State of the Estuary Report 2015

Summary

HABITAT – Open Water Habitat Indicators
Summary

Prepared by Christina Swanson
Natural Resources Defense Council
September 2015

State of the San Francisco Estuary 2015

HABITAT – Open Water Habitat Indicators
Summary

Prepared by Christina Swanson
Natural Resources Defense Council
September 2015

What are the indicators?

The State of the Estuary Report uses two indicators to measure and evaluate the frequency, magnitude, and duration of the occurrence of good quality open water habitat conditions in estuary. The Delta Open Water Habitat indicator measures hydrodynamics and the occurrence of net downstream flow in the Delta. The Estuarine Open Water Habitat indicator measures the occurrence of low salinity conditions in the Bay's upstream embayment, Suisun Bay, during the ecologically important spring period.

Table 1.

Attribute	Indicators	Benchmarks
Habitat (Open Water Habitat)	Two indicators measure the frequency, magnitude and duration of: 1) net downstream flow in the western Delta (Delta Open Water Habitat indicator); and 2) low salinity habitat in Suisun Bay during the spring (Estuarine Open Water Habitat indicator).	Benchmarks (or reference conditions) are based on: 1) relationships between hydrodynamic conditions and entrainment of fishes at the state and federal water export facilities; 2) relationships between X2 and estuarine species survival and population abundance; 3) current regulatory standards for seasonal Delta outflow (i.e., State Water Resources Control Board, 2006 Water Quality Control Plan); and 4) unimpaired, pre-dam (before 1944) and pre-water export facility (before 1970) flow conditions.

Why is open water habitat important?

Most of the area of the San Francisco Bay Estuary is open water habitat. In the large, mostly shallow embayments – Suisun, San Pablo and South Bays – open water habitat conditions are largely defined by salinity, which varies seasonally and can range from near freshwater conditions in Suisun Bay to as salty as the adjacent Pacific Ocean in South Bay. In the Delta, with its narrow, relatively deep channels, large inputs of freshwater from the estuary's tributary rivers, and large water diversion facilities which extract large volumes of water, open water habitat conditions are more defined by hydrodynamics, or the movement patterns of water in its channels.

Both of these open water habitat features are affected by freshwater inflows from the estuary's Sacramento-San Joaquin watershed and by diversions of those flows upstream of the estuary and in the Delta. High river inflows push water through the Delta from the north, east and south to the west into Suisun Bay where it mixes with saltier water from the Bay and Pacific Ocean, creating the low salinity, brackish water habitat that is a defining feature of estuaries. Low river inflows and/or high rates of water extraction in the Delta can alter and even reverse flow patterns in Delta channels, changing open water channel habitat conditions and, by reducing freshwater inflows to Suisun Bay, reduce the quality and quantity of low salinity, estuarine open water habitat.

What are the benchmarks? How were they selected?

The benchmarks (or reference conditions) for the two indicators are based on: 1) relationships between Delta channel hydrodynamic conditions and entrainment of fishes at the state and federal water export facilities; 2) relationships between X2 (a measure of the location of low salinity habitat in the estuary) and estuarine species survival and population abundance; 3) current regulatory standards for seasonal Delta outflow (i.e., State Water Resources Control Board, 2006 Water Quality Control Plan); and 4) unimpaired, pre-dam (before 1944) and pre-water export facility (before 1970) flow conditions. The benchmark (or primary reference condition) for the frequency, magnitude and duration components of the two indicators was set to conditions that correspond with low entrainment mortality and moderately good species abundance and survival per the relationships identified above.

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

The two open water habitat indicators show that the frequency, magnitude and duration of the occurrence of "good" quality open water habitat have declined significantly since the 1970s and are now poor in most years. Hydrodynamics conditions in the Delta have deteriorated consistently "good" prior to 1970 to "poor" or "very poor" in most (68%) years. Springtime low salinity habitat conditions are more variable but, since the 1990s, they have been "poor" or "very poor" in most years.

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; 1930-2014)**	**Trend since 1990**	**Current condition** (average for last 10 years)
Delta Open Water Habitat	Not met; goals achieved in 4% of years	Decline	Deteriorating	Poor Frequency, magnitude and duration net downstream flow conditions too low to support native species in the Delta
Estuarine Open Water Habitat	Not met; goals achieved in 20% of years	Decline	Mixed	Poor Frequency, magnitude and duration of good quality low salinity habitat in the spring too low support to

				flow-dependent fish and invertebrates

What does it mean? Why do we care?

Open water habitat in the San Francisco Bay Estuary is used by many fish and invertebrates species, including all six of the Endangered Species Act listed fish species. The open water habitat conditions measured by the two indicators affect the species composition, survival and population abundance of many fish and invertebrates species in the Estuary. The declines in habitat condition measured by the two indicators, channel flow patterns in the Delta and seasonal low salinity habitat quality and quantity in the Bay's upstream embayment, Suisun Bay, are the result of human activities: water management in the Estuary's watershed and in the Delta. Regulatory standards for freshwater inflows to the Estuary and Delta water export rates affect both of these open water habitat characteristics but those standards have not provided habitat conditions that, according to this evaluation, meet the CCMP goals nor prevented the continuing decline in these habitat conditions. Restoration of the San Francisco Bay's estuarine ecosystem and recovery of its many threatened species will require improving open water habitat conditions.

