State of the Estuary Report 2015

Summary

WILDLIFE – Estuary Fish Summary

Prepared by Christina Swanson, Natural Resources Defense Council; Jonathan Rosenfield, Ali Weber-Stover, The Bay Institute

2015

State of the San Francisco Estuary 2015

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What are the indicators?

The Bay Fish Index uses ten indicators to measure and evaluate the status and trends of the San Francisco Estuary's fish community in four sub-regions of the estuary; South, Central, San Pablo and Suisun Bays. The indicators are designed to measure and evaluate different attributes of the fish community: abundance (4 indicators for "how many fish"), diversity (2 indicators for "how many different kinds of fish"), species composition (2 indicators for "what kinds of fish"), and distribution (2 indicators for "where are the fish"). The combined result of the indicators in each attribute were aggregated results into a Bay Fish Index, which combines the results of all the indicators into a single metric for each sub-region.

Four indicators measure abundance:

- Pelagic Fish Abundance;
- Northern Anchovy Abundance;
- Demersal Fish Abundance; and
- Sensitive Species Abundance.

Two indicators measure species diversity:

- Native Fish Species Diversity; and
- Estuary-dependent Fish Species Diversity.

Two indicators measure species composition:

- Percent Native Species; and
- Percent Native Fish.

Two indicators measure fish distribution:

- Pelagic Fish Distribution; and
- Demersal Fish Distribution.

Except for the species composition indicators and the Sensitive Species Abundance indicator, all indicators measure only fish species that are native to the San Francisco Estuary and local coastal waters.

To provide a geographically comprehensive view of trends among fishes in the San Francisco Estuary, a smaller set of indicators were developed to reveal conditions in Suisun Marsh, Suisun Bay, and the Sacramento-San Joaquin Delta (collectively, the upper Estuary). The upper

Estuary's aquatic habitat and fish fauna differ from those found in the open waters of the estuary's main embayments and, as a result, different survey programs, using different fish sampling techniques, monitor fish in this area. Indeed, data for indicators in the upper Estuary comes from three different long-term sampling programs, each of which samples a different habitat and region using different gear.

As a result of large amount of data available in the upper Estuary and the heterogeneity of its habitats, only three indicators of fish assemblage health were developed for this region. One measure of abundance (Native Fish Abundance) and two measures of assemblage composition (Percent Native Species and Percent Native Fish) were calculated for the upper Estuary. These indicators were calculated for each sampling program and sub-regions within the upper Estuary and were designed to mirror the approach used for analogous indicators in the Bay Fish Index.

An additional indicator, portraying the fish assemblage's role in the Estuary's food web, was calculated for fishes of the upper Estuary. This indicator is a measure of total fish abundance (introduced and native species combined) in each region and sub-region of the three major habitat types of the upper Estuary. That indicator is described and presented in the Processes section of the 2015 State of the Estuary report.

Table 1.

Attribute	**Indicators**	**Benchmarks**
Living Resources (Bay fish)	Abundance, diversity, species composition and distribution the fish community in four sub-regions of the Bay (South, Central, San Pablo and Suisun Bays)	Benchmarks (or reference conditions) are 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.
Living Resources (Upper Estuary Fish)	Abundance and species composition indicators in Suisun Marsh; subregions of the upper Estuary's Pelagic Zone (Suisun Bay and the West Delta); four subregions of the Delta Beach Zone (littoral habitats)	Primary reference conditions are based on either measured values from early years of the sampling record (1980-1989 for the Suisun Marsh survey and Fall mid-water trawl and 1995-2004 for the Delta Beach Seine), recognized and accepted interpretations of ecological conditions and ecosystem health (e.g., native v non-native species composition), and best professional judgment.

Why is the estuary's fish community important?

San Francisco Bay's estuary is important habitat for more than 100 fish species, including commercially important Chinook salmon and Pacific herring, popular sport fishes like striped bass and white 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 estuary 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.

What are the benchmarks? How were they selected?

The benchmarks (or reference conditions) for the Bay Fish indicators are based on: 1) measured values from the earliest years for which quantitative data were available (1980-1989 for the Bay Study survey); 2) maximum measured values for the estuary or sub-regions; 3) recognized and accepted interpretations of ecological conditions and ecosystem health (e.g., native v non-native species composition); and 4) best professional judgment. The upper Estuary fish indicators mirror this approach for setting benchmarks. The 1980-1989 period was used as baseline for Suisun Marsh (representing the earliest data available) and the Pelagic Zone (data here extend back to 1967); the Delta Beach Seine survey methodology became more consistent in the mid-1990s, so the period 1995-2004 was used as the primary reference condition for those data. Reference conditions for evaluating assemblage composition (native vs. non-native species) were identical to those developed for the Bay Fish index.

What are the status and trends of the indicators and Index?

The conditions and trends of the Bay fish community differ among the four sub-regions of the estuary. Abundance, diversity, species composition and distribution are all highest in Central and South Bays, where overall conditions (meaning the regional Fish Index) were consistently "good", intermediate in San Pablo Bay, where conditions were "good" to occasionally "fair," and lowest in Suisun Bay, the upstream region of the estuary, where over the last 3 decades conditions have declined from "fair" to poor." Overall conditions (the Index) are also declining in South and San Pablo Bay, although the rate of decline is lower than that in Suisun Bay. Declines in n the Fish Index in these regions are driven by substantial declines in the abundance of pelagic (open water) fish species and, in Suisun Bay and San Pablo Bay, declines in species composition (i.e., non-native species are becoming more prevalent) and, in Suisun Bay, declines in distribution (i.e., native species are no longer consistently collected in some areas of the sub-region).

Table 2.

Indicator	**CCMP Goals** Fully met if goal achieved in >67% of years since 1990 Partially met if goal achieved in 33-67% of years Not met if goal achieved in <33% of years	**Trend (long term; 1980-2013)**	**Trend since 1990**	**Current condition** (average for last 10 years)
Pelagic Fish Abundance	Not met in any sub-region	Decline in all sub-regions except Central	Stable at low levels	Fair to Very Poor
Northern Anchovy Abundance	Not met in any sub-region	Decline in San Pablo and Suisun, stable in South and Central	Stable at low levels (Suisun, San Pablo) Declining (South, Central)	Fair to Very poor

Demersal Fish Abundance	Fully met (South and Central) Not met (San Pablo and Suisun)	Decline in Suisun, increase in Central and South, stable in San Pablo	Stable (Suisun) Increasing (South, Central, San Pablo)	Poor (Suisun) Fair to good (South, Central, San Pablo)
Sensitive Species Abundance	Not met on any sub-region	Decline in all sub-regions	Stable at low levels	Poor (all sub-regions)
Native Fish Diversity	Partially met (South) Not met (Central, San Pablo, Suisun)	Decline in San Pablo, increase in Central, stable in other sub-regions	Stable	Poor (Suisun) Fair to good (South, Central, San Pablo)
Estuary-dependent Fish Diversity	Fully met (South, Central) Not met (San Pablo, Suisun)	Decline in South and San Pablo, stable in Central and Suisun	Stable	Poor (Suisun) Fair to good (South, Central, San Pablo)
Percent Native Species	Fully met (South, Central) Not met (San Pablo, Suisun)	Decline in all sub-regions except Central	Stable (South, Central) Declining (San Pablo Suisun)	Good (South, Central) Fair to Poor (San Pablo, Suisun)
Percent Native Fish	Fully met (South, Central, San Pablo) Not met (Suisun)	Decline in Suisun, stable in other sub-regions	Stable	Good (South, Central, San Pablo) Very Poor (Suisun)
Pelagic Fish Distribution	Fully met (South, Central, San Pablo) Partially met (Suisun)	Decline in Suisun, stable in other sub-regions	Stable (South, Central, San Pablo) Declining (Suisun)	Good (South, Central, San Pablo) Fair to Poor (Suisun)
Demersal Fish Distribution	Fully met (South, Central, San Pablo) Partially met (Suisun)	Decline in Suisun, stable in other sub-regions	Stable (South, Central, San Pablo) Declining (Suisun)	Good (South, Central, San Pablo) Fair to Poor (Suisun)
Bay Fish Index	Fully met (Central) Partially met (South) Not met (San Pablo, Suisun)	Decline in all sub-regions except Central	Stable (South, Central, San Pablo) Declining (Suisun)	Good (Central) Fair (South, San Pablo) Poor (Suisun)

Because habitats and sampling programs operating within the upper estuary are substantially different, no synthetic index was calculated for the upper Estuary region. However, it is clear that the fish assemblage in the upper Estuary is in very poor condition (Table 3). Native fish abundance, the percentage of native fish, and the percent of native species are poor or very poor in almost every sub-region of the upper Estuary.

Table 3

Indicator	**Region (Sub-region if trends are different)**	**CCMP Goal Met**	**Evaluation**		**Trend**
			Reference Period	Short-Term (last five years)	Over the Period of Record
Native Fish Abundance	Suisun Marsh	No	Good	Poor	Decline
	Suisun Bay Pelagic	No	Good	Very Poor	Decline
	Central-West Delta Pelagic	No	Good	Very Poor	Decline

	Delta Beach Zone	No	Poor	Poor	Stable
Percent Native Fish	Suisun Marsh	No	Very Poor	Very Poor	Stable
	Suisun Bay Pelagic	No	Poor	Poor	Stable
	Central-West Delta Pelagic	No	Very Poor	Very Poor	Stable
	Delta Beach Zone	No	Very Poor	Very Poor	Stable
Percent Native Species	Suisun Marsh	No	Poor	Very Poor	Decline
	Suisun Bay Pelagic	No	Fair	Fair	Stable
	Central-West Delta Pelagic	No	Poor	Very Poor	Decline
	Delta Beach Zone	No	Very Poor	Very Poor	Stable

What does it mean? Why do we care?

The condition and trends of the fish community in the San Francisco Bay's estuary are key indicators of the health of the estuary and its function as habitat for resident and migratory fishes. The Bay Fish Index shows that the estuary is in healthy and stable condition in Central Bay, the downstream subregion that is strongly influenced by environmental conditions in the Pacific Ocean. The health of South and San Pablo Bays is fair, but the Bay Fish Index shows that conditions there are declining as well.

In contrast, the both the Bay Fish Index in the Suisun Bay Region and the individual indicators of the different habitats in the upper Estuary confirm that that the health of the upstream region of the estuary, (including Suisun Marsh, Suisun Bay, and the Delta), has declined markedly during the past three decades and is now (and has been for more than 20 years) in poor to very poor condition. During the past twenty years, the upper Estuary has been strongly influenced by fresh water management operations (in the Delta and in Central Valley rivers) that reduce and alter the patterns of freshwater inflows (see Freshwater Inflow Index, Open Water Habitat indicators, and Flood Events indicators).

State of the Estuary Report 2015

Technical Appendix

WILDLIFE– Bay Fish Indicators and Index
Technical Appendix

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State of San Francisco Estuary 2015

Wildlife – Bay 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

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

[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.

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 predominantly captures pelagic fishes that utilize open water habitats. This survey tends to 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.

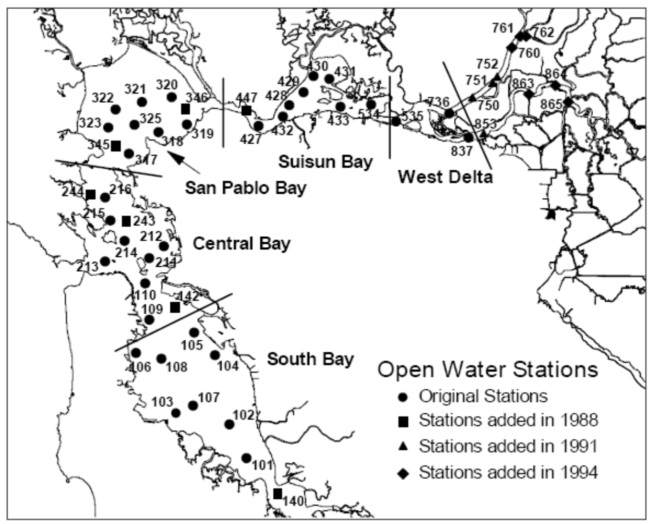

Figure 2. Locations of the sampling stations for the CDFW Bay Study Midwater Trawl and Otter Trawl surveys in the San Francisco Bay. For the Bay Fish Index, only data from the original stations that were sampled continuously from 1980-2013 were used to calculate the indicators for each of the four sub-regions: South Bay, Central Bay, San Pablo Bay and Suisun Bay and the western Delta..

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

Table 1. Sampling stations and total number of surveys conducted per year (range for 1980-2013 periods, excludes 1994) by the CDFW Bay Study Survey in each of four sub-regions of the 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 1980-2013 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/Western Delta	427, 428, 429, 430, 431, 432, 433, 534, 535, 736, and 837	87-132 (MWT) 88-132 (OT)

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 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

[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.

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., 2009-2013). Regression analyses were conducted using continuous results for the entire 34-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.

[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.

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

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

[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).

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, 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 (1980-2013, 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:

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

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[8] In California, longfin smelt are found in San Francisco Bay, Humboldt Bay, and the estuaries of the Russian, Eel, and Klamath rivers.

The **Northern Anchovy Abundance** indicator was calculated for each year (1980-2013, 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 (1980-2013) 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:

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

The **Sensitive Fish Species Abundance** indicator, the abundance of each of the four species was calculated for each year (1980-2013, 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.

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

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

Table 3. Quantitative reference conditions and associated interpretations for results of the Bay Fish abundance indicators. The primary reference condition, which corresponds to "good" conditions, is in bold italics.

Abundance indicators		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>150% of 1980-1989 average	"Excellent," greater than recent historical levels	4
>100% of 1980-1989 average	***"Good," meets CCMP goals***	***3***
>50% of 1980-1989 average	"Fair," below recent historical levels	2
>15% of 1980-1989 average	"Poor," substantially below recent historical levels	1
≤15% of 1980-1989 average	"Very Poor," extreme decline in abundance	0

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 2013, pelagic fishes were two to three times more abundant in Central Bay (65 fish/10,000m^3) than South (32 fish/10,000m^3) or San Pablo Bays (20 fish/10,000m^3) and more than 20 times more abundant than in Suisun Bay (3 fish/10,000m^3).

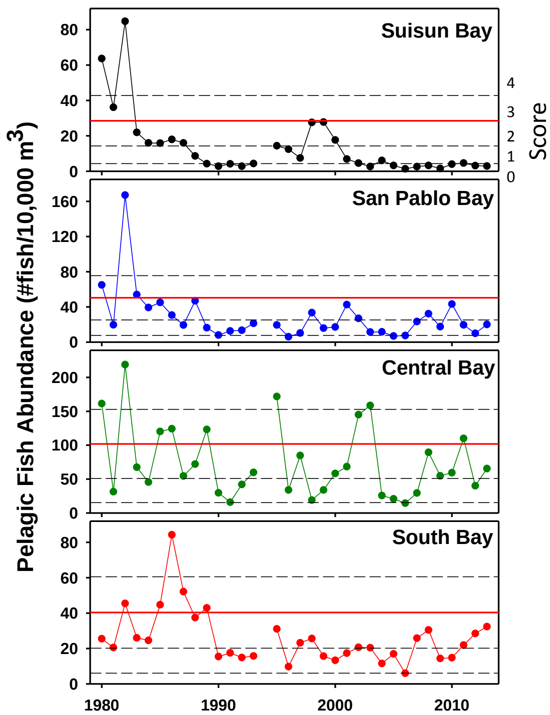

Figure 3. Results for the Pelagic Fish Abundance indicator, expressed as abundance (left Y axis) and score (right Y axis, top panel only for example), for 1980 to 2013. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

Abundance of pelagic fishes has declined in most sub-regions of the estuary.
Pelagic fish abundance declined significantly since 1980 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. In the last 10 years, pelagic fish abundance appears to be increasing in South and Central Bays (regression, $p=0.057$ for South Bay and $p=0.064$ for Central 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 and trends in pelagic fish abundance are below the 1980-1989 reference period for most sub-regions of the estuary: average pelagic fish abundance levels for the most recent five years (2009-2013) are "fair" in South Bay (55% of the 1980-1989 average) and Central Bay (65%), "poor" in San Pablo Bay (43%) and "very poor" in Suisun Bay (11%).

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 34 years, northern anchovy have been more abundant in Central Bay (mean: 913 fish/10,000m^3) than all other sub-regions, least abundant in Suisun Bay (16

fish/10,000m^3), and present at intermediate abundance levels in San Pablo (241 fish/10,000m^3) and South Bays (282 fish/10,000m^3) (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, all pairwise comparisons: $p<0.05$).

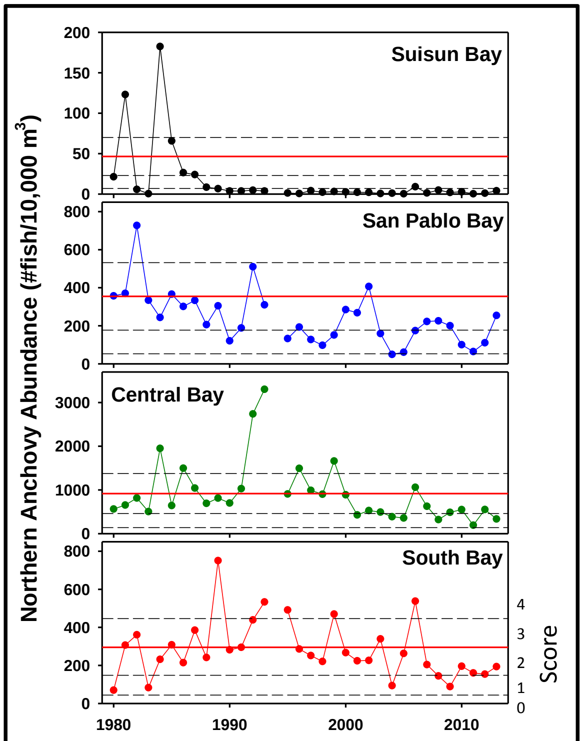

Figure 4. Results for the Northern Anchovy Abundance indicator, expressed as abundance (left Y axis) and score (right Y axis, bottom panel only for example), for 1980 to 2013. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

Trends in abundance of Northern anchovy differ in different sub-regions of the estuary.
During the past 34 years, abundance of northern anchovy has been variable but roughly stable in South and Central Bays although, in most recent years (2009-2013), Central Bay abundance has averaged about 54% lower than 1980-1989 levels. Northern anchovy abundance has steadily declined in San Pablo Bay (regression: $p<0.001$), falling to 41% of 1980-1989 levels during the most recent five years (2009-2013). 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 just 5% 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 significantly throughout the upstream regions of the estuary, San Pablo and Suisun Bays to levels substantially below the 1980-1989 average reference conditions: average northern anchovy abundance in the most recent five years (2009-2013) are "very poor" in Suisun Bay at just 4% of the 1980-1989 average, and "poor" in San Pablo Bay (41%). Although the trends in abundance over the 34-year record, and particularly during the late 1980s and 1990s, are different for Central and South Bays, recent northern anchovy abundance in those regions, "poor" in Central Bay (46%) and "fair" in South Bay, are also too low to meet the CCMP goal. 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 (1980-2013 median: 669 fish/10,000m^2) than in all other sub-regions of the estuary and least abundant in Suisun Bay (35 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 (254 fish/10,000m^2) and San Pablo Bays (227 fish/10,000m^2) are comparable. In 2013, demersal fishes were more than four times more abundant in Central Bay (2330 fish/10,000m^2) than South Bay (530 fish/10,000m^2), more than six times more abundant than in San Pablo Bays (367 fish/10,000m^2), and nearly 80 times more abundant than in Suisun Bay (30 fish/10,000m^2).

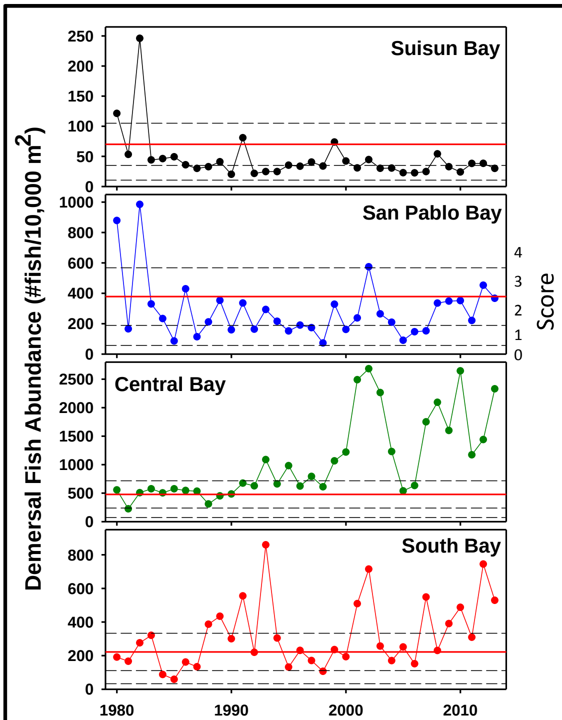

Figure 5. Results for the Demersal Fish Abundance indicator, expressed as abundance (left Y axis) and score (right Y axis, second panel from the top only for example), for 1980 to 2013. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

Abundance of demersal fishes has increased in Central and South Bays but declined in Suisun Bay.

During the past 34 years, abundance of native demersal fishes increased in Central and South Bays (regressions: $p<0.001$ and $p<0.05$, respectively) but declined in Suisun Bay (regression: $p<0.05$). In San Pablo Bays, demersal fish abundance has fluctuated widely but exhibited no significant trend over time. Compared to 1980-1989 levels, recent average abundances (2009-2013) were 53% lower in Suisun, similar in San Pablo Bay (8% lower), and 222% and 384% higher in South and Central Bays, respectively.

Increases in demersal fish abundance in Central and South Bays were driven by multiple species.

In South and Central Bays, increases in demersal fish abundance were largely attributable to high catches of Bay goby and Pacific staghorn sculpin, Bay resident species, and plainfin midshipman and 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 2009-2013 average) and trends in demersal fish abundance were higher or comparable to the 1980-1989 reference period for all sub-regions of the estuary except Suisun Bay, where demersal fish abundance decreased significantly and remain at less than half of recent historical levels. 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 34 years, combined abundance of the four sensitive fish species has declined in all sub-regions of the estuary (regression: $p<0.01$ all sub-regions). For the most recent five-year period (2009-2013), abundance of sensitive fish species abundance San Pablo is just 28% of that sub-region's 1980-1989 average, 30% in Central Bay, 33% in South Bay and 50% 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 South, Central, and San Pablo Bays (regression: $p<0.05$ both tests), striped bass declined in all sub-regions (regression: $p<0.05$ all regions). Pacific herring abundance was variable and did not exhibit significant declines in any sub-region.

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 (2009-2013) were significantly lower in only South and Central Bay (t-test or Mann-Whitney, $p<0.05$, both tests). Although recent abundance levels in San Pablo and Suisun Bay were markedly lower than during the 1980-1989 reference period, 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.

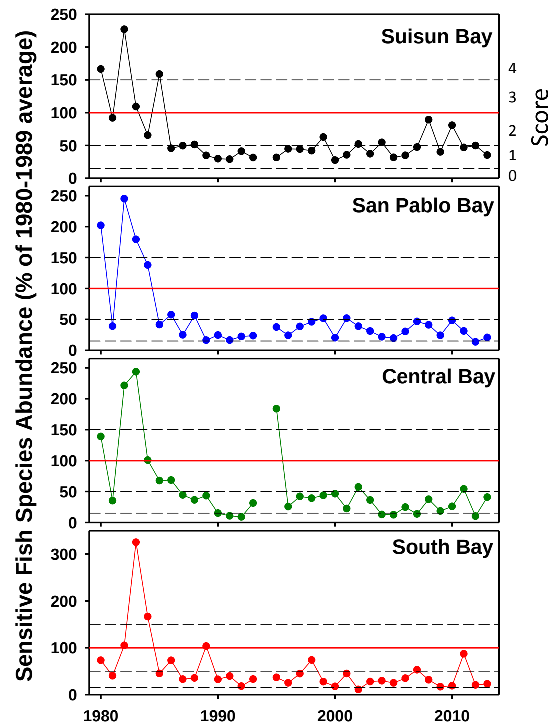

Figure 6. Results for the Sensitive Species Abundance indicator, expressed as abundance (left Y axis) and score (right Y axis, top panel only for example), for 1980 to 2013. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

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.

Table 4. San Francisco estuary-dependent fish species collected in the CDFW Bay Study 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	

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.

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

Diversity indicators		
Native Fish Species Diversity		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>60% of assemblage present	"Excellent," greater than 1980-1989 average	4
>50% of assemblage present	***"Good," meets CCMP goals***	***3***
>40% of assemblage present	"Fair," below recent historical levels	2
>30% of assemblage present	"Poor," substantially below recent historical levels	1
≤30% of assemblage present	"Very Poor," extreme decline in diversity	0
Estuary-dependent Fish Species Diversity		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>85% of assemblage present	"Excellent," greater than 1980-1989 average	4
>70% of assemblage present	***"Good," meets CCMP goals***	***3***
>55% of assemblage present	"Fair," below recent historical levels	2
>40% of assemblage present	"Poor," substantially below recent historical levels	1
≤40% of assemblage present	"Very Poor," extreme decline in diversity	0

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: $p<0.01$).

Trends in native species diversity differ among the sub-regions.
Native species diversity has increased significantly in Central Bay (regression: $p<0.05$) with an average of two more species in the most recent five-year period compared to the 1980-

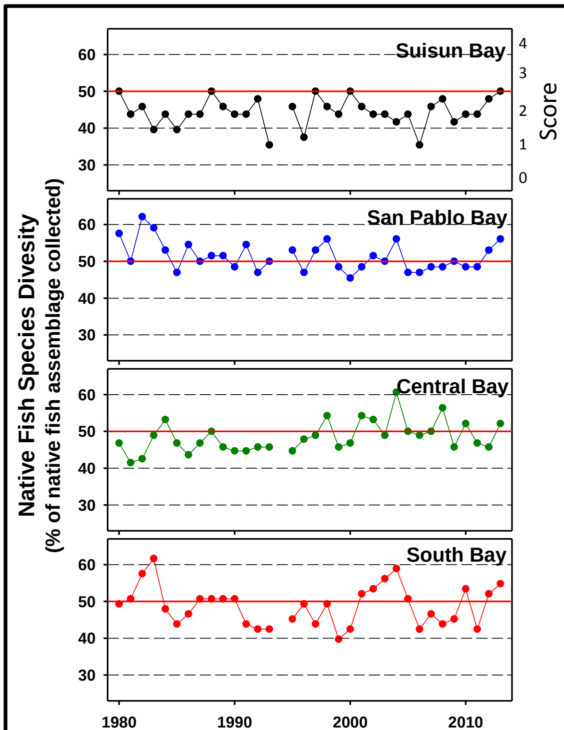

Figure 7. Results for the Native Fish Species Diversity indicator, expressed as percent of assemblage (left Y axis) and score (right Y axis, top panel only for example), for 1980 to 2013. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

1989 reference period. Native fish species diversity decreased significantly in San Pablo Bay (regression: $p<0.05$), with an average of two fewer species in the 2009-2013 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 (2009-2013) to that measured during the 1980-1989 period shows no significant differences in any sub-region. Recent diversity levels, 51%, 50%, 49% and 44% in San Pablo, South, Central and Suisun Bays, respectively, have been close to or exceeded the primary reference condition and/or historical conditions for all sub-regions.

