The Bay Institute

Protecting and Restoring San Francisco Bay from the Sierra to the Sea

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January 12, 2005

Arthur G. Baggett, Jr., Chair
State Water Resources Control Board
P. O. Box 100
Sacramento, CA 95812-0100

RE: BAY-DELTA PLAN PERIODIC REVIEW/DELTA OUTFLOW

Dear Mr. Baggett,

This letter is submitted as the opening comments of the Bay Institute regarding Topic 5 (Delta outflow) for the State Water Resources Control Board's (SWRCB) public workshops to consider potential amendments or revisions of the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay-Delta Plan).

We recommend that the SWRCB:

1. Find that the scientific basis for the February – June Delta outflow objective continues to be strong and statistically significant, and that any further reductions in outflows would adversely impact estuarine habitat and aquatic organisms.

2. Revise the February – June Delta outflow objective to maintain flows and X2 location assuming a 1956-68 Level of Development.

3. Review and revise the "three ways to win" methodology for measuring compliance with the February – June Delta outflow objective in order to ensure that desired X2 location is achieved.

4. Address potential upstream impacts of implementing the February – June Delta outflow objective through its water rights permitting authority and by other means, rather than by revising the objective.

1. The X2-abundance relationships underlying the February – June Delta outflow objective continue to be strong and statistically significant.

The Bay-Delta Plan's objective for Delta outflow during the February – June period is a fundamental and critical protection for estuarine habitat and aquatic organisms. This objective requires that the Net Delta Outflow Index (NDOI) described in Footnote 14 of Table 3 (and also Table A) of the Bay-Delta Plan be maintained between February 1 and June 30.[1] The NDOI is highly correlated with "X2", the location (measured as km from the Golden Gate) of the 2 parts per thousand (ppt) isohaline at a depth of one meter from the bottom of the channel.[2]

The February – June location of X2, a readily measured and controllable, flow-dependent environmental variable, has a strong and statistically significant correlation with the biological responses (e.g., abundance and/or survival) of numerous invertebrate and vertebrate Bay-Delta species. The February – June period is an ecologically important period when food web organisms bloom and many estuarine and anadromous fish species spawn, incubate, rear, and migrate. The precise mechanisms for how higher freshwater flows affect estuarine species' abundance and/or survival are not fully understood, and vary among species. However, based on the best available scientific information regarding flows and physical habitat conditions in the lower rivers and estuary (e.g., flood plain inundation, turbidity; see review by Kimmerer, 2004), estuarine food web dynamics (Jassby et al., 2003; Kimmerer, 2004), and the life histories, habitat use, movements, and mortality factors for many of the affected species (e.g., see Table 1 in Kimmerer, 2002a), a number of mechanisms have been hypothesized. For most species, it is likely that high flows affect survival and abundance in multiple ways, for example by increasing habitat area, increasing food supply, and facilitating transport within the estuary (Table 1). Some recent analyses suggest that, in addition to springtime location, seasonal and daily variability in X2 may be an important outflow characteristic for many of the possible mechanisms (personal communication, B. Herbold, U. S. Environmental Protection Agency).[3]

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[1] For the February-June period, the monthly objective is based on previous month's tributary flow conditions, measured as the Eight River Index, and/or EC measured at the Collinsville or Port Chicago stations.

[2] X2 is usually calculated from daily NDOI using the following equation:
$X2(d_i) = 10.16 + 0.945(X2, d_{i-1}) - 1.487(\log[\text{outflow}, d_i])$; where d_i is the current day, d_{i-1} is the previous day, and outflow is in cubic feet per second (cfs).

[3] In 2004, several meetings of the Estuarine Ecology Team (Interagency Ecological Program) were convened to further explore the role of X2 in Bay-Delta ecology. Preliminary analyses conducted during

The strong, statistically significant X2-abundance relationships first described by Jassby (1992) and Jassby et al. (1995) and on which the February – June Delta outflow objective in the Bay-Delta Plan is based have been repeatedly and consistently confirmed by subsequent analyses, and have not been altered by other substantial perturbations in the estuary such as the establishment of the non-native Asian clam (*Potamocorbula amurensis*) (Kimmerer, 2002a, b).

Figure 1 shows the abundance of Bay shrimp, longfin smelt and Pacific herring, and the survival of larval striped bass plotted against average springtime X2 (1980-2000 for Bay shrimp; 1967-2003 for longfin smelt; 1980-2000 for Pacific herring; 1969-1994 for striped bass). For each of these species, as well as for many others, high freshwater flows during the spring, which move X2 downstream into Suisun and San Pablo Bays (i.e., low X2 values), are correlated with higher population abundance and survival. Additional data collected since Jassby's analyses in the early 1990s have not changed the correlations (i.e., the overall slopes of the regressions), although for some species the intercept has changed (see below). The data presented here were provided by W. Kimmerer, San Francisco State University, and are the same as those he analyzed and published in several peer-reviewed journal articles and reviews (Kimmerer, 2002a; 2002b; and 2004; 2001-2003 data for longfin smelt added by C. Swanson using data from California Department of Fish and Game (CDFG) Fall Midwater Trawl survey and California Department of Water Resources (CDWR) Dayflow).

This relationship between X2 and abundance and/or survival is found for many other fish and invertebrate species that depend on the San Francisco estuary and the lower rivers. These include: starry flounder; Sacramento splittail; American shad; delta smelt (since the 1980s); and mysid shrimp (an important component of the estuary's food web). Figure 2, from Kimmerer (2002b), shows the relationship between abundance and/or survival for a number of estuarine species and X2: the negative X2 effect indicates that abundance and/or survival increase when the X2 value decreases (e.g., when X2 is further downstream in the estuary as the result of high flows).

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the meetings suggested that seasonal and daily variability in X2 might also be correlated with abundance and/or survival of some estuarine species. These preliminary results suggest that additional analyses of existing datasets could further improve our understanding of the mechanisms underlying the X2-abundance relationship in the San Francisco estuary.

Recommendation: The SWRCB should find that the scientific basis for the Delta outflow objective continues to be strong and statistically significant, and that any further reduction in outflows would adversely impact estuarine habitat and aquatic organisms.

2. The Delta outflow objective should be revised to maintain February – June flows and X2 values assuming a 1956-1968 Level of Development.

The February – June Delta outflow objective is not only based on a strong biological response but is highly sensitive to natural hydrologic variability. In the San Francisco estuary, average February – June X2 varies from year to year, in concert with inter-annual variations in rain and snowmelt runoff from the Sacramento-San Joaquin watershed (Figure 3). This year-to-year variation, as well as within-year or seasonal variation, is a key feature of estuaries and creates the dynamic habitat conditions upon which San Francisco estuary fish and invertebrate species depend (Kimmerer, 2002b).

The amounts, timing, and intra- and inter-annual variability of freshwater inflows to the estuary have all been significantly altered, especially during the ecologically important February – June period (Figure 4). Between the 1940s, when the federal Central Valley Project (CVP) completed a number of large dams on the largest rivers in the watershed, and the late 1980s, when the CVP and the State Water Project (SWP) operated at record high levels of export from the Delta, the amount of late winter and spring flows into the estuary was drastically reduced, as snowmelt runoff was captured for storage and diverted for use elsewhere. As a result of reduced inflows, February – June X2 has progressively shifted upstream (i.e., X2 values are greater). Figure 5 shows the difference between actual X2 (calculated from NDOI) and both "pre-dam" X2 values (1930-1943, normalized for water year type) and estimated X2 under unimpaired flow conditions. Between 1940 and 1990, average February-June X2 was shifted 15 km upstream, a change in habitat conditions that corresponded to substantially lower abundance and/or survival for many fish and invertebrate species. Although the largest upstream shifts in X2 have occurred in some critically dry years, substantial upstream movement occurs in all year types (Figures 6 and 7). In general, the upstream shift in X2 is greatest in "below normal" and "dry" years (Figure 6).[4]

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[4] For these analyses, which were part of the Bay Institute's San Francisco Bay Freshwater Index (TBI, 2003), we classified each year as one of five water year types: wet, above normal, below normal, dry, and

Based on the flow – X2 relationship, the Delta outflow objective requires sufficient February – June flows to locate X2 at one of three different compliance stations for a varying number days, effectively establishing a maximum average X2 value while concurrently ensuring that within-month and seasonal variability in X2 is similar to early 1970s values. It is important to understand that the objective is designed to replicate historic variability, but that the actual level of protection (e.g., actual flows and X2 location) is determined by which historic period the objective is intended to replicate.

The Delta outflow objective assumes flows and X2 values at a 1971.5 Level of Development (LOD) for water development. Based on total Delta exports,[5] this level of development would correspond to annual exports of 3.02 million acre-feet (MAF; average for 1970-1973, data from Dayflow). However, during the late 1960s and early 1970s, when the SWP began exporting from the Delta, estuarine habitat conditions (see Figure 5) and fish and invertebrate populations were already declining. As an example, Figure 8 shows abundance data for striped bass, one of the estuary-dependent fish species whose larval survival is correlated with spring X2 conditions and the most popular target of party-boat sport fisherman in the San Francisco Bay-Delta. (We selected striped bass as a surrogate for other estuary-dependent species because the sport fishery catch data are available for years prior to 1967, when CDFG began the Fall Midwater trawl survey, and the data also illustrates the human dimension of this fishery resource in the Bay and Delta). Throughout the 1970s, both the abundance of juvenile striped bass and fishing success for the larger fish declined.

While a significant increase over previous outflow requirements, the current objective with its 1971.5 LOD represents, on average, still only 35% of unimpaired flows. Minimum flows required to meet the February – June Delta

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critical. Using values for unimpaired outflow calculated by DWR (see below), year types were established based on frequency of occurrence during the period of 1921-1994, with each year type comprising roughly 20% of all years. Thus, despite use of the term "below normal", this year type includes the median, with half of all years receiving more runoff and the other half of years receiving less runoff. Terminology for the five year types follows that used by state and federal water management agencies although, for water management purposes in the Sacramento and San Joaquin basins as well as implementation of many of the Bay-Delta Plan objectives, water year types are determined using other factors, such as the previous year's precipitation, as well as than frequency of occurrence. Our frequency-based year type designation differed (by one year type, e.g., dry vs below normal) from the Sacramento basin year type identified by the water project agencies in just 24 of 74 years (1930-2003).

[5] Total Delta exports are calculated as the sum of exports by the Contra Costa Water District, North Bay Aqueduct, Central Valley Project, and State Water Project.

outflow objective result in average X2 values that range from 65 km in some wet years to 80 km in some critically dry years (Figure 9).[6] Based on population abundance and survival of numerous estuarine fish and invertebrate species, these X2 values correspond to "fair", or intermediate conditions in wet years (Figure 10), year types that would typically provide inflow conditions that promote high abundance and survival. In dry and critically dry years, minimum required inflows are greater than those that occurred during the 1976-1977 and 1987-1992 droughts but still result in X2 values that are significantly greater than would have historically occurred under those (or even drier) hydrological conditions (see Figure 7 for pre-dam and unimpaired X2 values for dry and critical years).

