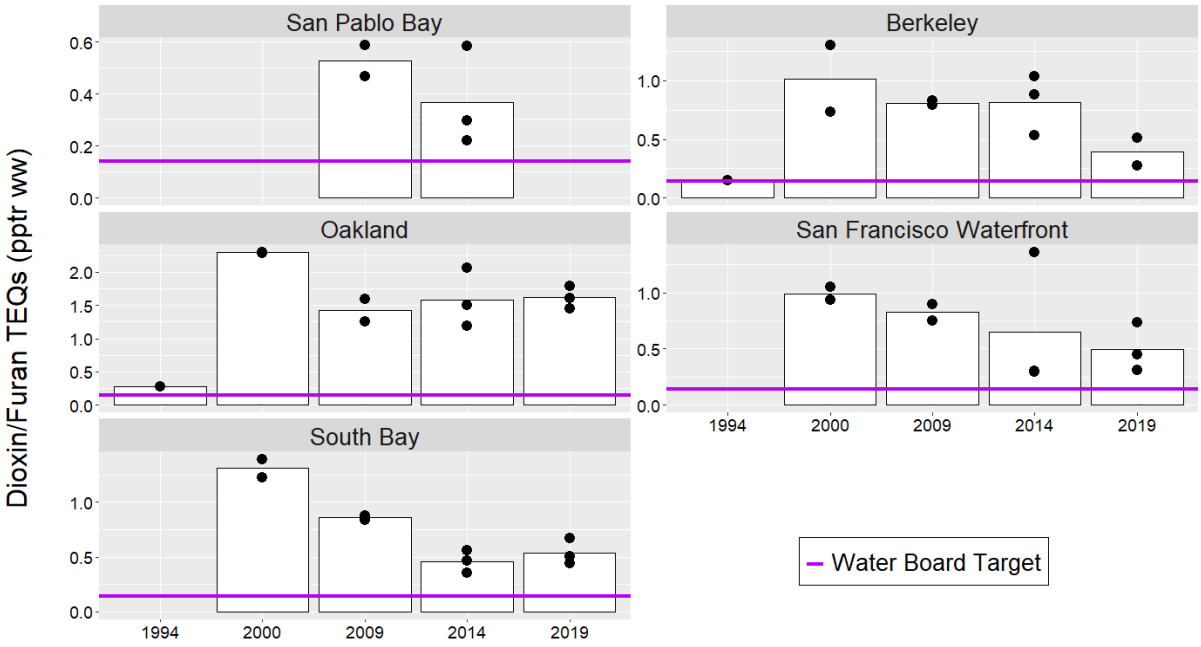

Figure 20. $TEQs_{PCDD/PCDF}$ (pptr ww) in shiner surfperch in each region of San Francisco Bay, 1994-2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. The Water Board screening level (0.14 pptr) is non-regulatory. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (2000, 2009, 2014, 2019).

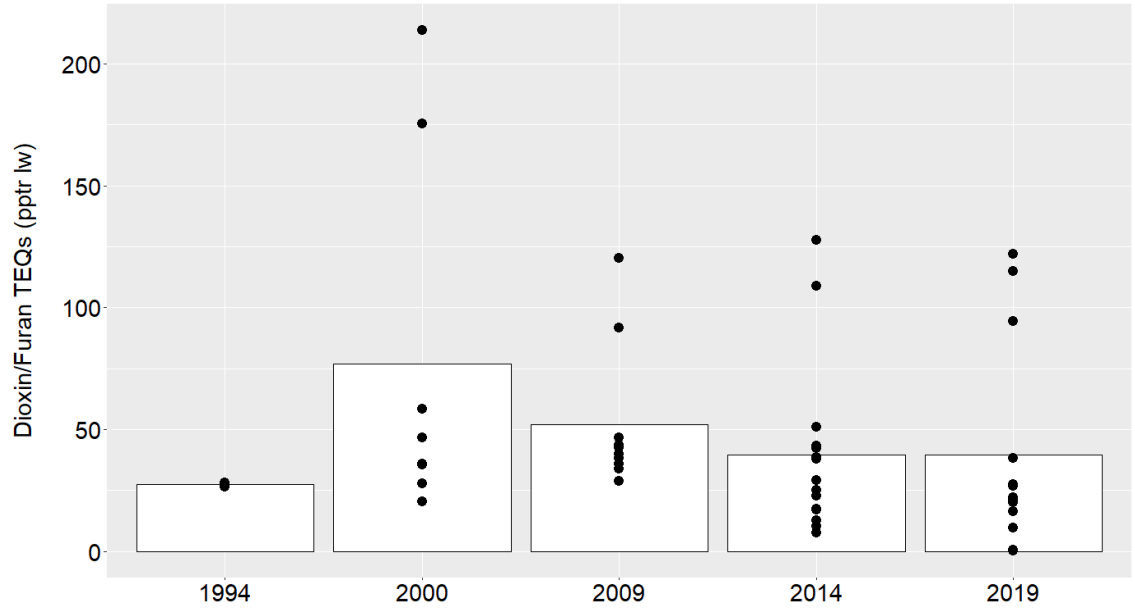

Figure 21. $TEQs_{PCDD/PCDF}$ (pptr lw) in shiner surfperch in San Francisco Bay, 1994-2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1997) and the Regional Monitoring Program (2000-2019). 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).

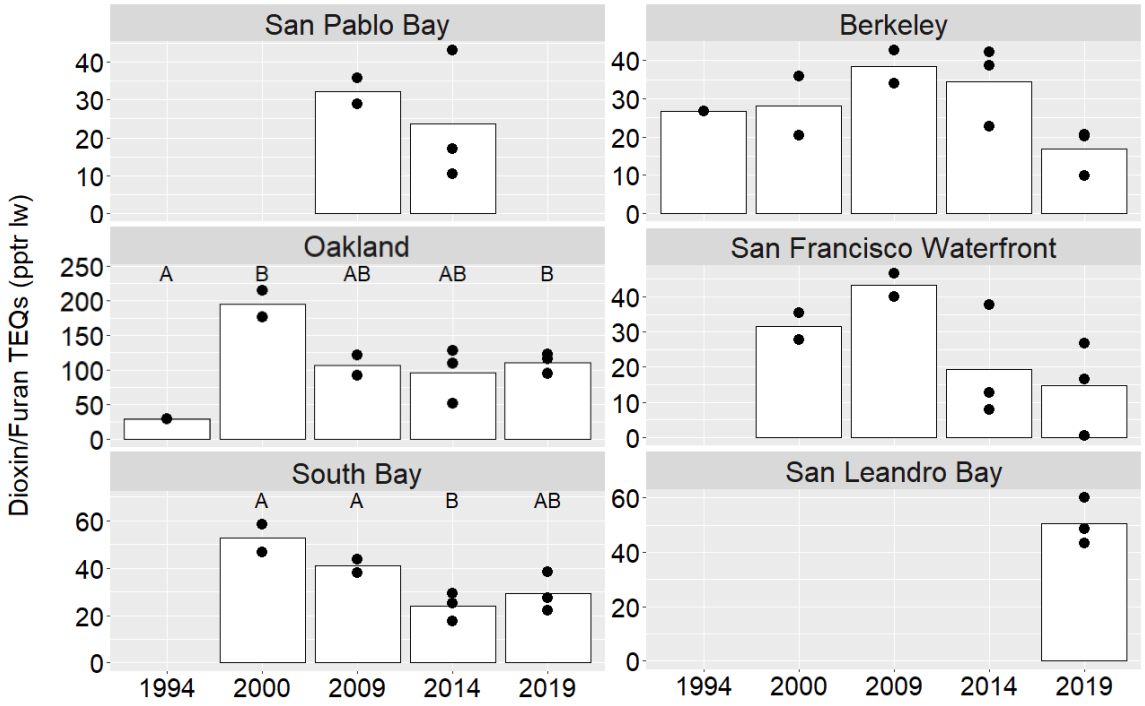

Figure 22. $TEQs_{PCDD/PCDF}$ (pptr lw) in shiner surfperch in each region of San Francisco Bay, 1997-2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1997) and the Regional Monitoring Program (2000-2019). 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).

RMP assessment of long-term trends in dioxins prior to 2009 focused on white croaker, for which the long-term time series is a bit more extensive, including data from two rounds of sampling that occurred in 2003 and 2006. In more recent sampling, as discussed above for PCBs, different tissue preparation methods have prohibited a direct comparison of wet weight $TEQs_{PCDD/PCDF}$ 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 $TEQs_{PCDD/PCDF}$ present. In 2014, samples were improperly analyzed as whole body composites (with the head, viscera and tail removed). In 2019, the croaker were again analyzed as fillets without skin.

As discussed above, $TEQ_{PCDD/PCDF}$ concentrations in white croaker in 2019 were much lower than in prior years, with a Bay-wide average concentration (0.19 pptr) very close to the Water Board target (Figure 18). The 2019 average was significantly lower than the 2009 average (0.69 pptr), and the 2009 and 2019 averages were significantly lower than the averages for 1997, 2000, 2003, and 2006.

Lipid-normalizing the $TEQs_{PCDD/PCDF}$ concentrations can in part account for differences across years due to different sample preparation. The lipid-normalized white croaker data

(Figure 23) present an interesting contrast to the wet weight data. As observed for the wet weight data, the lipid weight average for 2019 was significantly lower than all other years. However, the 2009 lipid weight average, unlike the 2009 wet weight average, was high relative to other years. This indicates that the low wet weight average in 2009 was due to relatively low lipid content in that year. In contrast, the low wet weight value in 2019 was matched by a low lipid weight value, which suggests a real reduction in dioxin exposure for white croaker in 2019.

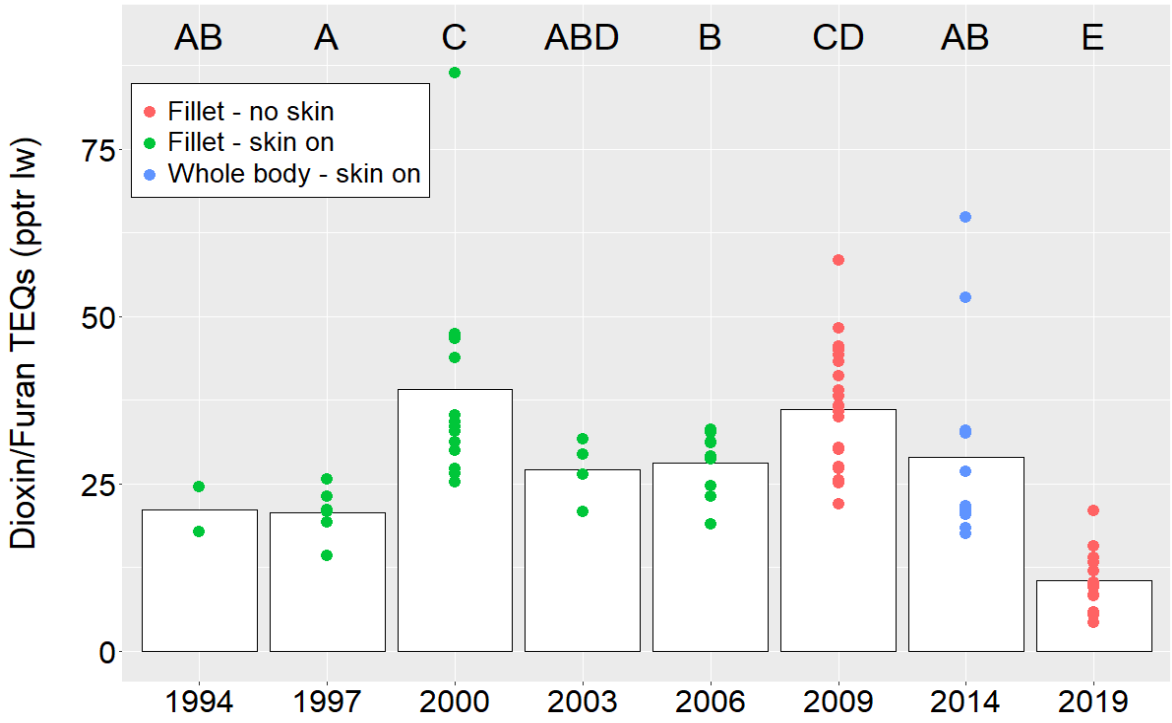

Figure 23. $TEQs_{PCDD/PCDF}$ (pptr lw) in white croaker in San Francisco Bay, 1994-2019. Bars indicate average concentrations. Points represent composite samples with 5 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1997) and the Regional Monitoring Program (2000-2019). 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).

Management Implications and Priorities for Further Assessment

$TEQs_{PCDD/PCDF}$ concentrations remain above the Water Board screening level, and are still particularly high in Oakland Harbor and San Leandro Bay. However there are signs of possible decline in both of the key indicator species: shiner surfperch and white croaker. In white croaker, the concentrations in 2019 were sharply lower than in the last year of comparable data in 2009 and only slightly above the screening level. In shiner surfperch, concentrations appear to be progressively decreasing across all of all of the monitoring stations, although not to a degree associated with statistical significance. Continued monitoring of these two species is needed to establish whether these possible trends are statistically significant and signs of real long-term declines.

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, as well as concentration in the food web, 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 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 were identified in the North Bay TMDL as the key indicator species for measuring 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 clams. 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 and in RMP special studies (Sun et al. 2019a,b) to continue evaluating this non-lethal monitoring method. As a result, the RMP is beginning to use sturgeon muscle plug samples in long-term monitoring for selenium in North San Francisco Bay. Sun et al. (2017) recommended continued comparison of concentrations in caudal and epaxial muscle tissue to better quantify the relationship between tissues from these two areas and aid in interpretation of muscle plug data. This recommendation was implemented in 2019, and yielded a highly significant regression (Figure 24A). This dataset is not that informative regarding the slope of the line, however, because the slope is highly influenced by one high outlier. Performing the same linear regression and excluding the high outlier data point from Suisun Bay, the slope of the resulting regression and associated R^2 value (Epaxial = 1.04*Caudal - 0.03, R^2 = 0.96, Figure 24B) suggests a strong 1:1 relationship between the two fillet locations.

