The Informational Proceeding to
Develop Flow Criteria for the Delta Ecosystem

Noticed for March 22, 23, and 24, 2010

WRITTEN TESTIMONY

Submitted on Behalf of
The San Luis & Delta-Mendota Water Authority,
State Water Contractors,
Westlands Water District,
Santa Clara Valley Water District,
Kern County Water Agency, and
Metropolitan Water District of Southern California

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CURRENT FLOW OBJECTIVES/REQUIREMENTS HAVE NOT FULLY RECOGNIZED THE BIOLOGICAL VALUE OF FLOW IN THE CONTEXT OF ITS FUNCTIONS AND RELATIONSHIPS TO OTHER BIOLOGICAL FACTORS IMPORTANT TO FISHERIES[1]

A.   Spring X_2

Abstract

The causal mechanisms behind the spring X_2 standard is not understood for most estuarine species. Since the spring X_2 standard was first established by the SWRCB, conditions have worsened in the Bay-Delta estuary. In Suisun Bay, a favored rearing area for a number of species, the invasion of the Amur River clam (Corbula amurensis) has devastated the foodweb. Ammonium concentrations in Suisuin Bay are frequently above 4uM, a level that inhibits the uptake of nitrates by diatom phytoplankton. Adding additional spring X_2 days cannot restore fish abundances; the underlying mechanisms must be addressed.

1.   Brief history of the spring X_2 standard

The spring X_2 standard had its beginnings in 1991-92 through a series of workshops sponsored by the San Francisco Estuary Project. The purpose of the workshops was to develop a policy variable that could be used to set standards for managing freshwater flow. It was noted that particulate matter, turbidity, nutrients, phytoplankton, zooplankton, and juvenile striped bass, accumulated in an area known as the entrapment zone.[2] This zone was believed to be plankton rich (Arthur and Ball 1979), which may have explained why juvenile fish congregated there. Maximal turbidity and organism abundance were believed to occur consistently at around 2 practical salinity units (psu), which is frequently in Suisun Bay (Kimmerer 2004). Mechanisms determining the location of 2 psu were thought to be associated with gravitational circulation of waters in Suisun Bay, where waters were vertically well mixed.

Workshop participants eventually decided on a scalar index consisting of the position of a particular near-bottom isohaline, measured as distance (kilometers) from the Golden Gate along the axis of the estuary, what we now know as X_2.

In 1994, the Bay-Delta Agreement established the X_2 salinity standard because it was thought there was convincing evidence that its environmental influence affected a wide variety of species and thereby represented a means of increasing abundance or survival through operation of the water projects. At the time, it was felt this outflow standard was a rather crude management tool

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[1] The State and Federal Water Contractors incorporate by this reference the information presented in their summary of the written testimony, SFWC Exhibit 1, to the extent it is not discussed herein

[2] The entrapment zone is defined as an area of an estuary or other watercourse where seaward-flowing fresh water overlays more dense, saline ocean water resulting in a two-layer mixing zone characterized by flocculation, aggregation, and accumulation of suspended materials from upstream.

(IEP 1996). There was also scientific uncertainty about the specific linkages between salinity and fish species abundance and about how the aquatic ecosystem within the Delta and Suisun Bay might respond to changes in water flow management.

The spring X_2 criteria was adopted by the SWRCB in its Decision 1641, although its equivalent salinity standard (2.64 mmhos/cm salinity) earlier appeared in the 1995 Bay-Delta Plan (SWRCB D-1641).

At approximately the same time, an influential science paper was published regarding use of a salinity isohaline as a habitat indicator for estuarine fish (Jassby et al. 1995). This paper published relationships between the position of the 2 psu bottom salinity position, expressed as kilometers upstream of the Golden Gate, to abundance of copepods, mysids, shrimp, delta smelt, longfin smelt, striped bass, and starry flounder (Figure 1). The authors acknowledged that the actual mechanisms for the relationships were understood for only a few of these species, a fact later corroborated by Kimmerer et al. (2009). The possibility exists that the causal mechanisms are poorly understood because they have not been examined using path analysis.
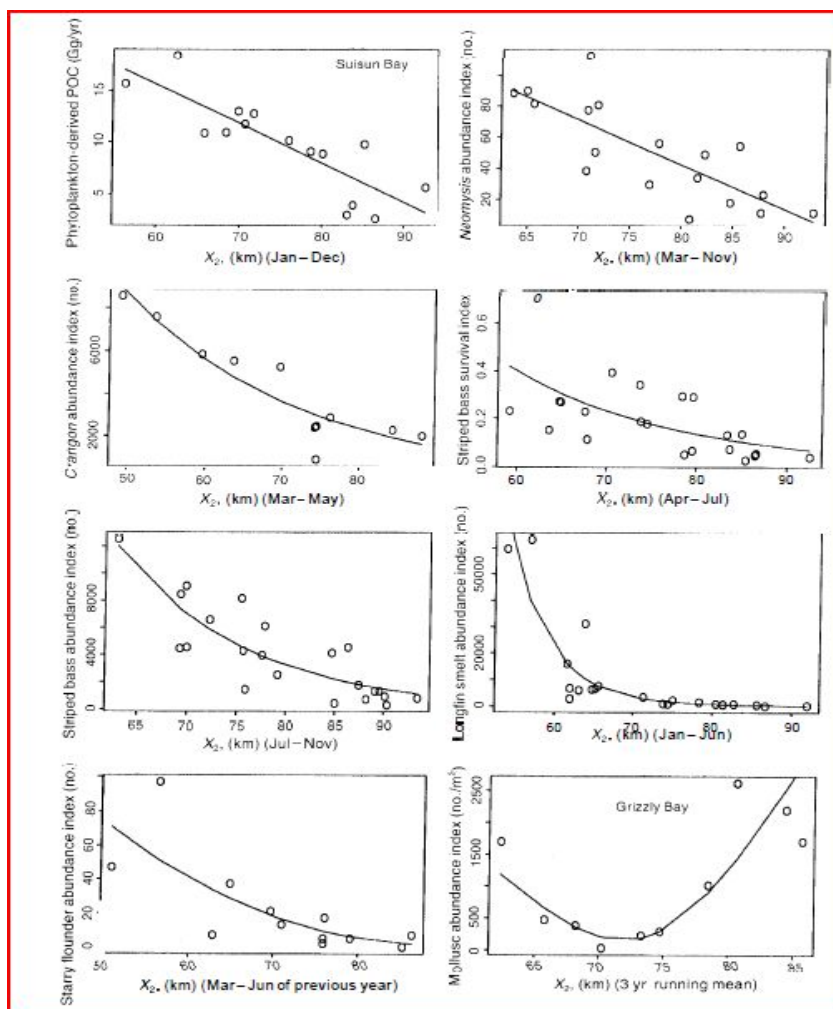
FIGURE 1. Relationships between various biological variables and X_2, the position of the 2 psu isohaline; (POC: particulate organic carbon). Months refer to averaging periods. From Jassby et al. (1995).

