2007 San Francisco Bay Fish Index

A Multi-metric Index to Evaluate the Health of San Francisco Bay's Fish Community in Four Sub-regions of the Estuary

Prepared by

Christina Swanson
The Bay Institute

for the

San Francisco Estuary Project
Indicators Consortium
November 30, 2007

A. Background

San Francisco Bay, the largest estuary on the west coast of the United States, is essential habitat for scores of fish species, including commercially important Pacific herring, popular sport fishes like striped bass, and a variety of less familiar species such as starry flounder, longfin smelt, and delta smelt. Some species live in the Bay for their entire lives; others use the Bay for spawning or as a nursery area where the young fish shelter and feed in estuary's brackish water and tidal marshes. For anadromous species such as Chinook salmon, steelhead, and sturgeon, the Bay is a critical migratory pathway between the Pacific Ocean and spawning areas in the estuary's tributary rivers. In addition, many marine and freshwater fishes periodically use the Bay.

Environmental and ecological conditions in the estuary, including freshwater inflows, availability of tidal wetlands, water quality and the productivity of the food web, affect the abundance and distribution of fishes in the Bay. In turn, characteristics of the fish community, including population size, diversity, and species composition are useful indicators of the ecological health of the environment in which they are found.

The San Francisco Bay Fish Index, first published in 2003 and subsequently revised and updated in 2005 (TBI 2003, 2005), used four indicators and a multi-metric index to characterize the Bay's fish community and to track ecological conditions and trends in the estuary. In 2006, the Fish Index was revised to use seven indicators to describe, evaluate and compare the conditions and trends of the fish community in four different sub-regions of San Francisco Bay: South Bay, Central Bay, San Pablo Bay, and Suisun Bay (Swanson and Pawley 2006). The 2007 San Francisco Bay Fish Index described in this report updates the 2006 Fish Index.

B. Data Sources

Surveying and monitoring the Bay's fish community is not an easy task. The Bay itself is a large and diverse region, characterized by wide geographic variation in environmental conditions (e.g., salinity, depth) and corresponding variations in fish assemblages. Many species are highly mobile, fast swimmers capable of evading capture by the relatively small nets used for surveys (as compared to those used in commercial fishing). Some species are present in the Bay only during certain seasons; others are unevenly distributed in the Bay, either concentrated in schools in few locations in the Bay or widely distributed over large areas and thus rarely captured. A number of key Bay fish species live in shallow, nearshore habitats such as tidal marshes that are not effectively sampled using nets deployed from boats.

The seven indicators of the 2007 Fish Index were calculated using data from the California Department of Fish and Game (CDFG) Bay Study Midwater Trawl and Otter Trawl surveys, conducted every year since 1980.[1] These two sampling methods selectively capture different types of fishes: the midwater trawl is towed through the middle of the water column and tends to collect pelagic fishes while the otter trawl is dragged along the Bay's bottom and thus preferentially captures demersal fish species that are more closely associated with the bottom. Both sampling methods tend to collect smaller and/or younger fish (e.g., "young-of-the-year" fish) that are too slow to evade the net. Both surveys sample the same 35 stations in the estuary, which are relatively evenly distributed among the four sub-regions of the estuary and among channel and shoal habitats, once per month for most months of the year.[2] 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 six of the seven indicators and the multi-metric 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 1 and Table 1.

Each of the indicators and the multi-metric index were calculated for each of four sub-regions in the estuary: South Bay, Central Bay, San Pablo Bay, and Suisun Bay. South Bay is not directly connected to the estuary's major watershed, the Sacramento-San Joaquin watershed, which provides >90% of total freshwater inflow to the estuary. It is characterized by relatively low freshwater inflow from its small local tributary streams (as well as treated wastewater from sewage treatment plants). Central Bay, except during periods of high freshwater outflow from the Sacramento-San Joaquin watershed, is a predominately marine environment. Environmental conditions in San Pablo Bay are more variable, ranging from moderately high salinities during periods of low freshwater inflow to brackish conditions during the winter and spring when inflows from the Sacramento-San Joaquin and local watersheds are typically higher. The Suisun Bay sub-region, which for this analysis includes portions of the lower Sacramento and San Joaquin Rivers in the western Delta, is the upstream region of the estuary, strongly influenced by the amounts and timing of the highly managed freshwater inflows from the estuary's largest rivers.

[1] Information on the CDFG Bay Study is available at www.delta.dfg.ca.gov/baydelta/monitoring/baystudy.asp.
[2] 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.

