EXHIBIT TBI-2

BEFORE THE STATE WATER RESOURCES CONTROL BOARD

WRITTEN TESTIMONY OF

JONATHAN ROSENFIELD, PH.D.
CONSERVATION BIOLOGIST, THE BAY INSTITUTE

CHRISTINA SWANSON, PH.D.
EXECUTIVE DIRECTOR AND CHIEF SCIENTIST, THE BAY INSTITUTE

REGARDING FLOW CRITERIA FOR THE DELTA
NECESSARY TO PROTECT PUBLIC TRUST RESOURCES:
DELTA OUTFLOWS

PREPARED FOR:

AMERICAN RIVERS
THE BAY INSTITUTE
ENVIRONMENTAL DEFENSE FUND
NATURAL HERITAGE INSTITUTE
NATURAL RESOURCES DEFENSE COUNCIL

EXHIBIT 2: DELTA OUTFLOWS

Winter – Spring (January – June) Outflows

Many pelagic species use the Delta, Suisun Bay, and Suisun Marsh during the winter and spring for spawning, migration, and/or rearing (Figure 1). The populations of these species are heavily impacted by freshwater flows through and out of the Delta during this period, and by human alteration of natural freshwater flow patterns. Many different causal mechanisms are likely to be in play, varying by species, but the relationships between winter – spring outflows and the abundance, spatial extent, diversity, and productivity of numerous public trust resources represent one of the strongest biological signals observed in the estuary. Outflows occurring outside of the winter – spring and fall periods considered here are also ecologically important but our recommended criteria are not based on data directly addressing those periods.

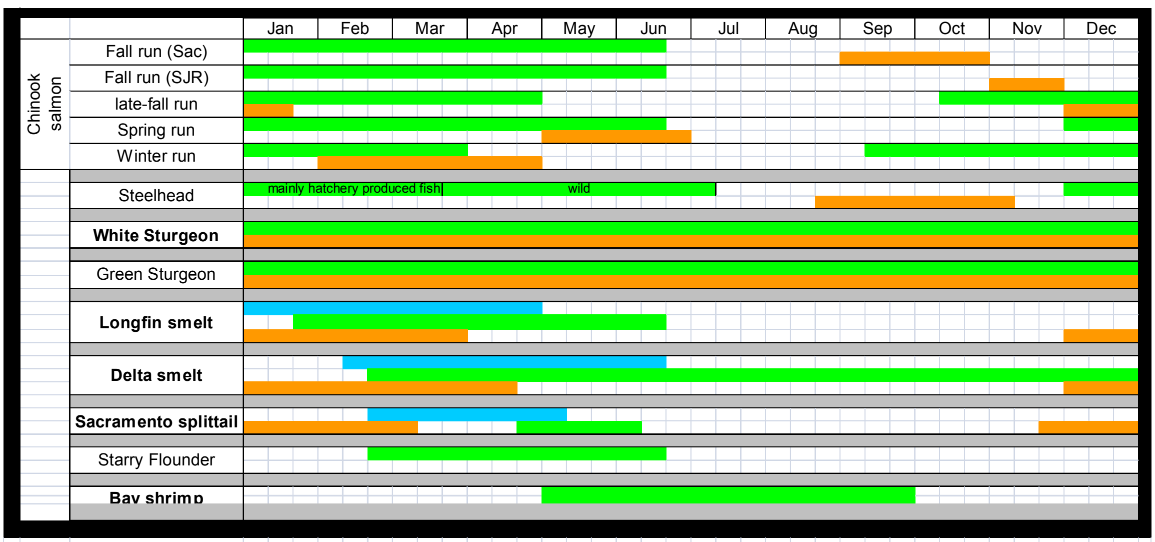


FIGURE 1: Approximate life history timing of native public trust species described in Exhibits 1-4. Life history timing varies with environmental conditions in any given year and some individuals will complete their life cycle earlier or later than indicated in every year. Species in boldface are those for whom individuals or the entire population may reside in the Delta + Suisun Bay year-round.

Juvenile migration and rearing
Adult migration
Spawning

Relationship between winter – spring Delta outflows and abundance and productivity of public trust resources

Summary points:

- *The relationship between winter – spring outflow and abundance of numerous Delta species with different life history requirements is high-magnitude, continuous (the more outflow, the more organisms), persistent over time, and as valid today as before the "step changes" of the late 1980s.*

- *Winter – spring outflows required to increase abundance and improve productivity for longfin smelt will increase abundance and productivity for other estuarine species as well – longfin serve as a useful umbrella species for evaluating public trust outflow criteria.*

Numerous scientific studies demonstrate a strong and statistically significant positive correlation between winter – spring fresh water Delta outflow (or surrogate metrics) and the abundance of numerous fish and wildlife species, including:

- American shad (Figure 2; Kimmerer 2002a; Kimmerer et al. 2009);
- Longfin smelt (*Spirinchus thaleichthys*) (Figures 3, 4; Kimmerer 2002a; Rosenfield and Baxter 2007; Sommer et al. 2007; Kimmerer et al. 2009)
- Striped bass (*abundance*: Sommer et al 2007; Kimmerer et al. 2009 and *survival*: Kimmerer 2002a; Kimmerer et al. 2009)
- Sacramento splittail (Figure 5: Kimmerer 2002a, Kimmerer et al. 2009), and
- Starry flounder (Figure 6; Kimmerer 2002a; Kimmerer et al. 2009)
- Bay shrimp (*Crangon franciscorum*) (Figure 7; Jassby et al. 1995; Kimmerer 2002a; Kimmerer 2009), and
- spring populations of the copepod *Eurytemora affinis* (Kimmerer 2002a).

FIGURE 2:
Relationship of Bay Study American Shad Index with Mar-May outflows for 1980 -1987 and 1988-2007. No significant difference in the slope of the relationship between the two time periods is detectable.

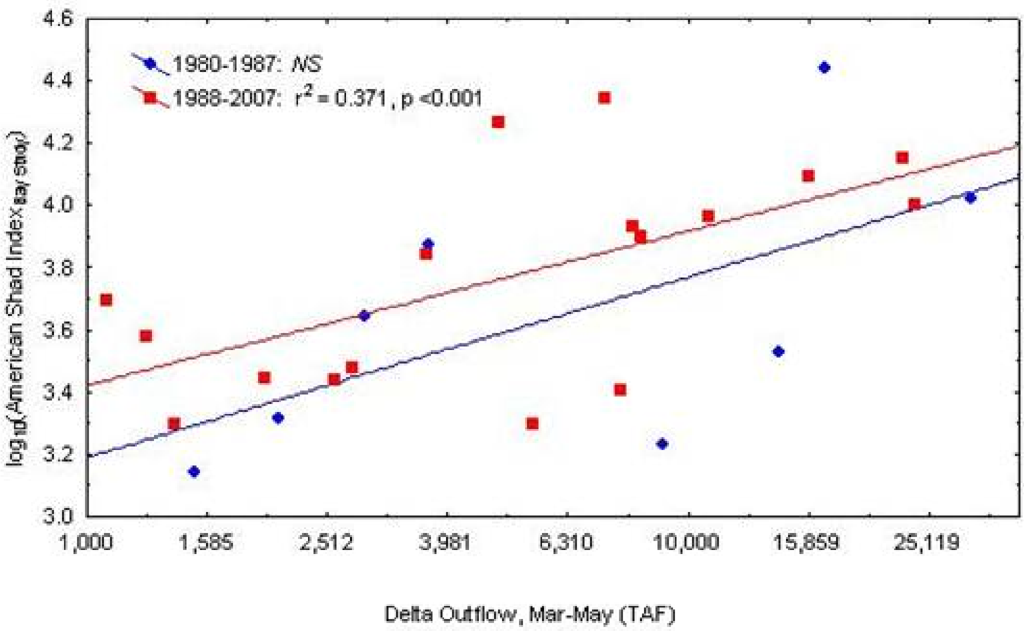


FIGURE 3:

Current v. historic relationship of FMWT LFS index with Mar-May outflows. No significant difference between the slopes of the two relationships are detectable. Arrow indicates the amount of Delta outflow consistent with abundance recovery goal under the *historical* relationship.

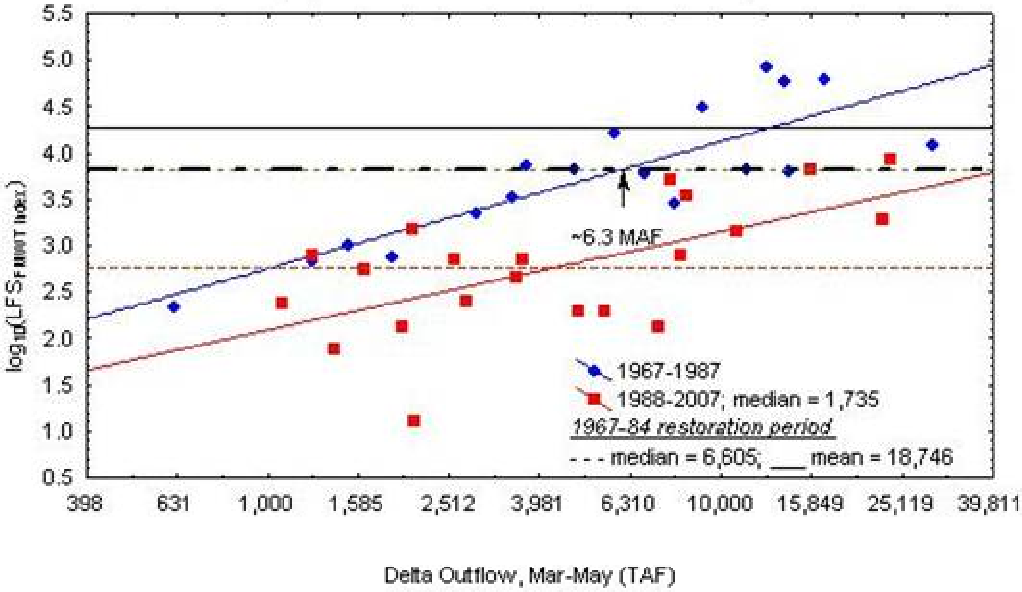


FIGURE 4:

Current v. historic relationship of FMWT LFS index with Jan-Mar outflows. No significant difference between the slopes of the two relationships are detectable. Arrow indicates the amount of Delta outflow consistent with abundance recovery goal under the *historical* relationship.

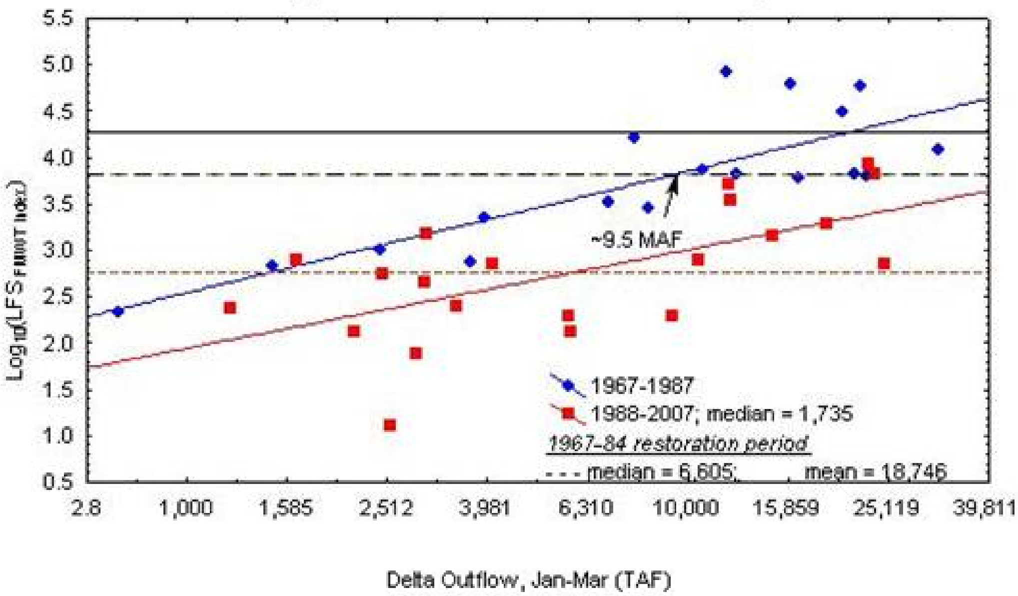


FIGURE 5:
Relationship of Sacramento splittail Index with Mar-May outflows, 1980-2007. The relationship has not changed over the sampling period.

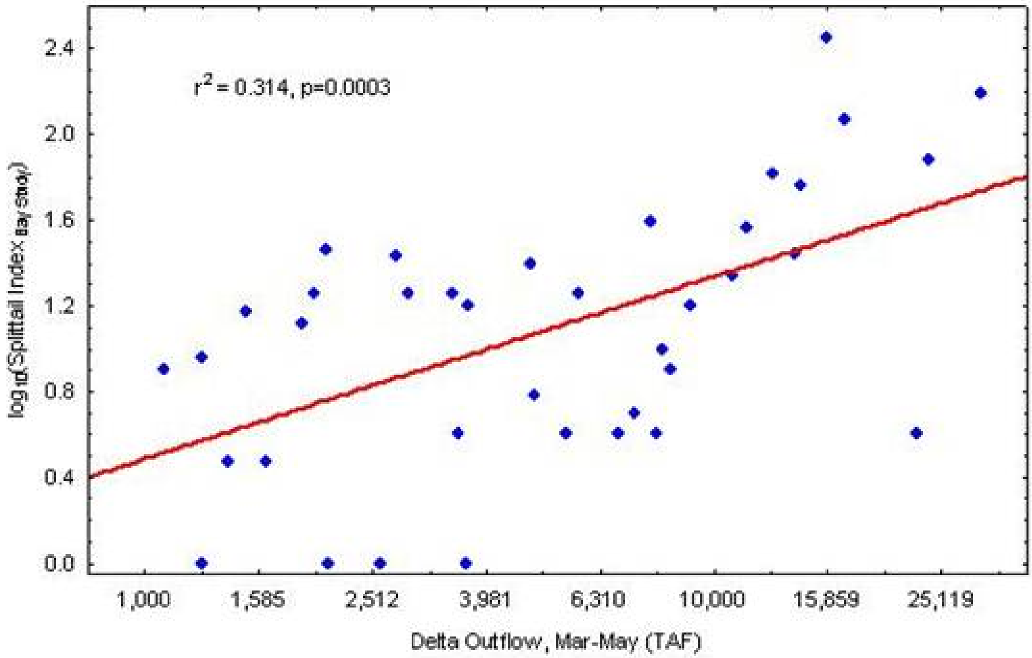


FIGURE 6:
Current and historic relationship between starry flounder populations and outflow in March-June. Increasing median flows to 6.3 MAF (that suggested for longfin smelt) in March-May and adding historic median flows is expected to produce an ~10% increase in starry flounder abundance.

