State of San Francisco Bay 2011
Appendix F

LIVING RESOURCES - Fish Indicators and Index
Technical Appendix

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I. Background

San Francisco Bay is important habitat for more than 100 fish species, including commercially important Chinook salmon and Pacific herring, popular sport fishes like striped bass and sturgeon, and delicate estuary-dependent species like delta smelt. These fishes variously use the estuary for spawning, nursery and rearing habitat, and as a migration pathway between the Pacific Ocean and the rivers of the estuary's watersheds. Environmental conditions in the estuary – the amounts and timing of freshwater inflows, the extent of rich tidal marsh habitats, and pollution – affect the numbers and types of fish that the Bay can support. Thus, measures of fish abundance, diversity, species composition and distribution are useful biological gauges for environmental conditions in the estuary. A large, diverse fish community that is distributed broadly throughout the Bay and dominated by native species is a good indicator of a healthy estuary.

The Fish Index uses ten indicators to assess the condition of the fish community within the San Francisco Bay. Four of the indicators measure abundance, or "how many?" fish the estuary supports. Two indicators measure the diversity of the fish community, or "how many species?" are found in the Bay. Two indicators measure the species composition of the fish community, or "what kind of fish?," in terms of how many species and how many individual fish are native species rather than introduced non-natives.[1] The final two indicators assess the distribution of fish within the estuary, or "where are the fish?," measuring the percentage of sampling locations where native fishes are found. For each year, the Fish Index is calculated by combining the results of the ten indicators into a single number.

Because the estuary is so large and its environmental conditions so different in different areas – for example, Central Bay, near the Golden Gate is essentially a marine environment while Suisun Bay is dominated by freshwater inflows from the Sacramento and San Joaquin Rivers – the types of fishes found in each area differ. Therefore, each of the indicators and the index was calculated separately for four "sub-regions" in the estuary: South Bay, Central Bay, San Pablo Bay and Suisun Bay and the western Delta (Figure 1). For each year and for each sub-region, the Fish Index is calculated by combining the results of the ten indicators into a single number.

II. Data Source

All of the indicators were calculated using data from the California Department of Fish and Game (CDFG) Bay Study surveys, conducted every year since 1980.[2] The Bay Study uses two different types of sampling gear to collect fish from the estuary: a midwater trawl and an otter trawl. The midwater trawl is towed from the bottom to the top of the water column and

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[1] Native species are those that have evolved in the Bay and/or adjacent coastal or upstream waters. Non-native species are those that have evolved in other geographically distant systems and have been subsequently transported to the Bay and established self-sustaining populations in the estuary.

[2] Information on the CDFG Bay Study is available at http://www.dfg.ca.gov/delta/projects.asp?ProjectID=BAYSTUDY

collect smaller and/or younger fish that are too slow to evade the net.[3] The otter trawl is towed near the bottom and captures demersal fishes that utilize bottom and near-bottom habitats and also tends to collect smaller and/or younger fish. Each year, the two survey sample the same 35 fixed stations in the estuary. These stations are distributed among the four sub-regions of the estuary and among channel and shoal habitats, once per month for most months of the year.[4] In one year, 1994, the Midwater Trawl survey was conducted during only two months, compared to the usual 8-12 months per year. Because the sampling period was limited, data from this year were not included in calculation of some indicators and of the Fish Index. Information on sampling stations, locations and total number of surveys conducted each year in each of the four sub-regions is shown in Figure 2 and Table 1.

It should be noted that, although the Bay Study midwater and otter trawl surveys sample the Bay's pelagic and open water benthic habitats reasonably comprehensively, they do not survey historic or restored tidal marsh or tidal flat habitats where many of the same fish species collected by the Bay Study, as well as other fish species, may also be found. Therefore, results of the Bay Study and of these indicators should not be interpreted to mean that these are the only fishes or fish communities found in the Bay or that these species are found in only these regions of the estuary.

III. Indicator Evaluation

The San Francisco Estuary Partnership's Comprehensive Conservation and Management Plan (CCMP) calls for "recovery" and "reversing declines" of estuarine fish and wildlife but does not provide quantitative targets or goals. However, the length of the available data records, which include the Bay Study surveys used for the indicator calculations here as well as several other surveys, allows for use of historical data to establish "reference conditions."[5] There is also an extensive scientific literature on development, use and evaluation of ecological indicators in aquatic systems and, because San Francisco Bay is among the best studied estuaries in the world, an extensive scientific literature on its ecology.

For each indicator, a "primary" reference condition was established. This reference condition was based on either measured values from the earliest years for which quantitative data were available (1980-1989 for the Bay Study survey), maximum measured values for the estuary or sub-regions, recognized and accepted interpretations of ecological conditions and ecosystem health (e.g., native v non-native species composition), and best professional judgment. Measured indicator values that were higher than the primary reference condition were interpreted to mean the indicator results met the CCMP goals and to correspond to "good" ecological conditions. For each of the four sub-regions, reference conditions were identically selected but

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[3] The Bay Study primarily catches fishes that range in size from approximately 1-12 inches (3-30 cm). Other survey programs that monitor fishes in the estuary target smaller or larger fishes (e.g., CDFG 20-mm survey for small juvenile fishes or CDFG creel surveys for adult fishes).
[4] The Bay Study samples more than four dozen stations but the 35 sampling stations used to calculate the indicators are the original sampling sites for which data are available for the entire 1980-2006 period.
[5] For example, CDFG's Fall Midwater Trawl Survey, conducted in most years since 1967, and Summer Townet Survey, conducted since 1959. However, the geographic coverage of the Fall Midwater trawl and Summer Townet surveys is less extensive than that of the Bay Study and does not extent into all of the four sub-regions of the estuary. Therefore, data from these surveys were less suitable for developing indicators for the entire estuary.

for some indicators their absolute values were calibrated to account for differences among the sub-regions. For example, a reference condition based on historical abundance (i.e., average abundance during the first ten years of the survey) was used to evaluate the abundance indicators but, because overall fish abundance levels differed among the sub-regions, the actual reference abundance level differed among the four sub-regions. In contrast, because the reference condition for the species composition indicators was based the ecological relationship between the prevalence of non-native species and ecosystem and habitat condition, the value of the reference condition was set at the same level for each of the regions, despite the large differences in species composition that already existed between the four sub-regions.

In addition to the primary reference condition, information on the range and trends of indicator results, results from other surveys, and known relationships between fish community attributes and ecological conditions were used to develop several intermediate reference conditions, creating a five-point scale for a range of evaluation results from "excellent," "good, "fair," "poor" to "very poor".[6] The size of the increments between the different evaluation levels was, where possible, based on observed levels of variation in the measured indicator values (e.g., standard deviations) in order to ensure that the different levels represented meaningful differences in the measured indicator values. Each of the evaluation levels was assigned a quantitative value from "4" points for "excellent" to "0" points for "very poor." An average score was calculated for the indicators in each of the fish community attributes (i.e., abundance, diversity, species composition and distribution) and the Fish Index was calculated as the average of these four scores. Specific information on the primary and intermediate reference conditions is provided in the following sections describing each of the indicators.

Differences among sub-regions and different time periods, and trends with time in the indicators and the multi-metric index were evaluated using analysis of variance and simple linear regression. Comparisons among sub-regions were made using results from the entire 29-year period as well as for the earliest ten-year period (i.e., the reference period; 1980-1989) and the most recent five years (i.e., 2004-2008). Regression analyses were conducted using continuous results for the entire 29-year period for each sub-region.

IV. Indicators

A. Fish Community Attributes

The ten indicators used to calculate the Fish Index assess four different attributes of the San Francisco Estuary fish community: abundance, diversity, species composition and distribution (Table 2). Information on indicator rationale, calculation methods, units of measure, specific reference conditions and results is provided in the following sections.

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[6] For example, data from the Fall Midwater trawl and Summer Townet surveys indicate that abundance of fish within the estuary was already in decline by the 1980s. Therefore, for indicator evaluation, abundance levels measured in the 1980s, which were already lower than they have been just ten years earlier, were interpreted to correspond to "good" conditions but not "excellent" conditions.

B. Abundance Indicators

1. Rationale

Abundance (or population size) of native fish species within an ecosystem can be a useful indicator of aquatic ecosystem health, particularly in urbanized watersheds (Wang and Lyons, 2003; Harrison and Whitfield, 2004). Native fishes are more abundant in a healthy aquatic ecosystem than in one impaired by altered flow regimes, toxic urban runoff and reduced nearshore habitat, the usual consequences of urbanization. In the San Francisco Bay, abundances of a number of fish (and invertebrate) species are strongly correlated with ocean conditions immediately outside of the estuary (Cloern et al., 2007; 2010) and freshwater inflow from the estuary's Sacramento and San Joaquin watersheds, which vary widely due to California's climate and but have been reduced and stabilized by water development, flood control efforts, agriculture and urbanization (Jassby et al., 1995; Kimmerer, 2002; and see Estuarine Open Water Habitat indicator, Freshwater Inflow Index and Flood Events indicator).