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

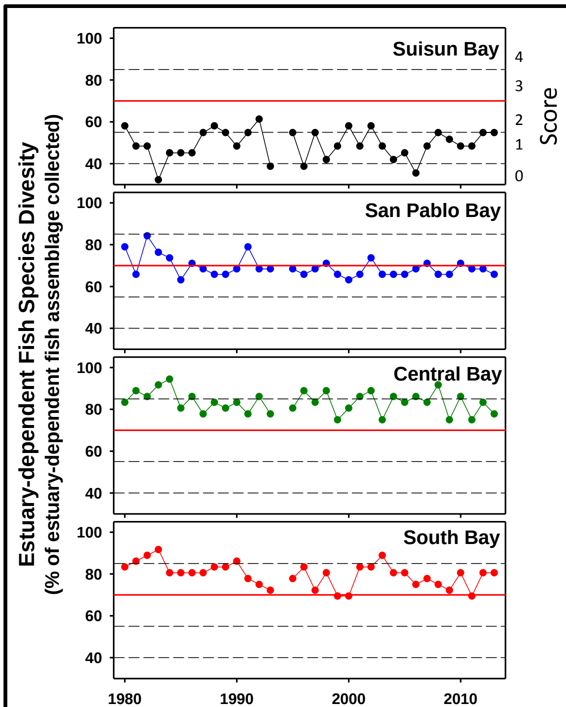

Figure 8. Results for the Estuary-dependent Fish Species Diversity indicator, expressed as percent of assemblage (left Y axis) and score (right Y axis, top panel only for example), for 1980 to 2013. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

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 (83% in Central Bay; 79% 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 1.3 species from the 1980-1989 period to the 2009-2013 period) and South Bay (regression: $p<0.05$, for an average decrease of 2.6 species). In all other regions, estuary-dependent diversity has fluctuated but remained relatively stable over the 34-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.
The percentages of the estuary-dependent fish assemblage that are present, 79%, 77%, 68%, and 52% in Central, South, San Pablo and Suisun Bays, respectively, generally meet or exceed the

primary reference condition in all regions except Suisun Bay, where diversity levels are similar to historical levels.

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.

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

Species Composition indicators (Percent Native Species, Percent Native Fish)		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>95% native	"Excellent," greater than recent historical levels	4
>85% native	***"Good," meets CCMP goals***	***3***
>70% native	"Fair," below recent historical levels	2
>50% native	"Poor," substantially below recent historical levels	1
≤50% native	"Very Poor," extreme decline in abundance	0

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 34 years, non-native species have been most prevalent in Suisun Bay where, on average, 26% of species are non-native (i.e., only 74% of species are native), intermediate in South and San Pablo Bays (12% and 14% non-native, respectively), and the least prevalent in Central Bay (8%) (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, all pairwise comparisons: $p<0.05$).

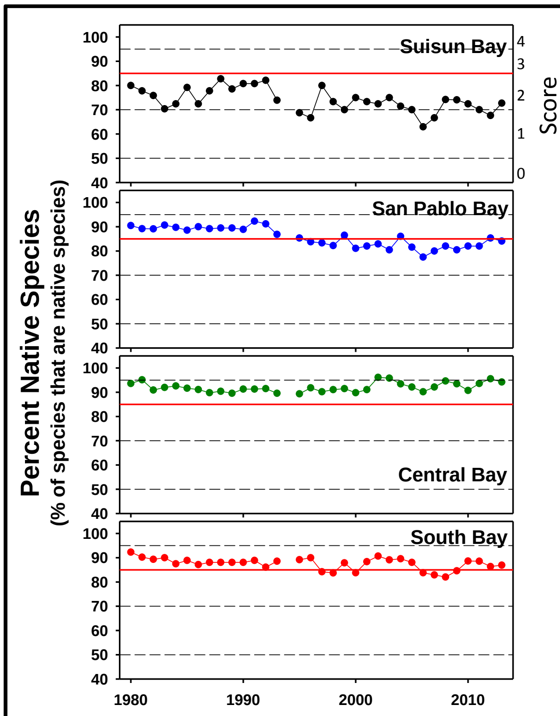

Figure 9. Results for the Percent Native Fish Species indicator, expressed as percent native species (left Y axis) and score (right Y axis, top panel only for example), for 1980 to 2013. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

The percentage of native species is declining in most sub-regions.

The percentage of native species has declining significantly in all sub-regions of the estuary except Central Bay ($p<0.01$, all tests except Central Bay). In South Bay, the percent native species declined from 89% in the 1980-1989 period to 87% in the most recent five-year period (2009-2013). In San Pablo Bay, the percent native species has declined more sharply, from 90% to 83% and in Suisun Bay from 77% to just 71% native species.

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 34 years, the number of native species in San Pablo Bay declined by an average of 1.6 species and the number of non-native species increased by an average of 2.9 species; in the most recent five years, there 7 non-native species in this sub-region, on average. The number of non-native species collected in Suisun Bay increased by 2.3 species, from 6.6 to 8.8 non-native 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 two 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 primary reference condition, recent measurements (2009-2013) of the percentage of native fish species in the fish community indicate that this characteristic has degraded in both San Pablo Bay (83% native species) and Suisun Bay (71% native species) to levels that do not meet the CCMP goals. In South Bay, the prevalence of native species is also declining but recent levels, 87%, are still "good" and meet CCMP goals.

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 34 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: 48%). Non-native fish are rare in the other three sub-regions. Central Bay and South Bay have the lowest prevalence of non-native fishes, 0.1% and 0.4%, respectively, and levels in San Pablo Bay are intermediate at 2.1% (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-regions of the estuary but not in Central or San Pablo Bays (regression, $p<0.5$, both tests). In Suisun Bay, the percent native fish declined from 63% in the 1980-1989 period to just 41% in the most recent five-year period. Percent native fish declined in South Bay from more than 99% to less than 98%. 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.

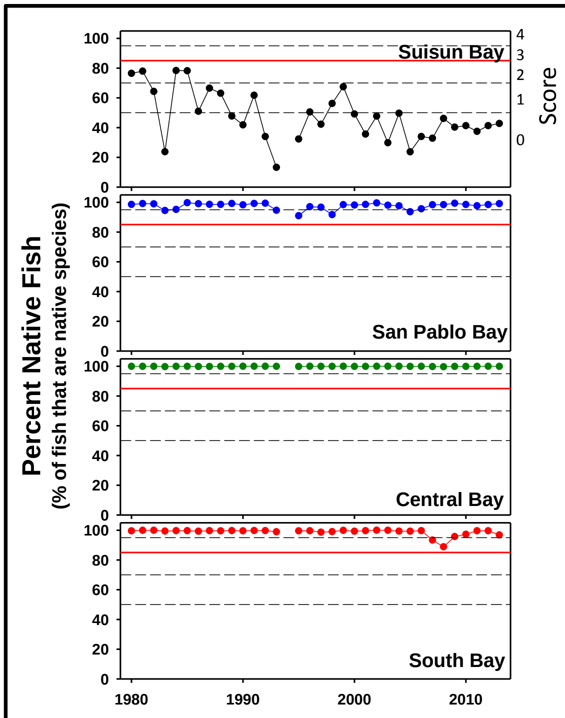

Figure 10. Results for the Percent Native indicator, expressed as percent native fish (left Y axis) and score (right Y axis, top panel only for example), for 1980 to 2013. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

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 sub-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.

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

Distribution indicators (Pelagic Fish, Demersal Fish)		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
100% of stations	"Excellent," greater than recent historical levels	4
>80% of stations	***"Good," meets CCMP goals***	***3***
>60% of stations	"Fair," below recent historical levels	2
>40% of stations	"Poor," substantially below recent historical levels	1
≤40% of stations	"Very Poor," extreme decline in abundance	0

7. Results

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

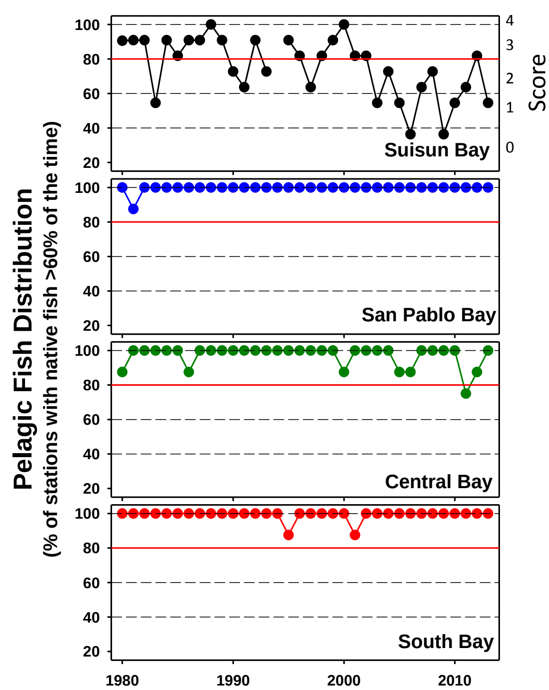

Figure 11. Results for the Pelagic Fish Distribution indicator, expressed as percent of stations (left Y axis) and score (right Y axis, top panel only for example), for 1980 to 2013. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

The percentage of Midwater trawl survey stations that regularly have native fish differs among the four sub-regions of the estuary.

For the past 34 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 1980-2013 period, native fish were present at 97-100% of survey stations in South, Central and San Pablo Bays. In contrast, native fish were present in only an average of 76% 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 distribution of native pelagic 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 58% in the most recent five years (2009-2013) (Mann-Whitney Rank Sum test; $p<0.01$; regression: $p<0.01$). This decline in distribution occurred abruptly in 2003; since 2003, native pelagic fish have been consistently present at only 59% of stations, on average, compared to being present at 84% of stations during the first 23 years of the survey. 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 34 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 74% 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 distribution of native demersal 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 88% of stations (1980-1991) to just 61% of stations (1992-1994), and then recovered to 85% (1995-2000). In 2001, distribution declined again and, even with the relatively high level in one year (2008), it has remained significantly lower since then, 62% on average (t-test, p<0.001 for 1980-2001 v 2002-2013). For the most recent five years (2009-2013), native demersal fish have been present at 65% of stations. Similar to pelagic fish, native demersal fish were most frequently absent from survey stations located in the western region of Suisun Bay.

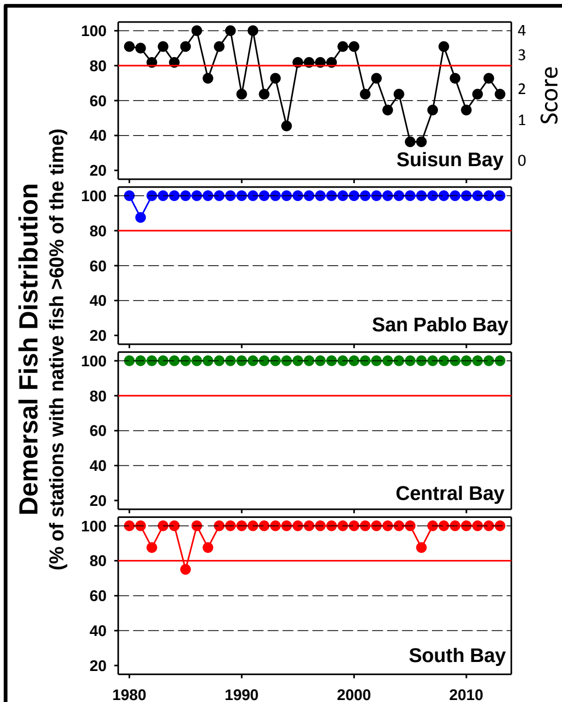

Figure 12. Results for the Demersal Fish Distribution indicator, expressed as percent of stations (left Y axis) and score (right Y axis, top panel only for example), for 1980 to 2013. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

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 or equal to 2.5, which reflects at least two community attributes with average scores greater than 3, was interpreted to represent "good" conditions and an index score less than 0.5 was interpreted to represent "very poor" conditions.

B. Results

Results of the four component metrics (Abundance, Diversity, Species Composition, and Distribution) and the Bay Fish Index for each sub-region are shown in Figures 13-16 (following pages).

The Bay Fish Index differs among the four sub-regions of the estuary.
For the 34 year survey period, the Bay Fish Index was equally high in the Central Bay (1980-2013 average: 3.1) and South Bay (3.0), lowest in Suisun Bay (1.5), and intermediate in San Pablo Bays (2.8) (Kruskal Wallis One-way ANOVA of Ranks: $p<0.05$; Central=South>San Pablo>Suisun). For the most recent five years (2009-2013), the pattern among the sub-regions was similar: the average Index was 3.0, 3.0, 2.7, and 1.2 for Central, South, San Pablo and Suisun Bays, respectively. Lower 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 Bay Fish Index differ among the sub-regions.
During the 34 year survey period, the Bay Fish Index has declined significantly in Suisun, San Pablo and South Bays but not in Central Bay (regression 1980-2013: $p<0.05$ 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: 2.2) to consistent "poor" conditions since the 1990s. This decline was driven by significant declines in abundance, species composition and diversity (regression, all test, $p<0.001$). In San Pablo Bay, the Index has declined steadily, from mostly "good" conditions in the early 1980s to "fair" conditions since the 1990s; this decline is largely attributable to significant declines in abundance and diversity (regression, $p<0.05$, both

tests). The decline in the Index in South Bay, while significant, is not as severe, with conditions fluctuating between “good” and “fair.” In Central Bay, the 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 Bay 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 Bay 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, over the 34-year period of record for these indicators, the condition of the fish community in San Pablo and South Bays is declining.
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.

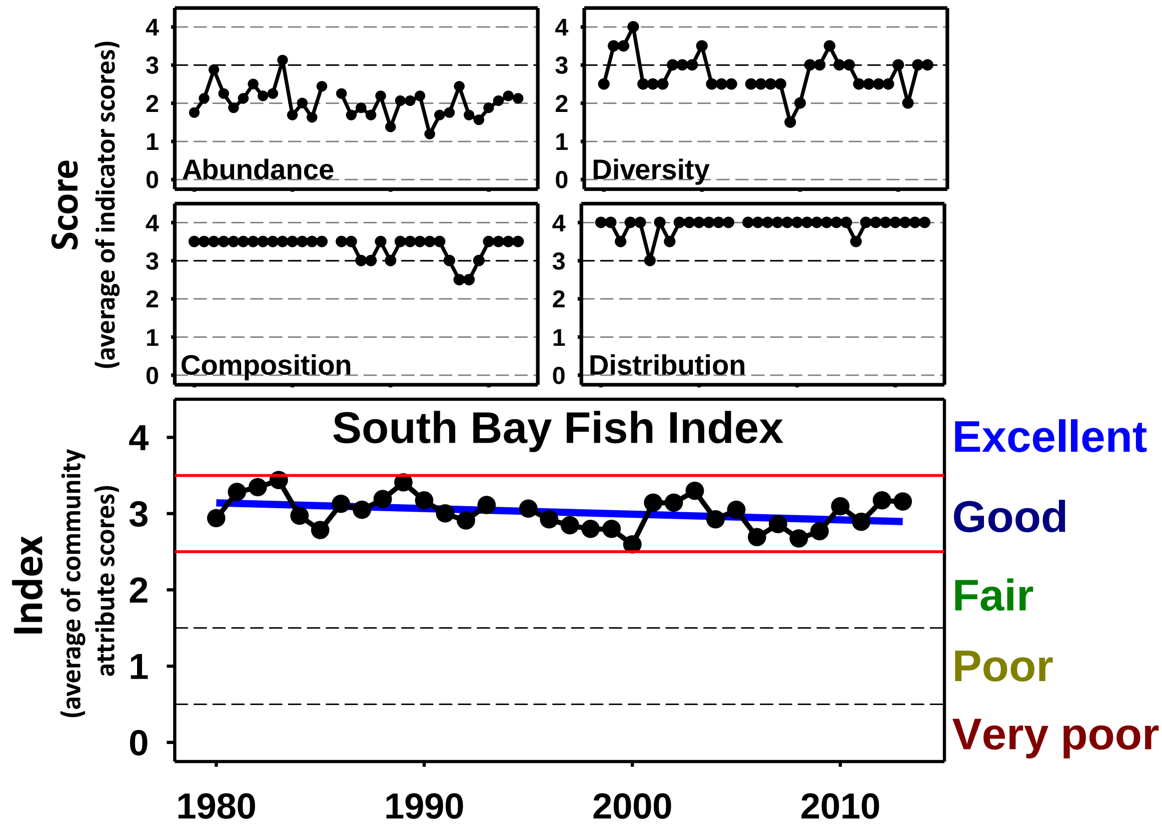

Figure 13. Results for the Bay Fish Index for South Bay for 1980 to 2013. The top four panels show results for the four fish community attributes, expressed as average scores. The large bottom panel shows the Index, calculated as the average of the scores of the four component community attributes. For those results with a significant trend over time, the regression line is shown in blue. For the Index graph, the horizontal red lines and dashed lines show the reference conditions and Index evaluation.

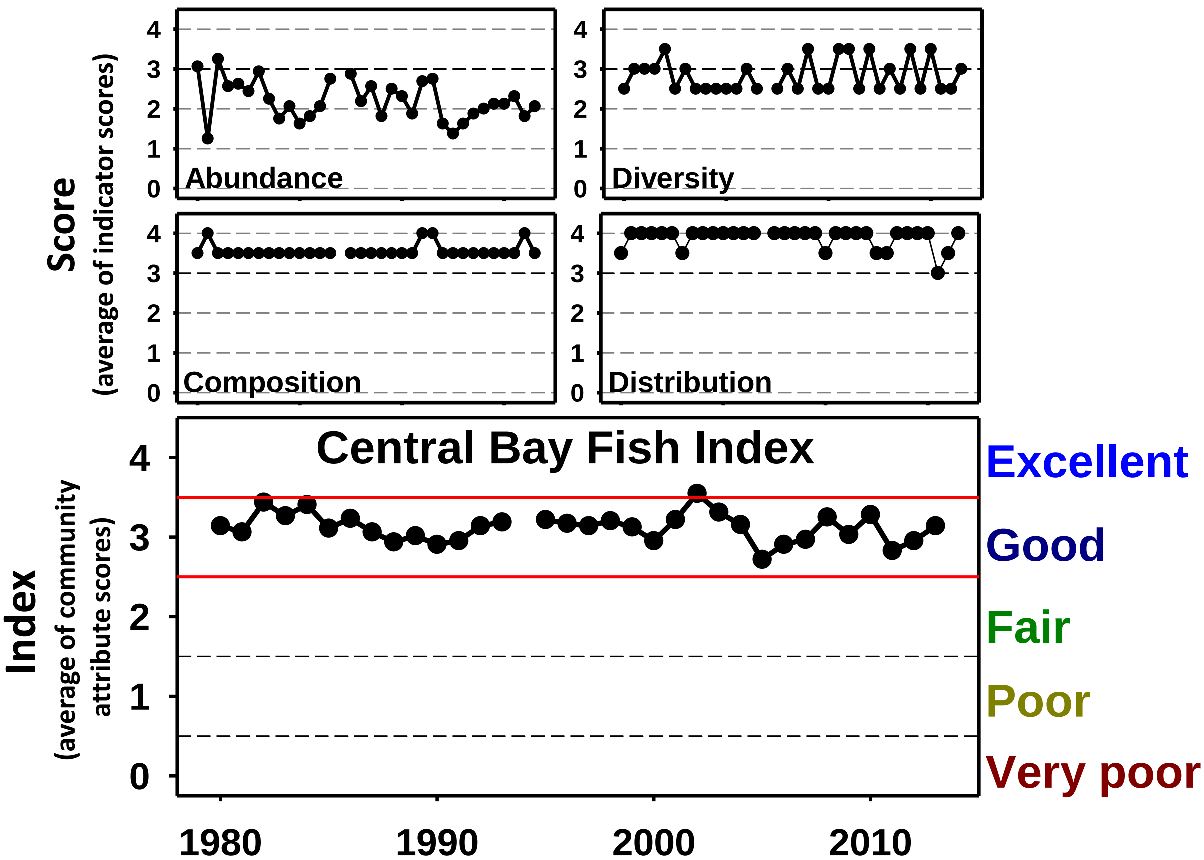

Figure 14. Results for the Bay Fish Index for Central Bay for 1980 to 2013. The top four panels show results for the four fish community attributes, expressed as average scores. The large bottom panel shows the Index, calculated as the average of the scores of the four component community attributes. For those results with a significant trend over time, the regression line is shown in blue. For the Index graph, the horizontal red lines and dashed lines show the reference conditions and Index evaluation..

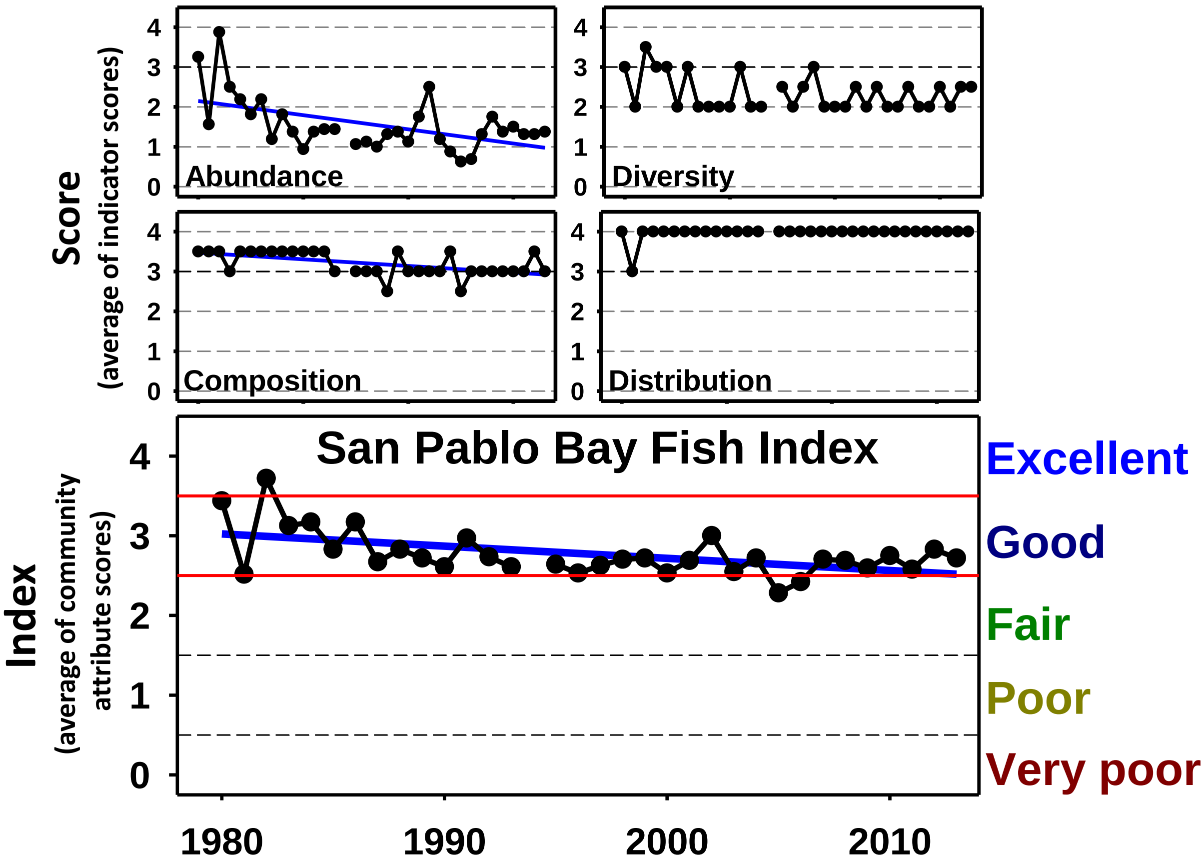

Figure 15. Results for the Bay Fish Index for San Pablo Bay for 1980 to 2013. The top four panels show results for the four fish community attributes, expressed as average scores. The large bottom panel shows the Index, calculated as the average of the scores of the four component community attributes. For those results with a significant trend over time, the regression line is shown in blue. For the Index graph, the horizontal red lines and dashed lines show the reference conditions and Index evaluation.

