# State of the Estuary Report 2015

## Technical Appendix
## WATER: Combined Water Quality
### Safe for Swimming, Safe for Aquatic Life, Fish Safe to Eat

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## I. GENERAL CONSIDERATIONS

Clean water is essential to the health of the San Francisco Estuary ecosystem and to many of the beneficial uses of the Bay-Delta that residents in the region enjoy and depend on. Billions of dollars have been invested in management of wastewater and other pollutant sources and pathways that impact Estuary water quality, and as a result the Estuary is in much better condition than it was in the 1970s. However, thousands of chemicals are carried into the Estuary by society's waste streams, and significant and challenging water quality problems still remain.

The region is fortunate to have one of the best water quality monitoring programs in the world (the Regional Monitoring Program for Water Quality in San Francisco Bay) in place to track conditions in the Bay and to provide the information that water quality managers need to address the remaining problems. This report card on Estuary water quality is based largely on information generated by the Bay Regional Monitoring Program. Other valuable sources of information are also available and were also considered.

Another major monitoring effort - the Regional Monitoring Program for the Delta - is beginning to collect samples in 2015. The Delta RMP will be a major source of information for future assessments of water quality in the Estuary. At present, however, there is a comparatively limited amount of readily available, systematic water quality data for the Delta. Also, the scope of the effort to conduct the present water quality assessment was limited due to a lack of funding. While this assessment represents an expansion relative to the 2011 State of the Bay Report with the inclusion of the Delta, only a few readily accessible Delta datasets could be incorporated.

The availability of appropriate assessment thresholds (i.e., water quality objectives or fish tissue contamination guidelines) is fundamentally important to evaluating the condition of the Estuary. For many pollutants such guidelines are not available. Pollutants can be placed into three categories with regard to the availability of assessment thresholds.

The first group includes pollutants that historically have posed the greatest threats to water quality and that have been the subject of intense scrutiny by managers and intensive study by scientists. Guidelines have been established for these pollutants that are generally based on extensive information on their effects on target organisms and that are accepted by regulators and scientists. This report card pays greater attention to these pollutants because they can be clearly assessed relative to the established guidelines.

A second group consists of pollutants where guidelines exist but the degree of concern is low. Many pollutants with established assessment thresholds are present at concentrations that are far below the thresholds and do not threaten to approach those thresholds in the foreseeable future. Some of these pollutants used to be problems in the past, but now do not pose a threat because of effective management. While it is important to recognize this category of pollutants and to continue monitoring them to make sure they stay below thresholds, this report card focuses on the pollutants that are the current focus of managers and where progress is most needed.

A third, and very large, group consists of pollutants where assessment thresholds are not available. Some of these pollutants are suspected to potentially be causing impairment in the Estuary, but regulators have not yet established thresholds either due to a lack of scientific information or resources to address the long list of pollutants of potential concern. While quantitative assessment of these pollutants is not possible, they are still addressed in a qualitative manner.

## II. EVALUATION SCHEME

This water quality element of the State of the Estuary Report addresses the three main beneficial uses of the Estuary that are affected by water pollution and protected by the Clean Water Act, addressing three key questions that are posed in a manner intended to be easilyunderstood by the public:

1. Is the Estuary safe for aquatic life?
2. Are fish from the Estuary safe to eat?
3. Is the Estuary safe for swimming?

Suites of indicators were identified to answer each of these questions. The basic approach to answering each of these questions is described below.

A fourth key question applies to the Delta: "Is Estuary water safe to drink?" Addressing this question in a quantitative manner was beyond the scope of this effort. A short summary of the issue is provided as a sidebar in the water quality chapter of the main report.

### *A. QUESTION 1: IS THE ESTUARY SAFE FOR AQUATIC LIFE?*

"Aquatic life" as used here refers to all of the animal and plant species that live in or depend upon the Estuary, including algae, zooplankton, macroinvertebrates, fish, aquatic birds, and marine mammals. A varied group of indicators is most appropriate for addressing question 1, including a target from the Bay Mercury TMDL and Delta Methylmercury TMDL for methylmercury concentrations in small fish, qualitative narrative objectives that apply to the occurrence of toxicity in Estuary water, and numeric water quality objectives that are based on measurement of concentrations in water.

For each parameter, average values for each sampling year are compared to the targets. The degree of risk for pollutants in this category are based on assessments in published studies and other considerations discussed below for each pollutant.

Although water quality objectives to protect aquatic life exist for many pollutants in the Delta, a lack of systematic monitoring limited the scope of the assessment for that part of the Estuary.

### *B. QUESTION 2: ARE FISH FROM THE ESTUARY SAFE TO EAT?*

This question refers to human consumption of fish from the Estuary. The appropriate indicators for this question are concentrations of pollutants of concern in the tissue of fish species that are popular for consumption by anglers. The Bay Regional Monitoring Program has conducted systematic and regular monitoring of Bay sport fish since 1994, providing a solid foundation for assessing this question (Davis et al. 2011). The California Surface Water Ambient Monitoring Program conducted fairly thorough monitoring of Delta sport fish in 2011 (Davis et al. 2013).

Thresholds for evaluating fish tissue concentrations have been developed by the California Office of Environmental Health Hazard Assessment (OEHHA) (Klasing and Brodberg 2008). OEHHA is the agency responsible for establishing safe eating guidelines for wild fish caught from California water bodies, including the Estuary. OEHHA issued consumption guidelines for the Bay in response to the first sport fish survey in 1994 (OEHHA 1994). OEHHA completed an update of these guidelines in 2011 (Gassel et al. 2011). OEHHA has also issued consumption guidelines for the Delta region in recent years (Gassel et al. 2007, 2008). OEHHA has developed thresholds called advisory tissue levels (ATLs) that are a component of their complex process of data evaluation and interpretation in the development of consumption advice. Other factors are also considered in this process, such as omega-3 fatty acid concentrations in a given species in a water body, and risk communication needs. 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. Given their role in development of safe eating guidelines, ATLs are used in this report for assessing fish tissue data with respect to question 2. Consistent with the description of ATLs above, however, it is important to note that the comparisons to ATLs presented in this report are general indications of potential levels of risk, and are not intended to represent consumption advice. The updated consumption guidelines for the Bay and the published consumption guidelines for the Delta represent the definitive statements for the public on the safety of consuming Estuary fish. The intent of using ATLs in the State of the Estuary Report is to convey a message to the public that is consistent with and supports the consumption advice.

OEHHA has not developed thresholds for interpreting dioxin concentrations. In the absence of OEHHA thresholds, a screening value developed by the San Francisco Bay Regional Water Quality Control Board as part of the PCB TMDL (SFBRWQCB 2008b) was used.

For evaluating question 2, time series plots are presented that show the average concentration for selected indicator species for each year sampled. Data are presented for the Delta, for the Bay as a whole, and for the three segments of the Bay that have consistently been sampled over the years: San Pablo Bay, Central Bay, and South Bay. ATLs are used as a frame of reference to indicate the general degree of risk posed by each pollutant. OEHHA has established ATLs for different levels of consumption. The ATLs used include the concentrations above which no consumption may be indicated ("no consumption ATLs") and concentrations below which consumption of up to three eight ounce (prior to cooking) servings per week may be indicated.

### *C. QUESTION 3: IS THE ESTUARY SAFE FOR SWIMMING?*

For question 3, the best available indicator is concentrations of bacteria in water near popular bathing beaches.

To protect beach users from exposure to fecal contamination, California has adopted standards developed for high use beaches and applies them during the prime beach season from April through October at beaches with more than 50,000 annual visitors that are adjacent to a storm drain that flows in the summer; these requirements are only mandatory in years that the legislature has appropriated monies sufficient to fund the monitoring. County Public Health and other agencies routinely monitor fecal indicator bacteria (FIB) concentrations at Bay beaches where water contact recreation is common and provide warnings to the public when concentrations exceed the standards (Table 1). FIB are enteric bacteria common to the digestive systems of mammals and birds, and are indicators of fecal contamination. While not generally pathogenic themselves, FIB are used because they correlate well with the incidence of human illness in epidemiology studies at recreational beaches and can be enumerated more quickly and cost-effectively than can pathogens directly.

Heal the Bay, a Santa Monica-based non-profit, provides comprehensive evaluations of over 400 California bathing beaches in both Annual and Summer Beach Report Cards as a guide to aid beach users' decisions concerning water contact recreation. Higher grades are considered to represent less health risk to swimmers than are lower grades. The Heal the Bay grades for Bay beaches were used as the primary indicator of whether the Bay is safe for swimming.

FIB monitoring data for Delta beaches are not available through Heal the Bay.

Toxins produced by blooms of harmful algae such as *Microcystis* are another threat to the health of people enjoying contact recreation in the Estuary. Although studies measuring algal toxins in the Estuary have been conducted, and thresholds developed by the state are available for assessment (OEHHA 2012), routine and systematic monitoring of algal toxins in the Estuary is not being conducted. A synthesis of the studies that have been performed was beyond the scope of the present report.

## III. IS THE ESTUARY SAFE FOR AQUATIC LIFE?

### *A. POLLUTANTS WITH APPROPRIATE THRESHOLDS*

#### 1. Methylmercury in Prey Fish

In addition to posing risks to humans who eat Estuary fish, methylmercury poses significant risks to Estuary wildlife. Extensive studies in Forster's Terns concluded that 48% of birds in the breeding season in this species in the Bay were at high risk of reproductive impairment due to methylmercury exposure (Eagles-Smith et al. 2009, Ackerman et al. 2014). They also estimated substantial, but lower risk, to Caspian Terns, Black-necked Stilts, and American Avocets. Methylmercury is also considered to pose significant risks to two endangered bird species in the Bay. The federally endangered Ridgway's Rail has poor reproductive success that may be related to methylmercury. An estimated 15–30% of the observed reduction below normal hatchability in this subspecies has been attributed to contaminants, with methylmercury principal among them (Schwarzbach et al. 2006). In the evaluation of risks to wildlife for the Bay Mercury TMDL, the greatest concern was for the federally endangered California Least Tern, based on an assessment by the U.S. Fish and Wildlife Service, and a prey fish tissue target to protect aquatic life was developed based on protection of this species (SFBRWQCB 2006). The Delta Methylmercury TMDL also employs this same target based on Least Tern exposure and risk. Other species where possible effects have been less thoroughly examined but the degree of exposure suggests potential risks to reproduction include the Black Rail and Tidal Marsh Song Sparrow (Grenier and Davis 2010).

Gathering information on where and when methylmercury enters the food web was a priority in the Bay RMP in recent years. In addition to their value as an indicator of wildlife exposure, small fish have been sampled extensively because they are a valuable indicator for obtaining this information. The young age and restricted ranges of small fish allow the timing and location of their mercury exposure to be pinpointed with a relatively high degree of precision.

Based on the TMDLs, methylmercury in prey fish tissue is the key regulatory target for protection of aquatic life (the piscivorous California Least Tern). The primary fish species upon which the opportunistic California Least Tern prey are whole fish in the size range of 3-5 cm, so the target is based on this class of fish. The target to protect reproduction in the Least Tern as well as other aquatic life is 0.03 ppm as an average concentration. These parameters were used to define and assess the indicator for methylmercury impact on aquatic life.

**Data Source** The methylmercury in prey fish indicator was calculated using data from the Bay RMP. The extensive prey fish sampling that was conducted in recent years was summarized by Greenfield et al. (2013a,b). Systematic prey fish sampling has not recently been conducted in the Delta. Although extensive sampling was performed in 2000 and 2001 by U.C. Davis, these data were not used in this assessment because they were collected more than 10 years ago.