The Fish Index includes four different abundance indicators, each measuring different components of the native fish community within the estuary. The **Pelagic Fish Abundance** indicator measured how many native pelagic, or open water, fish are collected in the Midwater trawl survey. This indicator does not include data for Northern anchovy because, in most years and in most sub-regions of the estuary, northern anchovy comprised >80% of all fish collected in the Bay and obscured results for all other species. **Northern Anchovy Abundance** was measured as a separate indicator, using data from the Midwater trawl survey. Northern anchovy, the most abundant species collected in the Bay, is consistently collected in all sub-regions of the estuary in numbers that are often orders of magnitude greater than for all other species. The **Demersal Fish Abundance** indicator measured how many native demersal, or bottom-oriented, fish are collected by the Otter Trawl Survey. The **Sensitive Fish Species Abundance** indicator measured the abundance of four representative species – longfin smelt, Pacific herring, starry flounder and striped bass[7] – using data from both the Midwater and Otter trawl surveys. All of these species are broadly distributed throughout the Bay and rely on the estuary in different ways and at different times during their life cycle. Each is relatively common and consistently present in all four sub-regions of the estuary, and all except starry flounder are targets of environmental or fishery management in the estuary. In addition, the population abundance of each of these species is influenced by a key ecological driver for the estuary, seasonal freshwater inflows (Jassby et al. 1995; Kimmerer 2002). Key characteristics of each of the four species are briefly described below

- **Longfin smelt** are found in open waters of large estuaries on the west coast of North America.[8] The San Francisco Estuary population spawns in upper estuary (Suisun Bay and Marsh and the Delta) and rears downstream in brackish estuarine and, occasionally,

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[7] Although striped bass is not native to the Pacific coast, the species was introduced to San Francisco Bay more than 100 years ago and, since then, has been an important component of the Bay fish community. On the North American west coast, the main breeding population of the species is in the San Francisco Bay (Moyle, 2002).
[8] In California, longfin smelt are found in San Francisco Bay, Humboldt Bay, and the estuaries of the Russian, Eel, and Klamath rivers.

coastal waters (Moyle, 2002). The species was listed as “threatened” under the California Endangered Species Act in 2008.

- **Pacific herring** is a coastal marine fish that uses large estuaries for spawning and early rearing habitat. The San Francisco Estuary is the most important spawning area for eastern Pacific populations of the species (CDFG, 2002). Pacific herring supports a commercial fishery, primarily for roe (herring eggs) but also for fresh fish, bait and pet food. In the San Francisco Estuary, the Pacific herring fishery is the last remaining commercial finfish fishery.

- **Starry flounder** is an estuary-dependent, demersal fish that can be found over sand, mud or gravel bottoms in coastal ocean areas, estuaries, sloughs and even fresh water. The species, whose eastern Pacific range extends from Santa Barbara to arctic Alaska, spawns near river mouths and sloughs; juveniles are found exclusively in estuaries. Starry flounder is one of the most consistently collected flatfishes in the San Francisco Estuary.

- **Striped bass** was introduced into San Francisco Bay in 1879 and by 1888 the population had grown large enough to support a commercial fishery (Moyle, 2002). That fishery was closed in 1935 in favor of the sport fishery, which remains popular today although at reduced levels. Striped bass are anadromous, spawning in large rivers and rearing in downstream estuarine and coastal waters. Declines in the striped bass population were the driving force for changes in water management operations in Sacramento and San Joaquin Rivers and the Delta in the 1980s. Until the mid-1990s, State Water Resources Control Board-mandated standards for the estuary were aimed at protecting larval and juvenile striped bass.

2. Methods and Calculations

The **Pelagic Fish Abundance** indicator was calculated for each year (1980-2008, excluding 1994) for each of four sub-regions of the estuary using catch data for all native species except northern anchovy from the Bay Study Midwater Trawl survey. The indicator was calculated as:

$$\text{\# fish}/10{,}000\ m^3 = [(\text{\# of fish})/(\text{\# of trawls x av. trawl volume, } m^3)]\ \text{x}\ (10{,}000)$$

The **Northern Anchovy Abundance** indicator was calculated for each year (1980-2008, excluding 1994) for each of four sub-regions of the estuary using catch data for northern anchovy from the Bay Study Midwater Trawl survey using the same equation as for pelagic abundance.

The **Demersal Fish Abundance** indicator was calculated for each year (1980-2008) for each of four sub-regions of the estuary using catch data for all native species from the Bay Study Otter Trawl survey. The indicator was calculated as:

$$\text{\# fish}/10{,}000\ m^2 = [(\text{\# of fish})/(\text{\# of trawls x av. trawl volume, } m^2)]\ \text{x}\ (10{,}000)$$

The **Sensitive Fish Species Abundance** indicator, the abundance of each of the four species was calculated for each year (1980-2008, excluding 1994) for each of four sub-regions of the estuary as the sum of the abundances from each of the two Bay Study surveys using the equations below.

fish/10,000 m^3 = [(# of fish)/(# of trawls x av. trawl volume, m^3)] x (10,000)
(for Midwater trawl)

fish/10,000 m^2 = [(# of fish)/(# of trawls x av. trawl area, m^2)] x (10,000)
(for Otter trawl)

The summed abundance for each species was then expressed as a percentage of the average 1980-1989 for that species. The indicator was calculated as the average of the percentages for the four species. Each species was given equal weight in this calculation.

3. Reference Conditions

For the four Abundance indicators, the primary reference condition was established as the average abundance for the first ten years of the Bay Study, 1980-1989. Abundance levels that were greater than the 1980-1989 average were considered to reflect “good” conditions. Additional information from other surveys and trends in fish abundance within the estuary was used to develop several other intermediate reference conditions. Table 3 below shows the quantitative reference conditions that were used to evaluate the results of the abundance indicators.

4. Results

Results of the **Pelagic Fish Abundance** indicator are shown in Figure 3.

Abundance of pelagic fishes differs among the estuary’s sub-regions.
Pelagic fishes are significantly more abundant in Central Bay than in all other sub-regions of the estuary (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, all pairwise comparisons: $p<0.05$). Abundance of pelagic fishes in South Bay is greater than that in Suisun Bay ($p<0.05$) but comparable to that in San Pablo Bay. In 2008, pelagic fishes were three times more abundant in Central Bay (89 fish/10,000m^3) than either South (30 fish/10,000m^3) or San Pablo Bays (32 fish/10,000m^3) and nearly 30 times more abundant than in Suisun Bay (3 fish/10,000m^3).

Abundance of pelagic fishes has declined in most sub-regions of the estuary.
Pelagic fish abundance declined significantly over time in all sub-regions of the estuary except Central Bay (regression: $p<0.05$ for South and San Pablo Bays, $p<0.001$ for Suisun Bay). Abundance of pelagic fishes in Central Bay showed no long-term trend and its high inter-annual variability reflects the periodic presence of large numbers of marine species such as Pacific sardine. However, for the most recent five years (2004-2008) compared to 1980-1989 levels, average abundance of native pelagic fishes was significantly lower in all regions: 55% lower in South Bay, 65% lower in Central Bay, 68% lower in San Pablo Bay and 88% lower in Suisun Bay.

Based on the abundance of pelagic fishes, CCMP goals to "recover" and "reverse declines" of estuarine fishes have not been met.
Both current levels (expressed as the 2004-2008 average) and trends in pelagic fish abundance are below the 1980-1989 reference period for all sub-regions of the estuary (t-test or Mann-Whitney, $p<0.05$, all regions). However, in the most recent two years there is some evidence of increases in pelagic fish abundance in all sub-regions of the San Francisco Estuary except Suisun Bay.

Results of the **Northern Anchovy Abundance** indicator are shown in Figure 4.

Abundance of northern anchovy differs among the estuary's sub-regions.
Although northern anchovy are always found in all sub-regions of the estuary, their abundance differs markedly. For the past 29 years, northern anchovy have been more abundant in Central Bay (mean: 1000 fish/10,000m^3) than all other sub-regions, least abundant in Suisun Bay (18 fish/10,000m^3), and present at intermediate abundance levels in San Pablo (259 fish/10,000m^3) and South Bays (304 fish/10,000m^3) (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, all pairwise comparisons: $p<0.05$).

Trends in abundance of Northern anchovy differ in different sub-regions of the estuary.
During the past 29 years, abundance of northern anchovy has been variable but roughly stable in South and Central Bays although, in most recent years, Central Bay abundance has averaged about 45% lower than 1980-1989 levels. Northern anchovy abundance has steadily declined in San Pablo Bay (regression: $p<0.01$), falling to 41% of 1980-1989 levels during the most recent five years (2004-2008). The decline was more abrupt in Suisun Bay (regression: $p<0.05$), with northern anchovy virtually disappearing from this upstream portion of the estuary: since 1995, northern anchovy population levels in this region of the estuary averaged less than 6% of 1980-1989 levels and less than 2% of populations in adjacent San Pablo Bay. This decline is contemporaneous with the establishment of the non-native overbite clam (*Corbula amurensis*) at high densities, the general disappearance of phytoplankton blooms and substantial declines in the abundance of several previously abundant zooplankton species.

Based on the abundance of northern anchovy, CCMP goals to "recover" and "reverse declines" of estuarine fishes have not been met in the upstream sub-regions of the estuary.
The abundance of northern anchovy, the most common fish in the San Francisco Estuary, has declined throughout the upstream regions of the estuary to levels that significantly below the 1980-1989 average reference conditions (t-test or Mann-Whitney, $p<0.05$ for San Pablo and Suisun Bays). In contrast, in Central and San Pablo Bays, recent northern anchovy abundance levels are comparable to levels measured in the 1980s (t-test or Mann-Whitney, $p>0.05$, both regions). As with demersal fishes, the markedly different trends between the upstream sub-regions (Suisun and San Pablo Bays) and downstream sub-regions (Central and South Bays) suggest that different environmental drivers are influencing northern anchovy in different sub-regions of the estuary: ocean conditions in the downstream sub-regions and watershed conditions, in particular hydrological conditions and planktonic food availability, in the upstream sub-regions.

Results of the **Demersal Fish Abundance** indicator are shown in Figure 5.

Abundance of demersal fish species differs among the estuary's sub-regions.
Demersal fishes are more abundant in Central Bay (942 fish/10,000m^2) than in all other sub-regions of the estuary and least abundant in Suisun Bay (50 fish/10,000m^2) (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, all pairwise comparisons: $p<0.05$). Demersal fish abundance in South (288 fish/10,000m^2) and San Pablo Bays (277 fish/10,000m^2) are comparable. In 2008, demersal fishes were nearly ten times more abundance in Central Bay (2093 fish/10,000m^2) than either South (231 fish/10,000m^2) or San Pablo Bays (335 fish/10,000m^2) and nearly 40 times more abundant than in Suisun Bay (54 fish/10,000m^2).