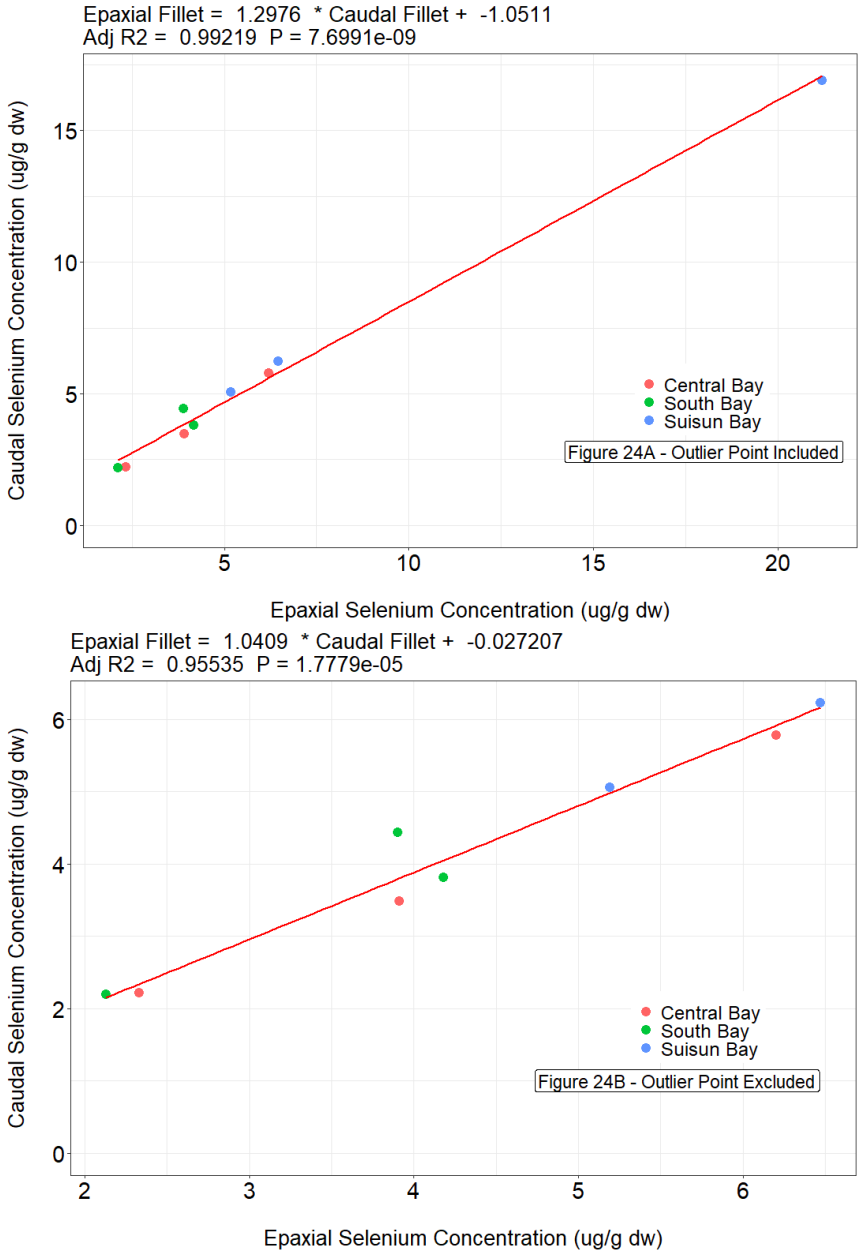

Figure 24. Selenium concentrations (ppm dw) in paired samples of muscle fillets from two locations on white sturgeon in San Francisco Bay. Points represent individual fish and fillets were taken from the epaxial muscle and adjacent to the caudal fin. The regression was run with (A) and without (B) the outlier value from Suisun Bay. In both scenarios the relationship between selenium concentrations in fillets was significant. A closer 1:1 slope occurred in the regression without the outlier.

Comparison to Thresholds and Variation Among Species

Selenium contamination in Bay fish remains a low concern in regard to human health. Average concentrations in all species were well below the OEHHA two servings/week ATL threshold of >2.5-4.9 ppm ww. Only one of the nine individual white sturgeon monitored had a selenium concentration above 2.5 ppm ww (this sample also exceeded the one serving/week ATL threshold of >4.9 ppm ww) (Figure 25).

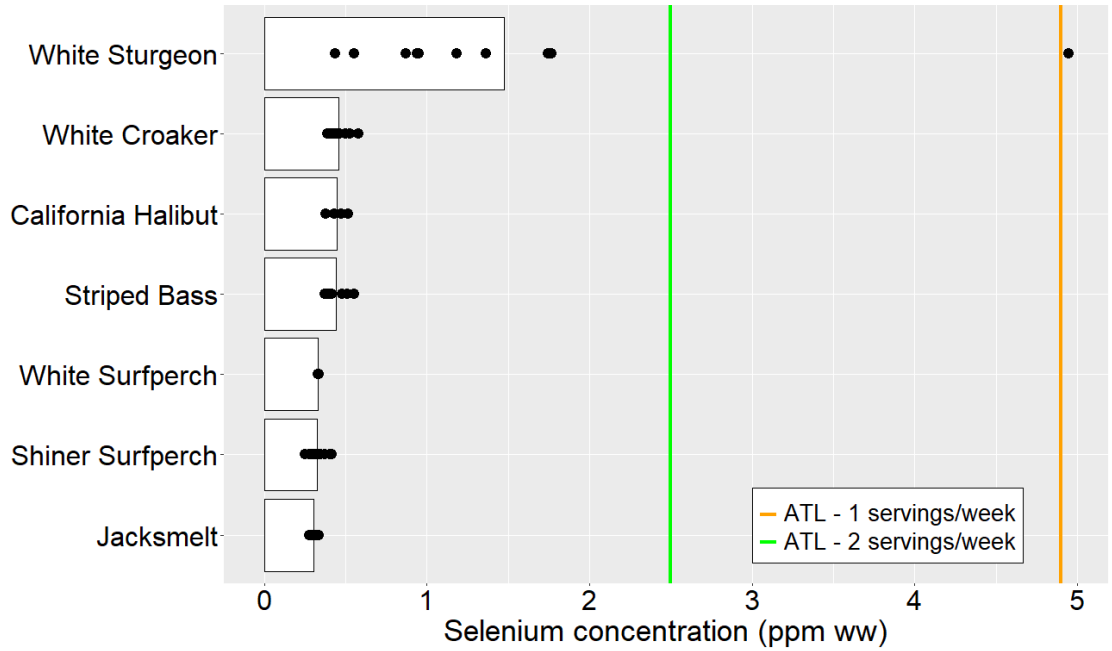

Figure 25. Selenium concentrations (ppm ww) in San Francisco Bay fish, 2019. Bars indicate average concentrations. Points represent individual samples (either composites or individual fish; white sturgeon samples were analyzed as individuals). The colored lines show the lower end of the advisory tissue level ranges.

Average concentrations in all species also remained below the North Bay TMDL target for protection of sturgeon (11.3 ppm dw; Figure 26). However, the selenium concentration in one individual white sturgeon exceeded this threshold. The high concentration in this one sample (21 ppm dw) stood out from the rest of the distribution: the other values ranged between 2.3 and 6.2 ppm dw).

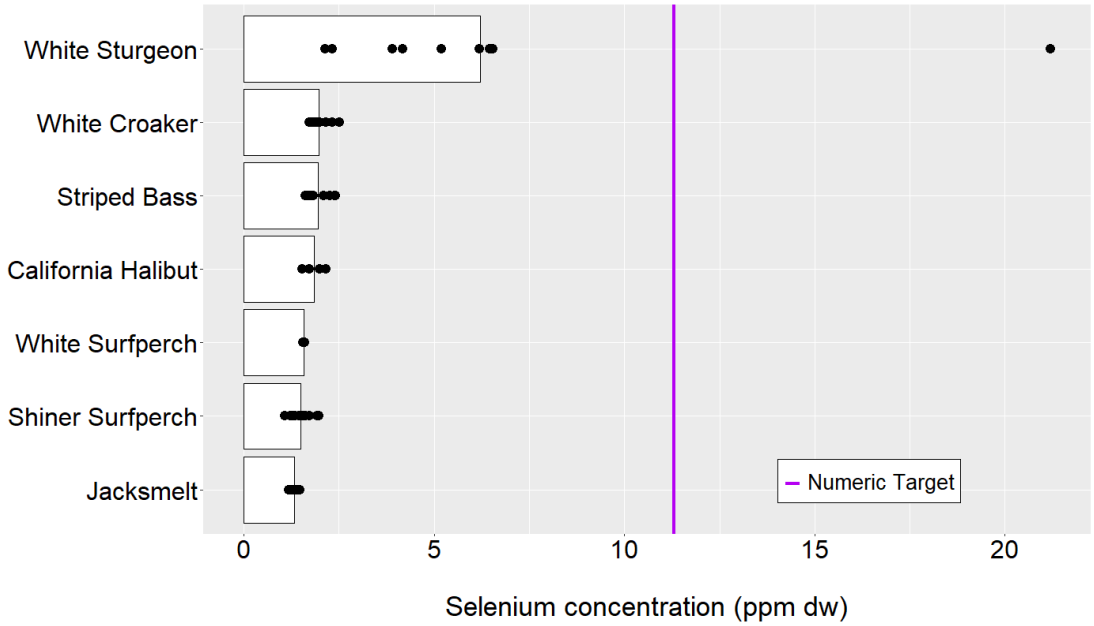

Figure 26. Selenium concentrations (ppm dw) in San Francisco Bay fish, 2019. Bars indicate average concentrations. Points represent individual samples (either composites or individual fish; white sturgeon samples were analyzed as individuals).

Spatial Patterns

In spite of small sample sizes (n = 3 for all stations), selenium concentrations measured in Suisun Bay sturgeon were significantly different from concentrations in Central Bay and South Bay sturgeon (Figure 27). The lowest concentrations were measured in South and Central Bay (averaging 3.4 ppm dw and 4.1 ppm dw, respectively), while the highest concentrations were measured in Suisun Bay (average = 9.9 ppm dw). The only exceedance of the TMDL muscle tissue target in 2019 occurred in a fish caught in Suisun Bay.

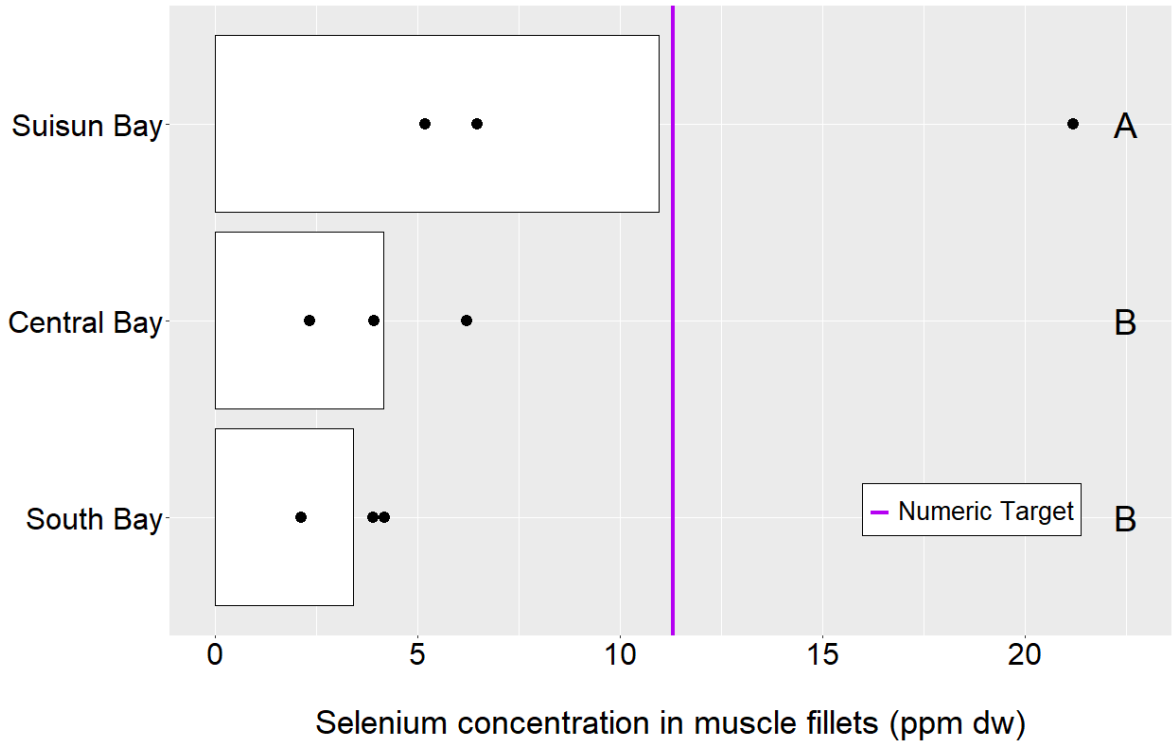

Figure 27. Selenium concentrations (ppm dw) in muscle fillets of white sturgeon in San Francisco Bay, 2019. Bars indicate average concentrations. Points represent individual fish. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha = 0.05). The purple line represents the 11.3 ppm dw fish tissue numeric target established in the North Bay Selenium TMDL.