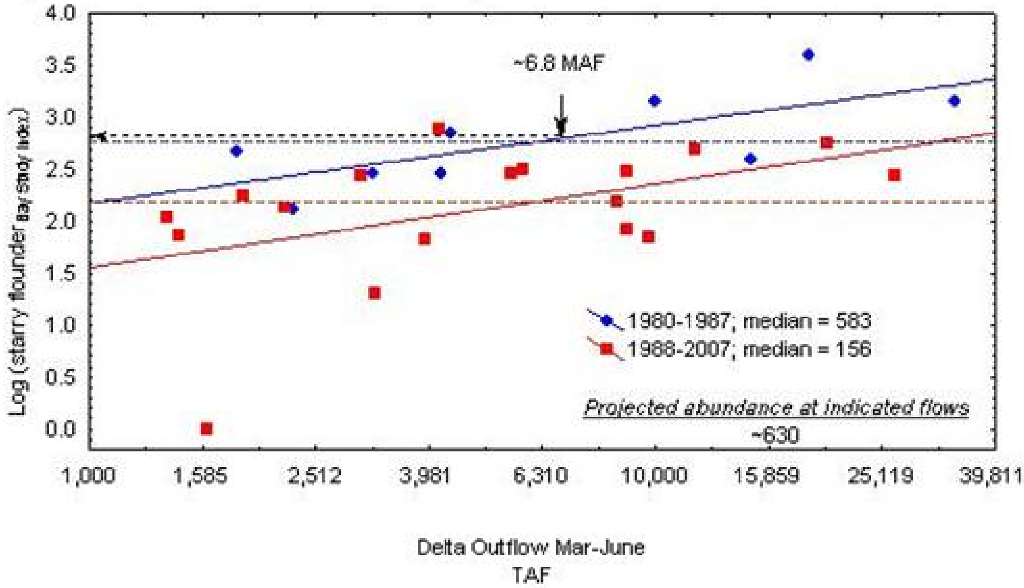
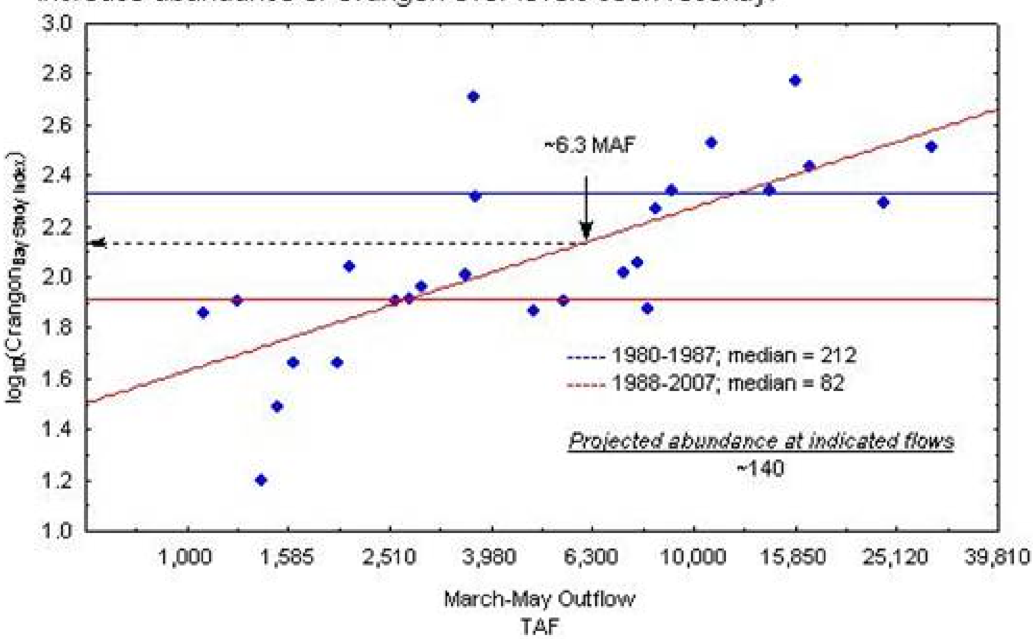


FIGURE 7:
Relationship of bay shrimp index with March-May Delta outflows. Increasing median flows to levels suggested for longfin smelt (6.3 MAF) is expected to increase abundance of *Crangon* over levels seen recently.

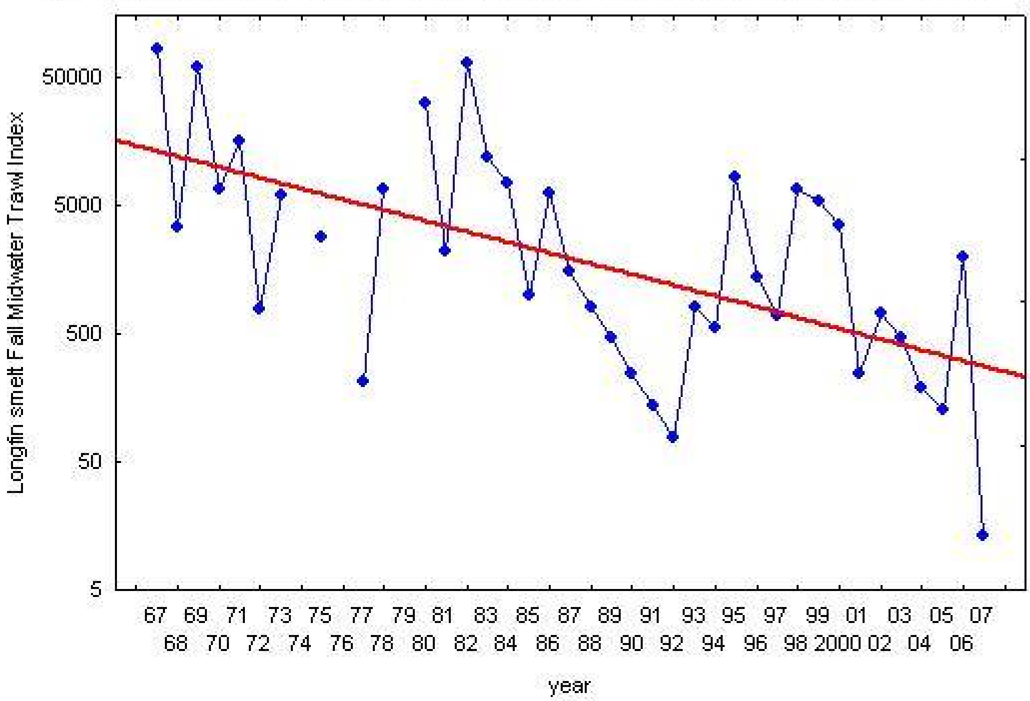


Although several recent studies have noted "step-changes" (the displacement of the regression line by a constant value) in the fresh water outflow-abundance relationships for some species, in most cases the statistical significance and slope (magnitude) of the relationship remain unchanged (e.g. Kimmerer 2002a; Rosenfield and Baxter 2007; Kimmerer et al. 2009) – in other words, incremental increases in freshwater flow out of the Delta correspond with the same proportional increases in the population of these species that have been evident over four decades. Despite the changes that have occurred in this ecosystem over recent decades (e.g., the introduction of numerous invasive species, changes in the planktonic food web; *see* Nichols et al., 1990), statistically significant, positive relationships between freshwater flow (measured as outflow, or X2) and abundance of many public trust resources are still strong. For other species of concern (e,g, Chinook salmon, steelhead, green sturgeon, white sturgeon), the relationship between abundance and winter-spring Delta outflows has not been studied (largely because these fish are not sampled well by long-term pelagic monitoring programs) but the natural history of these species and the multiple mechanistic effects of fresh water flow on estuarine environmental conditions (Kimmerer 2002b) make it highly likely that they also benefit from freshwater outflow from the Delta.

In the following pages, we demonstrate the high-magnitude impact of winter-spring Delta outflow for three species: longfin smelt, Bay shrimp, and starry flounder. These species have experienced long-term declines in abundance; declines over the past 10-15 years have been particularly severe (Figures 8, 9, 10). They represent a range of life histories and ecological interactions and use the estuary for different parts of their life history; the mechanism(s) driving the flow-abundance relationships probably differ across species (and across life stages within species) as well. They each also represent major components of the San Francisco Estuary Food web (Figure 11; USFWS 1995a; Jassby et al. 1995; Kimmerer 2002a) thus their conservation is intimately intertwined with protection of the entire estuarine ecosystem and its Public Trust benefits. Time and space do not permit analyses of the significant correlations between flow and abundance, productivity, and spatial distribution for every species known to display such relationships, Because of their former abundance,widespread distribution, and role in the ecosystem, we have chosen longfin smelt, starry flounder, and bay shrimp as representative of other estuarine species and ecosystem processes with regard to the beneficial impacts of Delta outflow on public trust values.

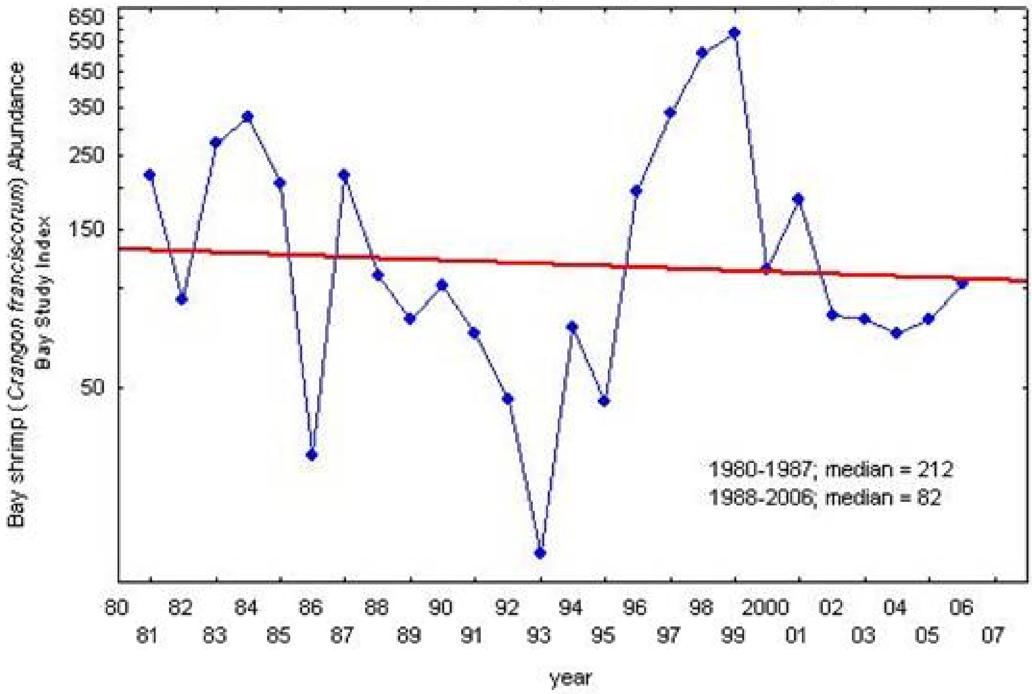
Longfin smelt were generally one of the most abundant native fish species in the Estuary (Baxter 1999; Dege and Brown 2004; Sommer et al. 2007). Adults aggregate in eastern Suisun Bay and the west Delta during late fall and winter in preparation for spawning (Rosenfield and Baxter 2007); their demersal eggs are deposited predominantly through December-March (though some spawning is believed to occur into April) producing pelagic larvae that are most abundant in the west Delta, Suisun Bay, and into San Pablo Bay from January-April (R. Baxter, CDFG, *personal communication*, December 3, 2009). Larvae begin to metamorphose into juveniles in late April and May and recruitment of juveniles continues through early fall (Rosenfield and Baxter 2007). Year class success is strongly correlated with fresh water flow from the Delta in March – May (Kimmerer 2002a; Kimmerer et al. 2009) and through the winter months of January – March (Rosenfield and Baxter 2007) – Jassby et al. (1995) found a significant relationship when studyin8 combined flows from January – June. The precipitous decline (Figure 8) of this formerly abundant species (and critical link in the estuarine food web) prompted petitions to list it under the state and federal Endangered Species Acts; the species is currently listed as endangered by the State of California and litigation to compel federal listing is in process.

FIGURE 8
Decline of the San Francisco Estuary Longfin Smelt population, 1967-2007.



After spawning in marine habitats of San Francisco Bay or the nearshore ocean, juvenile **bay shrimp** move into the estuary in the spring to rear. They serve as an important food source for many fish and wildlife species in the Delta (e.g. Figure 11). For the past three decades (since sampling began) their abundance has been correlated with March-May Delta outflows (Jassby et al. 1995; Kimmerer 2002a; Kimmerer et al. 2009; Figure 7). The abundance of bay shrimp (and thus, food supplies for numerous fish species) have declined by almost 2/3 since the latter part pf the 1990's and are experiencing a long-term abundance decline in the Estuary (Figure 9).

FIGURE 9:
Abundance dynamics of the bay shrimp (*Crangon franciscorum*), 1980-2006



Starry flounder are a native predator (Figure 11) that spawn in the near-coastal ocean and migrate into the estuary to rear as larvae and juveniles. Starry flounder abundance in a given year is significantly correlated with Delta outflow from the previous March-June (Jassby et al. 1995; Kimmerer 2002a; Kimmerer et al. 2009); the mechanism for this relationship may be increased transport of juvenile flounder by strong bottom currents that correspond to high outflows (Moyle 2002). Abundance in the Estuary has declined substantially over the past three decades (Figure 10).

