State of San Francisco Bay 2011
Appendix A

WATER - Water Quality
Technical Appendix

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GENERAL CONSIDERATIONS

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

The Bay Area is fortunate to have one of the best water quality monitoring programs in the world (the Regional Monitoring Program for Water Quality in the San Francisco Estuary) 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 Bay water quality is based largely on information generated by the Regional Monitoring Program. Other valuable sources of information are also available and were also considered.

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 Bay. 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. 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 as they are a primary focus of water quality regulators and scientists. Mercury and PCBs, for example, are two of the greatest concerns in the Bay, and highly scrutinized cleanup plans (TMDLs) have been incorporated into the Basin Plan for the Bay (http://www.swrcb.ca.gov/rwqcb2/basin_planning.shtml) in an effort to reduce their impacts on Bay water quality.

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 threshold 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 Bay, 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.

EVALUATION SCHEME

The water quality indicators presented in this report card were evaluated using a scheme that takes into account both 1) the distance of the data distribution relative from the relevant guideline in terms of the estimated length of time expected for the indicators to reach the desired condition and 2) the severity of the impairment of water quality.

This water quality element of the Bay report card addresses the three main beneficial uses of the Bay 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 easily understood by the public:

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

QUESTION 1: IS THE BAY SAFE FOR AQUATIC LIFE?

A varied group of indicators is most appropriate for addressing question 1. This group includes a target from the Mercury TMDL for methylmercury concentrations in small fish, a qualitative narrative objective that applies to the occurrence of toxicity in Bay sediments, and numeric water quality objectives that are based on measurement of concentrations in water.

For each parameter, the distribution of the data for each sampling year is compared to the target. The degree of risk for pollutants in this category are based on assessments in published studies and other considerations discussed below for each pollutant. A second measure for pollutants that do not meet the goal is the estimated recovery time. A quantitative recovery time estimate is available for methylmercury. For others, the estimates are based on conceptual considerations.

QUESTION 2: ARE FISH FROM THE BAY SAFE TO EAT?

For question 2, the appropriate indicators are concentrations of pollutants of concern in the tissue of fish species that are popular for consumption by Bay anglers. The Regional Monitoring Program has conducted systematic monitoring of Bay sport fish on a triennial basis since 1994, providing a solid foundation for assessing this question.

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 San Francisco Bay. 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 developed thresholds called advisory tissue levels (ATLs) that are a component of their complex process of data evaluation and interpretation in the development of safe eating guidelines. 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 safe eating guidelines for the Bay represent the definitive statement for the public on the safety of consuming Bay fish. The intent of using ATLs in the State of the Bay Report is to convey a message to the public that is consistent with and supports the safe eating guidelines.

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 2008) 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 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. Estimated recovery times for methylmercury and PCBs are based on analyses presented in the TMDLs.

QUESTION 3: IS THE BAY 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.

IS THE BAY SAFE FOR AQUATIC LIFE?

POLLUTANTS WITH APPROPRIATE THRESHOLDS

1. Methylmercury in Prey Fish

In addition to posing risks to humans who eat Bay fish, methylmercury poses significant risks to Bay wildlife. Extensive studies in Forster's Terns have concluded that 48% of birds in the breeding season in this species were at high risk of reproductive impairment due to methylmercury exposure (Eagles-Smith et al. 2009). 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 California Clapper 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 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). 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 has been a top priority in the RMP over the past several 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 Mercury TMDL, methylmercury in prey fish tissue is the key regulatory target for protection of aquatic life. 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 RMP. A summary report on the extensive prey fish sampling that has been conducted in recent years is in preparation.

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. The sampling has focused on two species: Mississippi silverside and topsmelt. Samples have been collected in all of the regional embayments.

Methods and Calculations The aquatic life methylmercury indicator (Figure 1) was calculated using available data from the 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 sampling year, methylmercury concentrations in prey fish exceeded the 0.03 ppm target in approximately 95% of the samples collected. Similar results were obtained in 2008, the other year 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 2009 was 0.051 ppm.

Evaluation of spatial and temporal trends should focus on data from 2008 and 2009, which are based on larger sample sizes. Median concentrations in each region in 2009 ranged from a high of 0.081 in South Bay to a low of 0.035 ppm in Suisun Bay.

As discussed below in the Methylmercury in Sport Fish section, methylmercury concentrations in the Bay food web have not changed perceptibly over the past 40 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. The summary rating for methylmercury risk to aquatic life is therefore one star (Figure 2).

2. Sediment Toxicity

The frequent occurrence of toxicity in sediment samples from the Bay is a significant concern. In every year since sampling began in 1993, at least 26% of sediment samples have been determined to be toxic to one or more test species. In 2009, 67% of the samples were found to be toxic to at least one of the two test species. No long-term trend is apparent in this time series. These toxicity tests indicate that pollutant concentrations in Bay sediments are high enough to affect the abundance of aquatic invertebrates. The pollutants causing this persistent toxicity have not yet been identified. Until the stressors driving this toxicity are reduced, this problem will persist into the future.

The State Water Board is in the process of developing quantitative sediment quality objectives (SQOs) for protection of aquatic life in enclosed bays and estuaries in California (SFEI 2009). Attainment of these objectives is to be assessed using a combination of data on sediment chemistry, sediment toxicity, and benthic community composition (the sediment quality triad). SQOs have been established for polyhaline (marine) habitats, and are still in development for lower salinity habitats, such as those that are present throughout much of San Francisco Bay. Assessments of triad data from the Bay using the SQO framework have concluded that some degree of impact was considered possible in 96% of the ecosystem (SFEI 2009). Most of the Bay (73%) was classified as "possibly impacted." Sediment toxicity was the primary driver of these assessment results. Until SQOs that cover the entire Bay are established, the incidence of sediment toxicity is an appropriate indicator of Bay sediment quality.

In the meantime, a narrative water quality objective in the Basin Plan applies to sediment toxicity. The objective states: "No toxic or other deleterious substances shall be present in receiving waters in concentrations or quantities which will cause deleterious effects on aquatic biota, wildlife, or waterfowl or which render any of these unfit for human consumption either at levels created in receiving waters or as a result of biological concentration." The implicit quantitative goal associated with this objective is a 0% incidence of toxicity in Bay samples.

Data Source The sediment toxicity indicator is based on data from the RMP, available on the RMP website (www.sfei.org/rmp/data). The RMP measures sediment toxicity annually at 27 stations 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. Two types of sediment bioassays are conducted at each station. Homogenized whole sediment is tested for toxicity using the amphipod *Eohaustorius estuarius* in a 10 day amphipod survival test. Sediment-water interface (SWI) cores are tested using the bivalve *Mytilus galloprovincialis* in a 48 hour static embryolarval development toxicity test.

Methods and Calculations The sediment toxicity indicator (Figure 3) is simply the percentage of the samples tested in each year that were determined to be toxic to at least one of the test organisms. 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 objective pertaining to sediment toxicity is 0% incidence of toxicity in Bay samples.

Results

On the whole Bay scale, the incidence of sediment toxicity has ranged from a low of 26% of samples in 2004 to a high of 85% in 2007 (Figure 3). In most years the incidence has been higher than 50%. In 2009, 67% of samples were toxic to the test organisms. The incidence of toxicity has shown no indication of a decline.

The incidence of sediment toxicity varies among the embayments. The incidence has been highest in Suisun Bay, where frequently 100% of samples have been toxic. South Bay has had the second highest incidence, with 50% or more samples toxic in all but two years. The incidence of toxicity has been lower in San Pablo Bay and Central Bay, where fewer than 50% of samples have been toxic in most years.

In most of these cases where toxicity has been observed, the degree of toxicity has not been severe, with severe toxicity defined as mortality rates for *Eohaustorius* approaching 100% or rates of abnormal development in *Mytilus* larvae approaching 100%. The observed degree of toxicity is considered to be moderate. In terms of the assessment scheme used in this report, this corresponds to the "moderate concern" category. The incidence of sediment toxicity has shown no sign of declining since 1993, and until the causes of the toxicity are identified it is not possible to say whether the goal of 0% toxicity will be attained in 30 years. These considerations place sediment toxicity in the "rapid progress unlikely" category. The summary rating for sediment toxicity is therefore two stars.

3. Copper in Water

Background and Rationale Copper pollution was a major concern in the Estuary 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 or nickel concentrations. A remaining concern regarding possible impacts of copper on olfaction in salmonids is currently being investigated by the National Oceanographic and Atmospheric Administration's Northwest Fisheries Science Center.

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 RMP. The data are available from the RMP website (www.sfei.org/rmp/data).

Methods and Calculations The copper indicator was calculated for each year of RMP monitoring from 1993 to 2009 (Figure 4). 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 2009. Due to the remaining uncertainty regarding the possible impact of copper on salmon olfaction, copper was placed in the "low concern/rapid progress likely" category.

4. Dissolved Oxygen in Water

Background and Rationale Enforcement of the Clean Water Act and other environmental laws over the past 39 years has resulted in tremendous improvements in overall Bay water quality, solving serious problems related to organic waste, nutrients, and silver contamination. In the early 1970s the Bay suffered from severely degraded water quality. The discharge of poorly treated wastewater, primarily from publicly-owned treatment works (POTWs) serving the Bay Area's growing population, was the cause of large and frequent fish kills, unsafe levels of bacteria in water and shellfish, and a notoriously foul stench (Krieger et al 2007). The Clean Water Act provided a major impetus toward cleaning up the Bay by setting clear goals and supplying over a billion dollars that supported construction of POTWs. In response, POTWs and industrial wastewater dischargers achieved significant reductions in their emissions of pollutants into the Bay, and the most noticeable problems of the 1970s have been solved. Inputs of organic waste and nutrients have been greatly reduced and no longer cause fish kills or odor problems.

Some concerns remain with regard to dissolved oxygen concentrations in the Bay. Low dissolved oxygen resulting indirectly from the large amount of freshwater input to the Bay in 2006 was considered a possible cause of a fish kill in June of that year. Dissolved oxygen and nutrient concerns still exist for salt ponds, lagoons, and other areas around the edges of the Bay. Recent observations of increasing transparency in the Bay due to declining suspended sediment concentrations (Schoellhamer 2009) and increasing chlorophyll concentrations (SFEI 2009) are raising concerns that dissolved oxygen concentrations could again decline to problematic levels.

Concentrations of dissolved oxygen in water are a key impairment indicator for organic waste and nutrients.

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

Methods and Calculations The dissolved oxygen indicator was calculated for each year of RMP monitoring from 1993 to 2009 (Figure 5). 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 There are two objectives for dissolved oxygen in the Bay. An objective of 5 mg/L applies to waters downstream of the Carquinez Strait. The objective for Suisun Bay is 7 mg/L.

Results Dissolved oxygen concentrations in the Bay have exceeded the objective for almost all samples measured from 1993 to 2009 (Figure 5). No pattern of declining dissolved oxygen is evident in the time series for each embayment. The overall score for dissolved oxygen is therefore "goal attained" (five stars). It should be noted, however, that increasing phytoplankton abundance in the South Bay has raised concern that concentrations could potentially decline again to problematic levels.

5. Silver in Water

Background and Rationale Enforcement of the Clean Water Act and other environmental laws over the past 35 years has resulted in tremendous improvements in overall Bay water quality, solving serious problems related to organic waste, nutrients, and silver contamination. In the 1970s the Bay had the highest silver concentrations recorded for any estuary in the world, but the closure of a major photo processing plant and improved wastewater treatment led to a reduction in concentrations in South Bay clams from 100 ppm in the late 1970s to 3 ppm in 2003, eliminating adverse impacts on clam reproduction. With the continued vigilance of regulators and treatment plant operators, broad-scale adverse impacts of dissolved oxygen, nutrients, and silver on Bay water quality are not likely.

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

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

Methods and Calculations The silver indicator was calculated for each year of RMP monitoring from 1993 to 2009 (Figure 6). 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 The water quality objective for silver in the Bay is 1.9 ug/L (SFBRWQCB 2007). The objective applies to dissolved concentrations.

Results Silver concentrations in the Bay have been far below the objective for all samples measured from 1993 to 2009, and are not expected to increase. The overall score for dissolved oxygen is therefore "goal attained" (five stars).

6. Other Priority Pollutants

In addition to the pollutants mentioned above, the RMP monitors many other pollutants that are present at concentrations below water quality objectives and are considered to pose low risk to Bay 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 Bay.

The 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" 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;
- nutrients - nitrate, nitrite, phosphate, ammonium;
- others – cyanide.

POLLUTANTS WITHOUT APPROPRIATE THRESHOLDS

1. Exotic Species

Exotic species released from ship ballast water are considered a water pollutant under the Clean Water Act, and they are included on the 303(d) list of impaired water bodies 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 exotic species have been immense. Introductions of hundreds of exotic species have irreversibly altered the Bay ecosystem in fundamental ways. Nonnative species introduced to the Bay 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. Recently adopted state interim ballast discharge regulations to be phased in over 2010-2016, if rigorously implemented and enforced, would essentially resolve one major introduction pathway. Several other pathways - including introductions due to aquaculture activities and importations of live bait, aquarium organisms, ornamental plants, live educational/research organisms and live seafood - could also be better managed by thoughtful regulation, or by a combination of regulations and public education and outreach.

Exotic species introductions do not fit neatly into the assessment framework used for this report card. 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. California's new ballast discharge regulations could have a significant impact in this regard, if rigorously enforced; and the USEPA is currently developing a revised Vessel General Permit (to be issued in 2013) that will include limits on organism concentrations in ballast water discharges into US waters; appropriate limits, effectively enforced, would be a tremendous help.

Focusing on the significant achievable goals mentioned above, exotic species fall in the "rapid progress likely" category. 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 exotic species, and if invasions are allowed to continue additional large impacts are likely. This places exotic species in the "high concern" category. The summary rating for exotic species is therefore two stars.

2. Trash

Trash is a continuing problem in the Bay 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. Trash is a concern at both 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, Central Bay and a portion of South Bay (in addition to many urban creeks) have been recommended for inclusion on the 303(d) List (SFBRWQCB 2009). 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 numerical 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 (MRP) 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 this permit term, municipalities are 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 Bay is a moderate concern in regard to impacts on aquatic life. Aggressive requirements in the MRP 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. The summary rating for trash is therefore three stars.

3. Other Suspected Threats

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

Selenium

Selenium concentrations found in Bay biota are thought to exceed levels that can cause reproductive impacts in white sturgeon and are often higher than levels considered safe for fish and other wildlife species in the Estuary. Concern for risks to aquatic life is the primary impetus for the North Bay Selenium TMDL that is in development (SFBRWQCB 2011). Thresholds to protect aquatic life are in development that will be more appropriate than existing water quality criteria.

Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are included on the 303(d) List for several Bay locations. 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.

Polybrominated Diphenyl Ethers (PBDEs)

PBDEs are considered a potential risk to Bay wildlife. However, a regulatory goal has not yet been established for PBDEs in aquatic life. The RMP is currently conducting a study to better understand threshold for risks to birds.

Perfluorooctanesulfonate (PFOS)

PFOS is also considered a potential risk to Bay wildlife. 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.

4. Contaminants of Emerging Concern

As discussed above relative to risks to human health, 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, and chemicals in consumer products, and many of these make their way from our homes, businesses, and watersheds into the Bay. Due to inadequate screening of the hazards of these chemicals, some may cause toxicity in Bay biota, either through direct exposure to contaminated water or sediment or through accumulation in the Bay 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 humans and wildlife.

