San Francisco Bay
Fish Index

INDICATOR ANALYSIS AND EVALUATION

A. Background

San Francisco Bay, the largest estuary on the west coast of the United States, is essential habitat for dozens 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. In addition, many marine, and freshwater fishes periodically use the Bay. 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 Bay's tributary rivers.

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.

B. Indicators

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

1. Abundance – 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). 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 urbanization and water development. More than 70 native fish species[1] 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. The Abundance indicator measures the overall population size (catch per unit effort) of the native fish species collected in the Bay each year.

[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 have established self-sustaining populations in the estuary.

2. Diversity – One of the most commonly used indicators of ecological health of aquatic ecosystems is diversity, or species richness, of the native biota that inhabit the ecosystem. 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 (Karr et al., 2000; Wang and Lyons, 2003). Many of the more the 70 native fish species that are collected in San Francisco Bay 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 and spending large portion of their life cycles in Bay waters. Of the fishes collected by the Bay Study, 33 species are considered "Bay-dependent" species (see Table 1).[2] The Diversity indicator measures the number of Bay-dependent native species that are collected in the Bay each year.

3. Percent native species – 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-natives 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. The Percent native species indicator measures the percentage of fish species collected in the Bay that are native to the estuary and its adjacent ocean and upstream habitats.

4. 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. Four species were selected for the indicator: longfin smelt, delta smelt, Pacific herring, and striped bass.[3] Each is relatively common and consistently present in the Bay and each is the target of environmental or fishery management in the Bay. Abundance of these representative species that rely on the Bay in different ways can be useful indicator of the health of the Bay and a "multi-purpose" habitat. The Sensitive species indicator measures the abundance of these four fish species. Key characteristics of each of the four species are briefly described below.

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[2] Note: Although northern anchovy are regularly present in the Bay, this species was not included as a Bay-dependent species in the analysis of the Diversity indicator. In the San Francisco Bay Fish Index report, the total number of Bay-dependent is incorrectly reported as 34 species. With the exclusion of northern anchovy, the correct number of Bay-dependent species is 33 species. This discrepancy does not affect the results of analyses or grading for this indicator.

[3] 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 west coast, the main breeding population of the species is in the San Francisco estuary (Moyle, 2002).

- **Longfin smelt** are found in open waters of large estuaries on the West Coast.[4] 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, the species was petitioned for listing under the Endangered Species Act. The federal listing was denied, but the State of California identifies longfin smelt as a "species of special concern".

- **Delta smelt** are found only in the shallow, tidally influenced waters of the upper San Francisco Bay, Suisun Marsh and the Delta. It is one of the few Bay-dependent species that spends its entire life cycle in the Bay and, during most of the species' typical one-year life span, the entire population is found in Suisun Bay and the upper portions of San Pablo Bay. Delta smelt were listed as threatened under the Endangered Species Act in 1993.

- **Pacific herring** is a coastal marine fish that uses large estuaries for spawning and early rearing habitat. On the basis of spawning biomass (i.e., an estimate of the number of spawning fish), 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 Bay, the Pacific herring fishery is the last remaining commercial finfish fishery.

- **Striped bass** was introduced into San Francisco Bay in 1879 and, by 1988, 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 (see Fishable-Swimmable-Drinkable Index, Fishable (catchable) indicator). 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.

C. Methods and calculations

1. Data sources

Quantitative fish abundance data for Bay fish species are not available prior to 1967, when the California Department of Fish and Game (CDFG) Fall Midwater Trawl Survey (FMWT) was begun.[5, 6] However, because the FMWT survey samples less frequently and fewer sites within

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[4] In California, longfin smelt are found in the San Francisco Bay estuary, Humbolt Bay, and the estuaries of the Russian, Eel, and Kalmath Rivers.
[5] Information on the CDFG Fall Midwater Trawl surveys is available at www.delta.dfg.ca.gov/baydelta/monitoring/fmwt.html.
[6] Fall Midwater Trawl survey has been conducted every year except 1974 and 1979 since 1967. Sampling in 1976 was extremely limited, therefore data from 1976 were not included in any analyses or figures.

the Bay region, the four indicators of the Fish Index were calculated using data[7] from the CDFG Bay Study Midwater Trawl and Otter Trawl surveys, conducted every year since 1980.[8] 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 fish while the otter trawl is dragged along the Bay's bottom and thus preferentially capture fishes 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 small to evade the net. 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 the Indicators and Index. Data from the FMWT survey were used to validate results of the Bay Study Midwater Trawl survey and to provide earlier reference points for two of the four Bay Index indicators (Abundance and Sensitive Species).

2. Calculations

Abundance – This indicator was calculated using data from the Bay Study Midwater trawl survey only. Abundance (catch per unit effort) was calculated as [(# of fish collected)/(# of trawls x average tow volume)]. For this indicator, catch data for northern anchovy, a marine fish that is periodically present in the Bay in numbers that are orders of magnitude greater than those for all other species combined, were not included because results for this single species obscured results for all other species (Figure 1). In most years of the Bay Study survey, northern anchovy comprised >90% of all fish collected in the Bay.

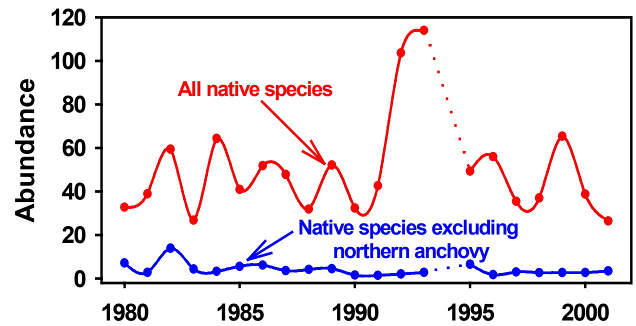

Figure 1. Comparison of abundance (catch per unit effort) of all native fish species (red) and native species excluding northern anchovy (blue) collected in the Bay Study Midwater Trawl Survey.

Utility of the Bay Study Midwater Trawl Survey data for evaluating long-term trends in Bay fish abundance was limited by the relatively short period during which the survey has been conducted (1980-2001). The earliest available quantitative fish abundance data for Bay fish species are from the Fall Midwater Trawl Survey, a similar monthly survey that has been conducted in most years since 1967.