The RMP began monitoring methylmercury in prey fish in 2005 as part of a three-year pilot study. This study sampled 10 or fewer sites per year. In 2008, the RMP began more extensive small fish monitoring in a concerted effort to determine patterns in food web uptake. This second three-year effort sampled approximately 50 sites per year. Sampling continued at four sites in 2011 to allow assessment of seasonal variation. The sampling focused on two species: Mississippi silverside and topsmelt. Samples were collected in all of the regional embayments.

**Methods and Calculations** The aquatic life methylmercury indicator (Figure 1) was calculated using available data from the Bay RMP for Mississippi silverside and topsmelt in the 3-5 cm size range. The time series plot shows the distribution of the data for each year sampled. The distribution is described with percentiles ($25^{th}$, $50^{th}$, and $75^{th}$).

**Goals, Targets, and Reference Conditions** The target established by the TMDL to protect reproduction in the Least Tern as well as other aquatic life is 0.03 ppm as an average concentration in prey fish in the 3-5 cm size range.

**Results**

In the most recent intensive sampling year (2010), methylmercury concentrations in prey fish exceeded the 0.03 ppm target in approximately 95% of the samples collected. Similar results were obtained in 2008 and 2009, the other years with a larger sample size. Results from the pilot study in 2005-2007 were lower, but the distributions for those years are based on a very small sample size. The Baywide median concentration in 2010 was 0.050 ppm.

Evaluation of spatial and temporal trends focused on data from 2008-2010, which are based on larger sample sizes. Median concentrations in each region in 2010 ranged from a high of 0.099 in South Bay and Lower South Bay to a low of 0.033 ppm in Suisun Bay.

As discussed below in the Methylmercury in Sport Fish section, methylmercury concentrations in the Estuary food web have not changed perceptibly over the past 45 years, and it is not anticipated that they will decline significantly in the next 30 years. Extensive studies on risks to Bay birds have concluded that substantial portions of some populations are facing very high risk of reproductive impairment. However, the species facing the greatest risks, the Forster's Tern, forages primarily in salt ponds. These relatively highly managed habitats may offer opportunities for intervention in the methylmercury biogeochemical cycle to reduce exposure of wildlife. It is therefore plausible that ways of reducing Forster's Tern exposure and risk may be identified and implemented within the next 30 years. While exposure of wildlife to methylmercury may be a somewhat tractable problem, it will be difficult to reduce exposure in other habitats (open Bay and tidal marsh) in the next 30 years (Davis et al. 2012).

Methylmercury concentrations in prey fish in the Estuary are clearly elevated above the regulatory goal and represent a significant problem. There is no benchmark, however, that can be readily used to judge whether the state of the Estuary with regard to this indicator should be classified as "fair" or "poor", although "poor" would merit consideration.

## 2. Water Toxicity

Toxicity in water samples is a concern in the Delta. These toxicity tests suggest that pollutant concentrations in Delta waters are occasionally high enough to affect the abundance of aquatic invertebrates or fish. Pesticides (see sidebar in the main report) are often the cause of this toxicity.

Toxicity in Bay water samples was a concern in the 1990s, also driven by pesticide concentrations, but has not been observed within the past 10 years.

A narrative water quality objective in the Bay Basin Plan applies to water toxicity. The Basin Plan states: "All waters shall be maintained free of toxic substances in concentrations that are lethal to or that produce other detrimental responses in aquatic organisms. Detrimental responses include, but are not limited to, decreased growth rate and decreased reproductive success of resident or indicator species. There shall be no acute toxicity in ambient waters. Acute toxicity is defined as a median of less than 90 percent survival, or less than 70 percent survival, 10 percent of the time, of test organisms in a 96-hour static or continuous flow test. There shall be no chronic toxicity in ambient waters. Chronic toxicity is a detrimental biological effect on growth rate, reproduction, fertilization success, larval development, population abundance, community composition, or any other relevant measure of the health of an organism, population, or community."

The Basin Plan for the Sacramento River and San Joaquin River Basins has a similar narrative objective for toxicity: "All waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life. This objective applies regardless of whether the toxicity is caused by a single substance or the interactive effect of multiple substances. Compliance with this objective will be determined by analyses of indicator organisms, species diversity, population density, growth anomalies, and biotoxicity tests of appropriate duration or other methods as specified by the Regional Water Board."

The implicit quantitative goal associated with these objectives is a 0% incidence of toxicity in Estuary samples.

**Data Source** For the Bay, the water toxicity indicator is based on data from the RMP, available on the RMP website (www.sfei.org/rmp/data). The RMP measured water toxicity intermittently over the past 15 years, with sampling occurring in 2002, 2007, and 2011. In the most recent sampling, water toxicity was measured at 22 stations distributed throughout the Bay. Most of the samples are collected at randomly selected locations, with a few fixed stations included to continue long-term time series. The test species was the mysid shrimp *Americamysis bahia*.

Water toxicity data for the Delta were retrieved from CEDEN. The compiled data consisted of a collection of datasets from various programs, including one-time studies (e.g., the Central Valley Water Board's Delta Island Monitoring Project and the Central Valley Water Board's SWAMP Delta Pyrethroid Study) and annual monitoring performed under the Central Valley Water Boards Irrigated Lands Regulatory Program. Test species have included invertebrates (*Ceriodaphnia dubia, Eurytemora affinis, Hyalella azteca*, and *Americamysis bahia*) and fathead minnows (*Pimephales promelas*). The number of samples for each year varied considerably, with a low of five in 2004 and a high of 118 in 2008.

**Methods and Calculations** The water toxicity indicator (Figure 2) is simply the percentage of the samples tested in each year that were determined to be toxic to at least one test species. Samples are considered to be toxic if they meet two criteria: 1) statistically significant difference from controls, and 2) a difference from controls that is of sufficient magnitude in absolute terms.

**Goals, Targets, and Reference Conditions** As discussed above, the implicit goal associated with the narrative objectives pertaining to water toxicity is 0% incidence of toxicity in Estuary samples.

**Results**

No water toxicity has been observed in the Bay in recent sampling. The narrative objective for water toxicity has therefore been met consistently over the past 10 years.

In the Delta, the incidence of water toxicity has been greater than zero, but still infrequent, ranging from 0% of samples in 2004 (though only five samples were analyzed) to 12% in 2006 (based on 64 samples that year). The severity of the toxicity has also been low, with only 4% of samples having lower than 50% survival, and only 2% of samples with less than 10% survival.

Overall, the status of the Estuary with regard to water toxicity is fair: the goal is being met in the Bay but not quite being met in the Delta.

## 3. Copper in Water

**Background and Rationale** Copper pollution was a major concern in the Bay in the 1990s, as concentrations were frequently above the water quality objective. An evaluation of the issue by the Water Board and stakeholders led to new site-specific water quality objectives for copper in the Bay (less stringent but still considered fully protective of the aquatic environment), pollution prevention and monitoring activities, and the removal of copper from the 303(d) List in 2002. Along with the new objectives, a program has been established to guard against future increases in concentrations in the Bay. The program includes actions to control known sources in wastewater, urban runoff, and use of copper in shoreline lagoons and on boats. More aggressive actions to control sources can be triggered by increases in copper concentrations. A remaining concern regarding possible impacts of copper on olfaction in salmonids was investigated by the National Oceanographic and Atmospheric Administration's Northwest Fisheries Science Center with funding from the RMP, and concluded that olfactory toxicity is of low concern in Bay waters (Baldwin 2015).

Copper toxicity is a greater concern in the Delta. Copper is one of the most widely applied herbicides in the Central Valley. Copper is toxic to fish at lower concentrations in fresh water than in saline water. Some concentrations measured in the Delta have exceeded levels at which effects could occur (3-5 ug/L) (Stephen Louie, personal communication).

Concentrations of copper in water are the key impairment indicator for this pollutant.

**Data Source** The copper indicator was calculated using data from water sampling conducted by the Bay RMP. The data are available from the Bay RMP website (www.sfei.org/rmp/data).

Systematic data for copper are not available from the Delta, and a synthesis of the work that has been done was beyond the scope of this report.

**Methods and Calculations** The copper indicator was calculated for each year of Bay RMP monitoring from 1993 to 2012 (Figure 3). The time series plot shows the distribution of the data (dissolved concentrations in water) for each year sampled. The distribution is described with percentiles ($5^{th}$, $25^{th}$, $50^{th}$, $75^{th}$, and $95^{th}$).

**Goals, Targets and Reference Conditions** Two different site-specific copper objectives have been established for the Bay. For Lower San Francisco Bay south of the line representing the Hayward Shoals shown and South San Francisco Bay the objective is 6.9 ug/L. For the portion of the Delta located in the San Francisco Bay Region, Suisun Bay, Carquinez Strait, San Pablo Bay, Central San Francisco Bay, and the portion of Lower San Francisco Bay north of the line representing the Hayward Shoals, the objective is 6.0 ug/L. The objectives are for dissolved concentrations.

**Results** Copper concentrations in the Bay have been below the site-specific objectives for all samples measured from 1993 to 2012, except for four samples from South Bay in 2011. The South Bay is the only segment with concentrations approaching or exceeding the objectives. Concentrations in the South Bay over the last six years have been above the long-term average.

Overall, water quality with respect to copper in water is good, but warrants continued tracking, especially in the South Bay.

**5. Other Priority Pollutants**

In addition to the pollutants mentioned above, the Bay RMP monitors many other pollutants that are present at concentrations below water quality objectives and are considered to pose low risk to aquatic life. In the 1970s, USEPA established a list of 129 pollutants that were identified as priorities for regulation. Objectives and analytical methods for these "priority pollutants" were developed and they became widely monitored. California has its own set of water quality criteria for these pollutants that was promulgated in 2000 under the "California Toxics Rule." These criteria apply to all inland surface waters in California, including the Estuary.

The Bay RMP measures many of the priority pollutants, either routinely or through special studies. A large number of these priority pollutants are present in the Bay at concentrations that are well below water quality criteria. These pollutants all fall in the "goals attained" or "good" category. Some of these pollutants are listed below by class:

- metals - arsenic, cadmium, cobalt, chromium, iron, manganese, nickel, lead, zinc, alkyltins;
- pesticides - diazinon, chlorpyrifos, dachthal, lindanes, endosulfans, mirex, oxadiazon;
- industrial chemicals - phthalates, hexachlorobenzene;
- others – cyanide.

## *B. POLLUTANTS WITHOUT APPROPRIATE THRESHOLDS*

### 1. Invasive Species

Invasive species released from ship ballast water are considered a water pollutant under the Clean Water Act, and they are included on the 303(d) listings for the Bay and Delta due to their disruption of benthic communities, their disruption of food availability to native species, and their alteration of pollutant availability in the food web. San Francisco Bay is considered one of the most highly invaded estuaries in the world (Cohen and Carlton 1998), and the ecological impacts of invasive species have been immense. Introductions of hundreds of invasive species have irreversibly altered the Estuary ecosystem in fundamental ways. Nonnative species introduced to the Estuary have reduced or eliminated populations of many native species so that in some regions and habitats virtually 100% of the organisms are introduced. They have also interfered with water withdrawals, boating, fishing (though also providing sport and forage fish), water contact recreation, and probably have eroded marshes in some areas though also accreting marsh elsewhere. These species are introduced through multiple vectors including: commercial shipping (including vessel fouling and ballast water), the aquaculture industry, live bait releases, intentional sport fishing introductions, release of aquarium pets and live seafood specimens, transfer via recreational watercraft, and association with marine debris. Vessel fouling and ballast water are responsible for the majority of the aquatic species invasions in California (Ruiz et al., 2011).