State of the Estuary Report 2015

Technical Appendix

HABITAT – Open Water Habitat Indicators
Technical Appendix

Prepared by Christina Swanson
Natural Resources Defense Council
June 2015

State of San Francisco Estuary 2015

HABITAT – Open Water Habitat Indicators Technical Appendix

Prepared by Christina Swanson
Natural Resources Defense Council
June 2015

I. Background and Rationale

The San Francisco Bay Estuary is large and geographically complex; the surface area of the entire waterbody is more than 1600 square miles (SFEI 1994). Therefore, not surprisingly, the physical and ecological characteristics of its open water habitats differ substantially among the estuary's different regions. In the Bay's large, mostly shallow embayments – Suisun, San Pablo and South Bays – open water habitat is largely defined by salinity, which can range from near freshwater conditions in Suisun Bay to as salty as the adjacent Pacific Ocean in South Bay (Kimmerer 2002, 2004). In contrast, the upstream region of the estuary, the Delta, is both highly channelized with open water habitat confined to narrow, relatively deep channels and, except during periods of extremely low freshwater inflows, predominately fresh water. In addition, the Delta receives large, localized inputs of freshwater inflow from the Sacramento, San Joaquin and eastside tributary rivers and is also the site of several water diversion facilities where large volumes of water are extracted from some Delta channels. Thus, in the Delta, hydrodynamics, or the movement patterns of water in its channels, is an important open water habitat characteristic.

Both of these open water habitat features are affected by freshwater inflows from the estuary's Sacramento-San Joaquin watershed and by diversions of those flows upstream of the estuary and in the Delta (see also Freshwater Inflow Index).[1] High river inflows push water through the Delta from the north, east and south to the west into Suisun Bay. There, the inflowing fresh water mixes with saltier water from the Bay and Pacific Ocean, creating the low salinity, brackish water habitat that is a defining feature of estuaries. Low river inflows and/or high rates of water extraction in the Delta can alter and even reverse flow patterns in Delta channels, changing open water channel habitat conditions and, by reducing freshwater inflows to Suisun Bay, reduce the quality and quantity of low salinity, estuarine open water habitat (Jassby et al. 1995; Kimmerer 2002, 2004; Feyrer et al. 2007; CCWD 20012).

[1] Flows in Delta channels and the Bay are also influenced by tidal action. The estuary experiences two tides every day, two high tides and two low tides, and magnitude of the high and low tides varies over a 28-day spring-neap cycle. Under conditions of low to moderate inflows, tidal flows in Delta channels can be an order of magnitude greater than the freshwater inflow and the direction of flow in the channels typically reverses twice daily with the tides. However, all flow data used to calculate the indicators are daily averages and have been filtered to remove tidal effects.

In the Delta and Bay, the conditions of these different habitat characteristics – salinity and hydrodynamics – have been shown to be related to the abundance, survival and species composition of fish and invertebrates that live in and move through these habitats. For example, native fish species are more prevalent in Delta channels with higher flows (as well as high turbidity) than in channels with lower or altered flows, which favor non-native species (Feyrer and Healey 2003). Further, alteration or even reversal of natural flow movements in Delta channels induced by operations of the local water export facilities can lethally entrain fish and other small pelagic organisms, with entrainment rates directly related to the magnitude of "reverse" flows in some Delta channels (Grimaldo et al. 2009). Downstream in the estuary, the location of low salinity habitat in Suisun Bay rather than further upstream in the Delta during the spring corresponds to higher survival and population abundance of numerous estuarine fish and invertebrate species (Jassby et al. 1995; Kimmerer 2004; Feyrer et al. 2007).

The State of the Estuary Report uses two indicators to measure and evaluate the frequency (or "how often?"), magnitude ("how much?") and duration ("how long?") of the occurrence of good quality open water habitat conditions in estuary. The Delta Open Water Habitat indicator measures hydrodynamics and the occurrence of "reverse flow" conditions in the Delta. The Estuarine Open Water Habitat indicator measures the occurrence of low salinity conditions in the Bay's upstream embayment, Suisun Bay, during the ecologically important spring period. Figure 1 shows the locations for the measurements of these two indicators.

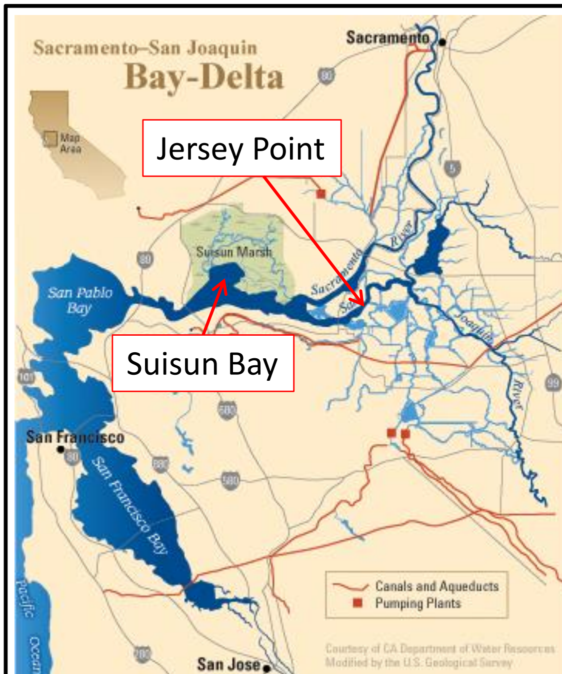

Figure 1. Open water habitats of the San Francisco Bay and Delta. The Delta Open Water Habitat indicator is measured in the western Delta at Jersey Point. The Estuarine Open Water Habitat indicator is measured in Suisun Bay, the upstream embayment of the San Francisco Bay.
Source: U.S. Geological Survey, available at: http://pubs.usgs.gov/fs/2010/3032/

II. Data Sources

The Delta Open Water Habitat and Estuarine Open Water Habitat indicators were calculated for each year using daily data from the California Department of Water Resources (CDWR) DAYFLOW model (using Qwest[2] for the Delta Open Water Habitat indicator and X2[3] for the Estuarine Open Water Habitat indicator). DAYFLOW is a computer model developed in 1978 as an accounting tool for calculating historical Delta outflow, X2 and other internal Delta flows.[4] DAYFLOW output is used extensively in studies by state and federal agencies, universities, and consultants. DAYFLOW