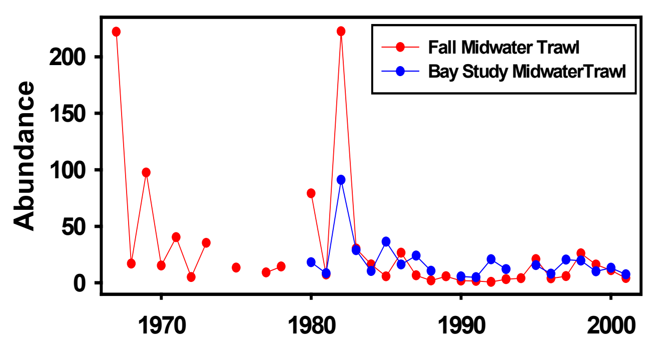

Figure 2. Comparison of native fish (excluding northern anchovy) abundance results from the Bay Study Midwater Trawl Survey and the Fall Midwater Trawl Survey.

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[7] Data from 32 Bay Study survey stations evenly distributed throughout the Bay were used to calculate each indicator. A map showing locations of the Bay Study survey stations is available at www.iep.ca.gov/sf_bay_monitor/mapboat.gif.

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

Results of the Bay Study were compared to those of the FMWT and found to be highly correlated (correlation coefficient: 0.88; $p<0.001$) (Figure 2).

For quantitative comparison of fish abundance between the two surveys, a correction factor for the differential in catch effort was generated by comparing catch per unit effort results from the two surveys for the 1980-1990 period.[9] Bay fish abundance for the 1967-1971 period (mean$\pm$1 standard error, SE), expressed in terms of Bay Study Midwater Trawl Survey catch per unit effort, was then estimated using FMWT results.

Diversity – This indicator was calculated as the number of Bay-dependent species (listed in Table 1) collected each year using data from both the Midwater Trawl and Otter Trawl surveys. A total of 33 Bay-dependent fish species were identified: 20 resident species that live in the Bay or require the Bay for nursery habitat, and 13 seasonal species with substantial connected populations outside the Bay but that use the Bay for part of their life cycle.

Table 1. 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 Bat ray Bay goby Bay pipefish Brown rockfish Brown smoothhound Cheekspot goby Delta smelt Dwarf surfperch Jack smelt Leopard shark Longfin smelt Pacific herring Pacific staghorn sculpin Pile perch Shiner perch Threespine stickleback Topsmelt, Tule perch White croaker	Barred surfperch California tonguefish Diamond turbot English sole Pacific tomcod Plainfin midshipman Sand sole Speckled sanddab Spiny dogfish Splittail Starry flounder Surfsmelt Walleye surfperch * Northern anchovy were not included in the Diversity calculation.

[9] In most years after 1980, the FMWT sampled the Bay only during the fall (September-December). Therefore, for quantitative comparison between the two surveys and development of the correction factors, only data from the September-December surveys were used.

Percent native species – This indicator was calculated using data from the Bay Study Midwater Trawl as [(# native species/# total species)*100]. For this indicator, Bay Study data were not compared to FMWT survey data because the indicator results varied significantly within the Bay subregions (see Results) and the FMWT survey sampling sites were concentrated in Suisun and San Pablo Bays.

Sensitive species – This indicator was calculated using data from the Bay Study Midwater Trawl as the abundance (catch per unit effort: {[# of fish collected]/[# of trawls x average tow volume]}) of longfin smelt, delta smelt, Pacific herring, and striped bass. Abundance was calculated and graded separately for each species. The individual grades for each species were then averaged (using their grade points) to calculate the grade (and grade point) of the Sensitive Species Indicator.

Use of the Bay Study Midwater Trawl Survey data for evaluating long-term trends in abundance of the four species was limited by the relatively short period during which the survey has been conducted (1980-2001). Therefore, species abundance data from the Fall Midwater Trawl Survey (FMWT), a similar monthly survey that has been conducted in most years since 1967, were compared to those of the Bay Study. For each species, results from the two surveys were highly correlated (all correlation coefficients: >0.75; all p<0.001) (Figure 3).

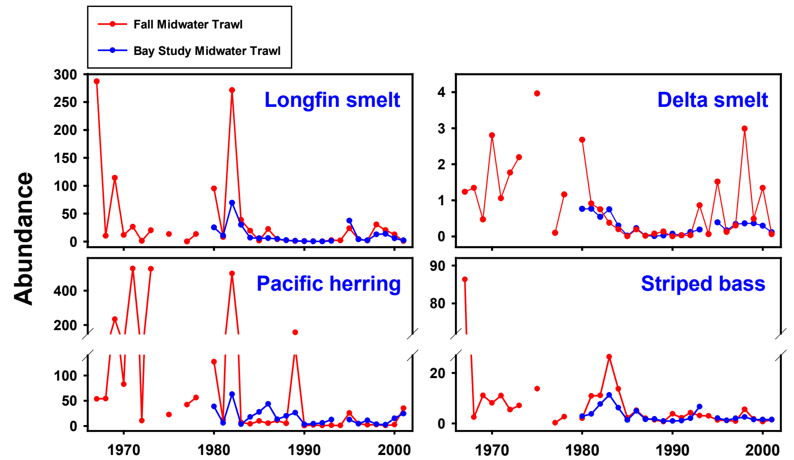

Figure 3. Comparison of longfin smelt, Pacific herring, and striped bass abundance results from the Bay Study Midwater Trawl Survey and the Fall Midwater Trawl Survey.

For quantitative comparison of species abundance between the two surveys, species specific correction factors for the differential in catch effort were generated by comparing catch per unit effort results from the two surveys for the 1980-1990 period.[10] Abundance for each of the four species for the 1967-1971 period (mean±1SE), expressed in terms of Bay Study Midwater Trawl Survey catch per unit effort, was then estimated using FMWT results.

[10] In most years after 1980, the FMWT sampled the Bay only during the fall (September-December). Therefore, for quantitative comparison between the two surveys and development of the correction factors, only data from the September-December surveys were used.

3. Regional differences

Because the Bay has such wide geographic variations in environmental conditions and corresponding variations in fish assemblages, most indicators were measured and evaluated for each of four subregions: South Bay, Central Bay, San Pablo Bay, and Suisun Bay (Figure 4). However, each indicator was ultimately evaluated and graded for the entire Bay region.

Figure 4. For analyses of some indicators, San Francisco Bay was subdivided into four subregions.

4. Evaluation and grading

For each indicator, upper and lower reference conditions, corresponding to "excellent" and "very poor" ecological conditions, were established. Reference conditions were based on historical data (where available, e.g., FMWT survey data for 1967-1971), geographic variation in indicator results within the region, recognized and accepted interpretations of ecological conditions and ecosystem health (e.g., native vs non-native species composition), and best professional judgment. 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. Each letter grade also corresponded to a "grade point", ranging from 0 (for F) to 4 (for A). The 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 is expanded to a 100-point scale using a multiplication factor of 25).