The RMP actively monitors contaminants of emerging concern that pose the greatest known threats to water quality. However, as mentioned above, 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 Bay.

ARE BAY FISH SAFE TO EAT?

POLLUTANTS WITH APPROPRIATE THRESHOLDS

1. Methylmercury in Sport Fish

Background and Rationale

Methylmercury is one of four pollutants (the others are PCBs, exotic species, and trash) that are classified as having significant impacts on Bay water quality because the entire Bay is considered impaired by these pollutants, and the degree of risk is above established thresholds of concern.

Methylmercury is arguably the Bay's most serious water quality concern. Methylmercury is a primary driver of the fish consumption advisory for the Bay (OEHHA 1994, Hunt et al. 2008), 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 has been 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 gets taken up into 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 (Hunt et al. 2008), 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 Bay on a grand scale is now beginning, raising concern that methylmercury concentrations could increase across major portions of the Bay. 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 concentrations were compared to OEHHA thresholds, as described previously.

Data Source 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 three 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 RMP collects sport fish from five popular fishing locations in the Bay (Figure 7). 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 2). In the most recent sampling in 2009, methylmercury was analyzed in striped bass, California halibut, and jacksmelt, but not white sturgeon or white croaker.

Methods and Calculations The sport fish methylmercury indicator (Figure 8) 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.

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

In the most recent sampling year, 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; this corresponds to the “moderate concern” category in Table 1. Methylmercury concentrations in the Bay food web have not changed perceptibly over the past 40 years, and it is not anticipated that they will decline significantly in the next 30 years. The summary rating for methylmercury in Bay sport fish is therefore two stars (Figure 9).

2. PCBs in Sport Fish

Background and Rationale

Polychlorinated biphenyls (PCBs) are also in the class of pollutants considered to have the most severe impacts on Bay water quality because the entire Bay is considered impaired, and the degree of risk is above established thresholds of concern.

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.

Data Source The PCBs indicator was calculated using data from the same RMP sport fish monitoring program described for the methylmercury in sport fish indicator. The data are available from the RMP website (www.sfei.org/rmp/data). Additional details on this sampling were provided in the methylmercury section. The two key indicator species for PCBs have been sampled consistently over the years (Figure 10).

Methods and Calculations The sport fish PCBs indicator (Figure 10) 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.

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, both of the PCB indicator species had average concentrations between 21 ppb and 120 ppb (Figure 10). 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. Given this determination by OEHHA, PCBs were placed in the “high concern” category. 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, placing PCBs in the “rapid progress unlikely” category. The summary rating for PCBs in Bay sport fish is therefore one star.

3. Dioxins in Sport Fish

Background and Rationale

Dioxins (including chlorinated dibenzodioxins and dibenzofurans) are a third member of the class of pollutants considered to have the most severe impacts on Bay water quality because the entire Bay is above thresholds for concern, and the degree of impairment is well above those thresholds (Connor et al. 2004a).

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. (2004a) 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. A TMDL for dioxins is currently in the early development stage. 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 11). 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 distribution of the data for each year sampled. Consistent with the evaluation scheme described under "Background and Rationale," the distribution is described with percentiles (5^{th}, 25^{th}, 50^{th}, 75^{th}, 95^{th}). 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. 2004a).

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 11). Median dioxin TEQ concentrations in white croaker have been over ten times higher than the target. Without no consumption ATLs for dioxins from OEHHA, however, there is an insufficient basis for determining that dioxins should be categorized as a high concern. Therefore dioxins were placed in the "moderate concern" 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. The overall assessment for dioxins was therefore two stars.

3. Dieldrin in Sport Fish

Background and Rationale Dieldrin is an organochlorine insecticide that was widely used in the U.S. from 1950 to 1974, primarily on termites and other soil-dwelling insects, as a wood preservative, in moth-proofing clothing and carpets, and on cotton, corn, and citrus crops (USEPA, 1995a). Restrictions on dieldrin use began in 1974. Most uses in the U.S. were banned in 1985. Dieldrin use for underground termite control continued until voluntarily canceled by industry in 1987 (USEPA, 1995a). Dieldrin and two other organochlorine pesticides (DDTs and chlordanes) are often referred to as "legacy pesticides" (Connor et al. 2004b).

Dieldrin and the other legacy pesticides have similar properties, and are also similar in many ways to PCBs and dioxins. They are highly persistent, strongly associated with sediment particles, widely distributed throughout the Bay and its watershed, and reach high concentrations in humans and wildlife at the top of the food chain. The human and wildlife health risks of the legacy pesticides are similar to those for PCBs. However, concentrations of the legacy pesticides in sport fish are not as elevated relative to their thresholds for concern.

Concentrations of dieldrin and the other legacy pesticides in sport fish tissue are the key indicators for these pollutants. The San Francisco Bay Regional Water Quality Control Board (Water Board) has not established targets for the legacy pesticides. A TMDL for legacy pesticides is currently in the early development stage. In the absence of a Water Board target, the same indicator species used for the PCBs TMDL (white croaker and shiner surfperch) were used.

Data Source The dieldrin indicator was calculated using data from the same RMP sport fish monitoring program described for the methylmercury in sport fish indicator. 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 and shiner surfperch, the key indicator species for the legacy pesticides, have been sampled consistently over the years (Figure 12).

Methods and Calculations The sport fish dieldrin indicator (Figure 12) is based on available data for shiner surfperch and white croaker each sampling year. As in the PCBs TMDL, comparison of these two species of fish to thresholds is protective and provides a margin of safety, because dieldrin 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 dieldrin 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.

Goals, Targets and Reference Conditions The no consumption ATL for dieldrin is 46 ppb. The level below which OEHHA considers recommending consumption of up to three eight ounce servings per week (the two serving ATL) is 15 ppb.

Results

In the most recent sampling year, both of the dieldrin indicator species had average concentrations well below the two serving ATL of 15 ppb (Figure 12). The Bay-wide averages for shiner surfperch and white croaker in 2009 were 1.1 ppb and 0.5 ppb, respectively.

No clear pattern of long-term decline in dieldrin concentrations has been evident in these species. Concentrations in white croaker in 2009 were the lowest observed since monitoring began in 1994, but this was due to the switch to analyzing white croaker fillets without skin (discussed further in the PCBs section above) and the unusually low average fat content of the croaker collected in 2009. Concentrations in shiner surfperch in 2009 were moderate compared to past years, and the time series does not suggest a trend. Dieldrin concentrations in mussels in the Bay declined sharply in the 1980s (Gunther et al. 1999), but have not declined appreciably in either sport fish or bivalves over the past 20 years (Davis et al. 2007).

No distinct differences among the three regions sampled were evident, although concentrations in the South Bay were more variable. The time series for shiner surfperch in San Pablo Bay suggests a possible downward trend.

The two dieldrin indicator species had Baywide average concentrations well below the two serving per week ATL of 15 ppb, corresponding to the “goal attained” category in Figure 9. Dieldrin concentrations can be expected to continue to gradually decline. The summary rating for dieldrin in Bay sport fish is therefore five stars.

4. DDTs in Sport Fish

Background and Rationale DDT is an organochlorine insecticide that was used very extensively in home and agricultural applications in the U.S. beginning in the late 1940s and continuing in the U.S. until the end of 1972, when all uses, except emergency public health uses, were canceled (USEPA 1995). The primary sources of DDT to the Bay are probably continuing transport of contaminated soils and sediments from urban and agricultural sites of historic use, and remobilization of residues from Bay sediments. The terms DDT or DDTs are often used to refer to a family of isomers (i.e., p,p’-DDT and o,p’-DDT) and their breakdown products (p,p’-DDE, o,p’-DDE, p,p’-DDD, and p,p’-DDD). DDT data are often expressed as the sum of these six components, and this approach is recommended by USEPA (2000). DDT and its metabolites DDE and DDD are neurotoxic and are also classified by USEPA as probable human carcinogens (USEPA 1995).

Concentrations of DDTs in sport fish tissue are the key impairment indicator for this pollutant. Other considerations regarding thresholds were described above in the Dieldrin section.

Data Source The DDTs indicator was calculated using data from the same RMP sport fish monitoring program described for the methylmercury in sport fish indicator. 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 and shiner surfperch, the key indicator species for the legacy pesticides, have been sampled consistently over the years (Figure 13).

Methods and Calculations The sport fish DDTs indicator (Figure 13) is based on available data for shiner surfperch and white croaker each sampling year. As in the PCBs TMDL, comparison of these two species of fish to thresholds is protective and provides a margin of safety, because DDT 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 DDT 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.

Goals, Targets and Reference Conditions The no consumption ATL for DDTs is 2100 ppb. The level below which OEHHA considers recommending consumption of up to three eight ounce servings per week (the two serving ATL) is 520 ppb.

Results

In the most recent sampling year, both of the DDT indicator species had average concentrations well below the two serving ATL of 520 ppb (Figure 13). The Bay-wide averages for shiner surfperch and white croaker in 2009 were 22 ppb and 9 ppb, respectively.

No clear pattern of long-term decline in DDT concentrations has been evident in these species. Concentrations in white croaker in 2009 were the lowest observed since monitoring began in 1994, but this was due to the switch to analyzing white croaker fillets without skin (discussed further in the PCBs section above) and the unusually low average fat content of the croaker collected in 2009. Concentrations in shiner surfperch in 2003, 2006, and 2009 were low relative to past years, possibly suggesting a trend. DDT concentrations in the Bay have declined since the ban in 1972 (Davis et al. 2007), and are expected to continue on a downward trajectory.

DDT concentrations and trends were similar in the three regions sampled. The time series for all three regions indicate relatively low concentrations from 2003-2009; continued monitoring will determine whether this is actually represents a decline.

The two DDT indicator species had Baywide average concentrations well below the two serving ATL of 520 ppb, corresponding to the “goal attained” category in Figure 9. DDT concentrations can be expected to continue to gradually decline. The summary rating for DDTs in Bay sport fish is therefore five stars.

5. Chlordanes in Sport Fish

Background and Rationale Chlordane is another organochlorine insecticide that was used extensively in home and agricultural applications (including corn, grapes, and other crops) in the U.S. for the control of termites and many other insects (USEPA 1995). Like PCB, chlordane is a term that represents a group of a large number (140) of individual compounds (Dearth and Hites 1991). Restrictions on chlordane use began in 1978, and domestic sales and production ceased in 1988 (USEPA 1995). As for DDT, the primary sources of chlordane to the Bay are probably continuing transport of soils and sediments from urban and agricultural sites of historic use and remobilization of residues from Bay sediments.

Chlordane data are usually expressed as the sum of several of the five most abundant and persistent components and metabolites of the technical chlordane mixture. Chlordane is neurotoxic and is classified by USEPA as a probable human carcinogen (USEPA 2000). Like PCBs and DDT, chlordane compounds are very persistent in the environment, resistant to metabolism, have a strong affinity for lipid, and biomagnify in aquatic food webs (Suedel et al. 1994).

Concentrations of chlordanes in sport fish tissue are the key impairment indicator for this pollutant. Other considerations regarding thresholds were described above in the Dieldrin section.

Data Source The chlordanes indicator was calculated using data from the same RMP sport fish monitoring program described for the methylmercury in sport fish indicator. 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 and shiner surfperch, the key indicator species for the legacy pesticides, have been sampled consistently over the years (Figure 14).

Methods and Calculations The sport fish chlordanes indicator (Figure 14) is based on available data for shiner surfperch and white croaker each sampling year. As in the PCBs TMDL, comparison of these two species of fish to thresholds is protective and provides a margin of safety, because chlordane 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 chlordane 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.

Goals, Targets and Reference Conditions The no consumption ATL for chlordanes is 560 ppb. The level below which OEHHA considers recommending consumption of up to three eight ounce servings per week (the two serving ATL) is 190 ppb.

Results

In the most recent sampling year, both of the chlordane indicator species had average concentrations well below the two serving ATL of 190 ppb (Figure 14). The Bay-wide averages for shiner surfperch and white croaker in 2009 were 7 ppb and 2 ppb, respectively.

No clear pattern of long-term decline in chlordane concentrations has been evident in these species. Concentrations in white croaker in 2009 were the lowest observed since monitoring began in 1994, but this was due to the switch to analyzing white croaker fillets without skin (discussed further in the PCBs section above) and the unusually low average fat content of the croaker collected in 2009. Chlordane concentrations in shiner surfperch in 2009 were similar to past years. Other Bay species have generally declined since the ban in 1988 (Davis et al. 2007), and chlordanes generally are expected to continue on a gradual downward trajectory.

The two chlordane indicator species had Baywide average concentrations well below the two serving ATL of 190 ppb, corresponding to the "goal attained" category in Figure 9. Chlordane concentrations can be expected to continue to gradually decline. The summary rating for chlordanes in Bay sport fish is therefore five stars.

6. Selenium in Sport Fish

Background and Rationale San Francisco Bay has been on the 303(d) List since 1998 for selenium because bioaccumulation of this element has led to recurring health advisories for local hunters against consumption of diving ducks. Moreover, elevated selenium concentrations found in biota often exceed levels that can cause potential reproductive impacts in white sturgeon and are often higher than levels considered safe for fish and other wildlife species in the Estuary. Sources and pathways leading to the possible impairment in northern and southern segments of the Bay differ significantly and therefore a separate approach to addressing the problem in these segments is being followed. Thus, a TMDL is being developed for the North San Francisco Bay segments only, which include a portion of the Sacramento/San Joaquin Delta, Suisun Bay, Carquinez Strait, San Pablo Bay, and Central Bay. This North Bay Selenium TMDL project was initiated in 2007 to assess the current state of impairment in the North Bay, identify pathways for bioaccumulation, enhance understanding of the relationship between sources of selenium and fish and wildlife exposure, and establish site-specific water quality targets protective of aquatic biota. In developing the TMDL, the Water Board, with support from stakeholders, is conducting a series of analysis to refine understanding of the behavior of selenium in the Estuary that will help formulate a strategy for attaining water quality standards. A Preliminary TMDL Project Report was published in January 2011 (SFBRWQCB 2011). As part of this information gathering effort, the RMP measured selenium concentrations in all eight sport fish species sampled in 2009 (Davis et al. 2011).

Concentrations of selenium in sport fish tissue are an impairment indicator of secondary importance for this pollutant. Risks to aquatic life are greater and are the impetus for the TMDL. The sport fish species of greatest concern is white sturgeon, which accumulates higher selenium concentrations than other sport fish due to its preference for *Corbula*, an abundant clam species that has a strong tendency to accumulate selenium (Stewart et al. 2004).

Data Source The selenium indicator was calculated using data from the same RMP sport fish monitoring program described for the methylmercury in sport fish indicator. 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 sturgeon, the key indicator species for selenium, has been sampled consistently over the years (Figure 15).

Methods and Calculations The sport fish selenium indicator (Figure 15) is based on available data for white sturgeon for each sampling year. Focusing on this species is protective and provides a margin of safety because it has the highest selenium concentrations among the fish species measured and sport recreational fishers likely consume a variety of fish species, including those with lower selenium concentrations. The time series plots show the average concentration 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.

Goals, Targets and Reference Conditions The no consumption ATL for selenium is 15 ppm. The level below which OEHHA considers recommending consumption of up to three eight-ounce servings per week (the two serving ATL) is 2.5 ppm.