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). The average concentration measured in North Bay (i.e., Suisun Bay) in 2019 (10.9 ppm dw) was not significantly greater than the historical North Bay average concentrations (7.2 ppm dw; p = 0.31).

Historically, the average selenium concentration measured in North Bay has been higher than South Bay (average = 7.2 and 5.7 ppm dw, respectively, 1997-2019) (Figure 28). Fewer exceedances of the TMDL numeric target have been observed in South Bay (two out of 30 samples over the 1997-2019 period of record), and these exceedances have been at lower concentrations than those measured in North Bay. The most recent exceedance of the target in South Bay occurred in 2003, while exceedances in North Bay occurred in 2019 and the previous two rounds of sampling.

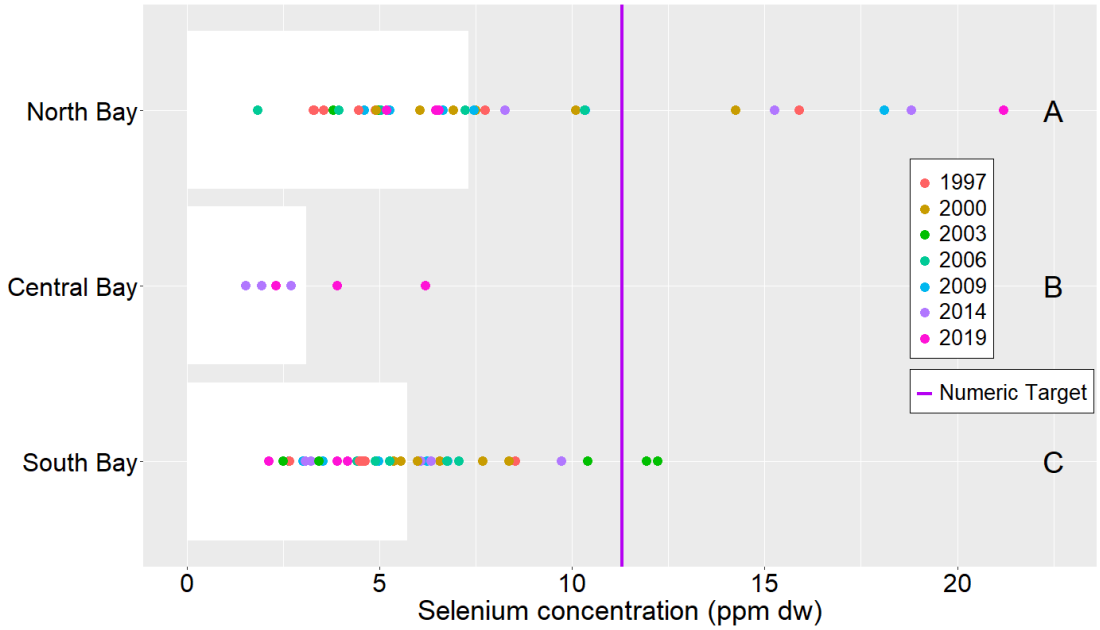

Figure 28. Selenium concentrations (ppm dw) in muscle fillets of white sturgeon sampled by the RMP in San Francisco Bay, 1997-2019. Bars indicate average concentrations. Points represent individual fish. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha = 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.

Temporal Trends

White sturgeon selenium data have been collected in 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 33 years (1987-2019) (Figure 29). 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 (1997-2019). Intra-annual variability has been high (coefficients of variation by year ranging from 34 to 101%), reducing the power for detecting 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. The average in 2019 was the second highest observed in the 1997-2019 period of record. This relatively high average in 2019 was primarily driven by one high value (21 ppm dw), which was the highest concentration measured by S&T in North Bay since 1997. The other samples analyzed in 2019 were in the middle of the distribution for the long-term dataset. Although weak, a significant increasing trend was observed in white sturgeon caught in North Bay as part of RMP Status and Trends monitoring since 1997 (linear regression; North Bay: p = 0.02, R2 = 0.04; Figure 30).

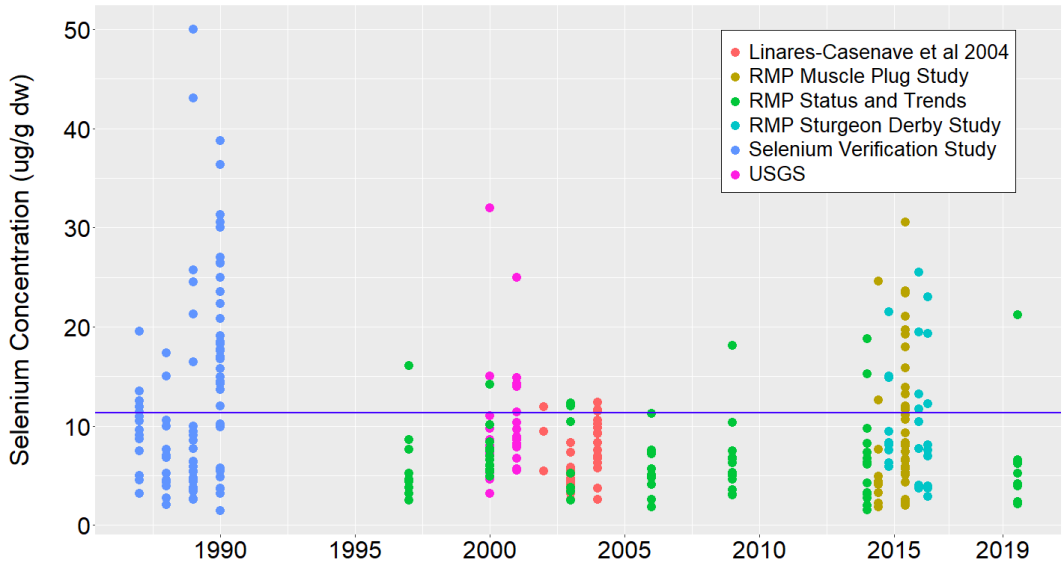

Figure 29. Selenium concentrations (ppm dw) in muscle fillets of white sturgeon in San Francisco Bay, 1987-2019. Points represent individual fish. Data were obtained from the California Department of Fish and Wildlife (CDFW) and State Water Resources Control Board's Selenium Verification Study (1987-1990); United States Geological Survey (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 (1997-2019). The purple line represents the 11.3 ppm dw fish tissue numeric target established in the North Bay Selenium TMDL.

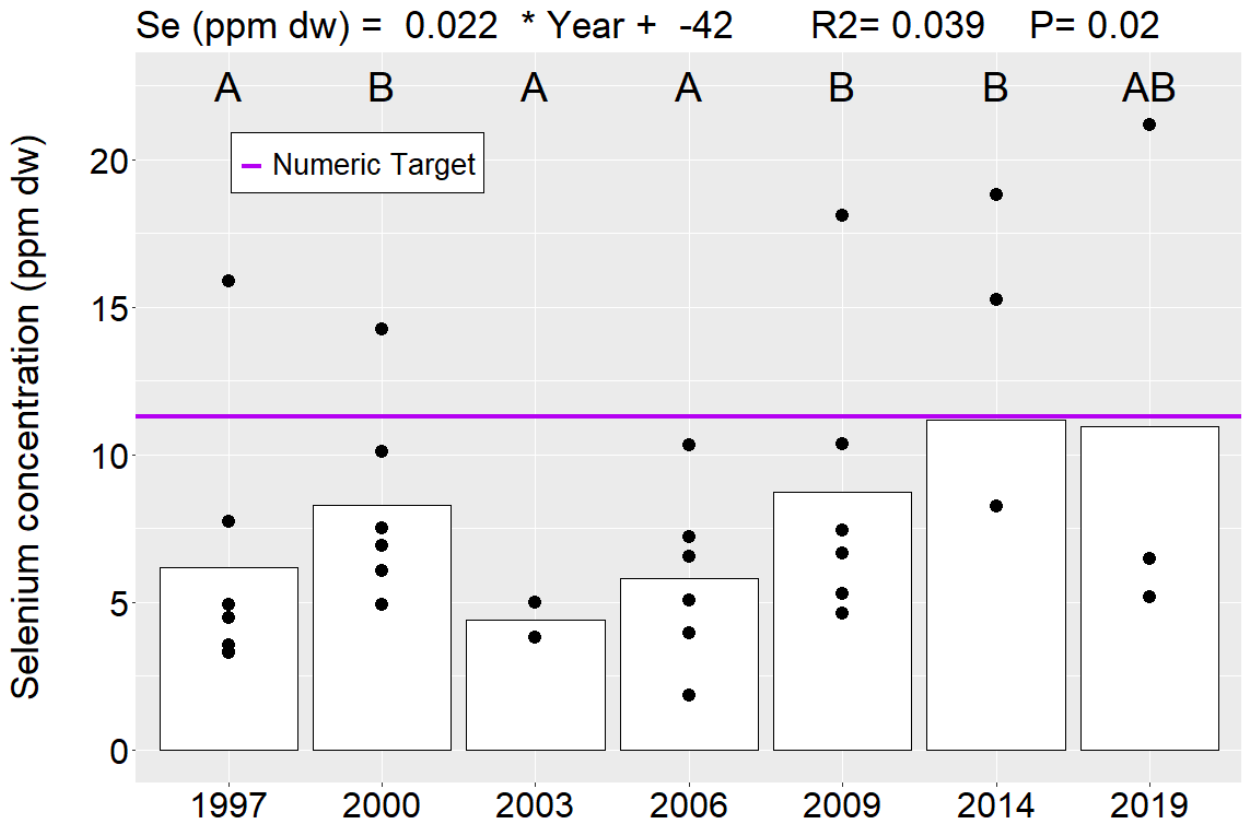

Figure 30. Selenium concentrations (ppm dw) in muscle fillets of white sturgeon sampled by the RMP in North San Francisco Bay, 1997-2019. Bars indicate average concentrations. Points represent individual fish. The purple line represents the 11.3 ppm dw fish tissue numeric target established in the North Bay Selenium TMDL. Years labeled with the same letter did not have significantly different means (Tukey HSD, alpha = 0.05). A weak, but statistically significant positive trend in selenium concentrations was observed; p = 0.02, R2 = 0.04.

Management Implications and Priorities for Further Assessment

The 2019 S&T data indicate that fish selenium concentrations remain below levels of human health concern. However, an exceedance of the North Bay TMDL numeric target (11.3 ppm dw) was observed in an individual white sturgeon caught in Suisun Bay, while the 2019 average was below the target. Consistent with past sampling, selenium concentrations in North Bay white sturgeon were significantly higher than concentrations in South Bay white sturgeon. Only two of thirty white sturgeon samples analyzed in South Bay since 1997 have exceeded the North Bay numeric target, and the long-term average concentration (5.7 ppm dw) is well below the target.

PBDEs

Polybrominated diphenyl ethers (PBDEs) are flame retardants once common in foam furniture, electronics, and many other products. Studies of PBDEs in laboratory animals have tied PBDEs to developmental neurotoxicity, reproductive toxicity, endocrine disruption, and for DecaBDE, liver and thyroid toxicity as well as possible carcinogenicity (reviewed in USEPA 2008a,b). Investigations of health concerns linked to PBDEs have also extended to wildlife, with observations of reproductive and developmental effects, as well as potential impacts to the immune and endocrine systems (Sutton et al. 2014).

In part due to unusual flammability standards established in California in the 1970s, PBDE concentrations in the Bay food web increased rapidly through the 1990s. However, concerns about toxicity led to a state ban on two of the three commercial PBDE mixtures, "PentaBDE" and "OctaBDE," passed in 2004. This ban quickly led to a voluntary nation-wide phase-out. 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. More recently, the state banned flame retardants in foam furniture, mattresses, and children's products, effective January 1, 2020. Sutton et al. (2015) documented significant declines in PBDEs in cormorant eggs, bivalves, and fish as a result of these management actions.

Comparison to Thresholds and Variation Among Species

In 2011, OEHHA published ATLs for PBDEs (Klasing and Brodberg 2011), but PBDEs have not been placed on the 303(d) List. Previous rounds of RMP monitoring showed that PBDE concentrations in Bay fish were well below the two serving per week ATL of 100 ppb. As a result, monitoring in 2019 focused primarily on assessing 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). Concentrations in shiner surfperch as well as largemouth bass and striped bass were well below even the seven servings/week ATL (45 ppb). The average concentration in shiner surfperch in 2019 was 6.2 ppb; the maximum concentration observed in this species was 9.4 ppb (Figure 31).

The highest concentration observed in a composite sample across all three species was 23 ppb in a single sample of largemouth bass collected at Artesian Slough. The striped bass samples analyzed all had lower concentrations than the minimum observed in shiner surfperch, along with the lowest average concentration (1.2 ppb) across species. In all species, PBDE 47, a major component of the PentaBDE mixture, was detected in 100% of samples and made up about 63% of the total PBDE sums (calculated using the median concentration across samples). Analytical improvements resulted in the first observations of trace amounts of PBDE 209, the primary component of the DecaBDE mixture, in Bay fish tissue; concentrations were low and did not meet quality assurance criteria and were not included in the calculation of PBDE sums.