Abundance of demersal fishes has increased in Central Bay and declined in Suisun Bay.
During the past 29 years, abundance of native demersal fishes increased in Central Bay (regression: $p<0.05$) but declined in Suisun Bay (regression: $p<0.05$). In South and San Pablo Bays, demersal fish abundance has fluctuated widely. Compared to 1980-1989 levels, recent average abundances (2004-2008) were 56% and 51% lower in Suisun and San Pablo Bays, respectively, and 22% and 161% higher in South and Central Bays, respectively.

Increases in demersal fish abundance in Central and South Bays were driven by multiple species.
In South Bay, increases in demersal fish abundance were largely attributable to high catches of Bay goby, a Bay resident species. In contrast, demersal fish abundance increases in Central Bay in the late 1990s and early 2000s were largely driven by two species of flatfishes, seasonal species that use the estuary as nursery habitat but which maintain substantial populations outside the Golden Gate. It is likely that increases in the abundance of these species reflected improved ocean conditions.

Based on the abundance of demersal fishes, CCMP goals to "recover" and "reverse declines" of estuarine fishes have been met in all sub-regions except Suisun Bay, the upstream reach of the estuary.
Both current levels (expressed as the 2004-2008 average) and trends in demersal fish abundance were comparable to the 1980-1989 reference period for all sub-regions of the estuary except Central Bay, where demersal fish abundance increased (t-test or Mann-Whitney, $p>0.05$, South, San Pablo and Suisun Bays; $p=0.012$ for Central Bay). However, demersal fish abundance fluctuates widely in all sub-regions of the San Francisco Estuary, suggesting that this indicator may be inadequately responsive to watershed conditions. In addition, the different trends between the upstream sub-regions (Suisun and San Pablo Bays) and downstream sub-regions (Central and South Bays) suggest that different environmental drivers are influencing demersal fish abundance in the different sub-regions of the estuary: ocean conditions in the downstream sub-regions and watershed conditions, in particular hydrological conditions, in the upstream sub-regions.

Results of the **Sensitive Fish Species Abundance** indicator are shown in Figure 6.

Abundances of longfin smelt, Pacific herring, starry flounder and striped bass differ among the different sub-regions of the estuary.

The Bay-wide abundance of the four species was roughly comparable (although starry flounder densities are generally lower than those of the pelagic species), but different species use different sub-regions within the estuary. Longfin smelt and starry flounder are most abundant in San Pablo, Suisun and Central Bays and rare in South Bay. Pacific herring are most commonly found in Central, South and San Pablo Bays and rarely collected in Suisun Bay. Striped bass are mostly collected in Suisun Bay and, to a lesser extent, San Pablo Bay and rarely found in Central and South Bays.

Abundance of sensitive fish species has declined in all sub-regions of the estuary.
During the past 29 years, combined abundance of the four sensitive fish species has declined in all sub-regions of the estuary (regression: $p<0.05$ all sub-regions). For the most recent five-year period (2004-2008), abundance of sensitive fish species abundance Central Bay is just 20% of that sub-region's 1980-1989 average, 32% in San Pablo Bay, 35% in South Bay and 51% in Suisun Bay. The higher abundances measured in Suisun Bay in 2008 reflect increases in Pacific herring and starry flounder, species that are relatively uncommon in that sub-region. In each sub-region, most of the decline occurred during the late 1980s and early 1990s and, with the exceptions of a few single years in different sub-regions, the abundance of the four sensitive fish species has remained below 50% of the 1980-1989 since then.

Abundance declines were measured for most of the species in most sub-regions of the estuary.
All of the species except Pacific herring declined significantly in the sub-region in which they were most prevalent (regression: $p<0.05$ for all species except Pacific herring in Central Bay). Longfin smelt declined in both San Pablo and Suisun Bays (regression: $p<0.05$ both tests), starry flounder declined in Central and San Pablo Bays (regression: $p<0.05$ both tests), striped bass declined in all sub-regions (regression: $p<0.05$ in all sub-regions except South Bay, where $p=0.051$), and Pacific herring declined in South Bay (regression: $p<0.05$).

Based on the abundance of sensitive fish species, CCMP goals to "recover" and "reverse declines" of estuarine fishes have not been met in any sub-region of the estuary.
The combined abundance of the four estuary-dependent species assessed with this indicator have fallen to levels that are consistently 50% or less than the 1980-1989 average abundance reference condition. However, sensitive species abundance exhibited high variability during the 1980s, thus recent levels (2004-2008) were significantly lower in only South and Central Bay (t-test or Mann-Whitney, $p<0.05$). Although recent abundance levels in San Pablo and Suisun Bay were markedly lower than during the 1980-1989 reference, the differences were not statistically significant due to high variability during the 1980s. The significant declines measured for three of the four individual species indicates that population declines of estuary-dependent species span multiple species and all geographic regions of the estuary.

C. Diversity Indicators

1. Rationale

Diversity, or the number of species present in the native biota that inhabit the ecosystem, is one of the most commonly used indicators of ecological health of aquatic ecosystems (Karr et al., 2000; Wang and Lyons, 2003; Harrison and Whitfield, 2004). Diversity tends to be highest in healthy ecosystems and to decline in those impaired by urbanization, alteration of natural flow patterns, pollution, and loss of habitat area.

More than 100 native fish species have been collected in the San Francisco Bay by the Bay Study surveys. Some are transients, short-term visitors from nearby ocean or freshwater habitats where they spend the majority of their life cycles, or anadromous migrants, such as Chinook salmon and sturgeon, transiting the Bay between freshwater spawning grounds in the Bay's tributary rivers and the ocean. Other species are dependent on the Bay as critical habitat, using it for spawning and/or rearing, spending a large portion or all of their life cycles in Bay waters.

Of the more than 100 fish species collected by the Bay Study since 1980, 39 species can be considered "estuary-dependent" species (Table 4). These species may be resident species that spend their entire life-cycle in the estuary, marine or freshwater species that depend on the San Francisco Estuary for some key part of their life cycle (usually spawning or early rearing), or local species that spend a large portion of their life cycle in the San Francisco Estuary. Just as diversity, or species richness, of the native fish assemblage is a useful indicator of the ecological health of aquatic ecosystems, diversity of the estuary-dependent fish assemblage is a useful indicator for the ecological health of the San Francisco Estuary.

The Fish Index includes two different diversity indicators. The **Native Fish Species Diversity** indicator uses Midwater and Otter trawl survey data to measure how many of the estuary's native fish species are present in the Bay each year. The **Estuary-dependent Fish Species Diversity** indicator uses data from both surveys to measure how many estuary-dependent species are present each year.

2. Methods and Calculations

The **Native Fish Species Diversity** indicator was calculated for each year and for each of four sub-regions of the estuary as the number of species collected, expressed as the percentage of the maximum number of native species ever collected in that sub-region, using catch data from the Bay Study Midwater and Otter Trawl surveys. The indicator was calculated as:

% of species assemblage = (# native species/maximum # of native species reported) x 100

The **Estuary-dependent Fish Species Diversity** indicator was calculated for each year and for each of four sub-regions of the estuary as the number of estuary-dependent species collected (see Table 4), expressed as the percentage of the maximum number of estuary-dependent species ever collected in that sub-region, using catch data from the Bay Study Midwater and Otter Trawl surveys. The indicator was calculated as:

% of species assemblage =
(# estuary-dependent species/maximum # of estuary-dependent species reported) x 100

3. Reference Conditions:

For the two diversity indicators, the primary reference condition was based on the average diversity (expressed as % of the native fish assemblage present), measured for the first ten years of the Bay Study, 1980-1989, and for all four sub-regions combined. Diversity levels that were greater than the 1980-1989 average were considered to reflect "good" conditions. The average percentage of the native fish assemblage present during the 1980-1989 period diversity differed slightly among the four sub-regions for the Native Fish Species Diversity indicator (1980-1989 average: 49%; Suisun Bay diversity was lower than that in the other three sub-regions) and significantly for the Estuary-dependent Fish Species Diversity indicators (1980-1989 average: 72%; Suisun Bay was lowest and Central and South Bay were highest). This approach tended to reflect the relatively lower species diversity observed in Suisun Bay in the indicator results. Table 5 below shows the quantitative reference conditions that were used to evaluate the results of the two diversity indicators.

4. Results

Results of the **Native Fish Species Diversity** indicator are shown in Figure 7.

Maximum native species diversity differs among the four sub-regions of the estuary.
The greatest numbers of native fish species are found in Central Bay (94 species) and the fewest are in Suisun Bay (48 species). A maximum of 73 native species have been collected in South Bay and 66 native species have been found in San Pablo Bay.

The percentage of the native fish species assemblage present differs among the sub-regions.
In addition to having a smaller native fish species assemblage, Suisun Bay has a significantly lower percentage (44%) of that assemblage present each year compared to all other sub-regions (48% in Central Bay; 49% in South Bay and 51% in San Pablo Bay) (ANOVA: $p<0.001$, all pairwise comparisons: $p<0.01$). In recent years (2004-2008), native fish diversity has been highest in Central Bay (ANOVA: $p<0.05$ for Central Bay compared to Suisun Bay).

Trends in native species diversity differ among the sub-regions.
Native species diversity has increased significantly in Central Bay (regression: $p<0.01$) with an average of six more species in the most recent five-year period compared to the 1980-1989 reference period. Native fish species diversity decreased significantly in San Pablo Bay (regression: $p=0.05$), with an average of four fewer species in the 2005-2008 period compared to the 1980-1989 period. Native fish species diversity fluctuated in both South and Suisun bays.

Based on the diversity of the native fish community, CCMP goals to "recover" and "reverse declines" of estuarine fishes have been met in all sub-regions of the estuary.
Comparison of average native fish species diversity in the most recent five years (2004-2008) to that measured during the 1980-1989 period shows no significant differences except for Central Bay, where diversity is significantly higher (t-test: $p<0.05$).

Results of the **Estuary-dependent Fish Species Diversity** indicator are shown in Figure 8.