A recent analysis by Kimmerer et al. (2009; see Figure 2) noted that abundance-X_2 relationships had changed for several species. For delta smelt, the relationship between FMWT indexes with X_2 had essentially flattened (indicating no relationship). For other species, the relationships had shifted downward, indicating the carrying capacity of the estuary may be lower (Kimmerer 2002).
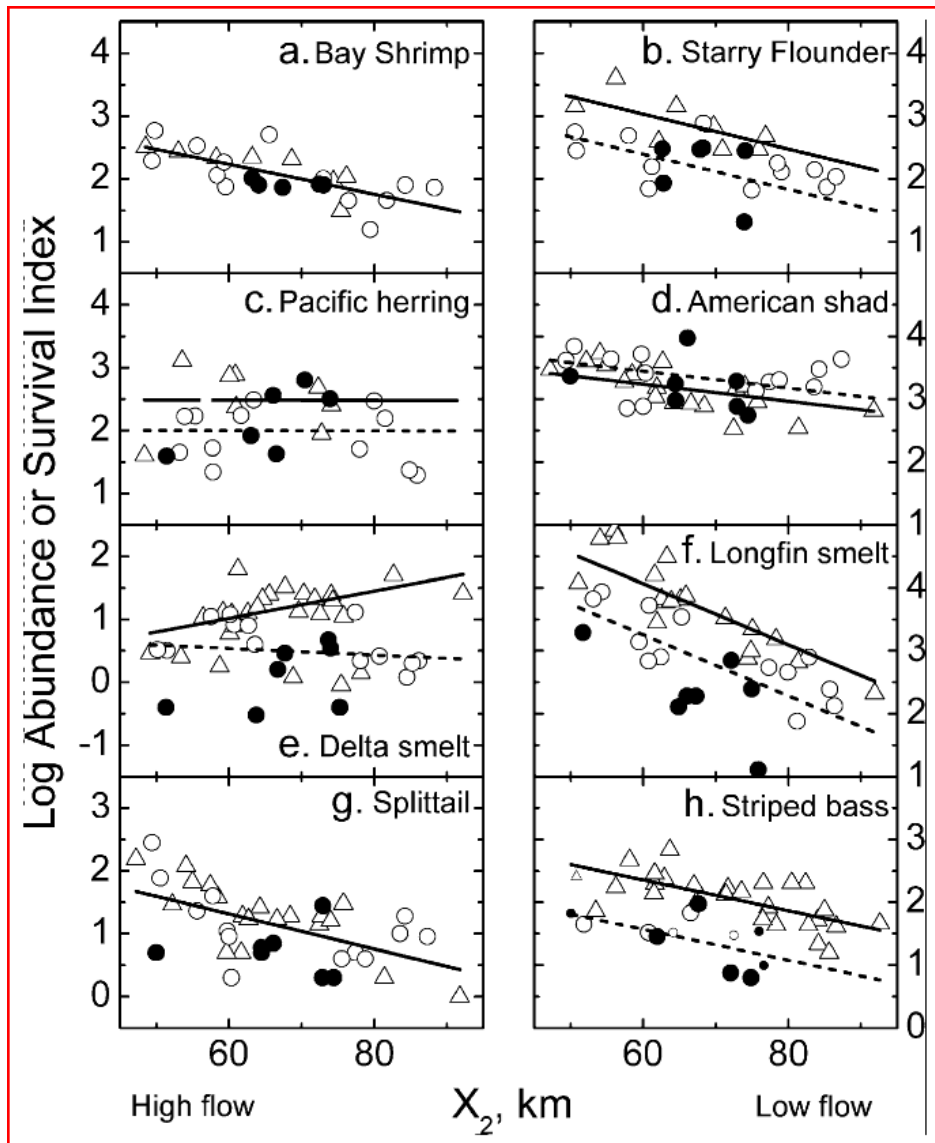
FIGURE 2. Log_{10} abundance indices for fish and shrimp (survival index for striped bass plotted against X_2. Symbols show data from three periods of generally consistent responses: triangles and solid lines, data up to 1987; circles and dotted lines, 1988-2006; filled circles, 2000-2007 (bay shrimp through 2006 only). Small symbols for striped bass based on interpolated or extrapolated egg production, not used in analysis. Lines drawn only when statistically significant. From Kimmerer et al. (2009).

2.   *Spring X_2 position may mask other effects on estuarine species*

Flow as referenced by the position of X_2 may mask other direct or indirect effects, unrelated to flows, that are limiting fish abundances. Kimmerer (2009) acknowledged that the mechanisms linking X_2 to abundance for several fish species, including longfin and delta smelt, bay shrimp, starry flounder, are as yet unidentified.

One possibility evaluated by Kimmerer et al. (2009) is that suitable habitat area expands when the location of X_2 is more seaward. Theoretically, increased suitable habitat area should yield more fish; however, Kimmerer et al. (2009) found that the physical quantity of spring habitat is related to abundance for only a few estuarine fish, notably northern anchovy, which have abandoned the estuary (Kimmerer 2006). In Suisun Bay, the location of X_2 is essentially irrelevant because of the Amur River clam's impact on food resources.

Higher flows simulated by a more seaward X_2 may also dilute contaminant concentrations. If anthropogenic contaminant loads are high, the obvious solution is not to dilute them with flows, but rather to reduce the loads. A comparison of Sacramento River flows and ammonia concentrations demonstrate the fact that higher flows result in lower concentrations (Figure 3).

Predation can also be masked by higher flows. Predators are known to congregate near structures and scour holes where they ambush their prey. Higher flows increase transport velocities, which are thought to sweep fish by predators more efficiently. This mechanism is at least partly behind the VAMP experiment. More straight-forward methods are to modify structures where possible to provide less hiding space and to control predator populations at key locations by physical means.