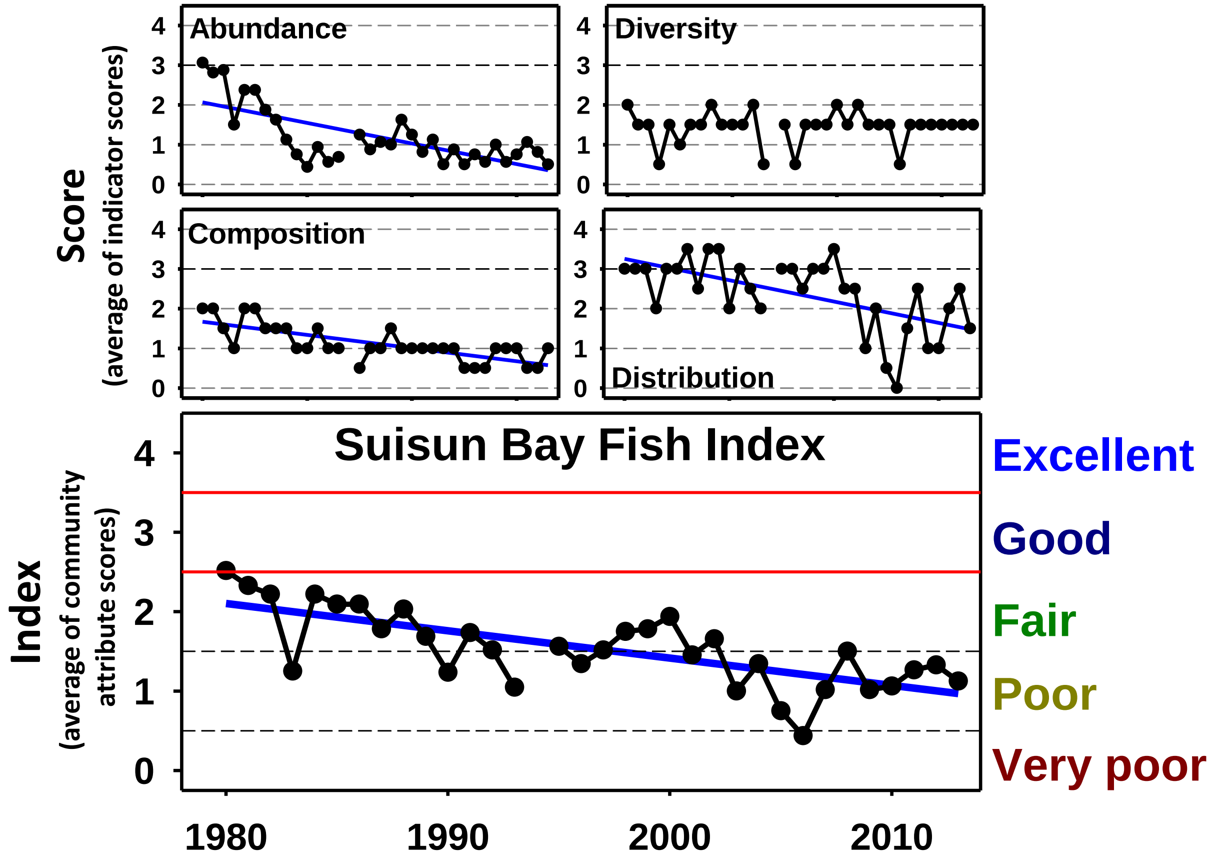

Figure 16. Results for the Bay Fish Index for Suisun Bay for 1980 to 2013. The top four panels show results for the four fish community attributes, expressed as average scores. The large bottom panel shows the Index, calculated as the average of the scores of the four component community attributes. For those results with a significant trend over time, the regression line is shown in blue. For the Index graph, the horizontal red lines and dashed lines show the reference conditions and Index evaluation.

Table 8. Summary of results for the ten Bay Fish indicators.

Indicator	CCMP Goals Fully met if goal achieved in >67% of years since 1990 Partially met if goal achieved in 33-67% of years Not met if goal achieved in <33% of years	Trend since 1990	Current condition (average for last 10 years)
Pelagic Fish Abundance	Not met in any sub-region	Stable at low levels	Fair to Very Poor
Northern Anchovy Abundance	Not met in any sub-region	Stable at low levels (Suisun, San Pablo) Declining (South, Central)	Fair to Very poor
Demersal Fish Abundance	Fully met (South and Central) Not met (San Pablo and Suisun)	Stable (Suisun) Increasing (South, Central, San Pablo)	Poor (Suisun) Fair to good (South, Central, San Pablo)
Sensitive Species Abundance	Not met on any sub-region	Stable at low levels	Poor (all sub-regions) Inflow reduced by 50%
Native Fish Diversity	Partially met (South) Not met (Central, San Pablo, Suisun)	Stable	Poor (Suisun) Fair to good (South, Central, San Pablo)
Estuary-dependent Fish Diversity	Fully met (South, Central) Not met (San Pablo, Suisun)	Stable	Poor (Suisun) Fair to good (South, Central, San Pablo)
Percent Native Species	Fully met (South, Central) Not met (San Pablo, Suisun)	Stable (South, Central) Declining (San Pablo Suisun)	Good (South, Central) Fair to Poor (San Pablo, Suisun)
Percent Native Fish	Fully met (South, Central, San Pablo) Not met (Suisun)	Stable	Good (South, Central, San Pablo) Very Poor (Suisun)
Pelagic Fish Distribution	Fully met (South, Central, San Pablo) Partially met (Suisun)	Stable (South, Central, San Pablo) Declining (Suisun)	Good (South, Central, San Pablo) Fair to Poor (Suisun)
Demersal Fish Distribution	Fully met (South, Central, San Pablo) Partially met (Suisun)	Stable (South, Central, San Pablo) Declining (Suisun)	Good (South, Central, San Pablo) Fair to Poor (Suisun)
Bay Fish Index	Fully met (South, Central and San Pablo) Not met (San Pablo, Suisun)	Stable (South, Central, San Pablo) Declining (Suisun)	Good (South, Central) Fair to Good (San Pablo) Poor (Suisun)

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State of the Estuary Report 2015

Technical Appendix Combined for WILDLIFE: Upper Estuary Fish and PROCESSES: Fish as Food

Fish Assemblage Health Indicators for the Upper San Francisco Bay Estuary, including Suisun Bay, Suisun Marsh, and Delta Technical Appendix

Alison Weber-Stover and Jonathan Rosenfield, Ph.D.
The Bay Institute

July 2015

State of the Estuary Report 2015

Fish Assemblage Health Indicators for the Upper San Francisco Bay Estuary, including Suisun Bay, Suisun Marsh, and Delta
Technical Appendix

Developed for the San Francisco Estuary Partnership

By

Alison Weber-Stover and Jonathan Rosenfield, Ph.D.
The Bay Institute

July 2015

I. BACKGROUND

Evaluations of "health" at the species or population level of biological organization require assessment of different attributes of viability, including abundance, diversity, spatial distribution, and productivity (McElhany et al. 2000). Although these attributes influence each other, they each reveal different and somewhat independent information about a populations' health. Developing conceptual analogs for these species-level attributes of viability can provide insight into the "health" of ecological communities and species assemblages. Tracking changes in and interactions among a suite of these indicators of assemblage health through time can increase understanding of fish assemblage dynamics and the drivers of those dynamics. Several fish-based indices have been developed to assess ecological quality of estuarine systems; indices commonly include species richness (diversity), abundance, fish condition, and nursery function (productivity) as metrics (Perez-Dominguez et al. 2011).

The San Francisco Estuary Partnership's State of the Bay report (2011) developed 10 indicators that reflected the health of the pelagic fish assemblage in the larger San Francisco Bay complex (including San Francisco Bay-proper, South San Francisco Bay, San Pablo Bay and Suisun Bay). Although the State of the Bay report (hereafter, SOTB 2011) developed indicators for Suisun Bay, it did not develop indicators of fish assemblage dynamics for many parts of the upper Estuary. The upper Estuary includes Suisun Marsh, the largest brackish marsh on the west coast of North America (CDWR 2014 – http://www.water.ca.gov/suisun/) and the Sacramento-San Joaquin Delta (hereafter, the "Delta"), a tidal freshwater region east of the confluence of California's two longest rivers. Together Suisun Marsh and the Delta comprise unique habitats in the largest estuary on the west coast of North America and serve as home to more than 55 species of fish. In the past 150 years major changes to the upper Estuary's habitats and patterns of freshwater flow have affected the region's fish assemblages (The Bay Institute 1998), as has introduction and invasion of this area by numerous non-native species (Matern et al. 2002; Light and Marchetti 2007).

SOTB (2011) synthesized pelagic fish sampling data from one long-term survey of the Bay's fish assemblage (the California Department of Fish and Wildlife's Bay Study) to develop indicators that portrayed long-term patterns in fish abundance, diversity, species composition, and spatial distribution from the Golden Gate to Suisun Bay. In addition, SOTB focused on indices of sub-strata of the fish assemblage (e.g., habitat guilds or trophic guilds) to gain further insight into ecological dynamics of the Bay and the forces driving those dynamics.

The Delta, Suisun Bay, and Suisun Marsh (collectively, the upper Estuary) are important habitats for native fish, including those that may inhabit the nearshore ocean, Bay, and/or Central Valley rivers during other parts of their life cycles. Here, indicators of native abundance and species composition (native vs. introduced) for the upper Estuary were developed for three major habitat types in this region – marsh, deep open water, and shallow, unvegetated waters – to compliment the Bay Fish Index from SOTB

(2011). These indicators enable evaluation of broad changes in fish abundance and species composition, two important attributes of the condition of the fish assemblage.

Fish also represent food to many species of birds, mammals, and other fish. Thus, the abundance of fish can be used as an indicator of foodweb productivity and food availability for piscivorous organisms. Here, abundance indices representing all fish (native and introduced) are developed as an indicator of food web productivity and overall ecosystem health.

The State of the Estuary report develops synthetic metrics of population dynamics and diversity (indicators) of the fish assemblage of the entire Estuary, including the embayments of the San Francisco Bay complex. Like its predecessor (SOTB 2011), the State of the Estuary Report presents fish indicators with the expectation that such indicators, correctly designed, can represent multi-species responses to major changes that have occurred in the Estuary and its watershed during the period for which sampling data are available. That said, it is important to recognize that no single indicator is capable of providing a full picture of "health" for ecosystems or even fish assemblages in any region of the Estuary; indeed, factors operating beyond the geographic area of the upper Estuary (e.g. the Central Valley or the nearshore ocean) certainly influence the abundance and diversity patterns described here. Additional indicators, focusing on other attributes of assemblage health, may be needed to relate ecological mechanisms local to the upper Estuary to patterns in the local fish assemblage.

Development of fish assemblage indicators for the upper Estuary was guided by the approach taken in SOTB (2011). Fidelity to that approach (as revised and updated) maximizes the potential to gain a comprehensive understanding of the fish assemblage dynamics across the Estuary as a whole. However, the dominant environments of the upper Estuary are very different physically from the brackish or near marine pelagic environments that dominate much of the San Francisco Bay complex that were the subject of SOTB (2011). The ratio of pelagic habitats to edge (littoral) plus bottom (benthic) habitats is much lower in the upper Estuary than in the San Francisco Bay complex as a whole; for example, the Delta-proper was historically dominated by myriad sloughs (which have now been simplified into a network of channels) that featured extensive shallow water habitat at their edges and productive benthic habitats as well. Because there is interest in restoring shallow, sub-tidal habitats and complex sloughs in the Delta (e.g., the Bay Delta Conservation Plan), measuring the health of the fish assemblage in the Delta should, to the extent possible, be sensitive to fish that specialize in these shallow, edge and bottom habitats. Also, Suisun Marsh, which neighbors the Delta-proper, is: (a) an ecosystem of great significance; (b) not covered by previous Bay indicators; and (c) somewhat representative of the types of habitats that once existed and may be restored in the Delta. Thus, it makes sense to add indicators of fish assemblage dynamics in Suisun Marsh to this section of the State of the Estuary report.

Why were these indicators chosen?

A suite of indicators of the Delta’s fish assemblage was considered with the goal of capturing assemblage-level analogs to the species-level attributes of viability defined by McElhany et al. (2000). In order to be regarded as “healthy”, fish assemblages in the upper Estuary should reveal good or excellent levels of:

- Abundance (numbers of native fish)
- Inter-specific diversity, including
    - number of species (richness)
    - distribution of abundance across species (diversity)
    - native species richness vs. non-native species richness
- Intra-specific diversity, including
    - life history diversity (e.g. time and size of migration, alternate life history strategies)
    - phenotypic and behavioral diversity
- Spatial distribution
- Productivity, including
    - life-stage specific survival rates
    - condition (weight/length, etc., e.g. Gartz 2005)

Indicators for most of these attributes have not been developed here, but there development in future iterations of this report is recommended.

In addition, we developed a metric of total fish abundance (native plus introduced species) as an indicator of food web productivity.

There are several challenges with interpreting available data for indicators of assemblage health. Several long-term data sets are available for the Delta (Table 1). For the purposes of indicator development, an ideal monitoring program would catch different age classes of all fish species with equal efficiency, over a wide spatial area, year-round, over a long time period, with consistent monitoring methods. No such sampling program exists – each of the existing programs was designed for particular purposes and not to measure or evaluate the health of the entire Delta fish assemblage. All the programs have different sampling biases specific to their respective programs (e.g. associated with sampling gear, detection probabilities, highly mobile species, as well as short- and long- term habitat variation). Even the San Francisco Bay Study (used in the SOTB 2011), which was designed to monitor the health of the entire fish assemblage, did not sample the entire spatial extent of the upper Estuary until recently. Also, this program only samples benthic and pelagic environments. With the exception of preliminary analyses done by the United States Fish and Wildlife Service (USFWS) Delta Juvenile Fishes Program, no monitoring programs have evaluated changes in detection probabilities over time (J. Kirsch, USFWS, personal communication).

To capture the range of different habitats sampled in the upper Estuary across the longest time-series possible, long-term data from three community sampling surveys were analyzed: California Department of Fish and Wildlife’s Fall Midwater Trawl (FMWT), the US Fish and Wildlife Service’s Juvenile Fishes Program (Beach Seine), and University of California at Davis’s Suisun Marsh Fish Survey (Otter trawl). These are not the only sampling programs in the Delta but, taken together, these three sampling programs provide a geographically diverse view of fish assemblage abundance and diversity in a range of habitats over multiple decades (Tables 1 and 2, Figure 1).

Table 1. Comparison of several sampling programs for Upper Estuary Fish Indicators (information adapted from Honey et al. 2004)

Survey	**Period of Record** (colors = new stations added)	**Sampling time during the year**	**Geographic coverage** (colors correspond to "period of record" when new stations added)	**Habitat type sampled**	**Effectively samples body sizes**	**Consistent methods, gear, and locations**	**Sampling effective for:**	**Existing detection probability assessment**	**Other notes**
Fall Mid-water Trawl	1967 1990 1991 2009 2010	Sep-Dec	Western Delta Channels Edge of N. Sac Northern/eastern N. Sac Channel Cache slough	Nearshore channel, open water	>40mm	Generally	**Designed for**: Age-0 Striped Bass **Captures**: Juvenile pelagic	No	Limited to one season, changes in distribution could appear to be abundance changes.
SF Bay Study	1980 1998 1988, 1991, 1994	Year round	Entire estuary, limited sampling in the north, east and south Delta South Suisun Bay San Joaquin River Channel and Delta	Channel, open water & benthic	>40mm	Some sampling missing from late '80s to early 90's	Two gears deployed **Designed for**: Fish and invertebrate assemblage **Captures**: Variety, otter trawl samples demersal fish, in open water	No	Does not sample the northern, eastern and southern Delta well.
Summer Townet	1959 2011 2009	June and then flexible ~August	Southern Delta well, Added channel in north Same as 2011 (2010 skipped)	Benthic	<390 mm Larval fish, juvenile delta smelt	Timing different, gear the same	**Designed for:** age 0 Striped Bass **Captures**: Pelagic, young striped bass	No	Irregular start and end dates, short sampling period in summer.
Salvage	1957 - Tracy 1968 - Skinner	Year round	Two locations South Delta	NA	Juvenile to adult of some species	Yes	**Designed for:** Enumerating entrainment, medium to large fish	No	Single location sampling, dependent on water export, not all fish identified.
Suisun Marsh Fish Survey	1980 1994	Year round	Suisun Marsh eastern Suisun Marsh	Benthic, marsh	Juvenile to adult of some species	Some change in sites, methods and gear relatively consistent	**Designed for:** Marsh habitat, demersal fish **Captures:** May capture pelagic fish in some sloughs	No	Problems with large and small sloughs for pelagic fish.
Delta Juvenile Fish Sampling	1976. 1990's 2002	Year round (more consistent after 1995)	Entire Delta Larger extent Site on the San Joaquin	Littoral zone, floodplain, open water in three locations	<25 mm Juvenile to Adult of some species (smaller fish than 25mm caught, but ID suspect)	Number of locations changed, methods generally consistent	**Designed for:** Salmon fry and cyprinids **Captures:** Most small to medium sized fish (<~150mm) in the littoral zone	Yes (not published)	Year round only since 1992 Boat ramp sites may bias results, problems with inter-annual comparisons of catch trends ID of fish less than 25mm suspect

Table 2. Sampling programs used as data sources for calculation of for Upper Estuary Fish Indicators in different regions and habitats of the Delta and Suisun Marsh.

	Habitats		
Region	Marsh/Demersal	Pelagic	Littoral
Suisun Marsh	UC Davis Suisun Marsh Fish Survey (Otter Trawl)		
Suisun Bay		CDFW Fall Midwater Trawl	
Central-Western Delta			U.S. Fish and Wildlife Service Delta Beach Seine
Northern Delta			
Southern Delta			

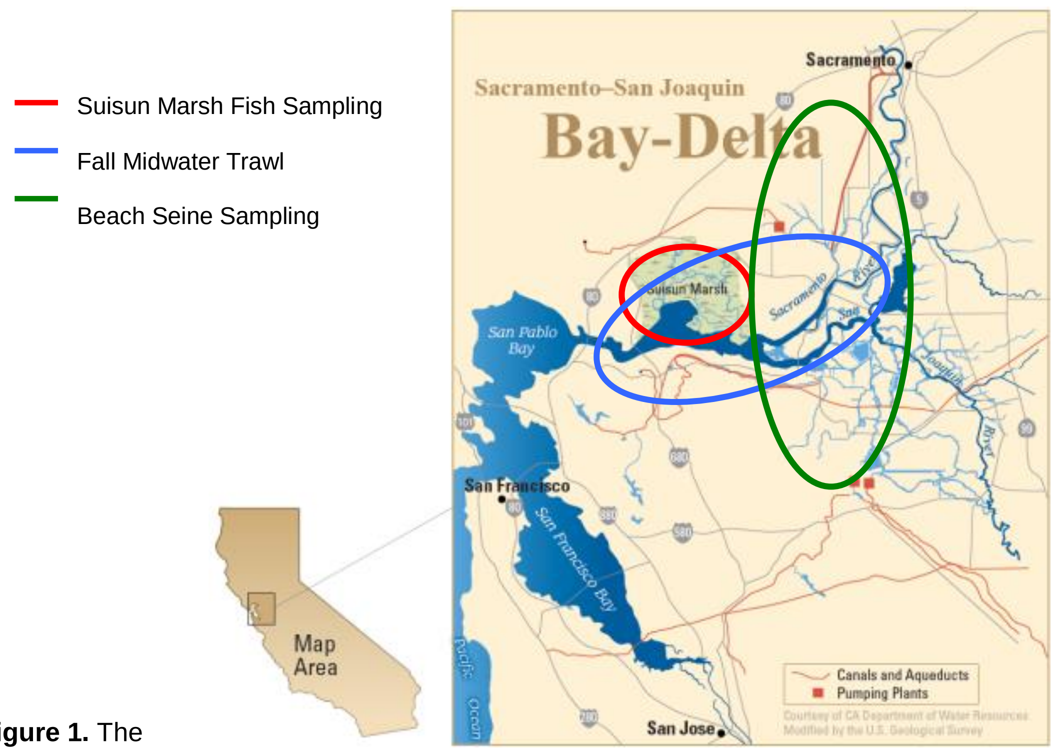


Figure 1. The Sacramento-San Joaquin Bay-Delta is where Central Valley Rivers meet the larger San Francisco Bay Estuary complex. Because the upper estuary is so large and contains a variety of habitats, the indicators of fish assemblage health in this area were calculated from three sampling programs that survey different habitats and regions of the upper estuary (Image accessed 1/12/14 at http://ca.water.usgs.gov/news/2012/SanFranciscoBayDeltaScienceConference.html).

We prioritized development of indicators of fish abundance and community composition for the upper Estuary (Table 6). Future iterations of the SOTER report should incorporate data from other long-term sampling programs. Data from additional sampling programs may help complete and unify the abundance and species composition indices presented here and they are necessary for developing additional indices that can link fish assemblage health in the upper Estuary to local ecosystem processes (e.g., productivity, spatial distribution, guild-specific evaluations, etc.).

The SOTB (2011) provided fish abundance indicators for pelagic, demersal, and sensitive fish species. Additionally, these indicators were measured separately within each of four regions. Here, separate indicators of abundance and assemblage diversity were produced for marsh species, pelagic species of the Delta's open channels, and littoral species in Suisun Marsh and the Delta-proper. Where appropriate, within each sampling program/habitat type, separate indices were produced to characterize sub-regions designated by the Interagency Ecological Program (IEP; Figure 2). Results for the different sub-regions were compared to determine whether data could be combined among regions within a sampling program (i.e. to determine whether regional trends were consistent). Due to the non-overlapping strengths and weaknesses of the different sampling programs available for this analysis (Table 1, Table 2), no effort was made to aggregate all indicators into a single index of fish assemblage health in the upper Estuary.

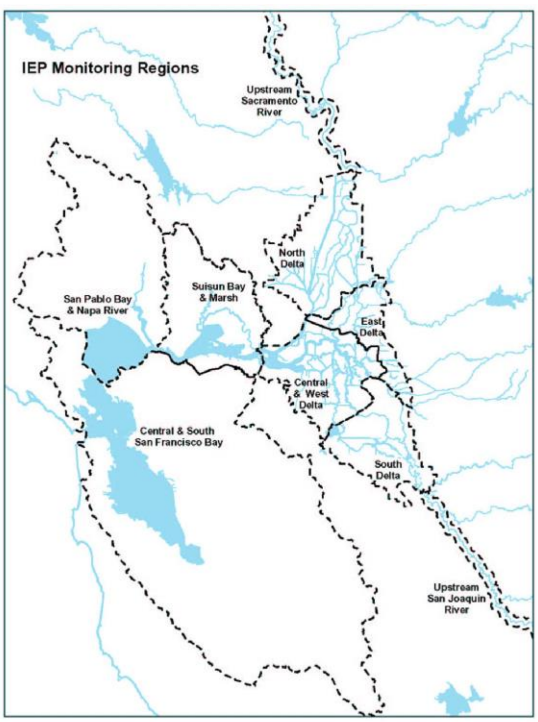


Figure 2. The Interagency Ecological Program's San Francisco Estuary Monitoring Regions (Figure from Honey et al. 2004, p. 6).

How were proposed indicators vetted with experts?
The methods used to calculate indicators of health for the fish assemblage of the upper Estuary were presented to, and sequentially peer-reviewed by, a group of experts in this region's fishes and fish sampling programs. Additional input was received from data administrators for the various sampling programs. A list of reviewers who provided input and direction through small group discussion, one-on-one discussions and written comment is provided below.

Name	**Agency/Organization**
Randall Baxter	California Department of Fish and Wildlife
Matt Dekar	United States Fish and Wildlife Service
Sam Harader	Delta Science Council
Daniel Huang	Delta Science Council
Kristopher Jones	California Department of Water Resources
Joseph Kirsch	United States Fish and Wildlife Service
Teejay O'Rear	University of California, Davis
Ted Sommer	California Department of Water Resources
Jonathon Speegle	United States Fish and Wildlife Service
Hildie Spautz	California Department of Fish and Wildlife
Christina Swanson	Natural Resources Defense Council
Susie Tharatt	United States Fish and Wildlife Service
Darcy Austin	Delta Stewardship Council

II. DATA SOURCES

Suisun Marsh abundance and species composition indicators.
Suisun Marsh Fish Survey (Otter Trawl, UCD).
Suisun Marsh indicators were calculated with data collected by the Suisun Marsh Fish Survey. The survey has been conducted monthly since 1979 in Suisun Marsh, sampling 17 sites consistently since 1980 (Figure 3, Tables 1 and 3); four additional sampling locations (which were not sampled as consistently in early years) were included in the data set as they provided greater spatial coverage, but did not materially affect long-term trends in catch-per-unit-effort data (T. O'Rear, personal communication). An otter trawl was used to sample benthic fish across the spatial extent of the Marsh in large and small sloughs; net tows in large sloughs lasted for 10 minutes and in small sloughs, for 5 minutes (https://watershed.ucdavis.edu/project/suisun-marsh-fish-and-invertebrate-study). Because the size of the net (1m x 2.5m opening) was large relative to the width and depth of some sloughs it samples, the Suisun Marsh Fish Survey may sample most of the water column in some areas – thus, these data provided a relatively good indication of fish occupying open water habitats in smaller Marsh sloughs.

This sampling program provided data from a critically important ecosystem, adjacent to the Delta-proper that is included in many discussions of "Delta" habitat restoration (e.g. the Bay Delta Conservation Plan). The habitats present in the Marsh, though modified, are similar to those that would have existed in the historical Delta and those that may be restored in a future Delta. The Suisun Marsh Fish Survey has been particularly effective at sampling native species that rely on shallow, marsh habitats (e.g., splittail (*Pogonichthys macrolepidotus*), tule perch (*Hysterocarpus traski*) and at detecting new invaders to the estuary ecosystem (Matern et al. 2002). Thus, data from this system are critical to any long-term assessment of the upper Estuary's fish assemblage. On the other hand, the Suisun Marsh Survey did not provide a comprehensive image of the Delta fish assemblage's health because it only sampled in the Marsh and therefore focused on species that are common in marsh slough habitats. Also, like any fish community sampling program, the Suisun Marsh Survey gear and methodology only reliably captured fish within a particular size range (generally ~35mm-250mm).

Figure 3. Locations of stations that have been sampled consistently by UC-Davis' Suisun Marsh Fish Survey. Map created by Amber Manfree. Fish assemblage indicators for Suisun Marsh were calculated from the Suisun Marsh Fish Survey data.

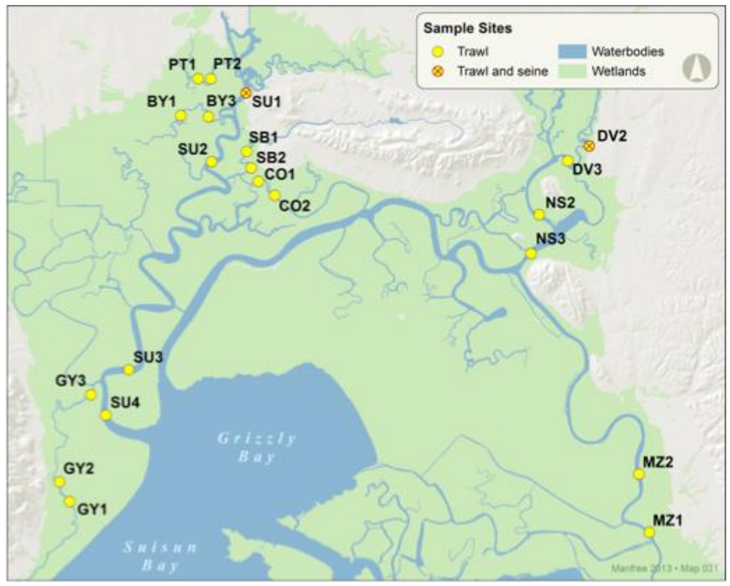


Table 3. Suisun Marsh Fish Survey sampling stations and total numbers of surveys for the 1980-2013 period of record used to calculate indicators (data from UCD Suisun Marsh Fish Survey Otter Trawl; provided by T. O'Rear). Catch per trawl indicators were based on data from 21 sites (despite the fact that only 17 were sampled consistently) following the reporting protocol of the Suisun Marsh Survey. Annual trends in CPUE are not affected by the inclusion of the four sites that were sampled less consistently (T. O'Rear, personal communication).