In most years, actual Delta outflows exceed the February – June objective because of operational and physical constraints on the capacity of the existing water supply system to capture, store, and divert freshwater flow before it reaches San Francisco Bay. The approval and adoption of the February – June objective was in part predicated on the occurrence of these "excess flows" and their beneficial effects on estuarine habitat conditions, as was acknowledged at the time in the environmental documentation prepared by state and federal agencies for the Bay-Delta Plan and associated actions (e.g., Endangered Species Act biological opinions and permits). Figure 11 compares actual average February – June inflows to the average flows that were required (or, prior to 1995, would have been required) by the Delta outflow objective for the 1930 to 2003 period.[7] During the first five years following adoption of the Bay-Delta Plan (1996-2000), an unusually wet sequence of years, freshwater flows into the Bay exceeded the minimums required, as anticipated. In contrast, during the following three years (2001-2003), February – June inflows to the estuary barely met required minimum flows (and did not always maintain the predicted X2 location, as discussed below). This period also coincided with marked population declines of most of the fish species whose abundance and/or survival is correlated with springtime X2, including delta smelt, longfin smelt, and striped bass (Figure 12). The frequency of years when these "excess flows" occur is likely to decrease if

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[6] Required X2 was calculated from the monthly required inflow as:
$X2(m_i) = 122.2 + 0.3278(X2, m_{i-1}) - 17.65(\log[\text{outflow}, m_i])$, where m_i is the current month, m_{i-1} is the previous month, and outflow is in cubic feet per second (cfs). Monthly inflows were calculated using Table A in SWRCB (1995, p. 26) without reference to EC triggers at Collinsville and Port Chicago or alternative compliance using daily or 14-day average $EC \leq 2.64$ mmhos/cm and therefore overestimate the monthly inflow that would be required for compliance.

[7] Minimum required flows were calculated for each year as described above in Footnote 6 and therefore overestimate the minimum required flows in many years. For further discussion of this issue, see below.

Delta exports (e.g., expansion of permitted capacity to 8,500 cfs and 10,300 cfs) and upstream diversions (e.g., increased CVP deliveries as anticipated in renewal of long-term contracts; CALFED's proposed construction and operation of new surface storage projects in the Sacramento and San Joaquin basins) increase in the near future, absent changes in Delta outflow requirements.

There is additional evidence to suggest that protecting flows currently in excess of the outflow objective may be necessary to maintain the desired level of protection as measured by population levels of estuary-dependent species. As noted earlier, although the establishment of the Asian clam did not change the direction (i.e., slope of the regression) or statistical significance of the X2-abundance relationships, for several species it changed the location of the regression intercept and "lowered" the regression line. Figure 13 shows the abundance of longfin smelt plotted against springtime X2 for 1967-1987, before the *Potamocorbula* invasion, and for 1988-2003, after the clam was established. For this species (as well as others; Kimmerer, 2002b), X2 conditions that prior to the *Potamocorbula* invasion would have supported high population level now only support moderate population levels. Based on the semi-log scale used in these analyses, the differences between X2-dependent population abundances before and after the *Potamocorbula* invasion are greatest in wetter years, suggesting that protection of the actual wetter year Delta outflows that exceed the level of outflow currently required by the objective may be an important component of protection for these affected species.

Recommendation: Based on the fact that estuarine habitat conditions were already impaired in the early 1970s; on the recent declines in populations of estuary-dependent species when little or no inflows to San Francisco Bay occurred in excess of the current Delta outflow objective requirement; and on the potential for decreasing ecologically important outflows in excess of the current objective as a result of implementing proposed increases in actual Delta exports and upstream diversions in the near future; the 1971.5 LOD assumption in the February – June Delta outflow objective should be replaced with an alternative level of flow and X2 location and biological response assuming a 1956 – 1968 LOD, a level "that existed before major environmental impacts of the State Water Project…[when] the probable habitat conditions of the Delta for salmon [have been identified]…and factors that controlled populations of striped bass are reasonably well understood" (SFEP, 1993). The SWRCB should also explicitly recognize the ancillary benefits to estuarine habitat and aquatic organisms of February – June outflows in excess of the regulatory objective, and adopt a policy of avoiding reductions in such flows when considering new applications for, or changes to existing, water rights permits.

3. The SWRCB should review and revise the "three ways to win" methodology for measuring compliance with the February – June Delta outflow objective in order to ensure that desired X2 location and variability are achieved.

The Delta outflow objective "requires that certain calculated flows, ... be maintained during each month" and that the required flows be "based on water year type or on the previous month's tributary flow conditions" (SWRCB, 2004). While this description captures the rationale and scientific basis for the February – June objective, it oversimplifies the actual implementation of this objective and overlooks important aspects of current compliance methods that affect the level of protection provided by the objective.

The Bay-Delta Plan allows three alternative measurements to determine compliance with the objective, the so-called "three ways to win": outflow (cfs), measured as the three-day running average of NDOI, and electrical conductivity (EC, mmhos/cm), measured as either a single daily value or as the 14-day running average. In addition, the levels of each of these three metrics required for each month during the February-June period, depend on two different factors: tributary flow conditions, measured as the Eight River Index (8RI) for the previous month, and the 14-day running average of EC at the Port Chicago compliance point on the last day of the previous month.

As described in the sections above, the basis for the Delta outflow objective is the well-documented relationship between outflow, X2, and abundance and survival of many estuarine fish and invertebrate species. The use of the 8RI to determine monthly required flows, as compared to an annual water year type metric, and of three substantially different flow levels (7100, 11,400, and 29,200 cfs) is also a sound basis for designing an objective that reasonably simulates year-to-year and seasonal variations in freshwater flows to the estuary. However, our analyses indicate that, in some years under certain conditions, the objective, as it is being implemented using the alternative compliance metrics, is not providing the level of protection anticipated based on the flow-X2 relationship. (See also our February 5, 2004 comment letter to the SWRCB regarding periodic review of the Bay-Delta Plan).

Table 2 and Figure 14 examine Delta outflow and compliance methods during February – June 2002. Table 2 provides quantitative comparisons of implementation of the Delta outflow objectives as 3-day average outflow (i.e., EC not considered) based entirely on tributary flow conditions (i.e., the 8RI only, no Port Chicago trigger) and actual operations, which incorporated the alternative compliance metrics of daily and 14-day average EC as well as the use of EC at Port Chicago to "trigger" implementation of the high flow level (i.e., 29,200 cfs). Figure 14 presents these comparisons graphically using daily data.

Our preliminary analyses suggest that the effects of the alternative compliance metrics and the use of the Port Chicago EC trigger have the greatest impacts in drier years. According to CDWR, water year 2002 was a "dry" year in both the Sacramento and San Joaquin watersheds with an estimated 19.3 MAF of total annual runoff in the ten largest rivers in the watershed (79% of the long term average for annual 10-river runoff). We applied correction factors developed from the CDWR's unimpaired Delta outflow dataset to this total annual runoff in order to estimate total annual unimpaired Delta outflow at 18.3 MAF (TBI, 2003). By comparison, actual annual outflow (NDOI) was 9.2 MAF, a 50% reduction in outflow. Nearly 11.4 MAF of runoff occurred during the February – June period; actual outflow during the February-June period was 3.7 MAF, just 33% of unimpaired runoff during that period.

Results of our analyses indicated that, despite high to moderate 8RI values that would be expected to trigger multiple days of high Port Chicago flows in four of the five months, these high flows were instead <u>never</u> implemented during any month of the five-month period (Table 2). The immediate cause of this was a large increase in Port Chicago EC as outflows from a January storm event declined extremely rapidly (Figure 14), a period during which Delta exports increased from 5800 to more than 11,500 cfs. Subsequent elimination of high flows during February drove Port Chicago EC even higher, effectively precluding sufficient outflow to reduce Port Chicago EC and trigger high flows in the following months. This set the stage for low, "flat-lined" outflows to the estuary during the entire February – June period, despite moderate to good tributary flow conditions. The biologically relevant habitat metric, X2, was also shifted dramatically upstream to greater than 70 km in the first month, where it remained for the entire duration of the five-month period and its seasonal variability cut in half. The overall result was generally poor habitat conditions and declining fish populations.

The Delta outflow objective is designed to require larger flows during the first few months of the February – June period than during the latter months; this has the effect of giving the estuary a "good start' for the spring season. Even in the driest of years, the objective requires minimum flows be increased starting in February. In contrast, the requirement of the 14-day average 2.64 EC at Port Chicago to trigger the high flow requirement regardless of January tributary flows conditions can, and in 2002 did, have the effect of reducing required flows at the onset of the season and, as a result, set the stage for chronically low flows throughout this ecologically important period. This criterion in the objective potentially provides an incentive for water managers to "game" the system, adjusting their January operations to reduce outflows and avoid triggering the Port Chicago flow requirement in February and possibly later months as well. Elimination of the Port Chicago trigger, at least for the first one or two months of the February-June period, and basing required outflows on the 8RI instead, could reduce this problem.

Recommendation: The SWRCB should review the use of the "three ways to win" methodology and revise the application of the EC compliance measurement alternatives, including elimination of the Port Chicago EC trigger in February and March, to ensure that compliance results in X2 location and seasonal variability that correspond more closely to the desired outflows and levels of protection based on the flow-X2 relationship.

4. Potential upstream resource impacts of implementing the February – June Delta outflow objective should be addressed by imposing new water rights permit conditions and other means, not by revising the Delta outflow objective.

The CVP and SWP make releases from Shasta, Oroville, Folsom and New Melones Reservoirs and modify export and Delta Cross Channel operations in order to comply with conditions of their water rights permits to meet Delta water quality objectives. In particular, the projects rely heavily on releases from Folsom Reservoir to meet Delta water quality objectives because of the facility's high refill potential and proximity to the Delta.

Concerns have been raised regarding impacts on upstream habitat conditions and biota, especially American River salmonid populations, as a result of changed Folsom operations to meet the Delta outflow objective's Port Chicago flow requirement. Specifically, in February 2003 and April 2004, additional

Folsom releases were made to maintain a 3-day Delta outflow of 29,200 cubic feet per second (cfs) when the Port Chicago objective was triggered. Flow fluctuations as a result of these releases have the potential to dewater and isolate salmon redds; strand fry; isolate juveniles; and deplete coldwater pool storage. In both of these years some adverse impacts were observed (SWRI, 2004).

According to the Staff Report, "adding flexibility to the Delta outflow objectives ...may be urgent in light of recent fisheries concerns...associated with implementation of this objective" (SWRCB, 2004). Some parties involved in the CALFED Operations Group process have proposed that the Delta outflow objective be changed to allow relaxation of the Port Chicago objective when increasing Folsom releases may cause adverse impacts to American River salmonids. While the concerns regarding these upstream resource impacts are legitimate, it is neither necessary nor justified to change the objective to address them.