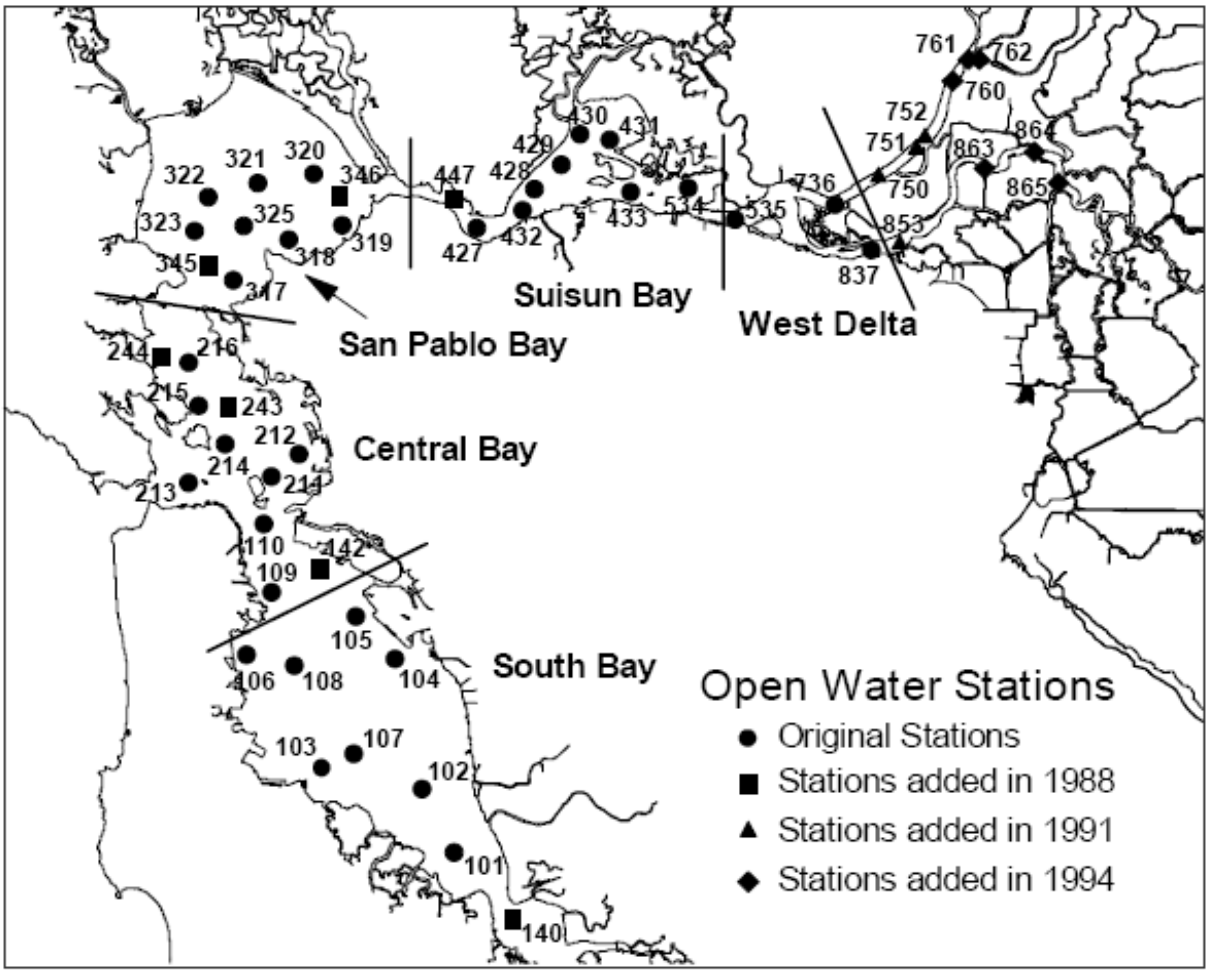

Figure 1. Locations of the sampling stations for the CDFG Bay Study Midwater Trawl and Otter Trawl surveys in different sub-regions of the San Francisco Bay. For the 2007 Fish Index, only data from the "original stations" (sampled continuously for 1980-2006 period) were used to calculated indicators 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, 214, 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)

C. Indicators

The 2007 San Francisco Bay Fish Index uses seven indicators to measure the abundance, diversity, and species composition of the Bay's fish community.

Abundance: Four of the seven indicators measure the abundance of various components of the estuary's native fish community. 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 addition, in San Francisco Bay, the population abundances of a number of fish (and invertebrate) species are strongly correlated with specific environmental conditions associated with freshwater inflow from the Sacramento and San Joaquin Rivers (Jassby et al., 1995; Kimmerer, 2002), watersheds that have also been impaired by water development, flood control efforts, agriculture and urbanization. More than 100 native fish species[3] use the San Francisco Bay for spawning, nursery and rearing habitat, and as a migration pathway between the Pacific Ocean and the rivers of the Bay's watersheds.

Indicator 1. Abundance of Pelagic Species – Pelagic fish species are those that live and feed in the open waters of the estuary. This indicator was calculated using catch data for all native species except northern anchovy from the Bay Study Midwater Trawl survey. Catch data for

[3] 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.

northern anchovy were not included in this indicator because results for this single species obscured results for all other species. In most years of the Bay Study survey and in most sub-regions of the estuary, northern anchovy comprised >80% of all fish collected in the Bay (see also Abundance of Northern Anchovy Indicator). Abundance was calculated as:

fish/trawl = [(# of fish)/(# of trawls x av. trawl volume)] x (av. trawl volume for 1980-2006) (*Equation 1*)

Indicator 2. Abundance of Demersal Species – Demersal fish species are those that live and feed near the bottom. This indicator was calculated using catch data for all native species from the Bay Study Otter Trawl survey.[4] Abundance was calculated using Equation 1.

Indicator 3. Abundance of Northern Anchovy – Northern anchovy is the most common native fish species collected in the Bay. It is consistently collected in all sub-regions of the estuary in numbers that are often orders of magnitude greater than for all other species. Abundance of northern anchovy was calculated from catch data from the Bay Study Midwater Trawl survey using Equation 1.

Indicator 4. Abundance of Sensitive Species – San Francisco Bay is essential habitat for diverse assemblages of marine, estuarine, and anadromous fish species. Marine species tend to use the Bay as spawning and nursery habitat while estuarine species reside in the Bay throughout their life cycle. For anadromous fishes, the Bay is an important segment of their migration route between upstream spawning areas and the ocean. Abundance of representative species that rely on the Bay in different ways is a useful indicator of the health of the Bay as a "multi-purpose" habitat. Three species were selected for the indicator: longfin smelt, Pacific herring, and striped bass.[5, 6] Each is relatively common and consistently present in all four sub-regions of the estuary and each is the target of environmental or fishery management in the Bay. 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 three species are briefly described below.

- **Longfin smelt** are found in open waters of large estuaries on the west coast of Norht America.[7] The San Francisco Bay population spawns in upper estuary (Suisun Bay and Marsh and the Delta) and rears downstream in brackish Bay and, occasionally, coastal waters (Moyle, 2002). In 1992 and again in 2007, the species was petitioned for listing under the Endangered Species Act. The State of California already identifies longfin smelt as a "species of special concern".

[4] Northern anchovies are not collected in the Otter Trawl survey.
[5] 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 estuary (Moyle, 2002).
[6] In early versions of the San Francisco Bay Fish Index, delta smelt was included in the Sensitive Species Indicator. However, delta smelt do not occur in the Central Bay or South Bay sub-regions of the estuary; therefore this species was not included in this version of the Sensitive Species Indicator.
[7] In California, longfin smelt are found in San Francisco Bay, Humbolt Bay, and the estuaries of the Russian, Eel, and Klamath Rivers.

- **Pacific herring** is a coastal marine fish that uses large estuaries for spawning and early rearing habitat. On the basis of spawning biomass, the San Francisco Bay 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 Bay, the Pacific herring fishery is the last remaining commercial finfish fishery.

- **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.

Abundance of each of these species was calculated as the sum of the abundances from each of the two Bay Study surveys using Equation 1. The summed abundance of each species was evaluated and scored individually (see Indicator Evaluation and Grading, below) and the indicator was then calculated as the average of the three scores.

Diversity: Two of seven indicators assess the diversity, or species richness, of the estuary's native fish community. 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 estuary 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.

Indicator 5. Native Species Diversity – Diversity was measured as the number of species collected in each sub-region, expressed as the percentage of the maximum number of species ever collected in that sub-region. The indicator was calculated using catch data for all native species from the Bay Study Midwater and Otter Trawl surveys as:

% of species assemblage = (# native species/maximum # of native species reported) x 100 (*Equation 2*)

Indicator 6. Bay-dependent Species Diversity – Of the more than 100 fish species collected by the Bay Study since 1980, 39 species can be considered "Bay-dependent" species (Table 2). These species may be resident species that spend their entire life-cycle in the estuary, marine or

freshwater species that depend on the Bay 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 Bay. This indicator is calculated using catch data for only these 39 species from the Bay Study Midwater and Otter Trawl surveys using Equation 2.

Table 2. San Francisco Bay-dependent fish species collected in the CDFG Bay Study Midwater Trawl and Otter Trawl surveys.