Results

In the most recent sampling year, white sturgeon had a Baywide average concentration (1.4 ppm) well below the two serving ATL of 2.5 ppm (Figure 15). Concentrations measured in seven other sport fish species in the Bay in 2009 were much lower than in white sturgeon (Davis et al. 2011). No clear pattern of long-term decline in selenium concentrations has been evident in Bay white sturgeon. Recent results for *Corbula* in the North Bay indicate declines (Stewart, USGS, personal communication). No differences among the three Bay regions sampled were evident.

White sturgeon had a Baywide average concentration well below the two serving per week ATL of 2.5 ppm, corresponding to the “goal attained” category in Figure 15. The summary rating for selenium in Bay sport fish is therefore five stars.

7. PBDEs in Sport Fish

PBDEs, a class of bromine-containing flame retardants that was practically unheard of in the early 1990s, increased rapidly in the Bay food web through the 1990s and are now pollutants of concern. They have not been placed on the 303(d) List, but information on them is lacking and they are being studied through the RMP to better understand their spatial distribution, temporal trends, and the risks they pose to wildlife and humans. The California Legislature has banned the use of two types of PBDE mixtures (“penta” and “octa”) in 2006, but one mixture remains in use (“deca”).

In May 2011, OEHHA published thresholds for PBDEs (Klasing and Brodberg 2011). PBDE concentrations in all samples were far below the lowest OEHHA threshold (the 100 ppb 2 serving ATL), indicating that PBDE concentrations in Bay sport fish are not a concern with regard to human health. The Baywide average for shiner surfperch, the species with the highest concentrations in 2009, was 8 ppb.

The Baywide average for shiner surfperch in 2009 was lower than the averages observed in 2003 and 2006. A decline might be anticipated in response to the bans on the penta and octa mixes, but how quickly the decline would occur as the overall inventory in the watersheds is reduced is unknown. Given the short time series available and a potential lack of comparability due to the switch to a new method in 2009, it is unclear whether the lower concentrations in 2009 are a sign of a real decline or not. Continued monitoring of sport fish and other matrices in the Bay will be needed to determine whether the bans of the penta and octa mixtures are indeed reducing PBDE concentrations in the Bay food web.

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 Bay. Due to inadequate screening of the hazards of these chemicals, some may accumulate in the Bay food web and cause exposure in people who consume Bay fish. As understanding advances, some of these contaminants emerge as posing risks to the health of humans and wildlife.

The 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 Bay, accumulating in the Bay food web, and leading to human exposure and risk through consumption of Bay sport fish. Past experience has shown that the Bay 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 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 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. 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.

IS THE BAY SAFE FOR SWIMMING?

Background and Rationale

Recreation, including water sports, provides numerous physical, social, and psychological benefits to participants and spectators. Every year countless Bay Area residents and visitors are drawn to Bay 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 Bay 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. In order to transmit infectious disease the infectious agent must be present, and in sufficient quantities to produce the infection and/or disease, and the susceptible individual must come into contact with the pathogen (Cooper 1991). Although a wide variety of pathogens have been identified in raw wastewater relatively few types appear to be responsible for the majority of waterborne illnesses caused by pathogens of wastewater origin (Soller, et al. 2010a). Further, and most importantly, reliable and effective wastewater treatment occurs consistent with State and Federal standards throughout the San Francisco Bay Area.

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 (Heal the Bay 2011). 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.

The frequency at which Bay beaches are posted or closed is another valuable indicator of whether the Bay is safe for swimming. This additional metric was also examined and is discussed below, along with other supplemental information relating to beach water quality.

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 30 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.

Methods and Calculations Heal the Bay (2011) 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 an 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 2.

Results

Overall, the monitoring data and resulting grades (Table 3) indicate that most Bay beaches are safe for swimming in the summer, but that bacterial contamination is a concern at a few beaches in the summer, and at most beaches in wet weather.

Data for the summer beach season in 2010 are available for 27 of the 30 beaches that have been monitored over the past five years. In 2010, 19 of the 27 monitored beaches received an A or A+ grade, reflecting minimal exceedance of standards. Ten of these beaches received an A+: Coyote Point, Alameda Point South, Bath House, Windsurf Corner, Sunset Road, Shoreline Drive, Hyde Street Pier, Crissy Field East, Crissy Field West, and Schoonmaker Beach. Most Bay beaches, therefore, are quite safe for swimming in the summer.

Seven of the 27 beaches monitored in the summer in 2010 had grades of B or lower, indicating varying degrees of exceedance of bacteria standards. Keller Beach was the one beach receiving an F. Five beaches received a D, including one in Contra Costa County, two in San Mateo County, and two in San Francisco County. These low grades indicate an increased risk of illness or infection.

Overall, the average grade for the 27 beaches monitored from April-October was a B (Table 3).

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, only five of 22 beaches with data received an A. Six of these 22 beaches, on the other hand, received an F. The average grade for these beaches in wet weather was a C+ (Table 3).

Additional Discussion

Beach Closure Data

The frequency of beach closures is another informative metric for evaluating how safe the Bay is for swimming. Based upon the number of days beaches were closed or posted with advisories warning against water contact recreation, Bay beaches were open 80% to 100% of the time during the prime beach season of April through October from 2006 through 2010 (Figures 16-20). Monitoring data from the City and County of San Francisco, required to monitor and apply the high-use standards year-round by NPDES permit, illustrate a pattern found throughout the Bay: bacteria water quality is generally very good during dry weather, but tends to degrade during wet weather (Figure 21).

For beach users trying to decide whether or not to engage in water contact recreation at a particular beach, the recent monitoring data provided by some Bay counties (Table 1) along with the Heal the Bay on-line grades (Table 1) represent the easiest, most robust, and consistent means of evaluating beach water quality. The Heal the Bay grading system incorporates established water quality thresholds and has been endorsed by regulators and beach managers. Beach users concerned about exposure to elevated FIB should heed beach closures and advisory warnings and avoid water contact recreation during and for up to 72 hours after rainstorms, especially at beaches with flowing creeks, storm drains, or combined sewer discharges.

FIB Sources

The sources of FIB at specific sites are often unknown, but potentially include fecal contamination from humans (leaky sewer systems, sanitary sewer overflows, storm water, combined sewer discharges during wet weather, septic tanks, illegal boat discharges, and babies and other people defecating directly at the beach); fecal contamination from non-humans (dogs and other pets, wildlife such as birds, seals, sea lions, deer, etc., and cattle, horses and other agrarian land uses); and non-enteric environmental FIB.

Environmental FIB are a relatively new discovery in California. Recent studies have shown that marine sands in California can serve as a reservoir of FIB that can contribute to water column concentrations (Ferguson, et al. 2005, Lee, et al. 2006, Yamahara, et al. 2007, 2009, Halliday, et al. 2010). Other sources of environmental FIB include beach wrack, salt marshes, and upland soils (Imamura, et al. in press, Grant, et al. 2001, Whitman, et al. 2006). One study has found an increased risk of enteric illness with sand contact at marine beaches (Heaney, et al. 2009). Several recent studies have used quantitative microbial risk assessments to estimate the health risks to humans from exposure to recreational waters contaminated by non-human fecal sources

(EPA 2010a, Schoen and Ashbolt 2010, Soller, et al. 2010b). They have found that the risk of illness ranged from similar for cattle impacted waters to substantially lower for chicken, pig, and seagull impacted waters than the risk from exposure to human impacted waters based upon current EPA (1986) Recreational Water Quality Criteria. Similar studies are needed for non-human sources likely important in the Bay such as dogs and marine mammals.

Currently used culture-based methods for identifying and enumerating FIB do not allow differentiation of the various possible sources. In addition, culture-based methods require 18 - 24 hours before results are available so warnings to the swimming public can only happen after elevated FIB concentrations occur. Moreover, FIB concentrations in recreational waters are highly variable from year to year as well as spatially, during time of day, and tidal cycle (Boehm and Weisberg 2005, Boehm 2007, Boehm, et al. 2009).

Best Management Practices

Best management practices for beach managers should include sanitary surveys to identify and mitigate contamination sources where possible. Low impact design installations may be possible at some sites to retain and treat storm water before it reaches beaches. Diversion of storm water away from bathing beaches where possible may provide another solution. Repair and replacement of defective and aging sanitary sewer systems will be necessary in many instances before human fecal sources are considered controlled. Sanitary surveys should also inform monitoring plans as should site-specific knowledge of how FIB concentrations vary diurnally, are affected by tidal forcing, and by photoperiod.

Future Directions

Beach monitoring is transitioning from the traditional culture-based methods for determining FIB to more rapid molecular methods that will allow same-day notification to the public. The EPA is currently involving scientists and stakeholders in a process to produce revised or new standards for recreational waters by October 2012. Possible changes could include adding new, human-specific indicators and rapid methods for detecting FIB. The rapid methods use quantitative polymerase chain reaction (qPCR) to amplify and identify genetic material present in the sample and thus also have the additional potential of source identification. The rapid techniques are not without logistical and technical constraints however.

Logistically, the qPCR sample analysis time of 2 to 4 hours can only begin once samples have arrived in the laboratory. Sample preparation, QA/QC, and data analysis are additional steps that add time to delivery of results to the public. Sample collection can take several hours, especially for large counties with monitoring sites on both ocean and bay coasts. Sample collection at first light would help decrease the time to notification, but that raises potential safety concerns for sample collectors and would not account for inactivation of FIB by sunlight (Boehm, et al. 2009) nor FIB contributions from the public directly at the beach. In addition, notification by late morning or mid-day, while an improvement, will not serve many local users who enjoy early morning water recreation. A demonstration project applying qPCR to beach monitoring in southern California successfully achieved notification by mid-day for a period of eight weeks (Griffith and Weisberg 2011). They overcame many of the logistical problems by limiting the number of sites to which the rapid methods were applied, modifying the sample collection routine for those sites, prudent method selection and automation of data analysis, and augmenting normal beach posting procedures with social media, the internet, and remotely operated electronic message boards at the test beaches. Interestingly, they recognized that adoption of rapid methods will create expectations of more frequent sampling.

Research and development will no doubt overcome the technological constraints of qPCR as applied to beach monitoring. One of the most important is the current inability of the method to distinguish between viable and non-viable microbes. This makes the technique problematic at beaches influenced by disinfected wastewater effluent and for FIB inactivated by sunlight. Methods are being developed to overcome this limitation, but they will necessitate longer processing and analysis times. Despite these constraints, qPCR represents a valuable new tool in beach monitoring, particularly because of the reduced analysis time and source identification potential.

Another probable outcome of the EPA revision of water quality standards for recreational waters is the incorporation of modeling into beach advisory decisions, at least at some beaches. One such model is the USEPA's Virtual Beach 2.0 which uses multiple linear regressions (USEPA 2011). A partial least squares regression model has been demonstrated effective at a beach in southern California (Hou et al. 2006).

Genetic microarrays are another tool that are just beginning to be applied to shoreline monitoring. Microarrays use genetic probes to match gene sequences present in the sample. The main advantage of a microarray is the ability to detect thousands of microbial taxa in a single sample. They can be customized to look for specific taxa, including strains of a single taxon (e.g., virulent and non-virulent strains of *E. coli*), and it should be possible to configure hybrid microarrays that detect both bacteria and viruses simultaneously so that pathogens can be detected directly rather than through indicators. Microarrays are not rapid technology (PCR is a preliminary step) and the bioinformatics involved in assessing the results are formidable, but tracking a larger proportion of the microbial community present at a beach may allow beach managers to customize warnings and advisories to the specific risks at each site. For example, the loading and seasonality of non-enteric environmental FIB on beaches can be significantly different from those of fecal pollution events (USEPA 2010b).

Adoption of new methods and new indicators will increase protection of public health by providing same day notification in many cases and identification of FIB sources, as well as targeting human-specific indicators and eventually pathogens directly. Sanitary surveys in conjunction with source identification and determining the timing and seasonality of environmental FIB vs. fecal contamination events, perhaps in combination with robust modeling, will allow beach managers to properly balance public health protection and access to recreational opportunity on a site by site basis.

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REFERENCES

Adelsbach, T.L. and T. Maurer. 2007. Dioxin Toxic Equivalents, PCBs, and PBDEs in Eggs of Avian Wildlife of San Francisco Bay. U.S. Fish and Wildlife Service, Sacramento, CA.

Boehm, A.B. and S.B. Weisberg 2005. Tidal forcing of enterococci at marine recreational beaches at fortnightly and semidiurnal frequencies. Environ. Sci. Technol. 39(15):5575-5583.

Boehm, A.B. 2007. Enteococci concentrations in diverse coastal environments exhibit extreme variability. Environ. Sci. Technol. 41(24):8227-8232.

Boehm, A.B., K.M. Yamahara, D.C. Love, B.M. Peterson, K. McNeil, and K.L. Nelson 2009. Covariation and photoinactivation of traditional and novel indicator organisms and human viruses at a sewage-impacted marine beach. Environ. Sci. Technol. 43(21):8046-8052.

Brant, S.V., A.N. Cohen, D. James, L. Hui, A. Hom, and E.S. Loker 2010. Cercarial dermatitis transmitted by exotic marine snails. Emerging Infectious Diseases 16(9):1357-1365.

Connor, M., D. Yee, J.A. Davis, and C. Werme. 2004a. Dioxins in San Francisco Bay Conceptual Model/Impairment Assessment. SFEI Contribution 309. Prepared for the Clean Estuary Partnership.

Connor, M., J.A. Davis, J. Leatherbarrow, and C. Werme. 2004b. Legacy Pesticides in San Francisco Bay Conceptual Model/Impairment Assessment. SFEI Contribution 313. Prepared for the Clean Estuary Partnership.

Cooper, R.C. 1991. Public health concerns in wastewater reuse. Water Science & Technology 24(9):55-65.

Davis, J.A., M.D. May, B.K. Greenield, R. Fairey, C. Roberts, G. Ichikawa, M.S. Stoelting, J.S. Becker, and R.S. Tjeerdema. 2002. Contaminant concentrations in sport fish from San Francisco Bay, 1997. Mar. Pollut. Bulletin. 44: 1117-1129.

Davis, J.A., J.A. Hunt, B.K. Greenfield, R. Fairey, M. Sigala, D.B. Crane, K. Regalado, and A. Bonnema. 2006. Contaminant Concentrations in Fish from San Francisco Bay, 2003. SFEI Contribution #432. San Francisco Estuary Institute, Oakland, CA.

Davis, J.A., F. Hetzel, and J.J. Oram. 2007a. Polychlorinated biphenyls (PCBs) in San Francisco Bay. Environmental Research 105: 67-86.

Davis, J.A., J.L. Grenier, A.R. Melwani, S.N. Bezalel, E.M. Letteney, E.J. Zhang, M. Odaya. 2007. Bioaccumulation of Pollutants in California Waters: A Review of Historic Data and Assessment of Impacts on Fishing and Aquatic Life. A Report of the Surface Water Ambient Monitoring Program (SWAMP). California State Water Resources Control Board, Sacramento, CA.