[2] Qwest is the estimated flow in the San Joaquin River at Jersey Point, located in the western Delta.
[3] X2 is a commonly used indicator of the location and quality of low salinity habitat in the San Francisco Bay Estuary. It represents the linear distance in kilometers upstream from the Golden Gate of the 2 ppt isohaline and it is calculated as a function of Delta outflow (or Bay inflow) from equations published in Jassby et al. (1995).
[4] More information about DAYFLOW is available at www.iep.ca.gov/dayflow.

output is available for the period 1930-2014. For the Delta Open Water Habitat indicator, additional information on interior Delta channel flows provided by the Contra Costa Water District was used to inform development of reference conditions and interpret indicator results (CCWD 2012).[5] For the Estuarine Open Water Habitat indicator, information on unimpaired Delta outflow (or Bay inflow) from CDWR's California Central Valley Unimpaired Flow dataset and calculated X2 conditions (Jassby et al. 1995) was used to inform development of reference conditions and interpret indicator results.[6]

III. Indicator Evaluation and Reference Conditions

The San Francisco Estuary Partnership's Comprehensive Conservation and Management Plan's (CCMP) goal for "restor[ing] healthy estuarine habitat" is non-quantitative. However, for a number of resident and migratory fish and invertebrate species, entrainment mortality, survival and population abundance are related to in-Delta hydrodynamic conditions and/or seasonal low salinity habitat conditions in the upper estuary, Suisun Bay. Therefore, the primary and intermediate reference conditions against which the measured values of the indicator component metrics were compared were based on relationships between hydrodynamic conditions and entrainment of fishes at the state and federal water export facilities (e.g., CCWD 2012), and relationships between X2 and estuarine species survival and population abundance (e.g., Kimmerer 2002, 2004), as well as examination of current regulatory standards, unimpaired flows, and pre-dam (before 1944) and pre-water export facility conditions (before 1970).

For each indicator and its frequency, magnitude and duration component metrics, a primary reference condition was established. Measured values that were higher than the primary reference condition were interpreted to mean that aspect of open water habitat conditions met the CCMP goals and corresponded to "good" ecological conditions. Specific information on the primary reference condition and additional intermediate reference conditions is provided below for each indicator.

Effects of Water Year Type on Flood Flows and the Indicators: Runoff from the Sacramento-San Joaquin watershed can vary dramatically from year to year, a function of California's temperate climate and unpredictable occurrences of droughts and floods.[7] Even in the current system, in which flows are highly altered by dams and water diversion, annual and seasonal flow volumes vary substantially between wet and dry years. However, for evaluation of these two

---

[5] Data from Contra Costa Water District's Flow Index for Old and Middle River flows were kindly provided by Deanna Sereno, Contra Costa Water District.

[6] Unimpaired inflow is the freshwater inflow that, under the same hydrological conditions but without the effects of dams and diversions in the Sacramento-San Joaquin watershed, would have flowed into the estuary (see Figure 2). Unimpaired inflow is not the same as "natural" or "historical" inflow that would have occurred in the watershed prior to human development and land use changes; it is instead an estimate of what flows over the existing landscape would have been if there were no dams or diversions. This report is available at: http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/docs/sjrf_spprtinfo/dwr_2007a.pdf.

[7] For these analyses, the water year type for each year was categorized based on the level of annual unimpaired Delta outflow and the frequency of occurrence of that level during the reference period of 1930-2009, with each year type comprising 20% of all years. Five water year types were used, each comprising 20% of all years: very wet (for the wettest 20% of years), wet, median, dry and very dry (for the driest 20% of years). For more information on this, see Freshwater Inflow Index and Figure 3.

indicators, water year type was not considered. Instead the indicators measure actual flow conditions for each year, and those measured levels are compared to reference conditions that do not vary with water year type. Therefore, measured values for frequency, magnitude and duration of Qwest and X2 and the evaluation results relative to habitat condition and the ecological services provided by those habitats (i.e., “good” v “poor”) are lower in dry years (and multi-year droughts) than in wetter years. (In contrast, the indicators of the Freshwater Inflow Index, which include measures of Delta inflow, outflow and in-Delta diversions, and spring inflow to the Bay, measure alteration in these flow conditions compared to unimpaired flow conditions and have therefore been at least partially normalized to account for differences in water year type.)

IV. Indicators

A. Delta Open Water Habitat

1. Rationale

The movement of water in Delta channels is influenced by the amounts of fresh water flowing in from upstream, the ebb and flood of the twice-daily tides, the amounts and locations of in-Delta water diversions, and the Delta’s geometry, including man-made channels and barriers. Before the massive transformation of the estuary’s Sacramento-San Joaquin watershed by humans, fresh water flowing into the Delta sloshed back and forth with the tides but ultimately moved downstream through Delta channels and west to the Bay (TBI 1998). Delta water diversions, particularly those located in areas of the Delta with low freshwater inflows, alter this flow pattern: when diversion rates are high, flows in some Delta channels may reverse, with water flowing “uphill” towards the point of diversion (CCWD 2012). Operations of the many barrier dams installed in Delta channels, most designed to deflect water towards diversion pumps, can further alter flow patterns and exacerbate reverse flows. Location of the large state and federal export pumps in the southern Delta, where freshwater inflows from the San Joaquin River were historically less than a quarter of the Delta total and have since been further reduced (see Freshwater Inflow Index, San Joaquin River Inflow indicator), concentrated the effects of their diversion operations in that portion of the Delta.

2. Methods and Calculations

The Delta Open Water Habitat indicator uses three component metrics to assess the frequency, magnitude and duration of occurrence of positive (or downstream) net flow conditions in the San Joaquin River in the western Delta at Jersey Point, referred to as Qwest, throughout the year. According to CDWR’s Dayflow model, Qwest is affected by Delta inflows from the San Joaquin, Cosumnes and Mokelumne Rivers, exports from the state and federal pumping facilities, cross Delta flows (e.g., through the Delta Cross Channel and Georgiana Slough), in-Delta depletions and diversions, and local precipitation. Net reverse flow, or negative flow, past Jersey Point indicates that higher salinity water from the Bay is being drawn into the interior Delta as a result of high depletions and exports compared to stream inflows, precipitation, and cross-Delta flows.