Bay-dependent fish species (common names)	
Bay resident species Species with resident populations in the Bay and/or Bay-obligate species that use the Bay as nursery habitat	**Seasonal species** Species regularly use the Bay for part of their life cycle but also have substantial connected populations outside the Bay
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	

Species Composition: 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). San Francisco Bay has been invaded by a number of non-native fish species. Some species, such as striped bass, were intentionally introduced into the Bay. Others arrive in ballast water or from upstream habitats, usually reservoirs.

Indicator 7. Percent Native Species – This indicator measures the percentage of fish species collected in the Bay that are native to the estuary and its adjacent ocean and upstream habitats. The indicator is calculated using catch data from the Bay Study Midwater and Otter Trawl surveys as:

% native species = [# native species/(# native species + # non-native species)] x 100 (*Equation 3*)

C. Indicator Evaluation and Grading

For each indicator, upper and lower reference conditions, corresponding to "excellent" and "very poor" ecological conditions respectively, were established. Reference conditions were based on either measured values from the earliest years for which quantitative data were available, 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. For each of the four sub-regions, reference conditions were identically selected but their absolute values were calibrated to account for differences among the sub-regions. For example, the maximum number of species collected, used to calculate the diversity indicators, differed among the sub-regions.

The range of the indicator results between the upper and lower reference conditions was subdivided into five categories, corresponding to letter grades A through F. The size of the increments between grades 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 grades represented meaningful differences in the measured indicator values. Each letter grade also corresponded to a "grade point", ranging from 0 (for F, very poor) to 4 (for A, excellent). The multi-metric Fish Index was calculated as the "grade point average" of the component indicators, and reported as a **Grade** (i.e., A-F) and a **Score** (i.e., the grade point average expanded to a 100-point scale using a multiplication factor of 25). Table 3 shows the reference conditions and scoring increments for each of the seven indicators.

Differences among sub-regions 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 27-year period as well as for the earliest and the most recent five year-long periods (i.e., 1980-1984 and 2002-2006). Regression analyses were conducted using continuous results for the entire 27-year period for each sub-region.

Table 3. Reference conditions and scoring increments for the seven indicators used in the San Francisco Bay Fish Index. A="excellent"; B="good"; C="fair"; D="poor"; and F="very poor".

Indicator	Reference conditions	Scoring increments
Abundance of Pelagic Species Abundance of Demersal Species Abundance of Northern Anchovy Abundance of Sensitive Species[a]	Average abundance 1980-1984 period for each sub-region[b]	A: >150% of 1980-1984 av. B: >1980-1984 av. C: >50% of 1980-1984 av. D: >15% of 1980-1984 av. F: ≤15% of 1980-1984 av.
Native Species Diversity	Upper reference condition set at the average+1SD percent of 1980-1984 native species assemblage for South, Central and San Pablo Bays	A: >60% B: >50% C: >40% D: >30% F: ≤30% Scoring increment of 10% corresponds to a difference of 4-9 species, depending on sub-region.
Bay-dependent Species Diversity	Upper reference condition set at the average+1SD percent of 1980-1984 Bay-dependent species assemblage for South, Central and San Pablo Bays	A: >80% B: >70% C: >55% D: >40% F: ≤40% Scoring increment of 15% corresponds to a difference of 4-6 species, depending on sub-region.
Percent Native Species	Upper reference conditions set at maximum 1980-1984 average % native species in Central Bay sub-region. Lower reference condition set at 50%[c]	A: >95% B: >85% C: >70% D: >50% F: ≤50%

[a] For the Abundance of Sensitive Species Indicator, the measured abundances for each species were scored separately using these reference conditions and the indicator was calculated as the average score for the three species.

[b] Based on results from other surveys of San Francisco Bay fishes (e.g., CDFG Fall Midwater Trawl survey), the abundance of native fishes in the estuary had already declined by the early 1980s. Therefore the average abundance measured during the first five years of the Bay Study was set as an intermediate reference condition (i.e., the break point between a B and C grade) rather than as the upper reference condition.

[c] Non-native fish species have been present in the Bay for >100 years. Therefore, 100% native fish species is unrealistic, but a low percent native species, e.g., <50%, is indicative of degraded conditions.

C. Results

Indicator 1. Abundance of Pelagic Species

Abundance of pelagic fishes differs among the estuary's sub-regions (Figure 2).
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: $p<0.05$). Abundances of pelagic fishes in other areas of the estuary have fluctuated and declined over time (see below) but are typically less than half of abundance levels measured in Central Bay (median pelagic fish abundance 1980-2006: South=14.96; Central=39.06; San Pablo=14.77; and South=7.13).

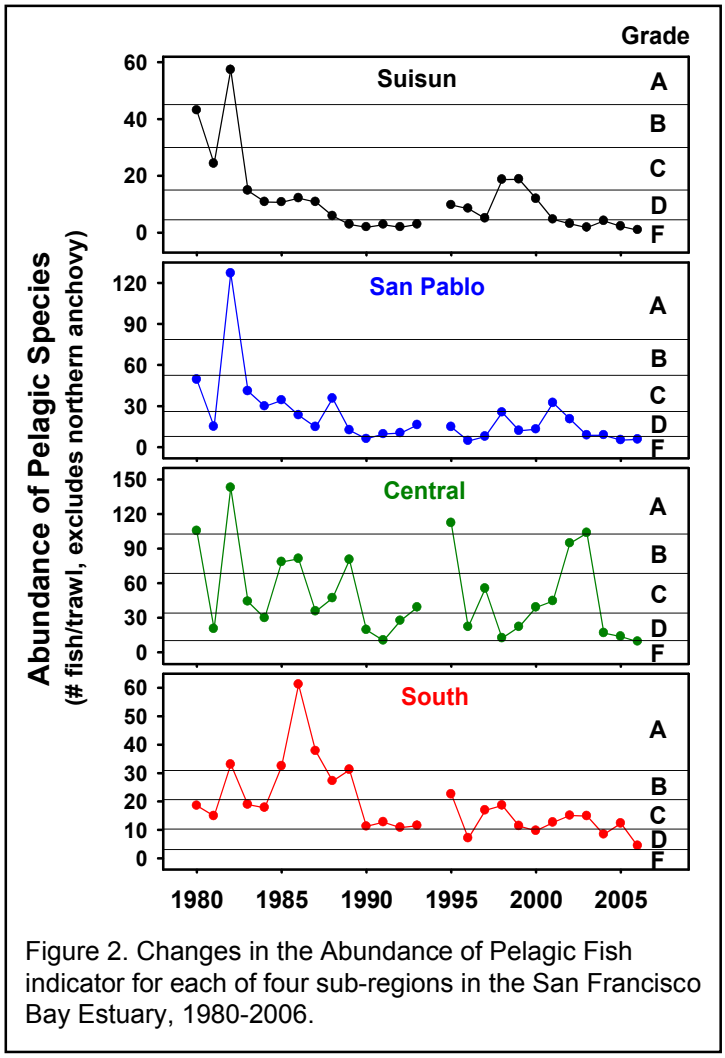

Figure 2. Changes in the Abundance of Pelagic Fish indicator for each of four sub-regions in the San Francisco Bay Estuary, 1980-2006.