Davis, J.A., K. Schiff, A.R. Melwani, S.N. Bezalel, J.A. Hunt, R.M. Allen, G. Ichikawa, A. Bonnema, W.A. Heim, D. Crane, S. Swenson, C. Lamerdin, and M. Stephenson. 2011. Contaminants in Fish from the California Coast, 2009: Summary Report on Year One of a Two-Year Screening Survey. A Report of the Surface Water Ambient Monitoring Program (SWAMP). California State Water Resources Control Board, Sacramento, CA.

Dearth, M.A. and R.M. Hites. 1991. Complete analysis of technical chlordane using negative ionization mass spectrometry. Environ. Sci. Technol. 25(2): 245–254.

Eagles-Smith, C.A., J.T. Ackerman, S.E.W. de la Cruz, and J.Y. Takekawa. 2009. Mercury bioaccumulation and risk to three waterbird foraging guilds is influenced by foraging ecology and breeding stage. Environmental Pollution 157: 1993–2002.

Fairey, R., K. Taberski, S. Lamerdin, E. Johnson, R. P. Clark, J. W. Downing, J. Newman, and M. Petreas. 1997. Organochlorines and other environmental contaminants in muscle tissues of sportfish collected from San Francisco Bay. Marine Pollution Bulletin 34:1058-1071.
Ferguson, D.M., D.F. Moore, M.A. Getrich, and M.H. Zhowandai 2005. Enumeration and speciation of enterococci found in marine and intertidal sediments and coastal water in southern California. Journal of Applied Microbiology 99:598-608.
Grant, S.B., B.F. Sanders, A.B. Boehm, J.A. Redman, J.H. Kim, R.D. Mrse, A.K. Chu, M. Gouldin, C.D. McGee, N.A. Gardiner, B.H. Jones, J. Svejkovsky, G.V. Leipzig, and A. Brown 2001. Generation of enterococci bacteria in a coastal saltwater marsh and its impact on surf zone water quality. Environ. Sci. Technol. 35(12):2407-2416.
Greenfield, B. K., J. A. Davis, R. Fairey, C. Roberts, D. Crane and G. Ichikawa. 2005. Seasonal, interannual, and long-term variation in sport fish contamination, San Francisco Bay. Science of the Total Environment 336: 25– 43.
Griffith, J.F. and S.B. Weisberg 2011. Challenges in implementing new technology for beach water quality monitoring: lessons from a California demonstration project. Marin Technology Society Journal 45(2):65-73.
Gunther, A.J., J.A. Davis, D. Hardin, J. Gold, D. Bell, J. Crick, G. Scelfo, J. Sericano, M. Stephenson. 1999. Long term bioaccumulation monitoring with transplanted bivalves in San Francisco Bay. Marine Pollution Bulletin 38(3): 170-181.
Halliday, E., J.F. Griffith, and R.J. Gast 2010. Use of an exogenous plasmid standard and quantitative PCR to monitor spatial and temporal distribution of Enterococcus spp. in beach sands. Limnol. and Oceanogr.: Methods 8:146-154.
Heal the Bay 2007. 17th Annual Report 2006 – 2007: Beach Report Card. Heal the Bay, Santa Monica, CA; 81 pp.
Heal the Bay 2008. 18th Annual Report 2007 – 2008: Beach Report Card. Heal the Bay, Santa Monica, CA; 83 pp.
Heal the Bay 2009. 19th Annual Report 2008 – 2009: Beach Report Card. Heal the Bay, Santa Monica, CA; 81 pp.
Heal the Bay 2010. 20th Annual Report 2009 – 2010: Beach Report Card. Heal the Bay, Santa Monica, CA; 77 pp.
Heal the Bay 2011. 21st Annual Beach Report Card 2010 – 2011. Heal the Bay, Santa Monica, CA; 98 pp.
Heaney, C.D., E. Sams, S. Wing, S. Marshall, K. Brenner, A.P. Dufour, and T.J. Wade 2009. Contact with beach sand among beachgoers and risk of illness. Amer. J. Epidemiolgy 170(2):164-172.
Hou, D., S.J.M. Rabinovici, and A.B. Boehm 2006. Enterococci predictions from partial least squares regression models in conjunction with a single-sample standard improve the efficacy of beach management advisories. Environ. Sci. Technol. 40(6):1737-1743.
Hunt, J.A., J.A. Davis, B.K. Greenfield, A. Melwani, R. Fairey, M. Sigala, D.B. Crane, K. Regalado, and A. Bonnema. 2008. Contaminant Concentrations in Fish from San Francisco Bay, 2006. SFEI Contribution #554. San Francisco Estuary Institute, Oakland, CA.
Imamura, G.J., R.S. Thompson, A.B. Boehm In Press. Wrack promotes the persistence of faecal indicator bacteria in marine sands and seawater. FEMS Microbiology Ecology [accepted, but not yet published]
Klasing, S. and R. Brodberg. 2011. Development of Fish Contaminant Goals and Advisory Tissue Levels for Common Contaminants in California Sport Fish: Polybrominated Diphenyl

Ethers (PBDEs). California Office of Environmental Health Hazard Assessment, Sacramento, CA.
Krieger, F., M. Pla, and C. Weir. 2007. The History of Municipal Wastewater Treatment: 35 Years of POTWs Protecting the Bay. In SFEI. 2007. The Pulse of the Estuary: Monitoring and Managing Water Quality in the San Francisco Estuary. SFEI Contribution 532. San Francisco Estuary Institute, Oakland, CA.
Lee, C.M., T.Y. Lin, C.-C. Lin, G.A. Kohbodi, A. Bhatt, R. Lee, and J.A. Jay 2006. Persistence of fecal indicator bacteria in Santa Monica Bay beach sediments. Water Res. 40(14):2593-2602.
OEHHA. 1994. Health advisory on catching and eating fish: Interim sport fish advisory for San Francisco Bay. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, Sacramento, CA.
Schoellhamer, D. 2007. Suspended Sediment in the Bay: Past a Tipping Point. In SFEI. 2009. The Pulse of the Estuary: Monitoring and Managing Water Quality in the San Francisco Estuary. SFEI Contribution 583. San Francisco Estuary Institute, Oakland, CA.
Schoen, M.E. and N.J. Ashbolt 2010. Assessing pathogen risk to swimmers at non-sewage impacted recreational beaches. Environmental Science and Technology 44(7):2286-2291.
Schwarzbach, S.E., J.D. Albertson, and C.M. Thomas. 2006. Effects of predation, flooding, and contamination on reproductive success of California Clapper Rails (*Rallus longirorostrus obsoletus*) in San Francisco Bay. The Auk 123(1):45–60.
SFBRWQCB (San Francisco Bay Regional Water Quality Control Board). 2006.Mercury in San Francisco Bay Proposed Basin Plan Amendment and Staff Report for
Revised Total Maximum Daily Load (TMDL) and Proposed Mercury Water Quality Objectives. San Francisco Bay Regional Water Quality Control Board, Oakland, CA.
SFBRWQCB (San Francisco Bay Regional Water Quality Control Board). 2007. San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan). San Francisco Bay Regional Water Quality Control Board, Oakland, CA. http://www.swrcb.ca.gov/sanfranciscobay/basin_planning.shtml
SFBRWQCB (San Francisco Bay Regional Water Quality Control Board). 2008a. Exhibit A: Proposed Basin Plan Amendment. San Francisco Bay Regional Water Quality Control Board, Oakland, CA. http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/TMDLs/sfbaypcbstmdl.shtml
SFBRWQCB (San Francisco Bay Regional Water Quality Control Board). 2008b. Total Maximum Daily Load for PCBs in San Francisco Bay: Final Staff Report for Proposed Basin Plan Amendment. San Francisco Bay Regional Water Quality Control Board, Oakland, CA. http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/TMDLs/sfbaypcbstmdl.shtml
SFBRWQCB (San Francisco Bay Regional Water Quality Control Board). 2008c. Adopted Basin Plan Amendment. http://www.swrcb.ca.gov/sanfranciscobay/basin_planning.shtml

SFEI. 2000. San Francisco Bay Seafood Consumption Study. San Francisco Estuary Institute, Oakland, CA.
SFEI. 2009. The Pulse of the Estuary: Monitoring and Managing Water Quality in the San Francisco Estuary. SFEI Contribution 583. San Francisco Estuary Institute, Oakland, CA.

Soller, J.A., T. Bartrand, N.J. Ashbolt, J. Ravenscroft, and T.J. Wade 2010a. Estimating the primary etiologic agents in recreational freshwaters impacted by human sources of faecal contamination. Water Research 44:4736-4747.

Soller, J.A., M.E. Schoen, T. Bartrand, J.E. Ravenscroft, N.J. Ashbolt 2010b. Estimated human health risks from exposure to recreational waters impacted by human and non-human sources of faecal contamination. Water Research 44:4674-44691.

Suedel, B.C., J.A. Boraczek, R.K. Peddicord, P.A. Clifford, and T.M. Dillon. 1994. Trophic transfer and biomagnification potential of contaminants in aquatic ecosystems. Rev. Environ. Contam. Toxicol. 136: 21–89.

Thompson, B., T. Adelsbach, C. Brown, J. Hunt, J. Kuwabara, J. Neale, H. Ohlendorf, S. Schwarzbach, R. Spies, K. Taberski. 2007. Biological effects of anthropogenic contaminants in the San Francisco Estuary. Environmental Research 105: 156–174.

USEPA 1986. Ambient water quality criteria for bacteria – 1986. U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Criteria and Standards Division, EPA 440/5-84-002; 18 pp.

USEPA. 1995. Guidance for assessing chemical contaminant data for use in fish advisories: Volume 1, Fish sampling and analysis. EPA 823-R-93-002, U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

USEPA. 2000. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories: Volume 1, Fish Sampling and Analysis, Third Edition. EPA 823-R-93-002B-00-007. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

USEPA 2010a. Quantitative microbial risk assessment to estimate illness in freshwater impacted by agricultural animal sources of fecal contamination. U.S. Environmental Protection Agency, Office of Water, EPA 822-R-10-005; 61 pp. + appendices.

USEPA 2010b. Sampling and consideration of variability (temporal and spatial) for monitoring of recreational waters. U.S. Environmental Protection Agency, Office of Water, EPA 823-R-10-005; 63 pp.

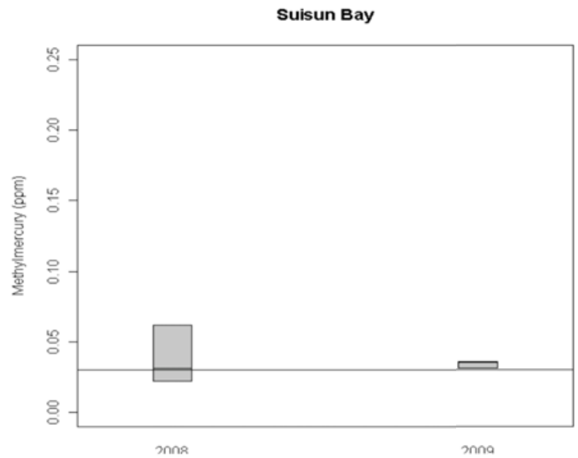
USEPA 2011. Exposure assessment models: virtual beach (VB). U.S. Environmental Protection Agency, Center for Exposure Assessment Modeling, <http://www.epa.gov/ceampubl/swater/vb2/> [accessed: 4/17/2011]

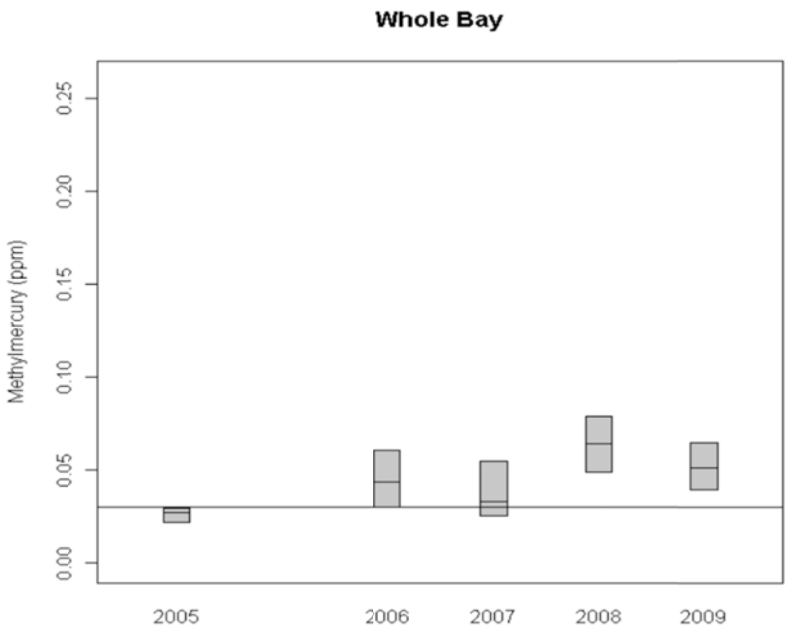
Whitman, R.L., M.B. Nevers, and M.N. Byappanahalli 2006. Examination of the watershed-wide distribution of Escherichia coli along southern Lake Michigan: an integrated approach. Applied Environ. Microbiol. 72(11):7301-7310.

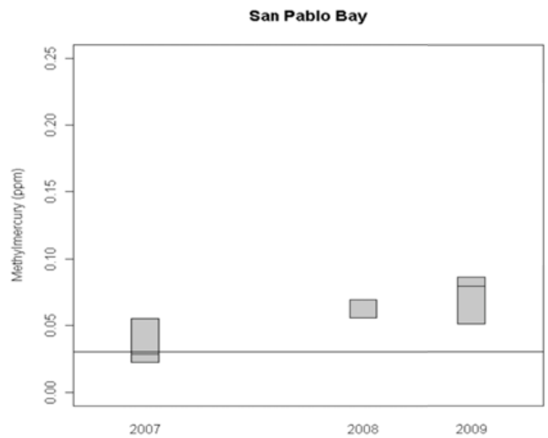
Yamahara, K.M., B.A. Layton, A.E. Santoro, and A.B. Boehm 2007. Beach sands along the California coast are diffuse sources of fecal bacteria to coastal waters. Environ. Sci. Technol. 41(13):4515-4521.

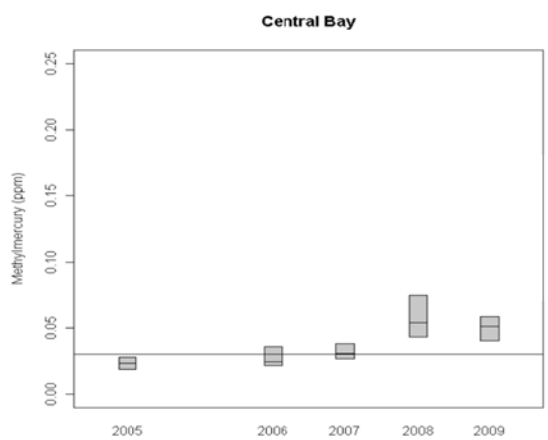
Yamahara, K.M., S.P. Walters, and A.B. Boehm 2009. Growth of enterococci in unaltered, unseeded beach sands subjected to tidal wetting. Appl. Environ. Microbiol. 75:1517-1524.

Figure 1. Methylmercury concentrations in small fish. Plots indicate the 25th, 50th, and 75th. 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 Mercury TMDL.