Invasive species introductions do not fit neatly into the assessment framework used for this report. Successful invasions of nonnative species are essentially irreversible, so, to a significant degree, goals of restoring native species are not achievable. Attention is best focused on a goal that is achievable in the near term: reducing the rate of introductions. Commercial vessels are regulated for ballast water management and there are pending regulations for vessel fouling on commercial vessels. The anticipated switch to a ballast water discharge standard and the shift to ballast water treatment systems has been delayed due to the lack of available technologies, but the 98% compliance rate of California's current ballast water management program (which requires either retaining ballast water or conducting an open ocean exchange before discharging ballast water) is providing a significant risk reduction (Dobroski et al. 2015). Unfortunately, it will likely be several more years before technologies are available to meet a discharge standard, which would reduce risk even further. The pending vessel fouling regulations on commercial vessels (anticipated completion of the rulemaking is late 2015) will result in an additional reduction of risk. The other vectors could also be better managed by thoughtful regulation, or by a combination of regulations and public education and outreach.

Focusing on the significant goals mentioned above, progress over the next 5-10 years is likely in reducing invasive species introductions from ballast water and vessel fouling. With regard to the degree of risk, this is hard to quantify but no pollutants have had a higher degree of impact on the ecology of the Bay than invasive species, and if invasions are allowed to continue additional large impacts are likely. This places invasive species in a "high concern" category.

## 2. Trash

Trash is a continuing problem in the Estuary both as an aesthetic nuisance and as a threat to aquatic life. Data suggest that plastic from trash persists for hundreds of years in the environment and can pose a threat to wildlife through ingestion, entrapment and entanglement, and this plastic can leach potentially harmful chemicals to the aquatic environment and to organisms that ingest plastic particles. Trash is a concern at a macro scale, with the aesthetic, ingestion, and entanglement associated with visible trash items. Trash is also a concern at a micro scale, as larger trash items degrade to small fragments that are not visible but may have significant impacts on small aquatic life through ingestion and through exposure of small aquatic life to the chemical constituents that leach from the particles, as well as the organic pollutants from other sources that accumulate on the particles.

In recognition of the risks posed by trash, the Central Bay and South Bay shorelines were included on the 2010 303(d) List. Beneficial uses adversely impacted by trash are supported by narrative water quality objectives and prohibitions in the Basin Plan regarding solid waste, floating material, and settleable material. An established numeric goal for trash abundance in the Bay does not exist.

Trash has recently been receiving increased attention from Bay Area water quality managers. Extensive requirements relating to trash were included in the municipal regional permit for stormwater issued in 2010. The trash reduction requirements in the MRP are multifaceted and focus both on short-term actions to remove trash from known creek and shoreline hot spots and long-term actions to significantly reduce trash discharged from municipal storm drain systems. During the first permit term, municipalities were required to develop and implement a Short-Term Trash Load Reduction Plan to attain a 40% reduction of trash loads by 2014. Municipalities are then required to use their short-term experiences and lessons learned to develop and begin implementation of a Long-Term Trash Load Reduction Plan, to attain a 70% reduction in trash loads by 2017 and 100% by 2022. Attaining these goals should greatly reduce the input of trash into Bay waters and hopefully allow the abundance of trash and microplastics to dissipate.

The severity of the trash problem is difficult to quantify and not well-characterized but a plausible argument can be made that trash in the Estuary is a moderate concern in regard to impacts on aquatic life. Aggressive requirements in the municipal regional permit for stormwater in the Bay should significantly reduce inputs in the next 30 years, and hopefully this will rapidly reduce the amount of trash and microplastic particles in the Bay.

## 3. Nutrients

Nutrient concentrations in the Estuary are a major concern. Efforts are in progress to develop definitive numeric goals for the Estuary. This topic, which encompasses an array of indicators of nutrient impacts (dissolved oxygen depletion, harmful algae and algal toxins, chlorophyll abundance, and others), is summarized in a sidebar in the main report.

## 4. Other Suspected Threats

There are several other pollutants that are suspected to possibly pose moderate to high risks to Estuary aquatic life, but for which appropriate thresholds have not yet been developed. A few of the most prominent examples are briefly described below.

### Selenium

Average selenium concentrations in the Bay food web in recent years are below thresholds for adverse effects in fish and wildlife, but a few samples have exceeded the thresholds. Concern for risks to aquatic life is the primary impetus for the North Bay Selenium TMDL that is in development by the San Francisco Bay Regional Water Board. Thresholds to protect aquatic life in the Bay are in development that will be more appropriate than existing water quality criteria. A TMDL for selenium in the San Joaquin River was completed by the Central Valley Regional Water Board and approved by US EPA in March 2002. The project area for this TMDL includes the area where the San Joaquin River enters the Delta.

### Polycyclic Aromatic Hydrocarbons (PAHs)

Several locations are included on the 303(d) List due to PAH contamination. There is also concern that PAH concentrations in sediment across much of the Bay exceed thresholds for impacts on early life stages of fish and on benthic invertebrates. PAH concentrations over the past 20 years have held fairly constant. Increasing population and motor vehicle use in the Bay Area are cause for concern that PAH concentrations could increase over the next 20 years. On the other hand, PAH concentrations in Bay Area air have declined over the past ten years, and if PAH inputs to the Bay can be decreased concentrations are expected to drop quickly.

### Perfluorooctanesulfonate (PFOS)

PFOS is also considered a potential risk to Estuary wildlife (SFEI 2013). A regulatory goal has not yet been established for PFOS in aquatic life. RMP monitoring has found concentrations of PFOS in bird eggs that approach levels associated with adverse impacts seen in studies elsewhere.

### Pesticides

Pesticides are of particular concern in urban creeks that flow to the Estuary and sometimes the water bodies into which they flow, such as the Delta, where recent studies have implicated pyrethroids as the cause of toxicity to invertebrate test organisms (Weston et al. 2014). A sidebar summarizing issues relating to pesticides is included in the main report. Data from routine, systematic monitoring of pesticides is not currently available for the Delta. However, the Delta Regional Monitoring Program began monitoring for pesticides in 2015. A detailed summary of the miscellaneous studies that have been done in the Delta was beyond the scope of this project.

### 5. Contaminants of Emerging Concern

In addition to the specific pollutants that pose threats to aquatic life, there are thousands of other chemicals used by society, including pesticides, industrial chemicals, pharmaceuticals, and chemicals in consumer products, and many of these make their way from our homes, businesses, and watersheds into the Estuary. Due to inadequate screening and regulation of these chemicals, some may cause toxicity in Estuary biota, either through direct exposure to contaminated water or sediment or through accumulation in the Estuary food web and dietary exposure in species at higher trophic positions. As understanding advances, some of these contaminants emerge as posing risks to the health of wildlife and humans. The Bay RMP published a summary of the extensive information available on Bay CECs in the 2013 Pulse of the Bay (SFEI 2013). Several studies have also been conducted in the Delta. A review article on this topic was included in the 2011 Pulse of the Delta (Aquatic Science Center 2011).

The Bay RMP actively monitors contaminants of emerging concern that pose the greatest known threats to water quality. However, these monitoring efforts to protect Bay water quality are severely hampered by the lack of information on the chemicals present in commercial products, their movement in the environment, and their toxicity. Ultimately, the reduction of use of toxic chemicals in products is the ideal way to prevent further additions to the list of legacy contaminants that is passed on to future generations of humans and wildlife that depend upon the Estuary.

## IV. ARE ESTUARY FISH SAFE TO EAT?

### *A. INTRODUCTION*

For the Bay, no new sport fish data are available since the publication of the State of the Bay Report in 2011. Additional samples were collected in 2014, but the data were not available at the time this report was written. The text below regarding pollutants in Bay fish has therefore not changed from the 2011 version.

Sport fish pollutant data from 2011 are available from the Delta as a result of monitoring by the State Water Resources Control Board's Surface Water Ambient Monitoring Program (SWAMP - Davis et al. 2013).

*B. POLLUTANTS WITH APPROPRIATE THRESHOLDS*

## 1. Methylmercury in Sport Fish

### Background and Rationale

Methylmercury is one of the Estuary's most serious water quality concerns. Methylmercury is a primary driver of the fish consumption advisory for the Bay (Gassel et al. 2012), and also is suspected to be adversely affecting wildlife populations, including the endangered California Clapper Rail and California Least Tern, as well as the Forster's Tern (Schwarzbach et al. 2006, Eagles-Smith et al. 2009). Due to these concerns, the first TMDL for the Bay was developed for mercury (SFBRWQCB 2006).

Methylmercury typically represents only about 1% of total mercury, but is the specific form that accumulates in aquatic life and poses health risks to humans and wildlife. Methylmercury is a neurotoxicant, and is particularly hazardous for fetuses and children and early life-stages of wildlife species as their nervous systems develop. The sources of methylmercury in the Bay, particularly the methylmercury that actually accumulates in the food web, are not well understood. Methylmercury concentrations in the Estuary (as indicated by accumulation in striped bass) have been relatively constant since the early 1970s (Davis et al. 2012), but could quite plausibly increase, remain constant, or decrease in the next 30 years. Wetlands are often sites of methylmercury production, and restoration of wetlands in the Estuary on a grand scale is now beginning, raising concern that methylmercury concentrations could increase across major portions of the Estuary. However, methylmercury cycling is not yet well understood, and recent findings suggest that some wetlands actually trap methylmercury and remove it from circulation.

Concentrations of methylmercury in sport fish tissue represent a key regulatory target for this pollutant. The mercury TMDL for the Bay established a water quality objective for mercury based on concentrations in the five most commonly consumed fish species in the Bay (striped bass, California halibut, jacksmelt, white sturgeon, and white croaker). Concentrations in these five species therefore provide a reasonable basis for a methylmercury indicator for the Bay.

The methylmercury TMDL for the Delta (Wood et al. 2010) established a water quality objective for methylmercury in muscle fillet of trophic level 4 (piscivorous) fish species.

The concentrations in sport fish were compared to OEHHA thresholds.

**Data Source** For the Bay, the methylmercury in sport fish indicator was calculated using data from the Regional Monitoring Program for Water Quality in the San Francisco Estuary (RMP) (www.sfei.org/rmp). The data are available from the RMP website (www.sfei.org/rmp/data). The RMP measures contaminant concentrations in Bay sport fish every five years. Monitoring began with a pilot study in 1994 (Fairey et al. 1997), and has continued to the present (Davis et al. 2002, Greenfield et al. 2005, Davis et al. 2006, Hunt et al. 2008, Davis et al. 2011).

The Bay RMP collects sport fish from five popular fishing locations in the Bay (Figure 4). The monitoring is specifically directed at assessing trends in potential human exposure to contaminants in fish tissue. Sampling in Suisun Bay was attempted in the early years of the program, but was discontinued due to the low catch per unit sampling effort in that region, and the correspondingly low fishing pressure. The species targeted and the pollutant analyte list have varied slightly over the years. The five most commonly consumed species that are designated by the mercury water quality objective for the Bay (striped bass, California halibut, jacksmelt, white sturgeon, and white croaker) have been inconsistently sampled (Figure 5). In the most recent sampling in 2009, methylmercury was analyzed in striped bass, California halibut, and jacksmelt, but not white sturgeon or white croaker.