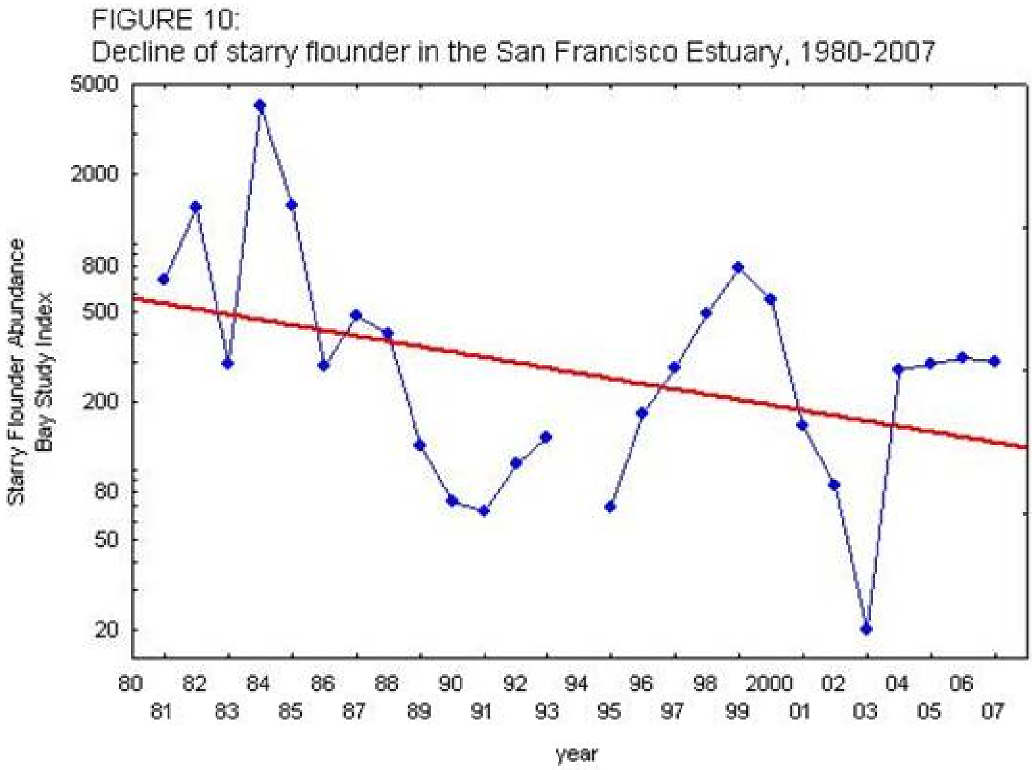


FIGURE 10:
Decline of starry flounder in the San Francisco Estuary, 1980-2007
Starry Flounder Abundance
Bay Study Index
5000
2000
800
500
200
80
50
20
80 82 84 86 88 90 92 94 96 98 2000 02 04 06
81 83 85 87 89 91 93 95 97 99 01 03 05 07
year

FIGURE 11: (reprinted from Jassby et al. 1995)

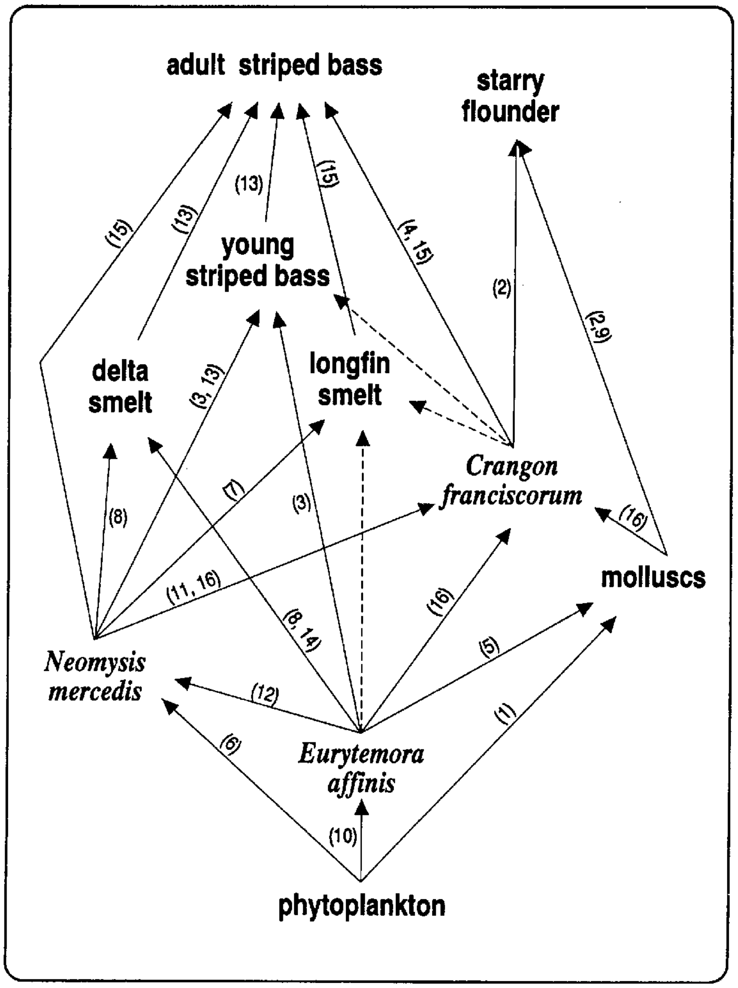


FIG. 3. Partial food web for the San Francisco Bay–Delta from various published sources, illustrating the trophic relationships among the populations and communities considered in this study. – – –; probable connections that have not actually been observed due to restricted sampling for stomach contents; ———; more substantiated connections. Numbers in graph refer to these references: (1), Alpine and Cloern 1992; (2), Boothe 1967; (3), Heubach et al. 1983; (4), Johnson and Calhoun 1952; (5), Kimmerer 1992; (6), Kost and Knight 1975; (7), Moyle 1967; (8), Moyle et al. 1992; (9), Orcutt 1950; (10), Orsi 1988; (11), Siegfried 1982; (12), Siegfried and Kopache 1980; (13), Stevens 1966; (14), Stevens et al. 1990; (15), Thomas 1967; (16), Wahle 1985.

Methods for developing winter-spring Delta outflow criteria necessary to increase abundance and improve productivity of public trust resources

Summary points:

- *Two methods were used to develop outflow criteria:*
    - *an analysis of the historical flow – abundance relationships that corresponded to recovery targets for longfin smelt abundance, and*
    - *an analysis of population growth response to outflows in order to identify those outflows that produced population growth more than 50% of the time for umbrella species.*
- *Applying these two methods produces very similar results regarding desirable outflow levels, resembling the frequency distribution of outflows during the 1956 – 1987 period.*

In order to determine the flows required to support desired abundances for longfin smelt in this estuary, we look to the strong statistical correlation between longfin smelt abundance and Delta outflows and ask: *What flows correspond to the population abundance targets identified in the US Fish and Wildlife Service's Native Fishes Recovery Plan (USFWS 1995a)*? For starry flounder and bay shrimp, which are not listed as endangered species and do not have established recovery targets, we show how increases in flow can contribute to recovery of historic abundances for these species.

In a separate analysis, we investigate the relationship between the productivity of bay shrimp and longfin smelt (in other words, the generation-over-generation change in abundance, or population increase vs. decrease) and ask: *What winter-spring flows correspond to population growth for these species*? The analysis represents a new approach to the data that transcends debates about levels of abundance that protect the public trust and whether abundances seen in the recent past can be attained today. Instead, we link the effect of Delta fresh water outflow to a simple fact: Restoring the abundance of estuarine public trust species requires that those populations increase to levels higher than those observed recently. If population growth is more likely at certain levels of winter-spring Delta outflow, then those are the flow levels that protect productivity. Maintaining productivity (positive population growth) is obviously necessary in order to increase abundances of these populations in the estuary. This analysis is not appropriate for starry flounder because of their life history and ecology and the nature of the sampling data.

Analysis: historical relationship between abundance and winter-spring Delta outflows

Previous studies demonstrate that longfin smelt, the bay shrimp (*Crangon franciscorum*), and starry flounder show high-magnitude, persistent relationships between freshwater outflow in the winter and/or spring and subsequent abundance (Figures 3, 4, 6, and 7). The statistical flow-abundance relationship for the bay shrimp has remained consistent since CDFG's Bay Study monitoring program began sampling them in 1980. The relationships for starry flounder and longfin smelt changed during the 1980's such that for any given Delta outflow populations were lower. The cause for this "step decline" is unknown. For longfin smelt, the difference between current and historic flow-abundance relationships may be related to other stressors operating in the ecosystem (e.g. invasion by the non-native *Corbula* clam and its impact on the planktonic food web; Kimmerer 2002a). For starry flounder (which spawn and live as adults in the nearshore ocean) the cause of the step-decline may be related to changes in their estuarine rearing or marine habitats or both. However, the relationship between *changes* in flow and *changes* in abundance (i.e., the slope of the regression lines) remains unchanged statistically – for a given incremental change in outflow, one still expects the same proportional change in abundance. It is also important to note that all of these relationships are continuous – the sudden breaks in the relationship that one might expect if the flow-abundance relationship was based on a threshold effect are not evident. In short, the fact that higher Delta outflows are strongly correlated with higher abundance of many public trust resources in the Delta has not changed during the entire period of record.

The Recovery Plan for the Sacramento/ San Joaquin Delta Native Fishes (USFWS 1995a:56; "Native Fishes Recovery Plan") sets the following recovery objectives for longfin smelt: *Longfin smelt will be considered restored when its population dynamics and distribution pattern within the estuary are similar to those that existed in the 1967-1984 period* (see the original document for justification of this time period and use of CDFG's Fall Midwater Trawl Index as the metric for this recovery objective). We asked: *What outflow levels correspond with attainment of the recovery objectives for abundance of longfin smelt?*

Figures 3 and 4 present the longfin smelt flow-abundance relationship in two different seasons; two recent studies show strong statistical correlations between FMWT abundance indexes and freshwater flow in these seasons (*Jan-Mar*, Rosenfield and Baxter 2007; *Mar-May*; Kimmerer et al. 2009). Different life stages of longfin smelt are present in the Delta during these two periods (spawning adults: *Jan-Mar* and larvae and juveniles: *Mar-May*) and the mechanisms that produce the flow abundance relationship may occur in some or all of the months during these periods. (Jassby et al (1995) used a longer period period related to flow (Jan-June) and found a significant relationship as well). Mean and median abundances for longfin smelt during the 1967-1984 period are indicated in Figures 3 & 4; the mean population index for longfin smelt during that period (18,746) dwarfs the median population index (6,605) because of very high populations during certain years.

In each season, the current significant relationship between flows and subsequent longfin smelt abundance for the 1988 – 2009 period predicts lower fish abundances at any given flow than the historical relationship that existed for the 1967 – 1987 period. The current relationship predicts that the desired abundance recovery target would only occur during wet periods. However, the flow required to support such populations in the past (prior to the introduction of putative "other stressors" or after their elimination) is indicated by the intersection of the 1967-1987 flow abundance relationship and the recovery target. Thus, we identify flows required to restore abundance of longfin smelt without the effect of "other stressors". (Doing so underscores the need to concurrently implement actions to mitigate for the effects of other stressors; otherwise higher flows would be required to fully protect public trust resources).

During the period of January through March, cumulative Delta outflows of > 9.5 MAF historically corresponded with populations equal to or exceeding the recovery target; during March through May, flows >6.3 MAF historically corresponded with attainment of the recovery target for abundance.

Flows protective of longfin smelt in the March – May period would be expected to measurably benefit other public trust resources as well. The March-May flow-abundance relationship for bay shrimp (this species does not show a "step decline" in the flow-abundance relationship after the mid-1980's) and the March-June flow-abundance relationship for starry flounder are depicted in Figures 7 and 6[1] respectively. Although these species have declined substantially, recovery targets for their abundance have not been identified. Flows above the identified thresholds would correspond with historical abundances that are higher than those observed in recent years. Furthermore, other public trust species (e.g. American Shad, *Eurytemora*, Sacramento splittail, striped bass) show strong correlations between Delta outflow and abundance, even in recent years. Increasing winter-spring outflows as recommended here will benefit abundance of these species as well (and those that prey on them). For instance, increasing *Eurytemora* abundance will benefit the endangered delta smelt. These increased flows will also help reverse the environmental conditions that encouraged the spread of harmful invasive species, such as the overbite clam, *Corbula amurensis*.

---

[1] The seasons used to study flow-abundance relationships for different species are the same as those used in Kimmerer (2002a) and Jassby et al. (1995) – the two papers use the same study season except where noted – and Rosenfield and Baxter (2007).

Analysis: relationship between productivity and winter spring Delta outflow

We calculated the productivity, or change in abundance from one generation to the next, for bay shrimp and longfin smelt (longfin have a two year life cycle) and compared these changes to the flows that occurred in the later generation. In this case, positive numbers (one generation has higher abundance than the one that preceded it) represent increases in abundance and negative numbers represent decreases in abundance. Because of the "step decline" that occurred in longfin smelt populations in the mid-1980's, generation-over-generation changes in abundance were calculated only in the post-1987 period. As a result, we determine the amount of freshwater flow associated with population growth in the recent past.

Both longfin and bay shrimp exhibit increases in productivity at high flows. Plotting generation-over-generation changes in abundance vs. Delta outflow in Mar-May shows that both species' populations tend to increase at higher outflows and decline at lower outflows (Figures 12 and 13). A similar plot (Figure 14) for longfin smelt compares generation-over-generation change in abundance with flows from January-March (the season studied by Rosenfield and Baxter 2007).

FIGURE 12:
Generation-generation change in abundance for bay shrimp (1980-2006) with regard to March-May Delta outflow in the later cohort. Horizontal line divides growing populations from those that declined. At outflows <6.3 MAF outflow, a positive change in abundance occured during only 3 years. At higher outflows, abundance declined in only one year.