The diversity of estuary-dependent species is lower in Suisun Bay than in other sub-regions of the estuary.

Although roughly the same number of estuary-dependent species are found in each sub-region (38 species in San Pablo Bay; 36 species in Central and South Bays; and 31 species in Suisun Bay), a significantly smaller percentage of the estuary-dependent fish assemblage occurs in Suisun Bay (49% of the assemblage) than in all other regions of the San Francisco Estuary (84% in Central Bay; 80% in South Bay; and 69% in San Pablo Bay) (ANOVA: $p<0.001$, all pairwise comparisons, $p<0.05$).

Diversity of Bay-dependent species is generally stable in most sub-regions of the estuary.
Estuary-dependent species diversity has declined slightly in San Pablo Bay (regression: $p<0.05$, for a decrease of 2 species from the 1980-1989 period to the 2004-2008 period) and South Bay (regression: $p<0.05$, for an average decrease of 1.5 species). In all other regions, estuary-dependent diversity has fluctuated but remained relatively stable over the 29-year period.

Based on the diversity of the estuary-dependent fish community, CCMP goals to "recover" and "reverse declines" of estuarine fishes have been met in all sub-regions of the estuary except South Bay.
Comparison of average estuary-dependent fish species diversity in the most recent five years (2004-2008) to that measured during the 1980-1989 period shows no significant differences, except for South Bay, where diversity of estuary-dependent fishes was significantly lower (Mann-Whitney Rank Sum test: $p<0.05$).

D. Species Composition Indicators

1. Rationale

The relative proportions of native and non-native species found in an ecosystem is an important indicator of ecosystem health (May and Brown, 2002; Meador et al., 2003). Non-native species are most prevalent in ecosystems that have been modified or degraded with resultant changes in environmental conditions (e.g., elevated temperature, reduced flood frequency), pollution, or reduction in area or access to key habitats (e.g., tidal marsh, seasonal floodplain). The San Francisco Estuary has been invaded by a number of non-native fish species. Some species, such as striped bass, were intentionally introduced into the estuary; others have arrived in ballast water or from upstream habitats, usually reservoirs.

The Fish Index includes two different indicators for species composition. The **Percent Native Species** indicator uses Midwater and Otter trawl survey data to measure what percentage of the fish species collected in each sub-region of the estuary are native species. The **Percent Native Fish** uses the survey data to measure what percentage of the individual fish collected in each sub-region of the estuary are native species.

2. Methods and Calculations

The **Percent Native Species** indicator was calculated for each year and for each of four sub-regions of the estuary as the percentage of fish species collected in the estuary that are native to the estuary and its adjacent ocean and upstream habitats using the equation below.

% native species = [# native species/(# native species + # non-native species)] x 100

The Percent Native Fish indicator was calculated for each year and for each of four sub-regions of the estuary as the percentage of fish collected in the estuary that are native to the estuary and its adjacent ocean and upstream habitats using the equation below.

% native fish = [# native fish/(# native fish + # non-native fish)] x 100

3. Reference Conditions:

There is an extensive scientific literature on the relationship between the presence and abundance of non-native species and ecosystem conditions and the length of the available data record for the San Francisco Estuary allows for establishment of “reference conditions”. In general, ecosystems with high proportions of non-natives (e.g., >50%) are considered to be seriously degraded. Furthermore, non-native fish species have been present in the San Francisco Estuary Bay for more than 100 years; therefore, 100% native fish species is unrealistic. Among the four sub-regions, the 1980-1989 average percentage of native species was 87% and the average percentage of native fish was 90%. For both indicators, Suisun Bay values were lowest. Based on this information, the primary reference condition for both indicators was established at 85%. Percent Native Species levels that were greater than this value were considered to reflect “good” conditions. Table 6 below shows the quantitative reference conditions that were used to evaluate the results of the two species composition indicators.

4. Results

Results of the **Percent Native Species** indicator are shown in Figure 9.

The percentage of native species in the fish community differs among the four sub-regions of the estuary.
For the past 29 years, non-native species have been most prevalent in Suisun Bay, where in most years less than 75% of species are natives, intermediate in South and San Pablo Bays (88% and 86% native, respectively), and the least prevalent in Central Bay (92%) (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, all pairwise comparisons: $p<0.05$).

Trends in the percentage of native species differ among the sub-regions.
The percentage of native species is declining in all sub-region of the estuary except Central Bay. In San Pablo Bay, the percent native species declined significantly (regression: $p<0.001$) from 90% in the 1980-1989 period to 81% in the most recent five-year period. Percent native species declined in Suisun Bay from 77% to 69% (regression: $p<0.01$) and in South Bay the percentage of native species declined from 89% to 85% (regression: $p<0.05$).

Trends in the percentage of native species in Bay fish assemblages are driven by declines in the numbers of native species and increases in non-native species.
During the past 29 years, the number of native species in San Pablo Bay declined by three species and the number of non-native species increased by three, to an average of seven non-

native species of the 2004-2008 period. The number of non-native species collected in Suisun Bay increased by an average of three species, from six species in the 1980-1989 period to nine species in the most recent five years. In South Bay, native species declined by one and non-natives increased by one. In Central, the total number of native species collected increased by six species.

Based on fish species composition, CCMP goals to "recover" and "reverse declines" of estuarine fishes have not been met in Suisun and San Pablo Bays.
Compared to the 1980-1989 period and the biologically based 85% native species reference condition, recent measurements (2004-2008) of the fish species composition indicate significantly poorer condition for San Pablo Bay (Mann-Whitney Rank Sum test: $p<0.01$) and Suisun Bay (t-test: $p<0.01$). Although both a long-term (1980-2008) and recent (2004-2008) decline were evident in South Bay, the average percentage of native species for the most recent five year period was not significantly different than that for the 1980-1989 reference period.

Results of the **Percent Native Fish** indicators are shown in Figure 10.

The percentage of native fish in the fish community differs among the four sub-regions of the estuary.
For the past 29 years, non-native fish have dominated the Suisun Bay sub-region, where in most years less than 50% of fish collected are natives (1980-2008 average: 49%). Non-native fish are rare in the other three sub-regions. Central Bay has the least (1980-2008 average: 0.1%), South Bay has just 1% non-native fishes and San Pablo Bay less than 3% non-native fishes (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, all pairwise comparisons: $p<0.05$).

Trends in the percentage of native fish differ among the sub-regions.
The percentage of native fishes is declining in the Suisun and South Bay sub-region of the estuary but not in Central or San Pablo Bays. In Suisun Bay, the percent native fish declined significantly (regression: $p<0.001$) from 63% in the 1980-1989 period to just 37% in the most recent five-year period. Percent native fish declined in South Bay from more than 99% to 96%% (regression: $p<0.01$). The increases in the numbers of non-native fish in South Bay in 2007 and 2008 were largely attributable to higher catches of two non-natives, striped bass and chameleon goby.

Based on fish species composition, CCMP goals to "recover" and "reverse declines" of estuarine fishes have been met in all sub-regions of the estuary except Suisun Bay.
In all regions of the estuary except Suisun Bay, native fish comprise the vast majority of the fish community, exceeding 95% of the total fish present in nearly all years. In Suisun Bay, the percentage of the fish community that is comprised of non-native fish is extremely high and increasing, indicating that the condition of this region of the estuary is poor and deteriorating.

E. Distribution Indicators

1. Rationale

The distribution of native fishes within a habitat is an important indicator of ecosystem condition (May and Brown, 2002; Whitfield and Elliott, 2002; Nobriga et al., 2005). Native fishes may be excluded or less abundant in degraded habitats with unsuitable environmental conditions and/or those in which more tolerant non-native species have become established. The Fish Index includes two indicators to assess the distribution of native fishes within the estuary. The **Pelagic Fish Distribution** indicator uses Midwater trawl survey data to measure the percentage of the survey's sampling stations at which native species were regularly collected. The **Demersal Fish Distribution** indicator uses Otter trawl survey data to make a similar measurement for bottom-oriented native fishes.

5. Methods and Calculations

The **Pelagic Fish Distribution** indicator was calculated for each year and for each of four sub-regions of the estuary as the percentage of Midwater trawl survey stations at which at least one native fish was collected in at least 60% of the surveys conducted in that year.

Pelagic Fish Distribution =
(# survey stations with native fish in 60% of surveys)/(# survey stations sampled) x 100

The **Demersal Fish Distribution** indicator was calculated identically using Otter trawl survey data.

6. Reference Conditions:

There is an extensive scientific literature on the relationship between the presence and abundance of non-native species and ecosystem conditions. The length of the available data record for the San Francisco Estuary allows for establishment of "reference conditions". For the two Distribution indicators, the primary reference condition was established based on the number of stations sampled by the Bay Study surveys (8-12 stations per sub-region; therefore the maximum resolution of this indicator is limited to 8-13% increments depending on sub-region) and the average percentage of stations with native species present for the first ten years of the Bay Study, 1980-1989 (~96%). Distribution levels that were greater than the reference condition were considered to reflect "good" conditions. Table 7 below shows the quantitative reference conditions that were used to evaluate distribution indicators.

7. Results

Results of the **Pelagic Fish Distribution** indicator are shown in Figure 11.

The percentage of Midwater trawl survey stations that regularly have native fish differs among the four sub-regions of the estuary.
For the past 29 years, native fish have been consistently present at nearly all Midwater trawl survey stations in all sub-regions of the estuary except Suisun Bay. During the 1980-2008 period, native fish were present at 98-99% of survey stations in South, Central and San Pablo Bays. In contrast, native fish were present in only an average of 81% stations in Suisun Bay (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, Suisun v all other sub-regions; $p<0.05$).