Region	Sampling Stations	Number of Surveys
Suisun Marsh	BY1, BY3, CO1, CO2, DV2, DV3, GY1, GY2, GY3, NS2, NS3, MZ1, MZ2, PT1, PT2, SB1, SB2, SU1, SU2, SU3, and SU4	8,403

Beach Zone abundance and species composition indicators.

Delta Juvenile Fishes Program (Beach Seine, USFWS).

This survey program sampled littoral habitat throughout the spatial extent of the Delta-proper, throughout the year (Figure 4, Table 1 and 4). Fish were caught in a seine that was 15.2m wide, pulled manually through shallow water (<1.3m) areas that had little bottom vegetation or obstructions (http://www.fws.gov/stockton/jfmp/Docs/Data%20Management/1214/Metadata%20(Upd ated%20September%2009,2014).doc. These habitats, and fish that specialize in them, are usually sampled ineffectively by gear towed behind a boat. Data were collected weekly or bi-weekly since 1976. Because year-round, monthly sampling became consistent in 1995, only data from 1995 onward were used in constructing indicator time trends from this data set. In order to develop a comprehensive image of dynamics in the Delta's fish assemblage, findings from this survey must be considered in the context of other surveys because sampling only occurred in the littoral zone and the gear (like all gear) captured fish efficiently only within a certain (species-specific) body size range (generally ~30mm-200mm).

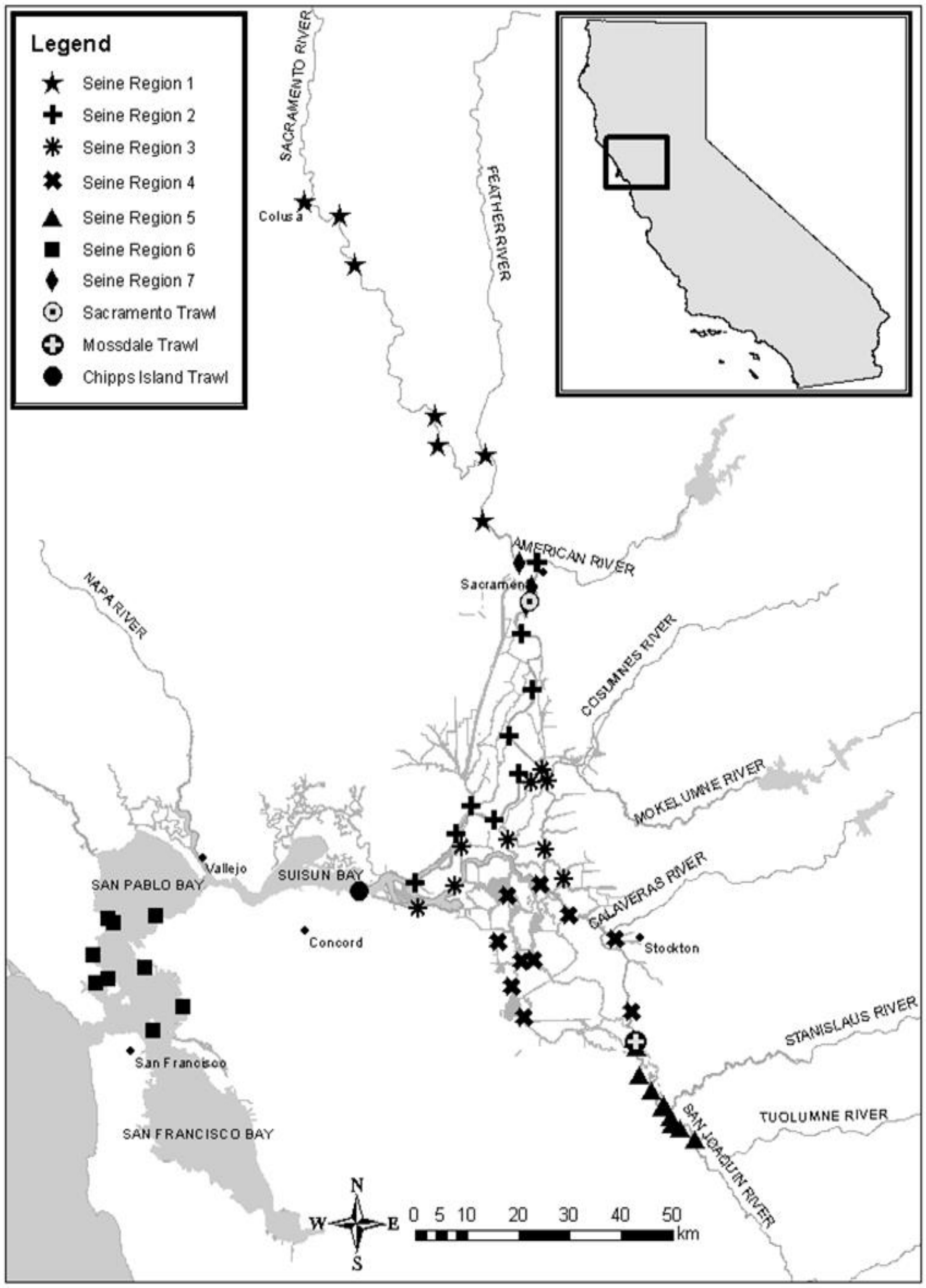


Figure 4. Sampling station locations of the USFWS Beach Seine Survey used to calculate Delta Beach Zone fish indicators. Only 1995-2013 data from four IEP regions, *North, East, South and Central-West) were used. Map from USFWS Delta Juvenile Fishes Program (http://www.fws.gov/stockton/jfmp/Docs/Data%20Management/12-14/Metadata%20(Updated%20September%2009,2014).doc).

Table 4. Delta Beach Zone sampling stations and total numbers of surveys for the 1995-2013 period of record used to calculate the indicators (USFWS Delta Juvenile Fishes Program, Beach Seine Survey, data provided by J. Speegle). *Indicates that the station is a substitute location for a station that was not accessible at the survey time.

Regions from the Delta Beach Seine Survey	Sampling Stations	Number of Surveys (1995-2013)
North Delta	**SR043W** **SR049E** **SR057E** **SR014W** **SR062E** **SR055E** **SR055A*** **SS011N**	6832
East Delta	**XC001N** **GS010E** **SR017E** **DS002S** **SR024E** **LP003E** **SF014E**	5900
South Delta	**SJ063W** **SJ063E*** **OR014W** **SJ041N** **SJ051E** **SJ068W** **SJ072E*** **SJ070N*** **OR003W** **SJ032S** **SJ026S** **SJ056E** **OR019E** **OR001X*** **SJ074W** **SJ074A*** **OR023E** **WD002W** **WD002E*** **SJ058W** **SJ058A*** **SJ058E***	7951

	MR010W **MR010A*** **SJO56E**	
Central-West Delta	**SJ001S** **MK004W** **TM001N** **SJ005N** **SR012W*** **MS001N** **MS001A*** **SR012E**	5023

Upper Estuary Pelagic Zone abundance and species composition indicators.
Fall Midwater Trawl (midwater trawl, CDFW).
This survey sampled open-water, pelagic species in the upper Estuary (San Pablo Bay to the western Delta) every month from September through December at fixed sampling locations (Figure 5; Table 1 and Table 5). Methods were relatively consistent over a long time period (since 1967); however, within the upper Estuary, many new sites were added since 1967. In addition, because the Fall Midwater Trawl (FMWT) only sampled during one season and did not sample littoral or benthic habitats that form a relatively large proportion of available space for fish in the upper Estuary, these data did not present a comprehensive picture of the entire fish assemblage in this region. On the other hand, the fact that the FMWT sampled pelagic waters of Suisun Bay and the Central-West Delta for such an extended period means that these data provided an excellent complement to results for Suisun Bay recorded by the Bay Study (e.g., this State of the Estuary Report; SOTB 2011).

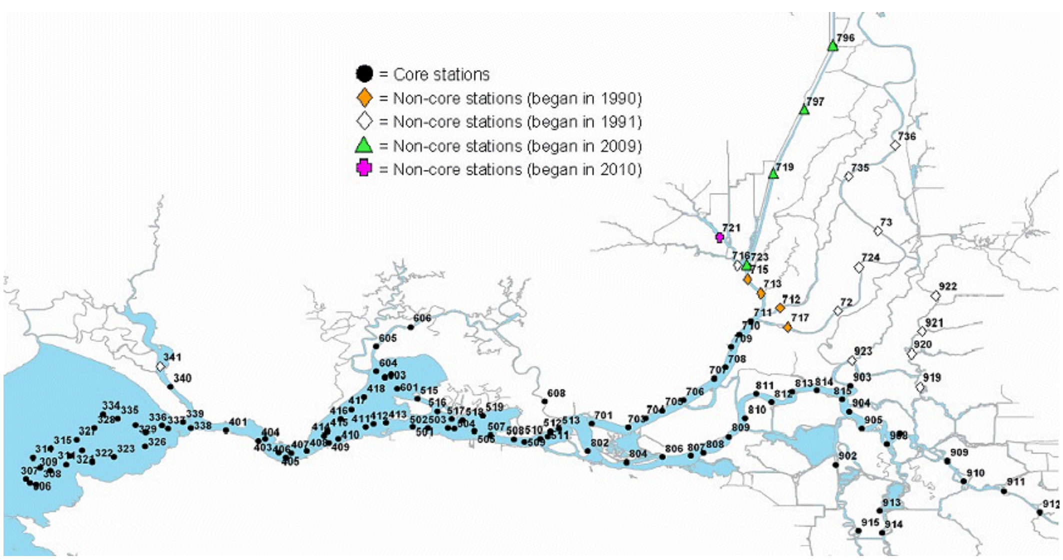


Figure 5. Locations of the sampling stations for the CDFW Fall Midwater Trawl survey used to calculate the Upper Estuary Pelagic Zone Fish Indicators. Only data from core stations, collected 1967-2013, in Suisun Bay and the Central-West Delta were used for calculations (Map from http://www.dfg.ca.gov/delta/data/fmwt/stations.asp).

Table 5. Sampling Stations and total numbers of surveys for the 1967-2013 period of record used to calculate Pelagic Zone Indicators (data from CDFW Fall Midwater Trawl, accessed at ftp://ftp.dfg.ca.gov/).

Regions from Upper Estuary Open Water	Sampling Stations	Number of Surveys (1967-2013)	Years Excluded from Analysis for Partial Sampling
Suisun Bay	401, 403-418, 501-505, 507-513,515-519, 601-606, 608	6376 (1967-2013)	1969-1972 and 1976 (Limited sampling) 1974 and 1979 (no sampling)
Central and West Delta	701, 703-711, 802, 804, 806-815, 902-906, 908-915	5280 (1967-2013)	1969 – 1973, 1975 and 1984 (Limited sampling) 1974 and 1979 (no sampling)

III. INDICATOR EVALUATION

Evaluating indicator trends in ecosystem health requires establishing reference conditions (*what value was the indicator in the past?),* designating thresholds (*what would be considered "good" or "poor"?),* and assessing the significance of any trends (*how does the current condition compare to the established thresholds*; Perez-Dominguez et al. 2011). References conditions may include "primary" reference conditions that reflect indicator status in a known historical period (SOTB 2011) or aspirational objectives – specific, measureable, achievable, relevant, and time-bound (S.M.A.R.T.) articulations of recovery goals. The San Francisco Estuary Partnership's Comprehensive Conservation and Management Plan (CCMP, SFEP 2007) calls for "recovery" and "reversing declines" of estuarine fish and wildlife but does not provide quantitative objectives that would allow for indicators to be referenced to desired outcomes. Thus, the indicators developed here are benchmarked to "primary reference conditions" (SOTB 2011) calculated from historical data. The primary reference conditions provide a scale against which improvement or deterioration can be evaluated. Identification of a primary reference condition does not indicate that such a condition is the desired state for the Estuary's fish assemblage; rather it provides a retrospective baseline with which one can evaluate the direction and relative magnitude of change.

For each indicator, primary reference conditions were established based on the earliest data available for each of the sampling programs studied, maximum measured values for the upper Estuary or sub-region, recognized and accepted interpretations of ecological conditions and ecosystem health (e.g., native versus non-native species composition), and/or best professional judgment. Wherever possible, indicator scoring was accomplished using methods equivalent or parallel to those used in SOTB (2011). In the case of abundance indicators, scores were calibrated to account for differences in absolute values of indicators among the sampling programs or sub-regions. The reference conditions for the assemblage composition indicators were based on the ecological relationship between the prevalence of non-native species and ecosystem and habitat condition (SOTB 2011). For these assemblage composition indicators, the value of the reference condition associated with a particular score (e.g., “good”, “poor”) was maintained in the upper Estuary at the same level as identified in SOTB (2011).

Following SOTB (2011), five intermediate reference conditions were created to provide a scale for assessing deviations from the primary reference condition. In order to ensure that the different levels represented meaningful differences in the measured indicator values, the range of indicator values assigned to each intermediate reference conditions was based on observed levels of variation in the measured indicator values. For each indicator, an assessment of current status was based on indicator trends and the average score of the most recent 5 years of the data set.

IV. INDICATORS

The following indicators were calculated for three regions of the Upper Estuary.

Table 6. Fish community characteristics and indicators calculated.

Fish Community Characteristics	Indicators
Abundance (Natives)	• Suisun Marsh native fish abundance • Pelagic Zone native fish abundance Regions: Central-West Delta and Suisun Bay • Beach Zone native fish abundance Regions: North, South, East, Central-West Delta
Species composition	• Percent Native Fish • Percent Native Species
Food Web Productivity (All fish)	• Suisun Marsh sum of standardized total fish abundance • Pelagic Zone sum of standardized fish abundance Regions: Central-West Delta and Suisun Bay • Beach Zone sum of standardized fish abundance Regions: North, South, East, Central-West Delta

A. Abundance Indicators
1. Rationale

The most obvious measure of fish abundance is a simple index of the number of fish caught. Abundance of native fish can be an indicator of aquatic ecosystem health (see full explanation in the State of the San Francisco Estuary Report Bay Fish Technical Appendix 2015 and Wang and Lyons 2003, Harrison and Whitfield 2004).

Because the Estuary’s fish assemblage is influenced by processes affecting fish production elsewhere (upstream in the Central Valley’s rivers or in the nearshore ocean), caution should be used in relating these abundance indices to local ecosystem processes. Additional indicators (e.g. spatial distribution, survival/productivity) will be useful for connecting trends in fish abundance to ecological drivers occurring within the Delta. For example, we constructed species composition indicators, which highlight the proportion of native to non-native species, to compliment the total abundance indicators. Studying both trends in native fish abundance and assemblage composition may help to reveal ecological changes underlying changes in total abundance. This approach tracks that employed by SOTB (2011) for its abundance indicators.

Limitations and future amendments to the abundance indicators

Catch-per-unit-effort (e.g. fish/trawl, fish/volume) is a measure of fish abundance that standardizes, within sampling programs and habitats, for variation in sampling effort across years. Use of this density metric as an indicator of total abundance relies on numerous assumptions. For example, use of the CPUE metric assumes that the density measured by the sampling program is representative of an “average” density across the region and habitat being sampled; if fish are more or less aggregated around sampling stations than they are throughout the area represented by those sampling stations, the relationship of CPUE to total abundance may be inaccurate. This is especially true if sampling stations are not chosen randomly for each sampling set or across years, as is the case with most fish sampling programs in this estuary. Also, average CPUE for all fish says nothing about the type of fish being caught, nor fish biomass. Because these are synthetic indicators, they also obscure particular relationships and trends that are occurring within sub-sets of the fish assemblage (e.g. individual species trends). Finally, as mentioned above, changes in indicators are not necessarily indicative of mechanistic drivers *within* the region being sampled, as migratory fish species’ populations may be responding to conditions elsewhere in their life cycle. However, fish density (and abundance) does represent a snapshot of conditions experienced by fish and other species (e.g. fish predators, anglers, etc.) in the sampling zone at a given time. Therefore, CPUE metrics present a partial picture of system health.

Future iterations of the SOTER should consider creating separate abundance indices for different ecological guilds (e.g., resident, nursery dependent, migratory fish, or sensitive species) to provide a more focused view of population trends within these different ecological groups. Our division of abundance into native vs. non-native species (see Food Web Productivity section) is on example of the additional information to be gained by studying subsets of the entire assemblage. Indicators that would present a more comprehensive view of ecosystem health when combined with abundance and diversity indices should be explored. For example, indicators of within Delta survival and spatial distribution may provide greater insight into local ecosystem processes affecting fish distribution. Also, measuring abundance as biomass would more accurately represent fish productivity and carrying capacity in the sampling zone.

2. Methods and Calculations, Assumptions, and Uncertainties

The SOTB (2011) methodology for constructing fish abundance indicators was applied wherever possible to each of the data sets (representing different sampling programs and major habitats). Differences among the sampling programs required some modification of methods for each sampling program and are explained below.

Suisun Marsh Fish Abundance Indicator
The Suisun Marsh Abundance Indicator was calculated as catch per trawl for each year (1980-2013):

fish/trawl = [native fish caught in year-x]/[trawls year-x]

The monitoring program does not estimate the volume of habitat sampled but has maintained a relatively consistent sampling protocol over the sampling period; thus, standardizing effort by the number of trawls was deemed appropriate (Matern et al 2002; T. O'Rear, personal communication, 2014). Data from sampling locations (n=17-21) that have been sampled throughout all or most of the sampling program (1980-2013) were used here (Table 4). While there are ecological gradients in the Marsh that might affect fish diversity and abundance (and the sampling program distinguishes between small sloughs and large sloughs), we analyzed the Marsh as one ecological unit without sub-regions.

Delta Beach Zone Fish Abundance Indicator
Delta Beach Zone Fish Abundance Indicators were produced for each of four, pre-determined IEP regions in the Delta (Figures 2 and 4). The sampling localities included in each region are identified in Table 4. Within each region, an abundance index was calculated as (1995-2013):

fish/10,000 m^3 = [native fish caught in year-x] / [total volume sampled in year-x] x(10,000)

The volume sampled was calculated as: (seine length x seine width x seine depth)/2 (http://www.fws.gov/stockton/jfmp/Docs/Data%20Management/12-14/Metadata%20(Updated%20September%2009,2014).doc). Because monthly sampling became routine in 1995, we constructed abundance indicators for only 1995-2014 using data from every month of the year. Native fish abundance in each of the Delta Beach Zone regions displayed broadly similar patterns (Figure 9); however, although the scores between regions were mostly well-correlated (Table x); the North Beach Zone patter was only marginally correlated with two other regions. As a result, the Native Fish Abundance Indicator was scored and displayed separately for each region of the Delta.

Upper Estuary Pelagic Zone
Upper Estuary Pelagic Zone Abundance Indicators were calculated using data from the Fall Midwater Trawl program, which samples fixed stations in the upper Estuary from September-December (Figure 5; Stevens 1977). We divided sampling stations into two IEP regions, Suisun Bay and the Central-West Delta and calculated a separate indicator for each region; sampling results from San Pablo Bay were excluded from our analyses. Sampling locations in each region are identified in Table 5. Within each region, an abundance index was calculated as (1967-2013):

$$\text{fish}/10{,}000\ m^3 = [(\text{native fish caught in year-x})/(\text{total trawls in year-x} * \text{tow volume } m^3)] * (10{,}000)$$

Sampling locations in the Delta-proper have been added to the FMWT several times over the program's existence (Table 1; Honey et al. 2004); however, in order to maximize the length of the time series, we restricted the sites used to create our abundance indicators to those that were sampled continuously in the years 1967-2013 ("Core 1" stations). Abundance indicators were not calculated in years where sampling effort (number of trawls) was much less (<68%) than the long-term modal average of trawls. Years included in our calculations are described in Table 5.

Total catch was divided by actual tow volume for 1985-2013 to produce a catch-per-unit-effort value for each year. Tow volume was not measured consistently for years prior to 1985; so, for this earlier sampling period annual catch was divided by the mean tow volume from the 1985-2013 period and, we also displayed annual catch by the 25th and 75th percentiles of 1985-2013 tow volume to bracket our estimated CPUE. Assumptions regarding average tow volume in the time series pre-1985 did not have any effect on scoring of this indicator (see, results section).

Cautions when interpreting results

The abundance indicators described above provide a measure of native fish assemblage health that is easy to understand and explain: *how many fish are caught for a given sampling effort*? However, such an indicator may not reveal the true state of the fish assemblage if the number of fish caught is dominated by one or a few species. In that situation, though the CPUE indicator is still of interest, it may reflect trends in the abundance of one species disproportionately, rather than trends in the assemblage as a whole.

A standardization method (described in the Food Web Productivity Indicator) was conducted for total fish abundance (native plus introduced species) for each data set and for native fish abundance in the Delta Beach Zone. There was no strong indication that one species was driving the trends observed in the Delta Beach Zone for native fish (standardized and raw CPUE values were highly correlated; p values were < 0.0, 0.0, 0.01 and 0.02 for North, East, South and Central-West respectively) or for total fish species in any region (see Food Web Productivity Indicator). Due to time constraints, we did not test whether *native* fish abundance (as opposed to total fish abundance) in Suisun Marsh and the Pelagic Zone was driven by fluctuations in one particular species; this approach is recommended for future iterations of the regional indices. However, there was no indication from the analyses of total fish abundance that one species was driving abundance patterns in those regions.

Reference Conditions

Wherever possible, the 1980-1989 average index value was used as the primary reference condition for abundance indicators. This is consistent with the Bay fish indicators (SOTB 2011). In the SOTB (2011), the 1980-1989 average is considered "good", recognizing that some fish populations were already in decline by the 1980's. A five-tier scale rates annual average CPUE over time from “very poor” to “excellent”. Any individual year in the record may be compared to the reference condition and scored.

Suisun Marsh

The 1980-89 average catch per trawl was established as the primary reference condition for this data set. These were the earliest years for which data was available. Following SOTB (2011), the 5-tiered scoring system was developed for other intermediate reference conditions as described in Table 7.

Table 7. Quantitative reference conditions and associated interpretations for the Suisun Marsh Fish Abundance Indicator. The average score during the primary reference period, which corresponds to “good” conditions, is in bold and all other reference conditions are calculated from that value (e.g. “excellent” is 150% of the 1980-1989 value).

Abundance Indicators Suisun Marsh Catch Per Effort (Data: UCD Suisun Marsh Fish Survey, Otter Trawl)			
Quantitative Reference Condition	**Interpretation**	**Low End of Range**	**High End of Range**
>150% of the 1980-1989 Average	Excellent	>28.71	N/A
>100% of the 1980-1989 Average	**Good**	**>19.1**	**28.7**
>50% of the 1980-1989 Average	Fair	>9.57	19.0
>15% of the 1980-1989 Average	Poor	>2.87	9.56
<15% of the 1980-1989 Average	Very Poor	N/A	<2.87

Delta Beach Zone

The Beach Zone was not consistently sampled year-round until 1995. Thus, average catch per effort from 1995-2004 was established as the primary reference condition for the Delta Beach Seine sampling program. The primary reference condition, during this period was assigned a “poor” score to match the average score of the Suisun Marsh and Pelagic Zone abundance indicators during the same period. Following SOTB (2011), the 5-tiered scoring system was developed for other intermediate reference conditions. Evaluation thresholds for these scores are described in Table 8.

Table 8. Quantitative reference conditions and associated interpretations of the results of the Delta Beach Zone fish abundance indicator. For each region in the Delta, the average of the primary reference condition, which corresponds to "poor" conditions, is in bold. The primary reference condition was rated "poor" to correspond to scores for the Pelagic and Marsh abundance indicators during the 1995-2004 period.

Abundance Indicators Delta Beach Zone Catch Per Effort (Data: USFWS Delta Juvenile Fishes Program, Beach Seine Survey)			
North Delta			
Quantitative Reference Condition	**Interpretation**	**Low End of Range**	**High End of Range**
> 150% of Good	Excellent	> 27976	NA
> (1995-2005 Average / 15%)	Good	> 18650	27976
> 50% of Good	Fair	> 9325	18650
> **1995-2005 Average**	**Poor**	**> 2798**	**9325**
< 1995-2005 Average	Very Poor	< 2798	NA
East Delta			
Quantitative Reference Condition	**Interpretation**	**Low End of Range**	**High End of Range**
> 150% of Good	Excellent	> 27127	NA
> (1995-2005 Average / 15%)	Good	> 18084	27127
> 50% of Good	Fair	> 9042	18084
> **1995-2005 Average**	**Poor**	**> 2713**	**9042**
< 1995-2005 Average	Very Poor	< 2713	NA
South Delta			
Quantitative Reference Condition	**Interpretation**	**Low End of Range**	**High End of Range**
> 150% of Good	Excellent	> 9619	NA
> (1995-2005 Average / 15%)	Good	> 6412	9619
> 50% of Good	Fair	> 3206	6412
> **1995-2005 Average**	**Poor**	**> 962**	**3206**
< 1995-2005 Average	Very Poor	< 962	NA
Central-West Delta			
Quantitative Reference Condition	**Interpretation**	**Low End of Range**	**High End of Range**
> 150% of Good	Excellent	> 19852	NA
> (1995-2005 Average / 15%)	Good	> 13235	19852
> 50% of Good	Fair	> 6617	13235
> **1995-2005 Average**	**Poor**	**> 1985**	**6617**
< 1995-2005 Average	Very Poor	< 1985	NA

Pelagic Zone of the Upper Estuary

The 1980-89 average catch per effort was established as the primary reference condition for this data set. Following SOTB (2011), the 5-tiered scoring system was developed for other intermediate reference conditions as described in Table 9.

Table 9. Quantitative reference conditions and associated interpretations for the results of the Upper Estuary Pelagic Zone Fish Abundance Indicator. The average during the primary reference condition, which corresponds to "good" conditions, is in bold.