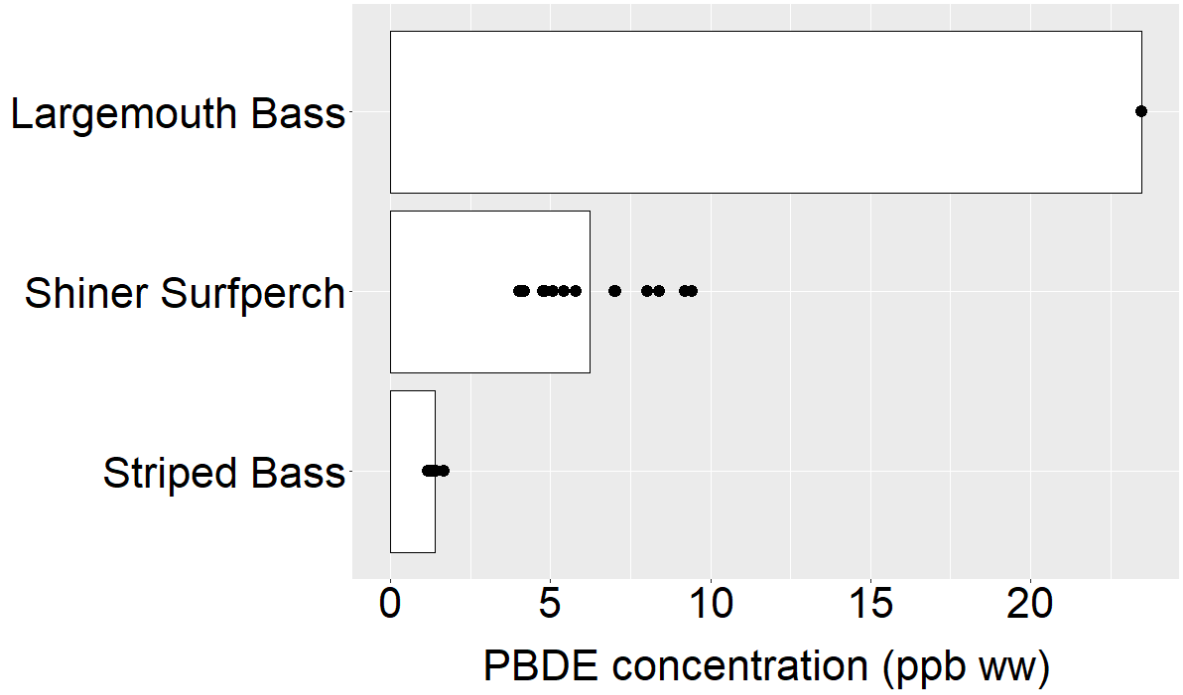

Figure 31. Sum of PBDE concentrations (ppb ww) in San Francisco Bay fish, 2019. Bars indicate average concentrations. Points represent composite samples. All samples were well below the OEHHA 2 serving/wk ATL (100 ppb).

Spatial Patterns

The spatial pattern of PBDE contamination in shiner surfperch in 2019 was consistent with previous observations, with the highest concentrations at the Oakland station. Oakland had one of the highest average concentrations (8.2 ppb), which was significantly greater than the averages for Berkeley (4.1 ppb), San Francisco (4.5 ppb), and South Bay (5.3 ppb) (Figure 32). Samples collected in San Leandro Bay as part of the 2019 PMU Special Study were analyzed and the average concentration (8.20 ppb) was very similar to that observed at Oakland.

The relatively high largemouth bass concentration observed at Artesian Slough in 2019 (23 ppb) is similar to the relatively high concentration measured at this location in 2014, suggestive of PBDE input to the Bay from the San Jose Santa Clara wastewater treatment facility.

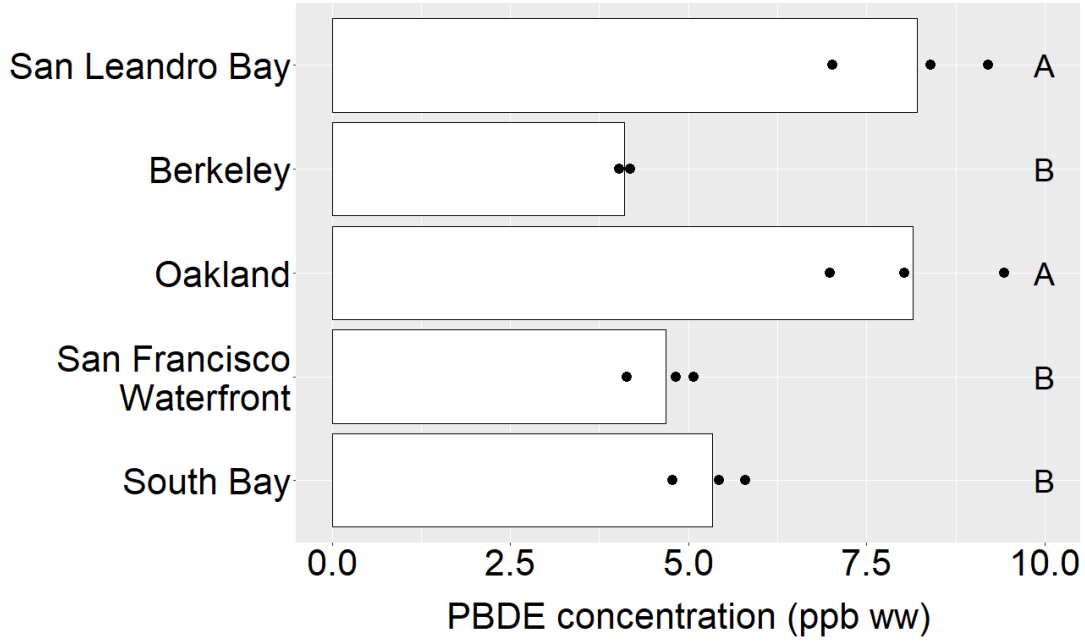

Figure 32. Sum of PBDE concentrations (ppb ww) in shiner surfperch in San Francisco Bay, 2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha = 0.05).

Temporal Trends

The most recent RMP data provide further evidence that PBDEs in shiner surfperch declined following the PBDE bans and phase-outs, but suggest that the rate of decline has levelled off in recent years. 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 lower concentrations measured in 2014 and again in 2019 support the conclusion that PBDE concentrations have declined following the phase-outs of commercial flame-retardant mixtures in the mid-2000s (60% reduction in PBDEs between 2003 and 2019) (Figure 33). Statistically significant declines were observed consistently across nearly all of the stations; the decline was not significant at Oakland, where PBDE levels in shiner surfperch remain at their highest (Figure 34).

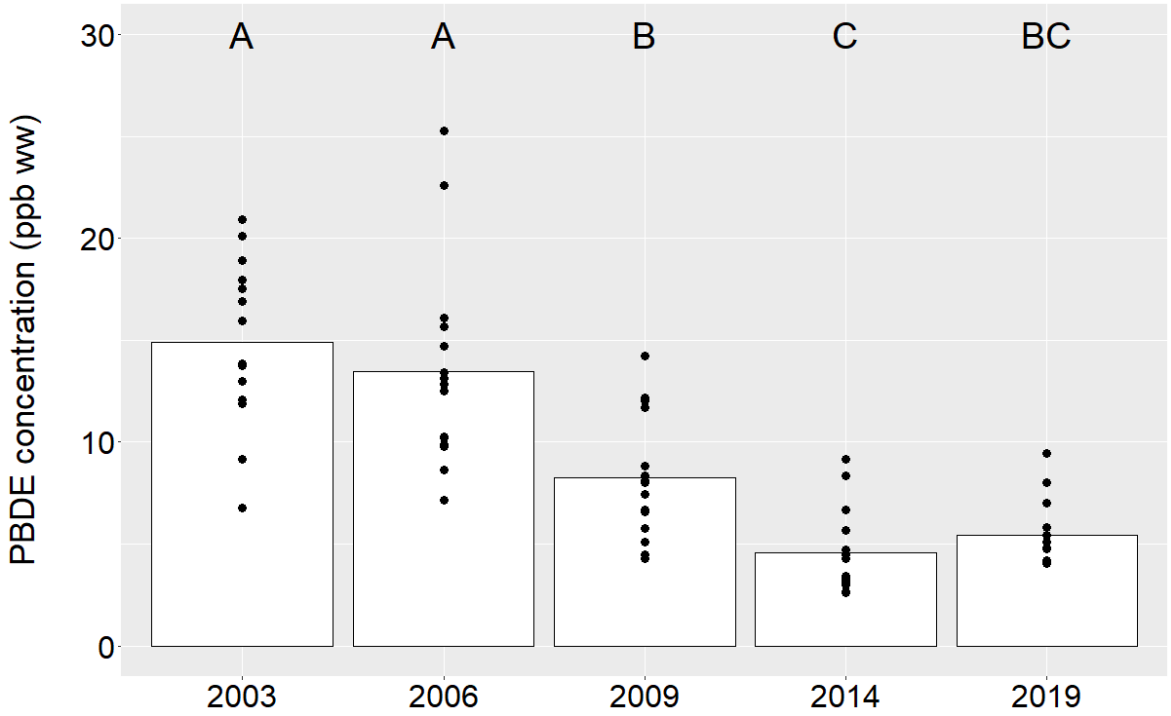

Figure 33. Sum of PBDE concentrations (ppb ww) in shiner surfperch in San Francisco Bay, 2003-2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. 2019 data excludes samples taken from San Leandro Bay, which was not sampled in prior years. Years labeled with the same letter did not have significantly different means (Tukey HSD, alpha = 0.05).

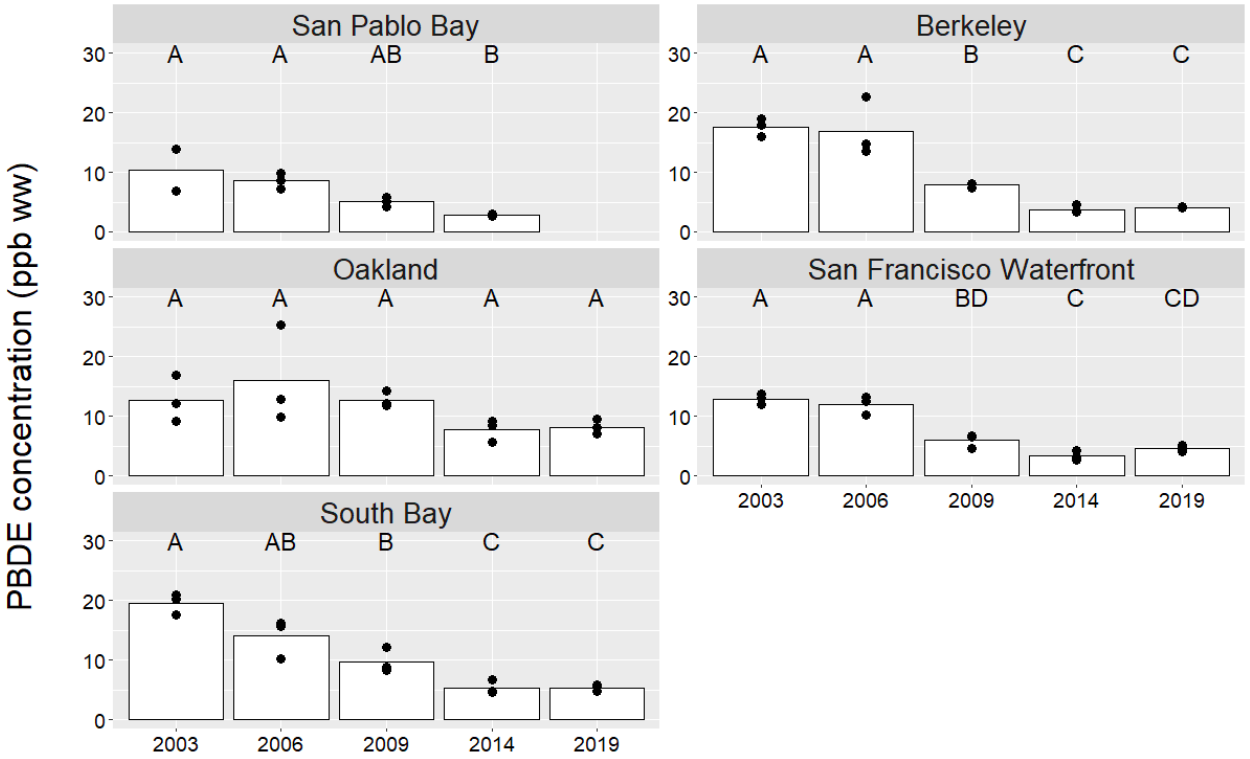

Figure 34. Sum of PBDE concentrations (ppb ww) in shiner surfperch in each region of San Francisco Bay, 2003-2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data from regions only sampled during individual years have been excluded (e.g., San Leandro Bay and Carquinez Strait). Years labeled with the same letter did not have significantly different means (Tukey HSD, alpha = 0.05).

Management Implications and Priorities for Further Assessment

The 2019 PBDE data provide further evidence of the decline of PBDEs in Bay sport fish since 2003, and are at levels well below guidelines for the protection of human health. Ongoing monitoring of these chemicals will be of interest to continue to measure the impact of the PBDE phase-outs. The RMP CEC Strategy (Sutton et al. 2017) calls for monitoring for at least two more cycles after a contaminant drops from the Moderate Concern category to the Low Concern category in the tiered, risk-based framework for emerging contaminants. PBDEs were moved to the Low Concern category in 2017, which means that one more round of monitoring of PBDEs in fish should be conducted in 2024.

PFAS

Per- and polyfluoroalkyl substances (PFAS; formerly referred to as PFCs or perfluorinated compounds, which make up a subset of PFAS) are a class of synthetic chemicals used to resist heat, oil, stains, grease, and water in a wide range of consumer and industrial products, including food packaging materials, waterproof textiles, stain-resistant carpets and furniture, fire-suppression foams, processing aids for the production of fluoropolymers like Teflon, mist suppressants in metal-plating, and hydraulic aviation fluids (Sedlak et. al. 2018). As a result of their chemical stability and widespread use, PFAS such as perfluorooctane sulfonate (PFOS) have been detected in the environment, including in fish, bird eggs, and seals monitored over the past 15 years in San Francisco Bay (Sedlak et al. 2018).