When triggered, the Port Chicago objective is in most cases met by natural runoff and does not require additional releases from storage (Herbold, 2004a). Once the Port Chicago objective has been triggered, the projects typically defer taking action until the latest possible time in the month (depending on the days of compliance triggered) with the expectation that natural runoff will meet the objective. In the infrequent event that runoff is not sufficient, then having forgone other options the projects may need to immediately begin making releases from Folsom.

The decision to anticipate and avoid last-minute release decisions and upstream impacts is in the hands of the project operators, however. Making earlier releases (and other actions) when runoff levels that triggered the Port Chicago objective are still relatively high (e.g., the trailing limb of the hydrograph) can significantly lower the water supply impacts of compliance and avoid the need to ramp up releases later in the month at increased cost and with the potential for adverse upstream fishery impacts (Figure 15, and see Herbold, 2004b). If it is unlikely or highly uncertain that natural runoff will be able to meet the Port Chicago objective, and Folsom releases are not desirable, then the projects could make earlier decisions to implement other options, including reducing exports, making releases from Shasta, Oroville and/or New Melones in addition to or in lieu of Folsom releases, and/or making arrangements with non-project water users to make releases from non-project storage or to limit diversions. In the event that natural runoff increases later in the month after the projects take earlier action, modify the water rights permits of the CVP and SWP to require implementation of an approved operational protocol to avoid upstream impacts, and revisit the water rights permits of non-project water users to add terms and conditions to help avoid these impacts.

Thank you for considering our recommendations regarding potential amendments and revisions to the Bay-Delta Plan objective for Delta outflow, and regarding related actions that the SWRCB should consider. Please contact us if you have any questions regarding these comments.

Sincerely,

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References

Herbold, Bruce. 2004a. Summary of months when Port Chicago would have triggered. Analysis prepared for CALFED Operations Group.

Herbold, Bruce. 2004b. February 2003/April 2004 graphs of Port Chicago X2. Analysis prepared for CALFED Operations Group.

Jassby, A.D. 1992. Isohaline position as a habitat indicator for estuarine resources: San Francisco Estuary. In: San Francisco Estuary Project. 1993. *Managing freshwater discharge to the San Francisco Bay/Sacramento-San Joaquin Delta Estuary: the scientific basis for an estuarine standard.*

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.

Jassby, A. D., J. E. Cloern, and A. B. Muller-Solger. 2003. Phytoplankton fuels Delta food web. *California Agriculture* 57(4):104-110.

Kimmerer, W. 2002a. Effects of freshwater flow on estuarine organisms: physical effects of trophic linkages? *Marine Ecology Progressive Series* 243:39-55.

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

Kimmerer, W. 2004. Open water processes of the San Francisco Estuary: from physical forcing to biological response. *San Francisco Estuary and Watershed Science* (online serial) Volume 2, Issue 1, Article 1. Available at http://repositories.edlib.org/jmie/sfews/vol2/iss1/art1.

San Francisco Estuary Project (SFEP). 1993. *Managing freshwater discharge to the San Francisco Bay/Sacramento-San Joaquin Delta Estuary: the scientific basis for an estuarine standard.*

State Water Resources Control Board (SWRCB). 2004. *Periodic Review of the 1995 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta estuary.* Staff Report. State Water Resources Control Board, California Environmental Protection Agency. 63 pp.

Surface Water Resources Inc. (SWRI). 2004. *Impacts on lower American River salmonids and recommendations associated with Folsom reservoir operations to meet Delta water quality objectives and demands.* Draft Report. Prepared for Sacramento Water Forum.

The Bay Institute (TBI). 2003. Bay-Delta Ecological Scorecard Project, San Francisco Bay Freshwater Inflow Index, Technical Appendix. Available at http://www.bay.org/ecological_scorecard.htm.

Table 1. Hypothesized mechanisms for the effects of high flows (i.e., low X2) on species abundance and survival. From Kimmerer, 2004.

Table 5. Conceptual model of fish- X2 relationships. This table summarizes potential mechanisms underlying the relationships, based on analysis by the Estuarine Ecology Team (1997) and other reports. The table does not include mechanisms occurring entirely upstream of the Delta. The order does not relate to relative importance or likelihood of the mechanisms.

Mechanism	*Species*	*Evidence or Source*
Habitat increases or becomes more available as X2 moves seaward		
Spawning habitat area or access	Pacific herring	Herring require rocky or seagrass substrate with somewhat reduced salinity to spawn
	Striped bass	Habitat on the lower San Joaquin is expanded when flow is high
	Splittail	Yolo bypass floods at high flows, providing feeding and spawning habitat for splittail (Sommer et al. 1997)
Rearing habitat area	Bay shrimp	Require intermediate-salinity habitat for rearing; area may increase as flow increases
	Pacific herring	Herring require low salinity for rearing; area may increase as flow increases
	Starry flounder	As for Bay shrimp
	American shad	Uncertain status
	Striped bass	Area of low-salinity habitat may increase as flow increases
	Longfin smelt	As for striped bass
Adult habitat	Splittail	As for spawning habitat; Sommer et al. 1997
Circulation patterns become more conducive to survival as flow increases		
Strength of gravitational circulation	Bay shrimp	Shrimp recruit from the ocean and therefore recruitment may vary with GC strength, potentially a function of X2
	Starry flounder	As for Bay shrimp
Residence time in Low-Salinity Zone	Mysids	Tidal vertical migration may be more effective when gravitational circulation is strong (Kimmerer et al. 1998)
	Longfin smelt	As for mysids (Bennett 1998)
	Striped bass	As for mysids (Bennett 1998)
Transport to rearing area	American shad	High flows may disperse eggs and larvae
	Striped bass	Egg-6mm larval survival positively related to flow, as is transport rate
	Longfin smelt	Similar to striped bass
Reduced entrainment	American shad	Peak emigration is in the low-flow time of year
	Striped bass	Entrainment losses of striped bass related to position of population, which is centered on salinity of about 2.
	Longfin smelt	As for striped bass (mainly larvae)
Feeding becomes more successful with seaward X2		
Higher food production	American shad	Abundance of mysids is higher in wet years
	Striped bass	Food supply may increase (Turner and Chadwick 1972)
	Longfin smelt	Food supply may increase with flow
Co-occurrence with food (match-mismatch)	Pacific herring	Timing of spring blooms may be important
	Striped bass	Timing of arrival in LSZ vs. food supply
	Longfin smelt	Timing of spring blooms may be important
Other mechanisms		
Predator avoidance through turbidity	Mysids	Turbidity in the LSZ increases with increasing flow, possibly reducing effectiveness of visual predators
Toxic dilution	Splittail	Splittail are vulnerable to agricultural and industrial discharges for most of life cycle
Migratory cues	American shad	Proportion of repeat spawners is related to flow in tributaries
Inputs of nutrients or organic matter	Various	Unlikely mechanism, since lower trophic levels have little response to flow.

Table 2. Comparison of monthly Delta outflow (cfs and MAF) as required by Bay-Delta Plan Table A (page 26, SWRCB, 1995, with required flows based on the Eight River Index for the previous month [PMI] but not electrical conductivity, EC, mmhos/cm, see Footnote 6), and actual outflow and implemented Bay-Delta Plan requirements incorporating the alternative compliance metrics (daily and 14-day average EC) and the Port Chicago EC "trigger" measurement. X2 values predicted under the Table A compliance method and actual X2 values are also shown. The Explanation column identifies the numbers of days that actual flows met or exceeded the outflow objective(s), describes the reasons for the differences, and compares actual X2 location to the maximum (i.e., most upstream) desired location targeted by the outflow objective.

Month (PMI) (MAF)	**Outflow required by Table A** (based on PMI, no Port Chicago EC trigger) Flow (days x flows) (MAF)	X2 (km) Aver. (1 SD)	**Actual outflow** (implemented outflow requirement) Flow (days x flows) (MAF)	X2 (km) Aver. (1 SD)	**Explanation**
Feb. (2.72)	24 x 29,200 cfs 4 x 11,400 cfs 1.48 MAF	67.2 (1.28)	28 x 11,400 cfs av. 11,942 cfs 0.66 MAF	72.3 (1.67)	Port Chicago (PCT) flow (29,200 cfs) not required because PCT EC>2.64. Chipps flow (11,400 cfs) not met in 17 of 28 days because Chipps EC≤2.64. X2 shifts 5 km upstream from maximum desired location.
March (1.73)	12 x 29,200 cfs 19 x 11,400 cfs 1.16 MAF	67.7 (1.16)	31 x 11,400 cfs av. 17,089 cfs 1.05 MAF	71.6 (0.89)	Port Chicago (PCT) flow (29,200 cfs) not required because PCT EC>2.64. Chipps flow (11,400 cfs) not met in 4 of 31 days because Chipps EC≤2.64. X2 remains nearly 4 km upstream of maximum desired location.
April (2.30)	5 x 29,200 cfs 25 x 11,400 cfs 0.84 MAF	71.8 (0.72)	28 x 11,400 cfs 2 x 7100 cfs av. 11,796 cfs 0.70 MAF	73.4 (0.78)	Port Chicago (PCT) flow (29,200 cfs) not required because PCT EC>2.64. Chipps flow (11,400 cfs) not met in 13 of 28 days because Chipps EC≤2.64. X2 is 1.6 km upstream of maximum desired location.
May (2.82)	3 x 29,200 cfs 20 x 11,400 cfs 8 x 7100 cfs 0.73 MAF	74.1 (0.78)	22 x 11,400 cfs 9 x 7100 cfs av. 13,589 cfs 0.84 MAF	73.8 (0.73)	Port Chicago (PCT) flow (29,200 cfs) not required because PCT EC>2.64. Chipps flow (11,400 cfs) not met in 4 of 22 days because Chipps EC≤2.64. Late May pulse flow stabilizes X2 just 0.3 km downstream of maximum desired location.

June (2.59)	1 x 11,400 cfs 29 x 7100 cfs 0.42 MAF	78.3 (1.13)	1 x 11,400 cfs 29 x 7100 cfs av. 7545 cfs 0.45 MAF	76.9 (1.87)	Chipps flow (11,400 cfs) not met in 1 of 1 days because Chipps EC≤2.64. Collinsville flow (7100 cfs) not met 11 of 30 days because Collinsville EC≤2.64. X2 is just 1.4 km downstream of maximum desired location.
Total (Feb. through June)	4.64 MAF (41% of unimpaired)	71.9 (4.26)	3.70 MAF (33% of unimpaired)	73.6 (2.22)	Delta outflow reduced by 0.83 MAF or 18%. Average X2 is located nearly 2 km upstream of maximum desired location. Seasonal variability in X2 cut in half. If actual operations had exactly met the implemented objectives, X2 would have been more than 3 km upstream of the maximum desired location (75.2 km; 2.47 SD).