C. Results

Indicator 1. Abundance

The Abundance Indicator (Figure 5) measures the overall population size (catch per unit effort) of the native fish species collected in the Bay each year. Native fishes are more abundant in healthy aquatic ecosystems than in those impaired by altered flow regimes, toxic urban runoff and reduced nearshore habitat.

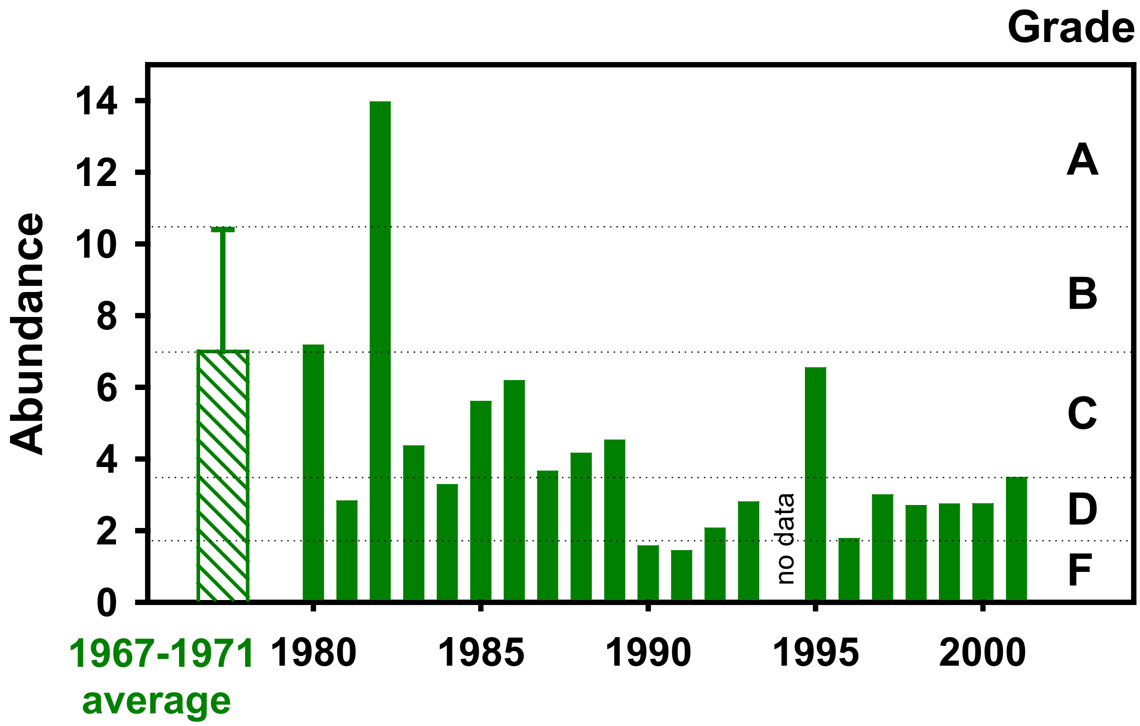

Figure 5. Changes in the Abundance Indicator from 1980 to 2001. The indicator measures the population size (as catch per unit effort) of the native fish species (excluding northern anchovy) collected by the California Department of Fish and Game Bay Study Midwater Trawl Survey. Abundance for 1967-1971(mean±SE) is estimated using data from the Fall Midwater Trawl Survey (see text).

Abundance	Grade	Trends: Long-term (1980-2001)	Trends: Short-term (5-year)
In 2001, abundance was 50% of the average abundance measured in 1967-1971	D	↓ (declining)	↔ (stable)

Key Findings:

Abundance of native fishes in the Bay is low compared to levels measured 15 to 30 years ago.

During the past five years (1997-2001), the average abundance of native fishes (measured as catch per unit effort) was 2.9, significantly lower than levels measured during the ten-year period of 1980-1989 (average: 5.6; Mann-Whitney, $p<0.05$) and barely 41% of average Bay fish abundance measured in the Fall Midwater Trawl Survey during 1967-1971.

Abundance of native fishes found in the Bay declined 80% during the 1980s and early 1990s.

Between 1980 and 1993, abundance of native fishes declined precipitously (regression, $p<0.05$). At its low point in 1991, abundance was 1.4, compared to 7.2 in 1980, the first year of the Bay Study survey. This period coincided with increased diversion of water from the rivers that flow into the Bay and a prolonged drought (1987-1992) (see Freshwater Inflow Index).

Since its low point in 1991, native fish abundance in the Bay has not increased.

Over the past decade (1991-2001), native fish abundance has not significantly increased (regression, $p>0.3$). Between the four-year 1989-1993 period, when the native fish abundance was at its lowest point, averaging 2.0, and the most recent five-year period (1997-2001), abundance has not significantly changed (ANOVA, $p>0.2$).

The greatest decline in native fish abundance occurred in Suisun Bay.

Between 1980 and 2001, abundance of native fish in Suisun Bay, the upstream portion of the Bay, declined significantly (regression, $p<0.05$) (Figure 6). Abundance was lowest during the late 1980s and early 1990s, a period during which extremely high rates of water diversion coincided with a prolonged drought (see Freshwater Inflow Index). Since that period, native fish abundance is significantly higher (Mann-Whitney, $p<0.05$), although still somewhat lower than levels measured 20 years ago.

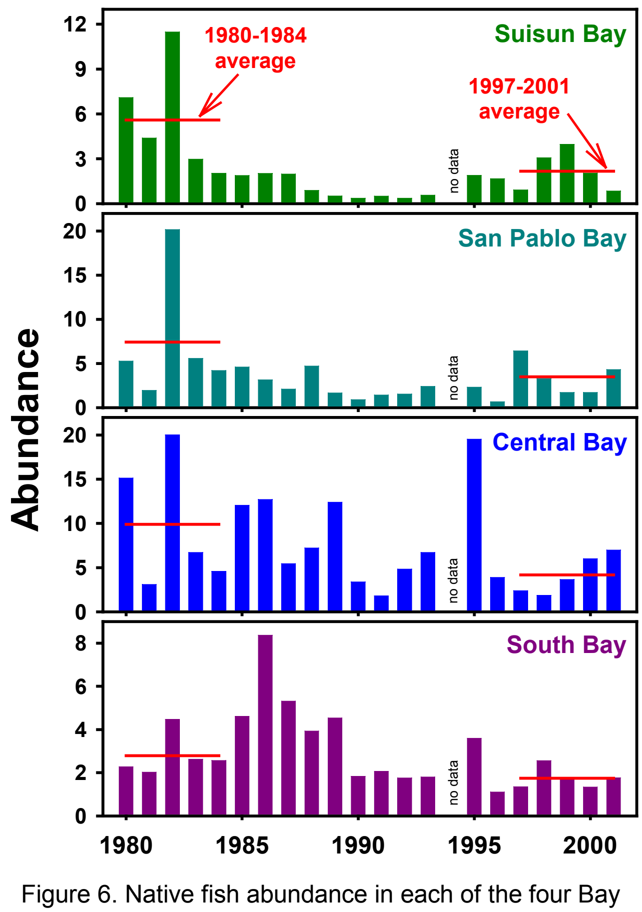

Figure 6. Native fish abundance in each of the four Bay subregions.