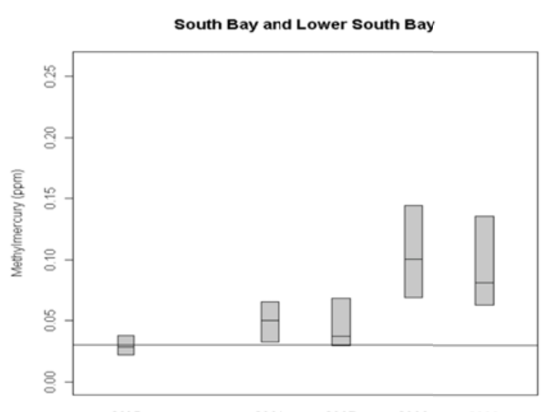


Figure 2. Summary assessment related to the "safe for aquatic life" question. The two key dimensions of water quality problems are their severity (degree of concern) and how quickly the Bay is anticipated to respond to pollution prevention actions (whether rapid progress is likely or not). The overall assessment scores indicated by the stars are based on a combination of these two factors.

	High Concern	*Moderate Concern*	*Low Concern*
Rapid Progress Likely	★★ Exotic Species	★★★ Trash	★★★★ Copper
Rapid Progress Unlikely	★ Methyl-mercury	★★ Sediment Toxicity	

Figure 3. Percent of Bay sediment samples exhibiting toxicity in laboratory assays. Sediment samples are tested in the RMP using amphipods and mussel larvae at xx stations each year.

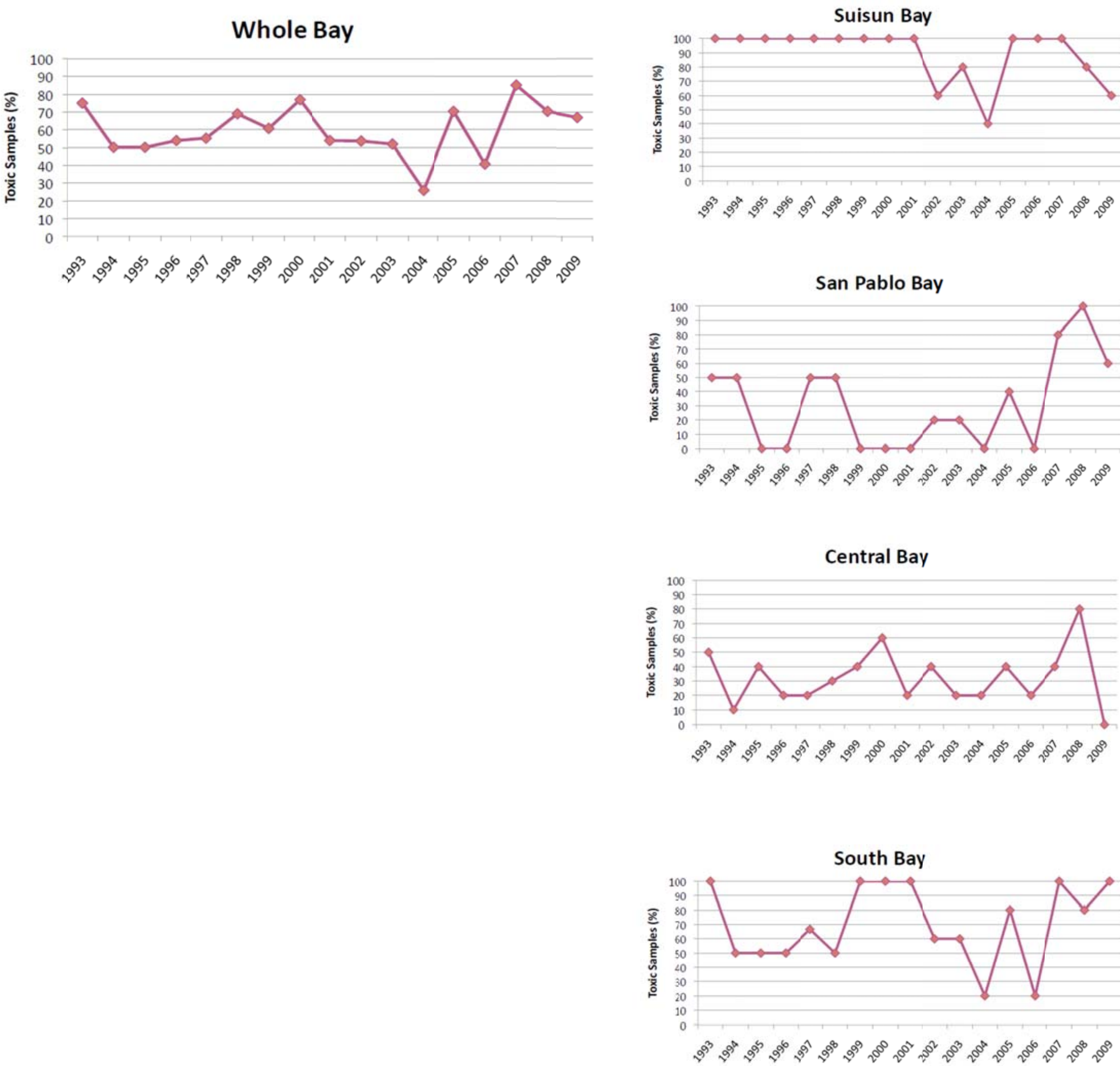


Figure 4. Dissolved copper concentrations in Bay water. Box and whisker plots indicate the 5th, 25th, 50th, 75th, and 95th percentiles. The water quality objective is a maximum of 6.9 ug/L in South Bay, and 6.0 ug/L in the other embayments.

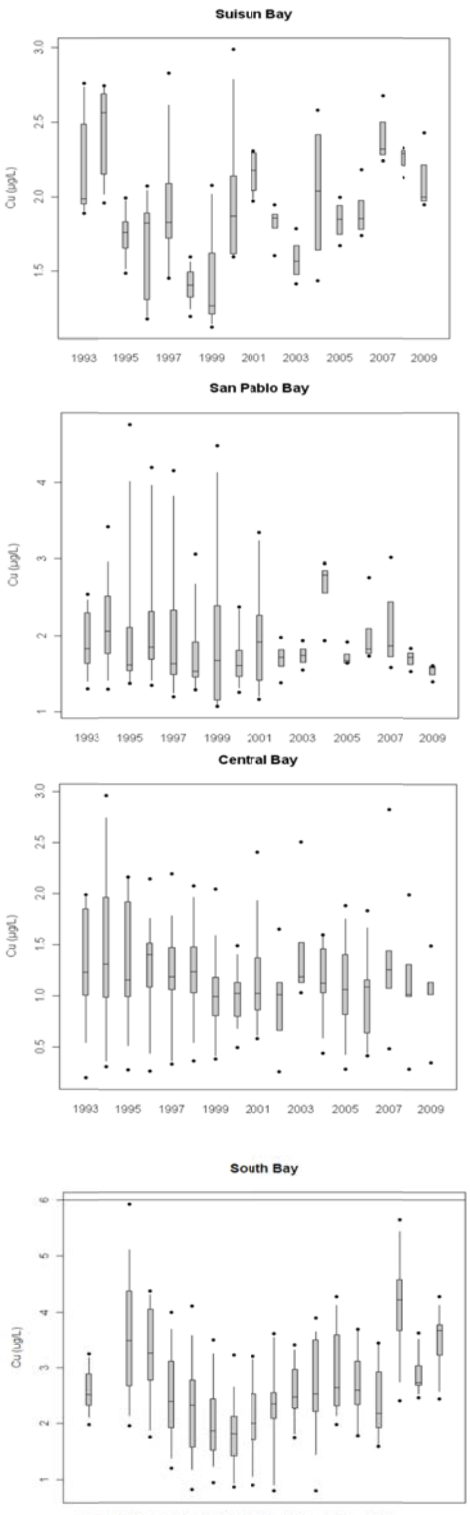


Figure 5. Dissolved oxygen concentrations in Bay water. Box and whisker plots indicate the 5th, 25th, 50th, 75th, and 95th percentiles. Water quality objectives are a minimum of 5 mg/L downstream of Carquinez Strait and a minimum of 7 mg/L upstream of Carquinez Strait.

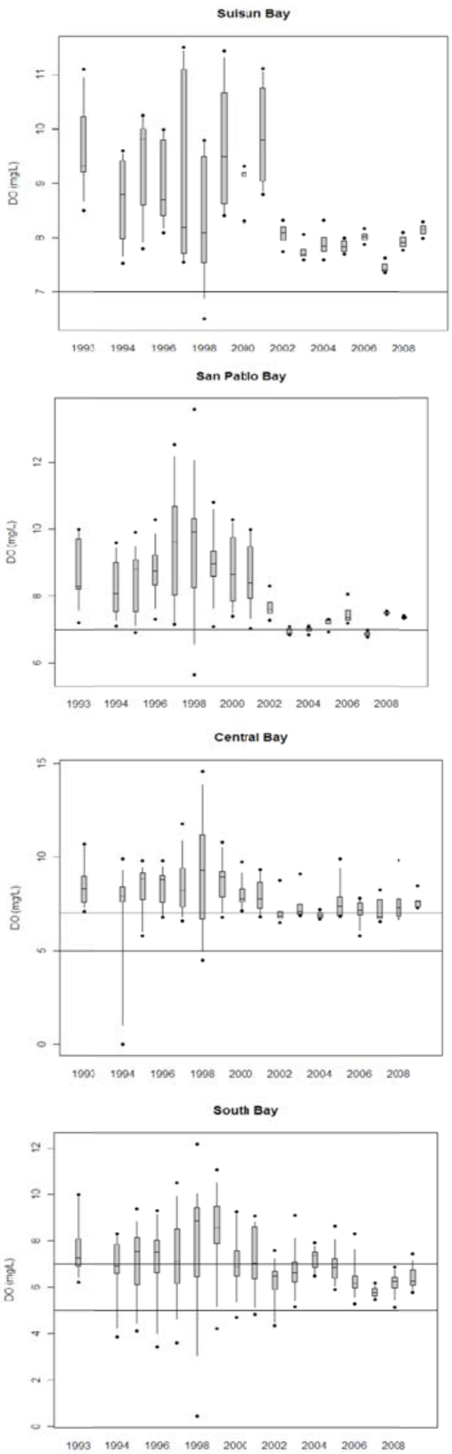


Figure 6. Dissolved silver concentrations in Bay water. Box and whisker plots indicate the 5th, 25th, 50th, 75th, and 95th percentiles. The water quality objective is a maximum of 1.9 ug/L.

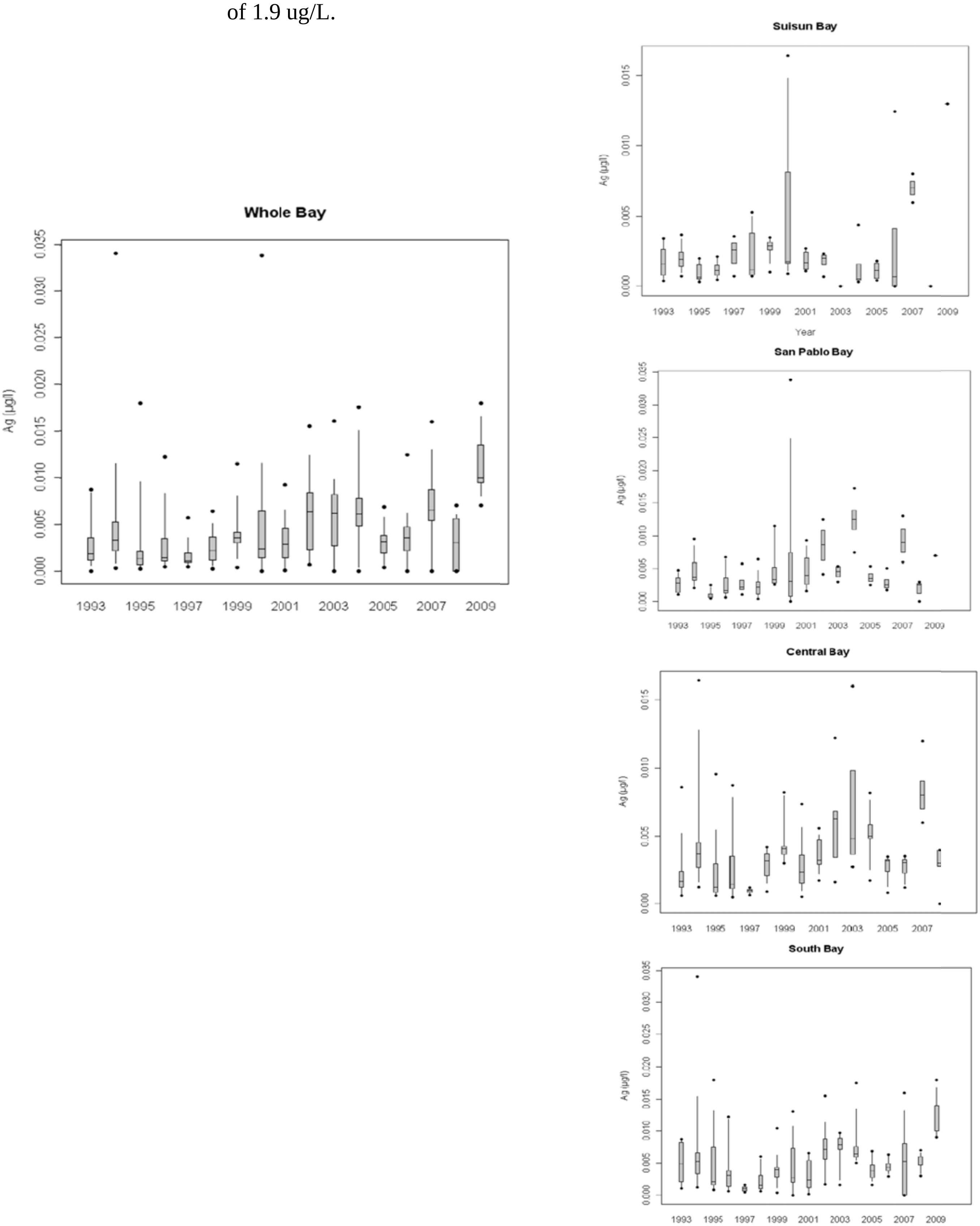


Figure 7. Locations of the five sampling stations in RMP sport fish monitoring.