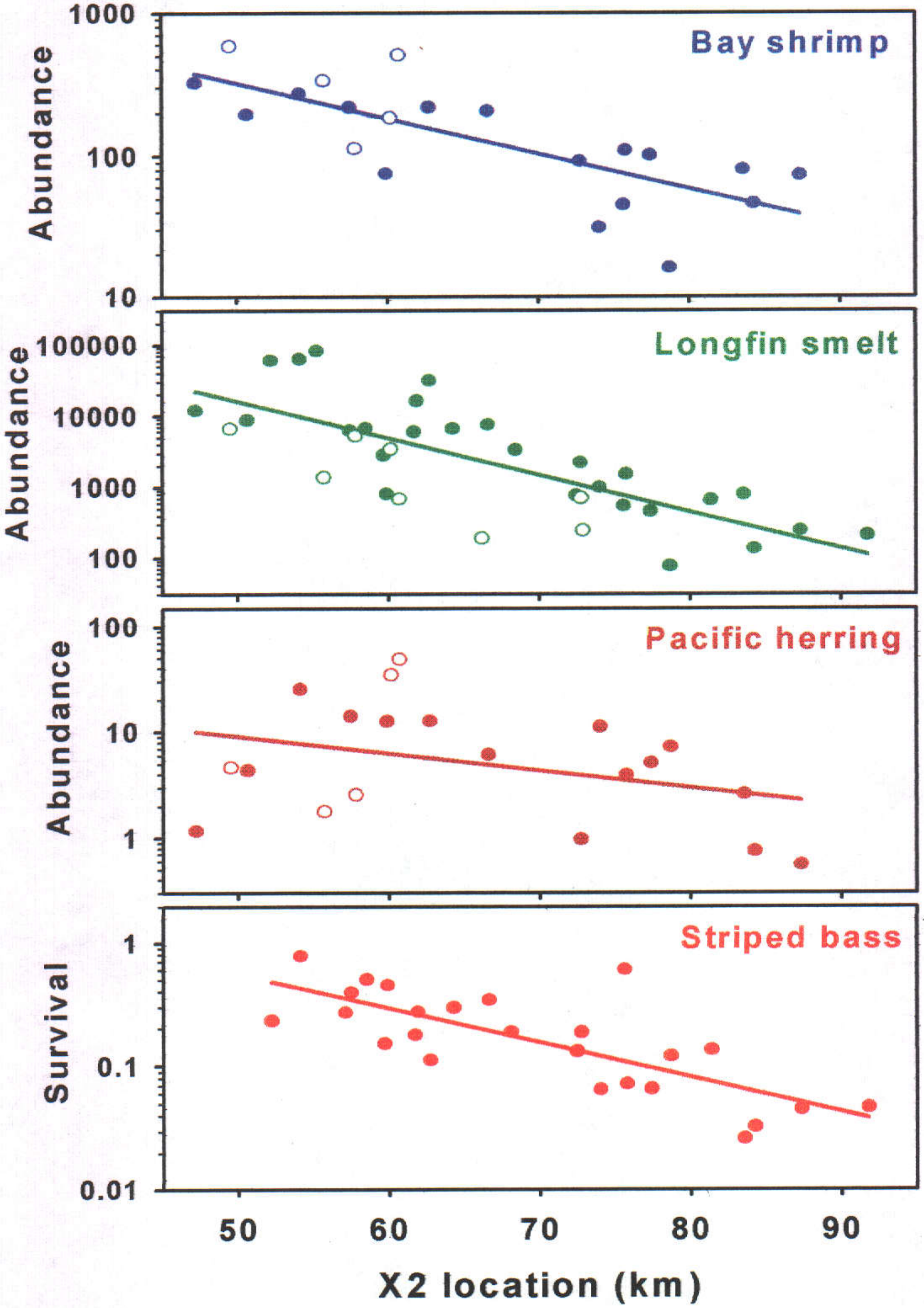

Figure 1. Abundance of Bay shrimp, longfin smelt and Pacific herring, and survival of larval striped bass plotted against average springtime X2 (closed circles = before 1996, open circles= 1996 and beyond). For each of these species, as well as many others, high freshwater flows during the spring, which move X2 downstream into Suisun and San Pablo Bays (i.e., low X2 values), are correlated with higher population abundance and survival. Data from W. Kimmerer, San Francisco State University.

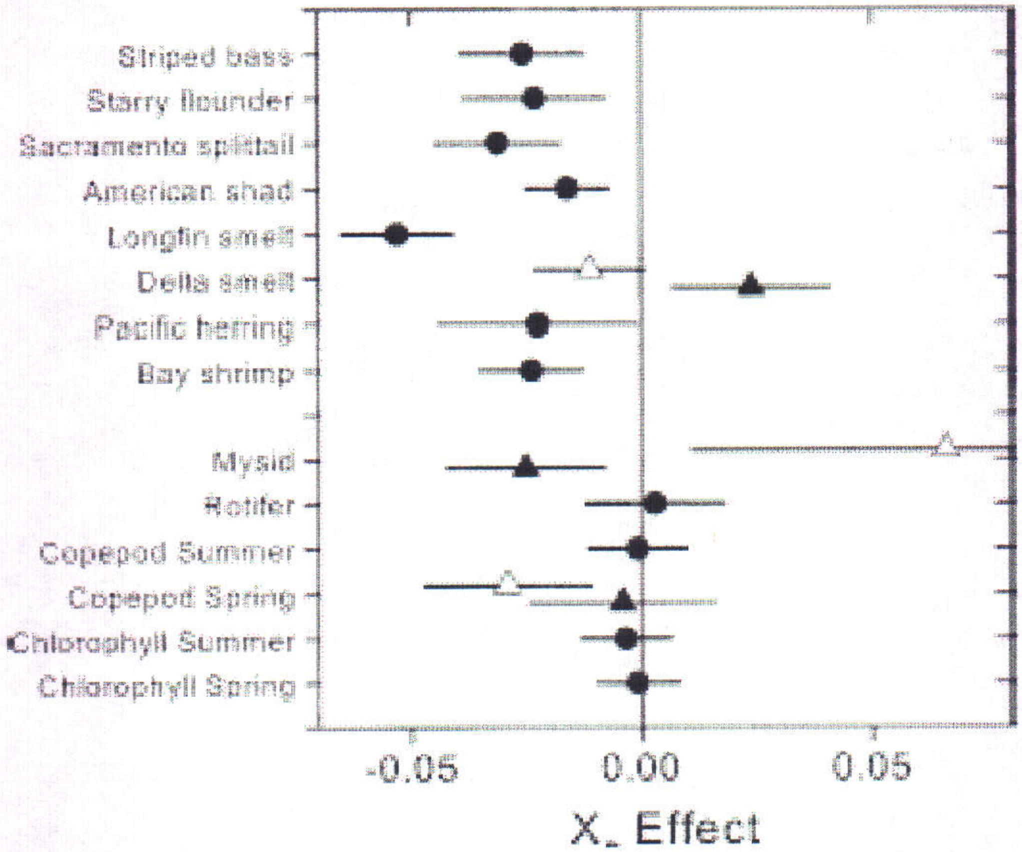

Fig. 8. Results of analyses of covariance or regressions of abundance or survival indices or estimates versus X_2 (Kimmerer 2002). Symbols indicate slopes and 95% confidence intervals; negative slopes indicate taxa whose abundance or survival is higher under high-flow than low-flow conditions. The upper 8 taxa are species of fish and bay shrimp, whose life histories encompass a variety of habitats; the bottom 6 are taxa from lower trophic levels in the low-salinity zone, including the rotifer *Synchaeta bicornis*, the copepod *Eurytemora affinis*, and the mysid *Neomysis mercedis* plus chlorophyll. Circles indicate variables for which slopes did not change in 1987–1988. Triangles indicate slopes that changed between the earlier (filled) and later (open symbols) period. The exception is Delta smelt, for which the breakpoint was 1981–1982. Data for striped bass and Pacific herring are egg-juvenile survival, and the remainder are abundance indices or estimates.

Figure 2. From Kimmerer (2002b). See caption above for explanation.

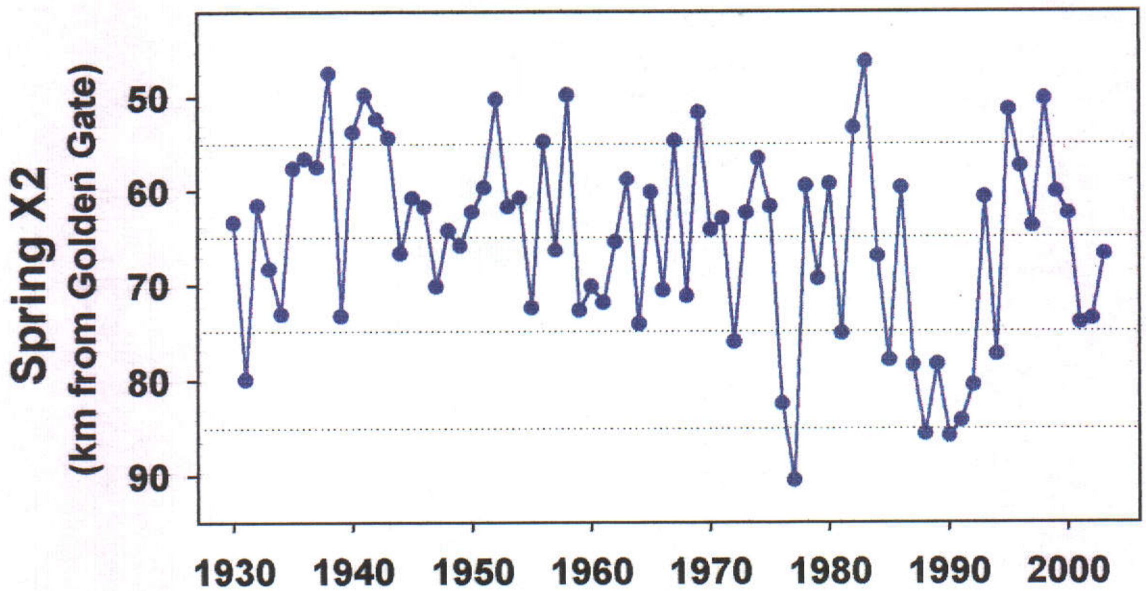

Figure 3. February-June X2 in the San Francisco estuary, 1930-2003. Data source: California Department of Water Resources, Dayflow.