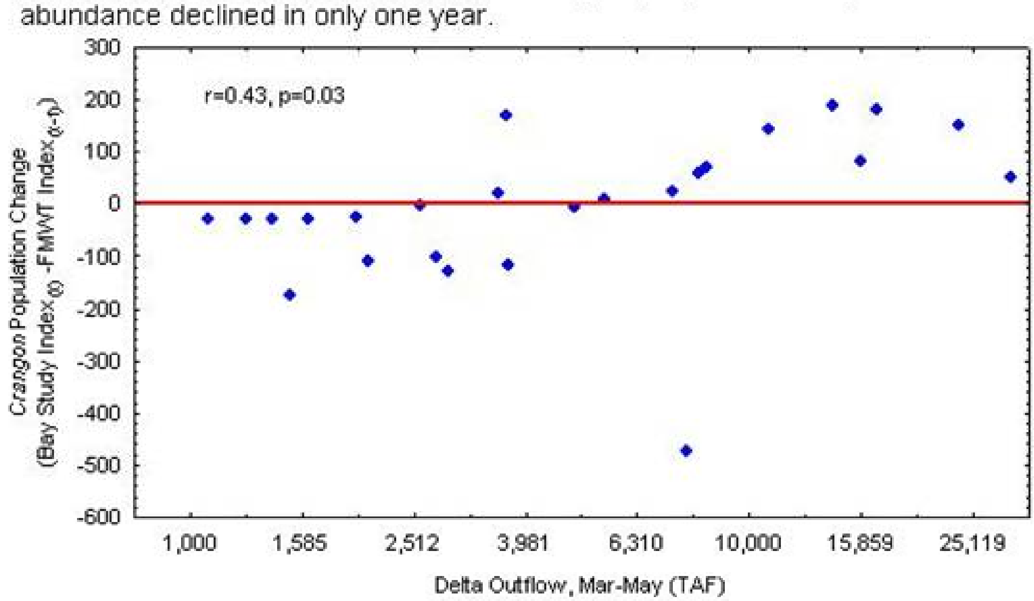


FIGURE 13:
Generation-generation change in abundance for longfin smelt (1988-2007) with regard to March-May Delta outflow in the later cohort. Horizontal line divides growing populations from those that declined. At outflows <6.3 MAF, a positive change in abundance occured during only two years.

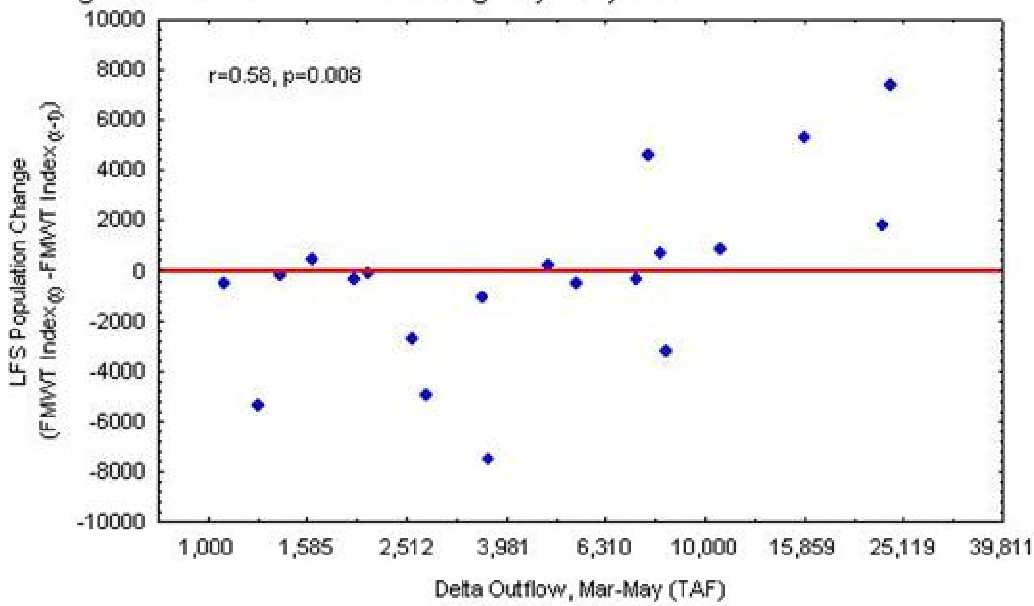
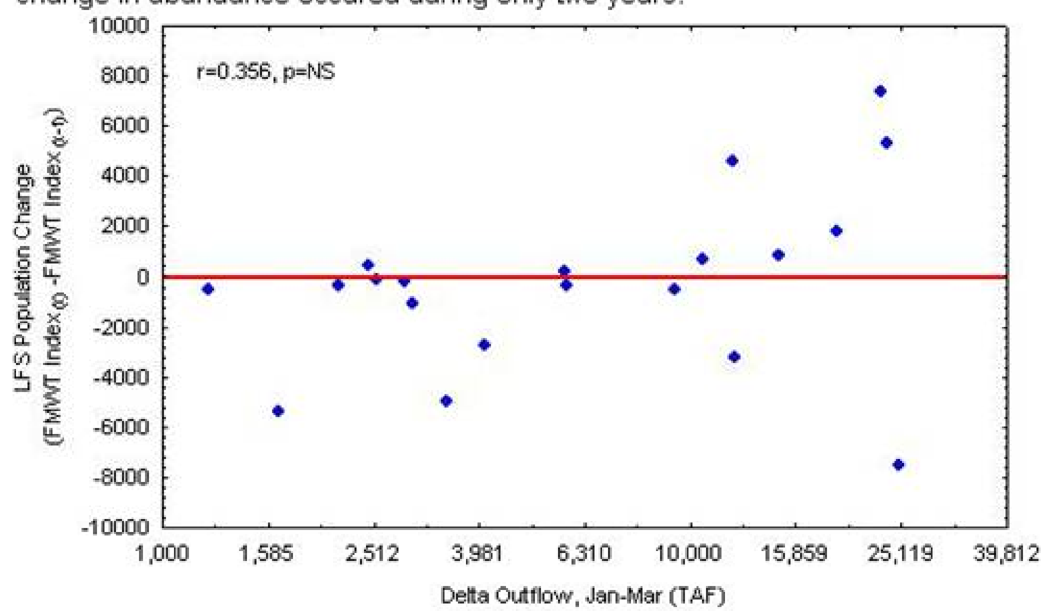


FIGURE 14:
Generation-generation change in abundance for longfin smelt (1988-2007) with regard to January-March Delta outflow in the later cohort. Horizontal line divides growing populations from those that declined. At outflows <10 MAF, a positive change in abundance occured during only two years.



In order to recommend Delta outflows that are likely to produce population growth a reasonable amount of the time, we asked: *What outflow level corresponds to positive population growth 50% of the time in the past*? We employed logit regression (StatSoft 2010) to address this question. Logit regression is used to find a regression solution when the response variable (population increase vs. decrease) is binary ("0" or "1", "yes" or "no", or, in this case, population increase vs. decrease). Although changes in abundance depicted in Figures 12, 13 and 14 vary continuously, they are not expressed relative to the actual population sizes involved. As a result, large absolute declines and increases tend to come from large initial populations and small absolute declines tend to come from small initial populations – this can lead to skewed interpretations. Said another way, Delta outflows are not likely to predict the absolute numerical change in abundance from one generation to the next (because that depends on the starting abundance) but flows appear to be a strong predictor of the direction of change in abundance. By converting productivity (measured as generation-over-generation changes in population indices) to a binary variable ("increase" or "decrease"), we remove the effect of initial population size from the analysis and present a conservative analysis of flows that allow populations to grow[2].

Results of the logit analyses were statistically significant ($p<0.015$ in all cases) and revealed that for longfin smelt the "likelihood" of positive productivity in 50% of years corresponded with Mar – May flows of ~6.3 MAF (Figure 15). The previous analysis revealed that this volume of flow was consistent with the abundance restoration objective identified in the Native Fishes Recovery Plan (*see* Figure 3). The logit analysis of bay shrimp productivity relative to March-May Delta outflow (Figure 16) suggests that populations in the estuary increased in about 50% of years when flows during March – May were ~ 5MAF. Thus flows that protect longfin smelt productivity are very likely to restore bay shrimp productivity as well.

---

[2] A different method (dividing the abundance in each generation by abundance in the preceding generation to form a ratio) was also employed and produced nearly identical results.

FIGURE 15:
Logit regression showing relationship between Mar-May Delta outflow and generation-over-generation change in abundance of longfin smelt (measured as the difference between annual FMWT abundance indices). Positive population changes were scored as "1" and population declines were scored as "0". Arrow indicates flows above which growth occured in more than 50% of years. Point labels indicate year of the more recent FMWT index.

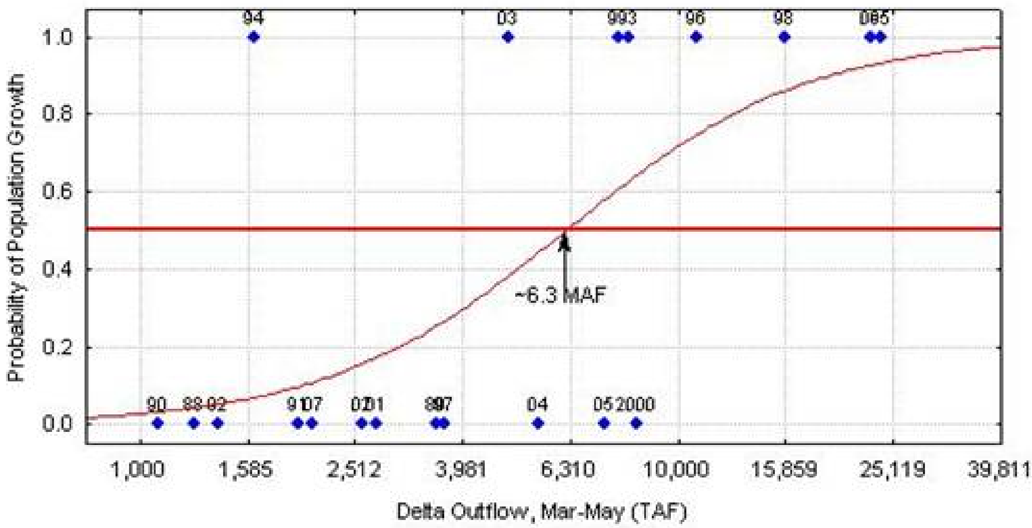
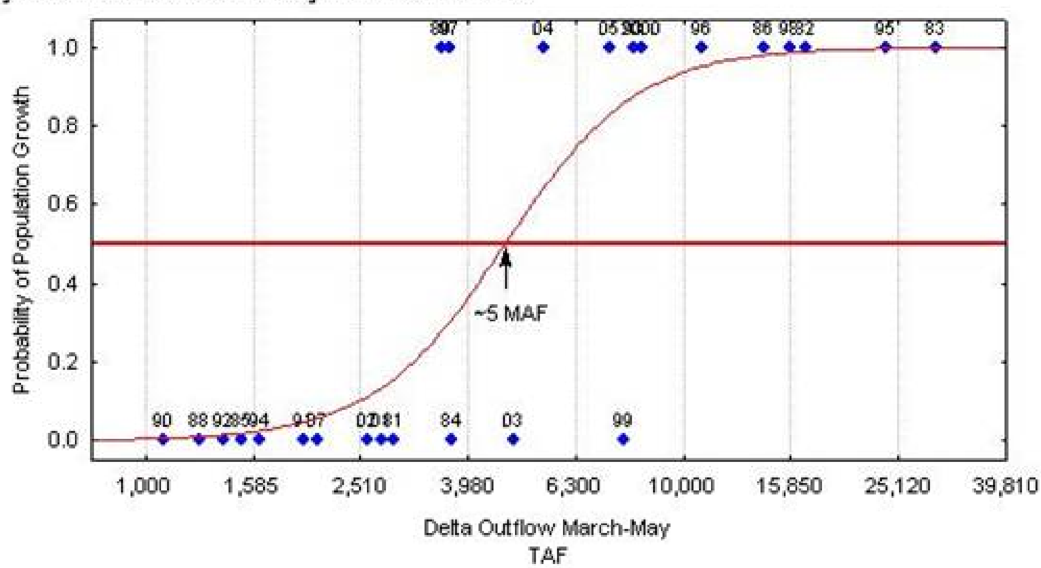


FIGURE 16:
Logit regression showing relationship between Mar-May Delta outflow and generation-over-generation change in abundance of bay shrimp (measured as the difference between annual Bay Study abundance indices). Abundance increases were scored as "1" and declines were scored as "0". Arrow shows flows above which growth occured in more than 50% of years. Point labels indicate year of later cohort.



For the January-March period, logit regression indicated that Delta flows ~9.1 MAF were likely to produce longfin smelt population growth in about 50% of years. This is slightly less than the ~9.5 MAF that corresponded with historical abundances at or above the recovery objective for longfin smelt (Figure 3).

Recommendation: winter – spring Delta outflows required to increase abundance and productivity of public trust resources

Summary points:

- *Outflow criteria are proposed for the January to March, March to May, June, and total January to June periods, based on the relationships in each period between outflow and the viability criteria evaluated above. The proposed outflows are intended to increase, for a number of estuarine species, (a) the number of years in which population growth occurs and (b) the estuary's ability to support increased abundances of these species.*
- *These criteria, expressed both as a frequency distribution of outflows and as a continuous hydrograph relating unimpaired runoff to outflow targets, require higher outflows, especially in drier and normal years, and set higher minimum requirements for outflows in all years.*

Increasing freshwater flows during January through June over those seen during the 1988-2007 period are likely to increase populations of longfin smelt by providing suitable conditions for spawning adults, dispersing larvae, and rearing juveniles. In addition to supporting increased abundance of longfin smelt and other species, the magnitude of outflows recommended here is highly likely to restore the longfin smelt distribution patterns specified in the Native Fishes Recovery Plan (USFWS 1995a). Longfin smelt larval distribution is known to respond to changes in X_2 (a close correlate and direct result of net Delta outflow; see USFWS 1996 and Dege and Brown 2004) and this has a direct impact both on their susceptibility to in-Delta stressors, such as entrainment mortality (Grimaldo et al. 2009; *see* Exhibit 4) and on the spatial extent of the early juvenile population (Figure 17).