The fact that the causal mechanisms between the location of X_2 and fish abundances are largely not understood is testament to the scientific uncertainty of the X_2 flow standard. Baxter et al. (2008), the U.S. Fish and Wildlife Service's (USFWS) biological opinion on delta smelt (USFWS 2008), and the National Marine Fisheries Service's (NMFS) biological opinion on salmonids (NMFS 2009), identify numerous contributing factors to fishery declines. These include contaminants, predation, food availability and co-occurrence, water clarity, grazing by the Amur River clam, shifts in nutrient concentrations, invasive species, Corp. of Engineers permitting activities that have resulted in simplifying stream and riparian habitat, upstream water temperatures, unscreened in-Delta diversions, ocean conditions, water project operations, and many other potential stressors. Further manipulations of the position of X_2 in the spring, absent scientific discovery of the causal mechanism(s) linking X_2 and abundance and considering the continued downward decline of populations in spite of previous flow standards, are unwarranted given the great number of other stressors.
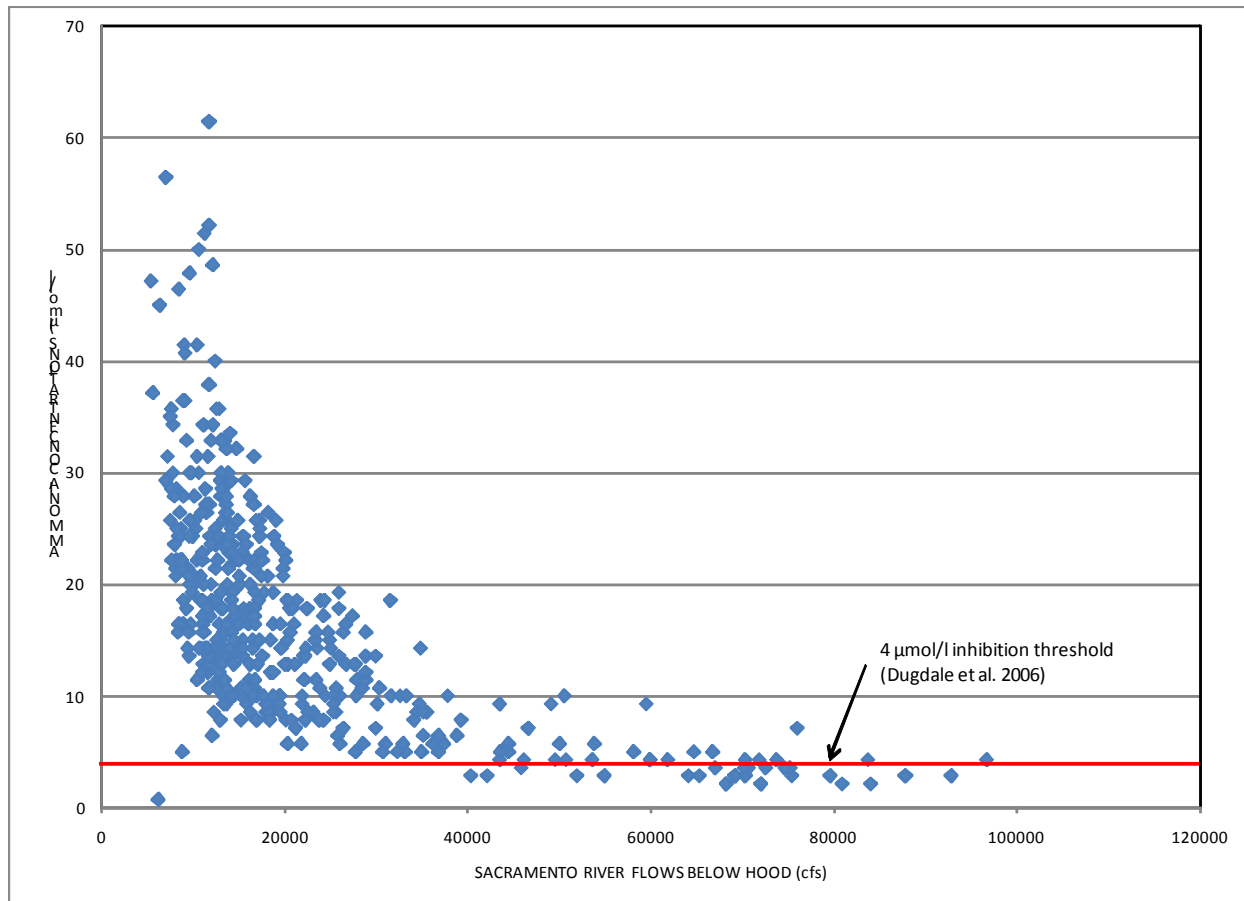
FIGURE 3. Hood ammonia concentrations (Stations C3 and C3A) and Sacramento River flows. Flow data from DAYFLOW. Ammonia concentrations from IEP environmental monitoring data available at http://www.bdat.ca.gov.

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B.   Flows Adopted For Salmon Migration

Abstract

Predation on salmon juveniles has a much greater effect on emigration than river flows. In recent years, the mortality of juvenile Chinook salmon and steelhead in the Sacramento River upstream of the Delta has been ~90%. The current population of striped bass (Morone saxitalis), only one of a number of predators, is estimated to be nearly 1 million fish. Striped bass alone have been shown to consume a large percentage of juvenile salmon. Predator control mechanisms offer a greater opportunity to improve juvenile emigration than adjusting Delta flows.

1.   *Ocean conditions*

Salmon population size as defined by escapement is affected by many factors both upstream (e.g., upstream water temperatures, availability of proper spawning substrate) and downstream (e.g. ocean conditions, harvest) of the Delta. While some people blame water project operations for the recent declines in salmon returns, unfavorable ocean conditions have been implicated as the real causal mechanism (PFMC 2008; NMFS 2009a). In its Status of the Fisheries report to the Fish and Game Commission, the State Department of Fish and Game reported on populations of Pacific herring (DFG 2008), a key prey of salmonids. Spawning biomass of herring dropped to an all-time low during the 2006-07 season; low spawning biomass occurs during or just after El Niño events (DFG 2008). Sardine and anchovy spawning populations have also dropped significantly from recent high levels (PFMC 2008; Brodeur et al. 2006). Krill, another prey item of Pacific salmonids, have also declined in recent years; the drop in krill populations was associated with massive die offs of seabirds and the complete reproductive failure of Cassin's auklets on the Farallon Islands (PFMC 2008). Changes in ocean conditions are associated with the decline in abundance of krill (PFMC 2008). The BiOp even admits (p. 56):

> The unusual and poor ocean conditions that caused the drastic decline in returning fall-run Chinook salmon populations coast-wide in 2007 (Varanasi and Bartoo 2008) are suspected to have also caused the observed decrease in the winter-run [Chinook] spawning population in 2007.

Conditions in 2008 and 2009 have mirrored those of 2007. When unfavorable ocean conditions persist, no amount of freshwater flow can mitigate; the mechanism is not flow but rather the carrying capacity of the ocean.

2.   *Predation*

Mortality resulting from predation by non-native fishes contributes significantly to the decline of Central Valley salmonids (NMFS 2009). Introduced predators such as striped bass and various centrarchid species (black bass, sunfishes) are among the most abundant fish species found in the Delta. Though much less abundant now than in the early 20th century, the adult striped bass population remains at nearly 1 million individuals (Nobriga 2009). Largemouth bass have also increased dramatically in the Delta since the 1980s, with catch more than quadrupling in most

Delta regions (Brown and Michniuk 2007). Striped bass predation in tributaries of the Delta appears to be the largest single cause of mortality of emigrating juvenile salmon. Studies have shown mortality of juvenile Chinook salmon and steelhead in the Sacramento River upstream of the Delta to be ~90% in recent years (MacFarlane *et al.* 2008; NMFS 2009). Acoustic tagging studies on the Delta portion of the San Joaquin River have found similar high rates of predation mortality (Holbrook et al. 2009). Hanson (2009) analyzed available diet composition data and estimated striped bass annually consume ~21% of juvenile winter-run Chinook salmon production, ~42% juvenile spring-run Chinook salmon production, ~7-15% of juvenile Central Valley steelhead production, and ~13% of delta smelt production. Consistent with Lindley and Mohr (2003) and NMFS (2009b), Hanson (2009) concluded mortality resulting from striped bass predation greatly increases the probability of salmonid extinction and also reduces the probability of species recovery. By comparison, for the years 1993-1998 (the last years for which complete data is available) the export projects annually entrained at most ~3% of all tagged salmon smolts released (Table 1).

Recognizing these dramatic predation losses, the NMFS (2009b) draft Recovery Plan for Central Valley salmon and steelhead concludes that: (1) predation on winter-run Chinook salmon is a "major stressor" with very high importance (p. 42, 48); (2) restoring the ecosystem for anadromous salmonids will require, among other actions, "significantly reducing the nonnative predatory fishes that inhabit the lower river reaches and Delta" (p. 90); and (3) reducing abundance of striped bass and other non-native predators must be achieved to "prevent extinction or to prevent the species from declining irreversibly" (p. 157, 183, 190).