Trends in the percentage of native fish differ among the sub-regions.
The percentage of survey stations with native fish was stable in all sub-regions of the estuary except Suisun Bay. In Suisun Bay, distribution of native fishes declined significantly from 88% of stations (1980-1989) to 63% in the most recent five years (2004-2008) (Mann-Whitney Rank Sum test; $p<0.01$; regression: $p<0.05$). This decline in distribution occurred abruptly in 2003 and is largely drive by low distribution in 2005, when native fish were collected in only five of 12 stations (42%). Prior to 2003, distribution of native pelagic fish in Suisun Bay was generally stable at 86% of stations (1980-2002 average) but since 2003 native pelagic fish were present at only 63% of Suisun Bay stations (2003-2008 average). Native fish were most frequently absent from survey stations located in the lower San Joaquin River and the western region of Suisun Bay.

Based on native pelagic fish distribution, CCMP goals to "recover" and "reverse declines" of estuarine fishes have been met in all sub-regions of the estuary except Suisun Bay.
In all regions of the estuary except Suisun Bay, native pelagic fish are regularly collected at all Midwater trawl survey stations. In contrast, native fish are increasingly absent from the western region of Suisun Bay, the most upstream region of the estuary, suggesting that the condition of this region of the estuary is deteriorating.

Results of the **Demersal Fish Distribution** indicator are shown in Figure 12.)

The percentage of Otter trawl survey stations that regularly have native fish differs among the four sub-regions of the estuary.
For the past 29 years, native fish have been consistently present at nearly all Otter trawl survey stations in all sub-regions of the estuary except Suisun Bay. During the 1980-2008 period, native fish were present at 98-100% of survey stations in South, Central and San Pablo Bays. In contrast, native fish were present in only an average of 81% stations in Suisun Bay (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, Suisun v all other sub-regions; $p<0.05$).

Trends in the percentage of native fish differ among the sub-regions.
The percentage of survey stations with native fish was stable in all sub-regions of the estuary except Suisun Bay. In Suisun Bay, distribution of native fishes declined briefly but significantly in the early 1990s, from 91% of stations (1980-1991) to just 64% of stations (1992-1994), and then recovered to 89% (1995-2000). In 2001, distribution declined significantly again, falling to 62% of stations (2001-2007) before returning to 91% in 2008 (Mann-Whitney Rank Sum test; $p<0.05$ both tests). For the most recent five years (2004-2008), native demersal fish have been present at 62% of stations. Similar to pelagic fish, native demersal fish were most frequently absent from survey stations located in the western region of Suisun Bay.

Based on native demersal fish distribution, CCMP goals to "recover" and "reverse declines" of estuarine fishes have been met in all sub-regions of the estuary except Suisun Bay.
In all regions of the estuary except Suisun Bay, native demersal fish are regularly collected at all Otter trawl survey stations. In contrast, native fish are increasingly absent from the western region of Suisun Bay, the most upstream region of the estuary, suggesting that the condition of this region of the estuary is deteriorating.

V. Fish Index

The Fish Index aggregates the results of the four abundance indicators (Pelagic Species, Demersal Species, Northern Anchovy, and Sensitive Species), two diversity indicators (Native Species and Estuary-dependent Species), two species composition indicators (Percent Native Species and Percent Native Fish) and the two distribution indicators (Pelagic Fish and Demersal Fish Distribution).

A. Index Calculation

For each year and for each sub-region, the Fish Index is calculated by combining the results of the ten indicators into a single number. First, results of the indicators in each fish community attribute (i.e., abundance, diversity, species composition and distribution) were combined by averaging the quantitative scores of each of the component indicators. Within the fish community attribute, each indicator was equally weighted. Next the average scores for each fish community attribute were combined by averaging, with each fish community attribute equally weighted. An index score greater than 3 was interpreted to represent “good” conditions and an index score less than 1 was interpreted to represent “very poor” conditions.

B. Results

Results of the Fish Index for each sub-region~~s~~ are shown in Figure 13.

The Fish Index differs among the four sub-regions of the estuary.
For the 29-year survey period, the Fish Index was highest in the Central Bay (1980-2008 average: 3.14), lowest in Suisun Bay (1.77), and intermediate in South and San Pablo Bays (3.01 and 2.78, respectively) (Kruskal Wallis One-way ANOVA of Ranks: $p<0.05$; Central>South and San Pablo>Suisun). For the most recent five years, the differences among the regions are even greater. The Fish Index was highest in Central (2004-2008 average: 3.025), lowest in Suisun (1.28) and intermediate in South and San Pablo Bays (2.84 and 2.56, respectively). Lower Fish Index values for Suisun Bay at the beginning of the survey period were attributable to lower diversity (i.e., smaller percentages of the sub-region’s species assemblage were present) and species composition (i.e., high prevalence of non-native species and non-native fish).

Trends in the Fish Index differ among the sub-regions.
During the 29-year survey period, the Fish Index has declined significantly in Suisun, San Pablo and South Bays but not in Central Bay (regression 1980-2008: $p<0.005$ all sub-regions except Central Bay). The overall condition of the fish community in Suisun Bay has declined from “fair” in the early 1980s (1980-1989 average: 2.21) to consistent “poor” conditions throughout the 1990s and 2000s. In 2006, when diversity, species composition and distribution all dropped, condition of the fish community in Suisun Bay was “very poor.” In San Pablo Bay, the Fish Index has declined steadily, from mostly “good” conditions in the early 1980s to “fair” conditions by the 1990s: since then, the San Pablo Bay Fish Index has not fallen to “poor” levels and has continued to decline. The decline in the Fish Index in South Bay, while significant, is

not as severe. In Central Bay, the Fish Index has been relatively stable with generally "good" fish community conditions.

Based on Fish Index, CCMP goals to "recover" and "reverse declines" of estuarine fishes have been met in only the Central Bay sub-region.
The overall condition of the fish community is "good" in Central Bay, the most downstream region of the San Francisco Estuary. In all other sub-regions of the estuary, the condition of fish community is declining. In Suisun Bay, the most upstream region of the estuary most directly affected by watershed degradation, alteration of freshwater inflows and declines in the quality and quantity of low-salinity habitat, the fish community is in "poor" condition. These declines in the Fish Index are largely driven by declines in fish abundance (all three sub-regions), declining diversity (South and San Pablo Bays), increasing prevalence of non-native species (all three sub-regions), and declines in the distribution of native fish within the sub-region (Suisun Bay).

C. Summary and Conclusions

Collectively, the ten indicators and the Fish Index provide a reasonably comprehensive assessment of status and trends San Francisco Estuary fish community. The results show substantial geographic variation in both the composition and condition of the fish community within the estuary and in the response of specific indicators over time. Table 8 below summarizes the indicator and Index results by sub-region. In addition, the following general conclusions can be made:

1. The San Francisco Estuary fish community differs geographically within the estuary in fish community composition, fish abundance, and trends in various attributes of its condition over time.
2. Different indicators show different responses over time, some demonstrating clear declines in condition over time, others no change, and a few increases. In some cases, the same indicators measured in different sub-regions of the estuary show different responses over time. These results suggest that different physical, chemical or biological environmental variables (or combinations of these variables) influence the fish community response in different sub-regions.
3. Overall condition, as measured individually by the fish indicators and by the Fish Index for the community response, is poorest in upstream region of estuary, Suisun Bay; best in Central Bay, the region most strongly influenced by ocean conditions and with a predominantly marine fish fauna; and intermediate in San Pablo and South Bays. However, condition of the fish community in San Pablo and South Bays is declining and, for San Pablo Bay, could deteriorate to "poor" condition if the current rate of decline continues for the next two decades.
4. Even 30 years ago, the condition of the fish community in Suisun Bay was poorer than in all other sub-regions of the estuary. The fish community was less diverse with relatively lower percentages of the native fish assemblage present, and dominated by high percentages of non-native species.
4. The abundance of pelagic fishes in the estuary (which include Northern anchovy and most of the sensitive species measured in those two indicators) has shown the greatest changes over time, indicating this component of the fish community has low resilience and/or is tightly linked to just one or a few environmental drivers that have also experienced substantial change in conditions during the sampling period.

VI. Peer Review

The Fish indicators and index build upon the methods and indicators developed by The Bay Institute for the 2003 and 2005 Ecological Scorecard San Francisco Bay Index and for the San Francisco Estuary Partnership Indicators Consortium. The Bay Institute's Ecological Scorecard was developed with input and review by an expert panel that included Bruce Herbold (US EPA), James Karr (University of Washington, Seattle), Matt Kondolf (University of California, Berkeley), Pater Moyle (University of California, Davis), Fred Nichols (US Geological Survey, ret.), and Phillip Williams (Phillip B. Williams and Assoc.). These recent versions of the indicators and indices were also reviewed and revised according to the comments of Bruce Herbold and Luisa Valiela (US EPA).

VII. References

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Figure 1. Because the San Francisco Estuary is so large and its environmental conditions so different in different areas, the Fish Index and each of its component indicators were calculated separately for four "sub-regions" in the estuary: South Bay, Central Bay, San Pablo Bay and Suisun Bay and the western Delta.

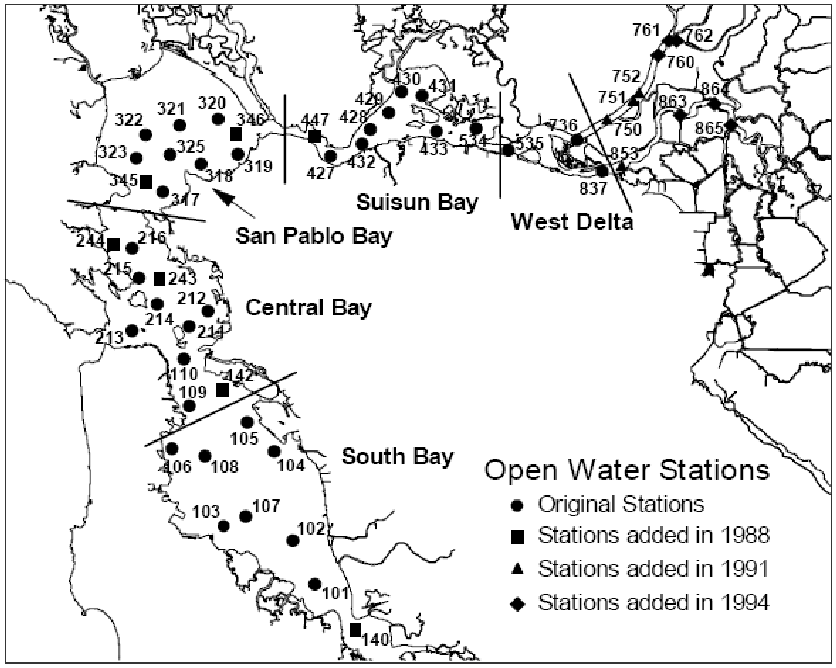

Figure 2. Locations of the sampling stations for the CDFG Bay Study Midwater Trawl and Otter Trawl surveys in different sub-regions of the San Francisco Bay. For the 2007 Fish Index, only data from the "original stations" (sampled continuously for 1980-2006 period) were used to calculated indicators for four sub-regions: South Bay, Central Bay, San Pablo Bay, and Suisun Bay (which for this study includes the West Delta sub-region).