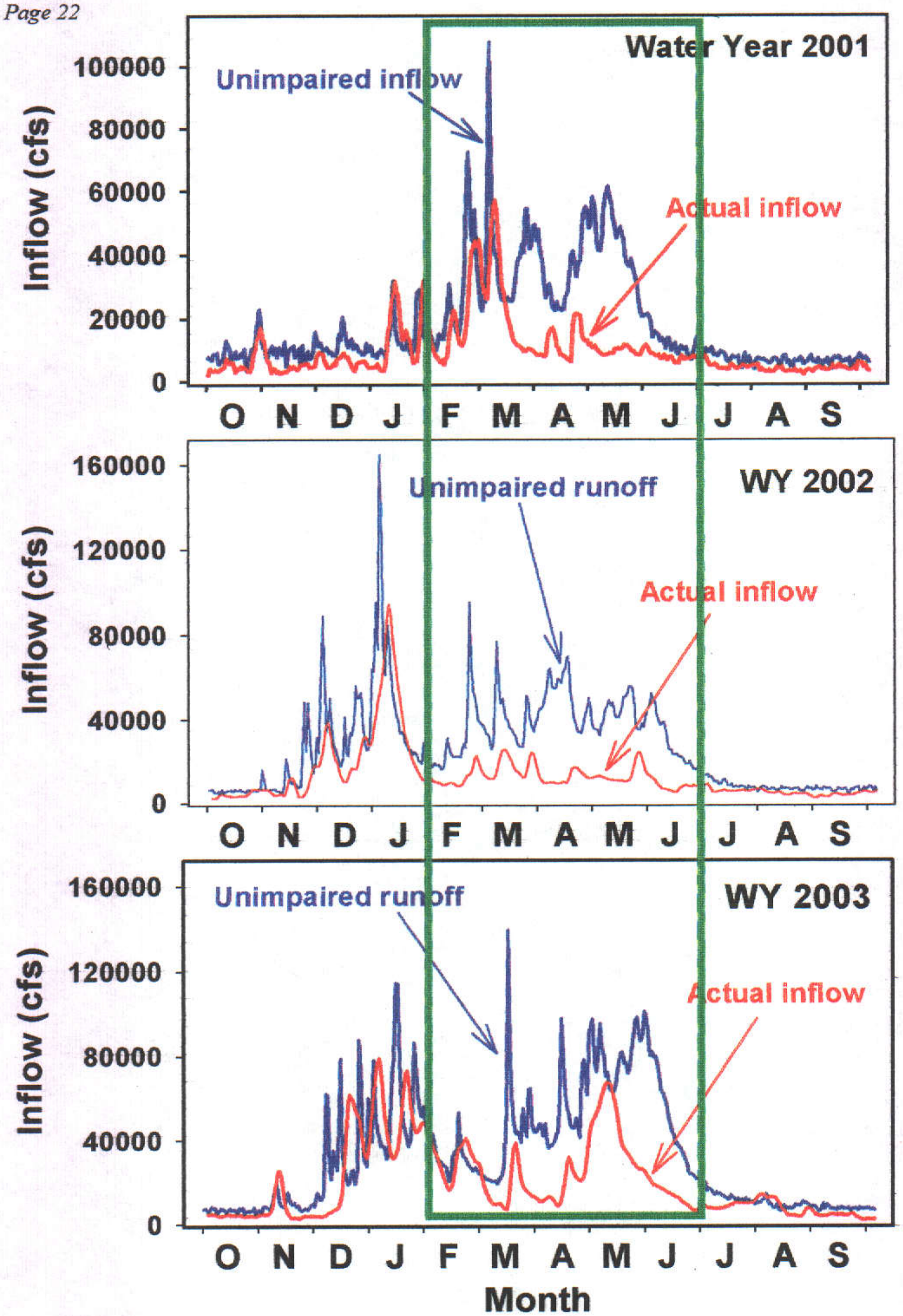

Figure 4. Actual and unimpaired freshwater inflow to the San Francisco estuary from the Sacramento-San Joaquin watershed. Data for actual inflow, or NDOI, are from Dayflow (Department of Water Resources). Unimpaired runoff is calculated as the sum of unimpaired runoff from the ten largest rivers in the watershed (Sacramento, Feather, Yuba, American, Mokelumne, Cosumnes, Staanislaus, Tuolumne, Merced and San Joaquin Rivers) reported by the California Data Exchange Center (CDEC). Upstream and in-Delta water project operations have the greatest effects on the amounts, timing, and variability of freshwater inflows to the San Francisco estuary during the late-winter and spring (February-June, green box). This period coincides with spawning, incubation, early rearing, and migration for many anadromous and estuarine fish and invertebrate species.

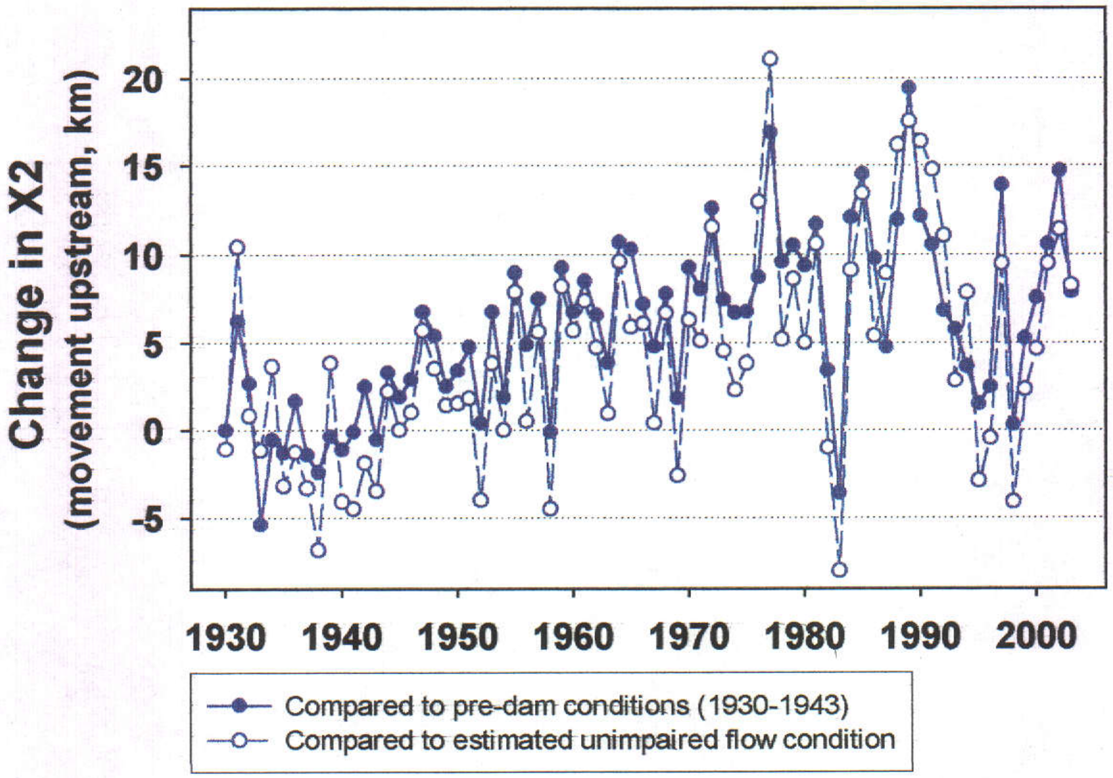

Figure 5. Change (i.e., movement upstream) in average February-June X2 in the San Francisco estuary, 1930-2003. Each point represents the difference between actual X2 (calculated from NDOI) and estimated X2 during the 1930-1943 "pre-dam" period (normalized for water year type) (solid circles) and estimated X2 under unimpaired flow conditions (open circles). Data sources: California Department of Water Resources, Dayflow and California Data Exchange Center (CDEC).

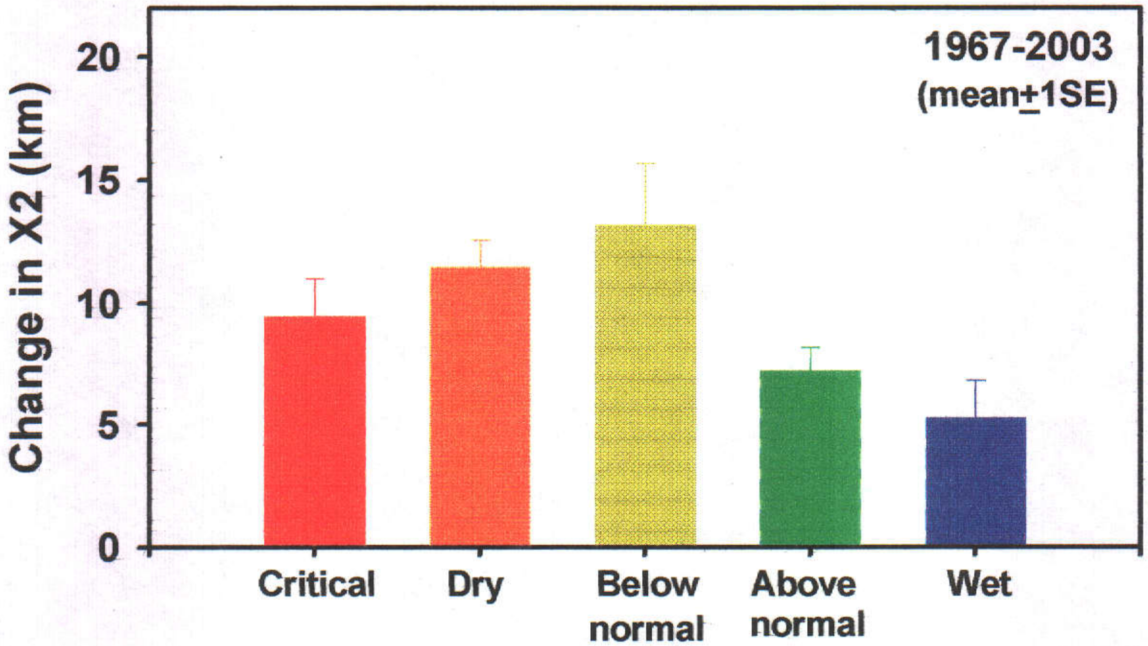

Figure 6. Average (+1 SE) upstream movement (km) of February-June X2 in each water year type during the 1967-2003 period. The greatest deviations in X2 resulting from upstream and in-Delta water management occur in average (below normal or median) and dry years. Note that water year type categories used in this analysis were determined based on frequency of occurrence for unimpaired runoff rather than the methods used by state and federal water management agencies (see Footnote 4 for more information).