Abundance of pelagic fishes has declined in most sub-regions of the estuary.
Pelagic fish abundance declined significantly in all sub-regions of the estuary except Central Bay (regression: $p<0.01$ for South, San Pablo and Suisun Bays). 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. For the most recent five years compared to 1980-1984 levels, average abundance of native pelagic fishes was 47% lower in South Bay, 30% lower in Central Bay, 81% lower in San Pablo Bay and 92% lower in Suisun Bay.

Pelagic fishes have experienced two sequential population declines in the past 27 years.
The first population decline occurred during the late 1980s and early 1990s, coincident with a severe, multi-year drought (1987-1992). By 1992, pelagic fish abundance had declined 60% in Central Bay, 81% in San Pablo Bay, and 94% in Suisun Bay. In South Bay, abundance increased during the late 1980s but then declined: in 1992, abundance of pelagic fish in this sub-region of the estuary was 48% lower than the 1980-1984 average. Pelagic fish abundance increased somewhat in most sub-regions of the estuary during the late 1990s, when hydrological conditions improved, but declined again in the 2000s despite moderate hydrological conditions. In 2006, abundance of pelagic fishes was the lowest ever measured during the 27-year survey in Suisun, Central, and South Bays and the third lowest level ever measured in San Pablo Bay.

The greatest declines in pelagic fish abundance have occurred in Suisun and San Pablo Bays.
Declines in the abundance of pelagic fishes, both during the late 1980s/early 1990s and the 2000s, were greatest in the upstream sub-regions of the estuary. The earlier decline is usually attributed to reduced freshwater inflows resulting from the six-year drought and concurrent high rates of water diversion upstream of the estuary. The recent decline, which followed a period of modest improvement during sequential wet years in the late 1990s, is the subject of intense research. Preliminary results of these studies suggest that, at least in the upper estuary, the decline is again attributable to intensified water diversions and alterations to freshwater inflows as well as ecological changes associated with new invasive species and degraded water quality conditions. However, these results do not explain the similar population trends and recent record low abundances observed in South and Central Bays.

Indicator 2. Abundance of Demersal Species

Abundance of demersal fish species differs among the estuary's sub-regions (Figure 3).
Demersal fishes are 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: $p<0.05$). Abundances of demersal fishes in other areas of the estuary have fluctuated and declined over time (see below) but are typically less than half of abundance levels measured in Central Bay (median demersal fish abundance 1980-2006: South=27.03; Central=67.79; San Pablo=24.62; and South=3.69). Abundance of demersal fishes is very low in Suisun Bay, averaging less than 20% of levels measured in adjacent San Pablo Bay

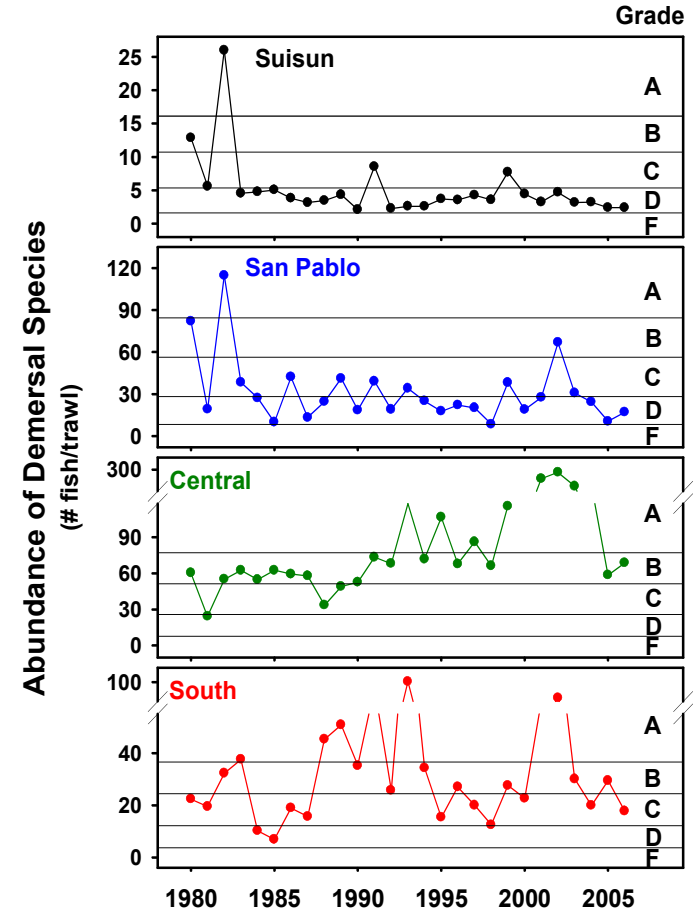

Figure 3. Changes in the Abundance of Demersal Fish indicator for each of four sub-regions in the San Francisco Bay Estuary, 1980-2006.

Trends in abundance of demersal fishes differ in different sub-regions of the estuary.
During the past 27 years, abundance of native demersal fishes generally declined in Suisun and San Pablo Bays (regression: Suisun, $p=0.023$; San Pablo, $p=0.07$), increased significantly in marine-dominated Central Bay (regression: $p=0.001$), and fluctuated widely in South Bay. Compared to 1980-1984 levels,

recent average abundances were 70% and 47% lower in Suisun and San Pablo Bays, respectively, and 48% and 210% higher in South and Central Bays, respectively.

Since the early 1980s, abundance of demersal fishes in the upstream areas of the estuary has been low and relatively stable.

The apparent declines in abundance of demersal fishes in Suisun and San Pablo Bays were driven by two years in the early 1980s (1980 and 1982) in which demersal fishes were relatively abundant, years during which pelagic fish species were also abundant (see Abundance of Pelagic Species Indicator). For both of these years, the high abundance levels reflected large numbers of a single species, longfin smelt, a Bay resident species that is collected by both the Midwater and Otter Trawl surveys (see also Abundance of Sensitive Species Indicator). Since those early years of the survey, abundance of demersal fishes has been relatively stable, despite marked increases in demersal fish populations in the downstream areas of the estuary and a modest increase in longfin smelt abundance during the late 1990s.

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.