Table 1. Sampling stations and total numbers of surveys conducted per year (range for the 1980-2006 period, excludes 1994) by the CDFG Bay Study Survey in each of four sub-regions of San Francisco Bay. MWT=Midwater Trawl survey; OT= Otter Trawl survey. See Figure 1 for station locations.

Sub-region	Sampling stations	Number of surveys (range for 1980-2005 period)
South Bay	101, 102, 103, 104, 105, 106, 107, and 108	64-96 (MWT) 64-96 (OT)
Central Bay	109, 110, 211, 212, 213, 214, 215, and 216	64-96 (MWT) 64-96 (OT)
San Pablo Bay	317, 318, 319, 320, 321, 322, 323, and 325	64-96 (MWT) 64-96 (OT)
Suisun Bay (includes West Delta sub-region shown in Figure 1)	425, 427, 428, 429, 430, 431, 432, 433, 534, 535, 736, and 837	87-132 (MWT) 88-132 (OT)

Table 2. Fish community characteristics and indicators used to calculate the Fish Index.

Fish Community Characteristic	Indicators
Abundance	• Pelagic Fish Abundance • Northern Anchovy Abundance • Demersal fish Abundance • Sensitive Species Abundance
Diversity	• Native Fish Diversity • Estuary-dependent Fish Diversity
Species Composition	• Percent Native Species • Percent Native Fish
Distribution	• Pelagic Fish Distribution • Demersal Fish Distribution

Table 3. Quantitative reference conditions and associated interpretations for the results of the fish abundance indicators. The primary reference condition, which corresponds to “good” conditions, is in bold.

Abundance Indicators (Pelagic Fish, Northern Anchovy, Demersal Fish, Sensitive Species)		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>150% of 1980-1989 average	“Excellent”	4
>100% of 1980-1989 average	**“Good”**	**3**
>50% of 1980-1989 average	“Fair”	2
>15% of 1980-1989 average	“Poor”	1
≤15% of 1980-1989 average	“Very Poor”	0

Figure 3. Changes in the Pelagic Fish Abundance indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition (1980-1989 average).

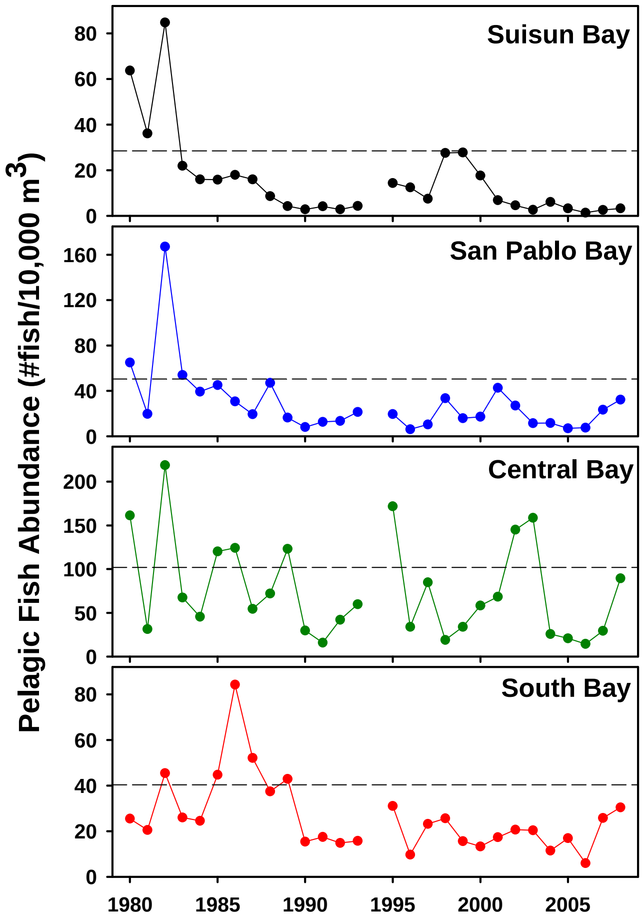

Figure 4. Changes in the Northern Anchovy Abundance indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition (1980-1989 average).

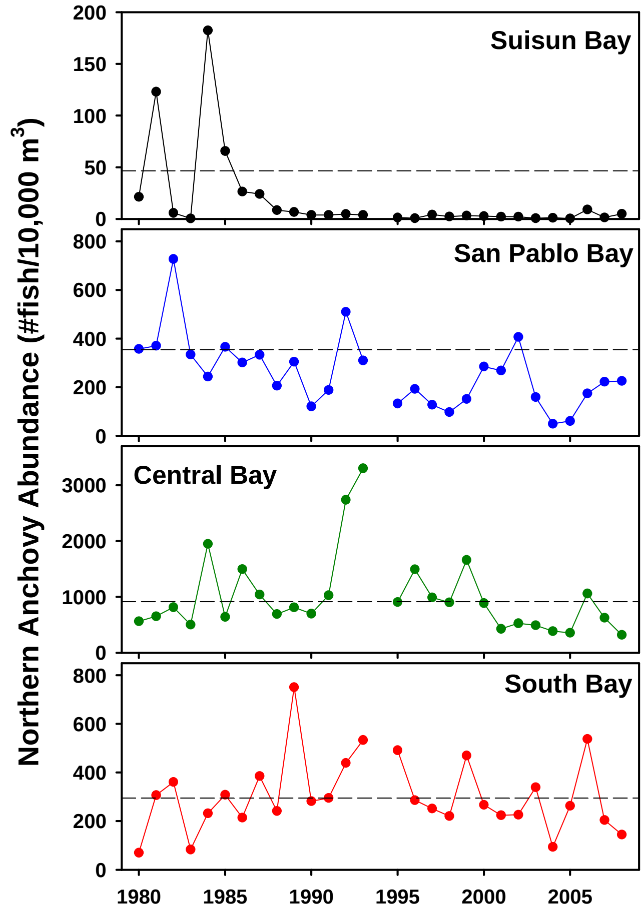

Figure 5. Changes in the Demersal Fish Abundance indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition (1980-1989 average).

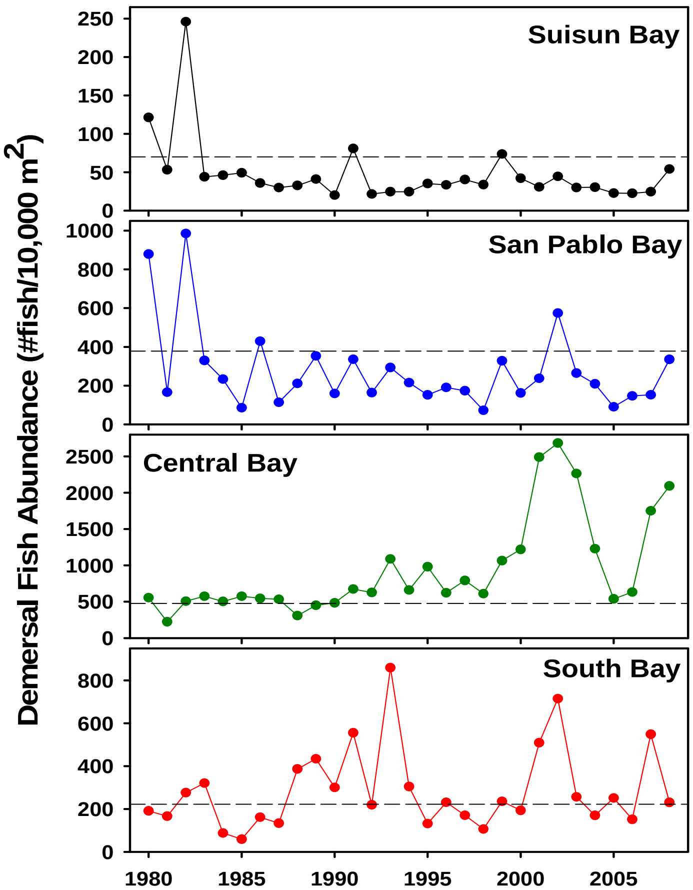

Figure 6. Changes in the Sensitive Fish Species Abundance indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition (1980-1989 average).

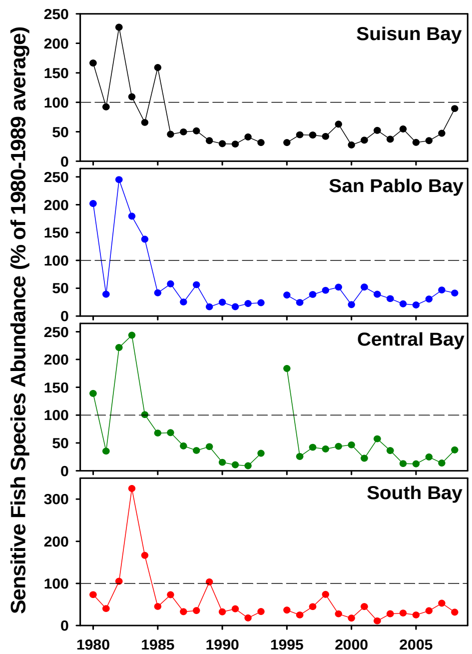

Table 4. San Francisco Estuary-dependent fish species collected in the CDFG Bay Study Midwater Trawl and Otter Trawl surveys.