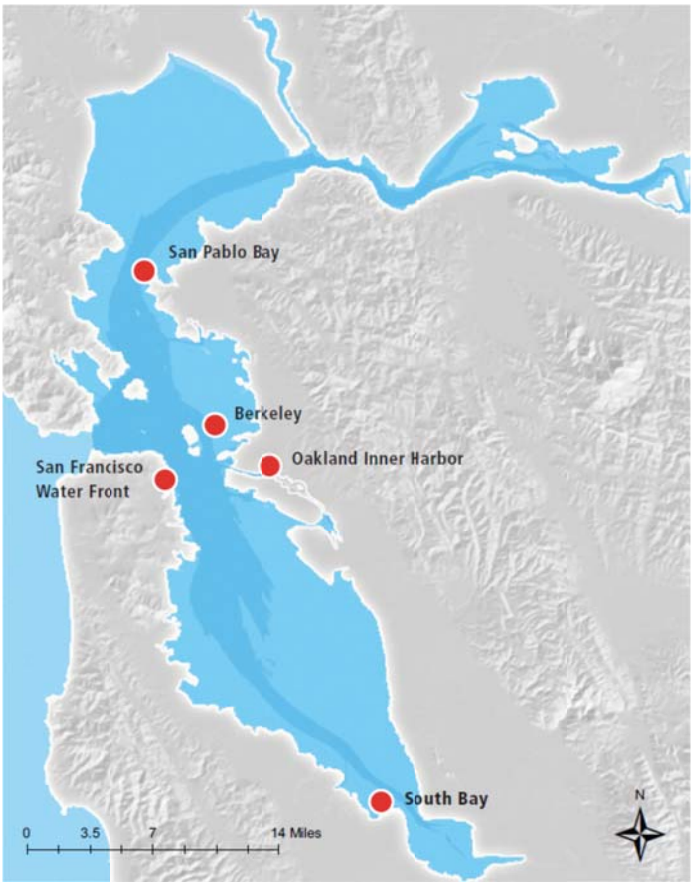


Figure 8. Average methylmercury concentrations in sport fish indicator species. Averages for striped bass based on concentrations for individual fish normalized to 60 cm. Sport fish are not routinely sampled in Suisun Bay. The no consumption advisory tissue level for mercury is 0.44 ppm, and the two serving advisory tissue level is 0.07 ppm. Average concentrations for each species in the most recent sampling were between these two thresholds.

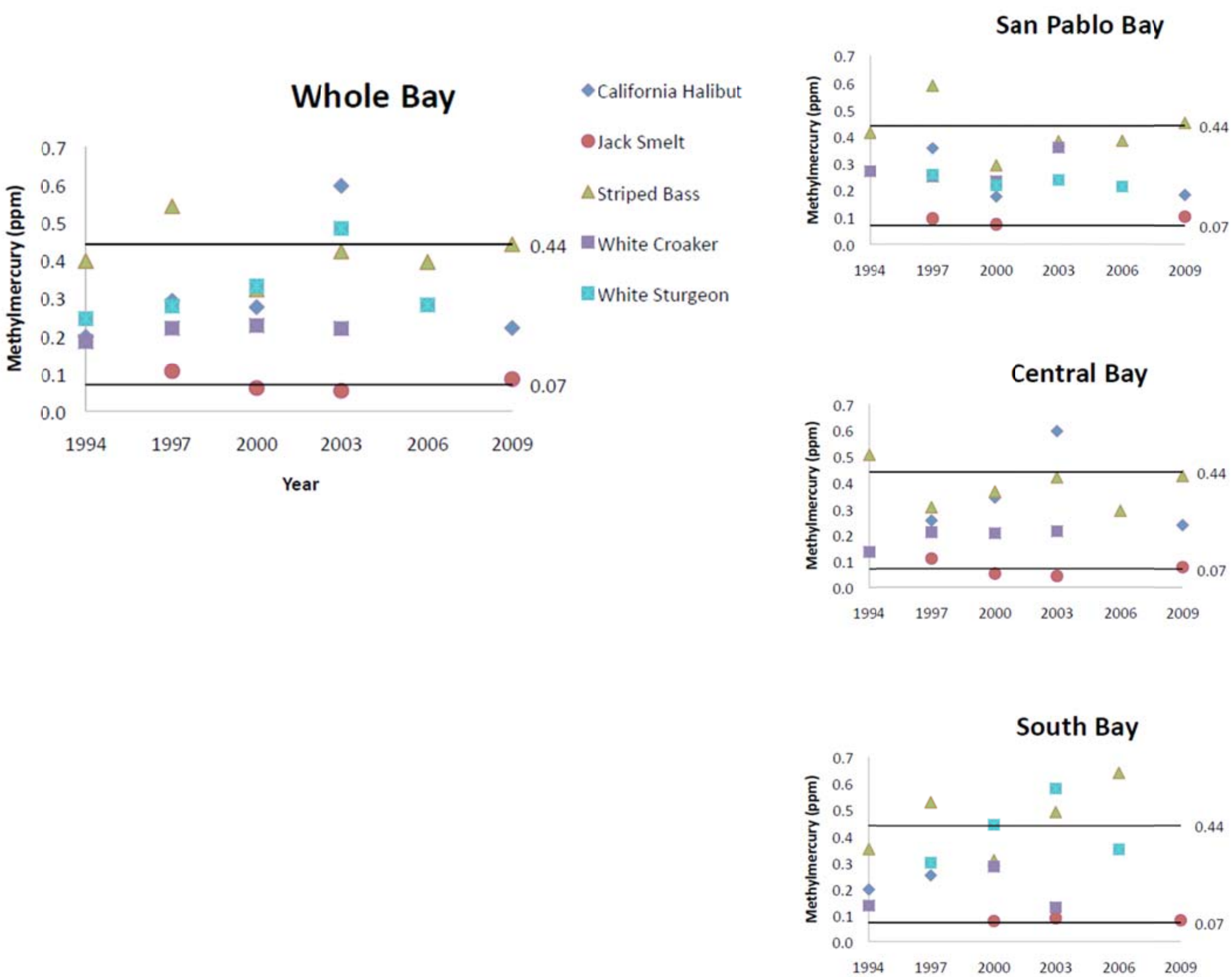


Figure 9. Summary assessment related to the "safe to eat" question. The two key dimensions of water quality problems are their severity (degree of concern) and how quickly the Bay is anticipated to respond to pollution prevention actions (whether rapid progress is likely or not). The overall assessment scores indicated by the stars are based on a combination of these two factors.

	High Concern	*Moderate Concern*	*Low Concern*
Rapid Progress Likely	★★	★★★	★★★★
Rapid Progress Unlikely	★ PCBs	★★ Methyl-mercury Dioxins*	

Footnote: * Dioxins were assessed using a San Francisco Bay Regional Water Quality Control Board target, rather than the Office of Environmental Health Hazard Assessment thresholds used for the other pollutants.

Figure 10. 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.

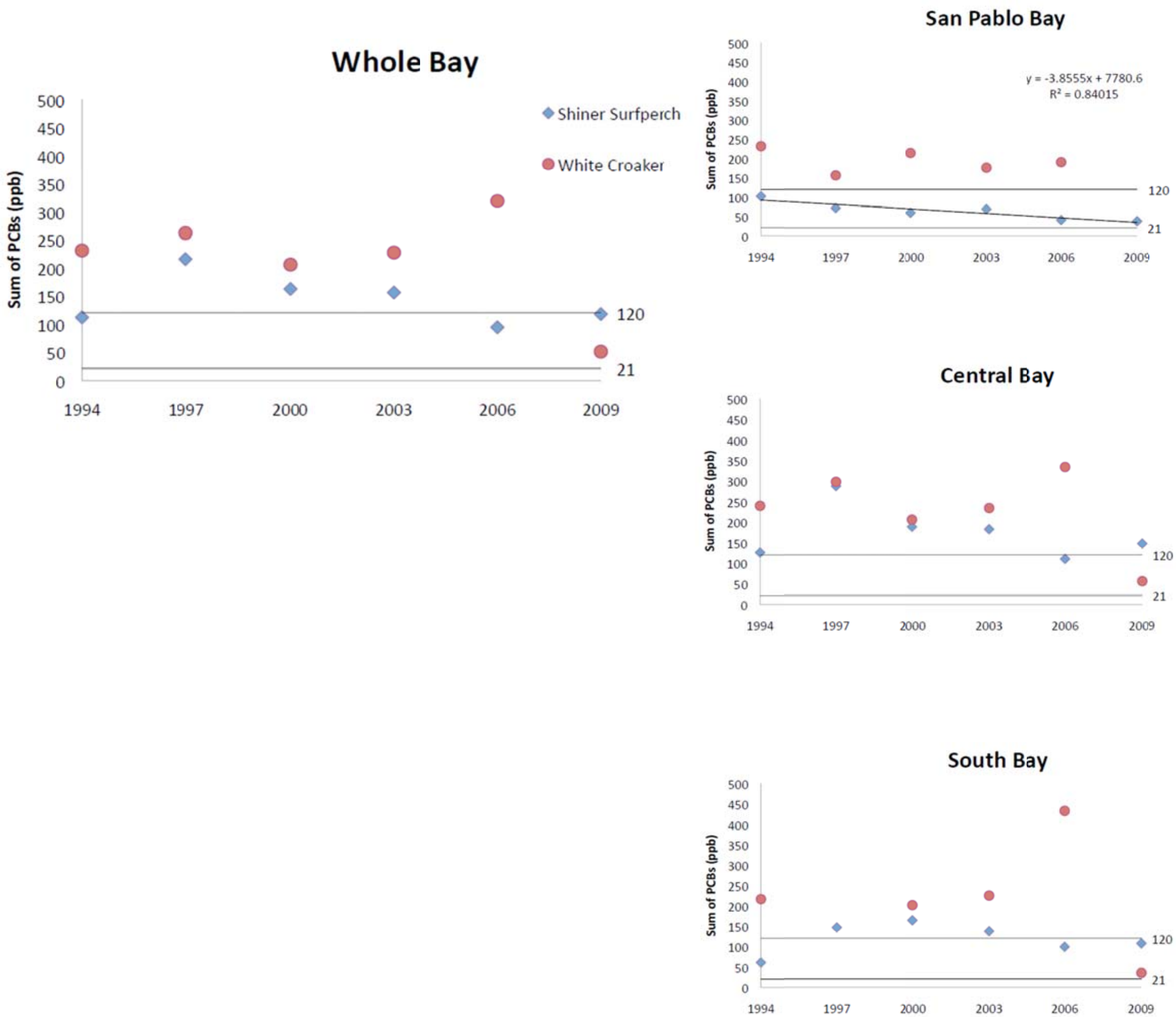


Figure 11. Average dioxin TEQ concentrations in shiner surfperch and white croaker, the key sport fish indicator species for organic pollutants. Sport fish are not routinely sampled in Suisun Bay. OEHHA has not established ATLs for dioxin TEQs. The San Francisco Bay Water Quality Control Board has developed 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.

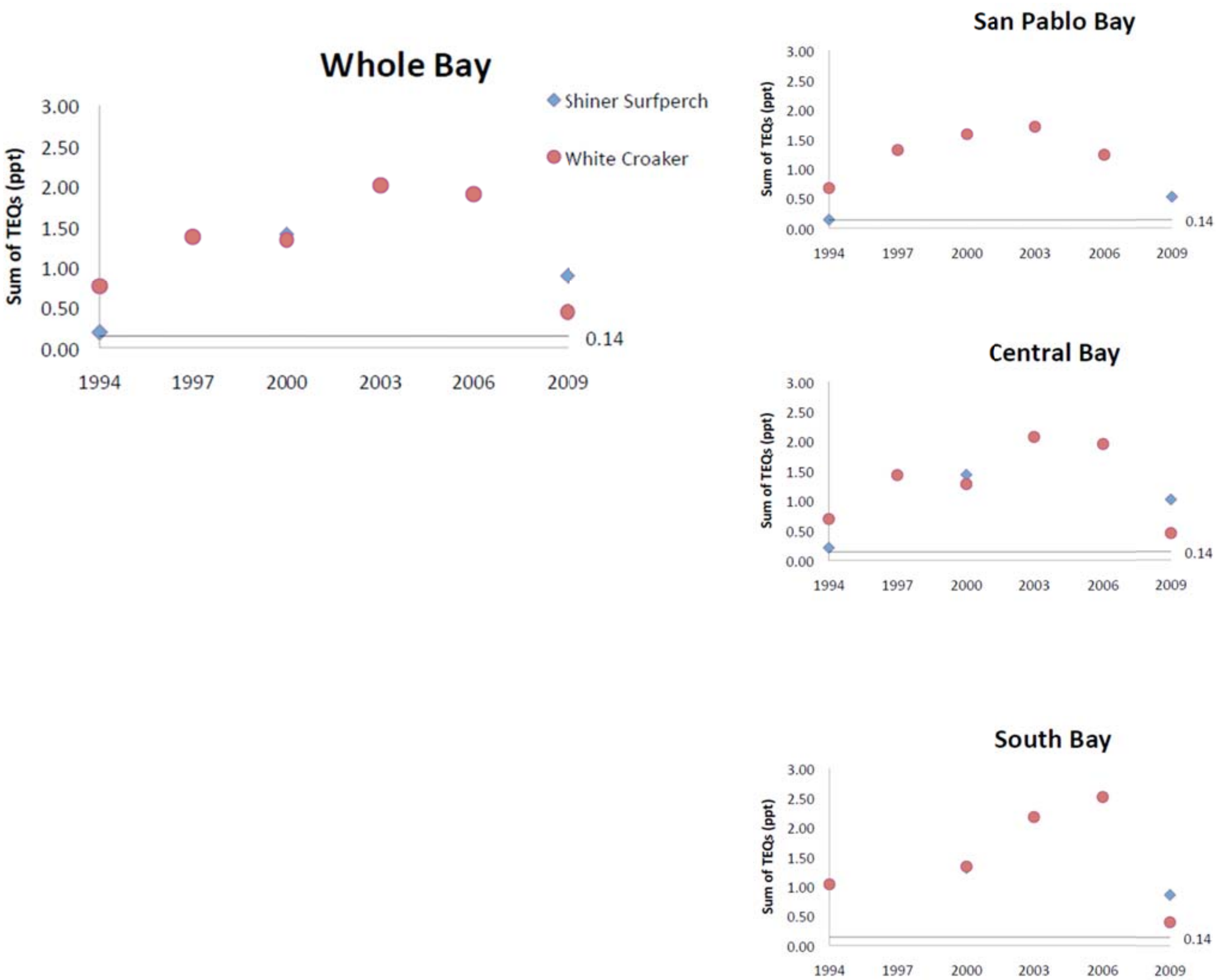


Figure 12. Average dieldrin concentrations in sport fish indicator species. Sport fish are not routinely sampled in Suisun Bay. The no consumption advisory tissue level for dieldrin is 46 ppb, and the two serving advisory tissue level is 15 ppb. Average concentrations for both species in the most recent sampling were well below these thresholds. White croaker were analyzed with skin from 1994-2006, and without skin in 2009.