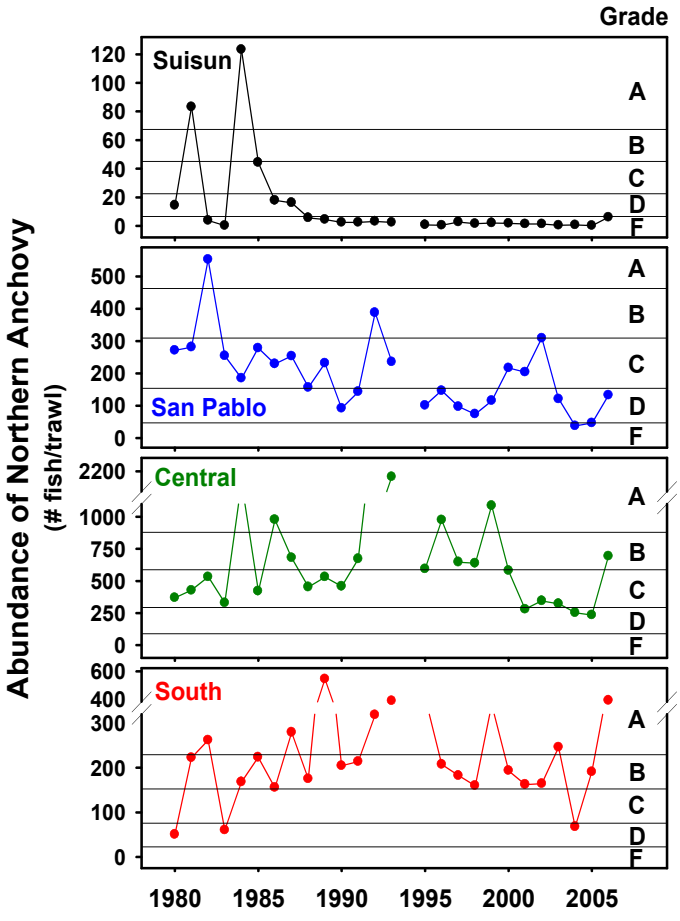

Figure 4. Changes in the Abundance of Northern Anchovy indicator for each of four sub-regions in the San Francisco Bay Estuary, 1980-2006.

Indicator 3. Abundance of Northern Anchovy

Abundance of northern anchovy differs among the estuary's sub-regions (Figure 4).

Although northern anchovy are always found in all sub-regions of the estuary, their abundance differs markedly. For the past 27 years, northern anchovy have been most abundant in Central Bay, least abundant in Suisun Bay, and present at intermediate abundance levels in San Pablo and South Bays

(Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, all pairwise comparisons: $p<0.05$; median northern anchovy abundance 1980-2006: South=204.63; Central=531.83; San Pablo=185.13; and South=2.56).

Trends in abundance of Northern anchovy differ in different sub-regions of the estuary. During the past 27 years, abundance of northern anchovy has been variable but roughly stable in South Bay and Central South Bays although, in most recent years, Central Bay abundance has been low. Northern anchovy abundance has steadily declined in San Pablo Bay (regression: $p=0.03$), falling to 42% of 1980-1984 levels during the most recent five years (2002-2006). The decline was more abrupt in Suisun Bay (regression: $p=0.01$), 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 4% of 1980-1984 levels. However, in 2006, northern anchovy abundance increased in all sub-regions of the estuary.

Indicator 4. Abundance of Sensitive Species

Abundances of longfin smelt, Pacific herring and striped bass differ among the different sub-regions of the estuary.
Although Bay-wide abundance of the three species was roughly comparable, different species use different sub-regions within the estuary. Longfin smelt are ten times more abundant in Suisun Bay (median longfin smelt abundance 1980-2006: 5.69) than in South Bay (0.54) and intermediate in abundance in Central and San Pablo Bays (3.27 and 3.92, respectively). Pacific herring are most abundant in Central Bay (median Pacific herring abundance 1980-2006: 15.80), intermediate in South and San Pablo Bays (4.26 and 6.10, respectively) and rare in Suisun Bay (0.21). Striped bass are most abundant in Suisun Bay (median striped bass abundance 1980-2006: 8.30), rare in South and Central Bays (0.06 and 0.05, respectively) and intermediate in abundance in San Pablo Bay (1.54).

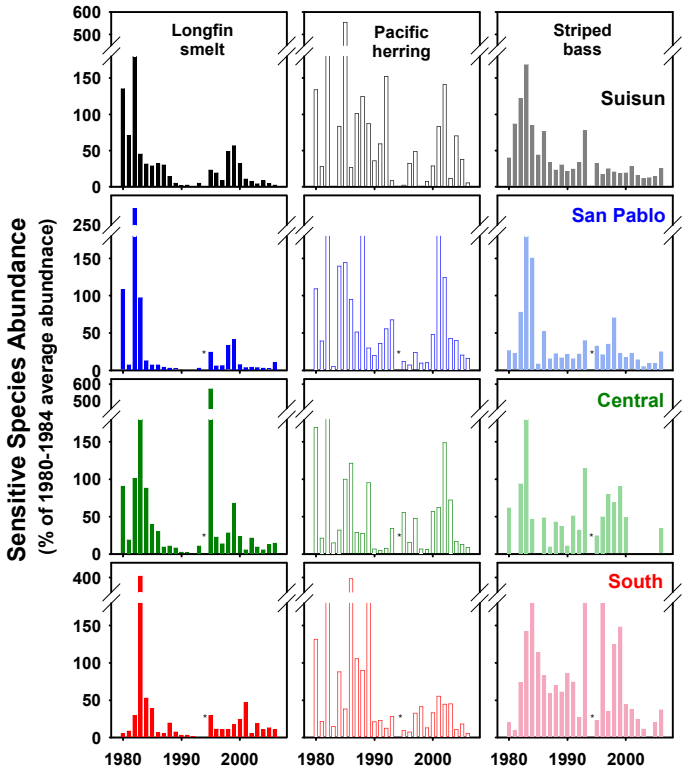

Figure 5. Trends in population abundance of longfin smelt, Pacific herring and striped bass for each of four sub-regions in the San Francisco Bay Estuary, 1980-2006. Population abundance is expressed as percent of the 1980-1984 average population abundance. *=no data collected in 1994.

Trends in abundance of the three sensitive species are similar among sub-regions of the estuary (Figure 5).
During the past 27 years, trends in abundance for all three species in all four sub-regions of the estuary have been roughly similar: populations were relatively high in the early 1980s, declined during the late 1980s and early 1990s, improved during the late 1990s and then declined again in the 2000s. For each species, abundance generally declined in those sub-regions of the estuary that they were most abundant. For example, in Suisun Bay, abundance of longfin smelt and striped bass declined significantly (regression: $p=0.005$ for longfin smelt and $p<0.001$ for striped bass).

Abundance of all three sensitive species is low compared to levels measured in the early 1980s in all sub-regions of the estuary.
During the most recent five years, the average abundance of longfin smelt was just 8% of the 1980-1984 average (range for four sub-regions: 5-12%). Pacific herring abundance was 45% of 1980-1984 levels (range for the four sub-regions: 25-53%). Striped bass abundance was 13% of levels measured in the early 1980s (range for the four sub-regions: 7-19%).

The Abundance of Sensitive Species Indicator has declined steadily during the past 27 years (Figure 6).
In all sub-regions of the estuary, the indicator, which aggregates the abundance results for the three species, has declined steadily and significantly (regression: South, $p=0.001$; Central, $p=0.011$; San Pablo, $p<0.001$; and Suisun, $p<0.001$). Collectively, the population abundances of these three sensitive species during the most recent three to four years were generally less than 15% of levels measured during the early 1980s.