FIGURE 17: Reprinted from USFWS (1995) Native Fishes Recovery Plan

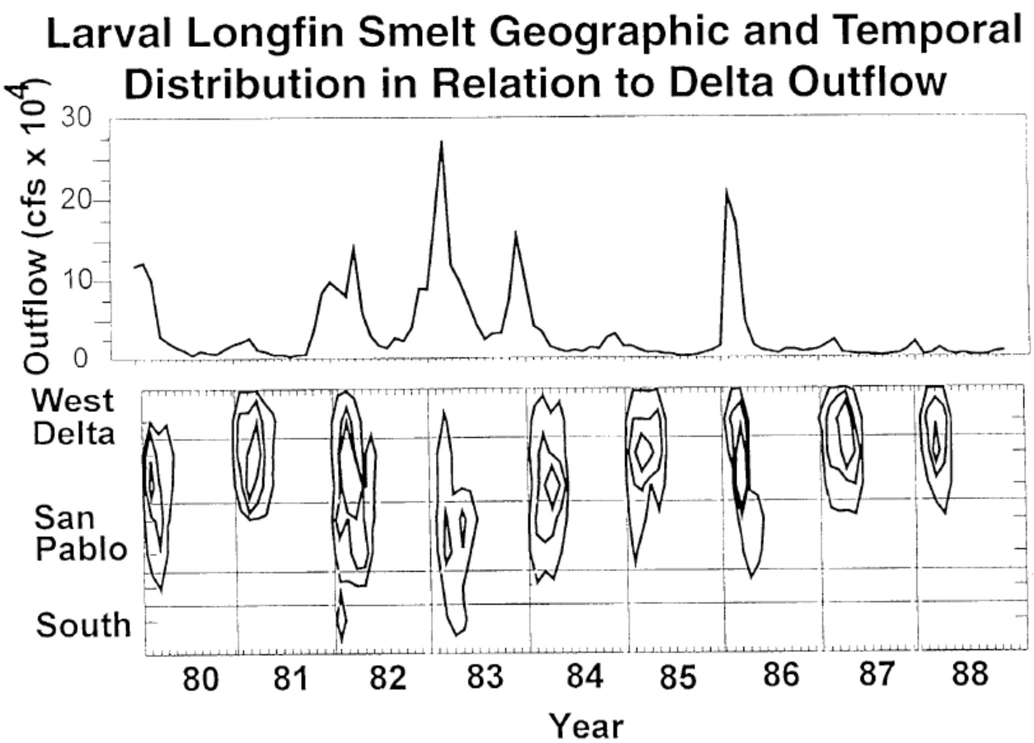


Figure 3.2 Distribution of larval longfin smelt abundance and outflow. High flows distribute longfin smelt west into San Pablo Bay including south San Pablo Bay.

Increasing Delta outflows in March through May over those available during the previous 2+ decades are expected to benefit productivity of other public trust species as well. For example, increasing the abundance of prey species (e.g. by increasing populations of bay shrimp and *Eurytemora* (*see* Kimmerer 2002a)) available in the Estuary will support productivity of the estuarine food web (Figure 11). Outflows required to restore longfin smelt during the winter-spring period are believed to also protect productivity of other public trust resources. For example, measures of striped bass survival from one life stage to the next (productivity) are strongly correlated with spring Delta outflows (Kimmerer 2002a; Kimmerer et al. 2009). In addition, Delta outflows are likely to increase productivity among migratory species where the outflow-abundance relationships have not been studied (e.g. Chinook salmon, steelhead, sturgeon).

The frequency distribution of winter-spring Delta outflows available during the 1956-1987 period are necessary to achieve recovery targets for longfin smelt and other estuarine species. Although ecological changes in the Estuary may mean that historical flows do not lead to historical abundances, there is no evidence at all that recovery targets can be attained with outflows *lower* than those that historically corresponded to the recovery target – in fact, the opposite is true. Based on the frequency distribution of winter – spring outflows that occurred between 1956-1987, we conclude that the outflows described in Figures 18 and 19 are the minimum needed to restore populations of longfin smelt and other estuarine species to abundances and levels of productivity that protect their public trust value. Our recommendations for flow criteria to mimic the frequency distribution of the 1956-1987 period is further premised on the assumption that flow criteria must be complemented by a comprehensive suite of actions to address the effect of ecological changes since that period, including invasive species, food web dynamics, and pollutant loading, on flow-dependent public trust resources. Failure to do so may result in the need for flows higher than those recommended here, in order to mitigate for the step change in the correlations in the post-1987 period.

Figure 18: Frequency distribution of Delta outflows as a percentage of time. Relationship of outflows criteria compared to both the 1) actual distributions over the past 22 years and 2) unimpaired flows. Months depicted include a) January-March, b) March-May, c) June, and d) Jan-Jun. Seasonal periods are linked to biologically relevant periods for public trust resources. Criteria call for higher magnitudes among intermediate and low outflows (to the right on each graph).

a)

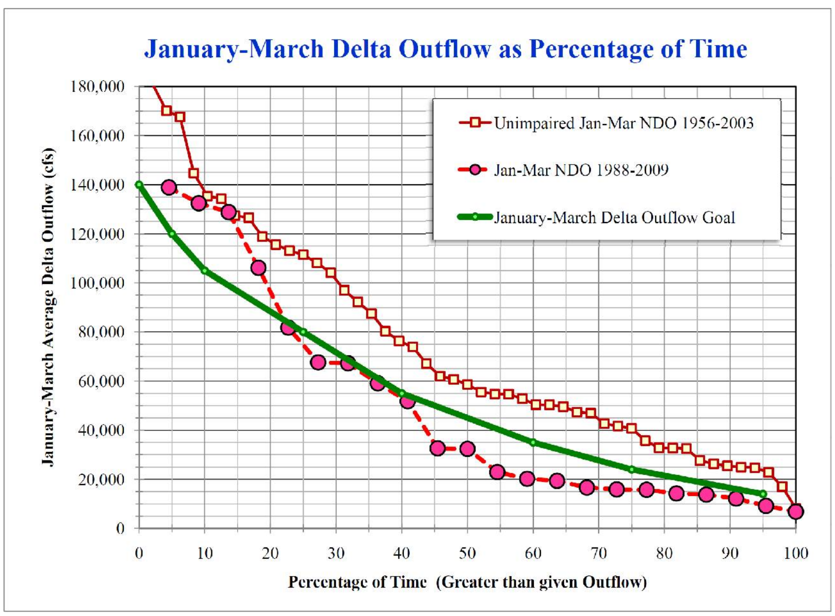


Fig 18b)

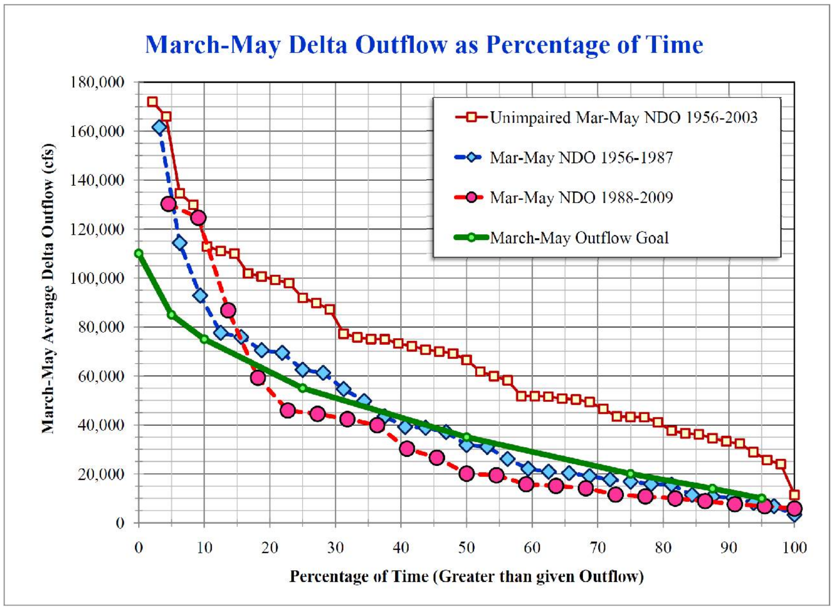


Fig 18c)

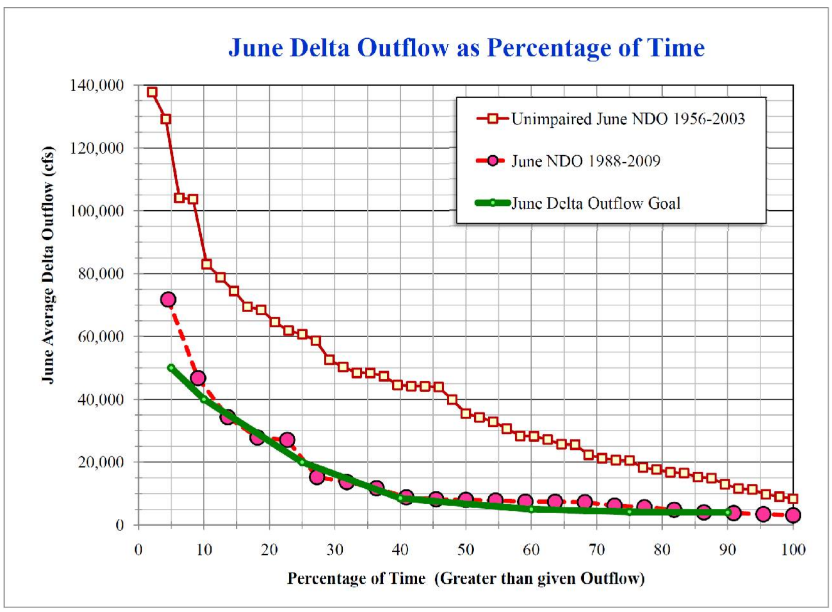
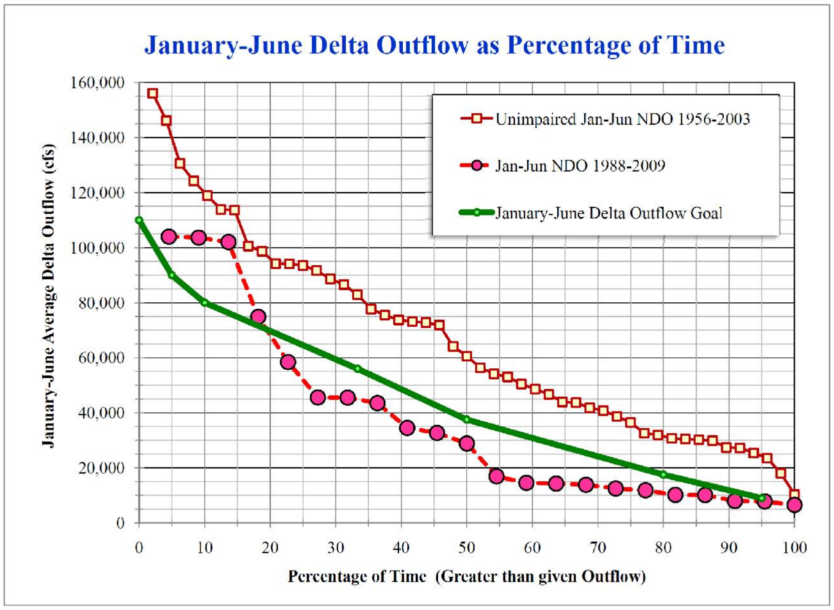


Fig 18 d)



The relationships depicted in Figure 19 are continuous relationships between the amount of unimpaired runoff resulting from hydrology in a given year to the minimum amount of Delta outflow required to protect the public trust. Below, we highlight some examples of the increased frequency of high magnitude outflows and decreased frequency of extremely low outflows that are required to protect the public trust.

Figure 19: Relationship of annual hydrology (runoff, MAF), 1988-2009 actual outflows, and recommended flow criteria. Months depicted include: a) January-March, b) March-May, c) June, and d) January-June. Seasonal periods are linked to biologically relevant periods for public trust resources.

a)

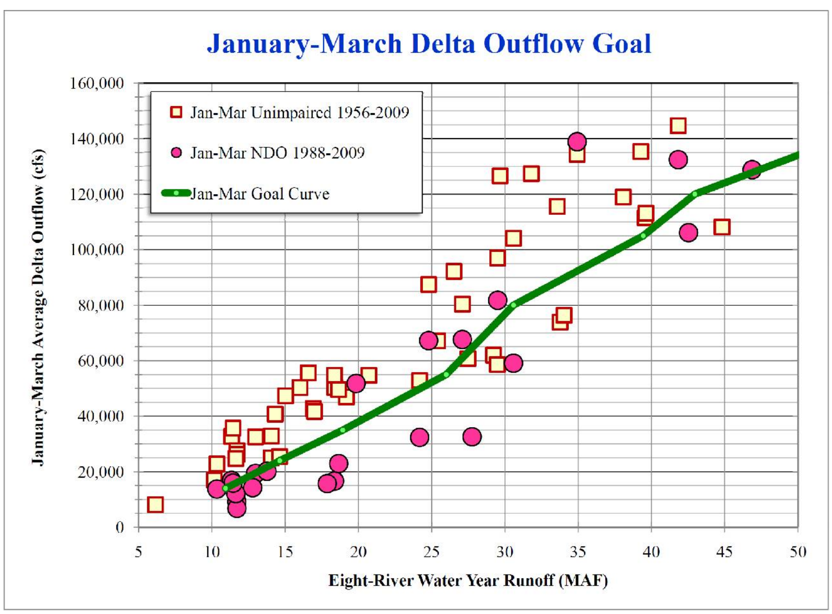


Fig 19b)