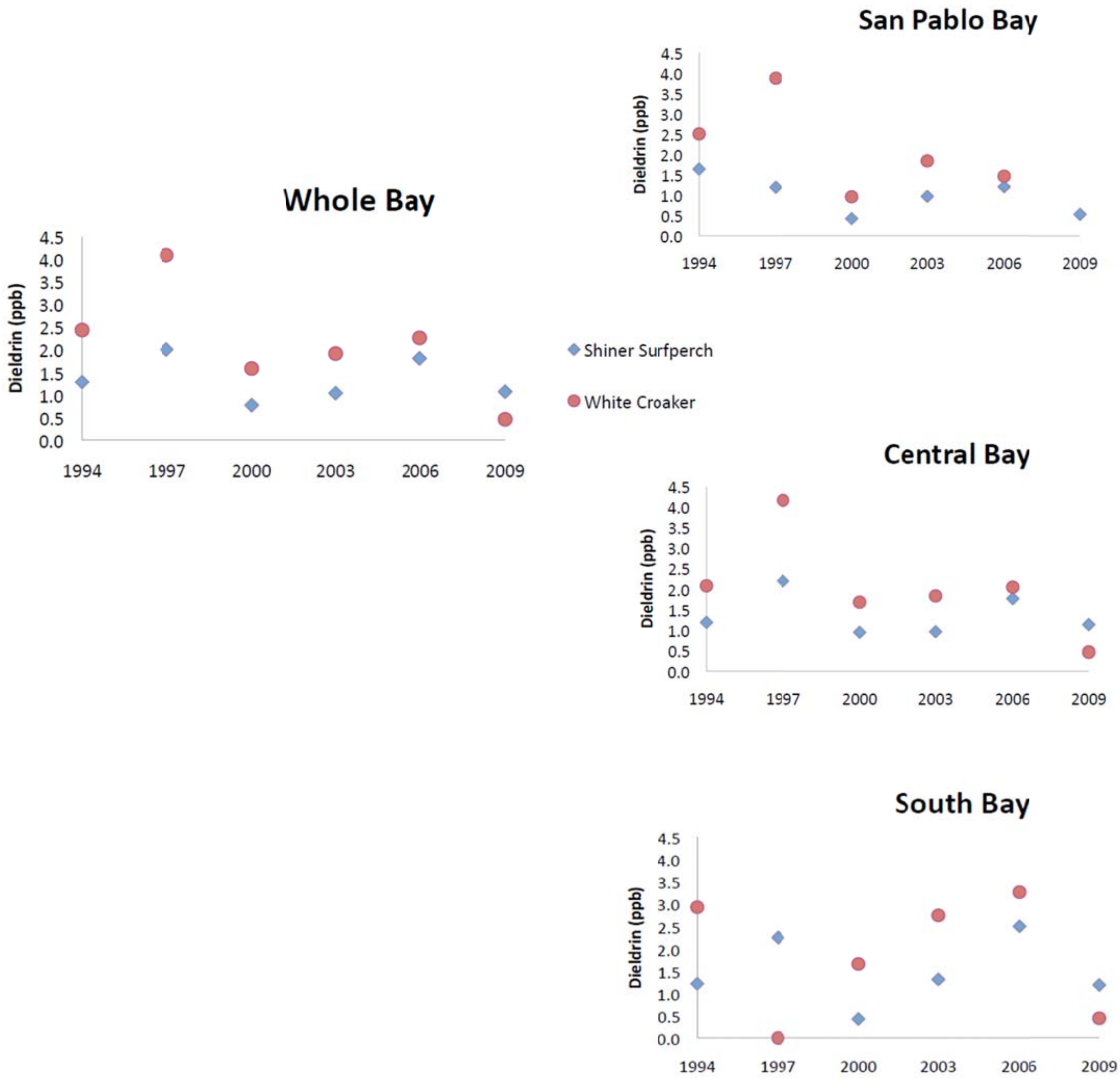


Figure 13. Average DDT concentrations in sport fish indicator species. Sport fish are not routinely sampled in Suisun Bay. The no consumption advisory tissue level for DDT is 2100 ppb, and the two serving advisory tissue level is 520 ppb. Average concentrations for both species in the most recent sampling were well below these thresholds. White croaker were analyzed with skin from 1994-2006, and without skin in 2009.

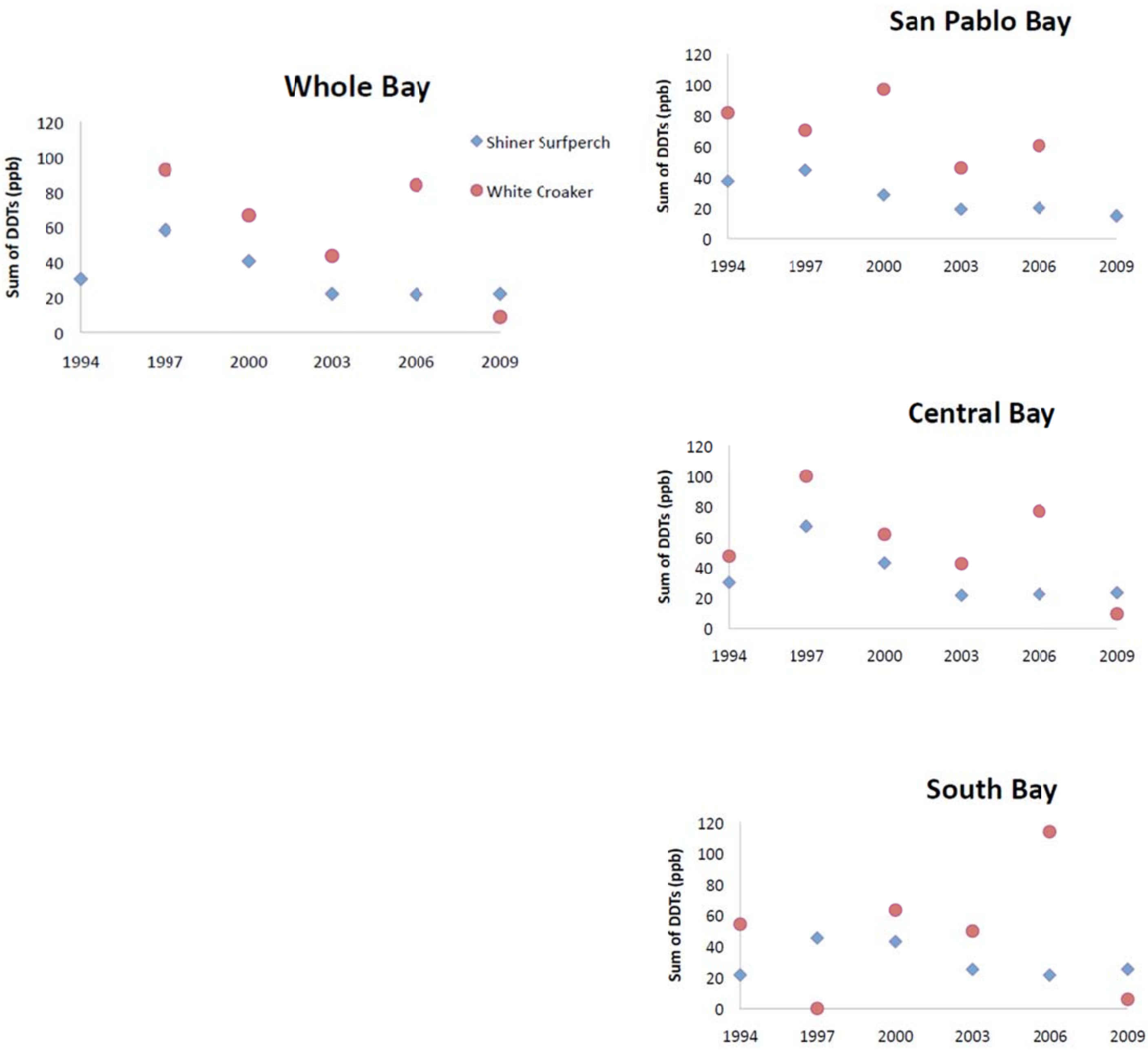


Figure 14. Average chlordane concentrations in sport fish indicator species. Sport fish are not routinely sampled in Suisun Bay. The no consumption advisory tissue level for chlordane is 560 ppb, and the two serving advisory tissue level is 190 ppb. Average concentrations for both species in the most recent sampling were well below these thresholds. White croaker were analyzed with skin from 1994-2006, and without skin in 2009.

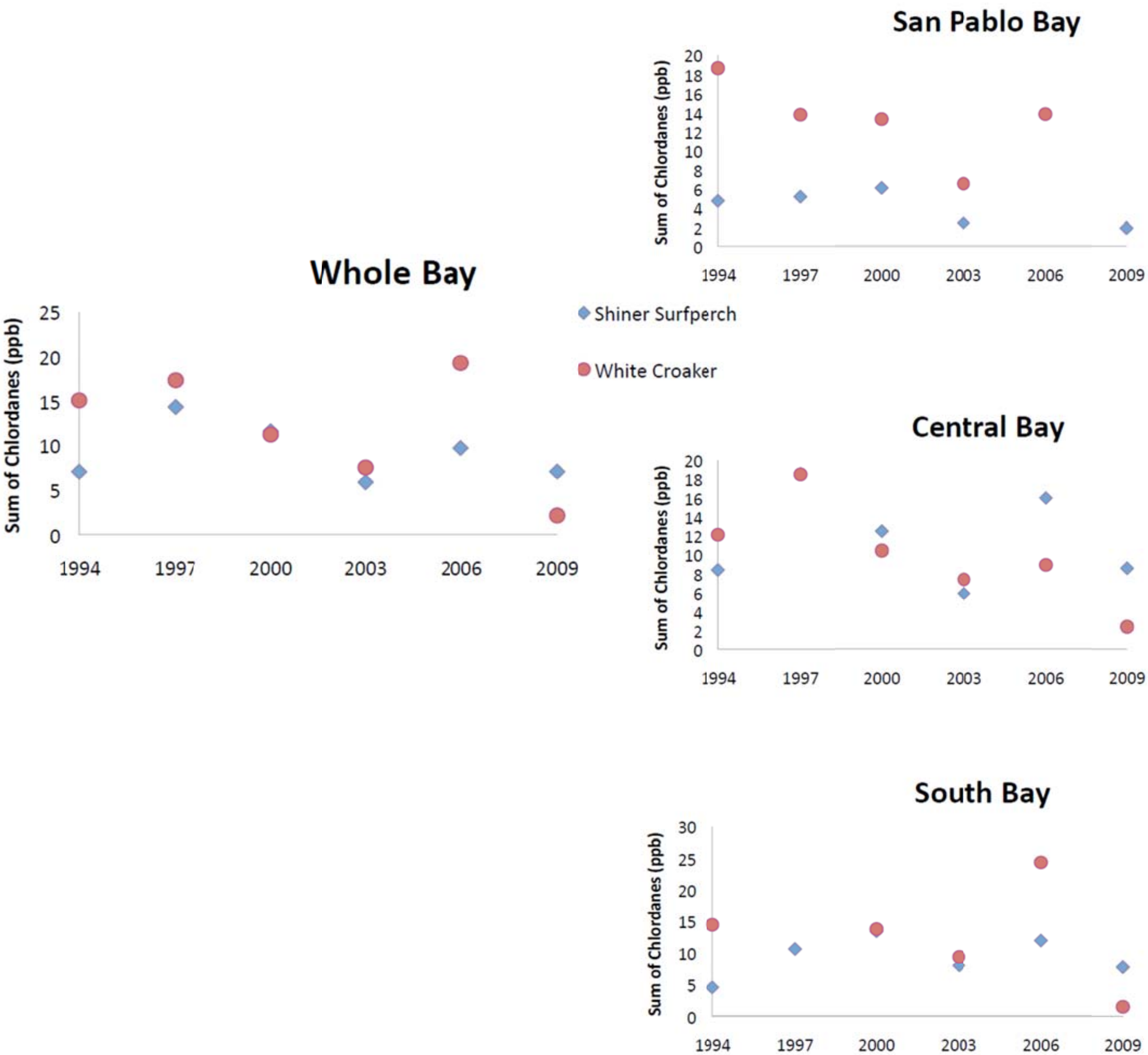


Figure 15. Average selenium concentrations in white sturgeon, the key sport fish indicator species. Sport fish are not routinely sampled in Suisun Bay. The no consumption advisory tissue level for selenium is 15 ppm, and the two serving advisory tissue level is 2.5 ppm. Average concentrations for white sturgeon in the most recent sampling were well below these thresholds.

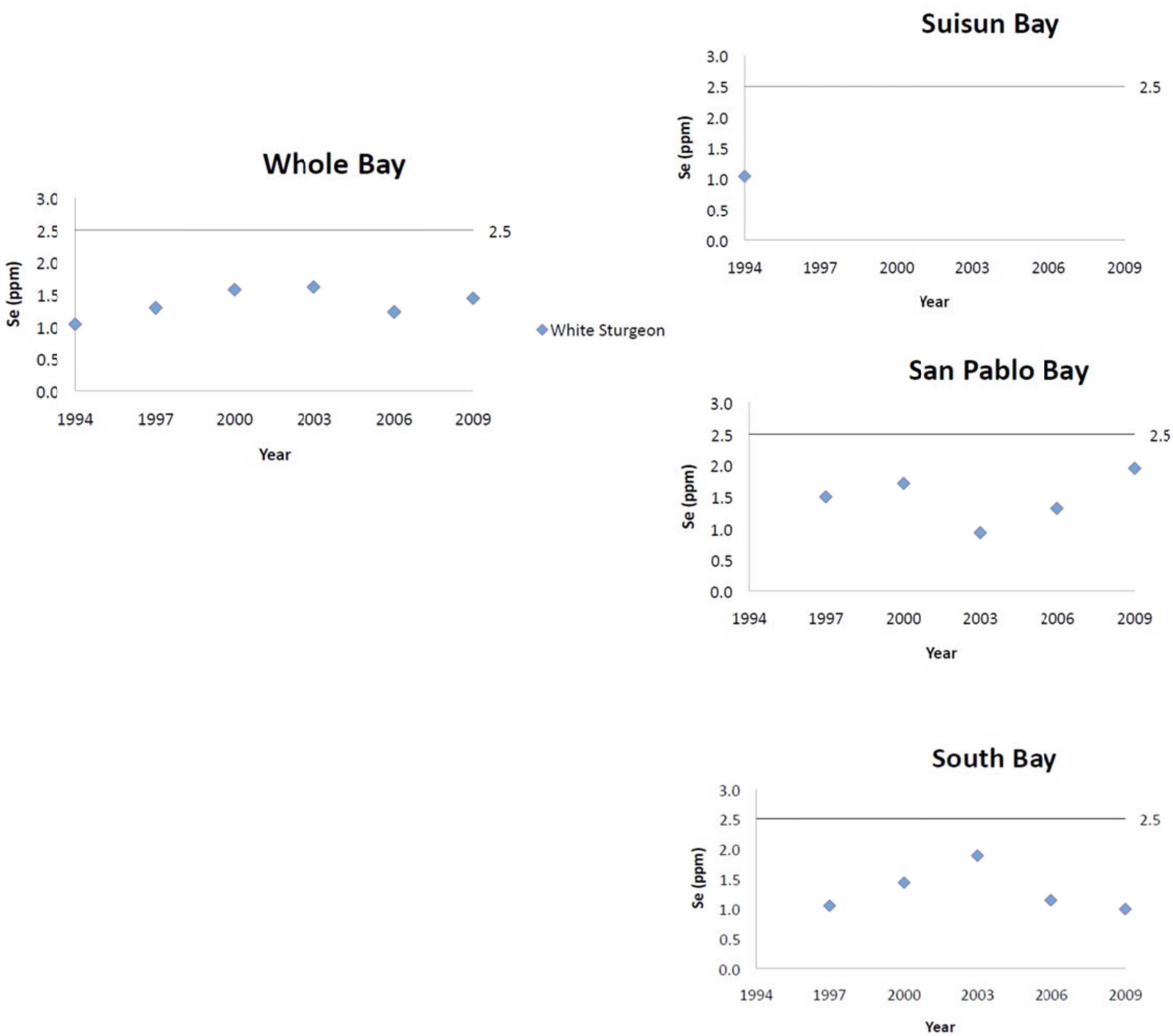


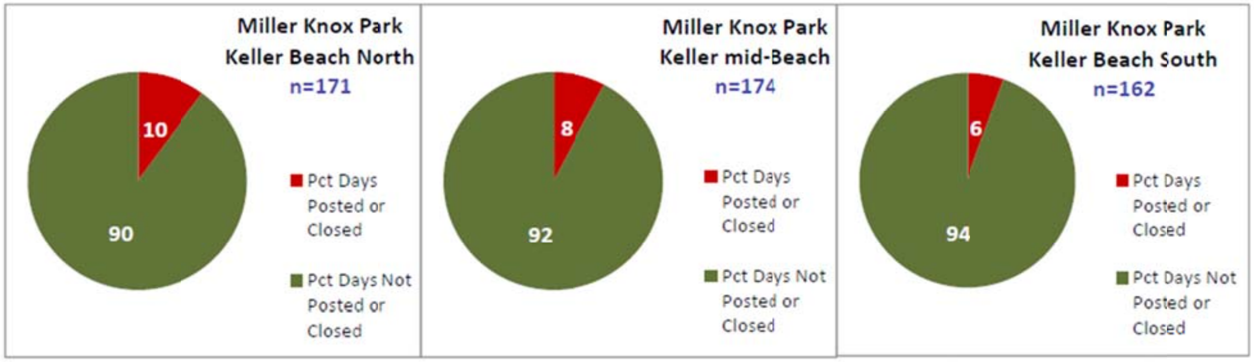
Figure 16. Frequency of beach closures, Alameda County.