An ESA-mandated tendency to focus on direct mortality and known sources of "take" have historically led to management actions focused on flows, reduced exports, and operating barriers to inhibit movement of fish towards export facilities (e.g. NMFS 2009a). These actions may have reduced export-related "take" (Kimmerer 2008), but they have not addressed predation mortality, the primary cause of poor through-Delta survival among juvenile salmonids. Reducing predator densities in key migration corridors of the Delta during migration periods could yield substantial improvements in through-Delta survival of salmon.

3. *Emigration and flows*

Chipps Island is located just downstream from the confluence of the Sacramento and San Joaquin Rivers (Figure 4). Downstream of Chipps Island is generally considered the bay portion of the estuary, while upstream of Chipps Island is generally considered to be the Delta (Brandes and McClain 2001; Perry et al. 2009). Cramer Fish Sciences used their Delta Pathway Model[3] defined a simplified Delta channel network following the reaches and junctions depicted in Perry et al. (2009). Specifically, this simplified Delta is composed of 10 reaches and four reach junctions (Figure 5) which represent primary salmonid migration corridors. For simplification, Sutter Slough and Steamboat Slough were combined as reach *SS* and the forks of the Mokelumne River were combined as reach *Mok* (Figure 5). At junction B, fish exit reach *Sac2* and enter either *Sac3*, Georgiana Slough (*Geo*), or *Mok* (Figure 5).

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[3] Information on the Delta Pathway Model is available at http://www.fishsciences.net/projects/delta_migration.php.

TABLE 1. Percent of all tagged salmon smolts released during 1993-98 that suffered direct mortality at export pumps.

(1)	(2)	(3)	(4)	(5)	(6)	PERCENT DIRECT MORTALITY PER RELEASE GROUP					
						(7)	(8)	(9)	(10)	(11)	(12)
				NUMBER OF RELEASE GROUPS	AVERAGE NUMBER OF FISH PER GROUP	TRACY PUMPING PLANT (CVP)			BANKS PUMPING PLANT (SWP)		
RIVER	SOURCE OF FISH	RACE OF SALMON	RELEASE LOCATION			MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM
SACRAMENTO RIVER SYSTEM	COLEMAN HATCHERY	LATE FALL RUN	COLEMAN HATCHERY	59	68,900	0.00	0.02	0.16	0.00	0.34	2.08
			DELTA [1]	17	39,000	0.00	0.07	0.35	0.00	1.76	10.30
		WINTER RUN	COLEMAN HATCHERY	104	1,600	0.00	0.00	0.00	0.00	0.00	0.19
		FALL RUN	COLEMAN HATCHERY	75	50,900	0.00	0.00	0.03	0.00	0.00	0.09
	FEATHER RIVER HATCHERY	FALL RUN	FEATHER RIVER HATCHERY	29	51,500	0.00	0.00	0.00	0.00	0.00	0.00
			DELTA [1]	99	41,600	0.00	0.23	1.87	0.00	0.13	1.43
		SPRING RUN	DELTA [1]	2	49,600	0.00	0.01	0.02	0.00	0.13	1.43
	TRAPPED WILD FISH	SPRING RUN	BUTTE AND MILL CREEKS	9	1,800	0.00	0.00	0.00	0.00	0.00	0.00
SAN JOAQUIN RIVER SYSTEM	MERCED HATCHERY	FALL RUN	MERCED HATCHERY	74	27,700	0.00	0.51	2.22	0.00	0.69	8.32
			DELTA [2]	21	34,700	0.00	0.11	0.77	0.00	0.10	0.65

[1] Consists of releases into the Sacramento River near Sacramento and downstream in the Delta.

[2] Consists of releases into the San Joaquin River near Mossdale and downstream in the Delta.

[3] Weighted average based on maximum percent mortality (columns 9 and 12).   0.03 [3]

[4] Data from Sheila Greene, DWR.

Next, the DSM2 HYDRO one-dimensional (1-D) numerical model outputs were used to describe Delta flow patterns. (A detailed description of the DSM2 HYDRO model, its functional basis, assumptions, and field calibrations, is provided in Kimmerer and Nobriga 2008. They used DSM2 HYDRO as an intermediate step to running a particle tracking model to evaluate a broad set of questions related to how inflows, exports, spring tides, neap tides, agricultural diversions, and artificial barriers influence the fate of particles released at 20 sites in the Delta.) DSM2 HYDRO outputs from 15 of the primary scenarios used by Kimmerer and Nobriga (2008) were used to describe Delta flow patterns. Scenarios included three levels of Delta inflows (high, medium, low), three export levels (high, medium, low), DCC gates open, and DCC gates closed (Table 2) and thus provide a total of 15 DSM2 HYDRO scenarios with which to evaluate potential effects on juvenile salmonid emigrants.

TABLE 2. Inflow and exports by source used to describe patterns of average daily flow and tidal flux (modified from Kimmerer and Nobriga 2008). DCC open and closed conditions were evaluated for all combinations of inflow and export except for high inflows. Flood control requires DCC gates be closed at Sacramento River flows in excess of 25,000 cfs.

Inflow Category	Inflow (total)		Inflow by Source (m^3s^{-1})			
	cfs	m^3s^{-1}	Sacramento R.	Yolo Bypass	San Joaquin R.	Eastern Delta
Low	12,000	340	292	0	40	8
Medium	21,000	595	493	6	78	18
High	38,000	1,077	837	32	162	47
Export Category	Export (total)		Exports by Source (m^3s^{-1})			
	cfs	m^3s^{-1}	SWP	CVP	Contra Costa	North Bay Aqueduct
Low	2,000	57	20	37	0.09	0.9
Medium	6,000	170	92	78	0.09	0.9
High	10,000	284	164	120	0.09	0.9

The effects of inflows, exports, and DCC position on daily average, reach specific flows are depicted in Figures 5 and Figure 6. Flow changes resulting from inflows, exports and DCC position differed substantially between reaches. Average daily flows in *SJ3* are always decreased (indicating net water movement towards south Delta export facilities) in response to increased exports. *SJ3* average daily flows are almost always negative except under conditions of San Joaquin River high inflows and low exports. Of the other eleven reaches considered in the Delta Pathway Model, none exhibited any apparent sensitivity to export level regardless of inflows (Figure 5) or DCC position (Figure 6).

The effects of inflow, exports, and DCC position on reach specific tidal flux is depicted in Figure 7. Tidal flux differs by orders of magnitude between Delta reaches. Reaches closest to Chipps Island (*SJ3* and *Sac4*) exhibit tidal flux in excess of 150,000 cfs, while for some upstream reaches (*SJ1*, *OLD*, *Geo*) maximum tidal flux is less than 5,000 cfs. Inflows exhibit relatively little influence on most reaches (<10% change), but higher inflows moderately reduce tidal flux in *Sac1*, *Sac2*, *Sac3*, and *SS* (Figure 7). Tidal flux is largely insensitive to export levels in all reaches except *OLD*, where exports change tidal flux by roughly 25%.