Abundance Indicators Pelagic Zone Catch Per Effort (Data: CDFW Fall Midwater Trawl)			
Central-West Delta			
Quantitative Reference Condition	Interpretation	Low End of Range	High End of Range
>150% of the 1980-1989 Average	Excellent	>11.8	NA
>100% of the 1980-1989 Average	**Good**	**>8**	**11.8**
>50% of the 1980-1989 Average	Fair	>4	8
>15% of the 1980-1989 Average	Poor	>1.2	4
<15% of the 1980-1989 Average	Very Poor	NA	<1.2
Suisun Bay			
Quantitative Reference Condition	Interpretation	Low End of Range	High End of Range
>150% of the 1980-1989 Average	Excellent	>155	NA
>100% of the 1980-1989 Average	**Good**	**>103**	**155**
>50% of the 1980-1989 Average	Fair	>52	103
>15% of the 1980-1989 Average	Poor	>15	52
<15% of the 1980-1989 Average	Very Poor	NA	<15

3. Abundance Results

Suisun Marsh

Native fish abundance in Suisun Marsh declined over the period of record (Figure 6). Levels detected in the first few years of the survey were "excellent" or "good", but became consistently "fair" or "poor" during the late 1980's and early 1990's. Over the last five years conditions the indicator was "poor".

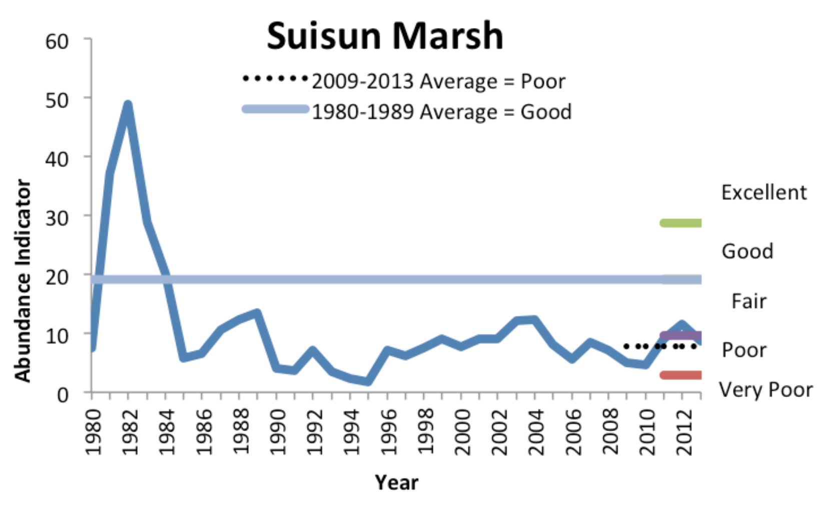


Figure 6. Suisun Marsh Fish Abundance Indicator from 1980-2013. Over the period of record the abundance indicator has declined and the recent five-year average is “poor”. Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 7). The primary reference condition (1980-1989 average), indicated by a light blue horizontal line, represented a “good” score. The dotted line, representing the 2009-2013 average, reveals that Suisun Marsh fish abundance is “poor”.

Upper Estuary Pelagic Zone

Native fish abundance in the Pelagic Zone has declined dramatically over time, with recent averages that were very poor. Small differences were detected in the native fish assemblage abundance patterns between the two regions sampled in the Pelagic Zone – Suisun Bay (Figure 7) and the Central-West Delta (Figure 8). Although native fish abundance indicators in both regions declined dramatically, they displayed different patterns of decline. The abundance indicator in Suisun Bay followed a trend that was broadly similar to that seen in Suisun Marsh abundance; abundance of native fish scored “excellent” in the early years of the survey and even in the earliest years of the primary reference period (1980-1989). However, scores declined rapidly just prior to the onset of the 1987-1994 drought. A small rebound in abundance was detected in the late-1990’s, but the indicator declined persistently through the early 2000’s. The average of the last five years indicates that the native fish assemblage in this region/habitat was in “very poor” condition.

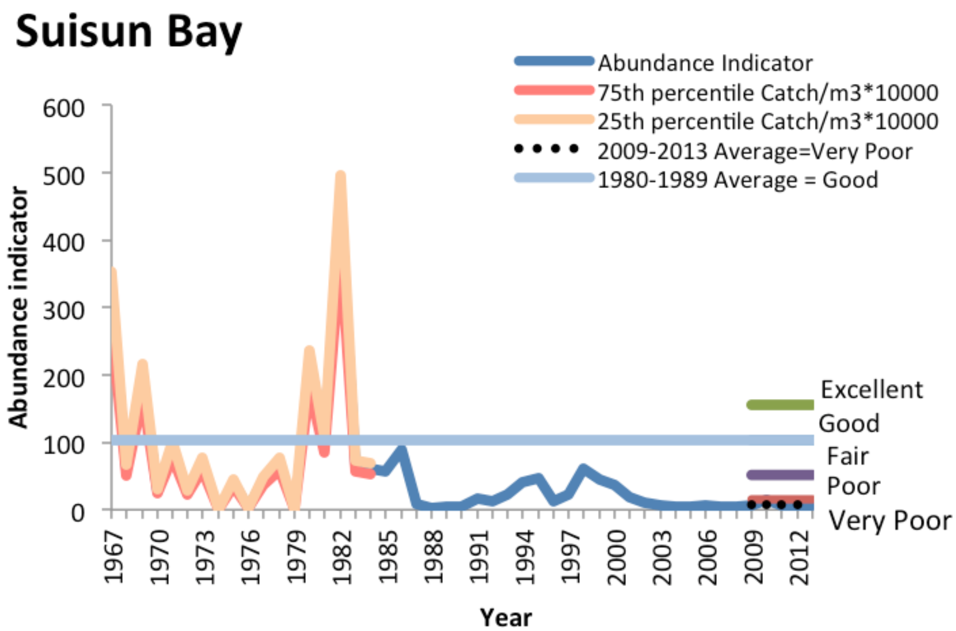


Figure 7. Upper Estuary Pelagic Zone Native Fish Abundance Indicator for the Suisun Bay region from 1967-2013. Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 9). The primary reference condition (1980-1989 average) is indicated by a light blue horizontal line. The dotted line represents the 2009-2013 average. Native fish abundance in the Pelagic Zone of Suisun Bay is "very poor". Volume sampled was not recorded consistently during 1967-1984 period; thus, for this period, volume sampled was estimated as the mean volume from 1985-2013. Catch-per-unit-effort (i.e., per volume) was also estimates using the 25th and 75th percentile values of volume sampled between 1985-2013; the effect of different sampling volume estimates are shown in peach and pink lines respectively.

Abundance trends in the Central-West Delta Pelagic Zone are different in degree from those described for the Suisun Bay Pelagic Zone and Suisun Marsh. Here, the abundance index appeared to be somewhat stable throughout the 1980's and early 1990's. Both, the increase in the late 1990's (to "excellent") and the precipitous decline in abundance after the early 2000's were consistent with patterns seen in Suisun Bay and Suisun Marsh. The average of the most recent five years indicated that the pelagic fish assemblage in this area is in "very poor" condition.

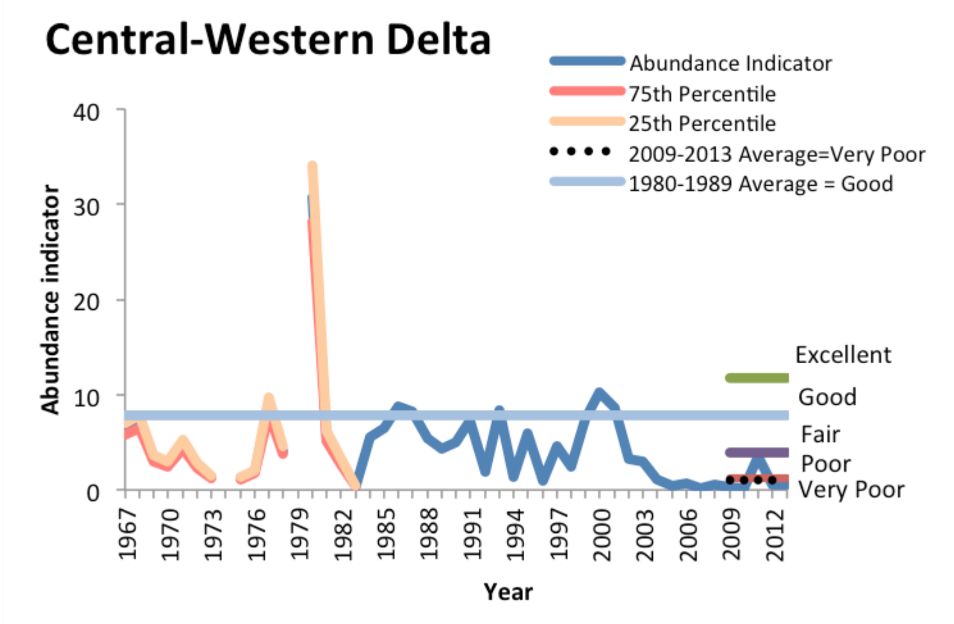


Figure 8. Upper Estuary Pelagic Zone Native Fish Abundance Indicator for the Central-West Delta region from 1967-2013. There has been a rapid decline in native fish abundance since the year 2000. Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 9). The primary reference condition (1980-1989 average) is indicated by a light blue horizontal line. The dotted line represents the 2009-2013 average and shows that native fish abundance in the Pelagic Zone of the Central-Western Delta is "very poor".

Delta Beach Zone

Native abundance trends in the Delta Beach Zone were similar in four regions. Trends in native fish abundance in were similar in the North, East, South and Central-West Delta Beach Zone, although the East region displayed greater peaks in abundance (Figure 9). Still, Delta Beach Zone region scores are plotted separately for greater resolution of patterns within the individual regions; a combined score for the Delta Beach Zone as a whole (not shown) produced similar patterns and current scores as the regions considered separately.

Abundance of native fish species remained "poor" in all regions of the Delta Beach Zone for most of the last 20 years (Figure 10) and the current score is "poor". Some regional indicator scores increased briefly in the most recent five years, however, this increase was not sufficient to raise the average score for the last five years above "poor" for any region.

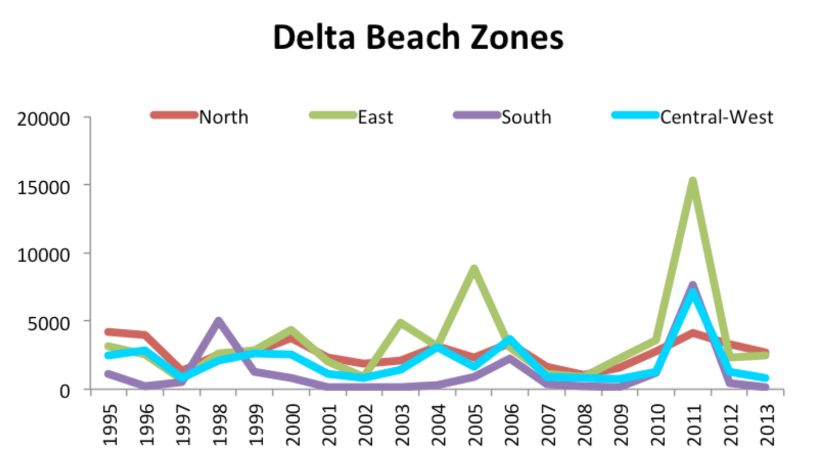
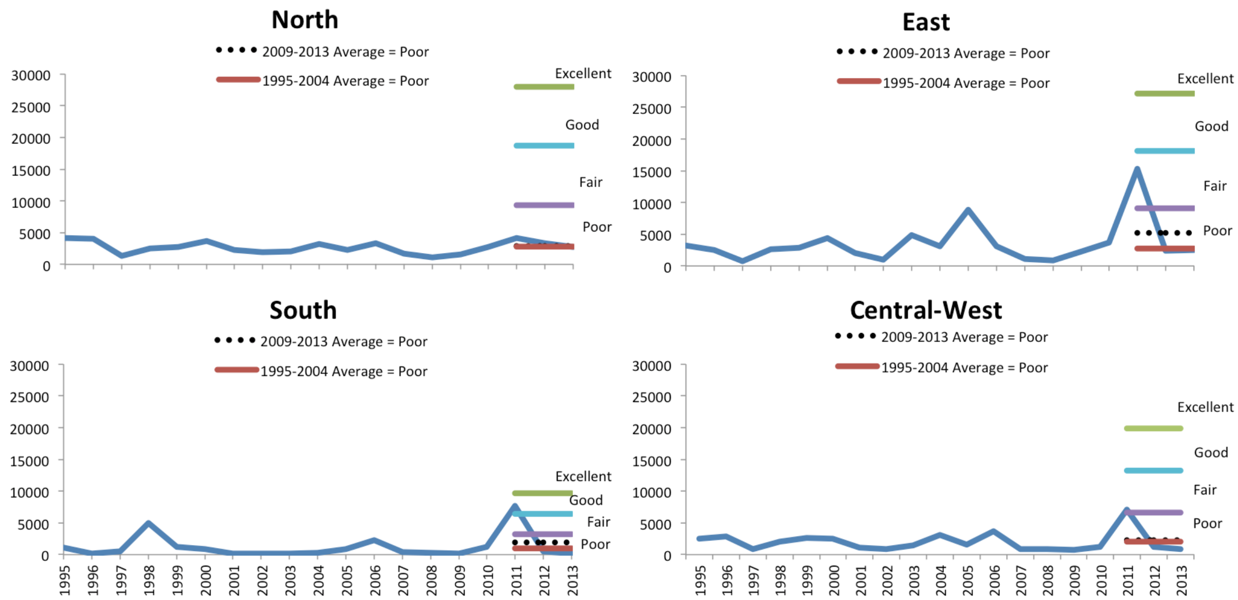


Figure 9. Comparison of native catch per unit effort for four Delta Beach Zone regions. Trends for native fish abundance were similar (see correlation matrix below) for most regions and exhibited different patterns than for total fish abundance (see Food Productivity Indicator).

Table x: Correlation values for comparison of trends between North, East, South and Central-West Delta Beach Zones. Values in red are significant (p <0.00). The correlation between North to East Beach Zones and the North to South Beach Zones were p=0.05 and 0.09 respectively.

Pearson Correlation Matrix	North	East	South	Central -West
North	1.00			
East	0.453	1.00		
South	0.400	0.712	1.00	
Central-West	0.706	0.773	0.787	1.00



Beach Zone regions**.** Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 8). The primary reference condition (1995-2004 average) was considered to be "poor" based on averages calculated from Suisun Marsh data and Pelagic Zone abundance indicators during that same time period. The dotted line represents the 2009-2013 average and shows that native fish abundance in each region of the Delta Beach Zone is currently "poor".

Summary of Beach Zone Abundance and Diversity Trends

Taken together, the Beach Seine data reveal that abundance of fish in the shallow, unvegetated waters of the Delta remained "poor" for the period of record with a peak in 2011. Increases in 2011 were not enough to raise the scoring for 2009-2013 average above "poor".

5. Summary of Abundance Results

Abundance of fishes in the Pelagic Zone and Suisun Marsh decreased substantially since the early 1980's and the decline accelerated in the early part of this century; trends in abundance were remarkably similar between these two habitats. Abundance of native species in the Delta Beach Zone has remained "Poor" during most of the period of record.

Based on abundance, the CCMP goals to recover and reverse declines of estuarine fishes (SFEP 2007) have not been met in the upper Estuary region.

B. Species Composition Indicators:

1. Rationale

An indicator for species composition was developed for the SOTB (2011) based on work by May and Brown (2002) and Meador et al. (2003) who found that the relative proportions of native and non-native species in an ecosystem are important indicators of ecosystem health. The SOTB (2011) states:

> *"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."* [p. 176]

As with the abundance indicators, it is important to note that indicators of assemblage composition are not necessarily tied to local processes as many species in a particular region may have spawned or reared in distant habitats – it is possible that, to some degree, the relative abundance or diversity of non-native species to native species reflects "propagule pressure" from other environments in the Central Valley.

As with the SOTB (2011), two different indicators for species composition were calculated:

- Percent Native Species reflects the species richness of native and non-native fishes in a given region.
- Percent Native Fish reflects the percentage of individual fish collected in each sub-region of the Estuary that were native species.

2. Methods and Calculations, Assumptions, and Uncertainties

In general, the same methodology for constructing species composition indicators was applied to each of the upper Estuary fish data sets (representing different sampling programs and major habitats). Differences among the sampling programs required some modification of methods for each sampling program.

A **Percent Native Species Indicator** was calculated for each year in each sampling program/sub-region as the percentage of fish species collected in the upper Estuary that are native to the Estuary, as follows:

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

A **Percent Native Fish Indicator** was calculated in each year in each sampling program/sub-region as the percentage of total individual 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 individuals/(total individual fish caught)] x 100

For each sampling program, the years incorporated into the composition indicators were the same as those described for their respective abundance indicators (see above).

3. Reference Conditions

Primary reference conditions for the assemblage composition indicators were the same as those used in SOTB (2011). These reference condition scores were based on inference from ecological literature and there was no compelling justification to use a different scoring system for the upper Estuary than had been used in the pelagic waters of the lower Estuary. The average percent native fish for the primary reference period, 1980-1989, (~85%) in the lower Estuary, was judged to be “good” (SOTB 2011). Index values where native fish represents less than 50% of total catch were judged to represent highly degraded conditions (SOTB 2011). Suisun Bay was reported to have lower percentages of native fish relative to total catch than other regions of the Bay (SOTB 2011). See Table 10 for quantitative reference conditions used here and in (SOTB 2011).

Table 10. Quantitative reference conditions and associated interpretations for the results of the Fish Species Composition Indicators (Percent Native Fish and Percent Native Species) for Suisun Marsh, Delta Beach Zone and Upper Estuary Pelagic Zone.

Quantitative Reference Condition	Interpretation	Low End of Range	High End of Range
>95%	Excellent	>95	N/A
>85%	Good	>85	95
>70%	Fair	>70	85
>50%	Poor	>50	70
≤50%	Very Poor	N/A	<50

4. Results of Species Composition

Suisun Marsh
The Percent Native Fish indicator is currently “very poor” in Suisun Marsh, a decline from its primary reference condition (1980-1989 average).
The 1980-1989 average percentage of native fish in total catch for the Suisun Marsh Survey was 47.0%. This means that the primary reference condition for Suisun Marsh (the earliest records from regular sampling) was “very poor” (Figure 11, Table 10). In the most recent 5 years, the percentage of native fish has been less than 50% (45. 9%), meaning that Suisun Marsh remains “very poor” for this indicator of assemblage health (Figure 11). Although most of the fish caught in Suisun Marsh are non-native species, it is worth noting that native fish abundance reached an all-time low in 1994 and has rebounded since that point.

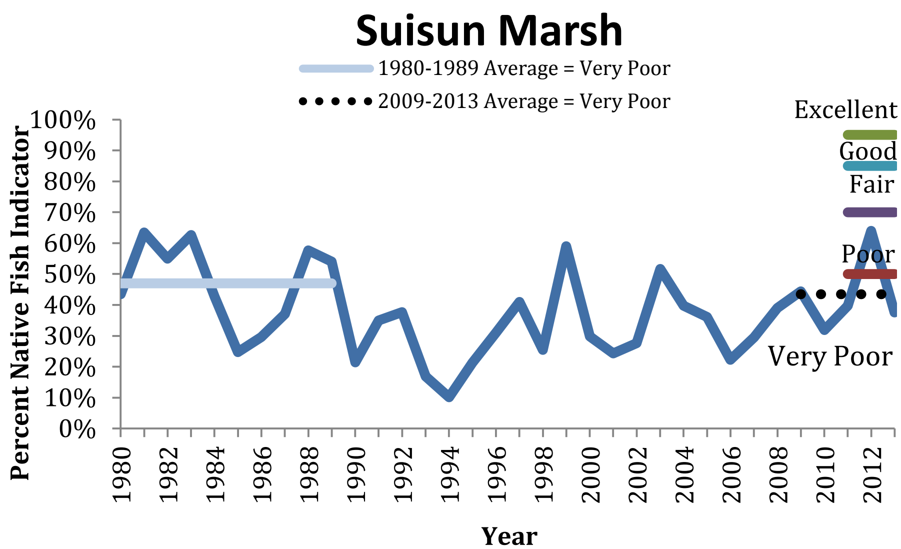


Figure 11. Changes in the relative abundance of native fish (Percent Native Fish Indicator) in Suisun Marsh from 1980-2013. Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 10). The primary reference condition (1980-1989 average) is indicated by a light blue horizontal line. The dotted line represents the 2009-2013 average. The primary reference condition and recent five-year averages are similar (47.0% and 43.5% respectively); both indicate "very poor" health of the local fish assemblage.

The Percent Native Species indicator is currently "very poor" in Suisun Marsh; this index declined from "poor" to "very poor" over the course of the survey. The 1980-1989 average percentage of native species detected in the Suisun Marsh Survey was 51.9%. This means that the baseline conditions for Suisun Marsh (the earliest records from regular sampling) rate "poor" (Figure 12, Table 10). In the most recent five years, the percentage of native fish species was less than 50% (45.9%), meaning that Suisun Marsh scored "very poor" on this index of assemblage health.

In addition to plotting the percent native species, the raw number of native vs. introduced species over the time series was compared (Figure 13) in an effort to assess whether changes in sampling effort (changes in trawl number) across years affected the total number of species detected. Native and non-native species richness was not significantly correlated and did not appear to respond to differences in the number of trawls conducted in the early years of the survey.

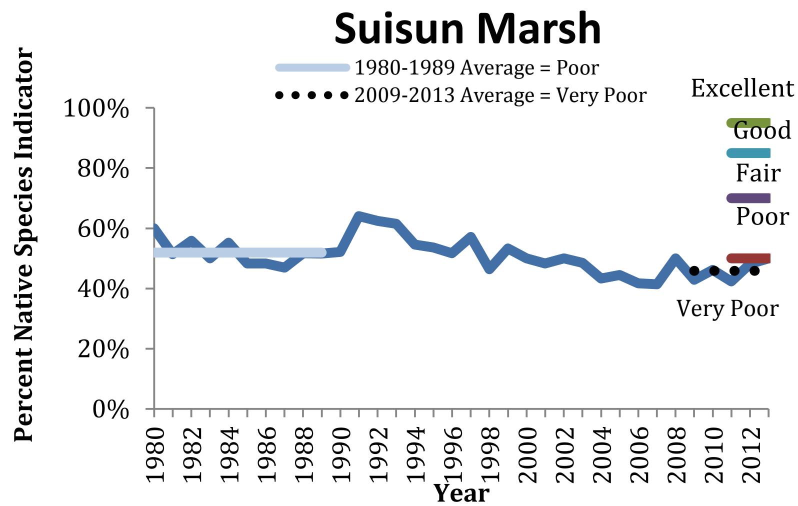


Figure 12. Changes in the Percentage of Natives Species Indicator in Suisun Marsh from 1980-2013. Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 10). The primary reference condition (1980-1989 average) is indicated by a light blue horizontal line. The dotted line represents the 2009-2013 average. Reference period averages and recent five-year averages are similar (51.9% and 45.9%, respectively, of species detected in the Suisun Marsh Survey are native). The early reference condition average represented “poor” health and last five-year average indicates that current conditions are “very poor”.

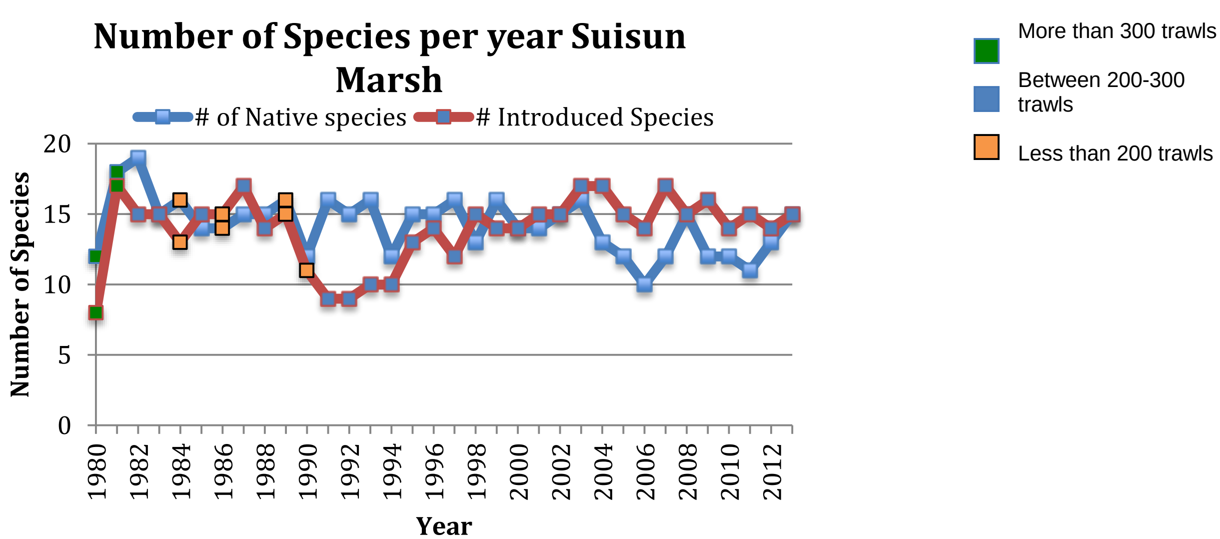


Figure 13. Comparison of native and non-native species richness through time (r = 0.059, p = 0.74) in Suisun Marsh. Native species richness is declining slowly, whereas non-native species richness has remained stable since the late-1990’s. Colored boxes indicate changes in sampling effort (number of trawls) in some years. No relationship between the number of trawls and the richness of native and non-native species or the native/non-native relationship was detected.

Upper Estuary Pelagic Zone

Suisun Bay. The percentage of native fish represented in the pelagic assemblage of Suisun Bay was "poor", indicating no change in score between the primary reference condition (1980-1989 average) and the average of the last 5 years. The 1980-1989 average percentage of native fish in total catch of Suisun Bay was 65.6%. This means that the primary reference condition for Suisun Marsh (the earliest records from regular sampling) was "poor" (Table 10). In the most recent 5 years, the percentage of native fish in the total catch declined slightly (to 60.4%), but this too indicates that assemblage health is "poor" (Figure 14). The indicator varied widely over the period of record from "good" to "very poor". Not captured in this comparison is the precipitous decline in the percentage of native fish in the community in the early 1990's and the early 2000's – during those periods, the Percent Native Fish index was "very poor".