Estuary-dependent fish species (common names)	
Estuary resident species Species with resident populations in the estuary and/or estuary-obligate species that use the estuary as nursery habitat	**Seasonal species** Species regularly use the estuary for part of their life cycle but also have substantial connected populations outside the estuary
Arrow goby	Barred surfperch
Bat ray	Black perch
Bay goby	Bonehead sculpin
Bay pipefish	California halibut
Brown rockfish	California tonguefish
Brown smoothhound	Diamond turbot
Cheekspot goby	English sole
Delta smelt	Northern anchovy
Dwarf surfperch	Pacific sandab
Jack smelt	Pacific tomcod
Leopard shark	Plainfin midshipman
Longfin smelt	Sand sole
Pacific herring	Speckled sanddab
Pacific staghorn sculpin	Spiny dogfish
Pile perch	Splittail
Shiner perch	Starry flounder
Threespine stickleback	Surfsmelt
Topsmelt,	Walleye surfperch
Tule perch	
White croaker	
White surfperch	

Table 5. Quantitative reference conditions and associated interpretations for the results of the diversity indicators. The primary reference condition, which corresponds to "good" conditions, is in bold.

Diversity Indicators		
Native Fish Species Diversity		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>60%	"Excellent"	4
>50% (~1980-1989 average)	**"Good"**	**3**
>40%	"Fair"	2
>30%	"Poor"	1
<u><</u>30%	"Very Poor"	0
Estuary-dependent Fish Species Diversity		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>85%	"Excellent"	4
>70% (~1980-1989 average)	**"Good"**	**3**
>55%	"Fair"	2
>40%	"Poor"	1
<u><</u>40%	"Very Poor"	0

Figure 7. Changes in the Native Fish Species Diversity indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition.

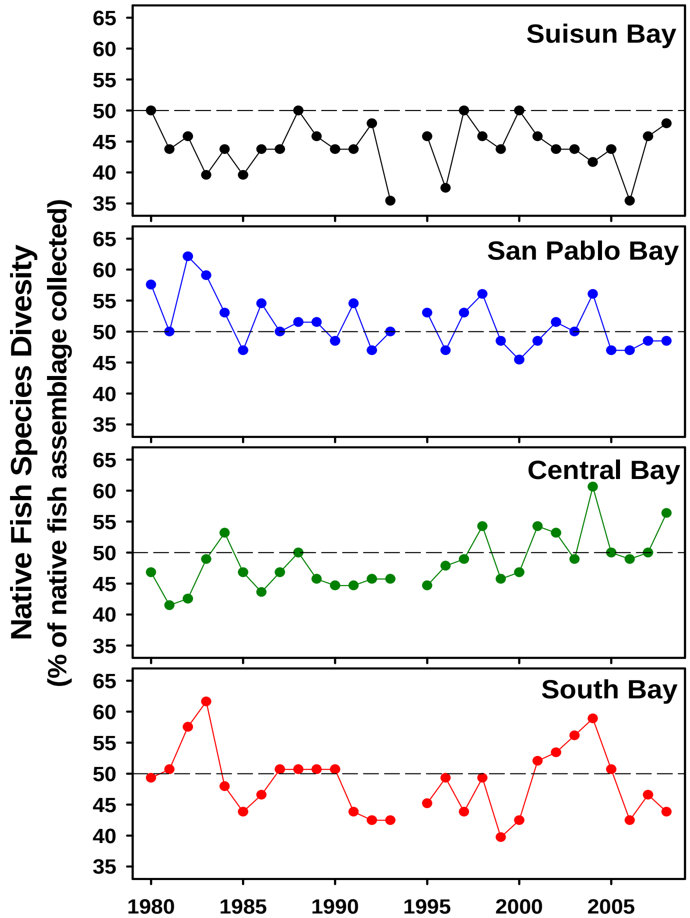

Figure 8. Changes in the Estuary-dependent Fish Species Diversity indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition (1989-1989 average).

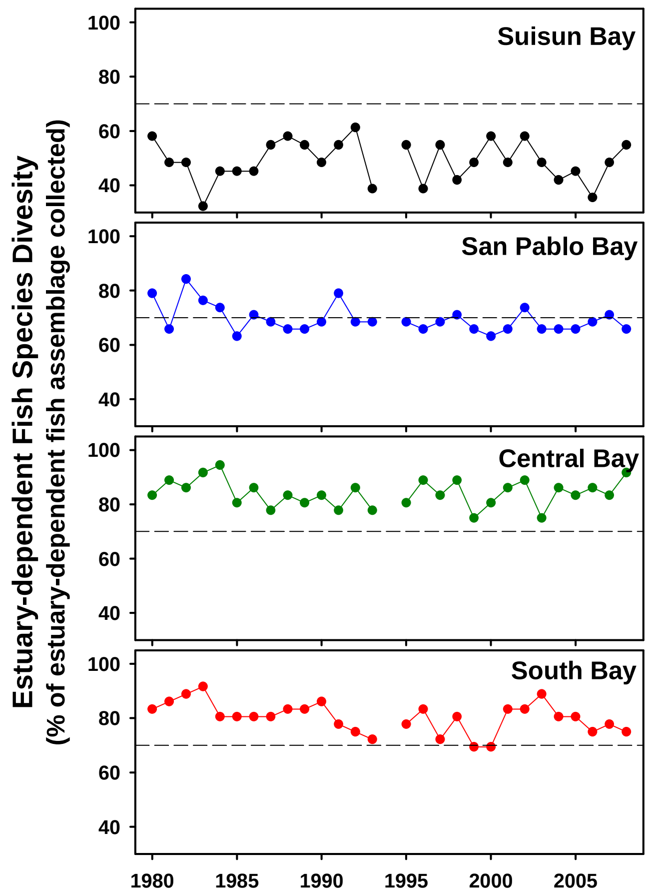

Table 6. Quantitative reference conditions and associated interpretations for the results of the species composition indicators. The primary reference condition, which corresponds to "good" conditions, is in bold.

Species Composition Indicators (Percent Native Species, Percent Native Fish)		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>95%	"Excellent"	4
>85% (~1980-1989 average)	**"Good"**	**3**
>70%	"Fair"	2
>50%	"Poor"	1
≤50%	"Very Poor"	0

Figure 9. Changes in the Percent Native Species indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition.

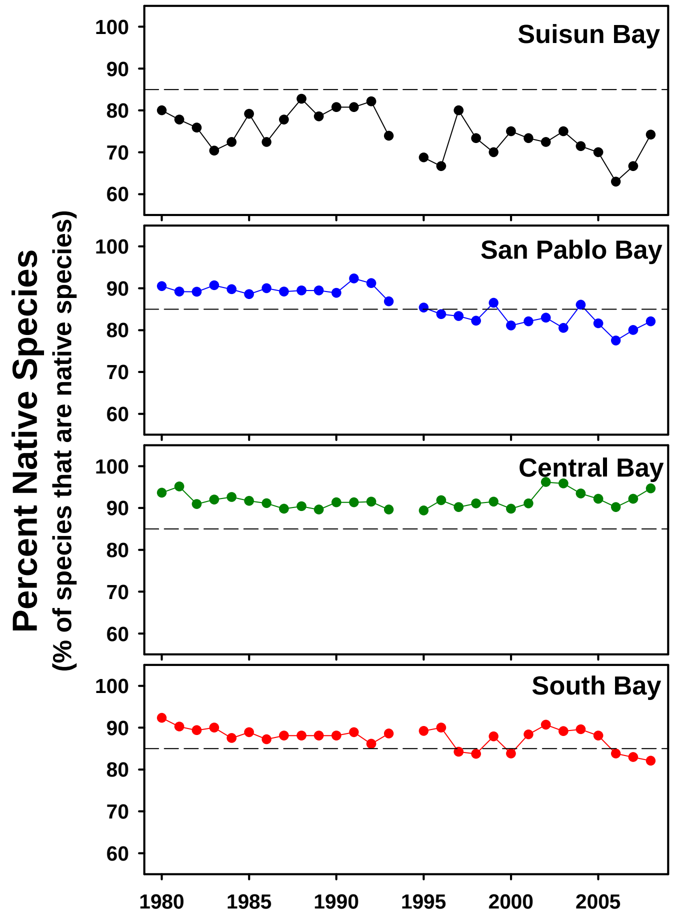

Figure 10. Changes in the Percent Native Fish indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition.

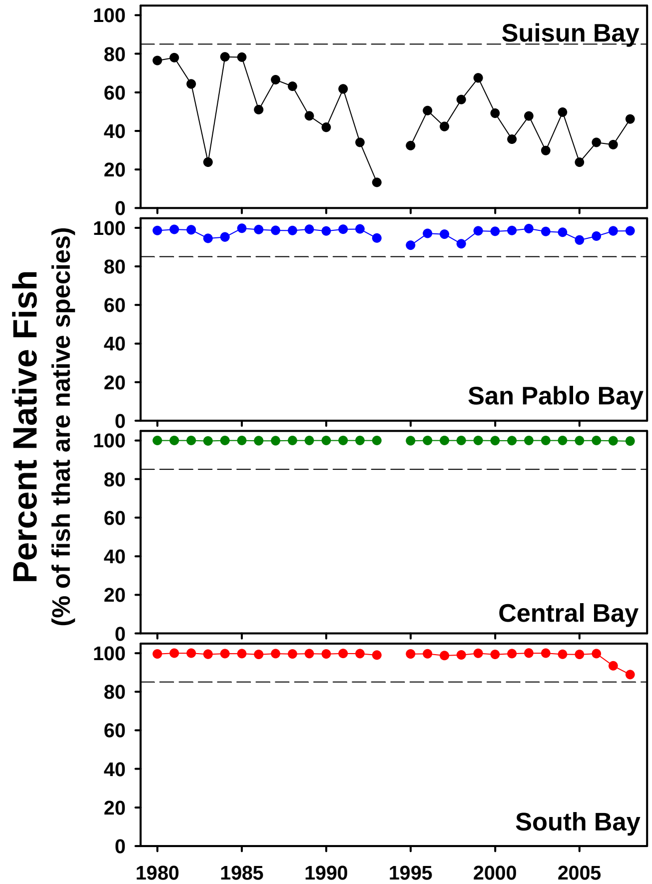

Table 7. Quantitative reference conditions and associated interpretations for the results of the distribution indicators. The primary reference condition, which corresponds to "good" conditions, is in bold.