Flows in *Sac3* exhibit a very large magnitude of tidal flux regardless of inflow or exports. DCC closures produce substantial changes in both tidal flux and average daily flow for downstream reaches (*DCC*, *Mok*, *Geo*, *SJ3* and *Sac3*), although closing the DCC simply increases the stage of the Sacramento River (Kimmerer and Nobriga 2008), allowing salmon to enter the interior Delta via other pathways. These results are significant because they differ from the PTM-based assessments of Delta hydrodynamics relied upon by NMFS (2009).
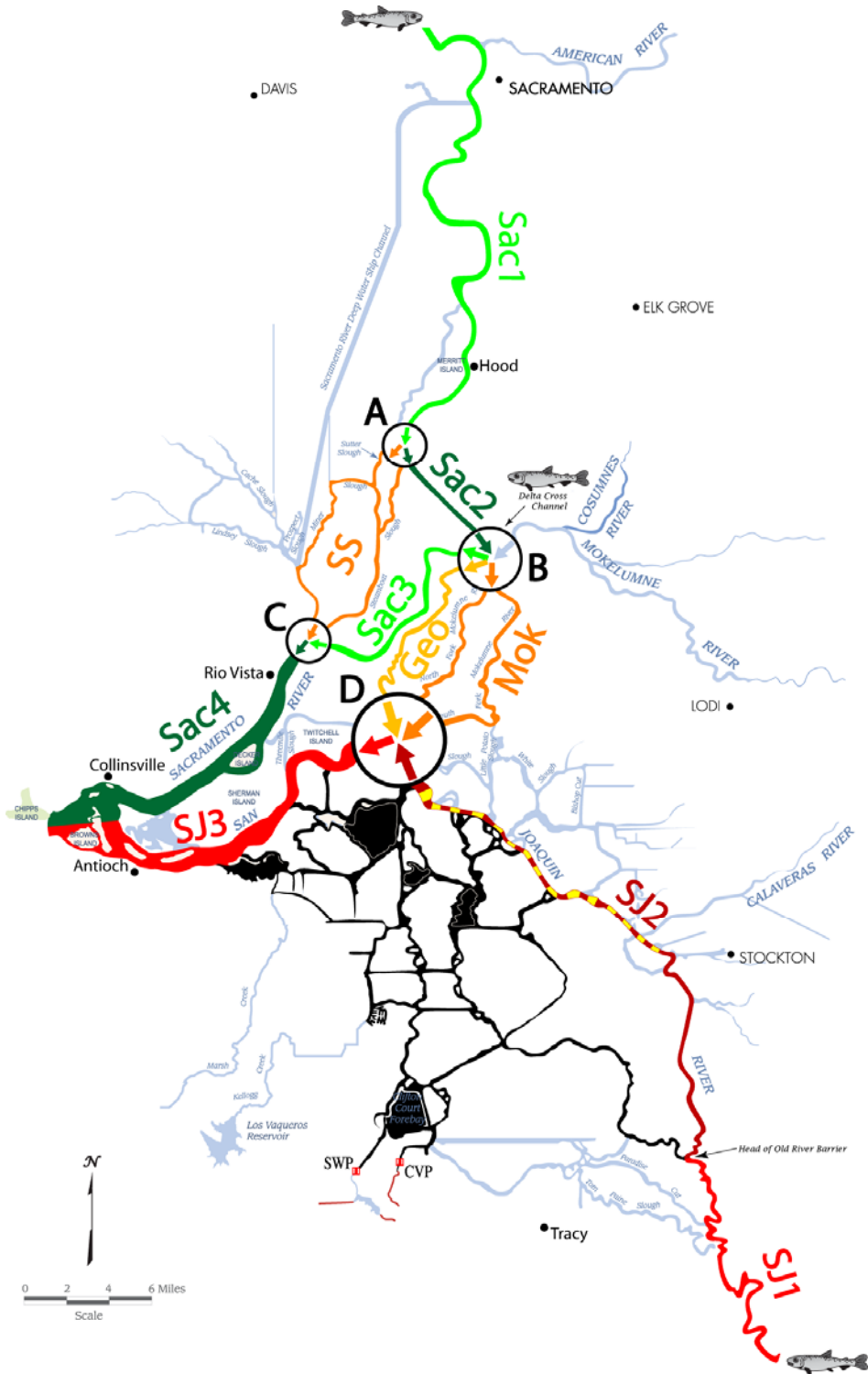
FIGURE 4. Map of the Sacramento-San Joaquin Delta depicting major migratory corridors for juvenile salmonids. Reaches are represented as colored segments of waterway where reach labels are colored to match the reach. Junctions in the model are represented as circles containing arrows that correspond to the various flows entering and exiting each junction. Junctions are labeled by black letters, A-D. Salmonid symbols indicate locations where most fish enter the Delta.

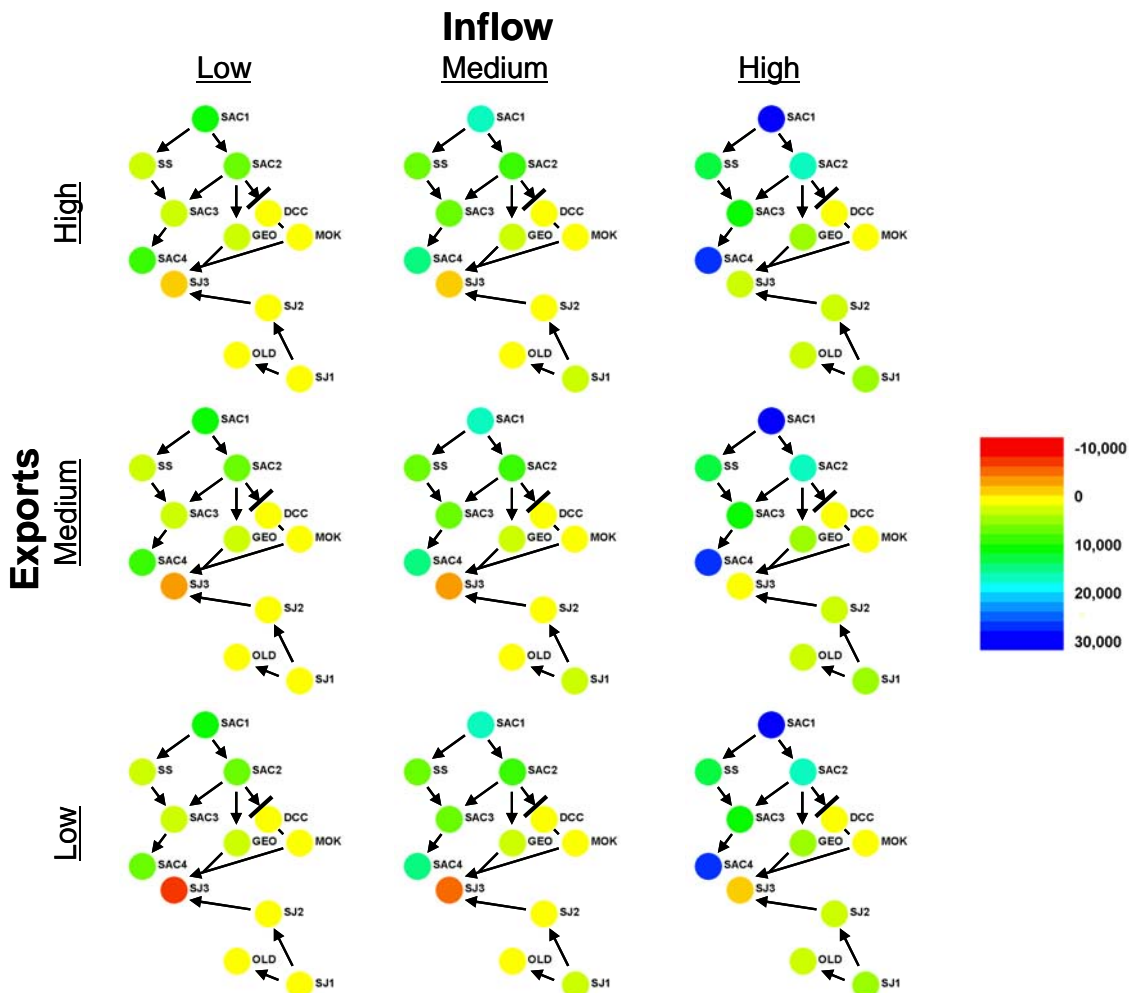FIGURE 5. Reach specific daily average flow (cubic feet per second) under different combinations of export and Delta inflows. Arrows indicate typical direction of flow between reaches. Blue-green-yellow bubbles indicate net flow towards the Bay. Orange-red bubbles indicate net flow toward the south Delta export facilities. Color changes represent 2,000 cfs increments.