For the Delta, sport fish pollutant data are available as a result of monitoring by SWAMP in 2011 (Davis et al. 2013). These data are available via CEDEN (http://www.ceden.org/) and also from the My Water Quality Portal (http://www.mywaterquality.ca.gov/). This sampling included six locations and six species (largemouth bass, smallmouth bass, striped bass, Sacramento sucker, common carp, and white catfish - only two species from this list were collected at each location). The data presented in this report are for largemouth and smallmouth bass (or “black bass”), adjusted to a standard size of 350 mm.

**Methods and Calculations** For Bay fish, the sport fish methylmercury indicator (Figure 5) was calculated using whatever data for these species that were available for each sampling year. The RMP sampling targets specific size ranges of each species (Hunt et al. 2008) to control for variation of concentrations of methylmercury and other pollutants with fish size. Methylmercury concentrations in striped bass have been analyzed over the years in individual fish, making it possible to normalize the concentrations to fish length. Statistics for striped bass are therefore based on results normalized to a standard size of 60 cm, using methods described in Greenfield et al. (2005). The time series plots show the average concentration for each species for each year sampled. Data are presented for the Bay as a whole and for the three segments of the Bay that have consistently been sampled over the years: San Pablo Bay, Central Bay, and South Bay.

For the Delta, black bass were available at five of the six locations. The average of the five length-adjusted means was 0.43 ppm.

**Goals, Targets and Reference Conditions** OEHHA has developed separate ATLs for methylmercury that apply to the most sensitive population (women of child-bearing age - 18-45 years - and children aged 1-17 years) and that apply to women over 45 years and men (Klasing and Brodberg 2008). The values for the most sensitive population are used in this report. The no consumption ATL for methylmercury is 0.44 ppm. The level below which OEHHA considers recommending consumption of up to three eight ounce servings per week is 0.07 ppm.

**Results**

For the Bay, in data from the most recent sampling year currently available, the three species sampled (striped bass, California halibut, and jacksmelt) all had average concentrations between 0.07 and 0.44 ppm. Concentrations of the five indicator species have fluctuated over the years, but no trend over the 15-year period of record is evident for any species. Spatial and temporal trends within San Pablo Bay, Central Bay, and South Bay have been similar to those observed at the whole Bay scale. Striped bass are a particularly important indicator species for methylmercury because they are the most popular fish species consumed from the Bay and a time series for methylmercury in Bay-Delta striped bass dates back to 1970. Comparisons of recent striped bass data to data from 1970 also indicate no decline (Davis et al. 2011). Preliminary modeling included in the Mercury TMDL suggested that recovery would take more than 100 years. Our current conceptual understanding of methylmercury sources and cycling in the Bay also indicates that reducing concentrations of methylmercury in the Bay food web poses a considerable challenge that is likely to take many decades.

Overall, all of the methylmercury indicator species had average concentrations between the no consumption ATL of 0.44 ppm and the two serving per week ATL of 0.07 ppm, although concentrations in striped bass were right at the 0.44 ppm threshold. OEHHA advises that women between 18 and 45 years of age and children (1-17 years of age) do not eat several species of Estuary fish (including the popular striped bass), largely because of methylmercury contamination. The existence of a "no consumption" recommendation for popular species (rather than limited consumption) seems an appropriate trigger for classifying the state of the Estuary as poor with respect to methylmercury concentrations in sport fish.

Methylmercury concentrations in the Estuary food web have not changed perceptibly over the past 40 years. For the Bay, it is not anticipated that they will decline significantly in the next 30 years. For the Delta, declines are possible if methylmercury inputs can be reduced.

## 2. PCBs in Sport Fish

### Background and Rationale

The term "polychlorinated biphenyl" refers to a group of hundreds of individual chemicals ("congeners"). Due to their resistance to electrical, thermal, and chemical processes, PCBs were used in a wide variety of applications (e.g., in electrical transformers and capacitors, vacuum pumps, hydraulic fluids, lubricants, inks, and as a plasticizer) from the time of their initial commercial production in 1929 (Brinkmann and de Kok, 1980). In the U.S. PCBs were sold as mixtures of congeners known as "Aroclors" with varying degrees of chlorine content. By the 1970s a growing appreciation of the toxicity of PCBs led to restrictions on their production and use. In 1979, a final PCB ban was implemented by USEPA, prohibiting the manufacture, processing, commercial distribution, and use of PCBs except in totally enclosed applications (Rice and O'Keefe, 1995). A significant amount of the world inventory of PCBs is still in place in industrial equipment (Rice and O'Keefe, 1995). Leakage from or improper handling of such equipment has led to PCB contamination of runoff from industrial areas. Other sources of PCBs to the Estuary are atmospheric deposition, effluents, and remobilization from sediment (Davis et al. 2007).

Like methylmercury, PCBs are highly persistent, bound to sediment particles, and widely distributed throughout the Bay and its watershed. PCBs reach high concentrations in humans and wildlife at the top of the food chain where they can cause developmental abnormalities and growth suppression, endocrine disruption, impairment of immune system function, and cancer. PCBs are another significant driver of the fish consumption advisory for the Bay (OEHHA 1994, Hunt et al. 2008). PCB concentrations in sport fish are above thresholds of concern for human health. There is also concern for the effects of PCBs on wildlife, including species like harbor seals (Thompson et al. 2007) and piscivorous birds (Adelsbach and Maurer 2007) at the top of the Bay food web and sensitive organisms such as young fish. General recovery of the Bay from PCB contamination is likely to take many decades because the rate of decline is slow and concentrations are so far above the threshold for concern. Due to concerns about PCB impacts, a PCBs TMDL for the Bay has been developed and incorporated into the Basin Plan (SFBRWQCB 2008a,b).

Concentrations of PCBs in sport fish tissue are the key regulatory target for this pollutant. The PCBs TMDL for the Bay (SFBRWQCB 2008a,b), approved by USEPA in 2010, established a fish tissue target for PCBs in the Bay for protection of both human health (and the fishing beneficial use) and wildlife (the preservation of rare and endangered species, estuarine habitat and wildlife habitat beneficial uses). The target applies to two commonly consumed fish species in the Bay that accumulate relatively high concentrations of PCBs: white croaker and shiner surfperch. Average concentrations for these two species therefore provide a reasonable basis for a PCB indicator for the Bay. Average concentrations were compared to OEHHA thresholds, as described previously.

The Delta is also on the 303(d) list because of PCB contamination, but a TMDL has not been developed.

**Data Source** The PCB indicator was calculated using data from the same RMP and SWAMP sport fish monitoring programs described for the methylmercury in sport fish indicator. The data are available from the RMP website (www.sfei.org/rmp/data), CEDEN (http://www.ceden.org/) and also from the My Water Quality Portal (http://www.mywaterquality.ca.gov/). Additional details on this sampling were provided in the methylmercury section. The two key Bay indicator species for PCBs have been sampled consistently over the years (Figure 6). For the Delta, the two best organics indicator species were Sacramento sucker (sampled at three locations) and common carp (sampled at two locations).

**Methods and Calculations** The sport fish PCBs indicator (Figure 6) is based on whatever data for shiner surfperch and white croaker were available for each sampling year. In the PCBs TMDL, comparison of these two species of fish to thresholds is considered to be protective and provide a margin of safety, because PCBs concentrations in these species are the highest of the fish species measured and sport recreational fishers likely consume a variety of fish species, including those with lower PCBs concentrations. The time series plots show the average concentration for each species for each year sampled. Data are presented for the Bay as a whole and for the three segments of the Bay that have consistently been sampled over the years: San Pablo Bay, Central Bay, and South Bay. PCB concentrations expressed as the sum of all reported congeners were used in the evaluation. Values for congeners reported as below the limit of detection were set to zero.

For the Delta, Sacramento sucker were available at three of the six locations, and had an average concentration of 15 ppb. Common carp were available from two locations, with an average concentration of 5 ppb.

**Goals, Targets and Reference Conditions** The no consumption ATL for PCBs is 120 ppb. The level below which OEHHA considers recommending consumption of up to three eight-ounce servings per week is 21 ppb.

**Results**

In the most recent sampling year for the Bay, both of the PCB indicator species had average concentrations between 21 ppb and 120 ppb (Figure 6). The Bay-wide average for shiner surfperch in 2009 (118 ppb) was just below the 120 ppb threshold. The average for white croaker (51 ppb) was closer to the two serving ATL of 21 ppb.

No clear pattern of long-term decline in PCB concentrations has been evident in these species. Concentrations in white croaker in 2009 were the lowest observed since monitoring began in 1994. This does not, however, signal a decline in PCB contamination in the Bay. The principal reason for the lower average in 2009 was that the RMP switched from analyzing white croaker fillets with skin to analyzing white croaker fillets without skin. This change was made to achieve consistency with OEHHA advice on fish preparation and with how white croaker are processed in other programs in California, and to reduce variability associated with the difficulty of homogenizing skin. Another reason for the low average concentration in white croaker in 2009 was the unusually low average fat content of the croaker collected in 2009. PCBs and other organic contaminants accumulate in fat, so concentrations rise and fall with changing fat content. Concentrations in shiner surfperch in 2009 were also lower than in most other years, but the time series does not suggest a trend. The time series for shiner surfperch in San Pablo Bay, however, does suggest a decline from an average of 103 ppb in 1994 to 38 ppb in 2009. A regression of these data was significant ($R^2$=0.84). Continued sampling will help establish whether this represents an actual decline and not simply interannual variation.

Significant regional variation in PCBs in shiner surfperch was observed in 2009, and consistently over the 1994-2009 period. Average concentrations in 2009 in Central Bay (147 ppb) and South Bay (107 ppb) were higher than the average in San Pablo Bay (38 ppb). Similar differences were also observed in earlier rounds of sampling. White croaker did not show variation among regions.

One of the key PCB indicator species, shiner surfperch, had an average concentration in 2009 just below the no consumption ATL. Based on the data for shiner surfperch, the new safe eating guidelines for the Bay recommend no consumption of any surfperch species by anyone eating Bay fish. The existence of a "no consumption" recommendation for this popular group of species (rather than limited consumption) was considered an appropriate trigger for classifying the state of the Estuary as "poor" with respect to PCB concentrations in sport fish.

The Baywide average PCB concentration in shiner surfperch did not decline over the period 1994-2009. The Baywide average concentration in white croaker was lower in 2009, but this was a function of low lipid and a shift to analyzing samples without skin. The model used in the PCB TMDL to forecast recovery (Davis et al. 2007) indicates that declines sufficient to bring fish concentrations down below 21 ppb are likely to take more than 30 years.

For the Delta, though the data are limited, both of the indicator species had concentrations below 21 ppb, which put them in the "good" category.

### 3. Dioxins in Sport Fish

**Background and Rationale**

Recent sport fish monitoring indicates that dioxins are a concern in the Bay. Dioxins have not recently been measured in Delta sport fish.

Dioxins have many similarities to PCBs. They are highly persistent, strongly associated with sediment particles, and widely distributed throughout the Bay and its watershed. Dioxins also reach high concentrations in humans and wildlife at the top of the food chain. The human and wildlife health risks of dioxins are similar to those for PCBs. Dioxins have not received as much attention from water quality managers because there are no large individual sources in the Bay Area and concentrations in the Bay are among the lowest measured across the U.S. Nevertheless, concentrations in sport fish are well above the threshold for concern and the entire Bay is included on the 303(d) List. Dioxins are similar to PCBs in their persistence and distribution throughout the Bay and its watershed, and are unlikely to decline significantly in the next 20 years.