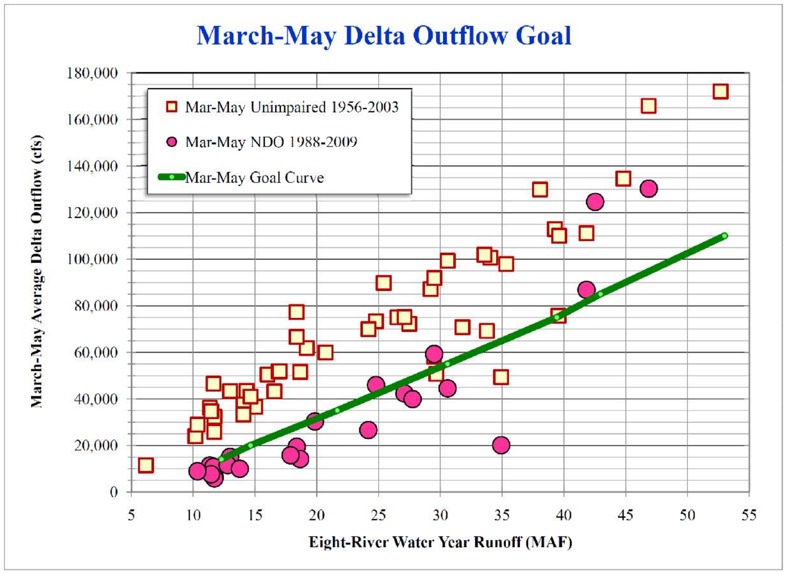


Fig 19c)

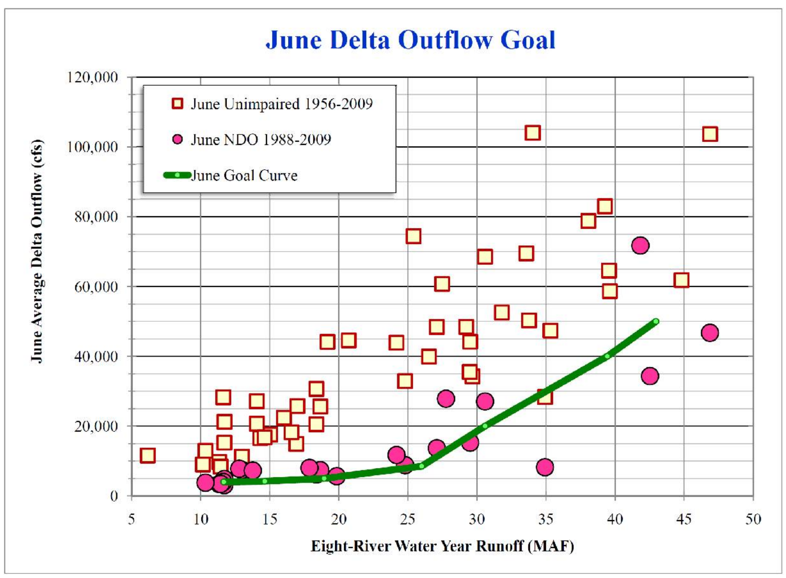
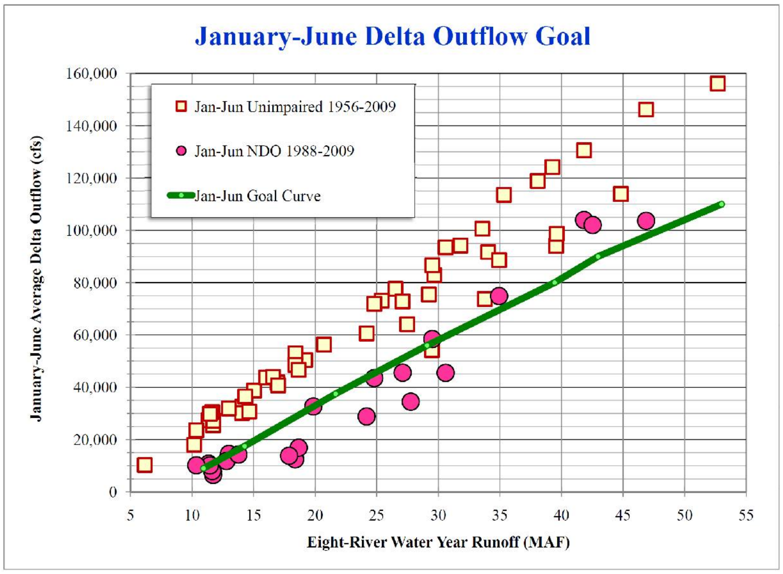


Fig 19 d)



Jan-Mar: January through March Delta outflows should exceed 6.3MAF in at least 60% of years, and exceed 10MAF in 40% of years. Flows should always exceed 2.5MAF in 95% of years during this season.

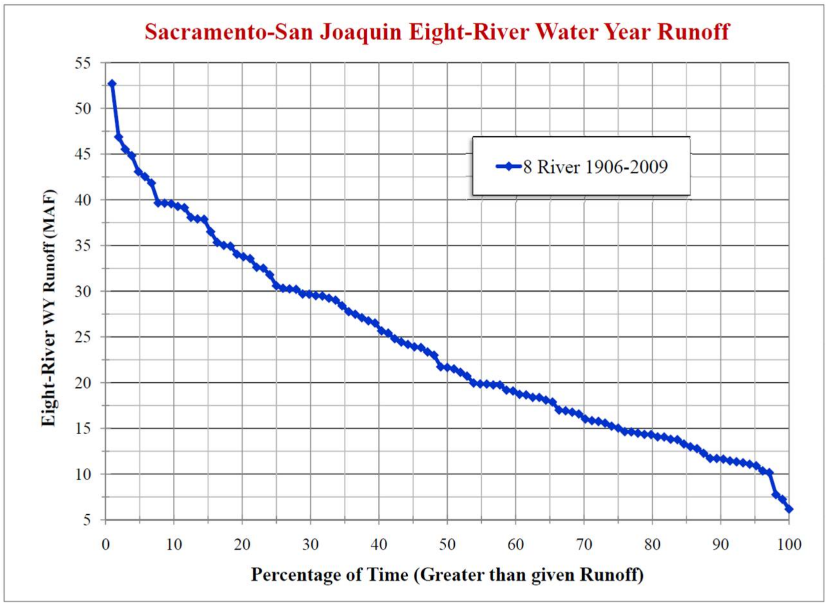
Mar-May: March through May Delta outflows (and, in parentheses, their corresponding historical probability of positive productivity for bay shrimp) should exceed 6.3 MAF (75% chance of increased abundance) in half of years, and exceed 10.0MAF (94%) in at least one quarter of years. Outflows less than 2.5MAF (10%) should occur in no more than 1 of 8 years.

Jun: June outflows should exceed 508 TAF in at least 50% of years, and exceed 1.2 MAF in at least 25% of years. Outflows less than 250 TAF should occur in no more than 25% of years.

Jan-Jun: In total, outflows in the January through June period (and, in parentheses, their corresponding historical probability of longfin smelt abundance increase) should exceed 6.3MAF (22% chance of population growth) in at least 8 of 10 years; exceed 13.5MAF (50%) in half of years; exceed 20MAF (60%) in at least one-third of years. Outflows less than ~3.2 MAF (which historically corresponded to a "likelihood" of positive productivity for longfin smelt in just 10% of years) should occur in no more than 1 out of 20 years.

For each season, cumulative historical frequency distributions of runoff for the 8 River Index (Figure 20) were used to generate the relationships between net Delta outflow and unimpaired runoff depicted in Figure 19.

Figure 20: Cumulative frequency distribution for the eight-river runoff index used to generate rule-curve goals for net Delta outflow.



Fall (September – November) Outflows

Delta outflow during the fall period significantly affects the quality and quantity of open water habitat in the upper San Francisco Bay estuary and western Delta. While fall outflows are naturally much lower than outflows in the winter – spring period, the relative change in fall outflow levels since the 1956-87 pattern has been just as dramatic, with significant impacts on both native and invasive species.

Relationship between fall Delta outflows and abundance and spatial distribution of public trust resources

Summary points:

- *As Delta outflow increases in the fall, more suitable habitat becomes available and greater beneficial spatial distribution occurs for delta smelt and striped bass, and abundance increases for delta smelt.*
- *Higher fall outflows also help control the spread of harmful invasive species such as the overbite clam and toxic algae.*

During fall, when delta smelt are maturing pre-adults, their primary habitat is the low-salinity zone of the estuary. The amount of this habitat that is available to this species is strongly controlled by the amount of fresh water outflow from the Delta and how that flow positions X_2, the location of the 2 ppt isohaline, geographically in the estuary. When Delta outflows are low, X_2 is located in the western and central Delta and lower river channels; when outflows are higher, X_2 is located west of the Delta and downstream of the Sacramento and San Joaquin Rivers' confluence in broad and shallow Suisun Bay. Greater habitat area is beneficial for delta smelt because it increases their geographic distribution and lessens the probability of adverse stochastic events that affect mortality, such as intense localized predation, exposure to contaminants, and the direct and indirect effects of Delta water diversions. For the critically endangered delta smelt, protecting the core habitat of maturing adults is a critical management target (Feyrer et al, *in review*). Given that much of this core habitat area is no longer suitable or available, releases from storage in the fall are necessary to meet this management target and support abundance.

Delta outflows also affect the occurrence, distribution and abundance of harmful non-native species, such as the overbite clam, *Corbula amurensis*, which has reduced the abundance of phytoplankton and zooplankton in the low salinity reaches of the San Francisco Bay estuary, and toxic algae blooms. *Corbula* is a moderately euryhaline species that prefers brackish waters (Nichols et al. 1996): under low outflow conditions, the center of its geographic distribution shifts upstream and, in some years, into the Delta and its overall abundance increases, expanding the range and intensity of its adverse impacts on the planktonic food web and, as a likely consequence, on pelagic plantivorous species (Baxter et al. 2008). Similarly, *Mycrocystis aeruginosa*, a toxic cyanobacteria that is detrimental to both water quality and the planktonic food web, is more prevalent in the Delta and upper estuary during conditions of low and stable flows and warm water temperatures (Lehman et al. 2008). These authors concluded that the most important management tool to control and reduce *Mycrocystis* blooms in the Delta and upper estuary, which are most severe in the late summer and fall, was improved flow conditions.

Methods for developing fall Delta outflow to increase abundance and spatial distribution of public trust resources

Summary points:

- *Higher fall outflows and associated habitat availability are correlated with higher delta smelt and striped bass abundance.*
- *Delta smelt are more abundant and higher quality habitat more available as outflows position X2 downstream of 80 km.*

In order to determine fall Delta outflows that are likely to increase abundance and distribution of delta smelt, we looked to recent research that demonstrates a strong connection between fall Delta outflow, fall habitat availability, and subsequent abundance of public trust species. Feyrer et al. (2007) showed that habitat suitability for delta smelt (as well as juvenile striped bass) is significantly and positively related to Delta outflow through its effect on both salinity and turbidity.[3] These authors also showed that, for the 1987-2004 period, fall habitat quality was a significant predictor of the abundance of juvenile delta smelt measured the following summer: more, better quality habitat in the fall resulted in higher abundance of juvenile delta smelt the following year. This suggests that fall habitat quality as measured by salinity and turbidity is important for the survival and/or reproductive success of maturing adult delta smelt. Subsequent analyses by the Delta Smelt Working Group (DSWG) showed that habitat suitability for delta smelt could be related to Delta outflow expressed in terms of X_2 (DSWG notes, Aug. 21, 2006).[4] This analysis showed that, for delta smelt, fall habitat suitability declines sharply at X_2 values greater than 80 km (Figure 21). Geographically, X_2 of 80 km is located in the western Delta, at the confluence of the Sacramento and San

---

[3] Habitat suitability is a function of habitat quality and quantity and expressed as an "environmental quality index" (EQ). For the analysis, Delta outflow was expressed in terms of specific conductance and turbidity as secchi disk depth.

[4] The Delta Smelt Working Group is a group of scientists from federal and state fisheries, water and environmental protection agencies established by the USFWS to evaluate current and historical data to make recommendations to manage real-time modifications of water project operations for the protection of delta smelt. Since longfin smelt were listed under the State Endangered Species Act, the group is now referred as the Smelt Working Group.

Joaquin Rivers. Recently, Feyrer et al. (*in review*) expanded their earlier analysis to relate delta smelt habitat suitability to Delta outflow, X_2 and habitat area. They showed that suitable habitat area is significantly related to Delta outflow and X_2 and that the area of habitat suitable for delta smelt has declined during the past 20 years (Figure 22). According to Feyrer et al. (*in review*), "[w]hen X2 is located downstream of the confluence it creates suitable abiotic habitat in the expansive Suisun and Grizzly Bays, which results in a dramatic increase in the total area of suitable abiotic habitat." Thus, for delta smelt, favorable abiotic habitat conditions are more geographically constrained when Delta outflow is low and X_2 is located upstream of the confluence than under conditions with higher Delta outflow (Figure 23). Feyrer et al. (*in review*) further reported that delta smelt abundance, as measured by CDFG's Fall Midwater Trawl Survey and the FMWT Index, was significantly correlated to fall habitat area for the same year (Figure 24). The lowest delta smelt abundances recorded only occurred in years with low fall Delta outflow when delta smelt habitat was constricted upstream into the lower river channel. Conversely, the highest delta smelt abundances recorded in recent years occurred in years with high fall Delta outflows and greater suitable habitat area – very low Delta smelt abundances did not occur under high outflow conditions

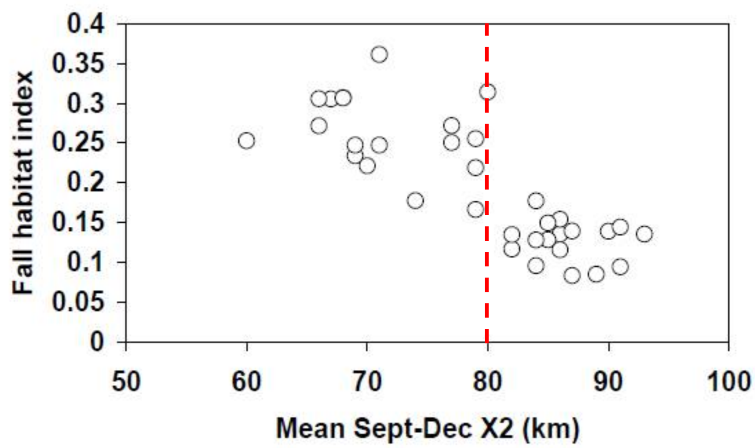


Figure 2. Relationship between fall X2 position and a delta smelt habitat index based on specific conductance, water clarity, and water temperature. Note that Chipps Island is approximately at X2 = 75 km and requires 11,400 cfs of Delta outflow to maintain its position there and higher flows to move it there from landward locations. Note that X2 was at approximately 85 km at the time of this meeting (August 2006).