Distribution Indicators (Pelagic Fish, Demersal Fish)		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
100%	"Excellent"	4
>80% (~1980-1989 average)	**"Good"**	**3**
>60%	"Fair"	2
>40%	"Poor"	1
≤40%	"Very Poor"	0

Figure 11. Changes in the Pelagic Fish Distribution indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition.

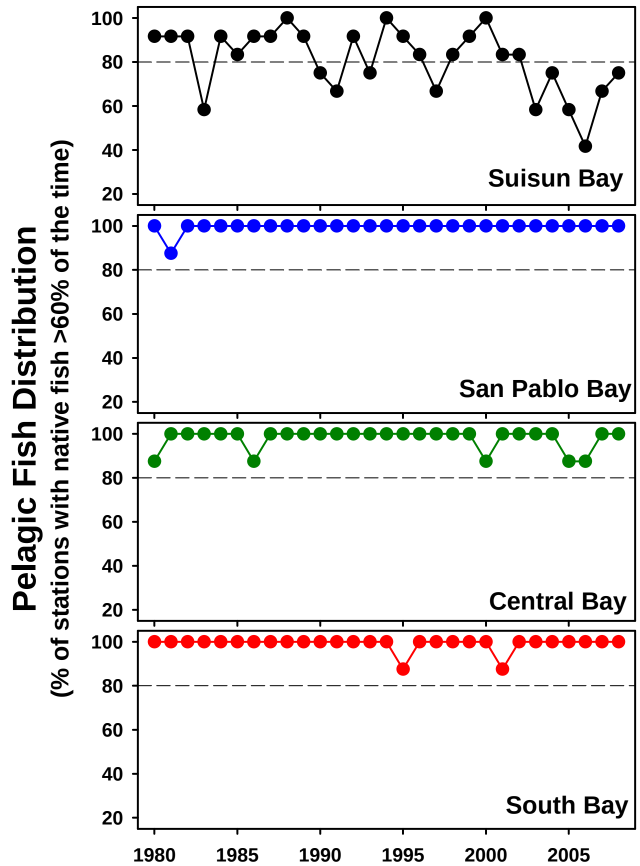

Figure 12. Changes in the Demersal Fish Distribution indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition.

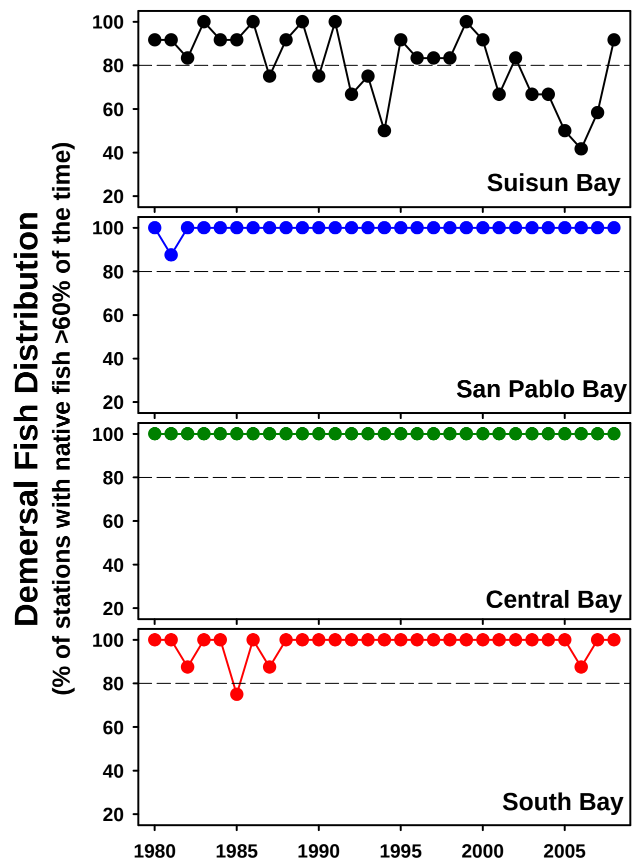

Figure 13. Changes in the Fish Index in each of four sub-regions of the San Francisco Estuary from 1980-2008. Black lines and symbols show the annual Index values, solid red line shows the linear regression for the 1980-2008 period. Horizontal dashed lines shows the reference conditions and associated interpretations.

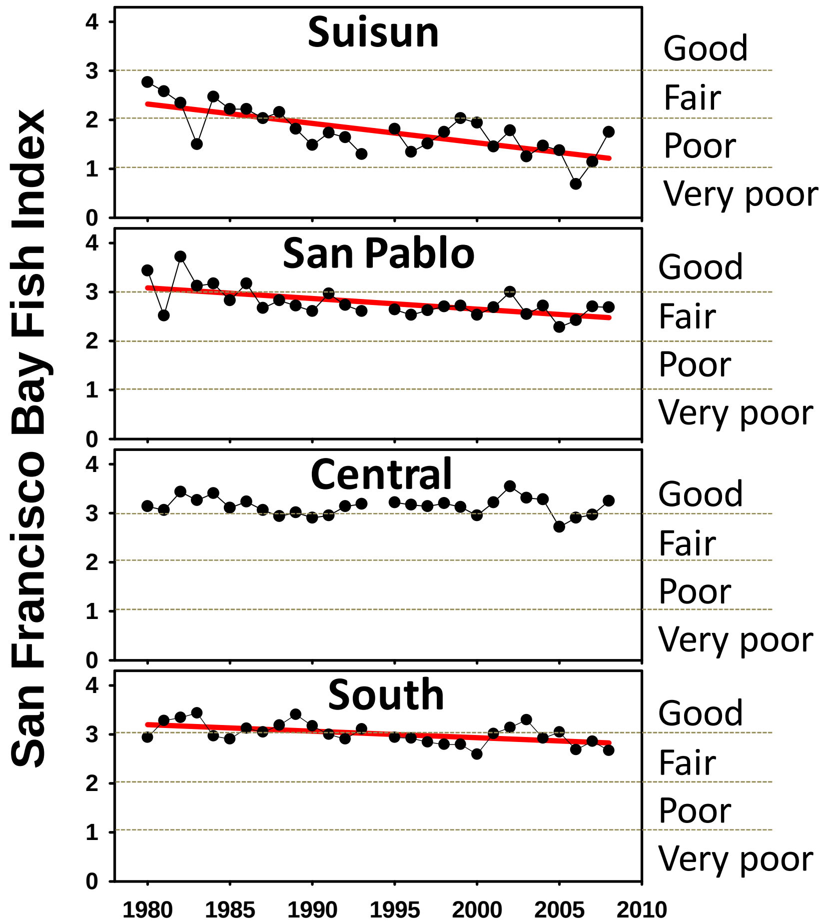

Table 8. Summary of results, relative to the CCMP goals to “recover” and “reverse declines” of estuarine fishes, of the seven fish indicators for each of the four sub-regions of the San Francisco Estuary.

Indicator or Index	Sub-region	CCMP Goal Met (yes or no)	Trend long-term (29 yrs)	Trend short-term (last 5 yrs)
Pelagic Fish Abundance	Suisun	No	Decline	Stable
	San Pablo	No	Decline	Stable
	Central	No	Stable	Stable
	South	No	Decline	Stable
Northern Anchovy Abundance	Suisun	No	Decline	Stable
	San Pablo	No	Decline	Increase
	Central	Yes	Stable	Stable
	South	Yes	Stable	Stable
Demersal Fish Abundance	Suisun	Yes	Decline	Stable
	San Pablo	Yes	Stable	Stable
	Central	Yes	Increase	Stable
	South	Yes	Stable	Stable
Sensitive Fish Species Abundance	Suisun	Yes	Decline	Stable
	San Pablo	Yes	Decline	Stable
	Central	No	Decline	Stable
	South	No	Decline	Stable
Native Fish Species Diversity	Suisun	Yes	Stable	Stable
	San Pablo	Yes	Decline	Stable
	Central	Yes	Increase	Stable
	South	Yes	Stable	Stable
Estuary-dependent Fish Species Diversity	Suisun	Yes	Stable	Stable
	San Pablo	Yes	Decline	Stable
	Central	Yes	Stable	Stable
	South	No	Decline	Stable
Percent Native Species	Suisun	No	Decline	Stable
	San Pablo	No	Decline	Stable
	Central	Yes	Stable	Stable
	South	Yes	Decline	Decline
Percent Native Fish	Suisun	No	Decline	Stable
	San Pablo	Yes	Stable	Stable
	Central	Yes	Stable	Stable
	South	Yes	Decline*	Decline
Pelagic Fish Distribution	Suisun	No	Decline	Stable
	San Pablo	Yes	Stable	Stable
	Central	Yes	Stable	Stable
	South	Yes	Stable	Stable
Demersal Fish Distribution	Suisun	No	Decline	Stable
	San Pablo	Yes	Stable	Stable
	Central	Yes	Stable	Stable
	South	Yes	Stable	Stable
Fish Index	**Suisun**	**No**	**Decline**	**Stable**
	San Pablo	**No**	**Decline**	**Stable**
	Central	**Yes**	**Stable**	**Stable**
	South	**No**	**Decline**	**Stable**