Frequency was measured as:

# of years in the past decade (i.e., ending with the measurement year) with Qwest>2500 cfs for at least 200 days during the year.

Magnitude was measured as:

average daily Qwest (cfs) during the year.

Duration was measured as:

# of days with Qwest>2500 cfs during the year.

For each year, the Delta Open Water Habitat indicator was calculated by combining the results of the three measurements into a single number by calculating the average of the measurements' "scores" described in the Reference Conditions section below.

3. Reference Conditions

The primary reference conditions for the component metrics of the Delta Open Water Habitat indicator were established as Qwest>2500 cfs for at least 200 days during the year in at least 6 out of 10 years. The Qwest level of 2500 cfs was based on comparison of Qwest and the CCWD's Flow Index for Old and Middle River flows, shown in Figure 2. This Qwest level roughly corresponds to reverse flows in Old and Middle Rivers (OMR), the two channels leading to the state and federal water export facilities, of approximately -2800 cfs. At OMR levels more negative than this, e.g., -5000 cfs, entrainment rates for fish and other small pelagic organisms in the central and south Delta increase markedly (CCWD 2012). The primary reference conditions for duration, 200 days, and frequency, ≥6 out of 10 years, specify that this Qwest level should occur for more than half of the year in more than half of all years. Qwest conditions that met or exceeded these levels were considered to reflect "good" conditions and meet the CCMP goals. Additional information about the relationship between Qwest and CCWD's OMR flow index, measured and modeled fish entrainment rates of the water export facilities (CCWD 2012), regulatory flow criteria for San Joaquin River inflows (SWRCB 2006), and pre-Delta export facilities Qwest flows were used to develop the other intermediate reference condition levels. Table 1 below shows the quantitative reference conditions that were used to evaluate the results of the component metrics for the Delta Open Water Habitat indicator.

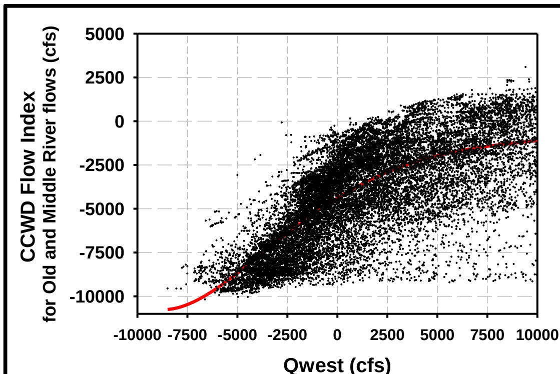

Figure 2. Relationship between daily Qwest (cfs) and daily CCWD Flow Index flows for Old and middle Rivers (cfs) (data from 1956-2014; graph axes are truncated to exclude extreme high and low flow levels)outside the range of the indicator reference conditions. The red line shows a best fit regression for visual reference.
Data sources: Contra Costa Water District for CCWD Flow Index, and CDWR Dayflow for Qwest.

Table 1. Quantitative reference conditions and associated interpretations for results for each of the three component metrics of the Delta Open Water Habitat indicator. The primary reference condition, which corresponds to "good" conditions, is in bold italics.

Delta Open Water Habitat				
Quantitative Reference Conditions			**Evaluation and Interpretation**	**Score**
Frequency	**Magnitude**	**Duration**		
≥8 years out of 10	Qwest>5000 cfs	>275 days	"Excellent," similar to pre-water export conditions	4
6 or 7 years out of 10	***Qwest>2500 cfs***	***>200 days***	***"Good," meets CCMP goals***	***3***
4 or 5 years out of 10	Qwest>0 cfs	>125 days	"Fair," corresponds to >-5,000 cfs CCWD OMR flow	2
2 or 3 years out of 10	Qwest>-2500 cfs	>50 days	"Poor," predicted entrainment high	1
0 or 1 years out of 10	Qwest≤-2500 cfs	≤50 days	"Very Poor," chronic, severe reverse flows	0

4. Results

The frequency of positive net flow in the Delta is low (Figure 3, top panel).

Prior to the 1970s, open water habitat conditions in the Delta were characterized by consistent, net positive flows that met or exceeded the primary reference condition: San Joaquin River flows in the western Delta were greater than 2500 cfs for more than 200 days per year in 93% of years. Beginning in the 1970s, frequency of occurrence of these conditions declined significantly (regression, p<0.001), falling to just 21% of years during the last 25 years and just 12% of years during the last decade. Based on frequency of occurrence of net positive flows, open water habitat conditions in the Delta are poor.

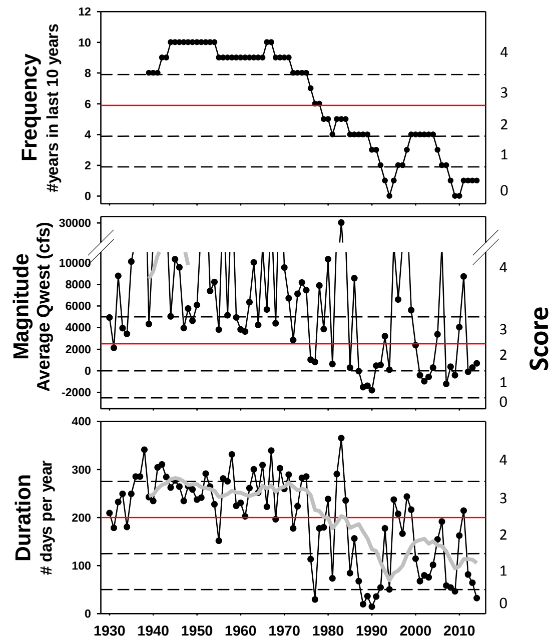

Figure 3. Results of the frequency (top panel), magnitude (middle panel) and duration (bottom panel) component metrics of the Delta Open Water Habitat indicator. Score is shown on the right Y axis. Each point shows the result for that year and, for the magnitude and duration metrics, the heavy solid grey line shows the 10-year running average. The horizontal red and dashed lines show the reference conditions for each metric and the numeric score is shown on the right Y axis.