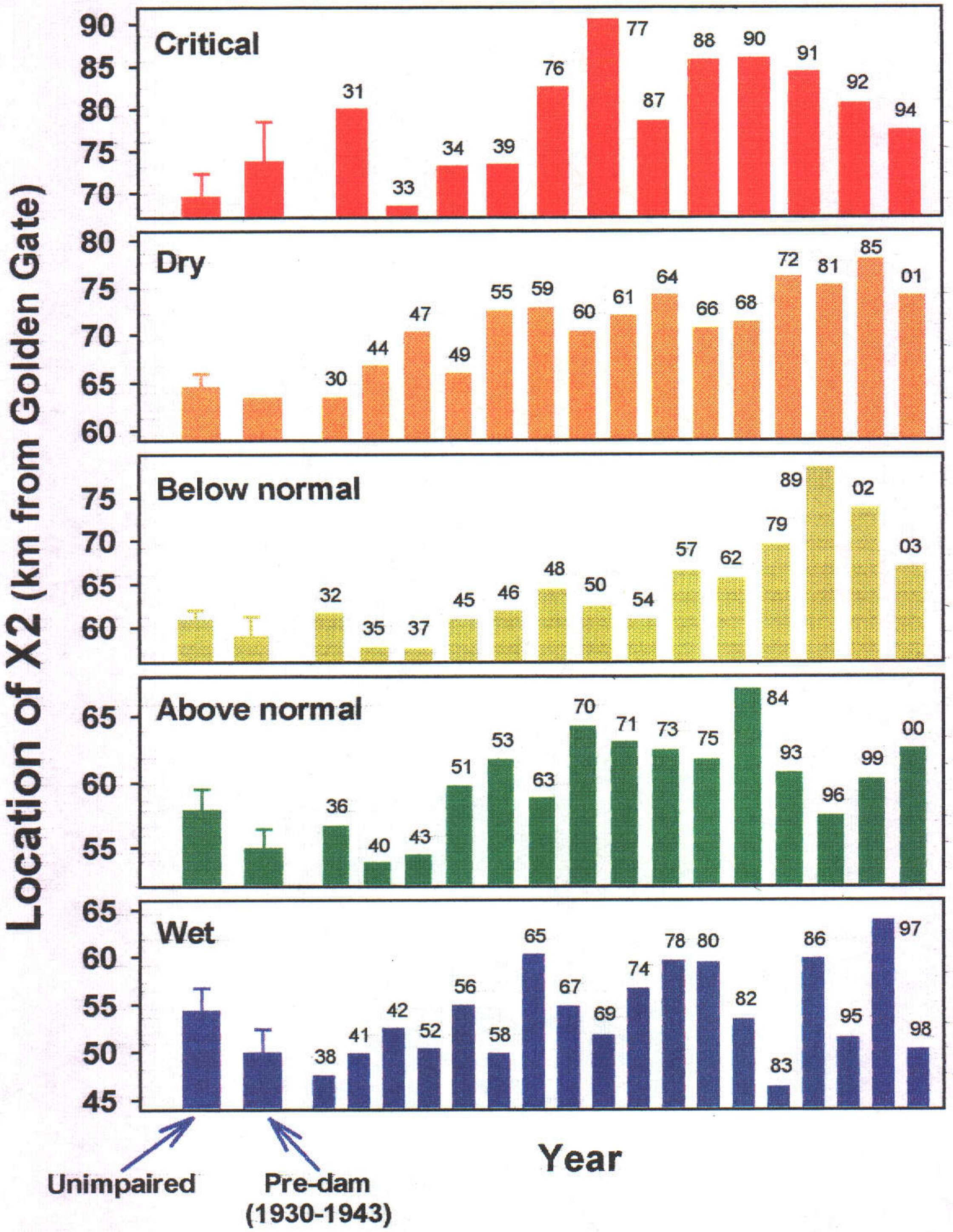

Figure 7. Location of February-June X2 (km from the Golden Gate) in different water year types, 1930-2003. Mean (±1 SD) estimated unimpaired X2 and pre-dam X2 are shown for each year type. The number above each bar is the year (shown as the last two digits). Note that water year type categories used in this analysis were determined based on frequency of occurrence for unimpaired runoff rather than the methods used by state and federal water management agencies (see Footnote 4 for more information).

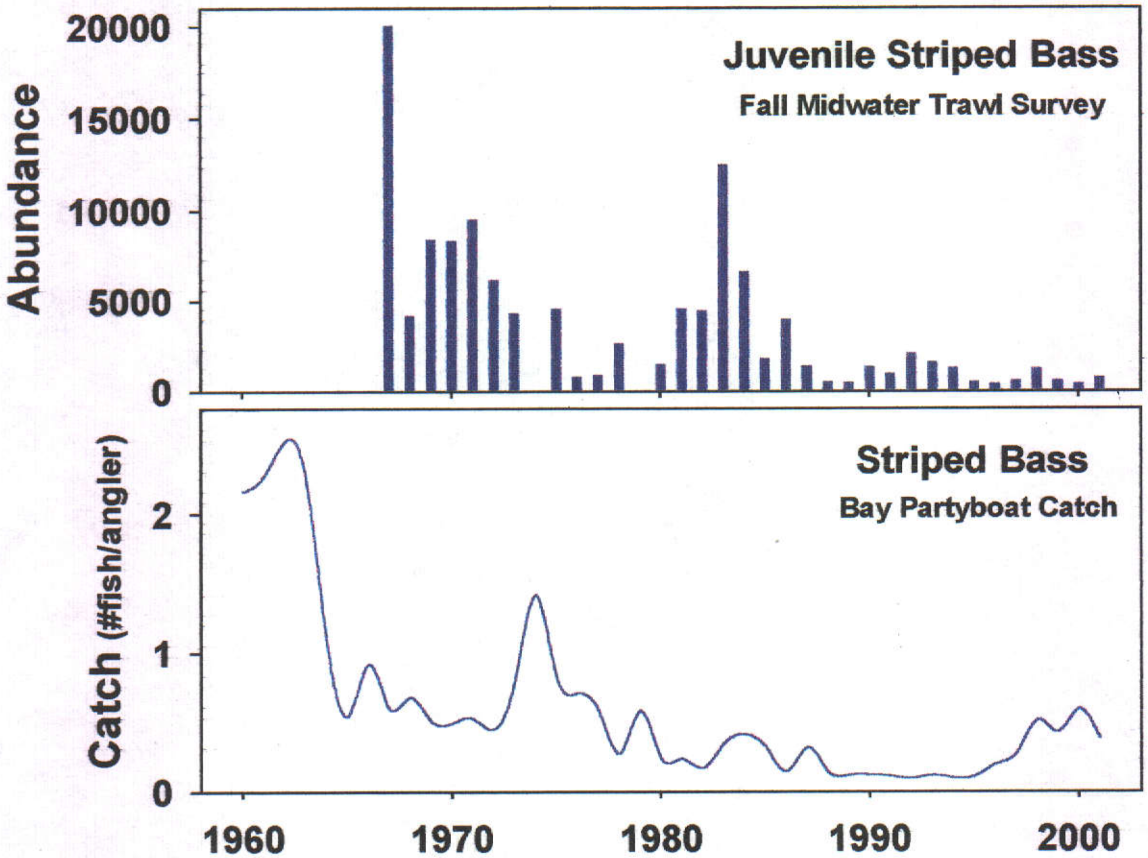

Figure 8. Recreational fishing success for striped bass in San Francisco Bay fell as abundance of juvenile fish, whose larval survival is strongly correlated with springtime Delta outflow and X2, declined. The steepest declines occurred during the 1970s, the period for which the level of water management development is the basis for the level of protection provided by the Delta Outflow Objective. Data sources: California Department of Fish and Game Fall Midwater Trawl and Commercial Passenger Fishing Vessel database.

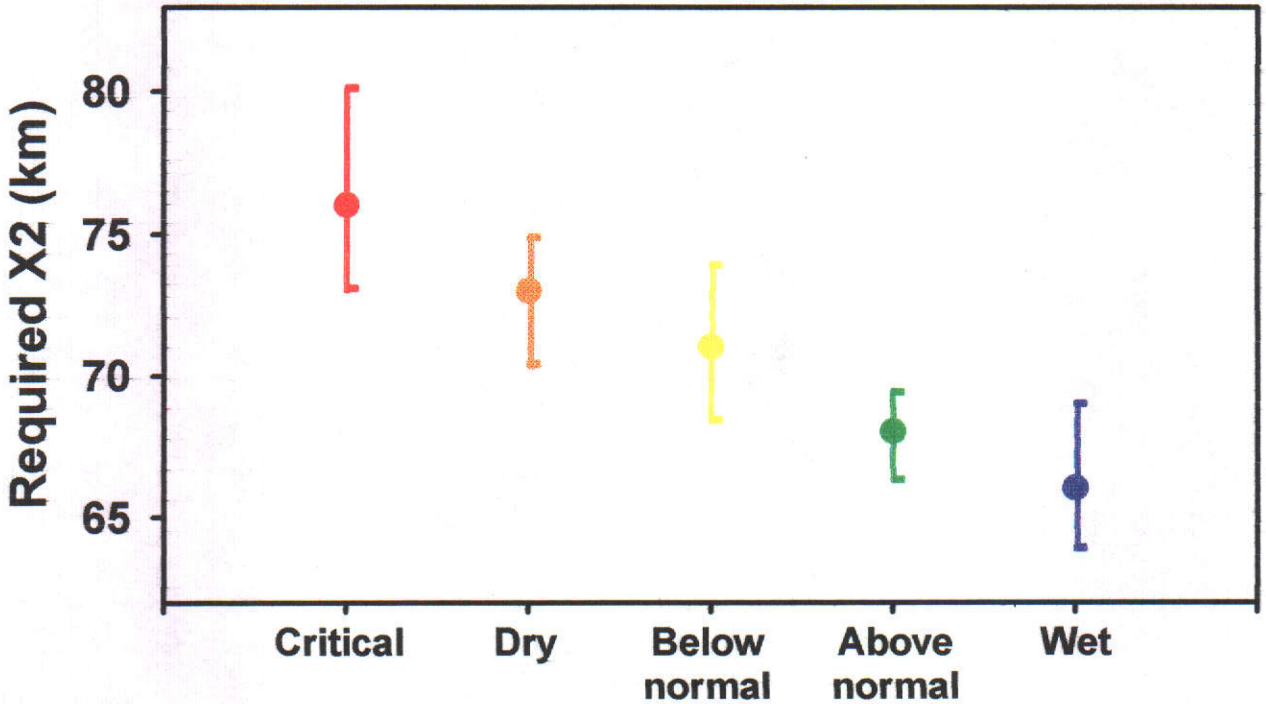

Figure 9. Average (closed circle) and range (vertical lines) of February-June X2 location required by the Bay-Delta Plan's Delta outflow objective for each water year type (calculated using data from 1930-2002). Required X2 was calculated from the monthly required inflows as described in SWRCB (1995, Table A, p. 26) without reference to alternative compliance based in EC or the Port Chicago EC trigger (see Footnote 6 for more information). Note that water year type categories used in this analysis were determined based on frequency of occurrence for unimpaired runoff rather than the methods used by state and federal water management agencies (see Footnote 4 for more information).