River flows are thought to effect juvenile salmon by influencing migration speed. Acoustic tagging studies for the north Delta show that fish typically pass through discharge-driven reaches like *Sac1*, *SS*, and *Sac2* quickly; an average of three days while mean residence time is eighteen days in *SJ3* where tidal influence is very strong (Russell Perry, personal communication). Thus, while river flows influence juvenile salmon migration speed, the relationship appears to be more dramatically influenced by the transition from discharge-driven to tidally-driven reaches of the Delta.
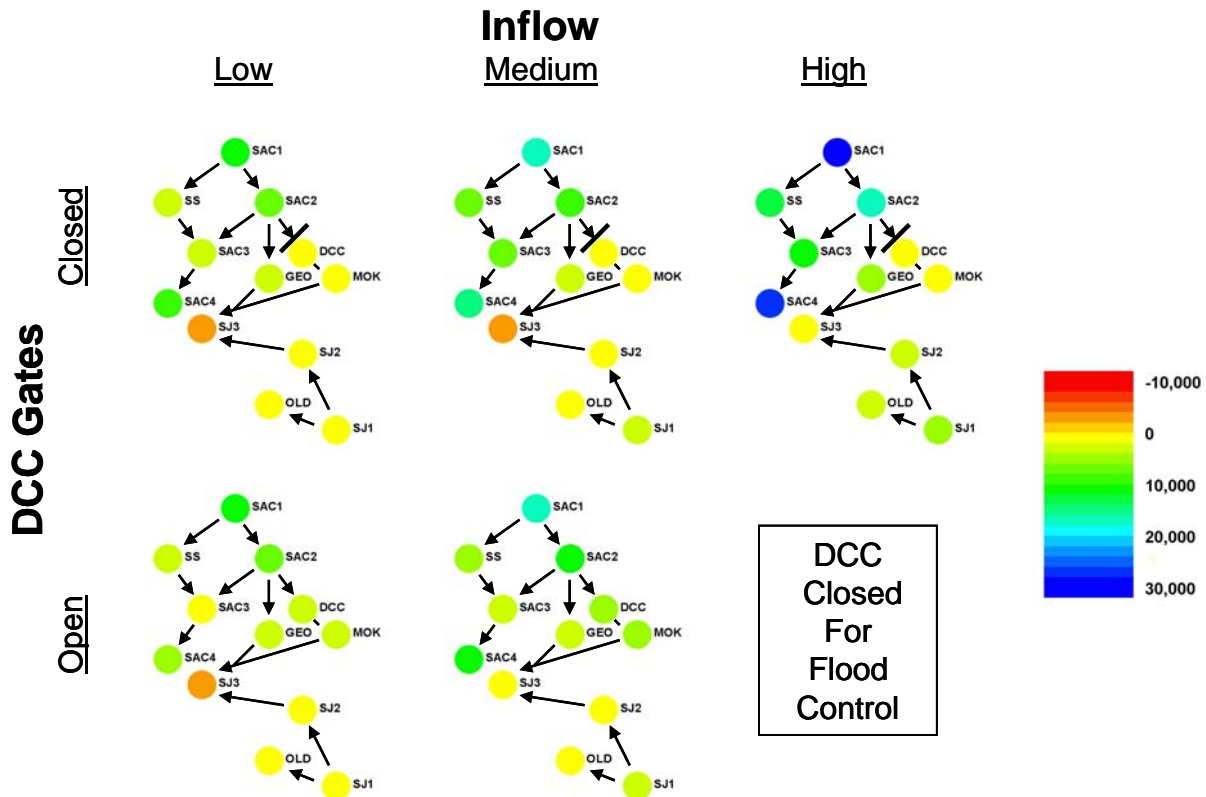
FIGURE 6. Reach specific daily average flow (cubic feet per second) with medium exports and different combinations of Delta inflows and DCC position. Arrows indicate typical direction of flow between reaches. Blue-green-yellow bubbles indicate net flow towards the Bay. Orange-red bubbles indicate net flow toward the south Delta export facilities. Color changes represent 2,000 cfs increments.

Besides migration speed, juvenile salmonid route selection is also important. Although fish route selection is variable, particularly over short periods of time, acoustic tagging studies in the Delta have found that, on average, salmon smolts arriving at distributary junctions tend to enter downstream reaches in proportion to the flow diverted down that junction (Perry et al. 2009; Holbrook et al. 2009). These findings are in contrast to conclusions based on PTM results. For example, at 12,000 cfs Delta inflows, PTM-based analyses by Kimmerer and Nobriga (2008) found that it took 50 days for 75% of particles released at Hood to exit the Delta. In contrast, acoustically tagged salmon smolts migrate through the Hood reach in three days and exit the Delta in just over two weeks. Thus, an abundance of caution must be used when interpreting PTM results for salmon. At present, a much more appropriate mechanism for analyzing salmon emigration is to examine fish migratory behavior using acoustic tagging. Reach-specific survival and associated error estimates are available for several Delta acoustic tagging studies (Burau et al. 2007; Perry et al. 2009; SJRGA 2007); the effect of flow on survival within Delta reaches remains highly uncertain.
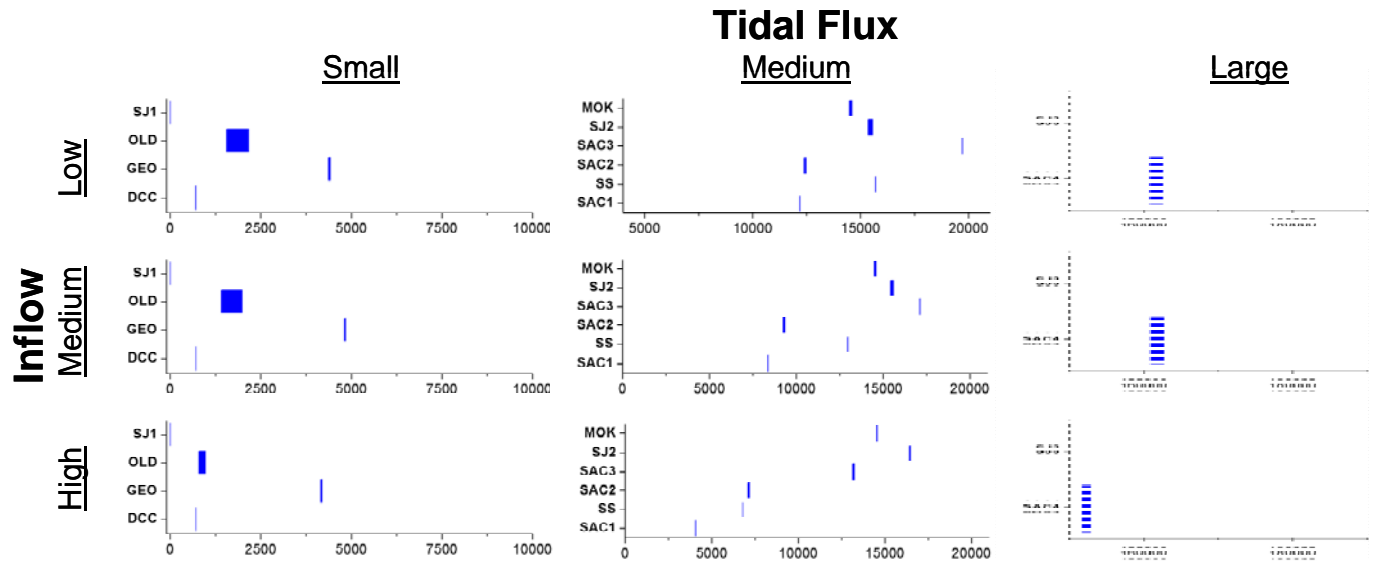
Tidal Flux