Concentrations of dioxins in sport fish tissue are the key regulatory indicator for this pollutant. Connor et al. (2004) discussed screening values and impairment relative to those values. The San Francisco Bay Regional Water Quality Control Board (Water Board) has not established a target for dioxins. In the absence of a Water Board target, a screening value for use in this report was calculated using the same parameters for consumption rate and risk that were employed in the PCBs TMDL. White croaker is the species that has been monitored for dioxins in Bay fish – the dioxins index is therefore based on data for this species.

**Data Source** The dioxins indicator was calculated using data from the same RMP sport fish monitoring program described for the methylmercury in sport fish index. The data are available from the RMP website (www.sfei.org/rmp/data). Additional details on this sampling were provided in the methylmercury section. White croaker have been sampled consistently over the years (Figure 7). Shiner surfperch have also been sampled intermittently.

**Methods and Calculations** The dioxins in sport fish index was calculated for each year of RMP monitoring. The time series plot shows the average concentration for each year sampled. Dioxins concentrations expressed as the sum of the dioxin toxic equivalents (TEQs) were calculated for comparison to the screening value, following USEPA guidance (USEPA 2000). TEQs express the potency of a mixture of dioxin-like compounds relative to the potency of 2,3,7,8-TCDD, the most toxic dioxin congener. The sum of TEQs for all of the congeners is the overall measure of the dioxin-like potency of a sample. Values for congeners reported as below the limit of detection were set to zero.

**Goals, Targets, and Reference Conditions** The calculated screening value to protect human health is a concentration of 0.14 pg/g wet weight in the tissue of white croaker. The same size class specified in the PCBs TMDL for white croaker (20 to 30 cm in length) was used. Comparison of white croaker and shiner surfperch data to the screening value is a conservative approach because these species are likely to have the highest concentrations among the species that are popular for consumption, and anglers likely consume a variety of fish species, including species with lower concentrations.

This screening value represents the maximum level that is considered to be safe for people consuming Bay fish at a rate less than the $95^{th}$ percentile rate (32 g/day, or 8 ounces per week) for all Bay fish consumers (Connor et al. 2004).

**Results**

Nearly all of the white croaker and shiner surfperch samples analyzed since 1994 have been higher than the dioxin TEQ screening value of 0.14 parts per trillion (Figure 7). Median dioxin TEQ concentrations in white croaker have been over ten times higher than the target. Without ATLs for dioxins from OEHHA, however, there is an insufficient basis for determining that dioxins should be categorized as a high concern (i.e., having concentrations above a “no consumption” ATL). Therefore dioxins were placed in the “fair” category.

No pattern of long-term decline has been evident in the dioxin time series, and there is no conceptual reason to expect a rapid decline.

**4. Other Pollutants With Appropriate Thresholds**

Several other pollutants have been measured in sport fish from the Bay and Delta and found to be present at concentrations of low concern. Legacy pesticides (DDT, dieldrin, and chlordane) and selenium have been measured in both the Bay and the Delta. PBDEs have been measured in Bay fish. More information on these pollutants in Bay fish was provided in Davis et al. (2011). Davis et al. (2013) presents and discusses the data for these pollutants in Delta fish.

*C. POLLUTANTS WITHOUT APPROPRIATE THRESHOLDS*

**Contaminants of Emerging Concern**

In addition to the pollutants discussed above, there are thousands of other chemicals used by society, including pesticides, industrial chemicals, and chemicals in consumer products, and many of these make their way from our homes, businesses, and watersheds into the Estuary. As understanding advances, some of these contaminants emerge as posing risks to the health of humans and wildlife.

The Bay RMP monitors contaminants of emerging concern that pose the greatest known threats to water quality. One important class of emerging contaminants monitored in 2009 was perfluorinated chemicals (PFCs). PFCs have been used extensively over the last 50 years in a variety of products including textiles treated with stain-repellents, fire-fighting foams, refrigerants, and coatings for paper used in contact with food products. As a result of their chemical stability and widespread use, PFCs such as perfluorooctane sulfonate (PFOS) have been detected in the environment. PFOS and related PFCs have been associated with a variety of toxic effects including mortality, carcinogenity, and abnormal development. PFCs have been detected in sport fish fillets in other studies. Sampling has been fairly extensive in Minnesota, where concentrations have been high enough that the state has established thresholds for issuing consumption guidelines (Delinsky et al. 2010). Neither OEHHA nor the Water Board have developed thresholds for evaluating the risks to humans from consumption of contaminated sport fish from San Francisco Bay. In 2009 only four samples had detectable PFOS concentrations. The highest concentration was 18 ppb in a leopard shark composite.

Other chemicals among the thousands in commerce may also be entering the Estuary, accumulating in the food web, and leading to human exposure and risk through consumption of sport fish. Past experience has shown that the Estuary is a sensitive ecosystem that is very slow to recover from contamination by persistent pollutants. Cleaning up this type of contamination is very challenging and very costly. Given these lessons learned, the Bay RMP has placed a priority on early identification of emerging water quality threats so they can be addressed before they affect sensitive species or are added to the pollutant legacy that we leave for future generations. However, these monitoring efforts to protect water quality are severely hampered by the lack of information on the chemicals present in commercial products, their movement in the environment, and their toxicity. Screening of chemical properties and toxicity is currently required for many chemicals, but this could be improved. Furthermore, much of the information that does exist is not made readily available to the public. Measuring chemicals in environmental samples at the low concentrations that can cause toxicity is challenging and requires customized analytical chemistry methods. When the identities of the potentially problematic chemicals are not known, it is exceptionally challenging. Ultimately, the reduction of use of toxic chemicals in products is the ideal way to prevent environmental contamination.

## V. IS THE ESTUARY SAFE FOR SWIMMING?

### A. *BACKGROUND AND RATIONALE*

Recreation, including water sports, provides numerous physical, social, and psychological benefits to participants and spectators. Every year countless Bay-Delta region residents and visitors are drawn to Estuary waters to engage in water contact recreation. Swimming, surfing, windsurfing, kite boarding, and stand-up paddling all have their enthusiasts. Water contact sports in the Estuary carry numerous inherent dangers including drowning, hypothermia, danger of collision with vessel traffic, exposure to marine life (jellyfish stings, parasites, sea lion bites, etc.), and waterborne diseases or infection from the ingestion of Bay water contaminated with fecal material. With the exception of information on cercarial dermatitis or swimmer's itch caused by parasites (Brant et al. 2010), morbidity rates associated with water-contact recreation in the Bay are lacking. Exposure to water contaminated by fecal matter can result in numerous diseases and illnesses including gastro-intestinal illnesses, respiratory illness, skin rashes and infections, and infections of the ears, nose, and throat. Reliable and effective wastewater treatment occurs consistent with State and Federal standards throughout the Bay-Delta region, but wastewater treatment plant overflows occasionally occur in wet weather. Stormwater runoff is another pathway for input of pathogens into the Estuary, especially in wet weather.

To protect beach users from exposure to fecal contamination California has adopted standards developed for high use beaches and applies them during the prime beach season from April through October at beaches with more than 50,000 annual visitors that are adjacent to a storm drain that flows in the summer; these requirements are only mandatory in years that the legislature has appropriated monies sufficient to fund the monitoring. County Public Health and other agencies routinely monitor fecal indicator bacteria (FIB) concentrations at Bay beaches where water contact recreation is common and provide warnings to the public when concentrations exceed the standards (Table 1). FIB are enteric bacteria common to the digestive systems of mammals and birds and are indicators of fecal contamination. While not generally pathogenic themselves, FIB are used because they correlate well with the incidence of human illness in epidemiology studies at recreational beaches and can be enumerated more quickly and cost effectively than the actual pathogens.

Heal the Bay, a Santa Monica-based non-profit, provides comprehensive evaluations of over 400 California bathing beaches in both Annual and Summer Beach Report Cards as a guide to aid beach users' decisions concerning water contact recreation (Heal the Bay 2014). Higher grades are considered to represent less health risk to swimmers than are lower grades. The Heal the Bay grades for Bay beaches were used as the primary indicator of whether the Bay is safe for swimming. Routine bacteria monitoring does not occur at beaches in the Delta.

Toxins produced by blooms of harmful algae such as *Microcystis* are another threat to the health of people enjoying contact recreation in the Estuary. Although studies measuring algal toxins in the Estuary have been conducted, and thresholds developed by the state are available for assessment (OEHHA 2012), routine and systematic monitoring of algal toxins in the Estuary is not being conducted. A synthesis of the studies that have been performed was beyond the scope of the present report.

**Data Source** Whether the Bay is safe for swimming was assessed using the FIB monitoring data from the counties, described above. Bay county public health and other agencies monitor bacteria at 28 Bay beaches. These agencies collect and analyze samples, then post the necessary health warnings to protect public health. Data from these agencies are used to generate the Heal the Bay report card grades. Special studies on bacterial contamination have been conducted by the Central Valley Water Board. Synthesis of this information was beyond the scope of this project.

**Methods and Calculations** Heal the Bay (2014) presents the methods used to generate the grades that appear in the statewide annual beach report card. The grading system takes into consideration the magnitude and frequency of exceedance above indicator thresholds over the course of the specified time period. Those beaches that exceed multiple indicator thresholds (if applicable) in a given time period receive lower grades than those beaches that exceeded just one indicator threshold. Water quality typically drops dramatically during and immediately after a rainstorm but often rebounds to its previous level within a few days. For this reason, year-round wet weather data throughout California are analyzed separately in order to avoid artificially lowering a location's year-round grade and to provide better understanding of statewide beach water quality impacts. Wet weather data are comprised of samples collected during or within three days following the cessation of a rainstorm. Heal the Bay's annual and weekly Beach Report Cards utilize a definition of a 'significant rainstorm' as precipitation greater than or equal to one-tenth of an inch (>0.1").

**Goals, Targets and Reference Conditions** California standards for fecal indicator bacteria established by the Department of Public Health are shown in Table 1.

**Results**

Overall, the monitoring data and resulting grades (Table 2) indicate that conditions are excellent at most Estuary beaches most of the time. Conditions have been poor at 7% of beaches in summer, and 27% of beaches in wet weather at times during recent years..

Data for the summer beach season in 2013 are available for 28 beaches. In 2013, 22 of the 28 monitored beaches received an A or A+ grade, reflecting minimal exceedance of standards. Four of these beaches received an A+: Crown Beach Bath House, Crown Beach Windsurf Corner, Jackrabbit Beach and Candlestick Point, and Horseshoe Cove SW at Baker Beach. Most Bay beaches, therefore, are quite safe for swimming in the summer.

Six of the 28 beaches monitored in the summer in 2013 had grades of B or lower, indicating varying degrees of exceedance of bacteria standards. Aquatic Park and Lakeshore Park in San Mateo County received an F. These low grades indicate an increased risk of illness or infection.

Overall, the average grade for the 28 beaches monitored from April-October was an A-.

During wet weather, which mostly occurs from November-March, water contact recreation is less popular but is still enjoyed by a significant number of Bay Area residents. Bacteria concentrations are considerably higher in wet weather making the Bay less safe for swimming. This pattern is evident in Heal the Bay report card grades for wet weather. In wet weather, six of 22 beaches with data (27%) had grades of D or F. Many of the beaches (14 of 22, 64%), however, still had grades of A or A+. The overall average grade for these beaches in wet weather was a B (Table 2).