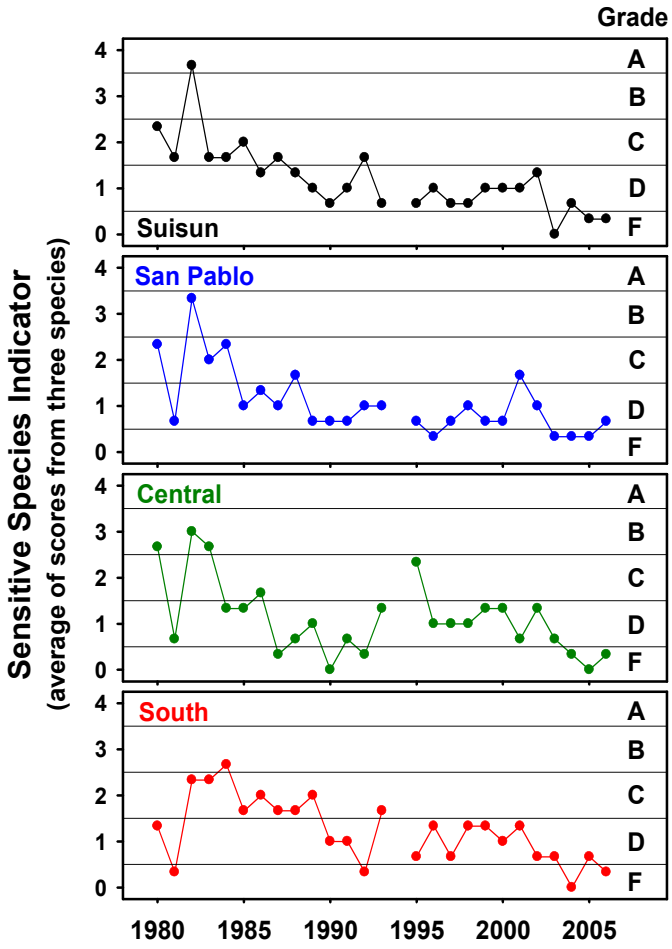

Figure 6. Changes in the Abundance of Sensitive Species indicator for each of four sub-regions in the San Francisco Bay Estuary, 1980-2006.

Indicator 5. Native Species Diversity

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 (90 species) and the fewest are in Suisun Bay (45 species). A maximum of 71 native species have been collected in South Bay and 61 native species have been found in San Pablo Bay.

The percentage of the native fish species present differs among the sub-regions (Figure 7).
For the 27-year period, the native fish assemblage was more diverse in San Pablo Bay than all other sub-regions of the estuary (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, all pairwise comparisons: $p<0.05$). The percentages of the native fish assemblages present in each sub-region fluctuated or changed over time (see below) but in most years more than 50% of the assemblage was collected in San Pablo Bay (median native species diversity 1980-2006: 55%). The percentages of the native fish assemblages collected in the other sub-regions were lower (median native species diversity 1980-2006: South=51%; Central=49%; and Suisun=47%). In recent years, native species diversity levels have been very similar in South, Central and San Pablo Bays (54-55%) but significantly lower in Suisun Bay (45%; Kruskal Wallis One-way ANOVA of Ranks: $p=0.012$, all pairwise comparisons: $p<0.05$).

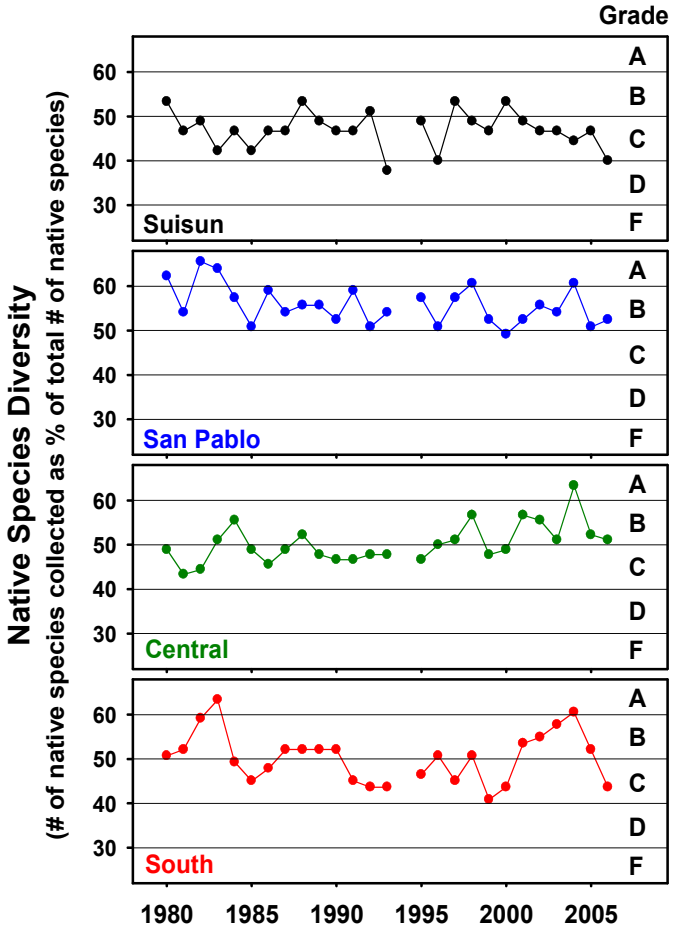

Figure 7. Changes in the Native Species Diversity indicator for each of four sub-regions in the San Francisco Bay Estuary, 1980-2006.

Trends in native species diversity differ among the sub-regions.
Native species diversity has increased significantly in Central Bay (regression: $p=0.006$ for an increase of five species in 27 years), decreased significantly in San Pablo Bay (regression: $p=0.032$ for a decrease of four species), and fluctuated in both South and Suisun Bays.

Indicator 6. Bay-dependent Species Diversity

The maximum number of Bay-dependent species was lower in Suisun Bay than other sub-regions of the estuary.
Only 30 of 39 Bay-dependent species have ever been collected in Suisun Bay, compared to a maximum of 35 species in South Bay, 36 species in Central Bay and 38 species in San Pablo Bay.

The percentage of Bay-dependent species present differs among the sub-regions (Figure 8).
For the 27-year period, the Bay-dependent fish assemblage was most diverse in South and Central Bays, intermediate in San Pablo Bay and lowest in Suisun Bay (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, all pairwise comparisons: $p<0.05$). Most of the Bay-dependent fish assemblage was regularly found in Central and South Bays (median Bay-dependent species diversity 1980-2006: 83% for each sub-region), compared to 68% in San Pablo Bay and just half of the assemblage (median Bay-dependent species diversity 1980-2006: 50%) in Suisun Bay.