Evaluation and Grading:

Because other data suggest that abundance of a number of Bay fish species declined during the early 1960s (e.g., see Fishable-Swimmable-Drinkable Index, Fishable (catchable) indicator), average 1967-1971 abundance, expressed in terms of Bay Study Midwater Trawl abundance values but calculated from Fall Midwater Trawl survey results for the Bay (see Methods and Calculations), was set as the break point between the B and C grades. Each lower grade was set at 50% of the grade above. The grading scale used for the Abundance Indicator is shown in the table below.

Abundance Indicator					
Reference condition	**Abundance (catch per unit effort)**	**Rationale for reference conditions**	**Ecological condition**	**Grade point**	**Grade**
Upper	≥14.0	Estimated average abundance of native fishes for 1967-1971 (7.0 fish/unit effort) was set as break point between the B and C grades. Each lower grade was set at 50% of the grade above.	Excellent	4	A
	7.0-<14.0		Good	3	B
	3.5-<7.0		Fair	2	C
	1.75-<3.5		Poor	1	D
Lower	<1.75		Very poor	0	F

2. Diversity

The Diversity indicator (Figure 7) measures the species richness of the Bay-dependent fish assemblage. 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 (Karr et al., 2000; Wang and Lyons, 2003).

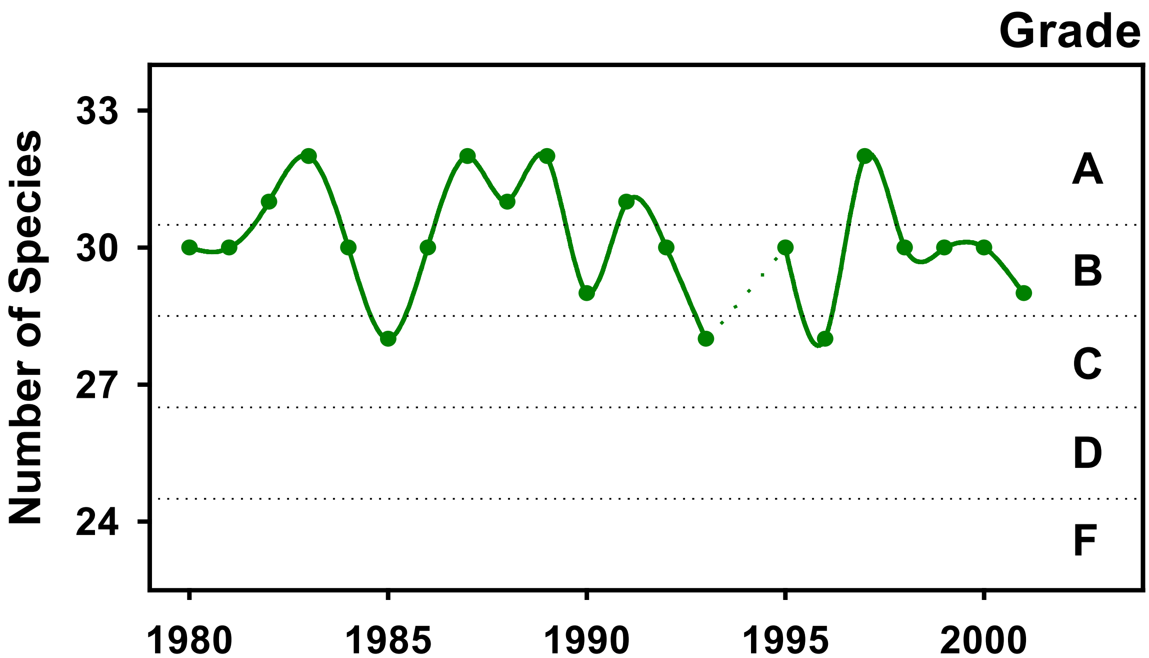

Figure 7. Changes in the Diversity Indicator from 1980 to 2001. The indicator measures species richness, calculated as the number of Bay-dependent species collected by the California Department of Fish and Game Bay Study Midwater Trawl and Otter Trawl surveys.

Diversity	Grade	Trends Long-term (1980-2001)	 Short-term (5-year)
In 2001, 29 of 33 Bay-dependent species were collected	B	↔ (fluctuating)	↓ (possible decline)

Key Findings:

Diversity of the Bay fish community fluctuated but did not significantly change during the 1980-2001 period.

Between 1980 and 2001, an average of 30 of the 33 Bay-dependent species, 91% of the Bay-dependent fish assemblage, was collected each year. The number of species collected each year did not changes significantly (regression, p>0.3). During the 1980-1984 period, an average of

30.6 species were collected, comnpared to an average of 30.2 species during the 1997-2001 period. Between 2001, 29 Bay-dependent species, 88% of the assemblage, were collected

Diversity of Bay-resident species did not change between 1980 and 2001 (Figure 8).

Of the 20 Bay-resident species, an average of 18 species were collected throughout the 21-year period. Six species (arrow goby, cheekspot goby, dwarf surfperch, pile perch, threespine stickleback and tule perch) were periodically not collected in either of the two Bay Study surveys.

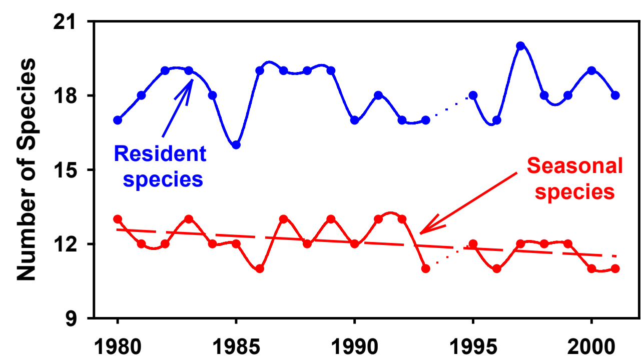

Figure 8. Diversity (# of species) of Bay resident species (blue) and seasonal Bay species (red). For the seasonal Bay species, the regression line shows the significant decline in diversity during the 1997-2001 period.

Diversity of seasonal Bay species declined between 1980 and 2001 (Figure 8).