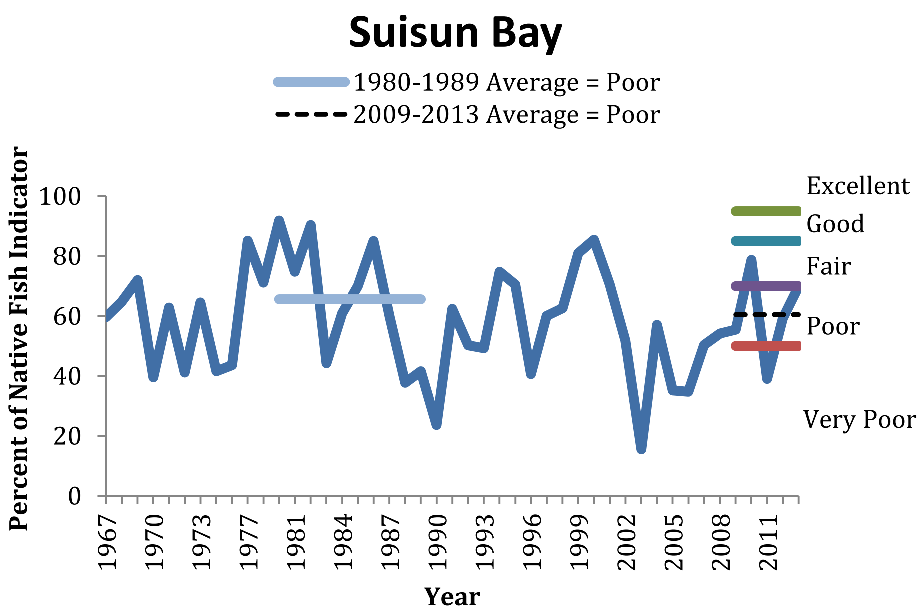


Figure 14. Changes in the relative abundance of native to non-native fish (Percent Native Fish Indicator) for the Pelagic Zone of Suisun Bay from 1967-2013. Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 10). The primary reference condition (1980-1989 average) is indicated by a light blue horizontal line. The dotted line represents the 2009-2013 average. Reference period averages and recent five-year averages are similar (65.6% and 60.4% respectively). Both the early reference condition average and last five-year average reflect "poor" health of the fish assemblage in this region of the upper estuary.

The percentage of native species in the pelagic assemblage of Suisun Bay was "fair" representing little change from its primary reference condition (1980-1989). In both the reference period and the last 5 years, slightly less than two-thirds of the species were native (Figure 15). There is no indication that variation in sampling effort in the early years of the program affected total or relative richness scores. Over the period of record the indicator varied between “fair” and “poor”.

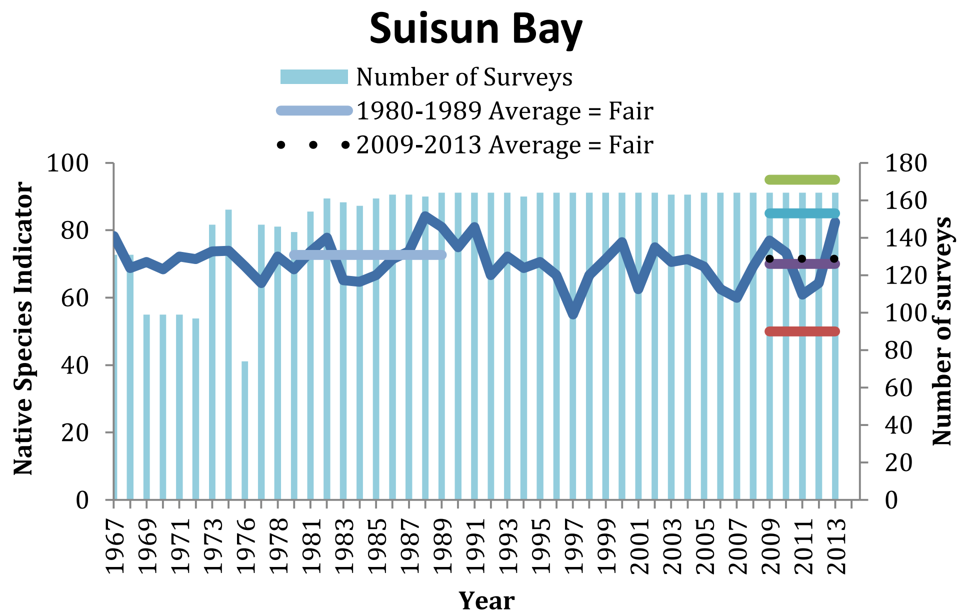


Figure 15. Changes in the Percent Native Species Indicator for the Pelagic Zone of Suisun Bay from 1967-2013. Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 10). The primary reference condition (1980-1989 average) is indicated by a light blue horizontal line. The dotted line represents the 2009-2013 average. The reference period and recent five-year averages are similar (72.67% and 71.55% respectively) indicating that the relative richness of native species remains “fair” in this region of the upper estuary. There was no significant correlation between the number of species detected and the number of surveys conducted (r=-0.007, p=0.96).

Central-West Delta*. *The percentage of native fish represented in the pelagic assemblage of the Central-Western Delta remained “very poor”. The indicator has remained solidly below 40% throughout the time series (Figure 16). Native species richness reached a peak in 2011, but this increase does not yet constitute a trend as native species richness declined again in the next two years.

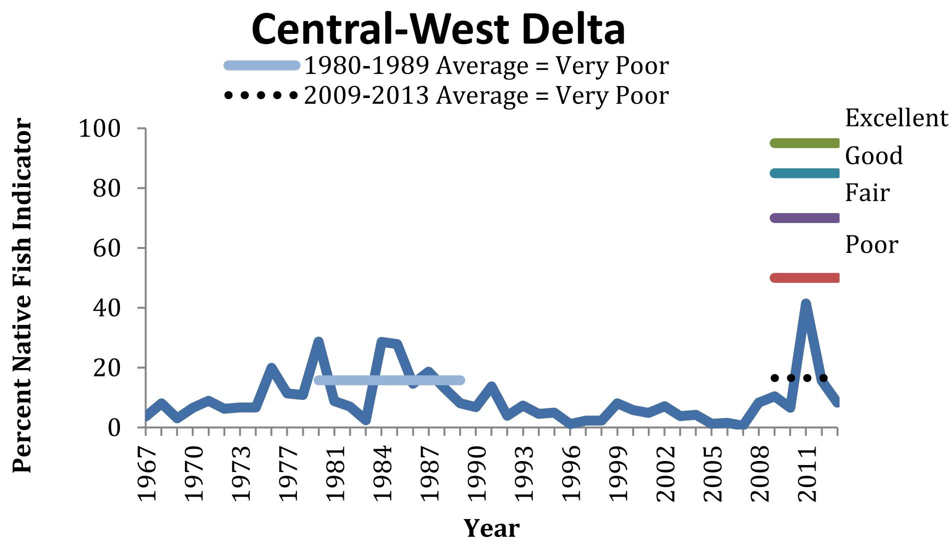


Figure 16. Changes in the Percent Native Fish Indicator for the Pelagic Zone of the Central-West Delta from 1967-2013. Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 10). The primary reference condition (1980-1989 average) is indicated by a light blue horizontal line. The dotted line represents the 2009-2013 average. Reference period averages and recent five-year averages are similar (15.78% and 16.51% respectively). Indicating that the relative richness of native species has remained "very poor" in this region of the upper estuary throughout the sampling program time series.

The percentage of native species in the pelagic assemblage of the Central-West Delta declined slowly but persistently following the primary reference period (1980-1989), this indicator was most recently "very poor". In the reference period native species made up exactly half of the total species caught by the FMWT pelagic sampling program when it sampled in the West Delta (Figure 17). In the last 5 years, that index has decline to less than 40%, on average. In this case, the decrease in relative native species richness came despite an increase in the number of trawls conducted in the western Delta.

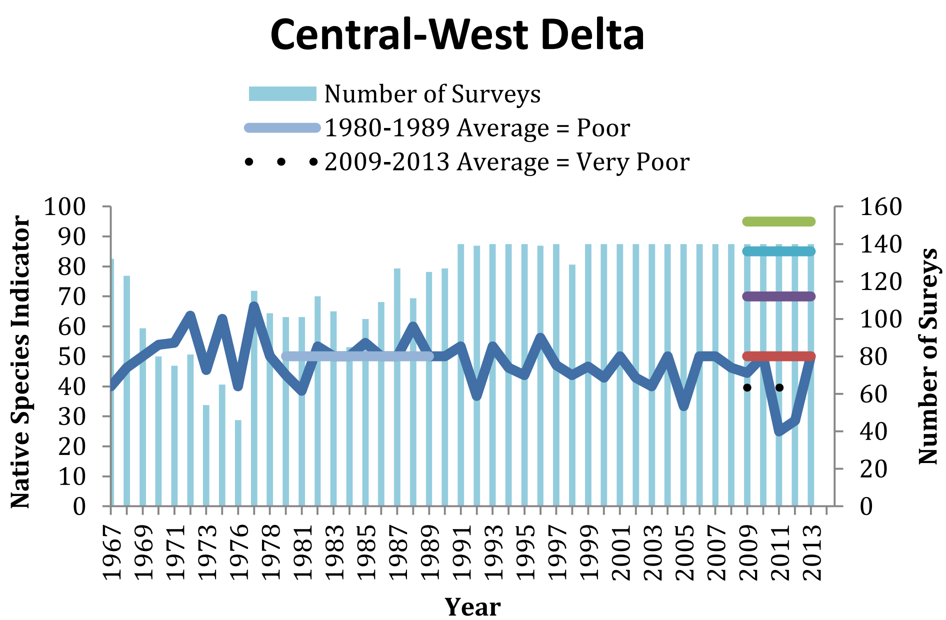


Figure 17. Changes in the Percent Native Species Indicator for the Pelagic Zone of the Central-West Delta from 1967-2013. Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 10). The primary reference condition (1980-1989 average) is indicated by a light blue horizontal line. The dotted line represents the 2009-2013 average. Reference period averages and recent five-year averages are different. Conditions in the reference period (50.0% native species) were "poor" but the average of the most recent five years (39.6% native species) was "very poor" There was no significant correlation between the number of species detected and the number of surveys conducted (r=0.10, p=0.51).

Delta Beach Zone.

The percentage of native fish and native species in all regions of the Beach Zone assemblage of the Delta was "very poor" in both the primary reference condition and in recent years. The percentage of native fish caught in the North and East Delta was higher than the South and Central-West and, in 2011, the percentage of native fish increased in all regions, driven largely by high numbers of juvenile Sacramento splittail produced in that year (Figure 18). Native species have accounted for less than 40% of the Beach Zone species assemblage in all Delta regions throughout most of the period of record (Figure 19).

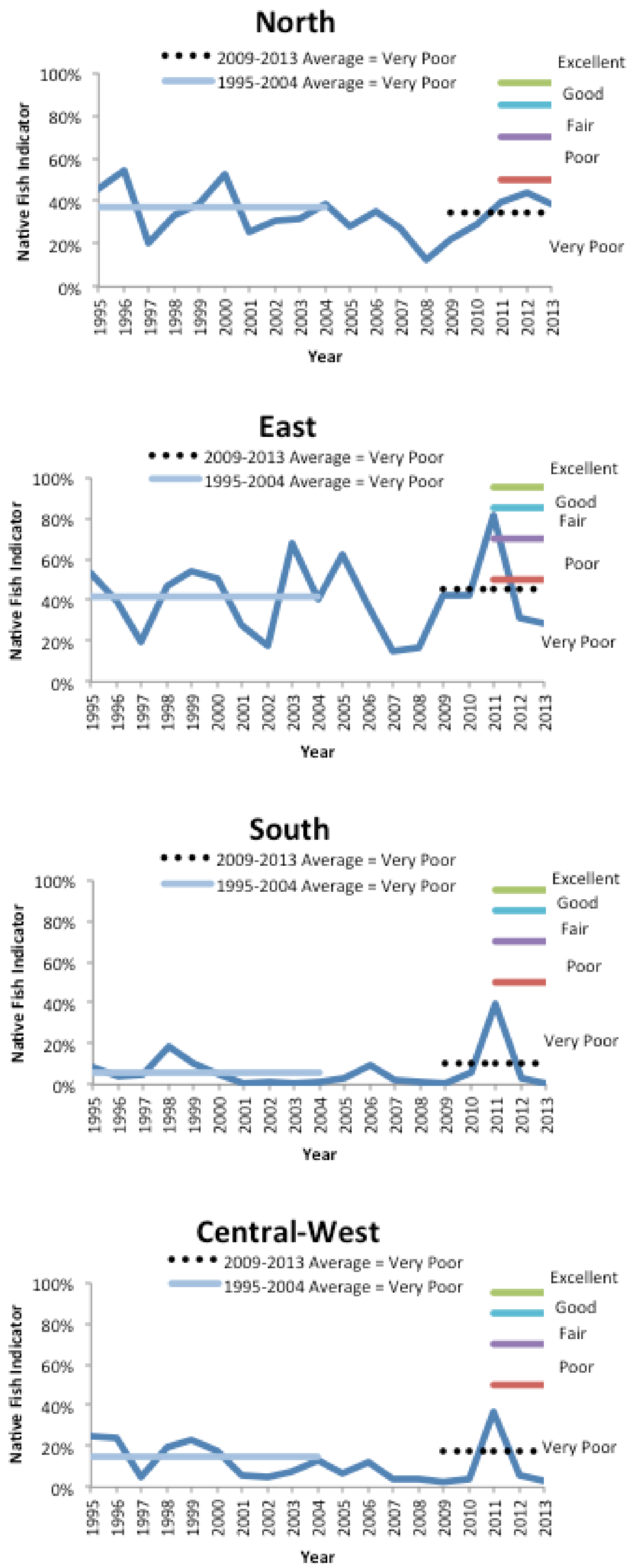


Figure 18. Changes in the relative abundance of native fish (Percent Native Fish Indicator) for the Delta Beach Zones from 1995-2013. Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 10). The primary reference condition (1995-2004 average) is indicated by a light blue horizontal line. The dotted line represents the 2009-2013 average.

The primary reference condition for North, East, South and Central-West was “very poor” (37.2%, 41.7%, 5.5%, and 14.5% respectively). The 2009-2013 averages remained “very poor” (34.6%, 45.3%, 10.1% and 17.6% respectively) in all regions of the Delta Beach Zone.

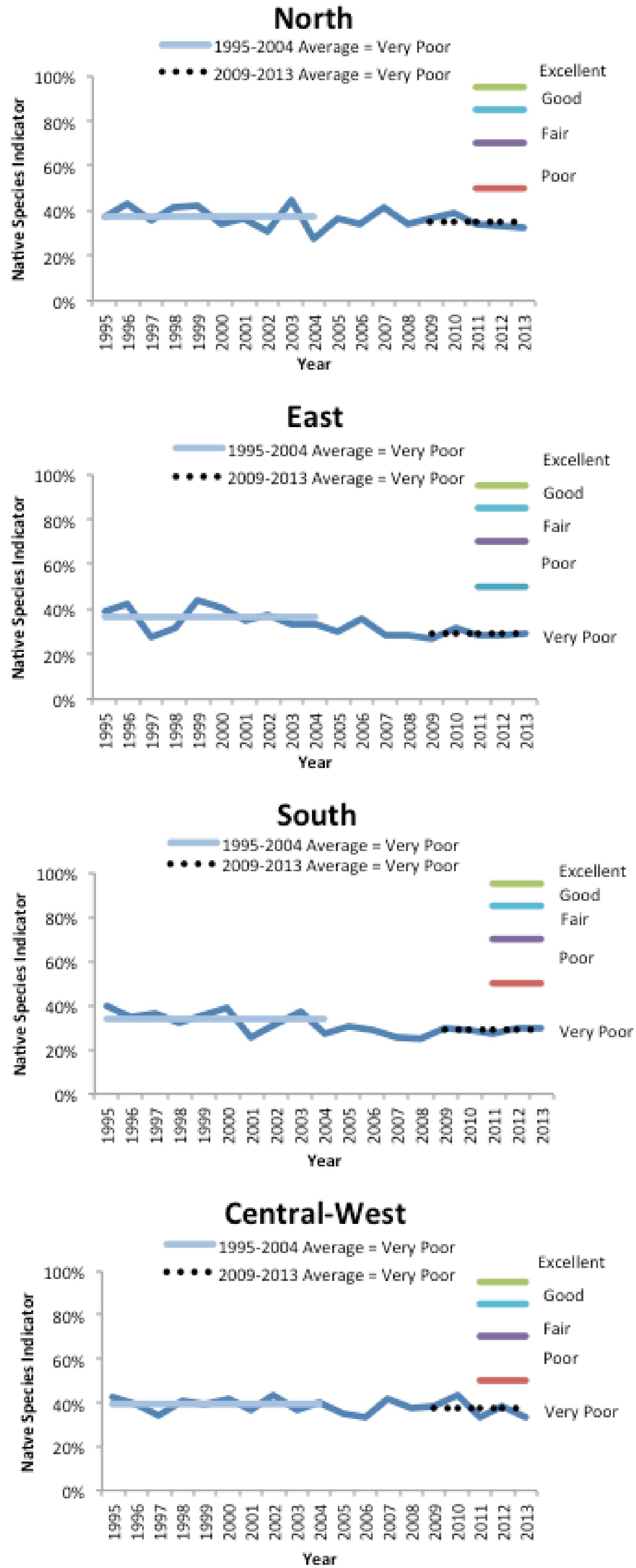


Figure 19. Changes in the Percent Native Species Indicator for the Delta Beach Zones from 1995-2013. Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 10). The primary reference condition (1995-2004 average) is indicated by a light blue horizontal line. The dotted line represents the 2009-2013 average.

The primary reference condition for native species richness North, East, South and Central-West was “very poor” (37.5%, 36.5%, 33.9%, and 39.4% respectively) and the 2009-2013 averages remained “very poor” (35.1%, 28.9%, 29.1%, and 37.5% respectively).

No significant correlations between the number of species detected and the number of surveys conducted were detected (e.g. in the South Delta; r=0.16, p=0.50).

C. Fish Part of the Food Web Productivity Indicators (Total Fish Abundance):

1. Rationale

The total abundance of fish, native and introduced, represents a snapshot of existing conditions in the ecosystem. Consumers of and competitors with fish may not distinguish between native and introduced fish species; therefore, abundance of all fish is a useful indicator of system productivity at a given time.

For each sampling program and major habitat sampled, we constructed indicators of overall catch (native plus introduced fish abundance), corrected for differences in effort expended catching those fish (catch-per-unit-effort; CPUE). These indices can be studied to determine the relative abundance of fish available (e.g., to fish predators) within different habitats of the Delta through time. Because the habitats and gears used to sample them differ so much across studies, no effort was made to aggregate abundance indicator scores across sampling programs into a single index; however, within sampling programs, if abundance indicators from different sub-regions were highly correlated through time, we combined sub-regions into a single overall indicator of abundance in that sampling program/habitat type.

Also, because different fish species have different value as prey for, competitors with, or consumers of other species, it was important to determine whether indices of total fish abundance reflected variations in the entire fish assemblage or, alternatively, were driven by individual species (see also, Limitations and future amendments to the abundance indicator above). Thus, we compared behavior of a raw abundance index with that of an index of abundance that summed standardized scores of fish abundance within species.

Because the Estuary's fish assemblage is influenced by processes affecting fish production elsewhere (upstream in the Central Valley's rivers or in the nearshore ocean), caution should be used in relating these abundance indices to local ecosystem processes.

2. Methods and Calculations, Assumptions, and Uncertainties

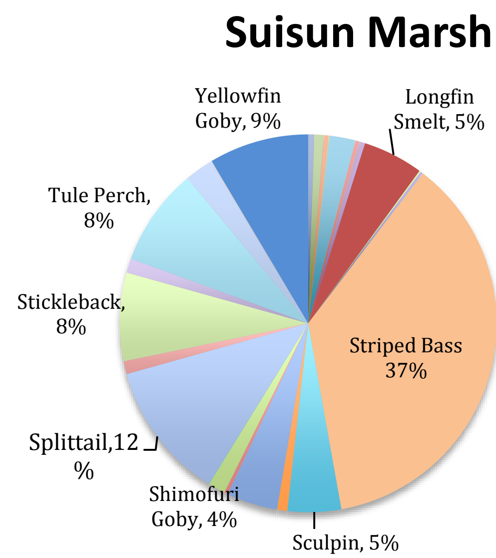
The Food Web Indicator was calculated the same as the abundance indicators, with the exception that both native and introduced fishes were included in the analyses**.** In addition standardized abundance (described below) was added to the analysis.

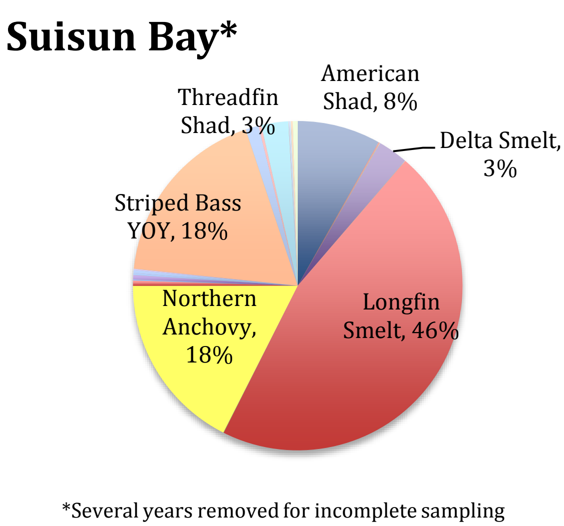
Indicators of Standardized Abundance: Checking for disproportionate effects of single species on annual trends

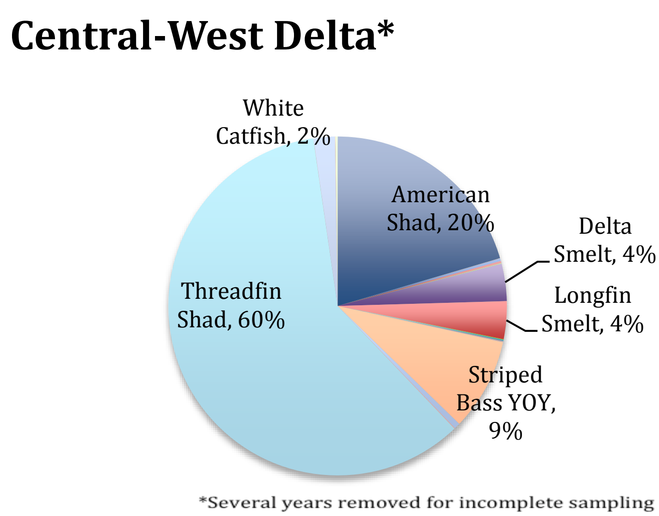
The abundance indicators described above provide a measure of fish assemblage health that is easy to understand and explain: *how many fish are caught for a given sampling effort*? However, such an indicator may not reveal the true state of the fish assemblage if the number of fish caught is dominated by one or a few species. In that situation, though the CPUE indicator is still of interest, it may reflect trends in the abundance of one species disproportionately, rather than trends in the assemblage as a whole.

The Fish Index for the State of the Bay Report (SOTB 2011) created a separate index for Northern Anchovy because, in most years, greater than 80% of the fish caught in the Bay Study were Northern Anchovy (SOTB 2011). Thus, variation in the catch of this one species within a year could mask abundance trends of other species in a combined total catch indicator. In the upper Estuary, a small number of species dominate all others numerically, but the species involved change depending on the habitat sampled. For instance, striped bass represented 37% of the entire catch in Suisun Marsh (Figure 20). In the open waters of Suisun Bay and the Central-West Delta five to six species dominated the catch (Longfin Smelt, Threadfin Shad, American Shad, Striped Bass, Northern Anchovy, and Delta Smelt, Figure 20) and catches of these species displayed high variance across years. In the Delta Beach Zone, Inland Silversides represented a large portion of the catch (62% of the total catch from 1995-2013, Figure 21).

Figure 20. Proportional catch of fish species caught by the Fall Midwater Trawl in Suisun Bay (1967-2013), the Central-West Delta (1967-2013) and Suisun Marsh Fish Survey (1980-2013).







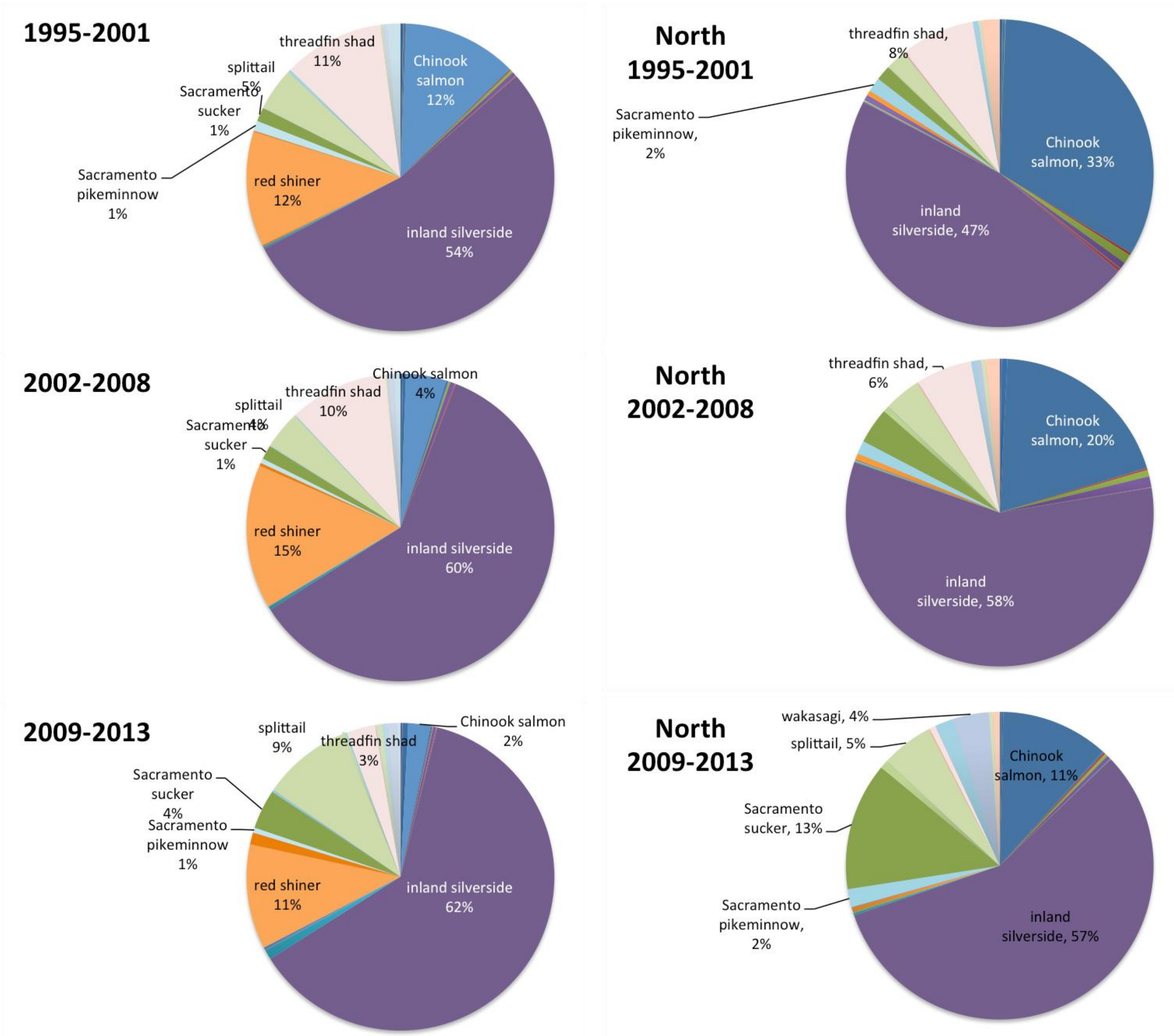


Figure 21. Proportional catch of fish species caught by the USFWS Beach Seine in all regions (left side) and the North subregion of the Delta (right side) during three time periods.