The magnitude of net positive flows in the Delta is variable but it has declined over time (Figure 3, middle panel).

The magnitude of average annual flows in the western Delta is highly variable and largely a function of water year type (i.e., wet v dry). Prior to the 1970s, average annual Jersey Point flows were always positive, ranging from 3539 cfs in very dry years (i.e., the driest 20% of years) to 17,941 cfs in very wet years (the wettest 20% of years). Beginning in the 1970s and 1980s, western Delta flows declined significantly in all water years except very wet years (regression, all years except very wet, p<0.001; very wet years, p=0.06). Since 1980, average annual flows have been negative in very dry and dry years (the driest 40% of years), averaging -291 cfs in very dry years and -125 cfs in dry years. Average annual flows have declined 89% in median years, from 8817 cfs to just 1018 cfs, by 45% in wet years and by 23% in very wet years. Based on the magnitude of net positive flows in the western Delta, open water habitat conditions in the Delta have been good in only 40% of the last 25 years.

The duration of net positive flows in the Delta has declined over time and is low in most years (Figure 3, bottom panel).

The number of days or net positive flow >2500 cfs has declined significantly from an average of 256 days per year prior to 1970 to an average of 115 days per year during the last 25 years (Mann-Whitney, $p<0.001$). During the last 10 years, Qwest flows>2500 cfs have occurred for an average of 106 days per year and in 2014, a very dry year, for only 32 days. Duration of Qwest flows>2500 cfs declined significantly in all water year types (regression, $p<0.01$, all tests) and differed significantly among most water year types (ANOVA, $p<0.05$ for very dry v all other year types and dry years v very wet and wet year types): duration in very dry years declined from an average 217 days prior to 1970 to an average of just 45 days since 1990 compared the pre-1970 average for very wet years of 322 days and its decline to 232 days since 1990.

Results of the Delta Open Water Habitat indicator, which combines the results of the frequency, magnitude and duration metrics, are shown in Figure 4.

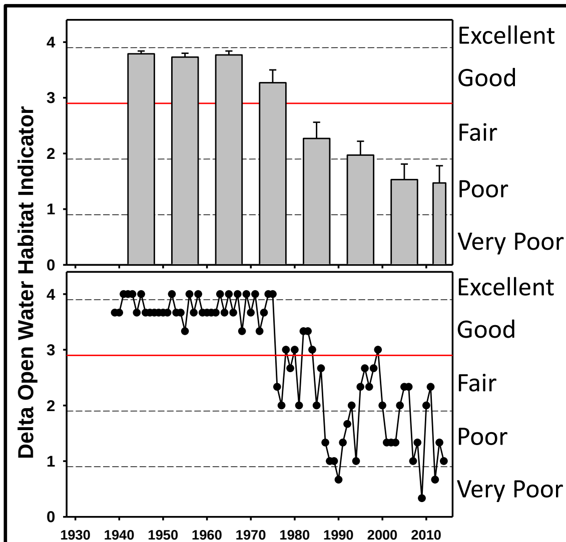

Figure 4. Results for the Delta Open Water Habitat indicator, which combines the results of the frequency, magnitude and duration component metrics (Figure 3) for 1939 to 2014. The top panel shows results as decadal averages±1 SEM (and for five years for 2010-2014) and the bottom panel shows results for each year. The horizontal red and dashed lines show the reference conditions and the indicator evaluation categories are at right.

Delta open water habitat conditions, as measured by the hydrodynamic conditions, have declined from consistently good to predominantly poor.

Hydrodynamic conditions in the western Delta deteriorated sharply starting in the 1970s; by the mid-1980s, the frequency, magnitude and duration of Qwest flows>2500 cfs were "poor" in all but a few wet years. This period of decline coincides with the ramp-up to full capacity operations of the state and federal water export facilities in the Delta. Declining habitat conditions were driven by reductions in all three component measurements of the indicator. Frequency of occurrence of good open water habitat has been cut by 77%, from an average of 9 out of ten years prior to 1970, to just 2 years out of 10 in the last 25 years. The magnitude of net positive flows has declined 65%, from an average of 9202 cfs prior to 1970 to just 3241 cfs since 1990. The number of days with "good" hydrodynamic conditions has declined by 55%, from an average of 257 days per year to 116 days per year.

Based on the Delta Open Water Habitat indicator, CCMP goals to restore healthy estuarine habitat and function have not been met.

Since the early 1990s, when the CCMP was implemented, open water habitat conditions in Delta have been "poor" or "very poor" in 17 years (68% of years) and "good" in only one year (4% of years).

B. Estuarine Open Water Habitat

1. Rationale

In an estuary, the place where fresh water from its tributary rivers begins to meet and mix with saltwater from the ocean is one of its most important habitats. The location, quantity and quality of this low-salinity habitat are largely determined by the amount of freshwater inflow. In the San Francisco Bay Estuary, the location of the low salinity zone and the associated amount and quality of this habitat is measured in terms of "X2," the point (in kilometers [km] upstream from the Golden Gate) where the salinity of the water near the bottom is 2 parts per thousand (approximately 6% seawater) (Jassby et al. 1995, Kimmerer 2002, 2004; Feyrer et al., 2007, 2010; Reed et al. 2014).[8] During the spring, high freshwater inflows driven by rain and snowmelt in the Bay's watershed shift X2 and low salinity habitat downstream into the broad shallow reaches of Suisun Bay and closer to the Golden Gate (i.e., X2 is low), creating a large expanse of estuarine open water habitat (Figure 5). When springtime inflows are low, fresh and ocean waters mix farther upstream, X2 is higher and the quality and quantity of the estuary's low salinity habitat is reduced (Feyrer et al. 2007). For a number of estuary-dependent fish and invertebrate species, each 10-kilometer upstream shift in average springtime X2 corresponds to a two- to five-fold decrease in abundance or survival (Kimmerer 2002, 2004; Kimmerer et al. 2009).