The numbers of Bay-dependent species that visit the Bay seasonally declined significantly between 1980 and 2001 (regression, $p<0.05$), from an average of 12.4 species in the early 1980s to 11.6 during the 1997-2001 period (t-test, $p<0.05$). Of the five species that were periodically not collected in the Bay during the 21-year period (barred surfperch, Pacific tomcod, sandsole, spiny dogfish, and surfsmelt), two species, spiny dogfish and surfsmelt, were captured less frequently in the 1990s than they were in the 1980s.

Evaluation and Grading:

Of the 33 Bay-dependent fish species collected by the Bay Study survey, 22 species have been collected in every year.[11] An additional two species have been collected in all but one of the years from 1980-2001.[12] Therefore the lower reference condition was set at 24 species. The upper reference condition was set at 30 species, approximately 91% of total assemblage of Bay-dependent species collected by the Bay Study Midwater Trawl and Otter Trawl surveys. Between these two reference conditions, the grade scale was linear using increments of 2 species, approximately 6% of the total number of Bay-dependent species and less than the average five-year variation (measured as standard deviation, mean SD: 1.4 species) in the number of Bay-dependent species measured for the survey period.

Diversity Indicator

Reference condition	Diversity (# Bay-dependent species)	Rationale for reference conditions	Ecological condition	Grade point	Grade
Upper	>30	Lower reference condition based on 24 Bay-dependent species that are collected in >95% of all years. Upper reference condition set at 30 species, ~91% to total number of Bay-dependent species. Each increment is 2 species, ~6% of the total number of Bay-dependent species.	Excellent	4	A
	>28-30		Good	3	B
	>26-28		Fair	2	C
	>24-26		Poor	1	D
Lower	≤24		Very poor	0	F

[11] Twenty-two Bay-dependent species have been collected in each year of the Bay Study Midwater Trawl and Otter Trawl surveys: bat ray, Bay goby, Bay pipefish, brown rockfish, brown smoothhound, California tonguefish, delta smelt, diamond turbot, English sole, jacksmelt, leopards shark, longfin smelt, Pacific herring, Pacific staghorn sculpin, plainfin midshipman, shiner surfperch, speckled sanddab, splittail, starry flounder, topsmelt, walleye surfperch, and white croaker.
[12] Cheekspot goby and barred surfperch have been collected in all but one of the years of the Bay Study surveys.

3. Percent Native Species

The Percent Native Species indicator (Figure 9) measures the relative proportions of native and non-native species found in the Bay's open water fish assemblage. Non-natives 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) (May and Brown, 2002; Meador et al., 2003).

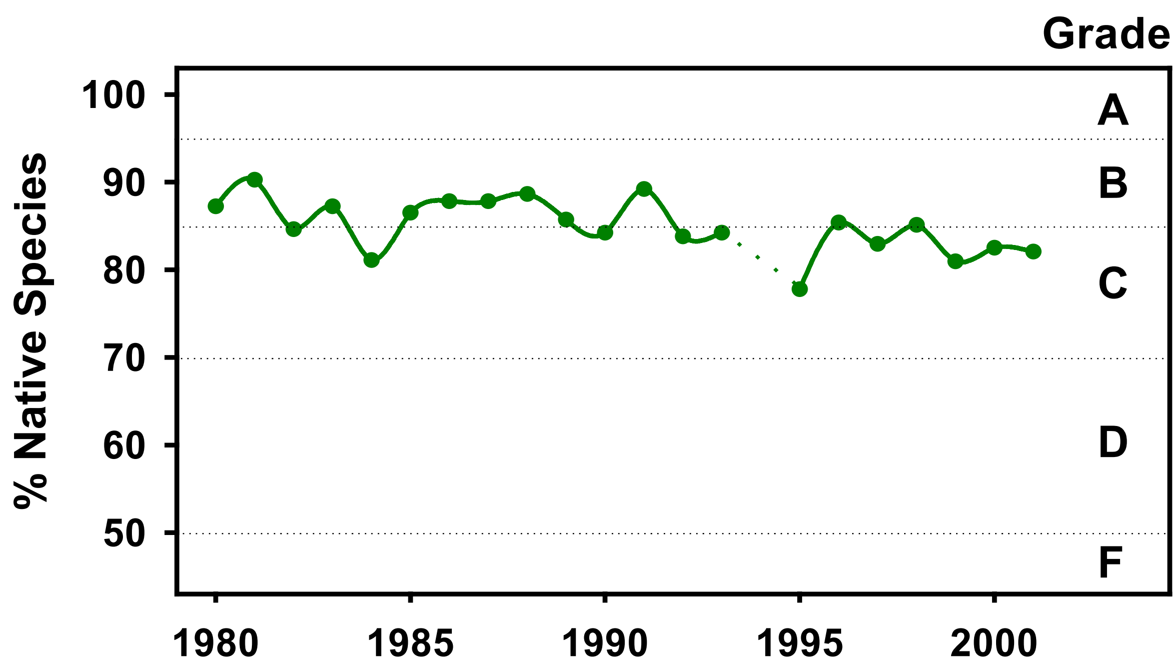

Figure 9. Changes in the Percent Native Species Indicator from 1980 to 2001. The indicator measures the percentage of fish species collected by the California Department of Fish and Game Bay Study Midwater Trawl Survey that are native to the Bay.

Percent Native Species	Grade	Trends Long-term (1980-2001)	Trends Short-term (5-year)
In 2001, 82% of fish species are natives	C	↓ (declining)	↔ (stable)

Key Findings:

The Bay fish community is dominated by native species.

On average, 85% of fish species collected in the San Francisco Bay are native to the Bay (1980-2001). Native species comprise a significantly greater proportion of the fish fauna in the Bay than in the adjacent Delta (~50%).

The percentage of fish species collected in the Bay that are native has declined.

In San Francisco Bay, the percentage of fish species collected in the Bay Study Midwater Trawl survey that are native to the Bay has decreased significantly during the past 22 years (1980-2001, regression, $p<0.05$) (Figure 10). During the first five years of the survey (1980-1984), on average, 86.1% of fish species collected were native, compared to the most recent five years of the survey (1997-2001) in which 82.7% of the species collected were native. The small (but significant) decline in percent native species measured for the entire Bay was largely driven by the considerably steeper decline in percent native species in Suisun Bay (see Figure 11 below). In South, Central, and San Pablo Bays, the percentage of native species was stable.

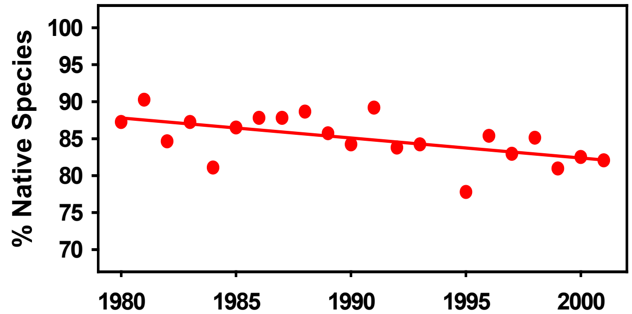

Figure 10. The percentage of fish species in the Bay that are native species has significantly declined.