Alameda County

Percent of days during the prime beach season (April - October) that beaches were posted and not posted due to possible fecal contamination from 2006 through 2010 (n=number of samples)

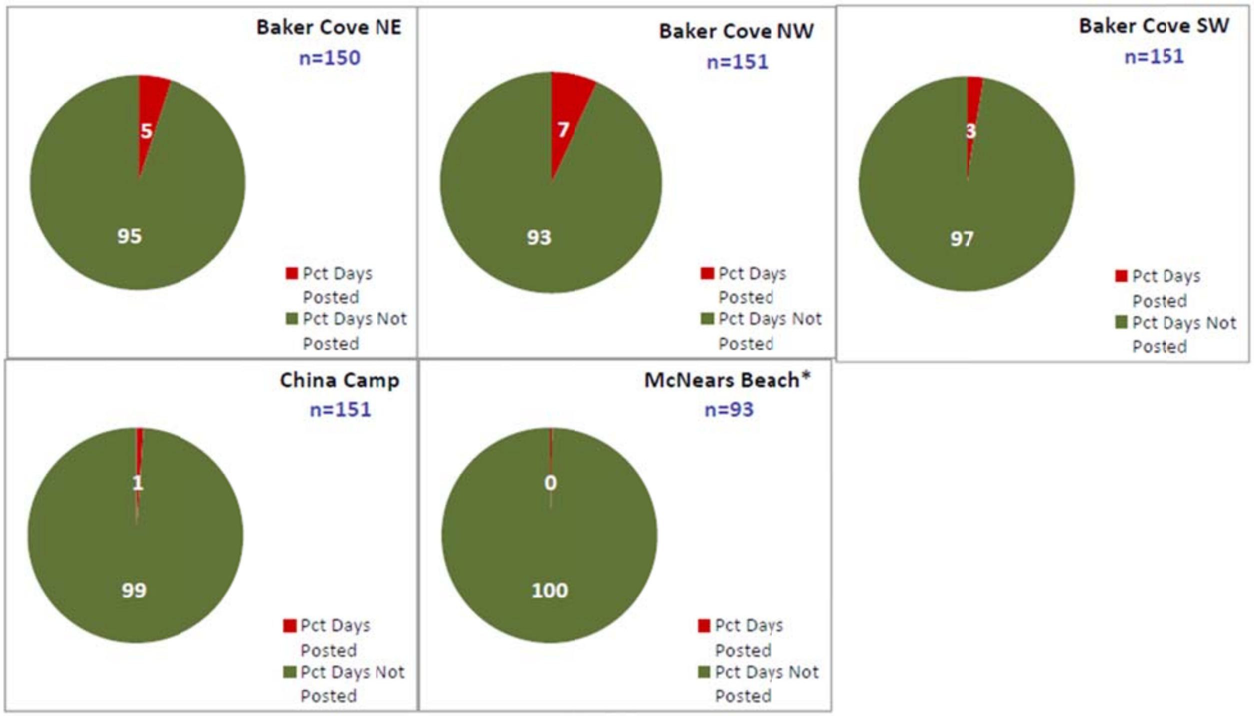
*Alameda Point sampled 2008 - 2010

Figure 17. Frequency of beach closures, Contra Costa County.



Contra Costa County
Percent of days during the prime beach season (April - October) that beaches were posted and not posted due to possible fecal contamination from 2006 through 2010 (n=number of samples)

Figure 18. Frequency of beach closures, Marin County.



Marin County

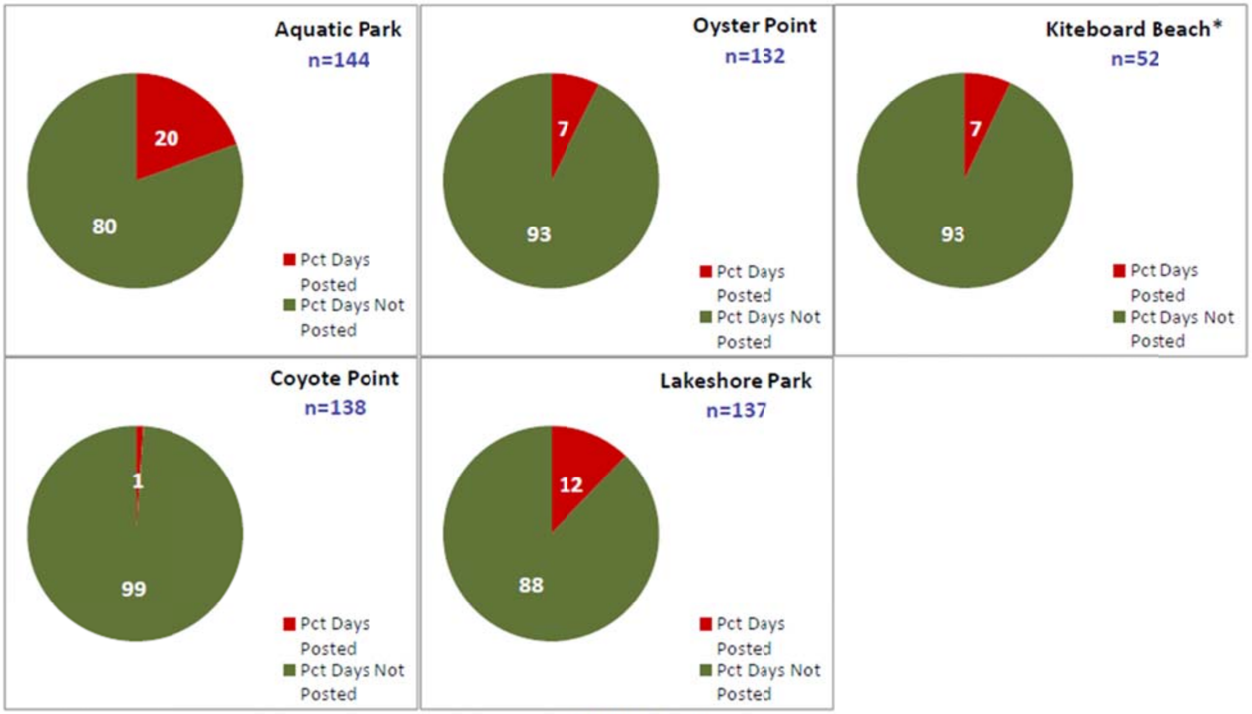
Percent of days during the prime beach season (April - October) that beaches were posted and not posted due to possible fecal contamination from 2006 through 2010 (n=number of samples)

*McNears Beach sampled 2006 - 2008

Figure 19. Frequency of beach closures, San Francisco County.

City and County of San Francisco
Percent of days during the prime beach season (April - October) that beaches were posted and not posted due to possible fecal contamination from 2006 through 2010 (n=number of samples)
*Crissy Field mid-Beach sampled 2006 - 2007 and Crissy Field West sampled 2008 - 2010

Figure 20. Frequency of beach closures, Alameda County.



San Mateo County

Percent of days during the prime beach season (April - October) that beaches were posted and not posted due to possible fecal contamination from 2006 through 2010 (n=number of samples)

*Kiteboard Beach sampled 2008 - 2010

Figure 21. Percentage of samples from San Francisco beaches that exceeded the Enterococcus single sample maximum standard of 104 MPN/100 mL by month, percentage that exceeded the Enterocccus 30-day geometric mean standard of 35 MPN/100 mL by month, and average rainfall by month for the five-year period 2006 - 2010. The graph illustrates a pattern of higher incidence of fecal indicator bacteria in wet weather than in dry weather, a pattern common in San Francisco Bay and throughout coastal California. N=2,285

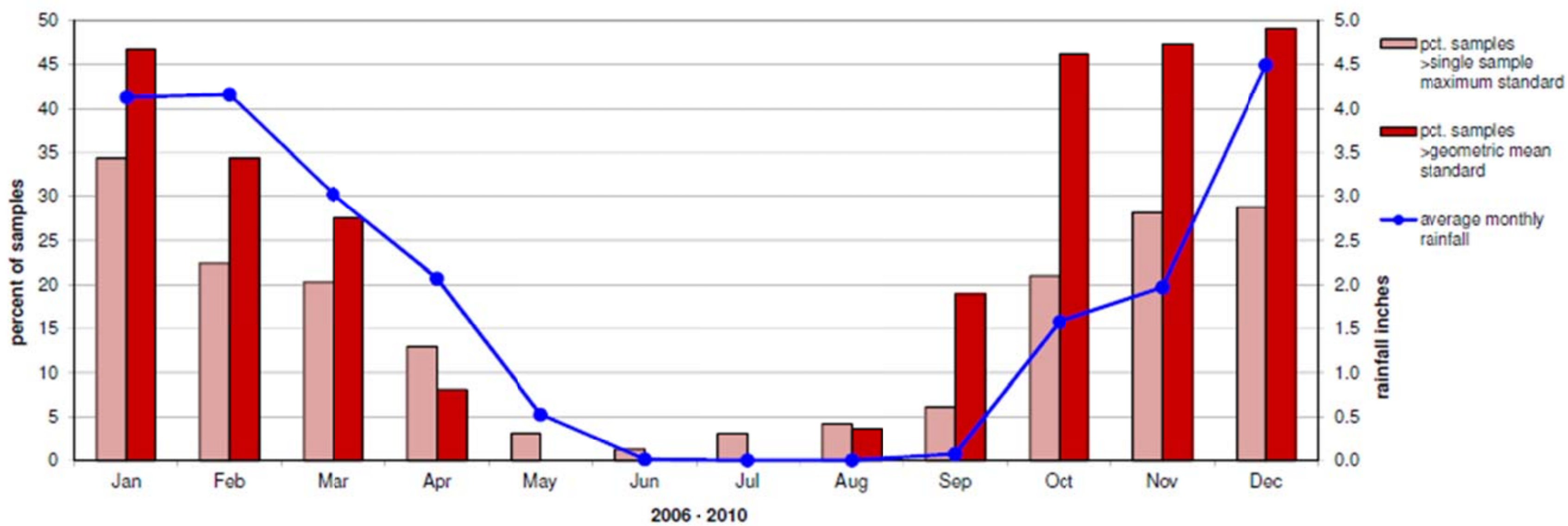


Table 1. Sources of Information on bacteria monitoring at Bay beaches.

Alameda County
website: www.ebparks.org/stewardship/water
hotline: 510-567-6706 (Crown Beach)

Contra Costa County
website: www.ebparks.org/stewardship/water

City and County of San Francisco
website: http://beaches.sfwater.org
hotline: 415-242-2214 or 1-877-SFBEACH (732-3224) toll free

San Mateo County
website: www.smhealth.org/environ/beaches
hotline: 650-599-1266

Heal the Bay Beach Report Cards
website: www.beachreportcard.org

California Safe to Swim Web Portal
website: www.waterboards.ca.gov/mywaterquality/safe_to_swim

California Beach Water Quality Information Page
website: www.swrcb.ca.gov/water_issues/programs/beaches/beach_water_quality/index.shtml

Table 2. 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 3. Heal the Bay grades for San Francisco Bay Area beaches.

	Heal the Bay Annual Beach Report Card Grades (year-round = April 1 - March 31)														
	APRIL - OCTOBER					DRY YEAR-ROUND					WET YEAR-ROUND				
	2006	2007	2008	2009	2010	2006 - 2007	2007 - 2008	2008 - 2009	2009 - 2010	2010 - 2011	2006 - 2007	2007 - 2008	2008 - 2009	2009 - 2010	2010 - 2011
San Mateo County															
Oyster Point		A	A	B	A		A		A	A		C		F	D
Coyote Point		A	A+	A+	A+		A		A	A+		A		B	C
Aquatic Park		A	B	F	D		B		F	D		F		F	F
Lakeshore Park		A	D	D	D		C		D	D		F		F	F
Kiteboard Beach			B						A					F	
Alameda Couty															
Alameda Point North			A	A+	A			A	A+	A			A+	A	C
Alameda Point South			A	A	A+			A	A	A			A+	A	A
Crown Beach Bath House		A	A	B	A+		A	C	B	A+		C	A+	A	A
Crown Beach Windsurf Corner		A	A	A	A+		A	A	A	A+		A	A+	B	B
Crown Beach Sunset Road		A	A+	A	A+		A	A	A	A+		F	A	B	B
Crown Beach Shoreline Drive		A	A	A+	A+		A	A	A	A		F	A+	C	B
Crown Beach Bird Sanctuary		A	A	B	A		C	A	B	A		F	B	D	C
Contra Costa County															
Keller Beach North		B	F	D	F		B	D	D	F		A	A	B	A
Keller Beach Mid-Beach		B	C	D	F		B	C	D	F		B	B	B	A
Keller Beach South		A	C	D	D		A	C	D	D		A	B	C	B
San Francisco County															
Crissy Field Beach West			A+	A+	A+			A+	A+	A			A	C	B
Crissy Field mid-Beach	A	A+				A	A+				B	A			
Crissy field Beach East	A	A	A	A	A+	C	A	B	A	B	D	A	B	B	C
Aquatic Park Beach	A	B	A	A	A	A	C	B	A	B	B	A	C	A	B
Hyde Street Pier	A	A	A	A+	A+	A	A	A	A	A	A	A	A+	A	A
Jackrabbit Beach	A	A	A	A	A	A	A	A	A	A	A	F	D	C	B
CPSRA Windsurfer Circle	A	A	A	A	D	A	A	B	A	F	F	F	F	F	F
Sunnydale Cove	A	A	A	B	D	A	C	A	C	C	F	F	F	F	F
Marin County															
Horseshoe Cove NE	A	A	A	A+	A										
Horseshoe Cove NW	A	B	A	A	A										
Horseshoe Cove SW	A	A	A	A	A										
Schoonmaker Beach	A	A+	A+	A	A+										
Paradise Cove	A	A	A+												
China Camp	D	A+	A+	A	A										
McNears Beach	C	A	A												
Overall GPA	3.64	3.88	3.61	3.30	3.23	3.71	3.44	3.31	3.12	2.91	2.14	2.05	3.11	2.14	2.38
Overall Grade	B+	A-	B+	B	B	A-	B+	B+	B	B-	C	C	B	C	C+