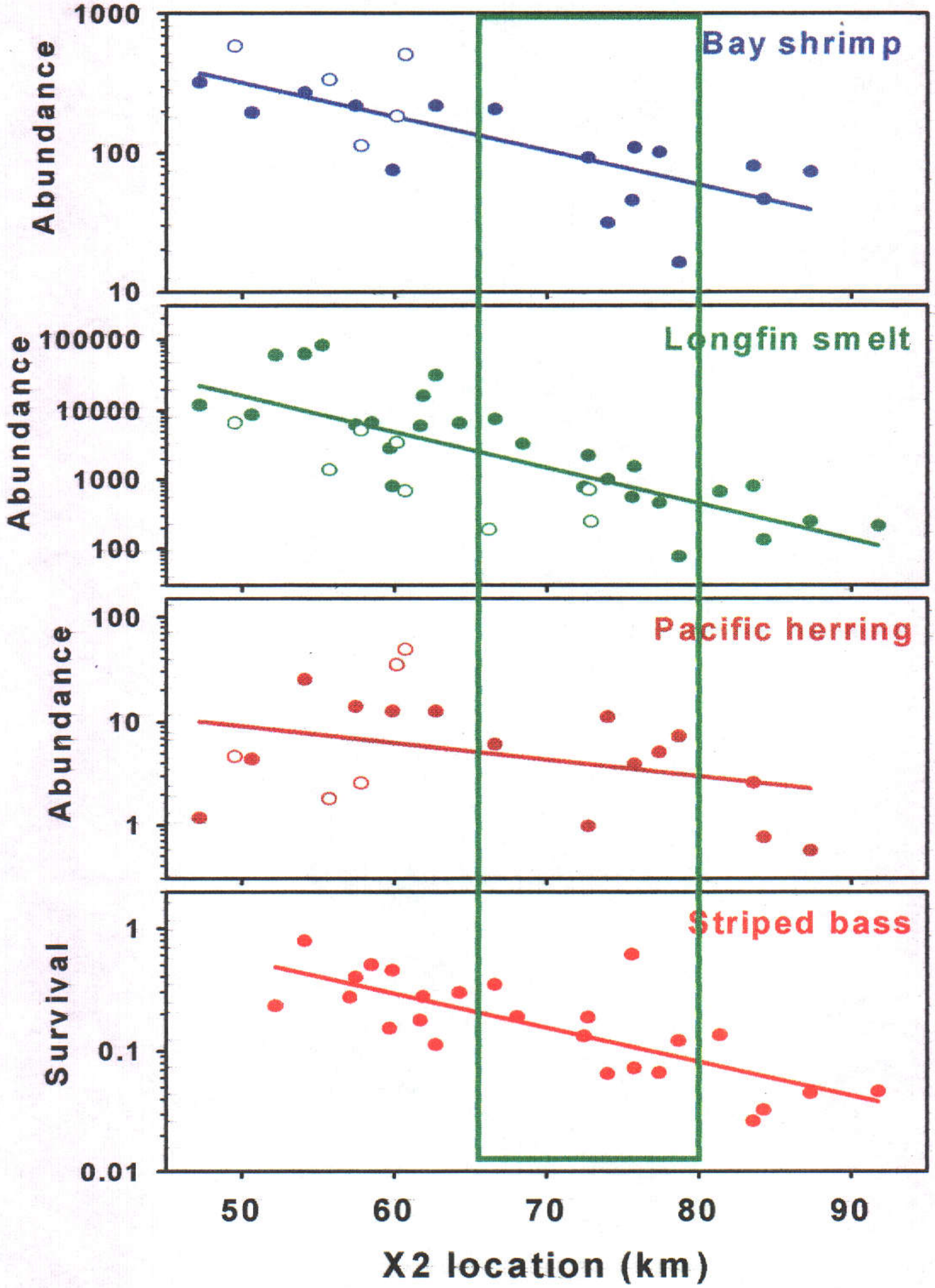

Figure 10. Abundance and survival of selected fish and invertebrate species plotted against average springtime X2 (closed circles = before 1996, open circles= 1996 and beyond). The range of X2 values required to meet the Delta Outflow (from a low of 65 km in wet years to a high of 80 km in critically dry years; see Figure 9) is shown in the green box. Based on abundance and/or survival for the species shown, this range of X2 values corresponds to "fair" (or intermediate) to "poor" conditions.

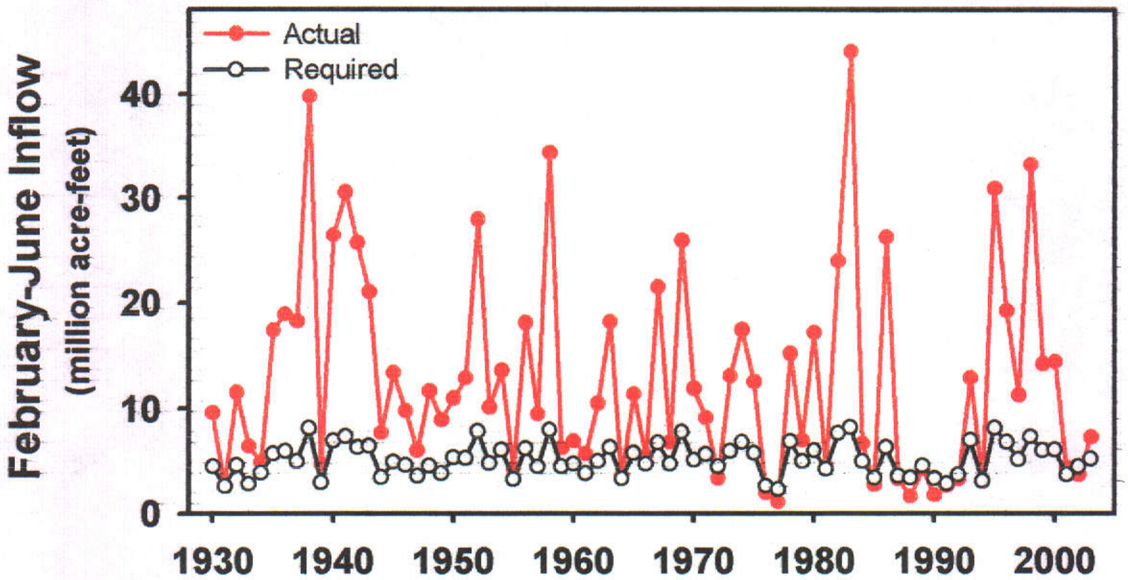

Figure 11. Comparison of the actual late-winter/spring freshwater inflows (average for February-June, closed red circles) with the amount of inflow required by Delta outflow objective during the February-June period (average, open black circles), 1930-2003. Required flows were calculated from the monthly required inflows as described in SWRCB (1995), Table A (p. 26) without reference to the Collinsville or Port Chicago EC triggers (see Footnote 6 for more information).

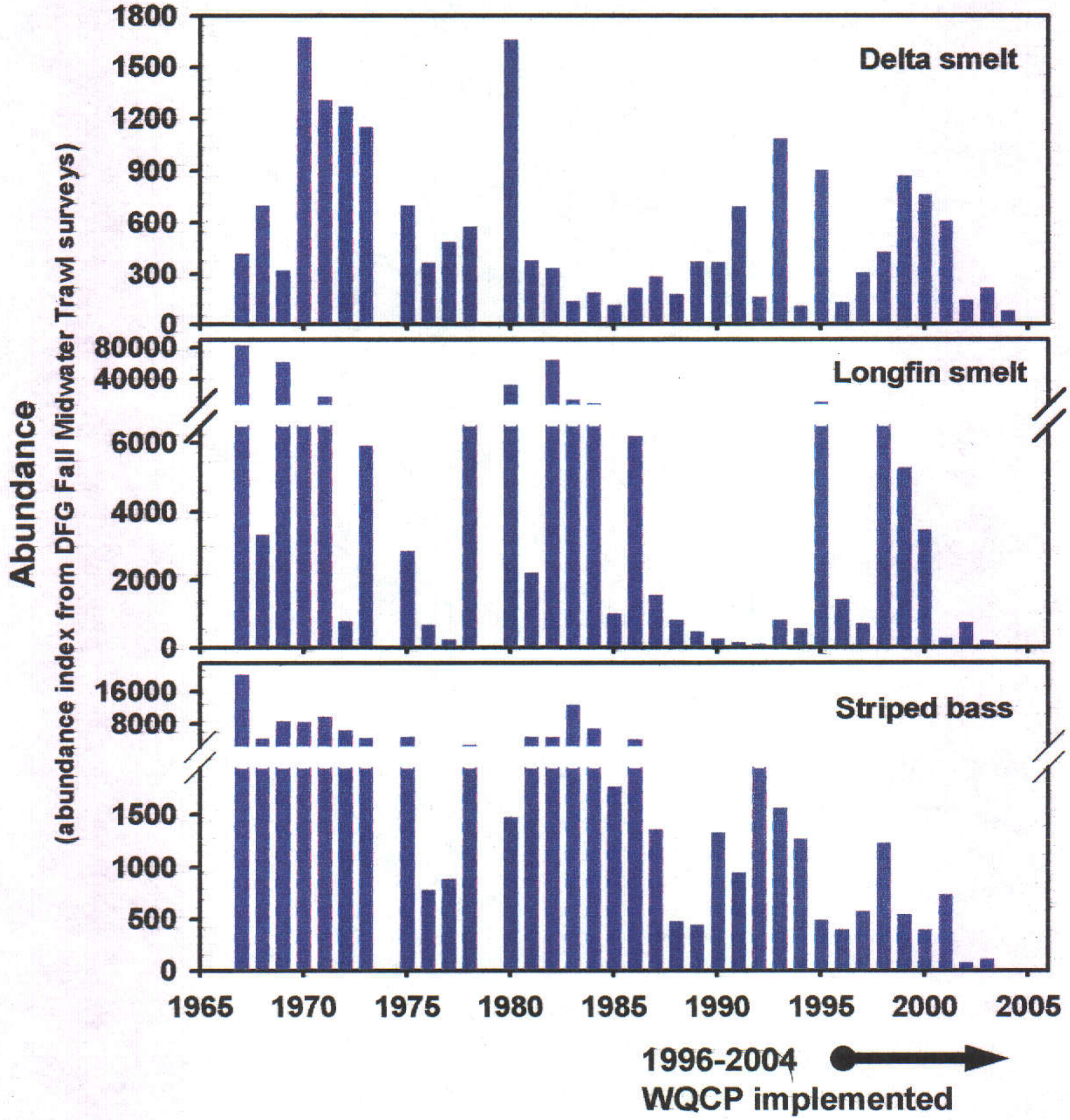

Figure 12 Population abundance of delta smelt, longfin smelt, and juvenile striped bass, 1967-2003 (2004 for delta smelt). Although each species exhibited some modest improvements in abundance during the late 1990s, all have experienced a marked population decline during the past three to five years. Data Source: California Department of Fish and Game Fall Midwater Trawl survey