Figure 7. Reach specific tidal flux defined here as the difference in absolute value of flow (cfs) between the largest ebb and largest flood tide with DCC gates closed. Reaches with similar tidal flux are grouped in stacked graphs from left to right as small, medium, and large; each plotted on a different X-axis scale. Width of blue horizontal bars depicts range of tidal flux observed between low and high exports.

River flows associated with migratory cues are an important mechanism for movement of upstream fry to downstream rearing areas in the Delta. Once the fry mature to become smolts, they migrate through the Delta to the ocean. The single largest factor influencing their success at emigration to the ocean is predation. Actions to reduce this major stressor will improve the survival of juvenile salmon through the Delta.

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C.   The Relationship Of Flows To Entrainment Of Delta Smelt And Of Entrainment To Adult Smelt Populations

Abstract

State and federal regulations both place restrictions on reverse flows in Old and Middle Rivers (OMR) as a means to address entrainment by the CVP and SWP into the export pumps. Statistical analyses used as a basis for establishing these regulations are not the best available science and, in fact, are in error. Regulations are premised on the concept that entrainment has important effects on delta smelt abundances. For at least the past five years, researchers have recognized that entrainment does not affect delta smelt abundances. In fact, there is a 50-fold change in abundances from the Summer Townet Survey to the Fall Midwater Trawl. There is simply no scientific evidence supporting OMR flow restrictions as a method of increasing the population abundance of delta smelt. Therefore, the SWRCB should not establish numeric standards aimed at OMR reverse flows.

Recent federal biological opinions for the protection of Delta smelt have focused on the entrainment of Delta smelt. This has resulted in the creation of OMR (Old and Middle River) flow criteria which track levels of reverse flow in those two river channels. In order to determine whether such flow criteria are needed to improve the condition of public trust resources, in this case Delta and longfin smelt populations, two distinct science based question have to be addressed. First, under what conditions do reverse flows cause measurable increases in entrainment. This involves biological and hydrodynamic considerations related to the ability of fish to hold their position in the water column when faced with the opposing forces of river flow and the tides on a twice daily basis. Second, if entrainment is shown to be influenced by flow levels does that entrainment have a population effect on the species? This investigation involves evaluating other stressors on the species in the hierarchal manner described in the Summary of Written Testimony.

   1.   Flows and Entrainment.

Certain studies, as well as the delta smelt BiOp, have concluded that once OMR reverse flows reach a certain level (generally around -1,000 cfs), the OMR reverse flows begin to significantly or exponentially increase the amount of salvage that occurs at the project pumps. Based on such purported "thresholds" or "break points" in the amount of salvage, the BiOp concluded that OMR reverse flows should be kept below this "threshold" value to protect delta smelt. These analyses are fatally flawed, and are based on a scientifically indefensible methodology that should not be adopted by the SWRCB.

The basic flaw is that the analyses evaluate salvage at different levels of OMR reverse flow using absolute salvage data. Absolute salvage is the estimated number of fish salvaged, without regard to the overall population or abundance of fish at that time. Use of absolute salvage affords no basis for judging whether that level of salvage would be harmful to the overall delta smelt population. A salvage of 1,000 delta smelt at the pumps may be insignificant if the overall population is 1,00,000 but highly significant if the population is only 1,500. Thus, absolute

salvage by itself is largely meaningless. Absolute salvage must be adjusted or "normalized" in relation to the abundance of delta smelt in the system in order to gauge whether the salvage of that number of fish will or will not have an effect on the overall population. (See Deriso Decl. 1, ¶¶ 18-21; Deriso Decl. 2, ¶¶ 27-33, 51-55; Deriso Decl. 3, dated January 26, 2010, ¶ 16; Deriso Decl. 5, ¶ 4.)

"Normalizing" salvage in relation to indices of abundance, i.e., taking absolute salvage numbers and dividing them by the overall abundance of the population to get a "salvage index" or "incidental take index," is the standard practice in quantitative fish population science. The failure to use this methodology constitutes a failure to use the best scientific information and analysis available. (See Deriso Decl 2, ¶¶ 55-61, 69; Deriso Decl. 5, ¶ 5.)

Yet, the statistical analyses of salvage vs OMR flows that were conducted by Pete Smith and relied upon in the 2008 delta smelt BiOp, and the analyses of salvage and OMR flows in Grimaldo et al 2009, did not use a conventional normalized salvage or incidental take index.

When Dr. Richard Deriso, an expert in fish population dynamics, conducted a scientifically appropriate analysis of the relationship between OMR flow and salvage using normalized salvage data, he concluded that until OMR reverse flows reach at least -6,100 cfs, there is no statistical impact on the rate of normalized salvage. (Deriso Decl. 2, ¶¶ 62-65; Deriso Decl. 3, ¶ 13) Deriso did further evaluations of the OMR-salvage relationship using daily OMR and salvage data, a larger set of years, and a weight-of-the-evidence approach. These investigations all confirmed that OMR reverse flow rates have no correlation with the rate of normalized salvage until OMR reverse flows are more negative than -6,100 (and -5,500 cfs in the case of daily data). In fact, Deriso's analysis of daily data showed that salvage at 0 cfs was actually higher than the salvage rate at -4,500 cfs. (Deriso Decl. 3, ¶ 11).

More importantly, even at that rate, there is no population-level effect on abundance. (Deriso Decl. 3, ¶¶ 14-21)

Deriso also analyzed data on winter salvage and population estimates that had been compiled by the Independent Peer Review Panel for the delta smelt Biological Opinion. This investigation further confirmed that there was no significant increase in the rate of normalized salvage until OMR reverse flows became more negative than -7,000 cfs. (Deriso Decl. 4, ¶¶ 26-29.)