Comparison to Thresholds and Variation Among Species

The RMP began monitoring PFAS in sport fish in 2009, with initial efforts focused on monitoring 13 compounds including PFOS, the PFOS precursor perfluorooctanesulfonamide (PFOSA), as well as perfluorooctanoic acid (PFOA). 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. As a result, a greater number of detections across a greater number of analytes were obtained. Of the 17 samples, 13 samples with detectable analytes revealed PFOS as the dominant congener detected (77% of the sum PFAS concentration), followed by PFOSA (12% of the sum PFAS concentration).

In 2019, the RMP nearly doubled the scope of PFAS chemical analysis, measuring 32 PFAS including a range of perfluoroalkyl carboxylates, perfluoroalkyl sulfonates, fluorotelomer sulfonates, fluorotelomer carboxylates, perfluorooctane sulfonamides, perfluorooctane sulfonamide ethanols, per- and polyfluoroether carboxylates, and ether sulfonates. Analyticalimprovements continued for the 2019 sampling, with detection limits as low as 0.2 ppb. In addition to the greater number of compounds measured, a higher frequency of detection was achieved due to reduced PFOS method detection limit, with PFAS observed in 14 of the 16 samples analyzed.

Similar to previous years, PFOS was the dominant PFAS (averaging 62% of total PFAS concentration across all samples), followed by PFOSA (7.4% of total PFAS) and perfluorododecanoic acid (PFDoA; 6.7% of total PFAS) (Figure 35). In general, short-chain perfluoroalkyl substances (e.g., perfluorobutanoic acid or PFBA, and perfluorohexane sulfonate or PFHxS), PFOA, and most precursors were rarely detected, and most reported concentrations were close to detection limits (Figure 36). Long-chain perfluorocarboxylates like PFDoA were typically detected at low levels, as observed in seals and bird eggs (Sedlak et al. 2018). The 2019 data appear to be some of the first fish tissue monitoring data in species consumed by humans for newer PFAS such as GenX and ADONA in the US - though neither were detected.

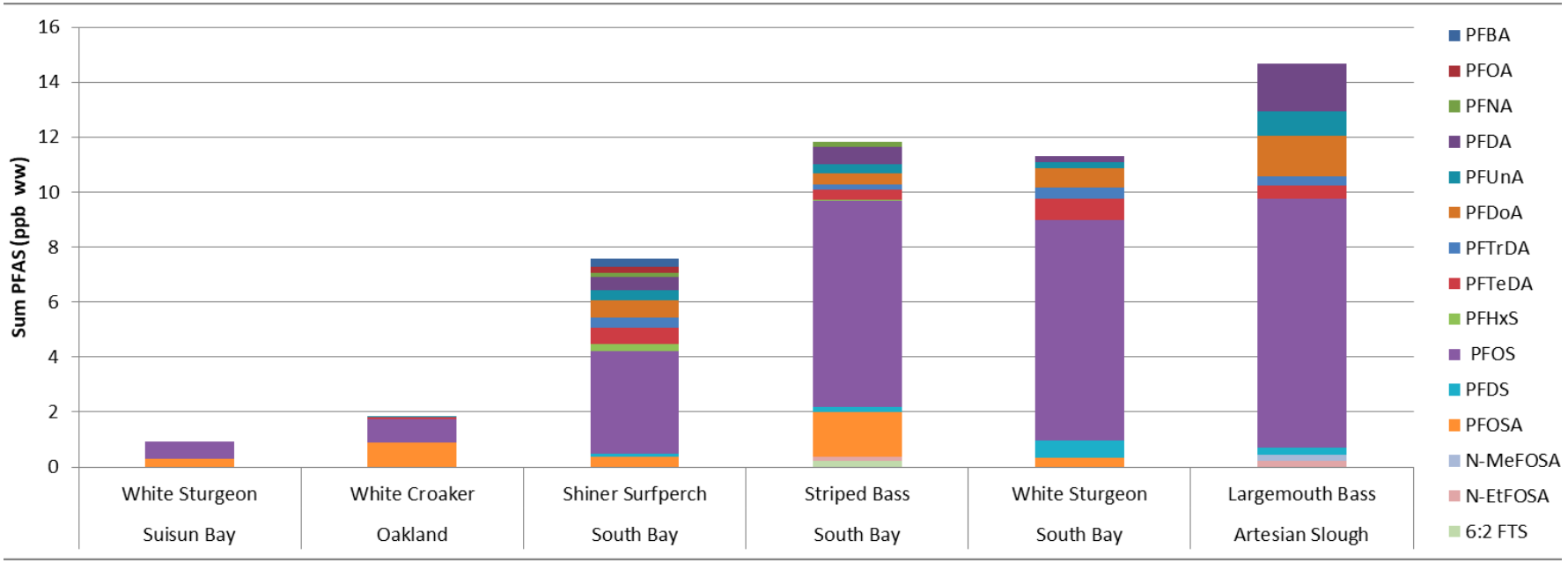

Figure 35. Sum of PFAS concentrations (ppb ww) and analyte contributions in San Francisco Bay fish, 2019. Bars represent average concentrations, with n = 1 for Suisun Bay white sturgeon, n = 3 for Oakland white croaker, n = 3 for South Bay shiner surfperch, n = 4 for South Bay striped bass, n = 1 for South Bay white sturgeon, and n = 1 for Artesian Slough largemouth bass. White sturgeon from Central Bay were not included in this figure because PFAS were below detection limits.

With the limited number of samples analyzed for PFAS (n = 16), the data obtained for each species are not necessarily representative of Bay-wide conditions. Most of the samples analyzed were from the South Bay region, which, based on this limited dataset, may have higher concentrations than other parts of the Bay (Figures 35 and 36). The highest average PFAS concentration for a species was 15 ppb in largemouth bass, though this was based on just one composite from Artesian Slough (at the outfall of the San Jose-Santa Clara wastewater treatment plant). Striped bass collected at South Bay (Coyote Creek), just downstream of this outfall, had the second highest average concentration (12 ppb). Shiner surfperch collected at South Bay (Redwood Creek) had the third highest average (7.5 ppb). Average concentrations in white sturgeon and white croaker, which came from other parts of the Bay (except for one white sturgeon composite), were lower. The highest concentration observed in any sample was 17 ppb in a striped bass sample.

As a point of comparison for the largemouth bass sample at Artesian Slough with 9 ppb PFOS, similar levels of PFOS were observed in a composite sample of largemouth bass collected in the Russian River north of San Francisco Bay in 2015 (10.5 ppb ww in the one largemouth bass sample analyzed; Maruya et al. 2018).

PFOS and other PFAS have been associated with a variety of toxic effects, including carcinogenicity and abnormal development. Infants, children, and pregnant/nursing people are considered to be at higher risk, as these compounds can cross the placental barrier and concentrate in breast milk. No human health or regulatory thresholds have yet been established for PFAS in San Francisco Bay fish. However, sampling for PFAS in fish has been more extensive in other states such as Minnesota and Michigan, where concentrations have been high enough that the states have established thresholds for issuing consumption guidelines. Currently, eight states have consumption guidelines for PFOS, the most commonly detected PFAS, and several of these states also have thresholds for other PFAS, including PFOA, perfluorononanoic acid (PFNA), and perfluorobutane sulfonate (PFBS) (Longsworth 2021). The lowest state thresholds for PFOS are currently in Minnesota and New Jersey. State thresholds vary because they may include not only an analysis of risk from the contaminant, but often also a risk-benefit analysis balancing toxicity of the contaminant with the known benefits of consuming fish. Thresholds may also vary because they evaluate different studies and endpoints or use different factors and assumptions (e.g., body weight and consumption rate).

All PFOS concentrations measured in 2019 were well below the USEPA human health fish tissue benchmark of 68 ppb ww (USEPA 2020) and below Connecticut, Maine, Michigan, New York, and Wisconsin state fish consumption guidelines (Figure 36). However, a single striped bass sample from South Bay was within the range of the Minnesota two servings/week consumption threshold of >10-20 ppb ww. All samples except for the white sturgeon from Central Bay exceeded the New Jersey General and High Risk Populations unlimited consumption threshold of 0.56 ppb ww (Figure 36) (Longsworth, 2021). A single largemouth bass from the Artesian Slough, the striped bass average from South Bay, the shiner surfperch average from South Bay, and a single white sturgeon from South Bay also exceeded the New Jersey General Population one serving/week consumption threshold of 3.9 ppb ww.

A few samples exceeded thresholds for other individual PFAS. The New Jersey General and High Risk Populations unlimited consumption threshold for PFNA of 0.23 ppb ww was exceeded in one shiner surfperch composite and two striped bass composites from South Bay, but no composites exceeded the New Jersey General Population one serving/week consumption threshold for PFNA of 1.6 ppb ww (Figure 37). All PFOA and PFBS concentrations were below other state consumption thresholds for these compounds (Figure 35).

Risk assessment of PFAS is increasingly being done as a sum of all PFAS instead of evaluating each compound individually. The European Food Safety Authority (EFSA) has established a tolerable weekly intake (TWI) of 4.4 ng/kg body weight for the sum of PFAS (using data for PFOA, PFNA, PFHxS, and PFOS; EFSA Panel on Contaminants in the Food Chain 2020). This threshold includes all exposure from foods and drinking water, so it is difficult to calculate back to a value specific to fish consumption. However, recent work in Sweden translated this threshold to a one fish serving per week threshold of 3.4 ppb ww (Augustsson et al. 2021). Only Oakland white croaker and Central and Suisun Bay white sturgeon PFAS concentrations were below this threshold (Figure 37).

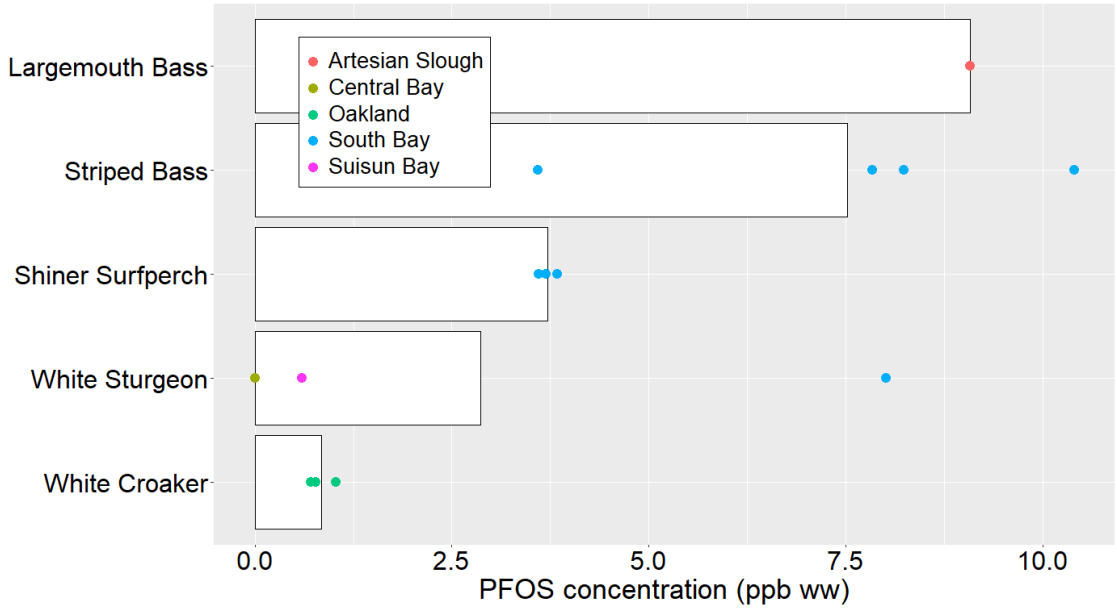

Figure 36. PFOS concentrations (ppb ww) in San Francisco Bay Fish, 2019. Bars indicate average concentrations. Points represent individual or composite samples. Points are colored by sampling location.

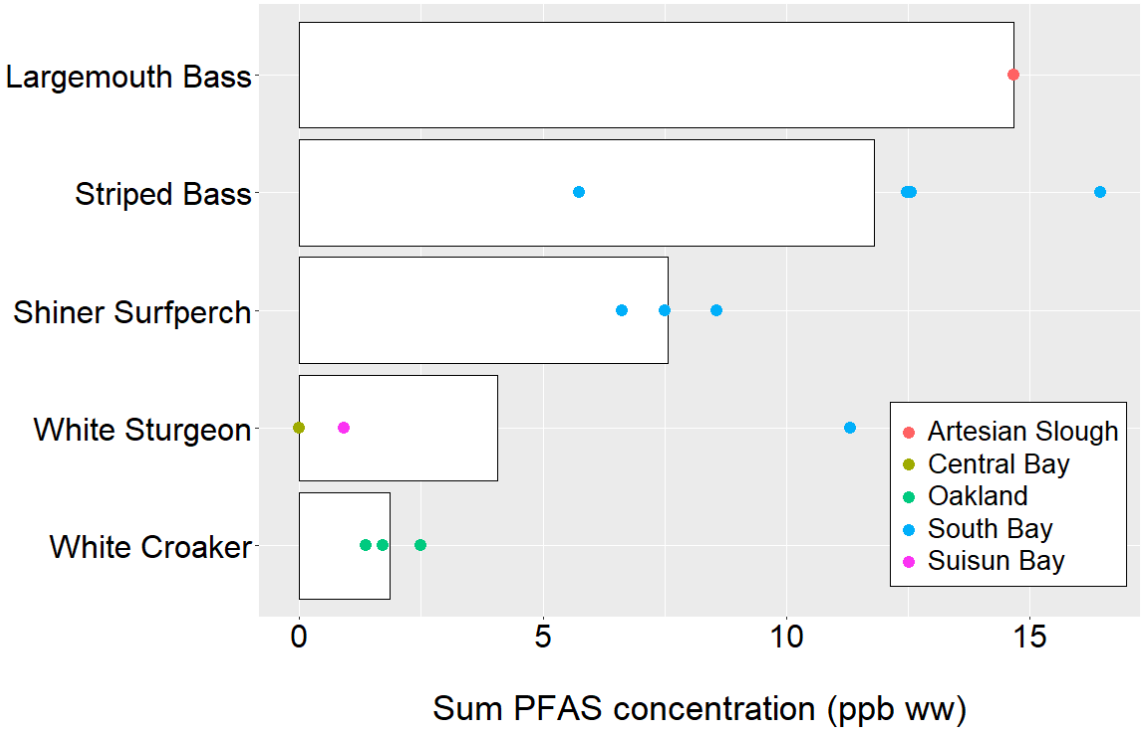

Figure 37. Sum of PFAS concentrations (ppb ww) in San Francisco Bay fish, 2019. Bars indicate average concentrations. Points represent individual or composite samples. Points are colored by sampling location.