In an effort to create an abundance indicator that reflects abundance changes for all species within habitat-specific fish assemblages measured by the surveys studied here, we created a separate metric – the sum of the standardized abundances of species that were regularly caught in each sampling program. Within each sampling program and sub-region, fish catches were standardized by subtracting the annual catch for each species' by the mean catch for that species over the entire time series; the difference between annual and mean catch was then divided by the species-specific standard deviation in catch over the time series. Thus, for each species an annual catch that equaled the mean long-term mean catch was scored as a 0 and catches one standard deviation above or below the species-specific mean were scored as 1 or -1, respectively. These annual, species-specific standardized scores were then summed for all species that were regularly caught by the sampling program. To avoid undue influence of very rare ("accidental") catches, species that are not well sampled by a given sampling program (either because the methodology or habitat or both) were not included in the sum of standardized scores. For a species to be included in the annual standardized index for Suisun Marsh, a species had to have been caught in more than one quarter of survey years (at least 9 years) and, in years when the species was detected, the mean catch of that species had to be ≥2.0. Species included in and excluded from the standardized abundance indicator for each sampling program and habitat are listed in Tables 11-13.

An example of the standardization calculations, for the Suisun Marsh data set, follows:

1) Exclude any species that was not detected in at least one-quarter of years sampled and for which catch did not average ≥2.0 in years where the species was detected. Species excluded by this filter were deemed to be those for which presence in the sample was accidental (e.g., accidental presence in the habitat or accidental catch by the gear) – in other words, presence of these species in the sample did not necessarily provide any information about local abundance. Steps that follow refer only to species that were not excluded in this manner.

2) Calculate CPUE for each species in each year,
CPUE = catch of species "x"/trawl = î = [Number of individuals of species "x" caught in year "y"]/ [trawls in year "y"].

3) Calculate overall mean CPUE and standard deviation of CPUE for each species over the 1980-2013 Suisun Marsh survey sampling period. For each species,
[Mean catch = ī = sum of CPUE from 1980-2013/years of survey (n=34)]
[Standard deviation =ŝ= $\sqrt{}$(î-ī)^2/(n-1) = square root of the average squared deviation from the mean].

4) Calculate annual standardized score for each species by subtracting its overall mean CPUE from its annual CPUE and dividing the difference by the standard deviation in CPUE for that species [(î-ī)/ŝ]. For example,

Suisun Marsh American Shad standardized score$_{1980}$ = (AmShadCPUE$_{1980}$ –AverageCPUE$_{1980-2013}$)/Standard Deviation
(0.0745 – 0.12)/0.16 = -0.304

5) Within each year, sum all the standardized values for each species identified above.

Correlation coefficients between these standardized annual abundance indices and their corresponding total abundance indices were calculated. If trends in the total abundance indicator for any sampling program/region/habitat represent trends across their respective local fish assemblages, then the standardized abundance indicator and the total catch abundance indicator ought to be highly correlated. When these two different metrics were not highly correlated, it indicates that a very small number of species drove trends in the total catch indicator. In that case, the standardized abundance indicator was reported as the measure of health for that sampling program/region instead of the total abundance (mean CPUE) indicator. Figures 22 -23 show the sum of the standardized values for catch/trawl for Suisun Marsh and in the Pelagic Zone of the upper Estuary, respectively. The correlation between the standardized and total abundance indicators (r = 0.77, p< 0.001 for Suisun Marsh and r=.0.74 and 0.76, p<0.001 for pelagic zone of Central-West Delta and Suisun Bay, respectively) indicates that trends in the total catch indices represent trends throughout the assemblage as a whole, rather than changes in one species.

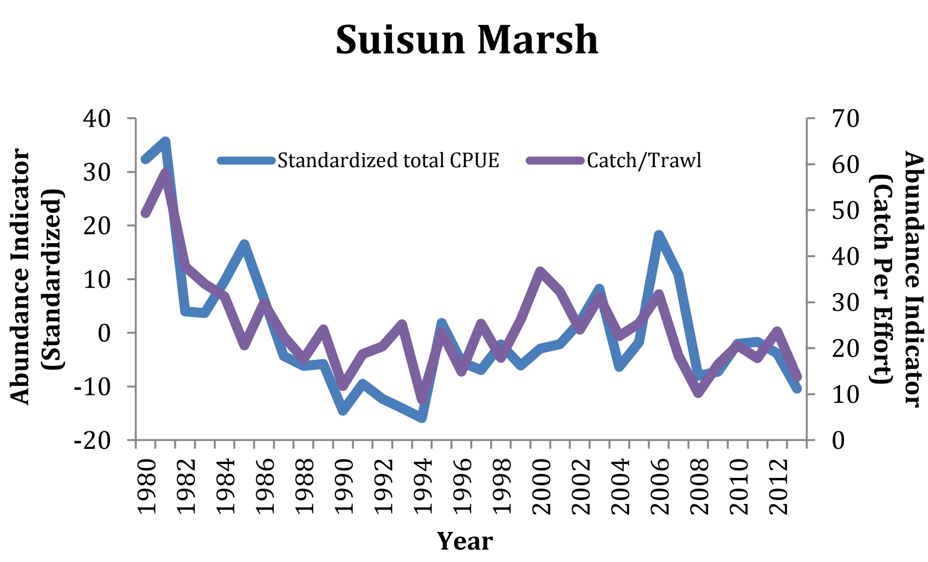


Figure 22. Comparison of raw catch-per-unit-effort (catch-per-trawl) indicator and the standardized catch-per-unit-effort indicator in Suisun Marsh. The correlation between the standardized and raw catch (r = 0.77, p <0.01) indicates that trends in the raw catch-per-unit-effort indicator represents actual trends throughout the assemblage as a whole, rather than changes in one species.

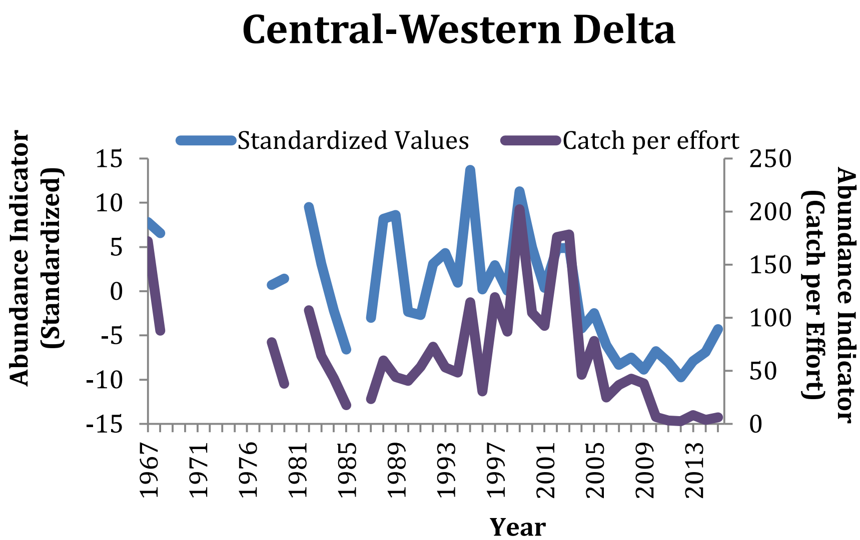


Figure 23. Comparison of raw catch-per-unit-effort indicator and the standardized catch-per-unit-effort indicator in the Pelagic Zone of the Central-West Delta. The correlation between the standardized and raw catch indicators (r = 0.74, p <0.001) suggests that trends in the total catch indicator represent actual trends throughout the assemblage as a whole, rather than changes in one species. Similar correlations were detected between raw catch and standardized values for Suisun Bay (not pictured here; r= 0.76, p<0.001).

The patterns of total fish abundance were more complicated in the Delta Beach Zone data. Regional trends in the CPUE indicator differed, with total abundance increasing through time in throughout Delta Beach Zone regions except for the North Delta regions (Figures 24 and 26). In addition, trends in CPUE were not always reflective of changes in the entire fish assemblage of each region. Standardized abundance scores correlated well with their analogous CPUE abundance indicator in the North Delta (r=0.72, p<0.001), East Delta (r=0.77, p<0.00), and Central-West Delta (r=0.52, p=0.02); but, these indices of relative abundance were not significantly correlated in the South Delta region (Figure 25; r=0.33, p=0.16). This suggests that the CPUE indicator in the South Delta was likely to reflect trends in abundance of just a few species, not the assemblage as a whole. Indeed, when standardized scores of native species and non-native species were compared within regions of the Delta Beach Zone, it became clear that abundance of non-native species had increased through time in the East, Central-West, and South Delta while long-term abundance trends for native species (as a whole) were less obvious (Figure 26). It is worth noting that the correlation of standardized scores between native and non-native species assemblages was positive in all regions of the Delta Beach Zone (and significantly so, in the North and East Delta, Figure 26). Because of differences between regions and between standardized and raw catch per effort values, Delta Beach Zone results are presented in separate regions in the standardized form.

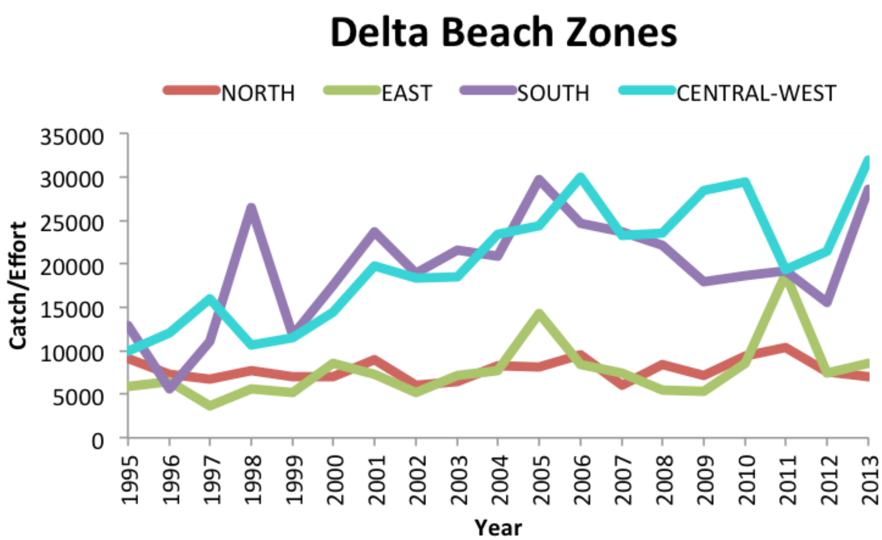


Figure 24. Comparison of Food Web Productivity Indicator (unstandardized, total catch per unit effort) for four Delta Beach Zone regions.

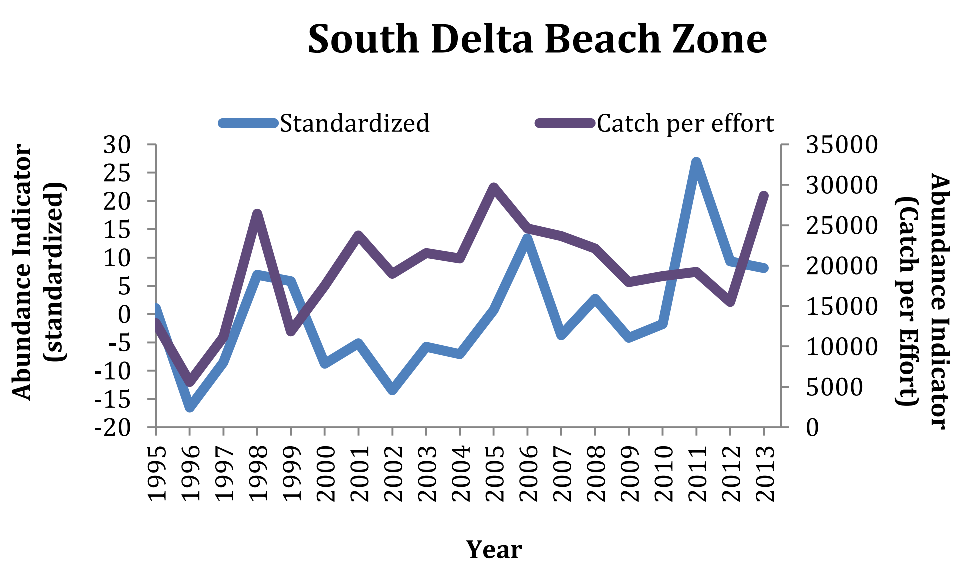


Figure 25. Comparison of raw catch-per-unit-effort indicator and the standardized catch-per-unit-effort indicator in the South Delta Beach Zone. The correlation between the standardized and raw catch indicators ($r = 0.33$, $p = 0.16$) suggests that trends in the total catch indicator may not represent actual trends throughout the assemblage as a whole.

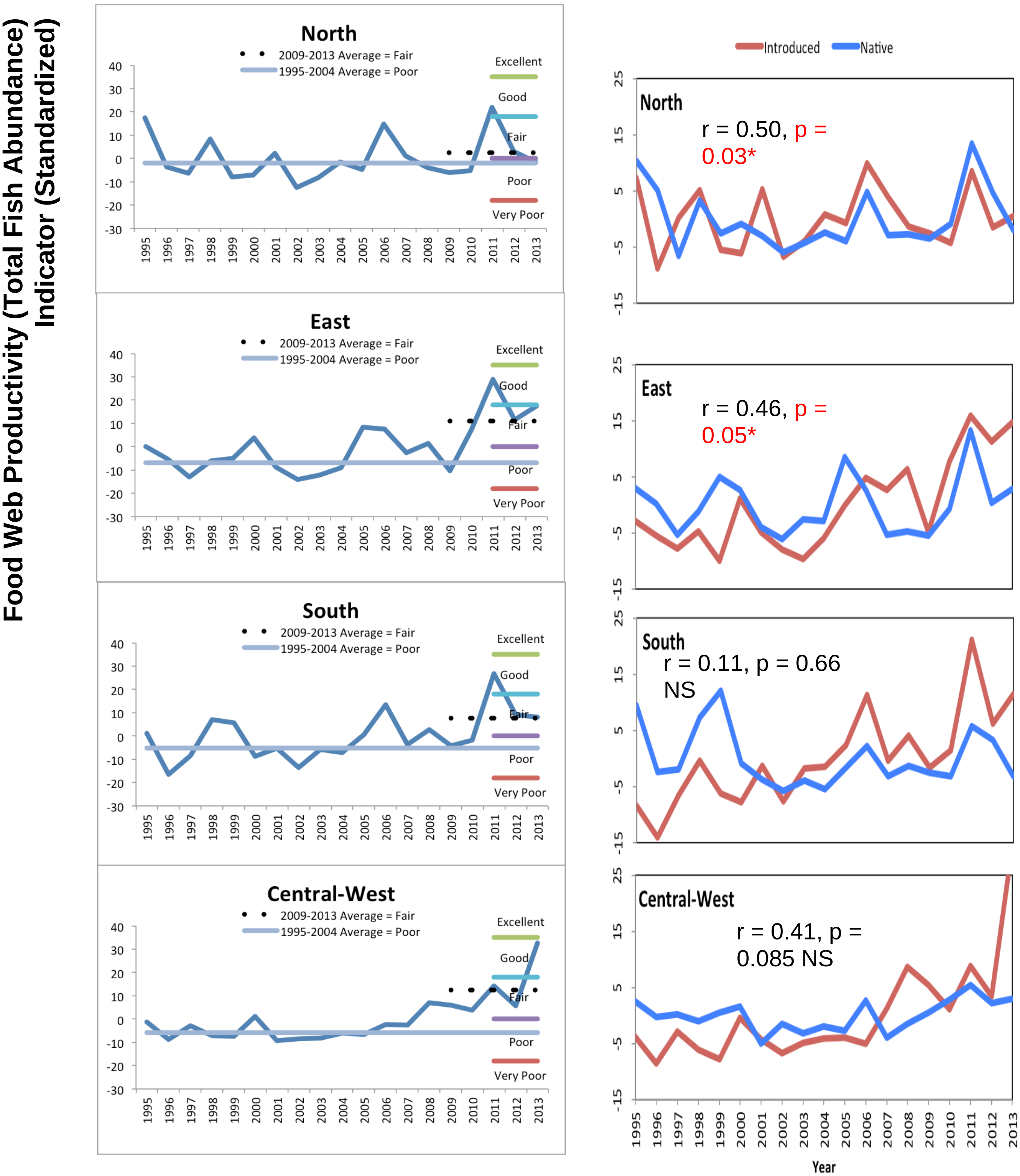


Figure 26. Changes in the four regions of Delta Beach Zone Abundance Indicators through time. *Panels on the left* present the sum of standardized abundance for all species that are well sampled in the regions. Short horizontal colored lines indicate

reference thresholds assigned to this indicator (see Table 15). Scores: above the green line are “excellent”; between the blue and the green lines are “good”; between the blue and light blue lines are “fair”; between the light blue and red lines = “poor”; and below the red line = “very poor”. The primary reference condition (1995-2004 average sum of standardized abundance) is indicated by a light blue horizontal line. For each region, the primary reference condition = 0, indicating that, on average, each species was at its 1995-2014 abundance. The dotted line represents the 2009-2013 average.

Panels on the right show the sum of standardized abundance scores for native (Blue lines) and introduced (red line) fishes. Abundance trends of natives and introduced species are significantly correlated in the North and East Delta. In the South and Central-West regions abundance for the average native and average introduced fish species are not significantly correlated; recent increases in abundance reflect increases in the introduced species assemblage.

Table 11. Species used in the abundance indicator for the Suisun Marsh. Species in bold were used in standardized abundance indicator calculations (Data: UCD Suisun Marsh Juvenile Fishes Sampling Survey Otter Trawl).

Species Used in The Suisun Marsh Abundance Indicator	Native (N) / Introduced (I)	Number of Years Caught	Sum of Catch
American Shad	I	31	1163
Brown Bullhead	I	14	28
Black Crappie	I	27	1850
Sac Blackfish	N	7	24
Bluegill	I	11	19
Black Bullhead	I	27	879
Bigscale Logperch	I	6	17
Bay Pipefish	N	2	2
Channel Catfish	I	24	167
California Halibut	N	3	5
Carp	I	34	5057
Chinook Salmon	N	16	72
Speckled Sandab	N	3	3
Delta Smelt	N	29	659
Fathead Minnow	I	13	36
Goldfish	I	28	298
Green Sturgeon	N	2	3
Green Sunfish	I	4	5
Golden Shiner	I	5	5
Hitch	N	24	114
Hardhead	N	1	1
Inland Silverside	I	34	716
Longfin	N	34	11790
Longjaw mudsucker	N	1	1
Plainfin Midshipman	N	6	11
MosquitoFish	I	10	18
Northern Anchovy	N	15	257
Pacific Herring	N	26	465
Pacific Lamprey	N	13	43
Pacific Sandab	N	2	2
Riffle Sculpin	N	2	2
Rainbow Trout	N	6	7
Rainwater Kilifish	I	14	32
Striped Bass	I	34	83784
Prickly Sculpin	N	34	10460
Strarry Flounder	N	34	2001
Shimofuri Goby	I	28	9974
Shokihaze Goby	I	14	722
Sacramento Sucker	N	34	3331
Shiner Perch	N	4	17

Sacramento Pikeminnow	N	23	148
Surf Smelt	N	3	5
Splittail	N	34	26875
Staghorn sculpin	N	34	2524
Stickleback	N	34	17231
Threadfin shad	I	34	2768
Tule Perch	N	34	19139
Wakasagi smelt	I	5	10
White Catfish	I	33	5453
White Crappie	I	14	112
White Croaker	N	1	1
Warmouth	I	1	1
White Sturgeon	N	26	113
Yellowfin Goby	I	34	19504

Table 12. Species used in the abundance indicators for the Delta Beach Zone. Species in bold were used in standardized abundance indicator calculations. Some species, such as Green Sunfish and Hardhead, were only used in standardized abundance calculations for the regions where they met the minimum requirement for inclusion. These species are indicated with a * (Data: USFWS Delta Juvenile Fishes Program, Beach Seine Survey).

Species Used in The Delta Beach Seine Abundance Index	Native (N) / Introduced (I)	North	Number of years Caught	East	Number of years Caught	South	Number of years Caught	Central-West	Number of years Caught
American Shad	I	464	20	1016	20	626	19	1231	20
Arrow Goby		1	1						
Bass Unknown	NA	18	4	87	3	109	5	81	4
Bigscale Logperch	I	124	18	150	18	1000	20	454	20
Black Bullhead	I	11	2	13	4	2	2	6	3
Black Crappie	I	42	12	27	10	182	14	38	12
Bluegill	I	802	20	975	20	5213	20	770	18
Brown Bullhead	N	1	1	2	2	9	5	15	4
California Roach	N	29	1			1	1	5	1
Chameleon Goby	I	9	3	13	2	1	1	10	5
Channel Catfish	I	13	5	2	2	6	5	2	2
Chinook Salmon	N	68284	20	24286	20	4302	20	20870	20
Common Carp	I	139	9	571	10	2269	18	19	6
Delta Smelt	N	523	20	170	15	38	11	545	19
Fathead Minnow	I	1610	20	89	19	1236	17	84	17
Golden Shiner	I	1793	20	1585	20	2912	20	2145	20
Goldfish	I	12	6	13	6	61	9		
Green Sunfish*	I	10	8	11	5	43	8	8	5
Hardhead*	N	114	11	5	4	28	6	37	6
Hitch	N	310	15	728	11	43	14	420	20
Mississippi Silverside	NA	137153	20	92311	20	544505	20	456867	20
Lamprey Unknown*	N	120	16	27	12	2	2	2	1
Largemouth Bass	N	261	18	2129	20	4298	20	2497	20
Longfin Smelt	I	3	2	8	2	1	1	16	8
Minnow Unknown	NA					2	2	33	2
Pacific Herring	N							18	2
Pacific Lamprey	N	6	4						
Pacific Staghorn Sculpin*	N	12	8	16	6	31	9	857	17
Prickly Sculpin	N	273	18	195	18	489	20	281	17

Rainbow/Steelhead Trout*	N	676	19	179	20	2	2	53	9
Rainwater Killifish*	I	8	5	37	9	1123	15	1331	18
Red Shiner	I	1284	19	284	13	254867	20	91	17
Redear Sunfish	I	76	15	2247	19	5810	20	2901	20
Redeye Bass*	I	1	1	19	6				
River lamprey	N	2	2						
Rosyface Shiner	I	1	1	2	1	10	2	4	2
Sacramento Blackfish*	N	18	6	46	4	61	12	21	3
Sacramento Pikeminnow	N	3857	20	2050	20	1473	20	4381	20
Sacramento Sucker	N	13273	20	18281	20	8628	20	1441	20
Sculpin Unknown	NA	1	1			2	1		
Shimorfuri Goby	I	1151	20	464	15	139	11	408	20
Shokahaze Goby	N					1	1	2	1
Smallmouth Bass	I	72	18	182	18	39	14	23	11
Splittail	N	8863	20	42047	20	31578	20	18884	20
Spotted Bass	I	143	11	1342	13	150	13	58	11
Starry Flounder*	N	9	4			3	3	26	11
Striped Bass	I	209	18	214	16	1801	20	1797	20
Striped Mullet	N							2	1
Threadfin Shad	I	11651	20	2958	19	107035	20	32450	20
Threespine Stickleback*	N	56	11	7	7	3	2	1039	20
Tule Perch	N	2083	20	621	19	241	19	3225	20
Unidentified Fish	NA	3	3	7	2	39	1	2	2
Wakasagi Smelt*	I	2932	20	32	7	2	2	293	13
Warmouth	I	2	1	14	8	6	5	3	3
Western Mosquitofish	I	934	20	2524	20	6520	20	4940	20
White Catfish	I	2	2	19	9	22	12	4	4
White Crappie	I	35	11	14	9	29	8	15	6
Yellow Bullhead	I					1	1		
Yellowfin Goby	I	3498	20	3480	20	1870	19	6040	20

Table 13. Species used in the abundance indicator for the upper estuary pelagic zone. Species in bold were used in standardized abundance indicator calculations. A minimum of being caught in 10 years was set for inclusion to the standardized index because this survey is only for four months of the year. Striped bass were summed for all ages. Some species, such as Channel Catfish and Jacksmelt, were only used in standardized abundance calculations for the regions where they met the minimum requirement for inclusion. These species are indicated with a * (Data: CDFW Fall Midwater Trawl).