Figure 21:
Relationship between fall Delta outflow (as X_2) and habitat quality and spatial extent for delta smelt. Vertical red dashed line indicates X_2=80 km, a threshold value for delta smelt habitat: habitat quantity and quality is substantially lower in years in which fall X_2 values are above 80 km.

<u>*Source*</u>: Figure 2 from Delta Smelt Working Group notes, August 21,2006. Red line added for this submission

FIGURE 22.
Time series of moderately and highly suitable physical habitat (top panel) and their relationship to freshwater outflow as indexed by X_2 (lower panel). Horizontal lines in the upper panel are median values of the time series for the respective habitat categories. Curves in the lower panel are LOESS fits to the data. The larger filled circles represent data points highlighted as examples of the geographic distribution of suitable abiotic habitat shown in Fig. 23.

In the bottom panel, vertical and horizontal solid and dashed lines (in red) depict the area of high and moderate suitability habitat attained when X_2 = 80 km.

<u>Source</u>: Figure 2 from Feyrer et al, *in review*. Red lines added for this submission.

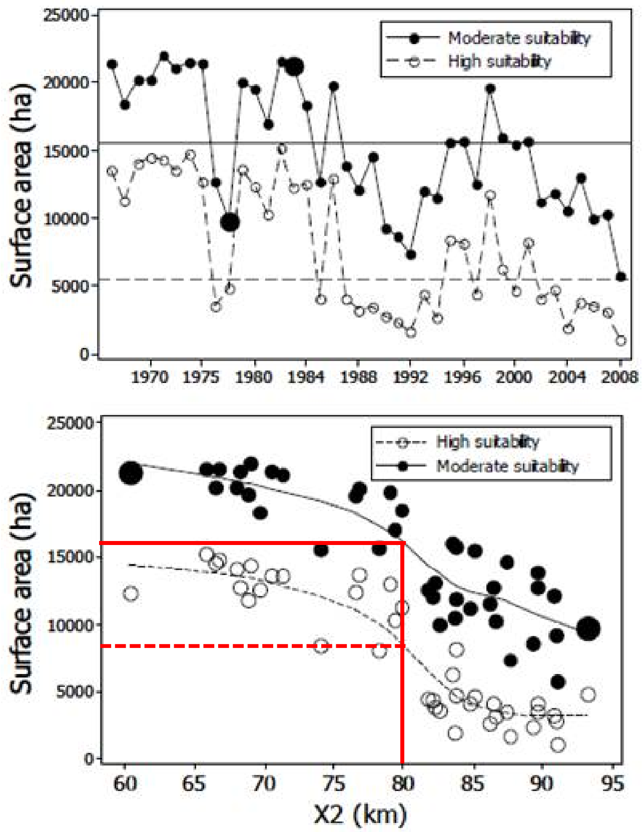
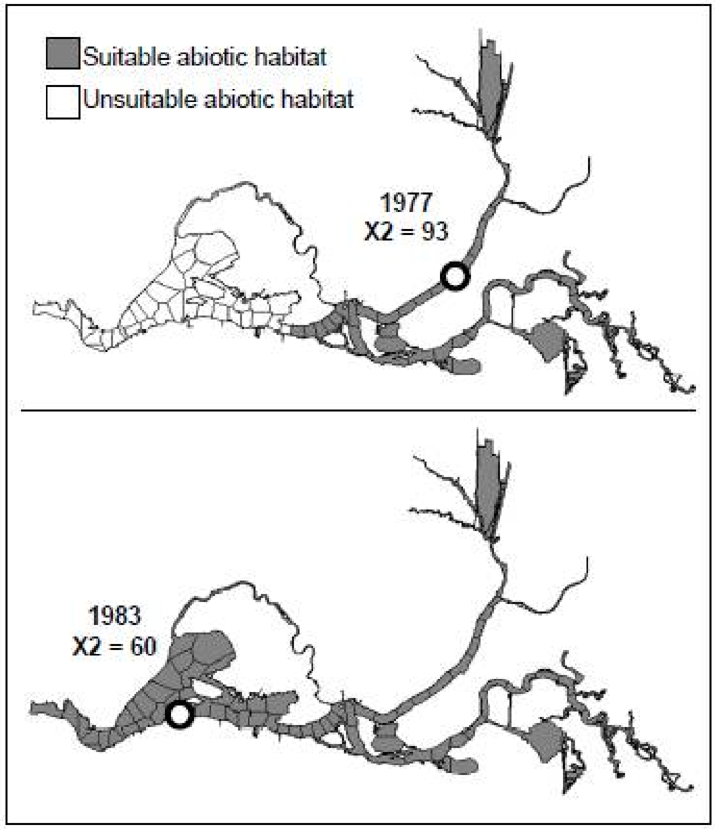


FIGURE 23.
Distribution of suitable abiotic habitat for Delta smelt in the Fall at two examples of X_2 locations (highlighted circles), above (top panel) and below (bottom panel) the confluence of the Sacramento and San Joaquin Rivers. The examples are based on data points highlighted in Fig. 22.

<u>Source</u>: Feyrer et al., in review (Fig. 3).



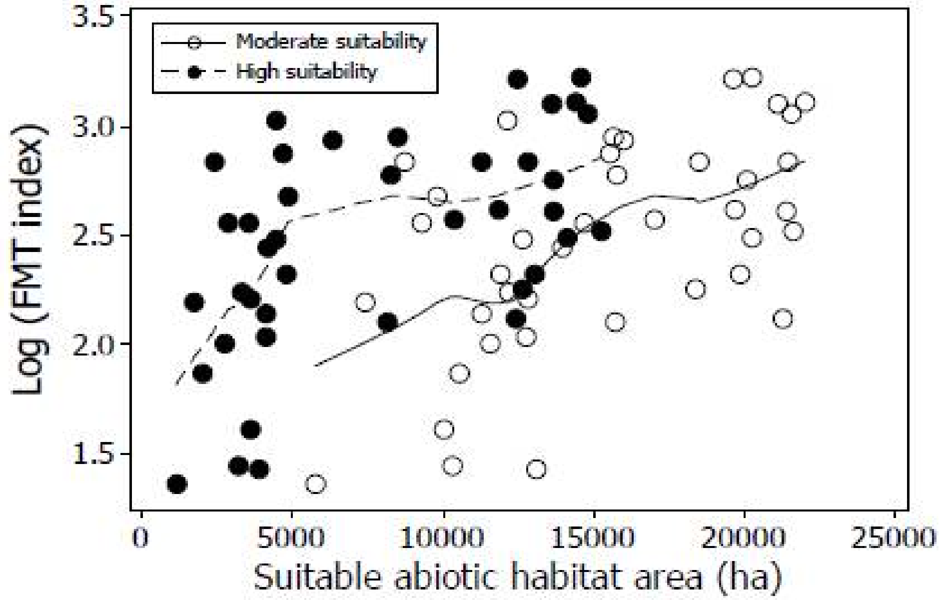


FIGURE 24
Log of the annual delta smelt abundance index from the fall midwater trawl (FMT) plotted against the area of two categories of suitable abiotic habitat (moderate and high). Curves are LOESS fits to the data.

The vertical red solid line identifies a threshold at ~5000 ha of high suitability habitat. Below that threshold, extremely low abundances of delta smelt have occurred; above that threshold, minimum FMT values increase rapidly with increasing area of suitable habitat. The habitat area-to-X_2 relationship in Figure 22 (bottom panel) reveals that this threshold corresponds to X_2= ~83 km and average September-December outflows of ~5750 cfs.

<u>Source</u>: Figure 4 from Feyrer et al., *in review*. Red line (threshold) added for this submission.

Based on the research described above, at least two threshold values for X_2 (and associated Delta outflows) relevant to delta smelt abundance and habitat area, or spatial distribution, are apparent. First, Delta outflows that result in X_2 located upstream of 80 km and the confluence of the Sacramento and San Joaquin rivers (~7,500cfs) result in generally poor habitat suitability (e.g., Figure 21). Second, Delta outflows that result in X_2 located upstream of approximately 83 km (~5750 cfs) have, in recent years, corresponded to extremely low abundances of delta smelt (Figure 24). In addition to these thresholds, results of Feyrer et al. (*in review*) also indicate that at X_2 values less than 80 km, overall habitat area (Figure 22, bottom panel) and delta smelt population abundance (Figure 24) increases with increases in Delta outflow and decreases in X_2.

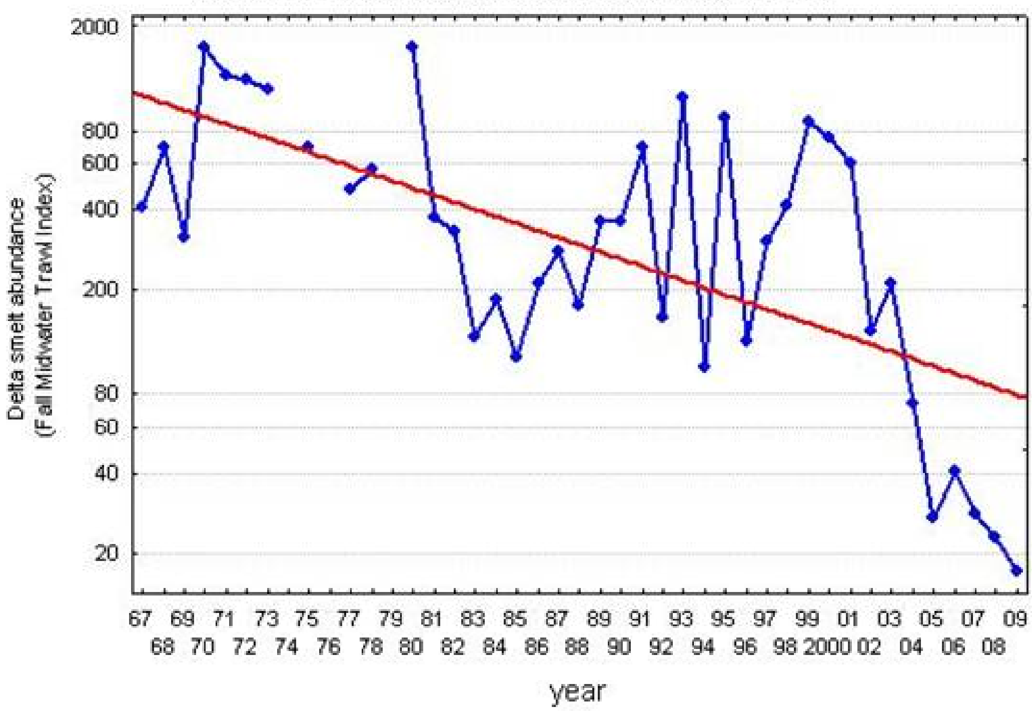
Recommendation: fall Delta outflow criteria to increase abundance and spatial distribution of public trust resources

Summary points:

- *Outflow criteria are proposed for the September to November period, expressed both as an average X2 location and as a continuous hydrograph relating unimpaired runoff to X2 values, requiring higher outflows under dry and normal conditions than have occurred recently.*
- *These criteria prohibit outflows that result in location of X2 upstream of 83 km.*

Delta smelt, the only public trust species whose entire population completes its life cycle in the Delta and upper estuary, is at record low abundance and at high risk of extinction (Figure 25). Reduced and/or degraded habitat and the current critically low population abundance are among the factors known to be contributing the species decline and current status (Sommer et al. 2007; Baxter et al. 2008).

FIGURE 25:
Decline of the Delta smelt (*Hypomesus transpacificus*), 1967-2009



Current Delta outflow conditions during the fall are consistently too low to provide conditions necessary to support and sustain delta smelt, are contributing to conditions that favor occurrence, establishment and high abundance of harmful non-native species and toxic algae blooms, and thus are inadequate to meet the needs of public trust fisheries and ecosystem resources. During the 1987-2009 period, Delta outflows during the fall were consistently low, with average September-December X_2 values greater than 80 km in 19 of 23 years (82% of years) and greater than 83 km in 13 years (57% of years) even though 12 of these years (52% of years) were wet or above normal (Figure 26). During the past ten years (2000-2009), fall X_2 has been upstream of 80 km in every year. Low outflows are particularly severe during the September to November period, before the usual onset of the first winter rains in late November and December. Based on the research described above, these low fall Delta outflows have constricted habitat area and quality for delta smelt, functioned as a contributing driver for low delta smelt population abundance, and exacerbated ecological problems associated with non-native species and toxic algae blooms.