The lowest percentages of native species occurred in Suisun Bay, the upstream portion of the Bay.

Among the four subregions of the Bay, the percentage of native species was significantly lower in Suisun Bay, on average 68.3% native species during the past five years, than in Central Bay (1997-2001 average: 90.3% native species, t-test, $p<0.05$), the portion of the Bay most influenced by ocean conditions and characterized by predominantly marine fish species (Figure 11). The percentages of native species in South Bay and San Pablo Bay were intermediate, 83.6 and 83.0%, respectively, for the period from 1997-2001.

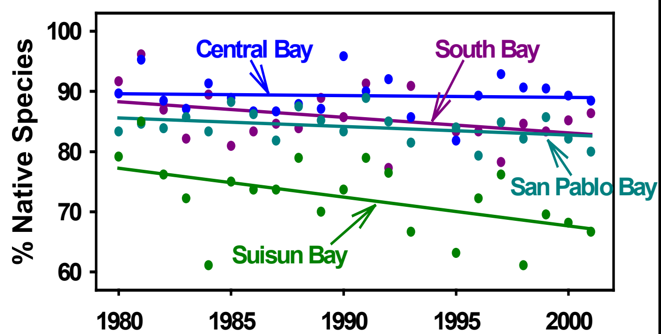

Figure 11. Comparison of the percentage of native fish species for the four subregions of the Bay.

Evaluation and Reference Conditions:

The Percent Native Species Indicator can range from 100%, indicating that all of the fishes collected by the Bay Study Midwater Trawl survey were native to the Bay, the upper estuary or local coastal waters, to 0%, indicating that all of the fish species collected were not native to the Bay. Because of its importance as a deep-water and fishing port, the Bay has been home to a number of non-native species for more than 100 years. Therefore, the upper reference condition (i.e., the break point between an A and a B grade) was set at 95%, a level at which native species predominate in the system, rather than at 100%. The lower reference condition (i.e., the break point between a D and an F grade), set at 50%, was a level at which non-native species comprise half of the fish community. Intermediate grades were assigned with each grade level (below the A-B break point) using sliding scale of increasing increment size. For example, the C-D increment, from 70% to 85% was larger than the 10% increment between a C and B grade. The grading scale for the Percent native Species is shown in the table below.

Reference condition	Percent native fish	Rationale for reference conditions	Ecological condition	Grade point	Grade
Upper	≥95%	Non-native fish species have been present in the Bay for >100 years. 100% native fish species is unrealistic but low % native species, <50%, is indicative of degraded conditions.	Excellent	4	A
	85-<95%		Good	3	B
	70-<85%		Fair	2	C
	50-<70%		Poor	1	D
Lower	<50%		Very poor	0	F

4. Sensitive Species

The Sensitive Species indicator (Figure 12) measures the abundance of four representative species: longfin smelt, delta smelt, Pacific herring, and striped bass. Each of these species is relatively common in the Bay (i.e., each has been collected in every year of both the Bay Study and Fall Midwater Trawl surveys) and each has been and is today a target of environmental and/or fishery management in the Bay.

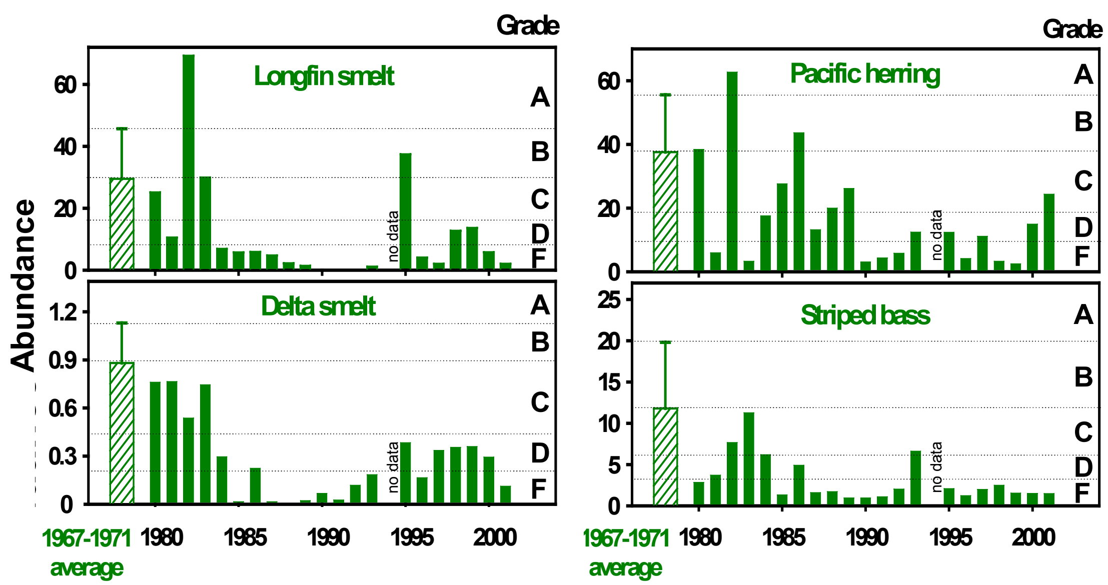

Figure 12. Changes in the Sensitive Species Indicator from 1980 to 2001. The indicator measures the population size (as catch per unit effort) of three representative Bay fish species collected by the California Department of Fish and Game Bay Study Midwater Trawl Survey. Abundance for 1967-1971 (mean±SE) is estimated using data from the Fall Midwater Trawl Survey (see text).

Sensitive Species	Grade	Trends Long-term (1980-2001)	Trends Short-term (5-year)
Longfin smelt	F	↓ (declining)	↔ (fluctuating)
Delta smelt	F	↓ (declining)	↔ (fluctuating)
Pacific Herring	C	↓ (declining)	↑ (increasing)
Striped bass	F	↓ (declining)	↔ (stable)
2001 Indicator Grade	**F**	Grade point average = 0.5	

Key Findings:

Abundances of longfin smelt, delta smelt, Pacific herring, and striped bass fluctuated during the 21-year-long Bay Study but recent numbers were low compared to levels measured at the start of the survey.