Spatial Patterns

The limited sample size, combined with the uneven distribution of species across stations, prevents a rigorous examination of spatial patterns within the Bay. However, both higher concentrations and a greater number of detected PFAS chemicals were found in fish collected from Artesian Slough and South Bay. The highest concentrations of total PFAS or any individual PFAS was almost always highest in fish collected either near Artesian Slough or in South Bay (Figure 36). White sturgeon was the one species with samples analyzed from South Bay and other regions, and the South Bay sample had a much higher PFAS concentration than the samples from Central Bay and Suisun Bay. South Bay samples also showed higher concentrations of commonly detected congeners (PFOS and PFOSA) (Figure 34). Artesian Slough and South Bay also had relatively high concentrations in 2014 (Figure 38).

Temporal Trends

The limited scope and inconsistency of PFAS sampling in the three rounds sampled (2009, 2014, and 2019) and changes in analytical methods prevent a rigorous analysis of temporal trends, but the available data indicate that PFAS contamination is persisting in the food web in the South Bay region. At the South Bay station, which has had the greatest and most consistent intensity of sampling over the three rounds, and where the contamination signal is relatively strong, the average concentration was higher in 2019 than in 2009 and 2014.

Artesian Slough has consistently had the highest concentrations, and the one sample measured in 2019 had a very similar concentration to the average from 2014.

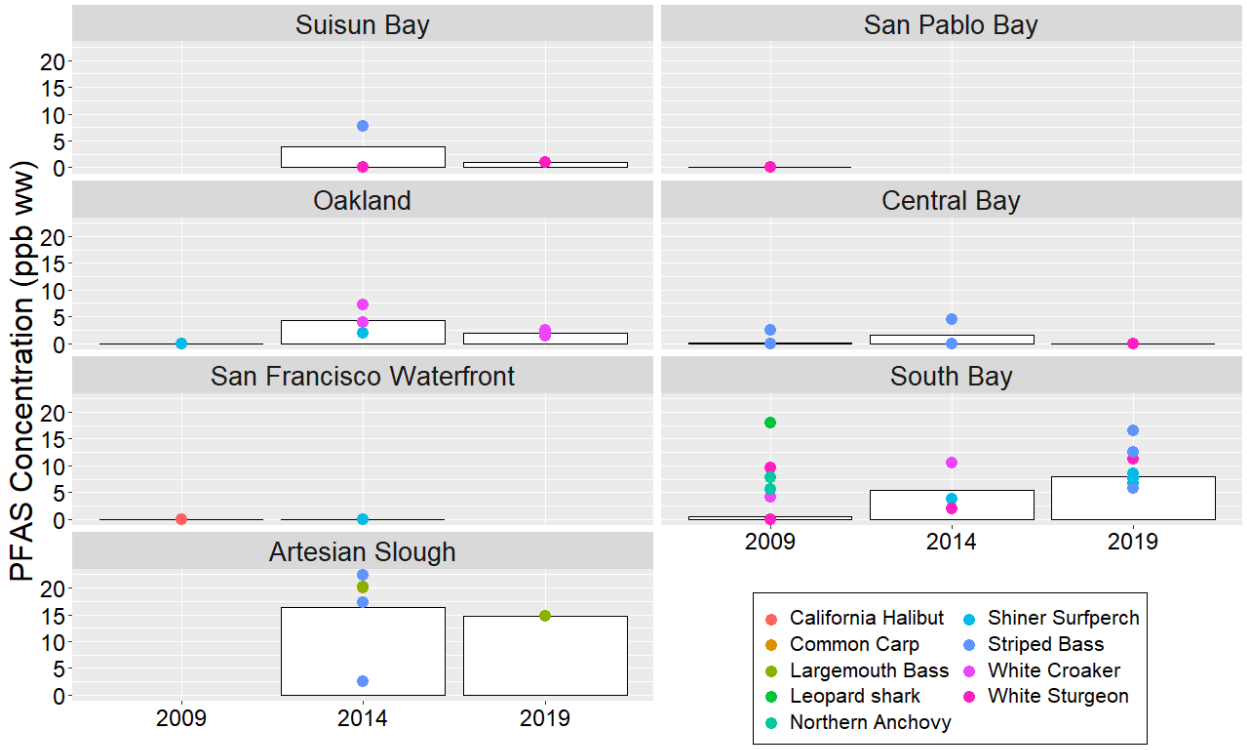

Figure 38. Sum of PFAS concentrations (ppb ww) in fish in each region of San Francisco Bay, 2009-2019. Bars indicate average concentrations. Points represent composite samples of indicated fish species. The number of PFAS analytes and MDLs varied across years.

Management Implications and Priorities for Further Assessment

No human health or regulatory thresholds have yet been established for PFAS in San Francisco Bay fish. Concentrations in Bay fish, however, particularly in the South Bay region, are persisting over time at levels that exceed thresholds that have been established by other states for development of consumption advisories. The thresholds applied by some states have become more stringent over time as the toxicity of PFAS is becoming better understood.

The monitoring conducted to date for PFAS in fish has been limited in scope, hindering evaluation of spatial patterns and long-term trends. More intensive monitoring is warranted to track long-term trends, understand spatial variation, and more firmly characterize concentrations for comparison to thresholds. More intensive monitoring for this class of chemicals is also warranted given their classification as CECs of Moderate Concern in the RMP tiered, risk-based framework for prioritizing CECs, and the increasing emphasis placed on CECs in the current reevaluation of RMP Status and Trends monitoring as a whole. The RMP CEC Strategy (Sutton et al. 2017) and a PFAS Strategy developed for the RMP (Sedlak et al. 2018) both prioritize PFAS sampling in fish, among a variety of other RMP PFAS monitoring elements.

The South Bay appears to be a region of particular concern; this could be established more definitively by expanded monitoring. Monitoring should continue in the South Bay to build on the time series that have been initiated for largemouth bass at Artesian Slough, for striped bass at South Bay (Coyote Creek), and for shiner surfperch at South Bay (Redwood Creek). Sampling other key species (e.g., shiner surfperch, striped bass, white croaker) more thoroughly across other Bay stations would provide a better characterization of this class of chemicals, and allow trend assessment more broadly for the Bay as a whole. Another possibility to enhance the dataset would be to analyze samples from 2019 that have been archived in a manner that allows for PFAS analysis.

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Appendix 1 - 2019 Sport Fish Cruise Report

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Appendix 2 - 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 by the labfor those samples 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. 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.

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 PFAS

Due to changes in analytical methods, different numbers of congeners are included in the "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). Congeners that are included in the Sum of 40 PCBs are in Table A-3 (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 patterns.

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 coeluted congeners reported by different analytical laboratories may vary from year to year, and the 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. Due to past method detection limits, many dioxins-furans results were reported as non-detect, the effect of this assumption can be 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. Both Sum methods are reported for dioxins-furans. Only Sums calculated using the ND = 0 assumption are reported for all other classes.

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.

3. Lipid Percent Measurements

Fish lipid content can vary substantially by species, year, and sample preparation method (skinon, 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.

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	
CommonName	
TissueCode	WNHTG or FIL
TissueName	whole organism; fillet; guts; whole, without Head, Tail, and Guts
PrepPreservationname	
NumberInComposite	
TotalLengthAvg	
UnitLengthAvg	
UnitLengthFish	
CompositeRowID	
CompositeID	
CompositeReplicate	
CompositeType	
ExportData	
ComplianceCode	
SampleTypeCode	
TissueResultRowID	
MatrixName	
MethodName	
AnalyteName	
AnalyteGroup	
UnitName	
LabReplicate	
Result	
ResultQualCode	
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
2RMPBERK	Berkeley-2RMPBERK	Berkeley
2RMPBERK3	Berkeley-2RMPBERK3	Berkeley
2RMPBERKI	Berkeley-2RMPBERKI	Berkeley
2RMPDMB	Dumbarton Bridge-2RMPDMB	South Bay
2RMPOIH	Oakland Inner Harbor - 2RMPOIH	Oakland
2RMPOIHF	Oakland Inner Harbor (Fruitvale)-2RMPOIHF	Oakland
2RMPOIHP	Oakland Middle Harbor Pier-2RMPOIHP	Oakland
2RMPOAK	Oakland-2RMPOAK	Oakland
2RMPOAKI	Oakland-2RMPOAKI	Oakland
2RMPRH	Richmond Harbor-2RMPRH	Richmond Harbor
2RMPRH	Richmond Harbor-2RMPRH	Richmond Harbor
2RMPSFWI	San Francisco Waterfront I-2RMPSFWI	San Francisco Waterfront
2RMPSFW	San Francisco Waterfront-2RMPSFW	San Francisco Waterfront
2RMPSFW3	San Francisco Waterfront-2RMPSFW3	San Francisco Waterfront
2RMPSLB	San Leandro Bay-2RMPSLB	San Leandro Bay
2RMPSPB	San Pablo Bay-2RMPSPB	San Pablo Bay
2RMPSPB3	San Pablo Bay-2RMPSPB3	San Pablo Bay
2RMPSPBI	San Pablo Bay-2RMPSPBI	San Pablo Bay
2RMPSOB	South Bay-2RMPSOB	South Bay
2RMPSOB3	South Bay-2RMPSOB3	South Bay
2RMPSOBI	South Bay-2RMPSOBI	South Bay
207SUISUN		Suisun Bay
206SNPBLO		San Pablo Bay
203BRKLEY		Berkeley
203EMRYVL		Emeryville
203OAKLND		Oakland
203SANFRN		San Francisco Waterfront

203CENTRL		Central Bay
204STHBAY		South Bay
204STNBGR		Steinberger Slough
ARTSLGH		Artesian Slough

Table A-3. Sum of 40 PCBs analyte list. IUPAC numbers are listed

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-4. 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).

AnalyteName	**TEF (WHO 2005)**
HpCDD, 1,2,3,4,6,7,8-	0.01
HpCDF, 1,2,3,4,6,7,8-	0.01
HpCDF, 1,2,3,4,7,8,9-	0.01
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
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
OCDD, 1,2,3,4,6,7,8,9-	0.0003
OCDF, 1,2,3,4,6,7,8,9-	0.0003
PeCDD, 1,2,3,7,8-	1
PeCDF, 1,2,3,7,8-	0.03
PeCDF, 2,3,4,7,8-	0.3
TCDD, 2,3,7,8-	1
TCDF, 2,3,7,8-	0.1

Appendix 3 - Quality Assurance Report

2019 RMP Sport Fish Tissue Data Quality Assurance report

Introduction

In 2019, fish tissue samples were collected from nine Bay/Delta areas and three additional wetland/slough areas for the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP). General descriptions of the sample collection methods are provided in the RMP Quality Assurance Program Plan, cruise plans, cruise reports, and field sampling reports. These documents are available from the SFEI website (http://www.sfei.org/content/status-and-trends-monitoring-documents).

Sport fish samples were analyzed for the following parameters by the laboratories indicated:

- BAL : Selenium
- DFW-MPSL : Mercury
- SGS-AXYS – PCBs, PBDEs, PCDD/Fs, PFAS

The SFEI Data Services Team checked the laboratory results using the methods and data quality objectives in the RMP Quality Assurance Project Plan (QAPP).

Due to lab closings for COVID 19, analysis was delayed for many samples. For the sportfish samples, 100% of the BAL selenium results were reportable, although many were flagged for being analyzed beyond the one year recommended hold time. However, samples were stored frozen, so the impact of the extended holding time is likely small. Sportfish mercury results similarly had no serious issues, with the primary flagging of data being for hold times exceeding the listed 28 days for the method (EPA 7473). However, that hold time is likely overly conservative given frozen storage of samples and volatile mercury species not typically found in tissue samples. Subsequent RMP QAPPs have been updated to extend tissue mercury hold times to a year if frozen, although there is no demonstration or expectation of significant loss for storage beyond the first year.

For the organic compounds reported by SGS-AXYS, many were also analyzed beyond the recommended hold time of one year. However, similar to mercury and selenium, losses of many of these compounds is expected to be small for samples in frozen storage. Other issues such as blank contamination were also occasionally found. Many of these issues occurred with less abundant congeners, but some compounds abundant in indoor environments such as PBDEs showed evidence of blank contamination for some of the most abundant congeners, possibly affecting reported concentrations (likely biasing results high). Overall around 80% of the PCB data were qualified, mostly due to hold time exceedances.

