State of San Francisco Bay 2011
Appendix C

HABITAT - Estuarine Open Water Habitat Indicator Technical Appendix

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I. Background and 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 is largely determined by the amount of freshwater inflow. In the San Francisco Bay, 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). 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, creating a large expanse of estuarine open water habitat (Figure 1: X2 is low, closer to the Golden Gate). When springtime inflows are low, fresh and ocean waters mix farther upstream, X2 increases and the quality and quantity of the estuary's low salinity habitat is reduced. 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).

Springtime runoff from the Sacramento-San Joaquin watershed and freshwater inflow to the Bay 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 Bay'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 also Freshwater Inflow Index). Reduced spring inflows and more upstream locations of low salinity habitat affect the quality and quantity of the estuarine open water habitat and the plants and animals that use it.

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 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, 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 also 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.

The Estuarine Open Water Habitat indicator uses three measurements to assess the frequency ("how often?"), magnitude ("how much?") and duration ("how long?") of the occurrence of high quality estuarine open water habitat in the San Francisco Bay during the spring.

II. Data Source

The Estuarine Open Water Habitat indicator was calculated for each year using daily X2 data from the California Department of Water Resources (CDWR) DAYFLOW model. DAYFLOW is a computer model developed in 1978 as an accounting tool for calculating historical Delta outflow, X2 and other internal Delta flows.[1] DAYFLOW output is used extensively in studies by State and federal agencies, universities, and consultants. DAYFLOW output is available for the period 1930-2010.

III. 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.

For each year, 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.

For each year, magnitude was measured as:

> average daily X2 during the February-June period.

For each year, 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 Indicator Evaluation and Reference Conditions section below.

VI. 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, based on the population and survival responses of a number of estuary-dependent species, estuarine open water habitat conditions with X2<65 km correspond 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. Therefore, the reference condition for high quality estuarine open water habitat conditions was set at X2<65 km for >100 days during the February-June period in seven out of ten years. Measured values that were above this reference condition were interpreted to correspond to "good" conditions. An additional "lower" reference condition was established to denote "poor" conditions. Measured values that were between the two reference conditions were

[1] More information about DAYFLOW is available at http://www.water.ca.gov/dayflow.

interpreted to correspond to "fair' conditions. Table 1 shows the reference conditions and associated interpretations for the indicator metrics.

Results of the indicator and its component measurements were analyzed using analysis of variance and simple linear regression to identify differences among different time periods and trends with time.

V. Results

Results of the three component measurements of the Estuarine Open Water Habitat indicator are shown in Figure 2.

The frequency of occurrence of high quality estuarine open water habitat has declined (Figure 2, 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 2010, the estuary experienced only two years (2005 and 2006) in which estuarine open water habitat conditions were "good."

The quality and quantity of estuarine open water habitat has declined (Figure 2, 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 2000s, X2 averaged 69 km, significantly higher (i.e., poorer conditions) than during the 1940s and 1950s (t-test, $p<0.05$).

The duration of occurrence of high quality estuarine open water habitat has declined (Figure 2, 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 43 days during the spring and, in five of those years, daily X2 was never downstream of 65 km.

Results of the Estuarine Open Water Habitat indicator are shown in Figure 3.

Springtime estuarine open water habitat conditions have declined.

Results of the indicator reveal a steady and significant decline the springtime estuarine open water habitat (regression, $p<0.001$), from consistently "good" or "fair" conditions 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. 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 seven out of ten years, or 70%, in the 1940s and 1950s to just 37% 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 2000s. 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 43 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.

The indicator shows that, for the past four decades, estuarine open water habitat conditions have been mostly "fair" or "poor." 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 19% of years. In the remaining 81% of years, open water habitat conditions have been "fair" (43% of years) or "poor" (38% of years).