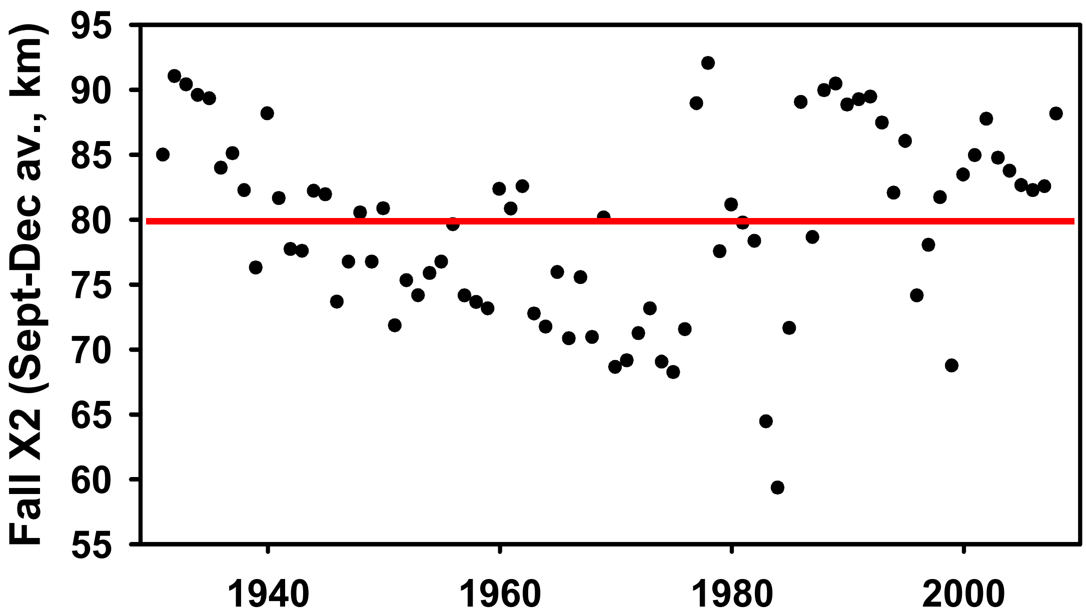


FIGURE 26
Changes in fall Delta outflow, as X_2 (average for September-December), from 1930-2008. Red horizontal line indicates X_2 = 80 km. Fall X_2 conditions >80 km correspond to very poor habitat conditions for Delta smelt. In 19 of the past 23 years (83% of years), fall X_2 has been upstream of 80 km even though 52% of those years have been wet or "above normal".

__Data source__: California Department of Water Resources, Dayflow.

Criteria for fall Delta outflow should: 1) significantly reduce the frequency of low outflow conditions that result in average September-November X_2 values greater than 80 km) as these are known to result in poor habitat quality and distribution; and 2) increase the frequency of fall outflow levels that that result in good habitat conditions for delta smelt and less favorable conditions for non-native species such as *Corbula* and for *Mycrocystis* blooms. Our fall outflow recommendations are summarized in Table 1 below and their relationship to recent conditions is shown in Figures 27 and 28.

Table 1. Recommended average monthly X_2 values and fall outflows (cfs) for September, October and November necessary to protect abundance and spatial extent of public trust resources, under five hydrological conditions.

Frequency	**X2**	**Delta outflow**
100% of years (all years)	<83 km	~5750 cfs
80% (dry years)	<80 km	~7500 cfs
60% (below normal years)	<77 km	~9700 cfs
40% (above normal years)	<74 km	~12,400 cfs
20% (wet years)	<71 km	~16,100 cfs

Figure 27: Frequency distribution of Delta outflows for three months (September, October, November) in two periods (1956-1987 and 1988-2009). Black line shows proposed fall outflow criteria, which is unchanged in each of these three months. Note that the proposed criteria call for fall outflows to increase over the recent period in order to improve delta smelt abundance and spatial distribution. In most years, the proposed criteria require less Delta outflow than occurred in the 1956-1987 period.

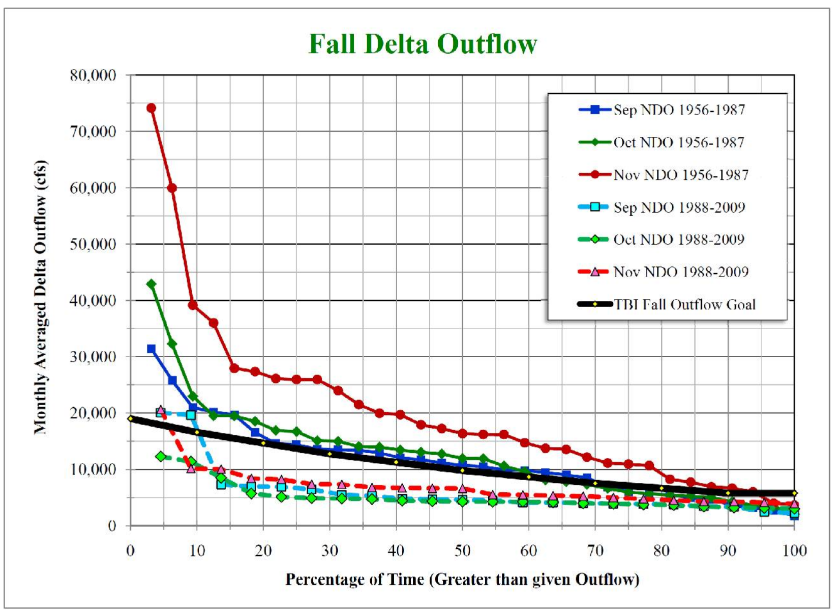
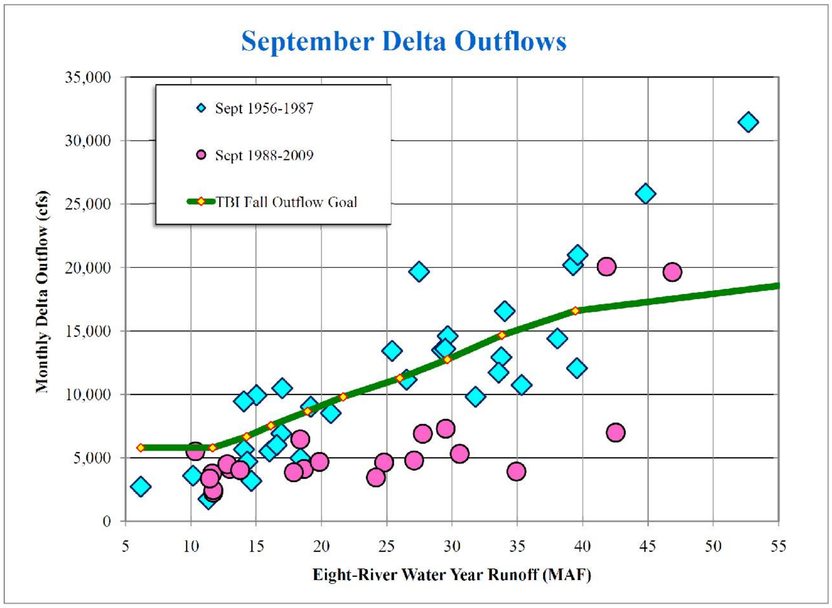
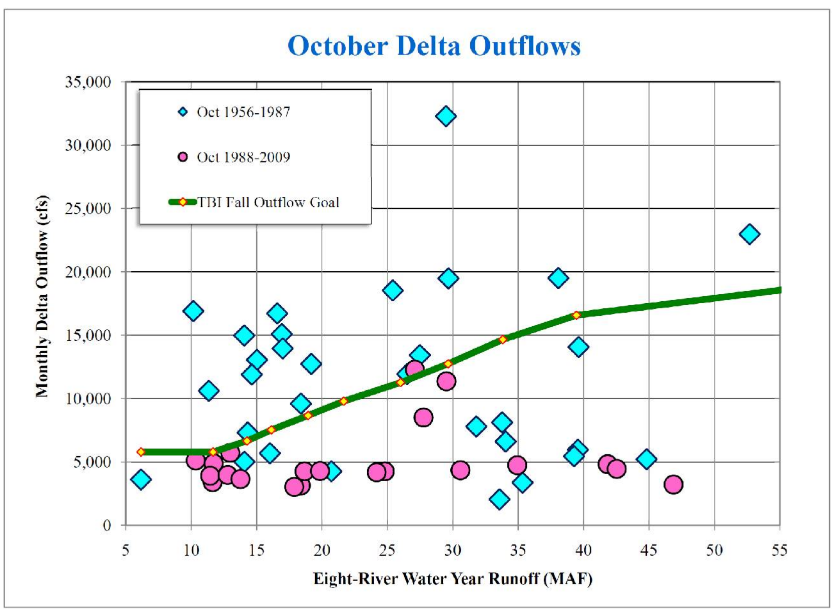


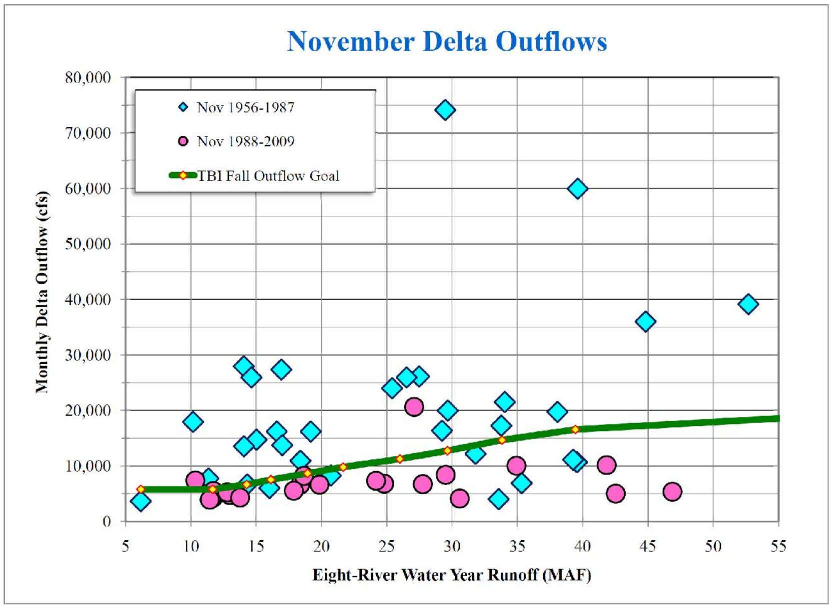
Figure 28: Relationship of annual hydrology (runoff in the previous year, MAF) to actual outflows during 1956-1987 and 1988-2009 as compared to recommended flow criteria in three months: a) September, b) October, and c) November. Note that the vertical axis (y-axis) changes in November to account for higher Net Delta Outflow that occurred in some years historically.



28 b)



28 c)


November Delta Outflows
Nov 1956-1987
Nov 1988-2009
TBI Fall Outflow Goal
Monthly Delta Outflow (cfs)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
5
10
15
20
25
30
35
40
45
50
55
Eight-River Water Year Runoff (MAF)

References

Baxter, R. 1999. Osmeridae. Pages 179-216 in J. Orsi, editor. Report on the 1980-1995 fish, shrimp, and crab sampling in the San Francisco Estuary, California. Technical Report #63. California Department of Fish and Game, Stockton, CA. http://www.estuaryarchive.org/archive/orsi_1999/

Baxter, R., R. Breuer, M. Chotkowski, F. Feyrer, M. Gingras, B. Herbold, A. Mueller-Solger, M. Nobriga, and T. Sommer. 2008. Pelagic organism decline progress report, 2007 synthesis of results. Interagency Ecological Program for the San Francisco Estuary.

Baxter, R. California Department of Fish and Game. Personal communication, December 3, 2009.

Dege, M., and L. R. Brown. 2004. Effect of outflow on spring and summertime distribution of larval and juvenile fishes in the upper San Francisco Estuary. Pages 49–65 in F. Feyrer, L. R. Brown, R. L. Brown, and J. J. Orsi, editors. Early life history of fishes in the San Francisco estuary and watershed. American Fisheries Society, Symposium 39, Bethesda, Maryland.

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

Feyrer, F., M. Nobriga, T. Sommer, and K. Newman. *In review*. Modeling the effects of future freshwater flow on the abiotic habitat of an imperiled estuarine fish. Submitted to *Estuaries and Coasts*.

Grimaldo, L.F., T. Sommer. N. Van Ark, G. Jones, E. Holland, P.B. Moyle, and B. Herbold. 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, AD, W.J. Kimmerer, S.G. Monismith, C. Armor, J.E. Cloern, T.M. Powell, J.R. Schubel, T.J. Vendlinksi 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications. 5:272-289.

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

Kimmerer, W.J. 2002b. 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]. 2(1):Article 1. http://repositories.cdlib.org/jmie/sfews/vol2/iss1/art1

Kimmerer, W. J., J. H. Cowan, Jr., L. W. Miller, and K. A. Rose. 2001. Analysis of an estuarine striped bass population: effects of environmental conditions during early life. Estuaries 24:556–574.

Kimmerer, W.J., M.L. Nobriga. 2008. Investigating particle transport and fate in the Sacramento-San Joaquin Delta using a particle tracking model. San Francisco Estuary and Watershed Science 6(1): [Article 4].

Kimmerer, W.J., E.S. Gross, M.L. Williams. 2009. Is the response of estuarine nekton to freshwater flow in the San Francisco Estuary explained by variation in habitat volume? Estuaries and Coasts.

Lehman, P. W., J. Sevier, J. Giulianotti, and M. Johnson. 2004. Sources of oxygen demand in the lower San Joaquin River, California. Estuaries 27:405–418.

Moyle, P.B. 2002. Inland fishes of California. University of California Press. Berekeley, CA.

Nichols, F.H., J.K. Thompson, and L.E. Schemel. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amerensis*. II. Displacement of a former community. Marine Ecology Progress Series 66:95-101.

Nobriga, M.L., T.R. Sommer, F. Feyrer, and K. Fleming. 2008. Long-term Trends in summertime habitat suitability for Delta smelt (*Hypomesus transpacificus*). San Francisco Estuary and Watershed Science. 6(1):, Article 1.

Rosenfield, J.A. and R.D. Baxter. 2007. Population dynamics and distribution patterns of longfin smelt in the San Francisco Estuary. Transactions of the American Fisheries Society 136:1577–1592.

Sommer, T., C. Armor, R. Baxter, R. Breuer, L. Brown, M. Chotkowski, S. Culberson, F. Feyrer, M. Gingras, B. Herbold, W. Kimmerer, A. Mueller-Solger, M. Nobriga, and K. Souza. 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. Fisheries 32:270-277.

StatSoft, Inc. (2010). Electronic Statistics Textbook. Tulsa, OK: StatSoft. WEB: http://www.statsoft.com/textbook/.

U.S. Fish and Wildlife Service (USFWS). 1995a. Recovery plan for the Sacramento/San Joaquin Delta native fishes.

U.S. Fish and Wildlife Service (USFWS). 1995b. Working paper on restoration needs: habitat restoration actions to double natural production of anadromous fish in the Central Valley of California. Volume 3. May 9, 1995. Prepared for the U.S. Fish and Wildlife Service under the direction of the Anadromous Fish Restoration Program Core Group. Stockton, CA.