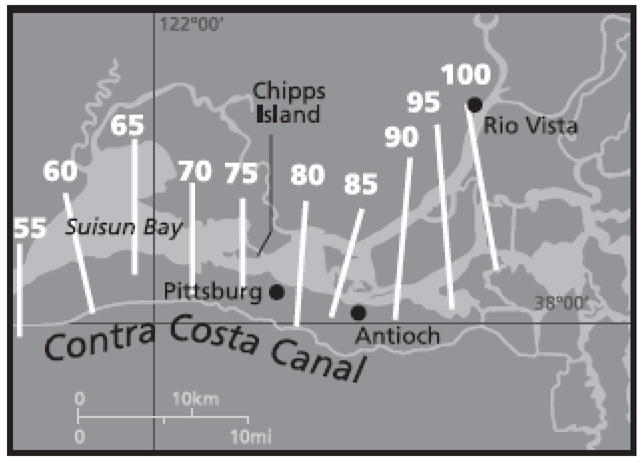

Figure 5. The location, quantity and quality of low salinity open water habitat is often measured in terms of "X2", the location in kilometers from the Golden Gate of the 2 parts per thousand isohaline. Based on survival and abundance of many estuary-dependent fish and invertebrate species, X2 locations at of downstream of 65 km provide good habitat conditions.
Figure from: The Bay Institute, 2003.

Springtime runoff from the Sacramento-San Joaquin watershed and freshwater inflow to the Estuary varies dramatically from year to year, a function of California's Mediterranean climate and unpredictable occurrences of droughts and floods. However, since the 1960s, large dams on the Estuary's major tributary rivers have captured and stored the majority of springtime snowmelt runoff in most years, with the result that less fresh water flows into the estuary during this ecologically sensitive period (see Freshwater Inflow Index).

It should be noted that the quantity and quality of low salinity open water habitat is important during all seasons, not just during the spring. For example, Feyrer et al. (2007, 2010) showed

[8] X2 can be measured directly as salinity but it is more frequently calculated using daily or monthly Delta outflow (or Bay inflow) data using equations first developed by Schubel et al. (1993). More recent analyses indicate that these equations may be underestimating and/or overestimating X2 under extreme flow conditions (Reed et al. 2014), however, the original X2 equation in CDWR's Dayflow data is still widely used.

that the suitability of low salinity habitat during the fall (September-December) was important for two San Francisco Bay estuary-dependent fish species, delta smelt and striped bass, and that declines in fall habitat quality were significantly correlated with declines in delta smelt abundance. However, in the San Francisco Bay Estuary, the high magnitude freshwater inflows that create the largest amounts of low salinity open water habitat, the strongest relationships between low salinity habitat (and X2) and abundance and survival of estuarine species, and the greatest anthropogenic alteration in freshwater inflows all occur during the spring period (see Spring Bay Inflow indicator, Freshwater Inflow Index). Therefore, this habitat indicator focuses on the springtime to evaluate the conditions and trends in the quantity and quality of this type of estuarine habitat.

2. Methods and Calculations

The Estuarine Open Water Habitat indicator uses three measurements to assess the frequency, magnitude and duration of the occurrence of high quality estuarine open water habitat in the San Francisco Estuary during the spring.

Frequency was measured as:

# of years in the past decade (i.e., ending with the measurement year) with X2<65 km for at least 100 days during the February-June period.

Magnitude was measured as:

average daily X2 during the February-June period.

Duration was measured as:

# of days with X2<65 km during the February-June period.

For each year, the Estuarine Open Water Habitat indicator was calculated by combining the results of the three measurements into a single number by calculating the average of the measurement "scores" described in the Reference Conditions section below.

3. Reference Conditions

The primary reference conditions for the component metrics of the Estuarine Open Water Habitat indicator were established as X2<65 km for at least 100 days during the February-June period in at least 6 out of 10 years. The X2 level of 65 km was based on review of the relationship between X2 and abundance and survival of selected estuary-dependent fish and invertebrate species that showed that open water habitat conditions with X2<65 km corresponded to relatively good survival and abundance levels. In addition, based on review of X2 data from the "pre-dam" period (1930-1943, before large storage dams were constructed on most of the estuary's major Sacramento-San Joaquin watershed tributary rivers), open water habitat conditions with X2<65 km occurred for an average of 106 days during the February-June period and X2<65 km for more than 100 days in 71% of years. Examination of unimpaired flow and X2 data yielded similar results: X2<65 km occurred in 83% of years for an average or 4.3 months during the spring in 7 to 8 years out of 10 years. Measured values that were above the primary reference condition were interpreted to correspond to "good" conditions. Other intermediate reference conditions were based on the pre-dam and unimpaired X2 data, abundance-X2 relationships, and current regulatory standards for seasonal Delta outflow (or Bay inflow; SWRCB 2006). Table 2 below shows the quantitative reference conditions that were used to evaluate the results of the component metrics for the Estuarine Open Water Habitat indicator.

Table 2. Quantitative reference conditions and associated interpretations for results for each of the three component metrics of the Estuarine Open Water Habitat indicator. The primary reference condition, which corresponds to "good" conditions, is in bold italics.

Estuarine Open Water habitat				
Quantitative Reference Conditions			Evaluation and Interpretation	Score
Frequency	Magnitude	Duration		
>8 years out of 10	X2<60 km	>130 days	"Excellent," similar to unimpaired conditions	4
6 or 7 years out of 10	***X2<65 km***	***>100 days***	***"Good," meets CCMP goals***	***3***
4 or 5 years out of 10	X2<70 km	>50 days	"Fair," similar to current regulatory standards	2
2 or 3 years out of 10	X2<75	>25 days	"Poor"	1
0 or 1 years out of 10	X2>75 km	<25 days	"Very Poor," spring inflows eliminated	0

4. Results

Results of the three component measurements of the Estuarine Open Water Habitat indicator are shown in Figure 6.