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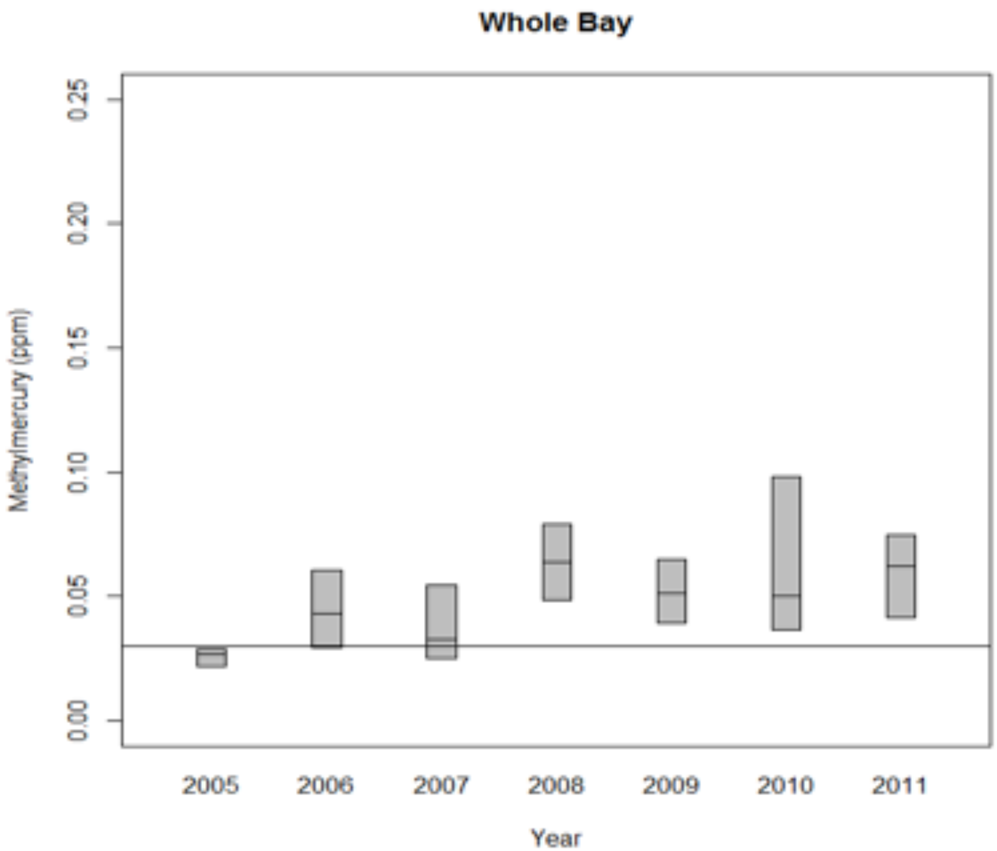
Figure 1. Methylmercury concentrations in small fish. Plots indicate the 25th, 50th, and 75th percentiles. Data for Mississippi silversides and topsmelt in the 3-5 cm size range sampled by the RMP. Reference line is the 0.030 ppm target from the Bay Mercury TMDL.



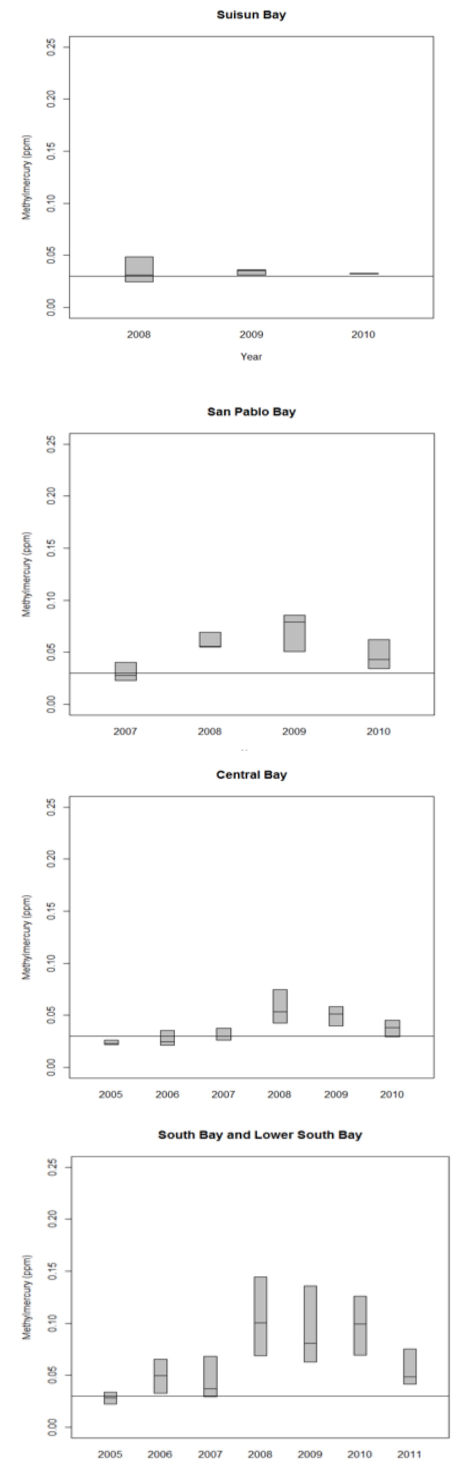



Figure 2. Percent of Estuary water samples exhibiting toxicity in laboratory assays. The RMP measured water toxicity in 2002, 2007, and 2011. In 2011, water toxicity was measured at 22 stations distributed throughout the Bay. Most of the samples are collected at randomly selected locations, with a few fixed historic stations included to continue long-term time series. The test species was the mysid shrimp *Americamysis bahia*. Water toxicity data for the Delta consisted of a collection of datasets from various programs, including one-time studies (e.g., the Central Valley Water Board's Delta Island Monitoring Project and the Central Valley Water Board's SWAMP Delta Pyrethroid Study) and annual monitoring performed under the Central Valley Water Boards Irrigated Lands Regulatory Program. Test species have included invertebrates (*Ceriodaphnia dubia, Eurytemora affinis, Hyalella azteca*, and *Americamysis bahia*) and fathead minnows (*Pimephales promelas*). The number of samples for each year varied considerably, with a low of five in 2004 and a high of 118 in 2008.

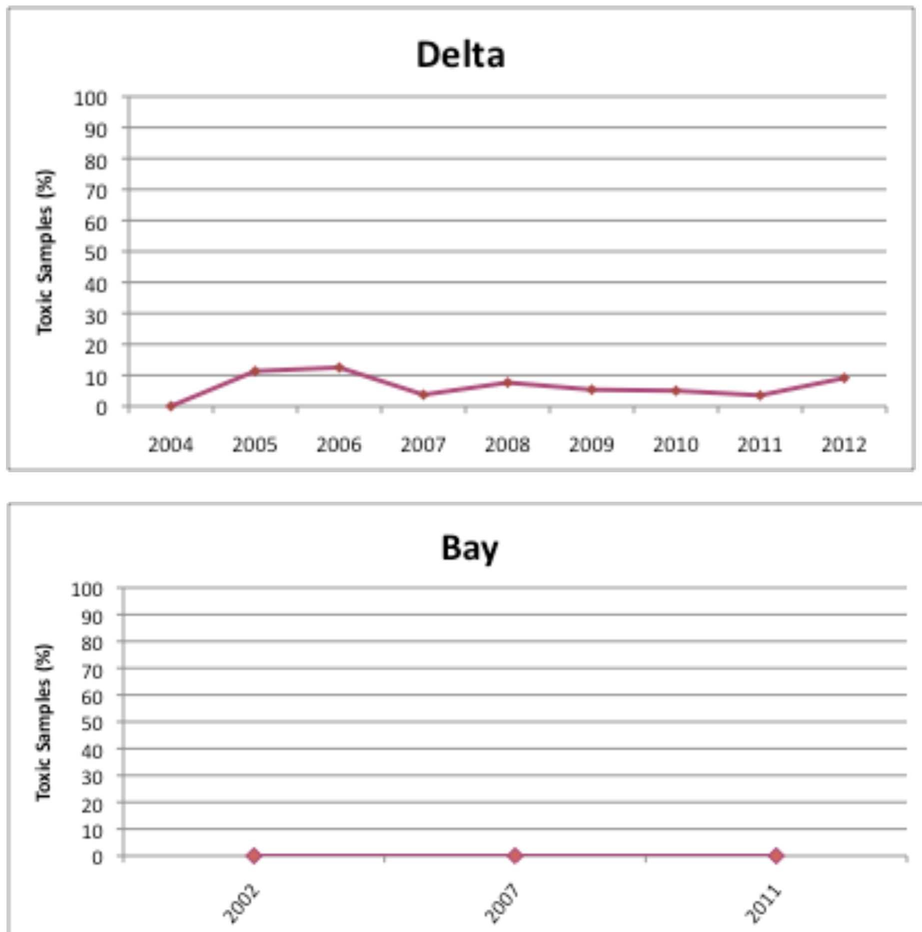


Figure 3. Dissolved copper concentrations in Bay water. Boxes indicate the 25th and 75th percentiles, whiskers the 5th and 95th percentiles. The water quality objective is a maximum of 6.9 ug/L in South Bay, and 6.0 ug/L in the other embayments.