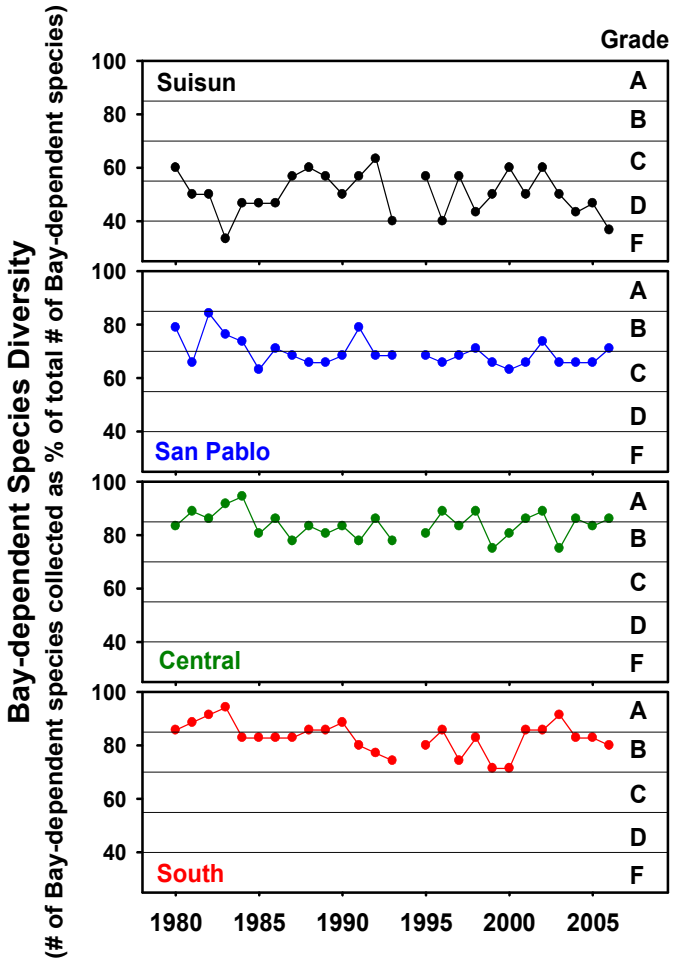

Figure 8. Changes in the Bay-dependent Species Diversity indicator for each of four sub-regions in the San Francisco Bay Estuary, 1980-2006.

Diversity of Bay-dependent species has been stable in most sub-regions.
Bay-dependent species diversity has declined slightly in San Pablo Bay (regression: $p=0.031$ for a decrease of three species from the 1980-1984 period to the 2002-2005 period). In all other regions, Bay-dependent diversity has fluctuated but remained relatively stable over the 27-year period.

Indicator 7. Percent Native Species

The percentage of native species in the fish community differs among the four sub-regions of the estuary. For the past 27 years, non-native species are the most prevalent in Suisun Bay, where in most years only 75% of species are native species, intermediate in South and San Pablo Bays (88% and 87% native, respectively), and the least prevalent in Central Bay (91%) ((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. In San Pablo Bay, the percent native species declined significantly (regression: $p<0.001$) from 89% in the 1980-1984 period to 82% in the most recent five-year period. Percent native species declined slightly in Suisun Bay, from 75% to 71% (regression: $p=0.011$). In South and Central Bay, the percentage of the species that are native has remained stable although, in 2006, the percentage of fish species that are native was lower in all sub-regions.

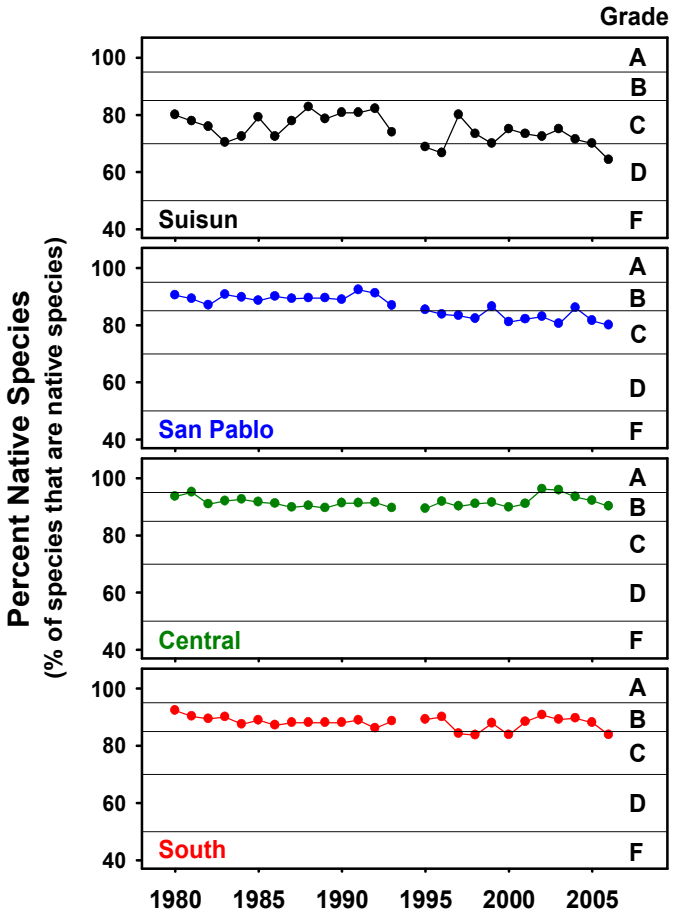

Figure 9. Changes in the Percent Native Species indicator for each of four sub-regions in the San Francisco Bay Estuary, 1980-2006.

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 27 years, the number of native species in San Pablo Bay declined by four species and the number of non-native species increased by three, to an average of 7 non-native species of the 2002-2006 period. The number of non-native species collected in Suisun Bay increased by an average of one species, from seven species in the 1980-1984 period to eight species in the most recent five years.

D. The 2006 Fish Index

The Fish Index aggregates the results of the four abundance indicators (Pelagic Species, Demersal Species, Northern Anchovy, and Sensitive Species), the two diversity indicators (Native Species and Bay-dependent Species) and the species composition indicator (Percent Native Species) for each of the four sub-regions of the estuary (Figure 10 and Table 4).

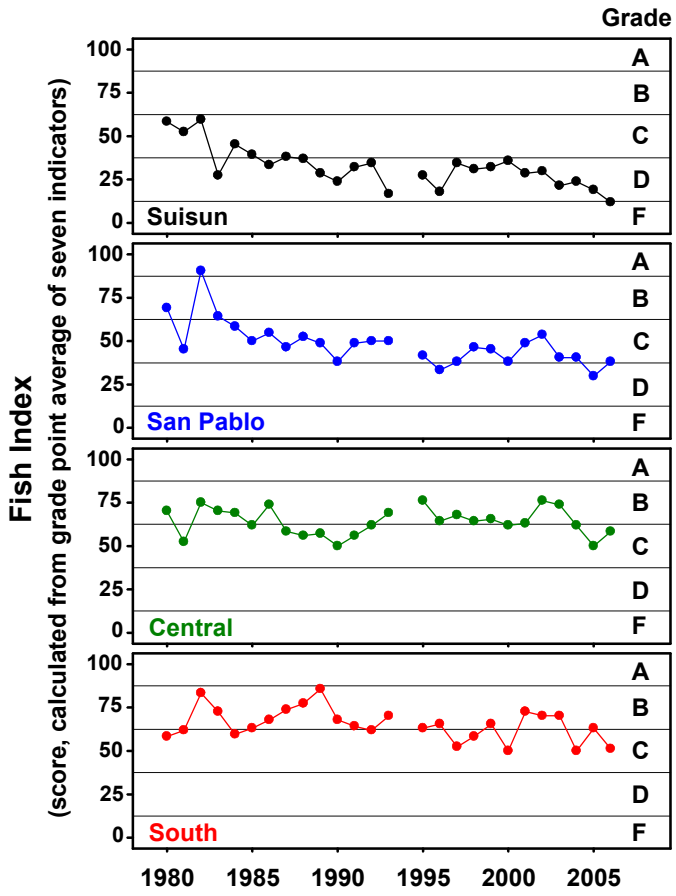

Figure 10. Changes in the Fish Index for each of four sub-regions in the San Francisco Bay Estuary, 1980-2006.