VI. Peer Review

The Estuarine Open Water Habitat indicator builds upon the methods and indicators developed by The Bay Institute for the 2003 and 2005 Ecological Scorecard San Francisco Bay Index and for the San Francisco Estuary Partnership Indicators Consortium. The Bay Institute's Ecological Scorecard was developed with input and review by an expert panel that included Bruce Herbold (US EPA), James Karr (University of Washington, Seattle), Matt Kondolf (University of California, Berkeley), Pater Moyle (University of California, Davis), Fred Nichols (US Geological Survey, ret.), and Phillip Williams (Phillip B. Williams and Assoc.). The version of the indicator presented in this report was also reviewed and revised according to the comments of Bruce Herbold and Peter Vorster (The Bay Institute).

VII. References

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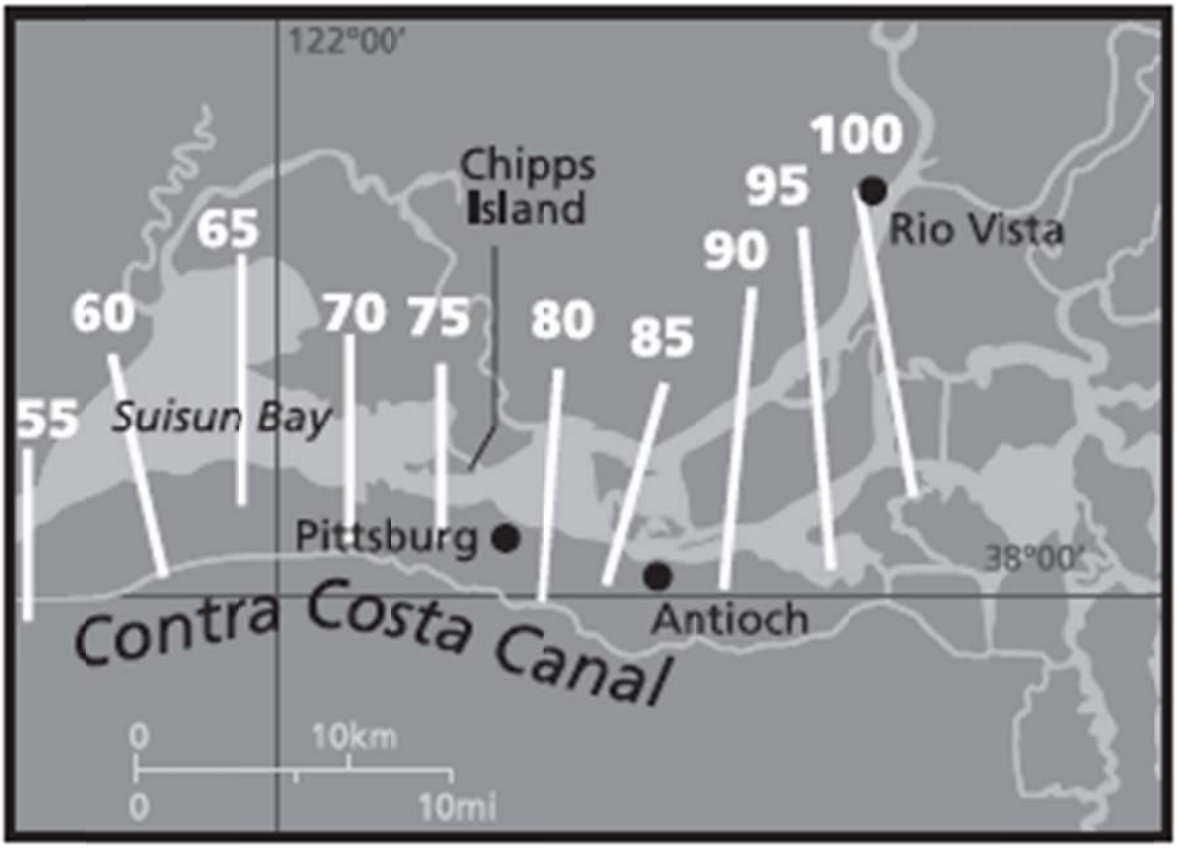

Figure 1. The location, quantity and quality of low salinity open water habitat is often measured in terms of "X2", the location in kilometers from the Golden Gate of the 2 parts per thousand isohaline. Based on survival and abundance of many estuary-dependent fish and invertebrate species, X2 locations at of downstream of 65 km provide good habitat conditions. Figure from: The Bay Institute, 2003.