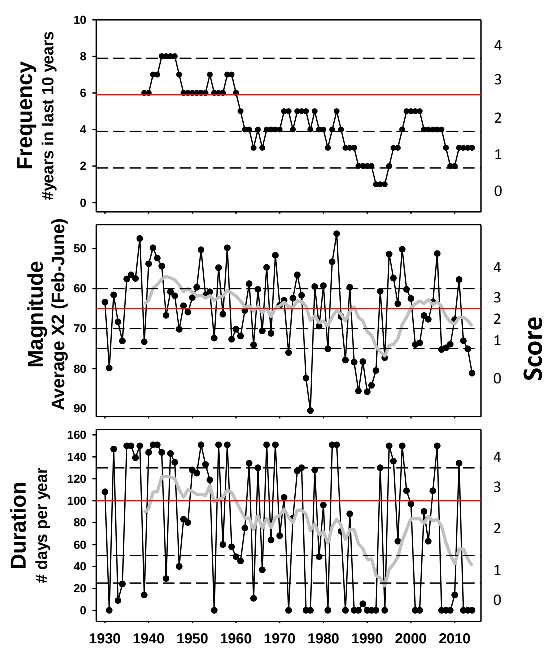

Figure 6. Results of the frequency (top panel), magnitude (middle panel) and duration (bottom panel) component metrics of the Estuarine Open Water Habitat indicator. Score is shown on the right Y axis. Each point shows the result for that year and, for the magnitude and duration metrics, the heavy solid grey line shows the 10-year running average. The horizontal red and dashed lines show the reference conditions for each metric and the numeric score is shown on the right Y axis.

The frequency of occurrence of high quality estuarine open water habitat has declined (Figure 6, top panel).

Frequency of occurrence of high quality estuarine open water habitat during the spring has declined significantly (regression, $p<0.001$). The first decline occurred during the 1960s (when most of the large dams in the estuary's main watershed were completed), with frequency falling from an average of 6.7 years out of 10 years in the 1940s and 1950s to an average of 4.6 years in the 1970s. Frequency declined again in the late 1980s and early 1990s during a severe multi-year drought, dropping to an average of just 1.9 years of good quality conditions per decade. Frequency increased during the late 1990s, concurrent with an unusually wet sequence of years, but then declined again in the 2000s. In the decade ending in 2014, the estuary experienced only 3 years (2005, 2006 and 2011) in which estuarine open water habitat conditions were "good."

The quality and quantity of estuarine open water habitat has declined (Figure 6, middle panel).

As measured by average springtime X2 values, the quality and quantity of estuarine open water habitat has declined significantly (regression, $p<0.05$). Spring X2 conditions have degraded from an average of 62 km in the 1940s and 1950s to an average of 77 km in the late 1980s and early 1990s (1985-1994 average). In the last decade (2005-2014), X2 has averaged 69 km, significantly higher (i.e., poorer conditions) than during the 1940s and 1950s (t-test, $p<0.05$). In 2014, a very dry year, springtime X2 was 81 km, the sixth highest level in the 85-year data record. Average springtime X2 has significantly increased in all water year types except very dry years (regression $p=0.12$) and very wet years ($p=0.10$; regressions for dry, median and wet year type, $p<0.05$, all tests). The greatest upstream shifts in low salinity habitat have occurred in the dry and median years; since the pre-dam period, average spring X2 has increased by 5, 9, 10, 6 and 6 km for very dry, dry, median, wet and very wet years, respectively (averages are for 1990-2014).

The duration of occurrence of high quality estuarine open water habitat has declined (Figure 6, bottom panel).

The number of days during the spring with "good" open water conditions and X2 downstream of 65 km has declined significantly (regression, $p<0.01$). Until the 1960s, X2 was downstream of 65 km for an average of 102 days during the February-June period. By the 1970s, the average had fallen to 69 days and, during the drought decade of the late 1980s and early 1990s, an average of only 22 days had "good" conditions. Conditions improved during the late 1990s but declined again in the 2000s. In the most recent ten years, X2 has been downstream of 65 km for an average of only 41 days during the spring and, in six of those years, daily X2 was never downstream of 65 km. The number of days with X2<65 km declined significantly in all water year types except wet and very wet (the wettest 40% of years) (regression, $p<0.01$ for very dry, dry and median years; for wet and very wet years, $p=0.1$ and $p=0.17$, respectively). Spring days with X2<65 km have been eliminated in the driest 40% of years, falling from an pre-dam (1930-1943) average of 12 days in very dry years and 108 days in dry years to 0 days in each of these year types since 1990. In median years, the number of days with X2<65 km has been cut by two thirds, from a pre-dam average of 146 days per year to just 53 days per year since 1990.

Results of the Estuarine Open Water Habitat indicator, which combines the results of the frequency, magnitude and duration metrics, are shown in Figure 7.

Springtime estuarine open water habitat conditions have declined.

Results of the indicator reveal a steady and significant decline in the springtime estuarine open water habitat conditions (regression, $p<0.001$), from consistently "good" or "fair" prior to the 1960s to mostly "poor" conditions by the 1990s. Conditions improved during the late 1990s, during a sequence of unusually wet years but declined again in the 2000s. In the last 25 years, springtime open water habitat conditions have been "good" only during wettest 40% of years (wet and above normal year types) and consistently "poor" in nearly all of the rest of the years. Declining habitat conditions were driven by reductions in all three component measurements of the indicator. Frequency of occurrence of high quality open water habitat has been cut in half, from an average of 7 out of 10 years, or 70% of years, in the 1940s and 1950s to just 31% of years in the last decade. The location of springtime X2 has shifted nearly 7 kilometers upstream from an average of 62 kilometers to 69 kilometers in the last ten years. The number of days with “good” habitat conditions during the spring has declined by two thirds, from an average of more than 100 days per year in the 1940s and 1950s to just 41 days per year in the most recent decade.