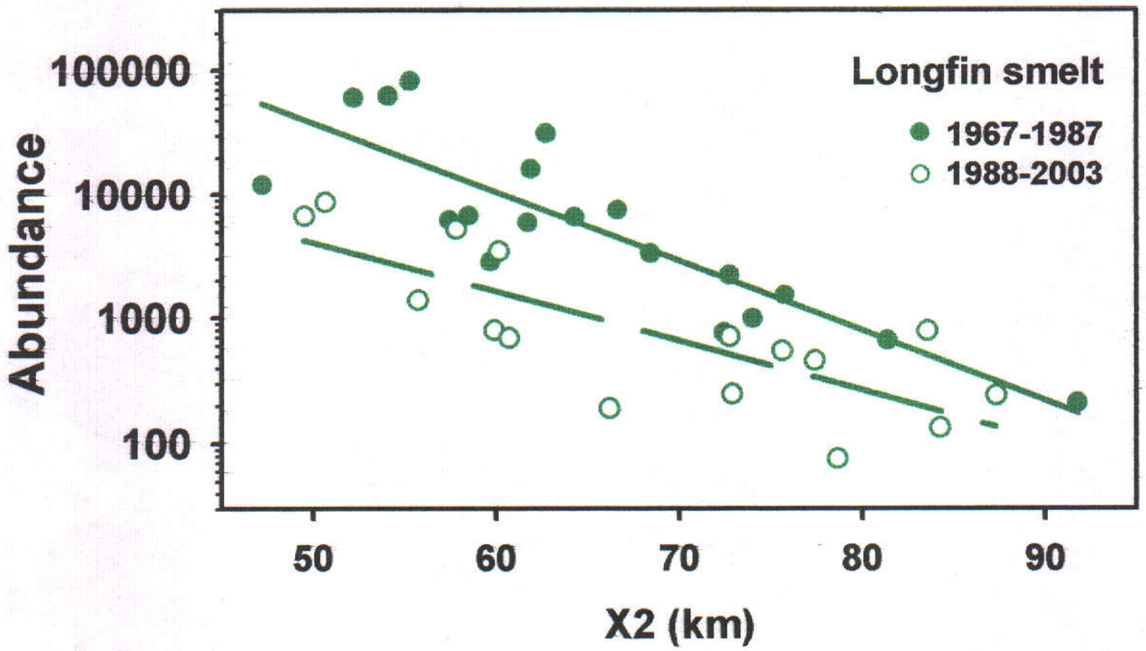

Figure 13. Abundance and survival of longfin smelt plotted against average springtime X2 for 1967-1987, before the Asian clam invasion (closed circles) and 1988-2003, after the non-native clam became established (open circles). The direction of the X2-abundance relationship has not changed but, since the establishment of the clam, X2 conditions that would have supported moderate to high population levels now only support moderately low population levels.

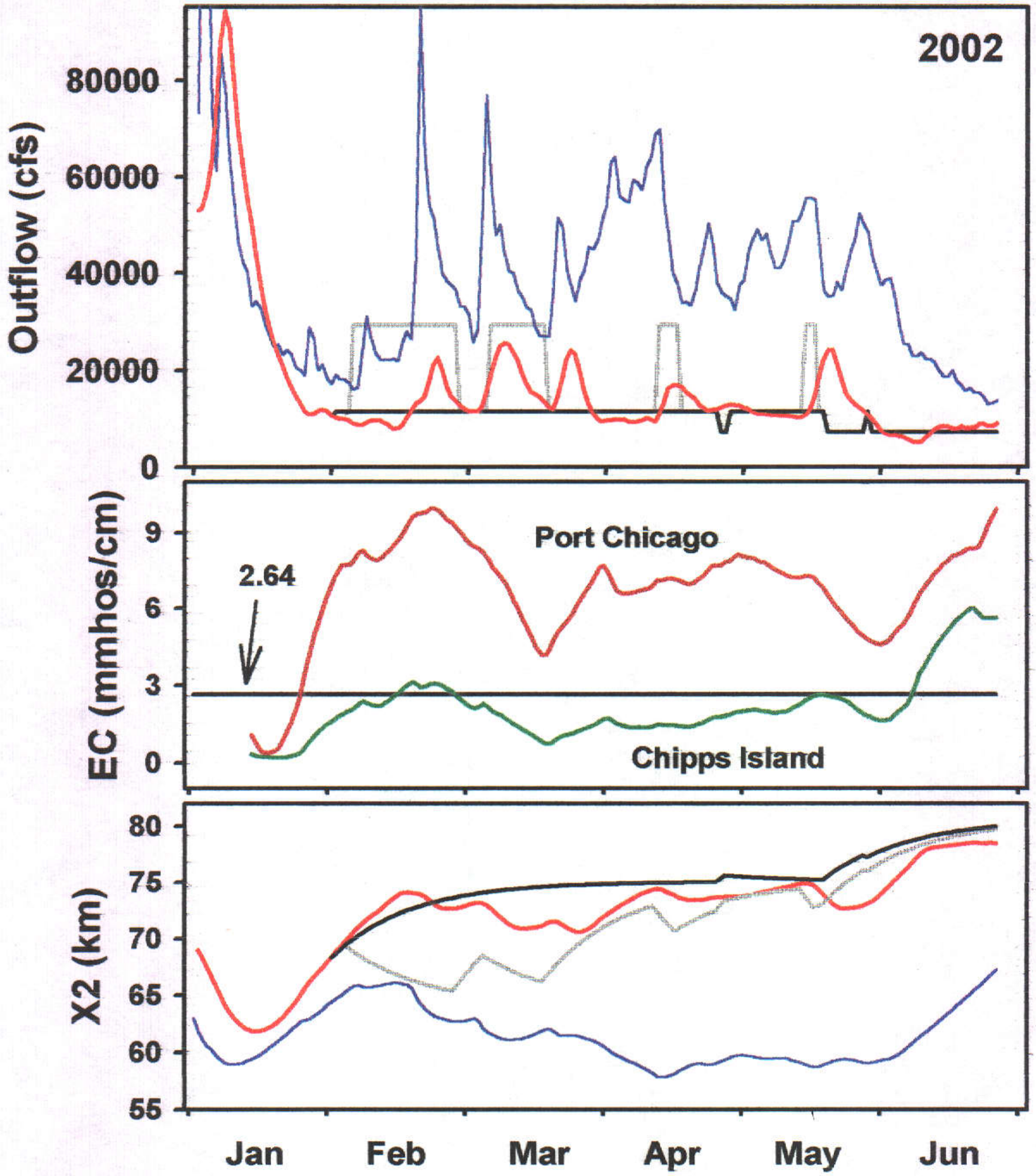

Figure 14. Comparison of February-June 2002 flow, electrical conductivity (EC), and X2 conditions in the San Francisco estuary. The top panel shows unimpaired runoff in the estuary's ten largest tributaries (blue line), actual Delta outflow (NDOI, red line), and minimum Delta outflow requirements as calculated based on the 8RI and Table A (SWRCB, 1995) (grey line), and minimum flow requirements as determined by the use of the alternative compliance metrics (EC) and the Port Chicago EC trigger. The middle panel shows EC measured at Port Chicago and Chipps Island, as well as the 2.64 mmhos/cm compliance level. The bottom panel shows X2 location as estimated from unimpaired runoff, actual X2 calculated from NDOI, and the predicted locations of X2 under the two alternative compliance methods (line colors same as top panel). See also Table 2. Data sources: California Department of Water Resources, Dayflow and CDEC.

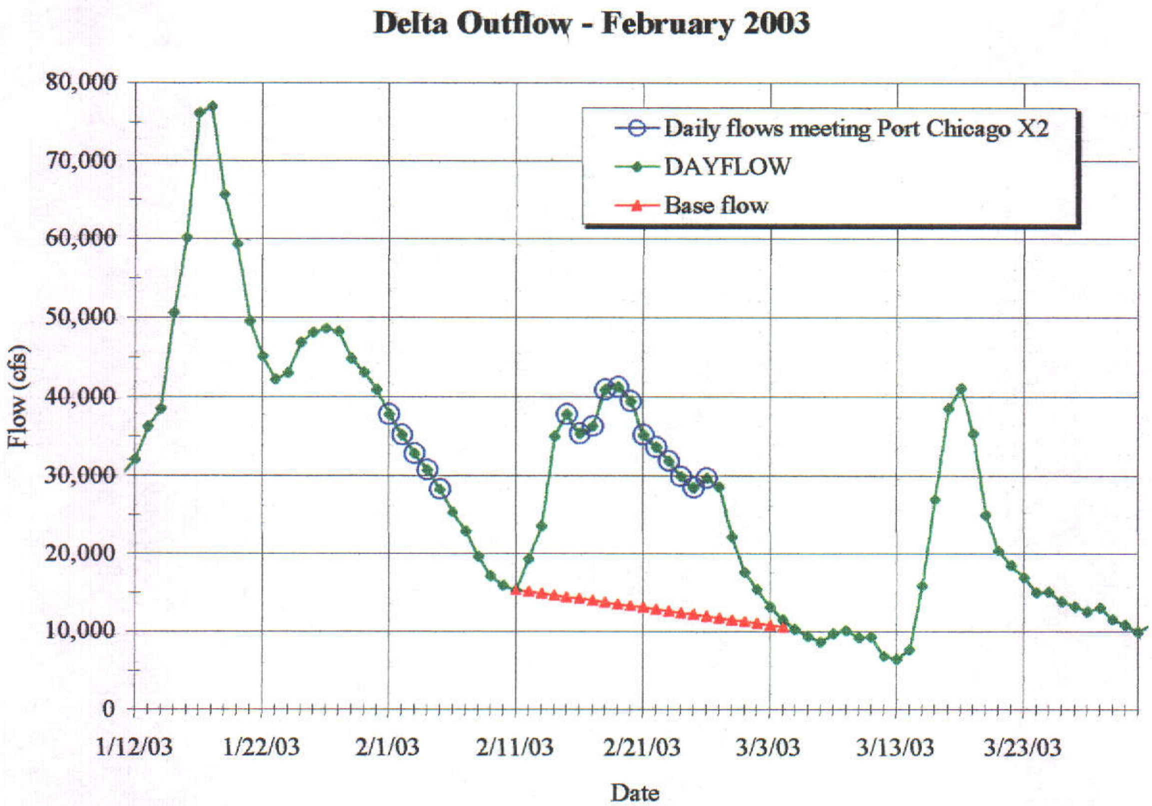

Figure 15. In February 2003, the Delta outflow objective required 25 days of high Port Chicago flows or the alternative metric, Port Chicago EC≤2.64 mmhos/cm. For the first five days of the month the objective was met by flow (open circles) and EC. For the next seven days the objective was met by 14-day EC, which was rapidly increasing as flow declined. On February 13, neither flow nor EC met the objective and, with little time remaining to meet the 25-day requirement, water project managers were forced to increase flows dramatically to meet the minimum 29,200 cfs requirement (because Port Chicago EC was so high, at this point there was no possibility of meeting the objective using that metric). The large flow fluctuations resulting from this operational strategy to meet the outflow objective had adverse impacts on upstream salmonids. An alternative compliance strategy, for example,maintaining higher flows starting in the second week to meet either the flow or EC objective, would have minimized upstream impacts and likely reduced the total water cost to the projects (in terms of reservoir releases) (see analysis in Herbold, 2004b). Graph from Herbold, 2004b.