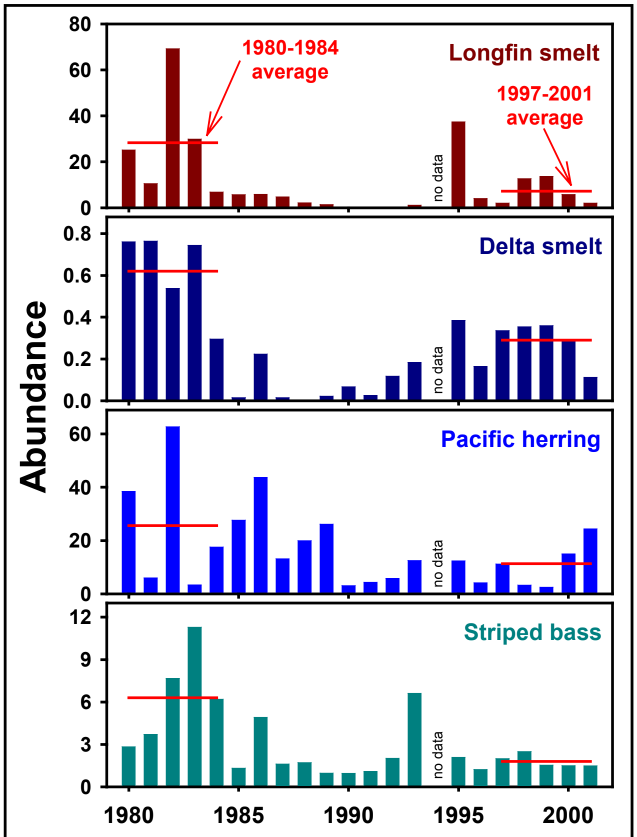

Figure 13. Abundance of longfin smelt, delta smelt, Pacific herring, and striped bass in the Bay.

Between 1980 and 2001, population abundances of Pacific herring and striped bass declined significantly (regression, $p<0.05$, both species, decline in longfin smelt abundance, $p=0.12$). Population abundance of longfin smelt declined significantly between 1980 and 1993 (regression, $p<0.05$). Abundance of delta smelt declined precipitously in the early 1980s (regression, $p<0.01$). Average abundances during the most recent five-year period (1997-2001) were 25%, 47%, 44% and 29% of 1980-1984 levels for longfin smelt, delta smelt, Pacific herring, and striped bass, respectively (Figure 13).

Longfin smelt abundance declined to critically low levels during the 1980s and early 1990s.

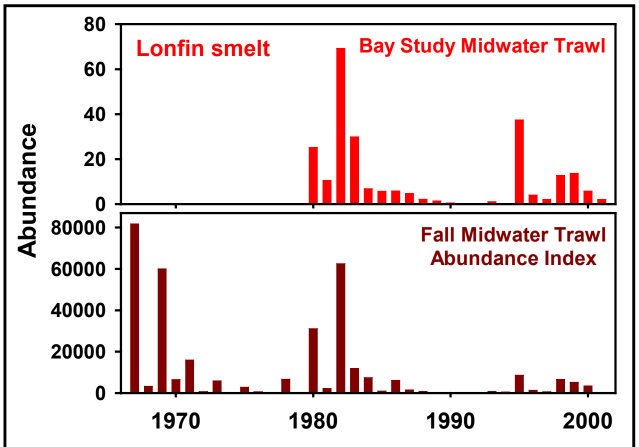

Figure 14. Comparison of longfin smelt abundance measured in two different surveys.

Between 1980 and 1989, the longfin smelt population decreased by 95%, a decline measured in both the Bay Study and Fall Midwater Trawl surveys (Figure 14). For a five-year period (1989-1993), abundance levels were <1-5% of the average abundance measured from 1980 to 1984. This population decline coincided with a period of increasing water diversions from rivers that flow into the Bay and a prolonged drought (1987-1992). Since 1995, the first year of successful recruitment by the species in more than a decade, population levels have improved somewhat, although 2001 levels were only 7% of the 1980-1984 average. Population abundance trends measured in Bay Study and Fall Midwater Trawl surveys were highly correlated (correlation coefficient: 0.898; $p<0.001$).

Delta smelt abundance declined to critically low levels in the 1980s but improved during the past decade.

Delta smelt abundance declined by 90% during the 1980s (Figure 15). In 1993, the species was listed under the Endangered Species Act as threatened. Since then, its population has increased but abundance remains at levels less than half of that measured twenty years ago. Population abundance trends measured in Bay Study and Fall Midwater Trawl surveys were similar although they were not significantly correlated (correlation coefficient: 0.357; p=0.11).

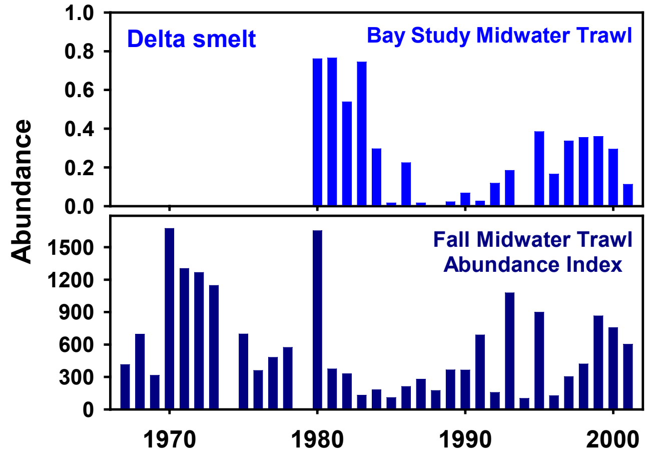

Figure 15. Comparison of delta smelt abundance measured in two different surveys.

Pacific herring abundance has gradually declined.

The long-term population decline demonstrated in the Bay Study survey results is weakly supported by results from an independent survey of Pacific herring spawning biomass.[13] In contrast to the juvenile Pacific herring that are sampled by the Bay Study survey, the spawning biomass survey assesses adult population size. Results of the two surveys are not significantly correlated (correlation coefficient: 0.109; p>0.6) but the spawning biomass survey shows a slight (but statically insignificant, p=0.2) decline in the San Francisco Bay Pacific herring population (Figure 16).

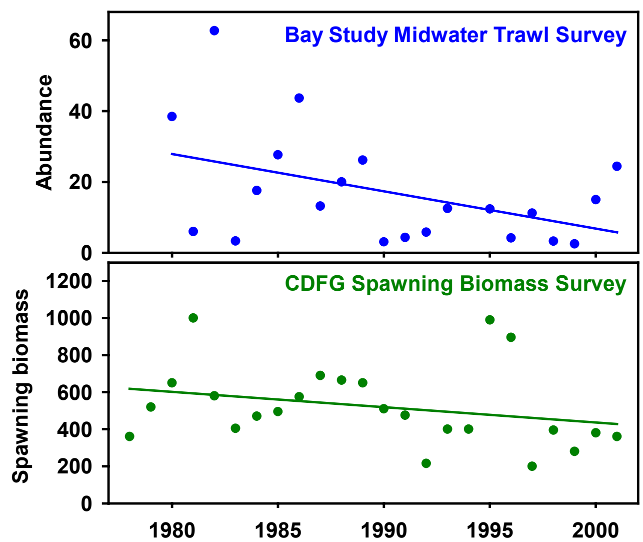

Figure 16. Comparison of Pacific herring abundance measured in two different surveys.