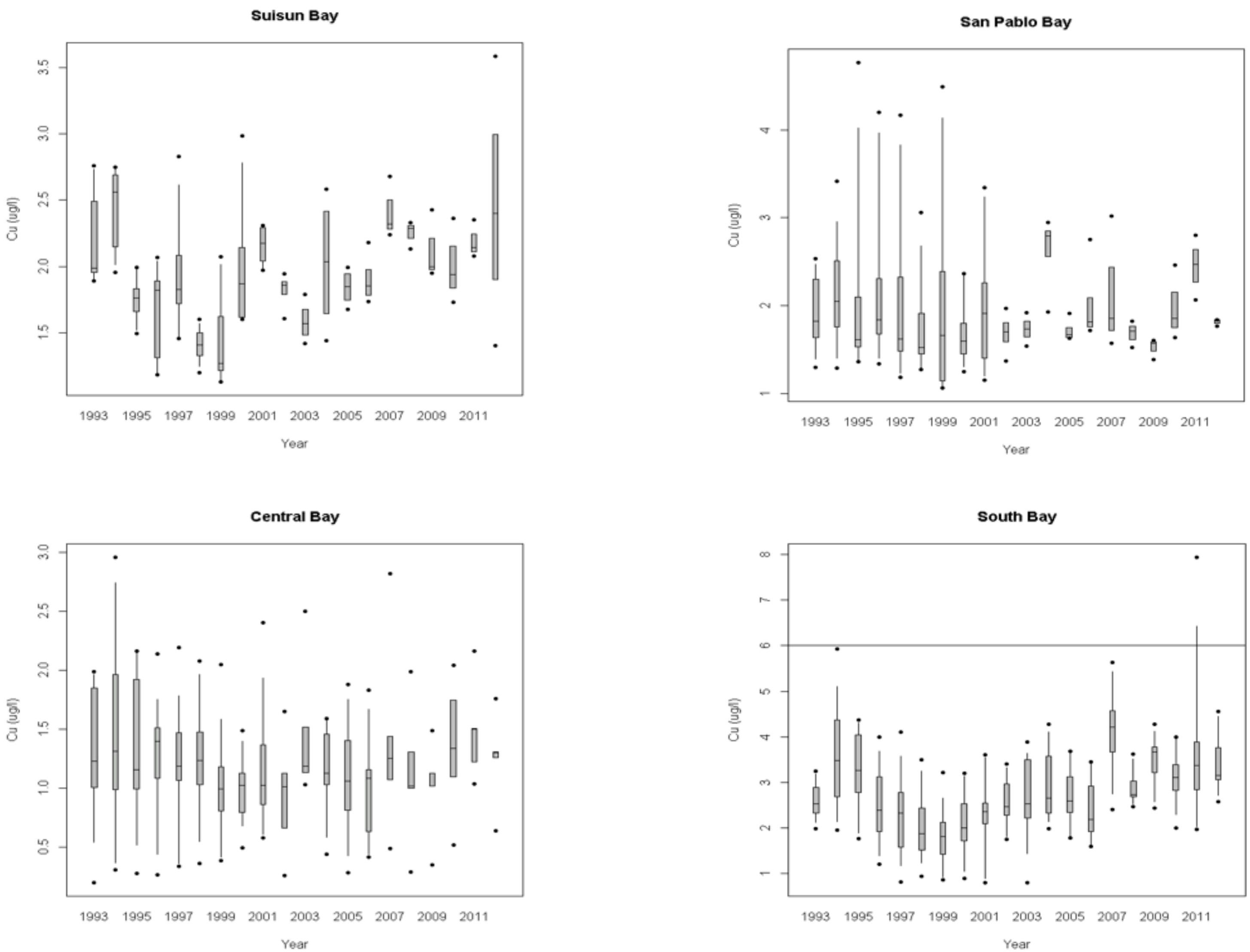
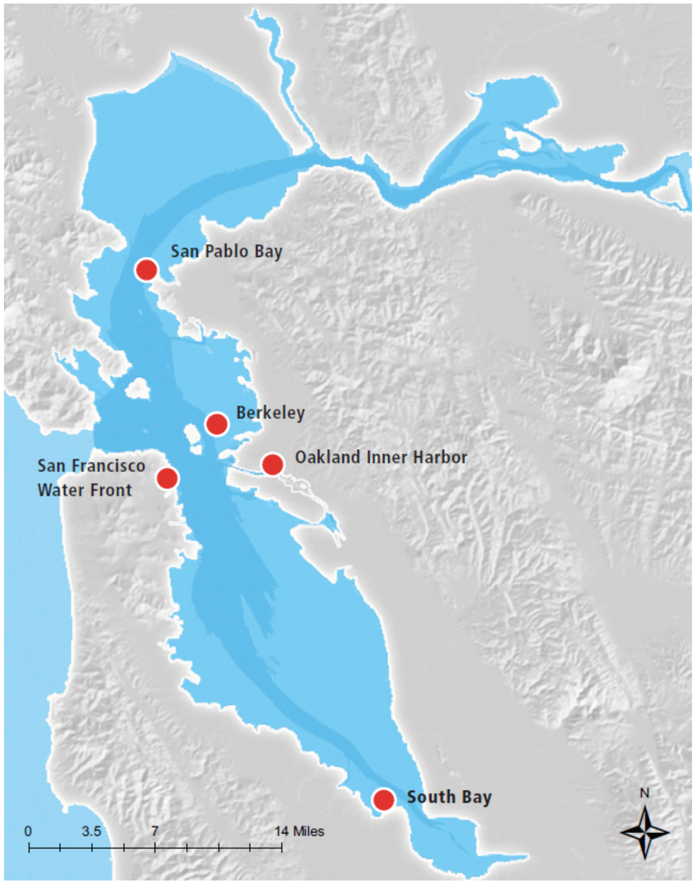


Figure 4. Locations of the five sampling stations in RMP sport fish monitoring and the six Delta stations sampled by SWAMP.



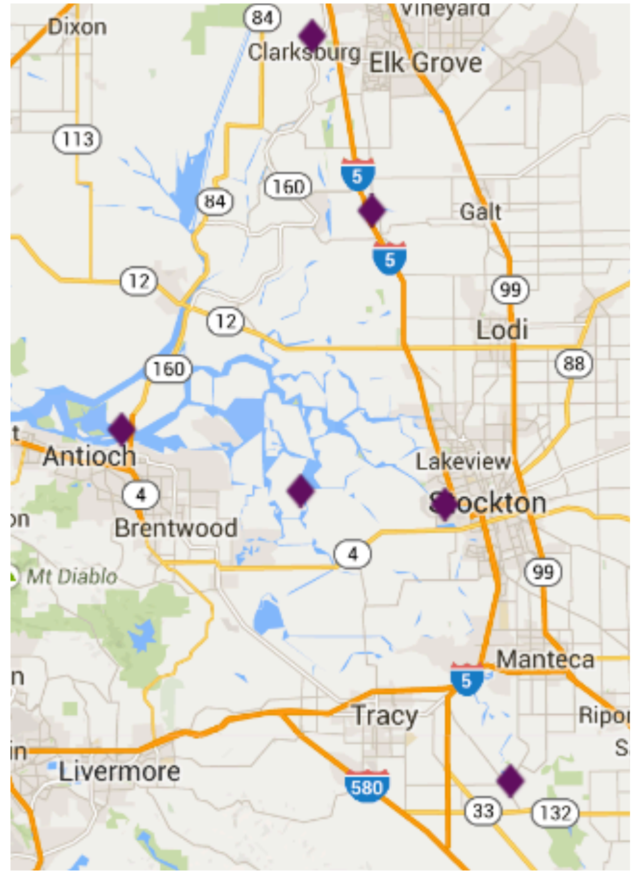



Figure 5. Average methylmercury concentrations in sport fish indicator species. Averages for striped bass based on concentrations for individual fish normalized to 60 cm. Sport fish are not routinely sampled in Suisun Bay. The no consumption advisory tissue level for mercury is 0.44 ppm, and the two serving advisory tissue level is 0.07 ppm. Average concentrations for each species in the most recent sampling were between these two thresholds.

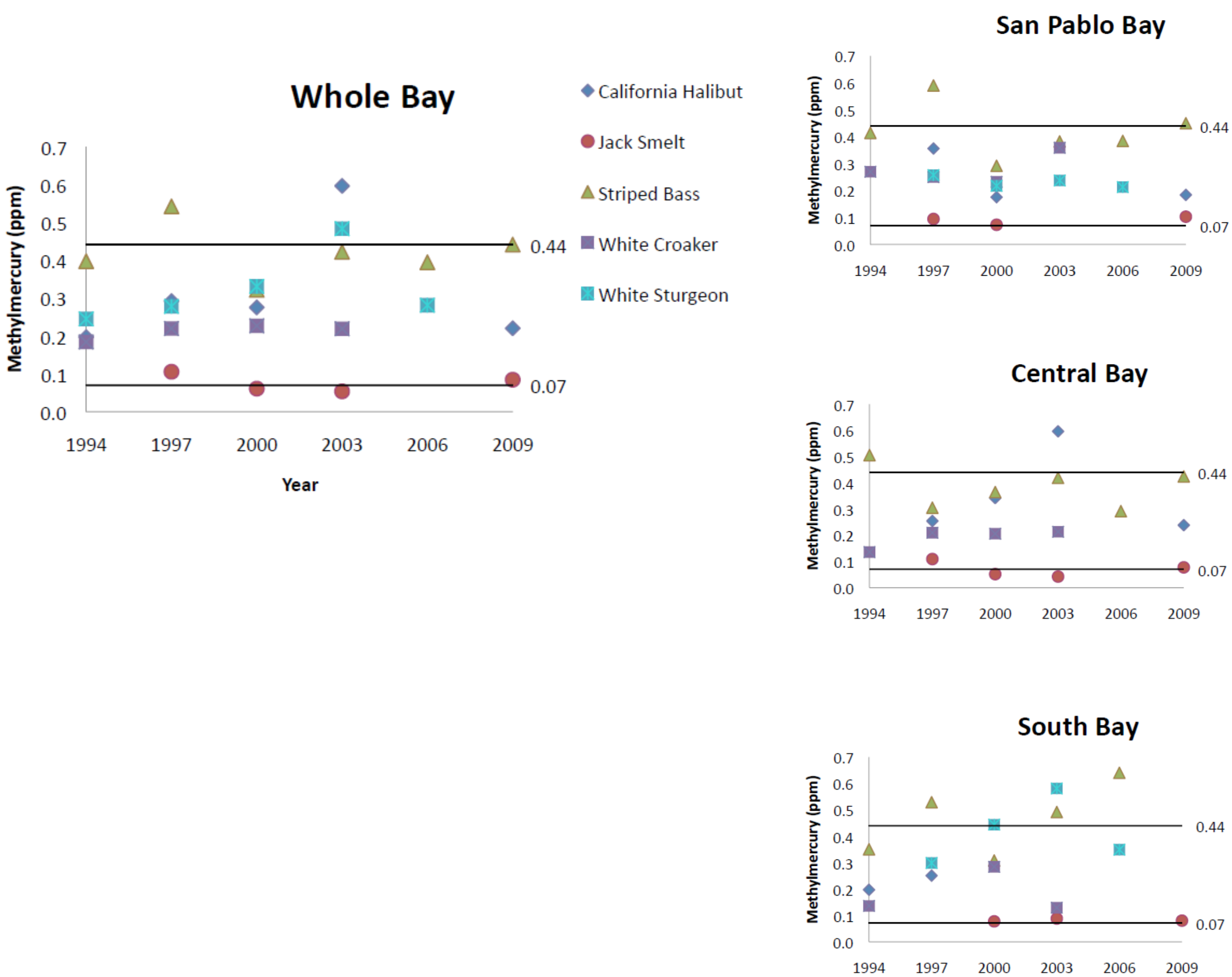


Figure 6. Average PCB concentrations in sport fish indicator species. Sport fish are not routinely sampled in Suisun Bay. The no consumption advisory tissue level for PCBs is 120 ppb, and the two serving advisory tissue level is 21 ppb. Average concentrations for both species in the most recent sampling were between these two thresholds. Concentrations in shiner surfperch in San Pablo Bay had a declining trend. White croaker were analyzed with skin from 1994-2006, and without skin in 2009.