Based on the Estuarine Open Water Habitat indicator, CCMP goals to restore healthy estuarine habitat and function have not been met.

Since the early 1990s, when the CCMP was implemented, open water habitat conditions in the estuary have been “good,” meeting the CCMP goal in just 5 of 25 years (20% of years). In the remaining 80% of years, open water habitat conditions have been “fair” in 7 years (28% of years), and “poor” or “very poor” in 13 years (52% of years).

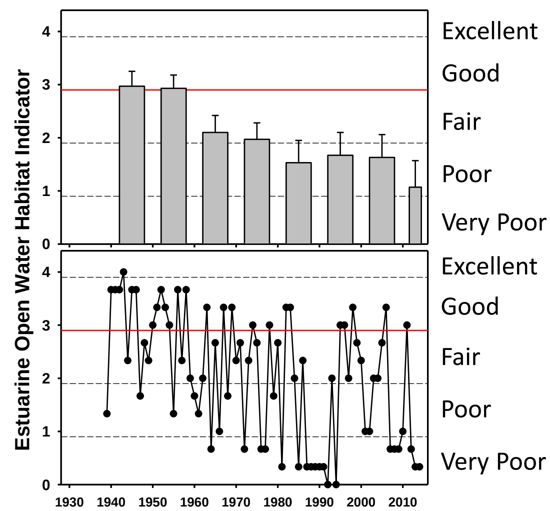

Figure 7. Results for the Estuarine Open Water Habitat indicator, which combines the results of the frequency, magnitude and duration component metrics (Figure 6) for 1939 to 2014. The top panel shows results as decadal averages±1 SEM (and for five years for 2010-2014) and the bottom panel shows results for each year. The horizontal red and dashed lines show the reference conditions and the indicator evaluation categories are at right.

V. References

Contra Costa Water District (CCWD) 2012. Use of an Index for Old and Middle River Flow Objectives. Submitted to the State Water Resources Control Board for their Comprehensive (Phase 2) Review and Update to the Bay-Delta Plan, Workshop 2: Bay-Delta Fishery Resources. Available at:
http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/cmnt091412.shtml

Feyrer, F. and M. Healey. 2003. Fish community structure and environmental correlates in the highly altered southern Sacramento-San Joaquin Delta. Environmental Biology of Fishes 66: 123–132. Available at: http://www.waterrights.ca.gov/BAYDELTA/docs/exhibits/DOI-EXH-33F.pdf

Feyrer, F., M. L. Nobriga and T. R. Sommer. 2007. Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Canadian Journal of Fisheries and Aquatic Sciences 64: 723-734.

Feyrer, F., K. Newman, M. Nobriga and T. Sommer. 2010. Modeling the Effects of Future Outflow on the Abiotic Habitat of an Imperiled Estuarine Fish. Estuaries and Coasts DOI 10.1007/s12237-010-9343-9.

Grimaldo, L.F., Sommer, T., Van Ark, N., Jones, G., Holland, E., Moyle, P., Herbold, B., Smith, P., 2009, Factors Affecting Fish Entrainment into Massive Water Diversions in a Tidal Freshwater Estuary: Can Fish Losses be Managed? North American Journal of Fisheries Management 29:1253-1270.

Jassby, A.D., W. J. Kimmerer, S. G. Monismith, C. Armour J. E. Cloern, T. M. Powell, J. R. Schubel and T. J. Vendlinski. 1995. Isohaline Position as a Habitat Indicator for Estuarine Populations. Ecological Applications 5:272-289.

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

Kimmerer, W. J. 2004. Open-Water Processes of the San Francisco Estuary: from physical forcing to biological responses. San Francisco Estuary and Watershed Science [online serial]. Vol. 2, Issue 1 (February 2004), Article 1.

Kimmerer, W.J., E.S. Gross, and M.L. MacWilliams. 2009. Is the Response of Estuarine Nekton to Freshwater Flow in the San Francisco Estuary Explained by Variation in Habitat Volume? Estuaries and Coasts 32:375-389.

Reed, D., J. Hollibaugh, J. Korman, E. Peebles, K. Rose, P. Smith, and P. Montagna. 2014. Workshop on Delta Outflows and Related Stressors: Panel Summary Report. Prepared for the Delta Stewardship Council, Delta Science Program. Available at:
http://swrcb2.swrcb.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/docs/delta_outflow_summary_report.pdf.

San Francisco Estuary Institute (SFEI) 1994. EcoAtlas for the San Francisco Bay Baylands. Available at: http://www.sfei.org/ecoatlas.

Schubel, J.R., et al. 1993, Managing Freshwater Discharge to the San Francisco Bay/Sacramento-San Joaquin Delta Estuary -- The Scientific Basis for an Estuarine Standard: San Francisco Estuary Project, U.S. Environmental Protection Agency, San Francisco, CA, 109 p. Available at: http://www2.epa.gov/sites/production/files/documents/sfep_1993_managing_fw_discharge_sf_bay_delta_estuary_0.pdf

State Water Resources Control Board (SWRCB) (2006) Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. December 13, 2006. Available at: http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/wq_control_plans/2006wqcp/.

The Bay Institute (TBI) 1998. From the Sierra to the Sea: An ecological history of the San Francisco Bay-Delta watershed. Available at: http://www.thebayinstitute.org/resources/publications/from-the-sierra-to-the-sea-the-ecological-history-of-the-san-francisco-baydelta-watershed

The Bay Institute (TBI) 2003. Ecological Scorecard: San Francisco Bay Index 2003. Available at: http://bay.org/assets/Scorecard_report.pdf.