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

Estuarine Open Water Habitat Indicator			
Metric	**"Good"** **Score=3**	"Fair" Score=2	"Poor" Score=1
Frequency	**≥7 years out of 10 years**	≥4 years out of 10 years	<4 years out of 10 years
Magnitude	**X2<65 km**	X2≥65 km and ≤75 km	X2>75 km
Duration	**>100 days**	>50 days	≤50 days

Figure 2. Changes in the frequency, magnitude and duration of occurrence of high quality estuarine open water habitat in the San Francisco Estuary during the spring, from 1930-2010. Black lines and symbols show the annual Index values, solid red line shows the 10-year running average for the Index. Horizontal dashed lines shows the reference conditions and associated interpretations.

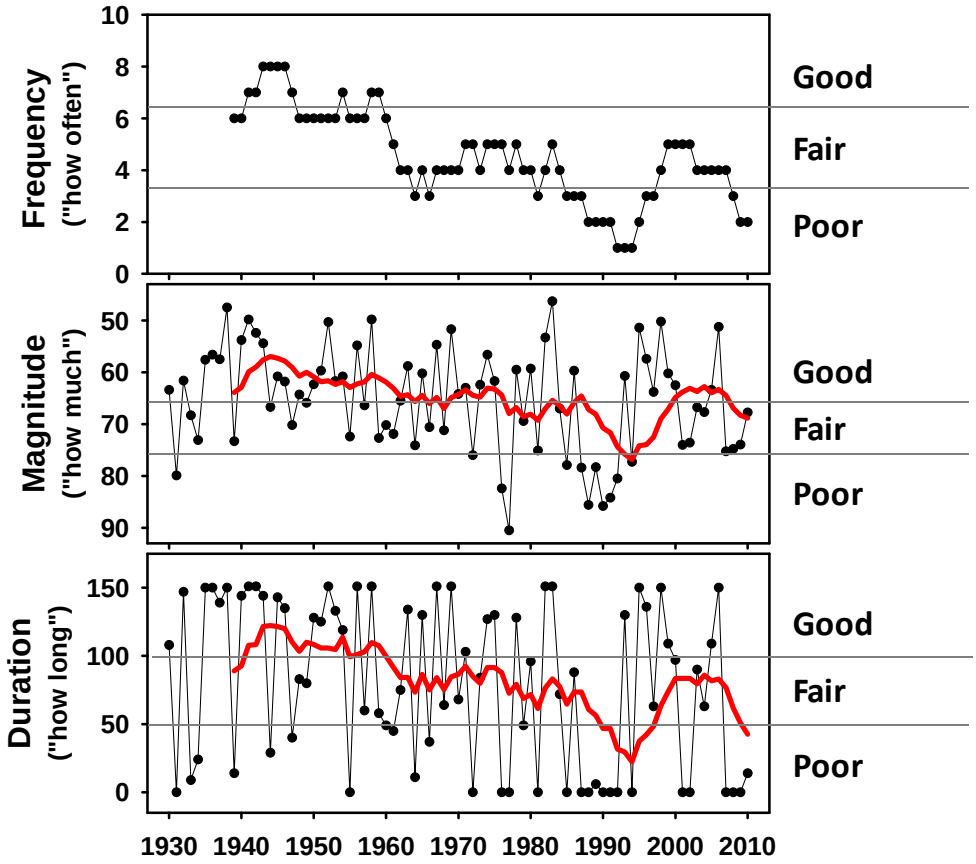

Figure 3. Changes in the Estuarine Open Water Habitat indicator from 1939-2010. Black lines and symbols show the annual indicator values, solid red line shows the 10-year running average for the indicator. Horizontal dashed lines shows the reference conditions and associated interpretations.