This memo provides a high-level summary of the quality assurance assessment for each dataset. Non-conformances with the QAPP and possible indicators of variability and uncertainty in reported values, with corrective actions needed for the next round of monitoring are

highlighted in gray shading. The details of the quality assurance assessment for each dataset are provided in Appendix A.

The data have been approved by the RMP Manager and Lead Scientist, and all results have been uploaded to the San Francisco Regional Data Center and CEDEN.

Quality Assurance Summary for 2019 RMP Sportfish Samples

Mercury in sportfish samples was reported for nine historical sites for the RMP S&T program and three wetland slough areas for special studies. There were no non-detects in field samples, no detects in blanks, and CRM and matrix spike recoveries were always within 15% of target values, and lab replicate RPDs always 15% or less. The only flags needed were for hold time exceedances, likely having no measurable impact on reported concentration.

The selenium data had nearly no issues or QA flags applied aside from hold time exceedances (again likely having minimal impact), with detections in all samples, no detections in method blanks, and recovery errors in matrix spikes and CRMs averaging <5%, and likewise precision <5% RPD on the lab replicate.

For PCBs, a majority of samples were analyzed past the one year hold time, leading to hold time flags, but PCBs are slow to degrade in frozen samples, so impacts on reported concentrations are likely small. Major congeners were always detected, but 25 were not detected in over half of samples. However this is typical given the large number of PCB congeners, with many minor contributors. Some congeners were detected in blanks for various batches, but only a handful of congeners were tagged with “VIPND” indicating blank concentrations being over ⅓ of the reported value. Precision on lab replicates was generally within the target range of <35% RPD. A handful of minor congeners had over 70% RPD, so were flagged “VJ” for estimated values to indicate the quantitation uncertainty in those batches. Recoveries were always within target ranges of <35% deviation from expected values for LCS samples, with CRM and MS samples deviating <35% most of the time. CRMs occasionally deviated >35% from the reported certified or reference consensus values with PCB 037 and 124 averaging outside of +/-70% of their expected values, and a “VJ” estimated flag indicating the uncertainty in recovery.

The PBDEs had more issues, especially PBDE 209 results, which are probably not quantitative (due to blank detects, variable precision, and no recovery on the CRM, although there were acceptable recoveries on the MS and LCS samples). About one-third of the PBDE analytes were non-detect in more than half the samples, but this was expected given inclusion of many minor congeners. Blanks were >⅓ of the reported field sample concentrations in two or more samples for 8 of the 50 congeners (PBDE 209 the worst, where the blank was over ⅓ the result for 90% of samples). PBDE 209 also had poor precision in lab replicates (72% RPD), along with PBDE 207 (200% RPD). CRM recoveries were within 35% of expected values for most compounds, but again PBDE 209 was poor (low, 0% of the expected value), despite MS and LCS recoveries within 35% of target. Thus although PBDE 209 is of interest due to deca-BDE being the last formulation phased out, the apparent difficulties in consistent analysis make it impossible to detect small or gradual changes. Future rounds of PBDE analysis should perhaps

be contingent on evidence of being able to better quantify PBDE 209 (lower blank concentrations, more consistent lab replicates, and better CRM recovery) from test samples or data from other projects.

For the 17 PCDD/PCDF compounds analyzed in sport fish samples, none of the data were rejected, but some OCDD results were within three-times the concentrations in blanks, so were considered estimated/not quantitative results. Although there were non-detects for nearly every analyte, the method was sufficiently sensitive to detect slightly less than half the PCDD/Fs in most samples, similar to prior years. Lab replicates had <35% RPD for all compounds that were at least 3x MDL, and recoveries on CRMs, MSs, and LCSs all were within 65-135% MQO targets for all PCDD/F analytes, so no added precision recovery flags were needed.

For PFAS compounds, 95% of the data are reportable, with 5% lab rejected (LRJ flag), likely due to poor LCS recovery (averaging over 200%) for one analyte. About half of the analytes were ND in all samples, with the rest ND in one or more samples. Perfluorotridecanoate, Perfluoroundecanoate, and Fluorotelomer Sulfonate, 6:2-, were all detected in the blank for batch WG73629-AXYS, at a concentration >⅓ of the sample results, so flagged VIPND (not distinguishable from blank). Few analytes averaged >3x MDL in replicate samples, but those that did had good precision (<5% RPD), well within the 35% target. Recoveries on LCS samples were between 65-135% targets, aside from Methyl-perfluorooctanesulfonamidoethanol, N- (flagged LRJ by the lab in two batches, with average LCS recovery of 248% across batches, and 148% in the third batch, so all were flagged VJ (estimated) by SFEI.) Despite some possible quantitation issues with minor/precursor compounds, concentrations of common compounds like PFOS were generally in an expected range.

Dataset QA Summaries Bay RMP 2019 Sportfish

DFW-MPSL; RMP S&T Fish

Hg

QA Issues for Project Manager to Review
None

Overall acceptability
Overall the data are acceptable

Reporting Issues for Lab to Review
None

Formatting Issues for Data Manager to Review
Protocolcode of Null for QC samples I will revise to accommodate in queries, but want to make sure that there is a controlled vocabulary for non-Null protocols that aren't truly real project protocols, so that QC doesn't end up unmatched to field samples. Either no placeholder values for protocol, or always using one specific value if a placeholder is used, is preferred. Those 2 variants is fine, just don't want numerous "Not *) variants.

Hold time review (especially desired by stormwater programs)
Hold time was technically over value (28 days for EPA 7473) in the QAPP in effect at the time, but EPA has research evidence that there are not detectable detriments of longer hold time up to a year. Subsequent QAPPs have updated that value to a year, but even that is likely overly conservative, non-volatile Hg species are unlikely to be lost from frozen samples.

QA Review

Dataset completeness
Results were reported for 134 field samples, analyzed in 10 lab batches.
At least 3 blanks, and 1 lab rep, CRM and MS was reported with each batch.

MDLs sensitivity
The method was sensitive enough to detect mercury in all samples.

QB averages (procedural, field blank)
Results were reported not blank corrected, and blanks were always below detection limit.

Accuracy (using a variety of SRMs or Matrix spike QRECs)
Recovery on CRMs was always within 10% of the target value or better, and matrix spikes were always within 13% of target recovery or better. No added accuracy qualifiers were needed.

Average precision from replicate field sample
Precision on lab dupes was 15% RPD or better, so no precision flags were needed. Within site variations of results were often quite large, due to differences among species and variations among individuals of a species.

Comparison of dissolved and total phases
Not Applicable

Comparison to previous years
Results are similar to past years, with tissue mercury around 1 ug/g ww or lower for nearly all species.

Ratio Checking Summary
Not applicable.

Sums Summary
Not applicable

SGS-AXYS; RMP S&T Fish

PCB

QA Issues for Project Manager to Review
None

Reporting Issues for Lab to Review
None

Formatting Issues for Data Manager to Review
None

Hold time review
A majority of samples were analyzed past the one year hold time, but PCBs are slow to degrade, especially in frozen samples, so the impact is likely negligible.

QA Review

Dataset completeness
Results were reported for 82 field samples in 7 lab batches, with a blank, lab rep, CRM, MS, and LCS in each batch except WG71834-AXYS, which had only a single sample and thus only a blank, CRM, and LCS (no MS or lab rep).

Percent usable (non-reject) field data
All the data are reportable, although ~80% of the records were qualified, mostly for hold time exceedance, some blank contamination, and variation on lab reps for minor congeners.

Overall acceptability
Overall the data were acceptable.

MDLs sensitivity
Major congeners were always detected, but eight congeners were ND in 100% of samples, and 25 were ND in over half of samples. However, this is to be expected given the large number of PCB congeners with many being only minor contributors to total PCBs in the environment.

QB averages (procedural, field blank)
A number of congeners were detected in blanks for various batches, but the vast majority of them were at concentrations <⅓ those present in field samples. Only a handful of congeners were tagged with “VIPND” indicating blank concentrations being over ⅓ of the reported value.

Average precision from replicate field sample
Precision on lab replicates was generally within the target range of <35% RPD. A handful of minor congeners varied by over 70%, so were flagged “VJ” for estimated values (in addition to the IL/VIL indicating variable precision) to indicate the quantitation uncertainty in those batches. Congeners that were variable across numerous batches also had notes added to their ResultComments in the form of “pjLRavg_RPDxx”, indicating project (pj) lab rep (LR) average (avg) RPD being xx%.

Accuracy (usg a variety of SRMs or Matrix spike QRECs)
Recoveries were generally within target ranges of <35% deviation from expected values for LCS samples all the time, and MS samples most of the time. CRMs more frequently deviated >35% from the reported certified or reference consensus values with that noted in result comments in the form of “pjCRMavg_PRxx” (project CRM average percent recovery xx%), and with PCB 037 and 124 averaging outside of +/-70% of their expected values, and a “VJ” estimated flag indicating the uncertainty in recovery.

Comparison of dissolved and total phases
Not applicable

Comparison to previous years
Concentrations look overall reasonable, with dominant congeners like PCB 138 and 153 averaging in the 10-20 ng/g ww range. Lipid and moisture also appear reasonable, averaging ~1% & ~80% respectively (across species).

Ratio Checking Summary
Not applicable.

Sums Summary
Not applicable

PBDE

QA Issues for Project Manager to Review
None

Reporting Issues for Lab to Review
Similar to other data sets PrepPreservation is not reported, likely should be FieldFrozen,LabFrozen, based on CoCs/narrative.

Formatting Issues for Data Manager to Review
Similar to other data sets PrepPreservation is not reported, likely should be FieldFrozen, LabFrozen, based on CoCs/narrative. Maybe update along with all other 2019 fish sets.

Hold time review
Hold times ranged 344 to 447 days, over the one year target hold time, but in frozen storage, likely inconsequential to the analysis given PBDE persistence.

QA Review

Dataset completeness
The dataset includes results for 19 field samples and 3 lab replicates, reported for 50 PBDEs (including some coeluters) in three batches. Also reported were three each of MS, CRM, LCS, and blank samples (one each batch).

Percent usable (non-reject) field data
Overall over 98% of the data were reportable, with some lab rejected data. About 6% of the data were estimated (in a non-quantitative range, or with blank contamination possibly accounting for >⅓ of the concentration, or RPD >70% in lab reps). A majority of the rest were qualified, mostly due to hold time, or smaller degrees of blank contamination (less than ⅓ of the sample concentration).

Overall acceptability
Overall the data are acceptable, except the PBDE 209 results are probably not quantitative (blank hits, variable RPD, no recovery on the CRM (although OK on the MS and LCS sample).

MDLs sensitivity
Methods were reasonably sensitive for most analytes, with 17 of 50 analytes having 50% to 100% non-detects. However given the large number of minor congeners included this is not unexpected.

QB averages (procedural, field blank)
Fourteen of the PBDEs were found in blanks, with eight of those at concentrations >⅓ of the reported field sample concentrations in two or more samples (PBDE 209 the worst, where the blanks was over ⅓ the result for 90% of samples).

Average precision from replicate field sample
Precision on lab replicates was good, within the target 35% RPD for all but two compounds, PBDE 207 (200% RPD) and 209 (72% RPD)

Accuracy (using a variety of SRMs or Matrix spike QRECs)
CRM recoveries were within 35% of expected values for most compounds, except PBDE 155 (averaging high, 145% recovery) and PBDE 209 (low, 0%). MS and LCS recoveries on PBDE 209 were within 35% of target however so no QACode was added, but comments noting the project average CRM recovery added (pjCRMavg_PR145%).

Comparison to previous years
Concentrations were generally in a similar range as previous years, with PBDE 47 and 99 the most abundant. Maximum concentrations were a little bit lower than in 2014, but the latter was done by a different lab and included some freshwater species samples analyzed in the same batches so may not be directly comparable on a whole batch basis.

Ratio Checking Summary
As expected, PBDE 47 and 99, components of Penta, were the dominant congeners observed in fish samples. Thanks to the lower detection limits now available, PBDE 209 has been observed in Bay fish for the first time; however, specific values are best considered semi-quantitative and are excluded from sums. There is one sample where BDE-209 makes up 7% of the sample, but the presence of other congeners at values greater than the mean plus two times the standard deviation (PBDE 208, 207, 203) is consistent with higher exposure to Deca or Octa (which can contain up to 50% BDE-209). Therefore, the overall fingerprint for that sample does not indicate a data quality concern.

The Artesian Slough sample shows a somewhat unusual distribution of Penta congeners relative to other samples (e.g., low PBDE 47, high PBDE 99). Prior monitoring in the Artesian Slough resulted in samples that had quite variable BDE-47 percentages relative to Bay fish, with one sample even lower (53% 2014, 56% 2019), consistent with this observation.

Sums Summary
Not applicable

Dioxin/Furan

QA Issues for Project Manager to Review
None

Reporting Issues for Lab to Review
None

Formatting Issues for Data Manager to Review
Although the lab reports TEQ values and sums of homolog groups (e.g., Hexa-furans, total), please verify that these are not uploaded to CEDEN.

Hold time review (especially desired by stormwater programs)
Many of the samples were analyzed beyond the one year hold time for dioxins/furans, but given their environmental persistence, the extended hold is unlikely to be consequential.

QA Review

Dataset completeness
Reported data include 14 shiner surfperch, 11 croaker reported for 17 PCDD/PCDF compounds, with two lab reps of each. Also reported were three fish samples for BOG of unspecified species. In addition to the lab replicates, four blank and LCS samples were reported (one per batch) and two CRMs and five MSs (with one a lab dupe of an MS).

Percent usable (non-reject) field data
None of the data were rejected, although some OCDD results were within three-times of the concentrations in blanks, and flagged with VIPND (not distinguishable from blanks) QAcodes, considered estimated/not quantitative results.