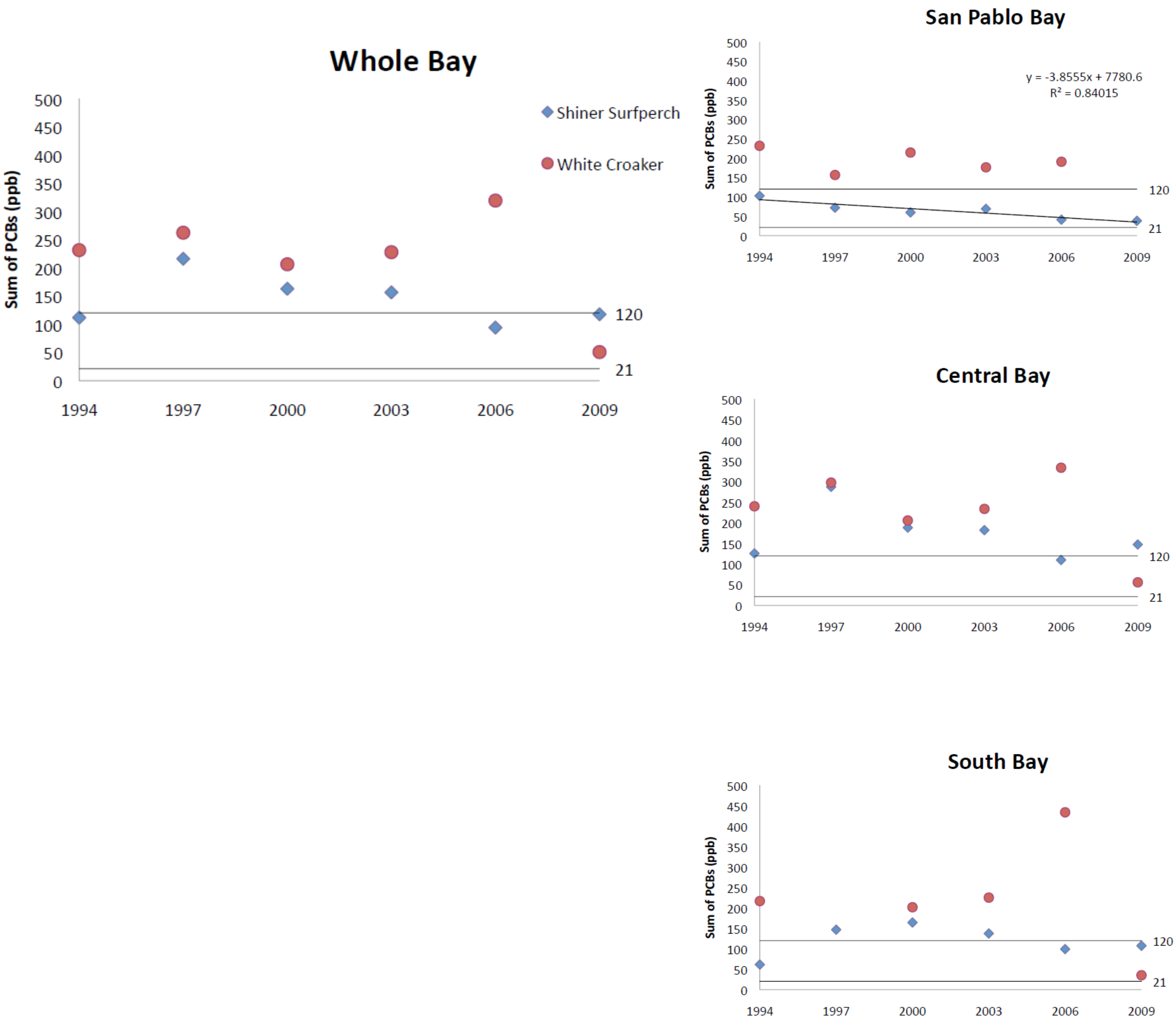


Figure 7. Average dioxin TEQ concentrations in shiner surfperch and white croaker, the key sport fish indicator species for organic pollutants. Sport fish are not routinely sampled in Suisun Bay. OEHHA has not established ATLs for dioxin TEQs. The San Francisco Bay Water Quality Control Board has developed a screeniung value for dioxin TEQs 0.14 parts per trillion (ppt). White croaker were analyzed with skin from 1994-2006, and without skin in 2009.

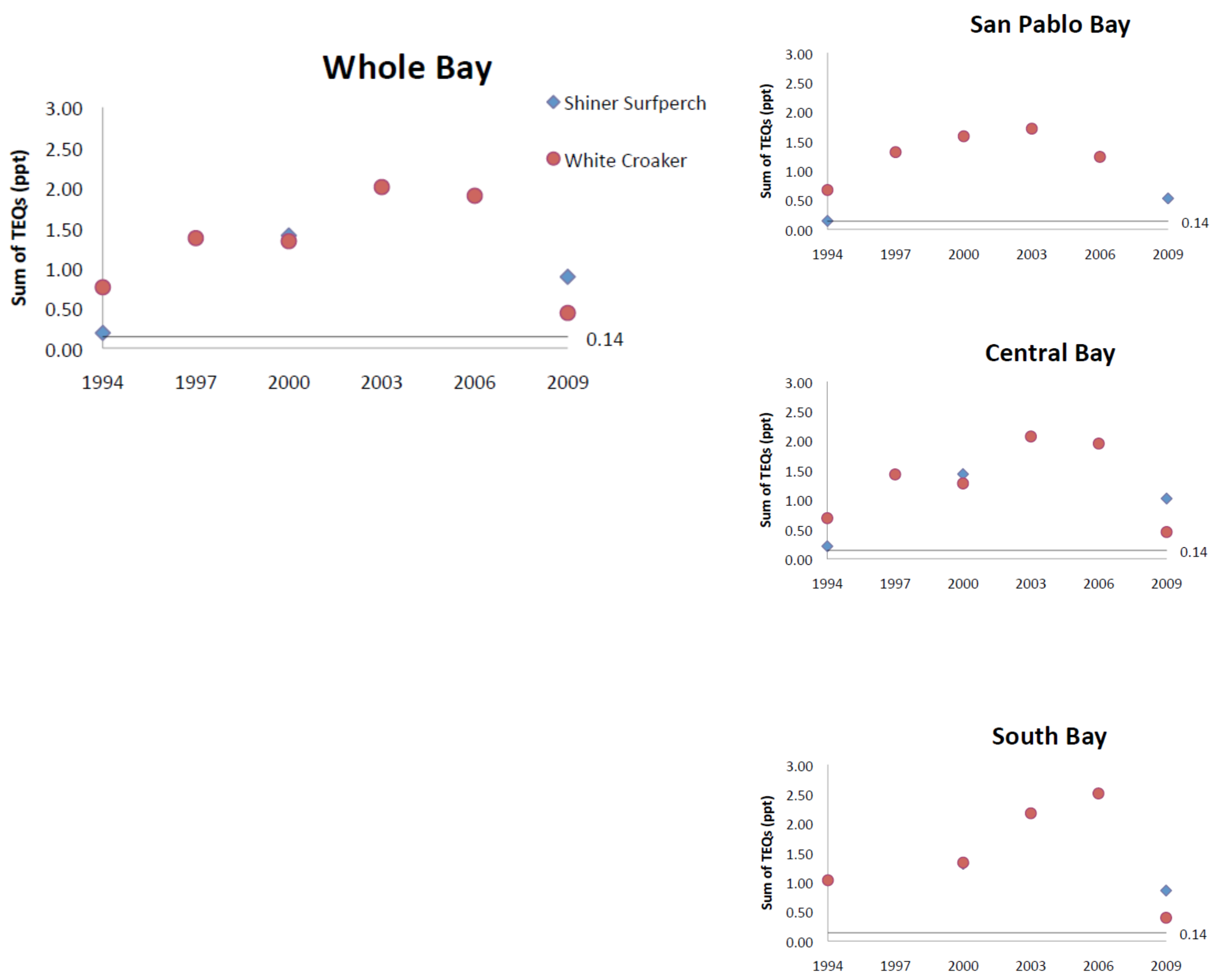


Table 1. California standards for fecal indicator bacteria.

**Single Samples**

| **Indicator** | **Standard (colony forming units per 100 mL of water)** |
|---|---|
| Enterococcus | 104 |
| Fecal Coliform | 400 |
| Total Coliform | 10,000 |
| Total:Fecal Ratio (when Total is greater than or equal to 1,000) | 10 |

**Geometric Means**

| **Indicator** | **Standard (colony forming units per 100 mL of water)** |
|---|---|
| Enterococcus | 35 |
| Fecal Coliform | 200 |
| Total Coliform | 1000 |

Table 2. Heal the Bay grades for San Francisco Bay Area beaches. From Heal the Bay (2014) and previous reports.

| | 2013 | | | 2012 | | | 2011 | | | 2010 | | | 2009 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **San Mateo County** | **Summer Dry (Apr-Oct)** | **Winter Dry (Nov-Mar)** | **Wet Weather (Year-Round)** | **Dry** | **Wet** | **ab411 (Apr-Oct)** | **Dry** | **Wet** | **ab411 (Apr-Oct)** | **Dry** | **Wet** | **ab411 (Apr-Oct)** | **Dry** | **Wet** | **ab411 (Apr-Oct)** |
| Oyster Point | A | A | D | A | D | A | A | B | D | A | D | A | A | F | B |
| Coyote Point | A | B | F | A | D | A | C | F | A | A+ | C | A+ | A | B | A+ |
| Aquatic Park | F | F | F | F | F | F | F | F | F | D | F | D | F | F | F |
| Lakeshore Park | F | F | F | F | F | D | F | F | F | D | F | D | D | F | D |
| Kiteboard Beach | C | A | D | B | D | A | F | | | | | | | | |
| | | | | | | | | | | | | | | | |
| **Alameda Couty** | | | | | | | | | | | | | | | |
| Alameda Point North | A | | A+ | | C | A | | | A | A | C | A | A+ | A | A+ |
| Alameda Point South | A | | A+ | | A+ | A | | | A | A | A | A+ | A | A | A |
| Crown Beach Crab Cove | A | F | A+ | | | | | | | | | | | | |
| Crown Beach Bath House | A+ | | A+ | | A+ | A | A+ | B | A | A+ | A | A+ | B | A | B |
| Crown Beach Windsurf Corner | A+ | | A+ | | A+ | A | | A | A | A+ | B | A+ | A | B | A |
| Crown Beach Sunset Road | A | | A+ | | A | A | A | A | A | A+ | B | A+ | A | B | A |
| Crown Beach Shoreline Drive | A | | A+ | | D | A | A | A | A | A | B | A+ | A | C | A+ |
| Crown Beach Bird Sanctuary | A | D | A | | F | A | C | C | B | A | C | A | B | D | B |
| | | | | | | | | | | | | | | | |
| **Contra Costa County** | | | | | | | | | | | | | | | |
| Keller Beach North | A | | A+ | | D | A | A | C | B | F | A | F | D | B | D |
| Keller Beach Mid-Beach | | | | | | | | | B | F | A | F | D | B | D |
| Keller Beach South | A | | A | | C | A | A | B | B | D | B | D | D | C | D |
| | | | | | | | | | | | | | | | |
| **San Francisco County** | | | | | | | | | | | | | | | |
| Crissy Field Beach West | A | A | A | A+ | A+ | A | A | A+ | A | A | B | A+ | | | |
| Crissy Field mid-Beach | | | | | | | | | | | | | | | |
| Crissy field Beach East | A | D | A | C | B | A | A | A | A | B | C | A+ | A | B | A |
| Aquatic Park Beach 211 Station | A | C | A | F | A | A | B | A+ | B | B | B | A | A | A | A |
| Aquatic Park Beach Hyde Street Pier | A | A | A+ | A | A | A | A+ | A | A | A | A | A+ | A | A | A+ |
| Candlestick Point Jackrabbit Beach | A+ | A | C | A | A | A | A | D | B | A | B | A | A | C | A |
| Candlestick Point Windsurfer Circle | C | F | F | F | F | C | D | F | B | F | F | D | A | F | A |
| Candlestick Point Sunnydale Cove | B | A | C | D | C | A | B | F | A | C | F | D | C | F | B |
| | | | | | | | | | | | | | | | |
| **Marin County** | | | | | | | | | | | | | | | |
| Baker Beach Horseshoe Cove NE | A | | | | | A | | | B | | | A | | | A+ |
| Baker Beach Horseshoe Cove NW | A | | | | | A | | | A | | | A | | | A |
| Baker Beach Horseshoe Cove SW | A+ | | | | | A | | | A | | | A | | | A |
| Schoonmaker Beach | A | | | | | A | | | B | | | A+ | | | A |
| Paradise Cove | | | | | | | | | | | | | | | |
| China Camp | A | | | | | A | | | A | | | A | | | A |
| McNears Beach | B | | | | | | | | | | | | | | |