Species Used in The Fall Midwater Trawl Abundance Index	Native (N) / Introduced (I)	Number of years Caught Suisun	Number of years Caught West Delta	Suisun Raw Catch	West Delta Raw Catch	Sum of Catch
American Shad	I	45	45	20272	36212	56484
Arrow Goby	N	1	0	5	0	5
Bat Ray	N	1	0	1	0	1
Bay Pipefish	N	1	0	1	0	1
Big Skate	N	0	1	0	29	29
Bigscale Logperch	I	0	1	0	1	1
Black Crappie	I	7	9	6	13	19
Bluegill	I	3	9	5	15	20
Brown Bullhead	N	4	1	1	1	2
Brown Smoothhound	N	2	0	2	0	2
Chameleon Goby	I	3	6	5	19	24
Channel Catfish*	I	1	26	1	421	422
Chinook Salmon	N	41	34	303	352	655
Common Carp	I	21	24	103	114	217
Delta Smelt	N	45	45	7343	6290	13633
Diamond Turbot	N	1	0	1	0	1
flatfish (Unid)	NA	1	0	1	0	1
Goldfish	I	0	4	0	5	5
Green Sturgeon	N	7	3	8	3	11
Green Sunfish	I	2	3	2	4	6
Hitch	N	0	3	0	3	3
Jacksmelt*	N	15	0	45	0	45
Largemouth Bass	N	0	3	0	4	4
Longfin Smelt	N	45	45	114523	6370	120893
Inland Silverside	I	17	21	76	125	201
Night Smelt	N	2	0	17	0	17
Northern Anchovy*	N	45	7	43513	168	43681
Pacific Herring*	N	39	6	1292	15	1307
Pacific Lamprey	N	2	1	1	1	2
Pacific Sanddab	N	1	0	3	0	3
Pacific Sardine	N	1	0	1	0	1
Pacific Staghorn Sculpin*	N	34	5	243	7	250
Pacific Tomcod	N	7	0	27	0	27
Plainfin Midshipman*	N	38	0	1023	0	1023
Prickly Sculpin	N	2	2	8	2	10
Rainwater Killifish	I	0	1	0	2	2
Redear Sunfish	I	0	2	0	2	2
River Lamprey	N	4	3	4	8	12
Sacramento Blackfish	N	0	5	0	8	8
Sacramento Perch	N	0	1	0	1	1
Sacramento Pikeminnow	N	3	2	5	2	7
Sacramento Sucker	N	0	1	0	1	1

Shimofuri Goby	I	8	13	14	57	71
Shiner Perch	N	11	1	461	3	464
Shokihaze Goby	I	4	1	7	1	8
Speckled Sanddab	N	2	0	2	0	2
Splittail	N	38	26	733	70	803
Spotted Bass	I	1	0	1	0	1
Starry Flounder	N	39	14	302	29	331
Steelhead	N	10	3	19	5	24
Striped Bass age0	I	45	45	45279	15613	60892
Striped Bass age1	I	45	43	3206	1000	4206
Striped Bass age2plus	I	43	35	666	118	784
Striped Bass age3plus	I	14	9	18	12	30
Surf Smelt	N	2	0	1	0	1
Threadfin Shad	I	45	45	6566	105948	112514
Threespine Stickleback*	N	22	4	48	5	53
Topsmelt*	N	26	0	150	0	150
Tule Perch	N	7	11	6	13	19
Wakasagi	I	4	2	7	4	11
Walleye Surfperch	N	1	0	1	0	1
Western Mosquitofish	I	1	3	1	3	4
White Catfish	I	19	41	331	3612	3943
White Crappie	I	2	7	3	16	19
White Croaker*	N	23	0	88	0	88
White Seaperch	N	2	0	1	0	1
White Sturgeon	N	36	28	390	74	464
Whitebait Smelt	N	2	0	6	0	6
Yellowfin Goby	I	40	29	1228	351	1579

3. Reference Conditions

Wherever possible, the 1980-1989 average index value was used as the primary reference condition for abundance indicators. This is consistent with the Bay fish indicators (SOTB 2011). In the SOTB (2011), the 1980-1989 average is considered "good", recognizing that some fish populations were already in decline by the 1980's. A five-tier scale rates annual average CPUE over time from "very poor" to "excellent". Any individual year in the record may be compared to the reference condition and scored.

Suisun Marsh

The 1980-89 average catch per trawl was established as the primary reference condition for this data set. These were the earliest years for which data was available. Following SOTB (2011), the 5-tiered scoring system was developed for other intermediate reference conditions as described in Table 14.

Table 14. Quantitative reference conditions and associated interpretations for the Suisun Marsh Fish Abundance Indicator. The average score during the primary reference period, which corresponds to "good" conditions, is in bold and all other reference conditions are calculated from that value (e.g. "excellent" is 150% of the 1980-1989 value).

Abundance Indicators Suisun Marsh Catch Per Effort (Data: UCD Suisun Marsh Fish Survey, Otter Trawl)			
Quantitative Reference Condition	**Interpretation**	**Low End of Range**	**High End of Range**
>150% of the 1980-1989 Average	Excellent	>48.78	N/A
>100% of the 1980-1989 Average	**Good**	**>32.52**	**48.78**
>50% of the 1980-1989 Average	Fair	>16.26	32.51
>15% of the 1980-1989 Average	Poor	>4.88	16.25
<15% of the 1980-1989 Average	Very Poor	N/A	<4.88

Delta Beach Zone

The Beach Seine survey was not consistently conducted year-round until 1995. Thus, average catch per effort from 1995-2004 was established as the primary reference condition for this sampling program. The primary reference condition, during this period was scored as "fair" to match the average score of the total fish abundance indicator (native plus introduced species) scores for Suisun Marsh and Pelagic Zone abundance indicators during the same period. Following SOTB (2011), the 5-tiered scoring system was developed for other intermediate reference conditions. Evaluation thresholds for these summed standardized scores are described in Table 15.

Because the Delta Beach Zone Indicator for Food Web Productivity is standardized, cut-offs for different intermediate reference conditions (qualitative scoring categories) were calculated differently than for other sampling programs/habitats. Standardization within each species set each species long-term average abundance to 0 and the standard deviation of abundance to 1. In a given year, if the average species was at its long term average, the sum of all species standardized abundance values would also be 0. The 1995-2013 long term average for all species (cumulative index score = 0) was considered to be "fair" to account for the fact that species abundance had already declined by 1995 and to correspond with averages from Suisun Marsh and Fall

Midwater Trawl during this time period. “Excellent” conditions indicated that the average species was 1 standard deviation above its long term average. Because there were 36 species included in this index, if the average standardized fish species abundance was 1, the cumulative index score would 36 (i.e. standardized score* number of species = 1* 36). “Good” conditions reflected the average species being ½ standard deviation above its long term average (cumulative score = 18), and “poor” conditions reflected that the average species abundance was 0.5 standard deviations below its long term average (cumulative index score = -18). “Very poor” conditions represented that the average species was more than 0.5 standard deviations below its long term average abundance (cumulative index score: <-18).

Table 15. Quantitative reference conditions and associated interpretations for the results of the Delta Beach Zone standardized fish abundance indicator. The average of the primary reference condition, which corresponds to “fair” conditions, is in bold. The primary reference condition was rated “fair” to correspond to scores for the Suisun Marsh and Fall Midwater trawl during the 1995-2009 time period.

Standardized Abundance Indicators Delta Beach Zone (Data: USFWS Delta Juvenile Fishes Program, Beach Seine Survey)			
North Delta, East Delta, South Delta and Central-West Delta			
Quantitative Reference Condition	**Interpretation**	**Low End of Range**	**High End of Range**
>One standard deviation above the 1995-2013 average	Excellent	>36	NA
> One half the standard deviation above the 1995-2013 average	Good	>18	36
>Standard Average of 1995-2013 (0)	**Fair**	**0**	**18**
> One half the standard deviation below the 1995-2013 average	Poor	-18	0
< One half the standard deviation below the 1995-2013 average	Very Poor	NA	<-18

Pelagic Zone of the Upper Estuary

The 1980-89 average catch per effort was established as the primary reference condition for this data set. Following SOTB (2011), the 5-tiered scoring system was developed for other intermediate reference conditions as described in Table 16.

Table 16. Quantitative reference conditions and associated interpretations for the results of the Upper Estuary Pelagic Zone Fish Abundance Indicator. The average during the primary reference condition, which corresponds to “good” conditions, is in bold.

Abundance Indicators Pelagic Zone Catch Per Effort (Data: CDFW Fall Midwater Trawl)			
Central-West Delta			
Quantitative Reference Condition	Interpretation	Low End of Range	High End of Range
>150% of the 1980-1989 Average	Excellent	>75.54	NA
>100% of the 1980-1989 Average	**Good**	**>50**	**75.54**
>50% of the 1980-1989 Average	Fair	>25.18	50
>15% of the 1980-1989 Average	Poor	>7	25.18
<15% of the 1980-1989 Average	Very Poor	NA	>7
Central-West Delta			
Quantitative Reference Condition	Interpretation	Low End of Range	High End of Range
>150% of the 1980-1989 Average	Excellent	>195.85	NA
>100% of the 1980-1989 Average	**Good**	**>131**	**195.85**
>50% of the 1980-1989 Average	Fair	>65.28	131
>15% of the 1980-1989 Average	Poor	>19.58	65.28
<15% of the 1980-1989 Average	Very Poor	NA	<19.58

4. Results of Food Web Productivity Indicator (Total Fish Abundance)

Suisun Marsh

Total Fish abundance in Suisun Marsh declined over the period of record (Figure 27). Levels detected in the first few years of the survey were “excellent” or “good”, but became consistently “fair” or “poor” during the late 1980’s and early 1990’s. A rebound in fish abundance caused the indicator to reach “good” conditions in the year 2000, but since that time, abundance has declined and was “fair” or “poor” (on average, “fair”), over the last five years.

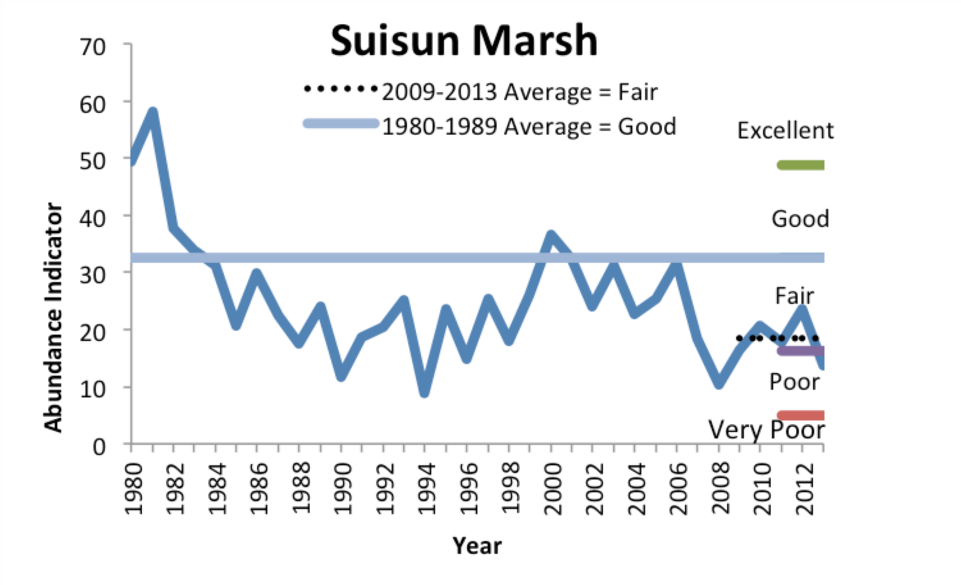


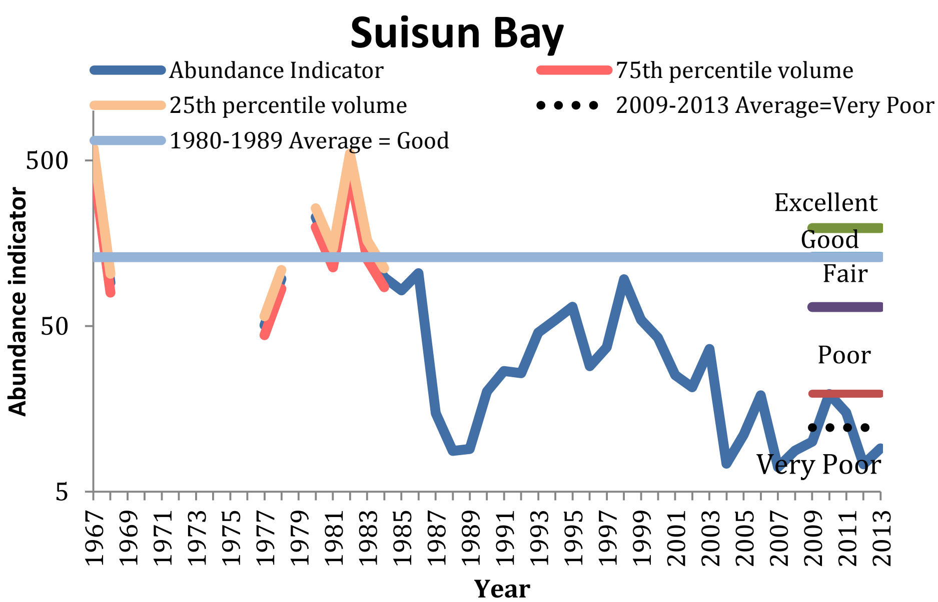
Figure 27. Suisun Marsh Food Web Productivity Indicator (Total Fish Abundance) from 1980-2013. Over the period of record the abundance indicator has declined and the recent five-year average is "fair". Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 14). The primary reference condition (1980-1989 average) is indicated by a light blue horizontal line.

Upper Estuary Pelagic Zone

Total fish abundance Indicators in the Pelagic Zone have declined dramatically over time, with recent averages that were "very poor". Small differences were detected in the fish assemblage abundance patterns between the two regions sampled – Suisun Bay (Figure 28) and the Central-West Delta (Figure 29). Although total fish abundance indicators in both regions declined dramatically, they displayed different patterns of decline. The abundance indicator in Suisun Bay followed a trend that was broadly similar to that seen in Suisun Marsh abundance; the abundance indicator was "excellent" in the early years of the survey and even in the earliest years of the primary reference period (1980-1989). However, they declined rapidly just prior to the onset of the 1987-1994 drought. A small rebound in abundance was detected in the late-1990's, but the indicator declined persistently through the early 2000's. The average of the last five years indicates that the fish assemblage in this region/habitat was in "very poor" condition.

Total fish abundance trends in the Central-West Delta Pelagic Zone are different in degree from those described for the Suisun Bay Pelagic Zone and Suisun Marsh. Here, the abundance index appeared to be somewhat stable throughout the 1980's and early 1990's. Both, the increase in the late 1990's (to "excellent") and the precipitous decline in abundance after the early 2000's were consistent with patterns seen in Suisun Bay and Suisun Marsh. The average of the most recent five years indicated that the pelagic fish assemblage in this area is in "very poor" condition.

a. Log-Scale



b. Actual CPUE

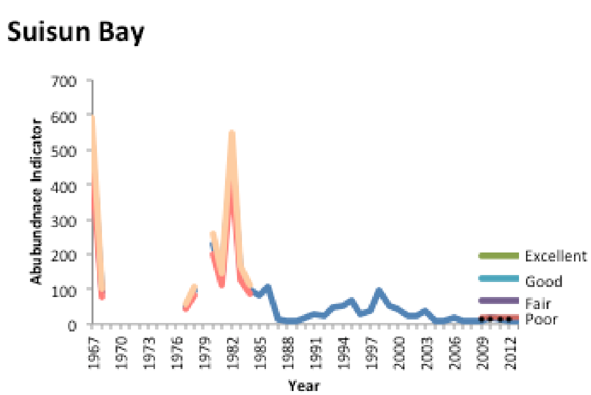
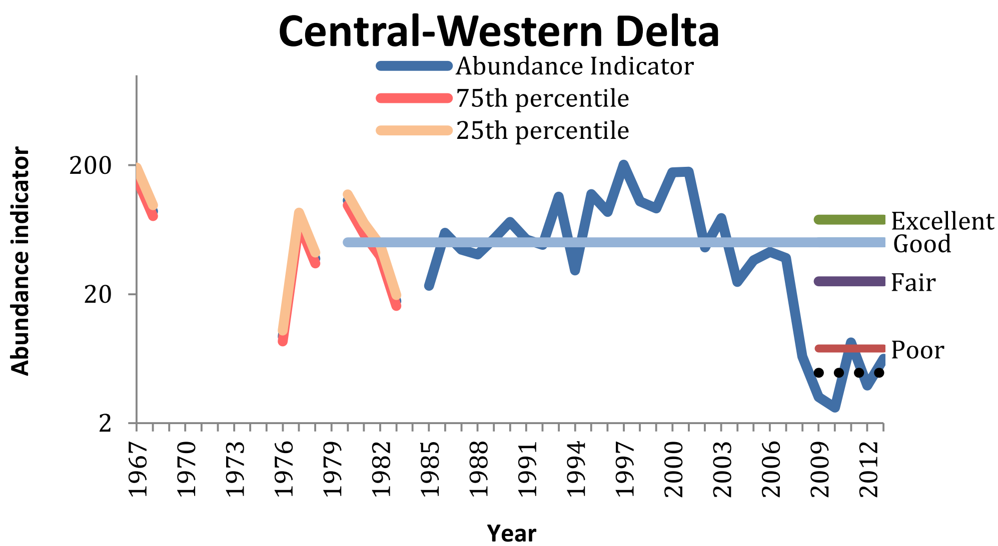


Figure 28. Upper Estuary Pelagic Zone Food Web Productivity Indicator (Total Fish Abundance) for the Suisun Bay region from 1967-2013. In Panel a, the y-axis is log scale; declines appear more pronounced on an untransformed scale (Panel b). Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 12). The primary reference condition (1980-1989 average) is indicated by a light blue horizontal line. The dotted line represents the 2009-2013 average. Fish abundance in the Pelagic Zone of Suisun Bay is “very poor”. Volume sampled was not recorded consistently during 1967-1984 period; thus, for this period, volume sampled was estimated as the mean volume from 1985-2013. Catch-per-unit-effort (i.e., per volume)

was also estimates using the 25th and 75th percentile values of volume sampled between 1985-2013; the effect of different sampling volume estimates are shown in peach and pink lines respectively.

a. Log Scale



b. Actual CPUE

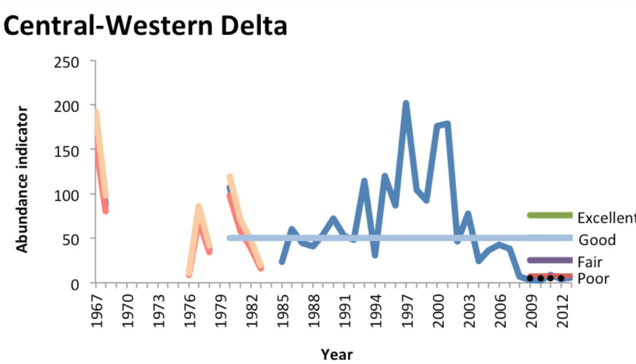


Figure 29. Upper Estuary Pelagic Zone Abundance Indicator for the Central-West Delta region from 1967-2013. In Panel a, the y-axis is log scale; declines appear more pronounced on an untransformed scale (Panel b). In either case, there has been a rapid decline in fish abundance since the year 2000. Short horizontal colored lines indicate scoring thresholds assigned to this indicator (see Table 12). The primary reference condition (1980-1989 average) is indicated by a light blue horizontal line. The dotted line represents the 2009-2013 average and shows that fish abundance in the Pelagic Zone of the Central-Western Delta is "very poor".

Beach Zone

In most regions of the Delta Beach Zone, total fish abundance has increased over the period of record (Figure 24). Trends in total fish abundance in the South and Central-West Delta Beach Zone but differed from trends in the North Delta Beach Zone (Figure 24). ***In some regions, fluctuations in the raw abundance indices were clearly driven by extreme population changes in abundance of just a few species (Figures 21 and 25).*** Fish that dominate the raw abundance indices (the most common fishes) may or may not represent prey or competitors to other species in the area. As a result, indicators of standardized fish abundance are presented for all species in each region of the Delta and standardized abundance of native and non-native species are compared to determine if different parts of the fish assemblage displayed different abundance trends.

North Delta. Abundance of the average fish species increased slightly from "poor" to "fair" in the Beach Zone of the northern Delta over the last 20 years (Figure 26, left panel). Abundance trends in the North Delta Beach Zone were generally more stable than those in other regions of the Delta Beach Zone (Figure 24). When standardized abundance scores of native species and introduced species were compared (Figure 26, right panel), standardized abundance of the two groups were significantly and positively correlated. This indicates (slight) improvement in the average abundance of the average fish species in the North Delta regardless of whether they were native or non-native.

East Delta. Abundance of the average fish species increased from "poor" to "fair" in the East Delta Beach Zone over the last 20 years (Figure 24; Figure 26, left panel). As with the North Delta Beach Zone, the standardized abundance indicator was "poor" in the early sampling period, hitting a low in the early 2000's. After the early 2000's, the index increased hitting a high for the period of record in 2011 (Figure 24 and 26) -- the average of the last five years is "fair". As in the North Delta, standardized abundance scores of native species and introduced species were significantly correlated (Figure 26, right panel), indicating that native and introduced species are contributing to the improvement in overall abundance.

South Delta. Abundance of the average fish species in the South Delta Beach Zone increased from "poor" to "fair", with some recent years scoring "good" on our scale (Figure 26, left panel); however, standardized abundance scores of native species and introduced species reveal that non-native species accounted for all of the apparent increase in abundance in recent years (Figure 26, right panel). Native species declined in the early years of sampling but the abundance of the average native species remained relatively stable since about the year 2000. The abundance of the average non-native species increased driving an increase in overall fish abundance in this region (see also Figure 24).

Central-West Delta. Abundance of the average fish species in the central and western Delta Beach Zone has increased from "poor" to "fair" (Figure 26, left

panel). Total fish abundance has increased dramatically over the past twenty years in this region of the Delta Beach Zone (Figure 24). As in the South Delta Beach Zone, standardized abundance scores of native species and introduced species were not significantly correlated in this region and introduced species accounted for all of the increase in fish abundance in recent years (Figure 26, right panel).

Summary of Beach Zone Total fish abundance and Diversity Trends
Taken together, the Beach Seine data reveal that abundance of fish in the shallow, unvegetated waters of the Delta increased in recent years, from “poor” to “fair”. Much of this increase was due to a consistent increase across regions in the abundance of introduced species. While our standardized indicator reduces the effect of any one species on the overall pattern for the assemblage, it is worth noting that two non-native species (Inland Silverside and Red Shiner) accounted for the vast majority of all fish caught in the Delta beach seine (Figure 21). Native species abundance increased in concert with introduced species in two regions (North and East Delta) and remained mostly stable in the South and Central-West data.

Analysis of abundance data from this sampling survey reveals important lessons about the construction and application of indicators to measure the health of an assemblage or larger ecosystem. For example, the fact that abundance has increased in all of the four regions of the Delta does not necessarily indicate that the health of the local fish assemblage is improving. Although native species abundance remained stable in some regions and increased in others, most of the change in Delta Beach Zone fish abundance has been due to large increase in abundance of introduced species. Finally, the increases in abundance of native species in some regions of the Delta Beach zone were primarily due to species that spawn predominantly outside of the Delta-proper and then migrate into the sampling area (e.g. Sacramento sucker and Sacramento splittail). These findings reveal the value of evaluating multiple “health” indicators and emphasize the need to dissect trends in synthetic indicators to increase resolution of underlying trends.

5. Summary of Food Web Productivity Indicator (Total Fish Abundance)

Total abundance of fishes in the Pelagic Zone and Suisun Marsh decreased substantially since the early 1980’s and the decline has accelerated since the early part of this century; trends in abundance were remarkably similar between these two habitats. Total fish abundance and abundance of the average fish species in the Delta Beach Zone has increased in recent years; most (but not all) of this change is attributable to increases in abundance of introduced fish species in this habitat/region.

Based on abundance, the CCMP goals to recover and reverse declines of estuarine fishes (SFEP 2007) have not been met in the upper Estuary region.

V. SUMMARY

Collectively the results of fish indicators for the upper Estuary provide insight into a few key attributes of fish assemblage health. **Although no synthetic index of our measures of assemblage health was constructed, it is clear that the fish assemblage in the upper Estuary is in very bad condition (Table 17).** The "good news" is that food web productivity (total fish abundance) indicators in Suisun Marsh (Figure 27) and the Delta Beach Zone (Figure 26) scored "fair" (a decline for the former, but an increase for the latter habitat). Pelagic Zone food web productivity indicators were "very poor" across the upper Estuary (Figures 28 and 29). Total fish abundance in all zones was dominated by introduced fish as most regions scored "very poor" or "poor" for assemblage composition indicators and native fish abundance.

Also, there was no suggestion that introduced species abundance negatively affected indicators of native species abundance, as a whole. In the Delta Beach Zone, the pattern indicated that abundance of native and introduced assemblages were positively correlated or uncorrelated, not negatively correlated as one would expect if introduced species were bad for native species, as a whole. In other habitats, the fraction of fish caught that were native species remained very low throughout the period and were not correlated with the declines in indicators of total fish abundance over the period of record.

Because this coarse metric does not reveal where the fish sampled were produced, a more refined investigation is warranted to determine whether native species and introcued species abundances responded to the same environmental processes and/ or the local operation of those processes. Also, these indicators were designed to reflect trends across a broad range of species and, as a result, they say little about the trends in any one species and the particular forces that drive those changes. Thus, it is possible that certain native fish species are responding to direct or indirect effects of introduced fish species, even though the assemblage-wide trends do not detect a general pattern of this type. Future indicators that assess species distribution and other attributes of health will likely increase our understanding of the health of fishes in upper Estuary and the local mechanisms that contribute to assemblage health.

Table 17. Summary of Results relative to the CCMP goals to “recover” and “reverse” declines of estuarine fishes for the fish indicators in the Upper San Francisco Estuary.

Indicator	Region (Sub-region if trends are different)	CCMP Goal Met	Evaluation		Trend
			Reference Period	Short-Term (last five years)	Over the Period of Record
Native Fish Abundance	Suisun Marsh	No	Good	Poor	Decline
	Suisun Bay Pelagic	No	Good	Very Poor	Decline
	Central-West Delta Pelagic	No	Good	Very Poor	Decline
	Delta Beach Zone	No	Poor	Poor	Stable
Percent Native Fish	Suisun Marsh	No	Very Poor	Very Poor	Stable
	Suisun Bay Pelagic	No	Poor	Poor	Stable
	Central-West Delta Pelagic	No	Very Poor	Very Poor	Stable
	Delta Beach Zone	No	Very Poor	Very Poor	Stable
Percent Native Species	Suisun Marsh	No	Poor	Very Poor	Decline
	Suisun Bay Pelagic	No	Fair	Fair	Stable
	Central-West Delta Pelagic	No	Poor	Very Poor	Decline
	Delta Beach Zone	No	Very Poor	Very Poor	Stable
Food Web Productivity Indicator	Suisun Marsh	NA	Good	Fair	Decline
	Suisun Bay Pelagic	NA	Good	Very Poor	Decline
	Central-West Delta Pelagic	NA	Good	Very Poor	Decline
	Delta Beach Zone – North	NA	Poor	Fair	Increase
	Delta Beach Zone – East	NA	Poor	Fair	Increase
	Delta Beach Zone – South	NA	Poor	Fair	Increase
	Delta Beach Zone – Central-West	NA	Poor	Fair	Increase

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