Overall acceptability
Overall the data are acceptable. Nothing appears to be a serious problem in the quantitation of PCDD/Fs overall.

MDLs sensitivity
Although there were non-detects for nearly every analyte, the method was sufficiently sensitive to detect slightly less than half the PCDD/Fs in a majority of samples. This is largely in line with past years' analyses.

QB averages (procedural, field blank)
Only OCDD was detected in some blanks, and with very low OCDD concentrations in most samples, in many cases field concentrations were <3x higher than the blank and flagged VIPND, indicating estimated values not distinguishable from blanks.

Average precision from replicate field sample
Precision on lab replicates was generally good, within the <35% RPD target for all the compounds that were at least 3x MDL. Some homolog groups (Hexa-furans, total, and others) had RPDs over the 35% target and flagged with a VIL QACode, but the RMP does not normally report total homologs or sums of congeners directly as provided by labs (RMP normally sums independently after data QA review).

Accuracy (using a variety of SRMs or Matrix spike QRECs)
Recoveries on CRMs, MSs, and LCSs all were within 65-135% MQO targets for all PCDD/F analytes. No added recovery flags were needed.

Comparison to previous years
Concentrations were in a pretty similar range as in previous years, for example the average concentration of the most abundant compound (2,3,7,8 TCDF) averaged 2.5 pg/g ww, similar to the 2014 average of 2.1 pg/g ww.

Ratio Checking Summary
The data did not appear with any apparent problems. The internal consistency is very good, and the prominent congeners match historic data.

Sums Summary
Not applicable

PFAS

QA Issues for Project Manager to Review
None

Reporting Issues for Lab to Review
Sample receiving doc says FieldFrozen, narrative says stored at -20C (LabFrozen), so PrepPreservationName should say at least FieldFrozen (if not both)

Formatting Issues for Data Manager to Review
PrepPreservation is listed as not recorded, although these samples are likely FieldFrozen,LabFrozen before analysis (based on the narrative in the data package PDF and shipping form).

Hold time review (especially desired by stormwater programs)
The EPA water method for PFAS has a hold time listed of 28 days. However, this is in a solid matrix so some of the partitioning loss issues in that form are likely not as significant. All samples had hold times between 246 to 413 days; given the persistence of many PFAS, there is not likely significant degradation, especially in frozen storage.

QA Review

Dataset completeness
The dataset includes results for 14 field samples with two lab replicates in three batches (one batch with only one sample, another with one and a lab rep). A blank and LCS was included in each batch, and one MS in the large batch. Thirty-three results for PFAS analytes, lipid, and moisture were reported.

Percent usable (non-reject) field data
95% of the data are reportable (not-rejected) with the remaining 5% lab rejected (LRJ flag), likely due to poor LCS recovery (averaging over 200%) for one analyte.

Overall acceptability
Overall the data are acceptable.

MDLs sensitivity
About half of the analytes were ND in all samples, with the remaining analytes occasionally to often ND (in one or more samples).

QB averages (procedural, field blank)
Perfluorooctanesulfonamide, Perfluorotridecanoate, Perfluoroundecanoate, and Fluorotelomer Sulfonate, 6:2-, were all detected in the blank for batch WG73629-AXYS. The blank accounted for >⅓ of the reported field sample in the latter three, so flagged VIPND (not distinguishable from blank) in the field sample for that batch.

Average przecision from replicate field sample
Few analytes averaged >3x MDL in replicate samples, but those that did had good precision (<5% RPD) well within the 35% target.

Accuracy (using a variety of SRMs or Matrix spike QRECs)
Recoveries on LCS and MS samples were generally good. LCS recoveries were all between 65-135% targets, aside from Methyl-perfluorooctanesulfonamidoethanol, N- (flagged LRJ by the lab in two batches, with average LCS recovery of 248% across batches, and 148% in the third batch, so flagged VJ by SFEI.) MS recovery on Ethyl-perfluorooctanesulfonamidoethanol, N- was just below 65%, so that MS and its parent sample were flagged (VGB). Although MS recovery could vary among samples, since there was only one MS, all other samples for that analyte had pjMSavg_PR64 (pj = project MS average percent recovery 64%) added as a warning in the comments field.

Comparison of dissolved and total phases
Not applicable

Comparison to previous years
Concentrations were generally in an expected range, with PFOS averaging 1 to 9 ng/g ww depending on species, a similar range as in 2014.

Ratio Checking Summary
As expected, PFOS is generally the dominant compound, followed by PFOSA, with ranges of each comparable to previous measurements. In one sample, PFOSA is significantly greater than PFOS, but since these compounds are likely derived from separate uses (rather than commercial mixtures with more consistent distributions, like for PBDEs and PCBs), that unusual fingerprint does not suggest a data quality concern.

In general, detections of short-chain compounds (PFBS, PFHxS), PFOA, and most precursors are limited and close to detection limits, as would be expected. One exception is a detection of 6:2 fluorotelomer sulfonate at levels reasonably well above the detection limit; this compound is used in metal plating and AFFF, so perhaps there's a nearby source contributing to the exposure. Long-chain carboxylates are more commonly detected at low levels, as often observed in Bay seals and bird eggs.

There have been significant improvements to the detection limits associated with previously monitored compounds, along with the addition of new compounds to this improved analytical method. These appear to be some of the first fish monitoring data for newer PFAS such as GenX and ADONA in the US - none detected. In contrast, serum of striped bass from a heavily impacted region of North Carolina have detectable levels of GenX (Perfluoro-2-Propoxypropanoic Acid or HFPO-DA).

Sums Summary
Not applicable

Brooks Applied; RMP S&T Fish

Selenium and Moisture

QA Issues for Project Manager to Review
None

Reporting Issues for Lab to Review
PrepPreservation method is listed as none, although the narrative states the samples were field frozen for organics sets.

Formatting Issues for Data Manager to Review
PrepPreservation method is listed as none, although the narrative states the samples were field frozen for organics sets.

Hold time review (especially desired by stormwater programs)
Hold times were between 329-429 days, many beyond the one year target, but in frozen storage degradation or loss is unlikely.

QA Review

Dataset completeness
Data reported included 64 field samples for Selenium and moisture, with seven lab reps, four each of CRMs, LCS, LabBlanks, and seven matrix spike samples.

Percent usable (non-reject) field data
All data were reportable, no data were rejected.

Overall acceptability
Overall the data are acceptable.

MDLs sensitivity
The method was sufficiently sensitive to detect selenium in all samples.

QB averages (procedural, field blank)
Results were reported blank corrected, and the stdev of blanks was below MDL, so no results needed to be flagged.

Average precision from replicate field sample
Precision on lab replicate samples was always 10% RPD or less, averaging 5%. No added precision qualifiers were needed.

Accuracy (using a variety of SRMs or Matrix spike QRECs)
Recovery on LCS samples ranged 102-106%, averaging 104%, CRM recoveries averaged 99% (range 97 to 99.5%) so no recovery flags were needed for those sample types.

MS recoveries ranged 108 to 140%, with a few individual results over the target 65-135% of the expected value, but the average was within target, so only a few individual MS samples and their parents were flagged.

Comparison of dissolved and total phases
Not applicable

Comparison to previous years
Se concentrations were pretty similar to prior years, with *Acipenser transmontanus* (sturgeon) selenium averaging 9 ug/g dw, similar to 2014 average of 1.5 ug/g ww (with moisture content ~75% = approximately 6 ug/g dw).

Ratio Checking Summary
Not applicable

Sums Summary
Not applicable

Appendix 4 - White Croaker Data Supplemental Figures

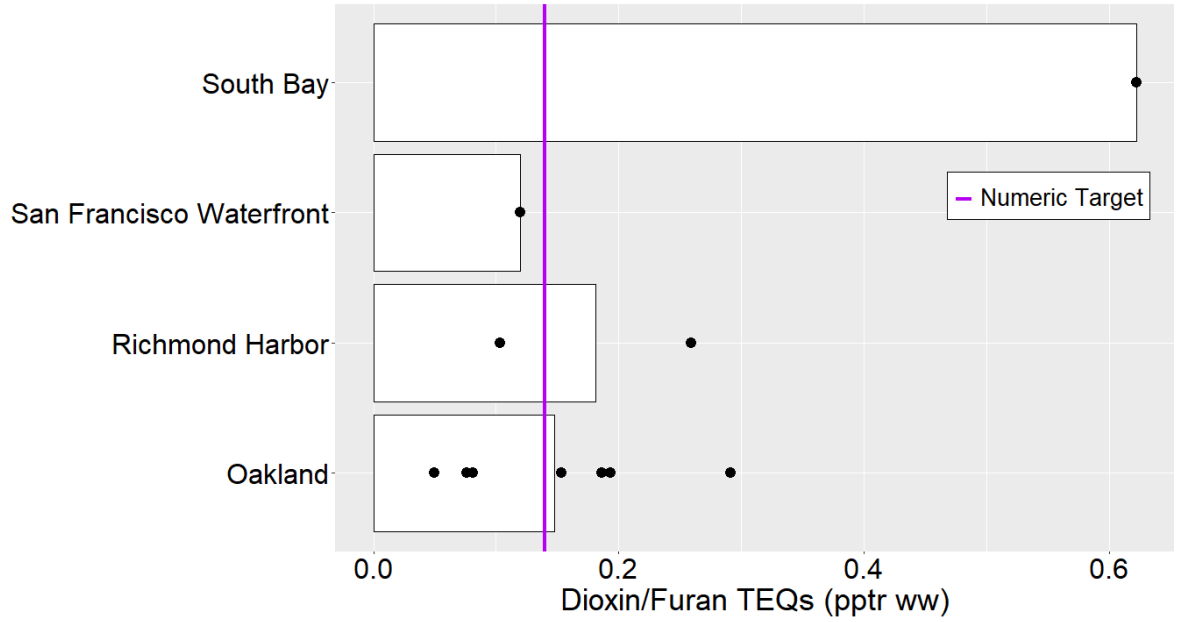

Figure S-1. $TEQs_{PCDD/PCDF}$ (pptr ww) in white croaker in San Francisco Bay, 2019.
Bars indicate average concentrations. Points represent composite samples with 5 fish in each composite. The Water Board screening level (0.14 pptr) is non-regulatory.

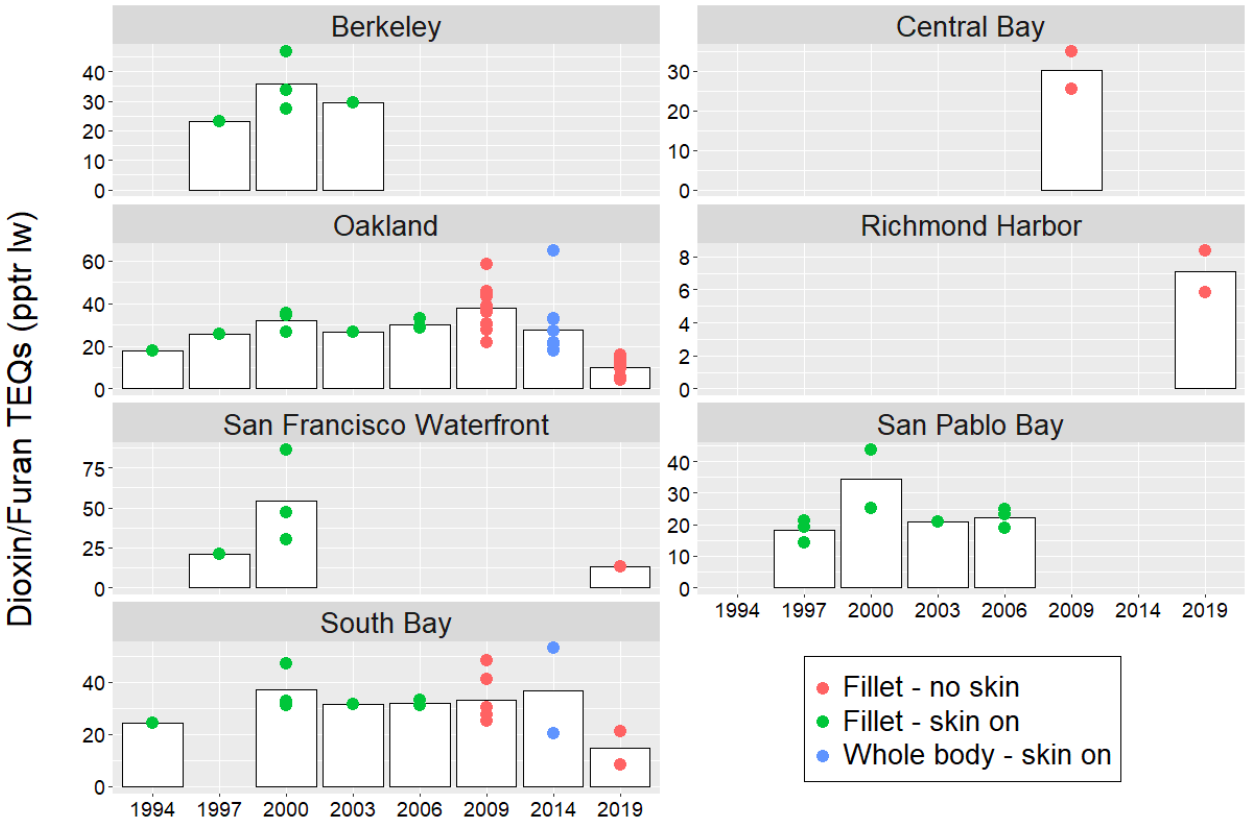

Figure S-2. $TEQs_{PCDD/PCDF}$ (pptr ww) in white croaker in each region of San Francisco Bay, 1994-2019. Bars indicate average concentrations. Points represent composite samples with 5 fish in each composite.