The Fish Index differs among the four sub-regions of the estuary.
For most the 1980-2006 period, the Fish Index has been consistently higher in the Central and South Bay sub-regions of the estuary (median Fish Index: 65 or B- for South Bay; 64 or B- for Central Bay) than in San Pablo Bay (48 or C) and Suisun Bay (32 or C-) (ANOVA and all pairwise comparisons: $p<0.001$). In the early 1980s, the Fish Indexes for all sub-regions except Suisun Bay were roughly comparable: for the 1980-1984 period, the average South, Central and San Pablo Bay Fish Indexes were 67 (B), 67 (B) and 65 (B-), respectively, compared to the Suisun Bay Fish Index of 49 (C).

Trends in the Fish Index differ among the sub-regions.
The Fish Index has declined significantly in both San Pablo and Suisun Bays (regression 1980-2006: $p<0.001$ both sub-regions). In overall condition of the fish community in Suisun Bay has declined from "fair" in the early 1980s (1980-1984 average score: 49, grade: C) to consistent "poor" conditions throughout the 1990s and early 2000s (1990-2005 average score: 27; grade: D) conditions, and finally in 2006 to "very poor" conditions (2007 score: 12; grade: F+).[8] In San Pablo Bay, the Fish Index has declined steadily, from "fair" to "good" conditions in the early 1980s (1980-1984 average score: 65, grade: B-) to "fair" to "poor" conditions in the most recent five years (2002-2006 average score: 43; grade: C-). The Central Bay Fish Index has been relatively stable with generally "good" fish community conditions. In the South Bay, the Fish Index has also been roughly stable and indicated a fish community in "fair" to "good" conditions.

[8] For each sub-region, the 2007 Fish Index grade and score are based on results of indicators calculated using data for 2006, the most recent year for which complete data are available.

Table 4. Summary of the 2007 indicator grades and 2007 San Francisco Bay Fish Index grades and scores for each sub-region in the estuary. Grades and scores are based on data from 2006, the most recent year for which complete data are available.

Sub-region	Indicator	2007 Grade (based on 2006 data)	2007 Fish Index (based on 2006 data)
Suisun Bay	Abundance of Pelagic Species	F	**Score: 12** **Grade: F+**
	Abundance of Demersal Species	D	
	Abundance of Northern Anchovy	F	
	Abundance of Sensitive Species	F	
	Native Species Diversity	D	
	Bay-dependent Species Diversity	F	
	Percent Native Species	D	
San Pablo Bay	Abundance of Pelagic Species	F	**Score: 38** **Grade: C-**
	Abundance of Demersal Species	D	
	Abundance of Northern Anchovy	D	
	Abundance of Sensitive Species	D	
	Native Species Diversity	B	
	Bay-dependent Species Diversity	B	
	Percent Native Species	C	
Central Bay	Abundance of Pelagic Species	F	**Score: 58** **Grade: C+**
	Abundance of Demersal Species	B	
	Abundance of Northern Anchovy	B	
	Abundance of Sensitive Species	F	
	Native Species Diversity	B	
	Bay-dependent Species Diversity	A	
	Percent Native Species	B	
South Bay	Abundance of Pelagic Species	D	**Score: 51** **Grade: C**
	Abundance of Demersal Species	C	
	Abundance of Northern Anchovy	A	
	Abundance of Sensitive Species	F	
	Native Species Diversity	C	
	Bay-dependent Species Diversity	B	
	Percent Native Species	C	

E. References

CDFG (2002) Pacific herring commercial fishing regulations. Final Supplemental Environmental Document. California Department of Fish and Game, SCH No. 98052052.

Harrison, T. D. and A. K. Whitfield (2004) A multi-metric fish index to assess the environmental condition of estuaries. J. Fish Biology. 65:283-710.

Huston, M. A. (1994) Biological diversity: The coexistence of species on changing landscapes. Cambridge University Press: Cambridge, UK.

Jassby, A. D., W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel, and T. J. Vendlinski (1995) Isohaline position as a habitat indicator for estuarine populations. Ecol. Appl. 5:272-280.

Karr, J. R., J. D. Allan, and A. C. Benke (2000) River conservation in the United States and Canada: science, policy and practice. In: P. J. Boon, B. R. Davies, and G. E. Petts (eds.), *River Conservation: Science Policy and Practice*. J. Wiley & Sons, New York, pp. 502-528.

Kimmerer, W. J. (2002) Physical, biological, and management responses to variable freshwater flow into the San Francisco estuary. Estuaries 25:1275-1290.

May, J. T. and L. R. Brown (2002) Fish communities of the Sacramento River Basin: implications for conservation of native fishes in the Central Valley, California. Env. Biol. Fish. 63:373-388.

Meador, M. R., L. R. Brown, and T. Short (2003) Relations between introduced fish and environmental conditions at large geographic scales. Ecological Indicators 3:81-92.

Moyle, P. B. (2002) Inland Fishes of California. University of California Press, Berkeley. 502 pp.

Swanson, C. and A. Pawley (2006) The 2006 San Francisco Bay Fish Index: A Multi-metric Index to Evaluate the Health of San Francisco Bay's Fish Community in Four Sub-regions of the Estuary. Final report submitted to the San Francisco Estuary Project Indicators Consortium. 20 pp.

The Bay Institute (TBI) (2003) Ecological Scorecard: 2003 San Francisco Bay Fish Index. Technical Appendix. Available at: http://www.bay.org/Scorecard/Fish.pdf.

The Bay Institute (TBI) (2005) Ecological Scorecard: 2005 San Francisco Bay Index. Available at: http://www.bay.org/Scorecard/2005.Bay.Index.Expanded.Report.pdf.

Wang, L. and J. Lyons (2003) Fish and benthic macroinvertebrate assemblages as indicators of stream degradation in urbanizing watersheds. In *Biological Response Signatures. Indicator Patterns Using Aquatic Communities,* (ed. T. P. Simon), pp. 227-249. CRC Press: New York.