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[13] California Department of Fish and Game conducts annual Pacific herring spawning biomass surveys using hydroacoustic techniques (CDFG, 2002).

Striped bass populations declined during the 1970s and 1980s and have not recovered.

For most of the past decade, striped bass population abundance has been stable at levels significantly lower than the average abundance measured between 1980 and 1984 (t-test, $p<0.05$). Population abundance trends measured in Bay Study and Fall Midwater Trawl surveys were highly correlated (correlation coefficient: 0.88; $p<0.001$) (Figure 17).

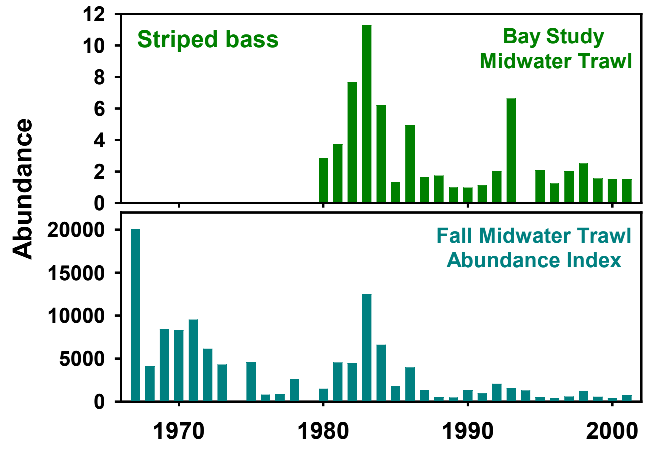

Figure 17. Comparison of striped bass abundance measured in two different surveys.

Grading and Evaluation:

For each of the four species, mean 1967-1971 abundance plus 1 standard error (SE), expressed in terms of Bay Study Midwater Trawl abundance values but calculated from Fall Midwater Trawl survey results for the Bay (see Methods and Calculations), was used as the lower bound for the upper reference condition (i.e., the break point between an A and a B grade). The lower reference condition (i.e., the break point between a D and an F grade) was set at approximately 25% of the upper reference conditions. Between the upper and lower reference conditions, intermediate grades were assigned using a linear scale. For each of the species, the size of grade intervals (i.e., the range of abundance values within a single grade level) also corresponded to >1 standard deviations (SD) measured for abundance results for most sequential five-year intervals for the 20-year period during which the Bay Study survey was conducted. The grading scale used for the each species in the Sensitive Species Indicator is shown in the table below.

Sensitive Species Indicator					
Reference condition	**Abundance (catch per unit effort)**	**Rationale for reference conditions**	**Ecological condition**	**Grade point**	**Grade**
Upper	LFS: ≥46 DS: ≥1.1 PH: ≥56 SB: ≥20	Estimated abundance of each species for 1967-1971 (mean+1 SE) was set as lower bound for the upper reference condition. Lower reference condition was set at ~25% of the upper reference condition.	Excellent	4	A
	LFS: 30-<46 DS: 0.9-<1.1 PH: 38-<56 SB: 12-<20		Good	3	B
	LFS: 15-<30 DS: 0.45-<0.9 PH: 19-<38 SB: 6-<12		Fair	2	C
	LFS: 7.5-<15 DS: 0.22-<0.45 PH: 9.5-<19 SB: 3-<6		Poor	1	D
Lower	LFS: <7.5 DS: <0.22 PH: <9.5 SB: <3		Very poor	0	F

6. Fish Index

The San Francisco Bay Fish Index aggregates the results of the Abundance, Diversity, Percent Native Species, and Sensitive Species indicators (Figure 18).

The Fish Index declined between 1980 and 1993 (Figure 19). Since 1993, the Fish Index has not changed.

Between 1980 and 1994, the health of the Bay fish community, as measured by the Fish Index, declined significantly (regression, $p<0.01$). The average score in the early 1908s (1980-1984) was 61.6, significantly greater than the average score measured for the 1990-1993 period, 37.1 (t-test, $p<0.01$). Since 1993, the Fish Index has not significantly increased (regression, $p>0.05$); the 1997-2001 average score was 43.1. The decline in the Fish Index was largely the result of decreases in population abundance of native fish species, including each of the common species included in the Sensitive Species indicator. Declines in the Percent Native Species, which were more apparent during the late 1990s, also contributed.

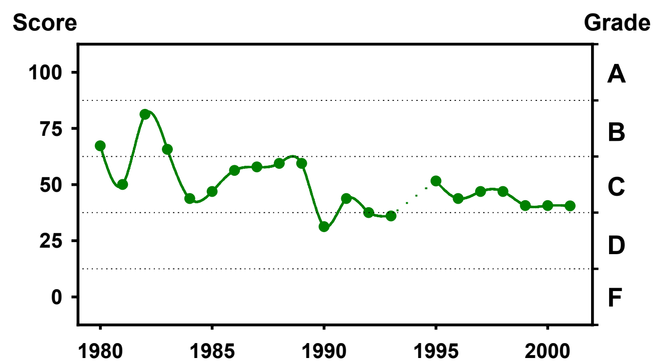

Figure 18. The Fish Index aggregates the results of the Abundance, Diversity, Percent Native Species, and Sensitive Species indicators.

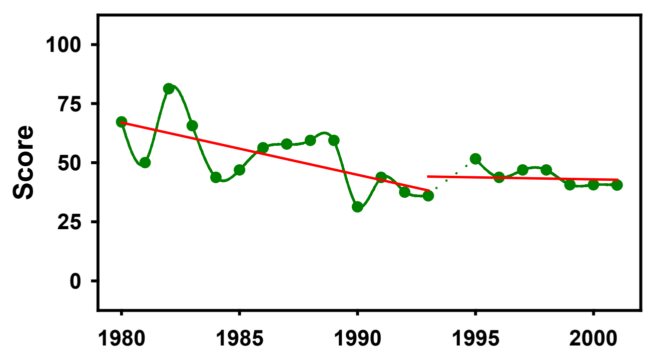

Figure 19. Changes in the Fish Index between 1980 and 2001. The red lines show the linear regressions for the 1980-1993 and 1993-2001 periods.

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