Thus, OMR reverse flows do not even begin to correlate with rates of normalized salvage until very high levels of reverse flows are reached (i.e., at least more negative than -6100 cfs for December-March averages).

Finally, Kimmerer (2008) has been misunderstood or misrepresented as having empirically established that OMR reverse flows have a directly proportional impact on salvage. In fact, as stated in his article, Kimmerer assumed a direct proportional relationship between OMR flows and salvage. With that assumption, he then "mechanistically" calculated what percentage of the population would be entrained at different OMR flow levels. Deriso, however, used actual OMR

and salvage data to test the assumption of a direct proportional relationship and he found that that assumption in Kimmerer's analysis was not supported for OMR flow greater than -6,100 cfs.[4]

2.   *The Population Effect of Entrainment*

Determining that OMR flows less than -6,100 or -7,000 cfs may increase proportional entrainment, as measured by normalized salvage, and using that data to find that a flow criteria is needed to limit how negative OMR flows is a perfect example of focusing on a single stressor in the face of overwhelming evidence that multiple stressors have important effects. Multiple published studies pointing out the absence of a relationship between entrainment of fish at the project pumps and important, statistically significant population level effects on subsequent abundance. For example, Kimmerer et. al. (2001)[5] noted that although striped bass were entrained in large numbers during larval and juvenile stages, the effect of entrainment on recruitment to the adult population appeared to be negligible. Kimmerer (2002)[6] also found little scientific support for the proposition that restrictions on project exports would provide population-level benefits.

Bennett (2005)[7] investigated and summarized the literature on entrainment impacts on delta smelt. Using a Beverton-Holt stock recruitment model, Bennett found evidence of density dependence during the summer which, in years of high abundance, limited the number of juvenile smelt that reach the pre-adult life stage in the fall, regardless of entrainment impacts at an earlier juvenile life stage. (*Id.* at 26-30).

Bennett also identified the preferred methodology for investigating whether entrainment is having an overall population-level effect. The first step in "assessing the potential impacts of the water project operations on delta smelt <u>requires estimating the proportion lost relative to population abundance</u>." (*Id.* at 37) (Emphasis added). In other words, the number of fish

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[4] Deriso also investigated the impact of OMR flow and export-to-inflow (E/I) ratios upon the "take index" for winter-run and spring-run Chinook salmon. The "take index" consists of the absolute numbers of fish salvaged divided by some measure of overall population or abundance. (Deriso Decl. 5, ¶ 5.) Thus, a take index represents salvage "normalized" in relation to abundance. In testing the relationships between OMR and E/I ratios and salvage, Deriso consistently found that there was no statistical evidence that OMR flows or E/I ratios were having any significant effect on normalized salvage of Chinook salmon. (Deriso Decl. 4, ¶¶ 6-12.)

[5] Kimmerer, W.J., J.H. Cowan, 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.

[6] Kimmerer, W.J. 2002. Physical, Biological, and Management Responses to Variable Freshwater Flow into the San Francisco Estuary. *Estuaries* 25:1275-1290. See p. 1286 ("Reductions in export flow are <u>inadequately supported by evidence</u>, and there is <u>little understanding of population-level effects of entrainment in export pumping facilities</u>. The effectiveness of export reductions using environmental water <u>has not been put in a population-level context</u> or compared with alternative actions in the watersheds.") (Emphasis added)

[7] Bennett, W.A., 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. *San Francisco Estuary Watershed Science* 3(2): 1-71

entrained had to be put in the context of the overall population, or "normalized" in relation to population abundance. Otherwise, as Bennett found with certain larger sized juveniles, "the number salvaged merely tracks the abundance of the juveniles" (*id.* at 37), i.e., high salvage may merely reflect a large population size rather than any entrainment effect. As described later, certain of the studies that have been used to justify limits on OMR reverse flows fail to follow this basic requirement of "normalizing" salvage in relation to population abundance. (See below, p. 18).

Second, according to Bennett, "losses to the water export facilities are <u>analogous to harvest in a fishery</u>, with the main exception that 'harvest' in this case includes all life stages (except eggs)." (*Id.* at 37). (Emphasis added). Because fish population models are routinely used in the management of harvest in sustainable fisheries, see below, p. 23, and because project entrainment is analogous to fish harvest, it is unsurprising that Bennett not only utilized a stage population model, but stated that: "[p]opulation modeling may be the <u>best way to evaluate the potential impacts of water export operations</u> relative to other sources of mortality." (*Id*. at 41). (Emphasis added). See also *id.* at 60 (noting that even with better knowledge of the factors relating to project entrainment mortality "their impacts need to be evaluated in a similar context with other known sources of mortality <u>in population models</u>.") (Emphasis added).

Bennett also stressed that a simple focus on entrainment losses by themselves without taking into account the greater context of density dependence and other sources of mortality at later life stages, misrepresented the impact of project entrainment on the species:

> In reality, … <u>estimating the proportion lost to exports misrepresents their actual impact on the population, especially during years if and when other sources of mortality (e.g., density dependent effects) are important at later life stages</u>. As in many fisheries, estimates of "harvest" by the water export facilities <u>also need to be evaluated in the context of other sources of mortality</u>. In years of high juvenile abundance, density dependent effects may minimize the impact of export losses. For example, even though an estimated 73,380 juveniles were lost during Spring 1999 (Nobriga and others 1999), adult abundance later in the year (MWT+864) was one of the highest recorded since the population declined. Thus, fish lost to entrainment in export facilities in some years <u>may not have survived anyway</u>. Conversely, in years when few cohorts are spawned (e.g., during warm years such as 1983; Figure 11, 16) entrainment losses may severely affect year-class success. However, even in years of low abundance it is possible that many fish lost in the water exports were weak and destined to die after exposure to toxic chemicals or low feeding success. Thus, <u>it is unlikely that losses of young fish to the export facilities consistently reflect a direct impact on recruitment success later in the year</u>.

(*Id.* at 38.) (Emphasis added).

Bennett then investigated the sensitivity of water export mortality on changes in population growth rates using a stage population model with different cohorts and life stages. Bennett found that even high export losses had little effect on the elasticity of the population growth rate, leading him to conclude that "export impacts may be difficult to detect on delta smelt population dynamics" and that "export mortality could be easily offset or masked by very small changes in

mortality at other life stages." (*Id*. at 44.) (See also 56 (modeling of entrainment losses "imply that their influence on annual abundance may be difficult to detect compared to small changes in survival during late summer as juveniles advance into the pre-adult life stage.") In discussing the implications of his investigation for management actions, Bennett thought that "export incidental 'take' limits clearly provide benefits to <u>individual</u> delta smelt, yet there does not appear to be a defensible biological basis for the levels chosen." (*Id.* at 57.) He went on to state: "For delta smelt … <u>it has never been established</u> that <u>reducing water exports</u> at the critical times <u>has any benefit for the population</u>" and that "it is currently unclear if losses to the water projects are a major impact on their abundance." (*Id.*) (Emphasis added).

Kimmerer (2008)[8] estimated the percentage or proportion of the overall population of winter-run salmon and delta smelt that was lost to entrainment in different years when different levels of OMR reverse flows occurred. Even if one assumes that Kimmerer's "mechanistic" assumptions and his resulting proportional loss estimates are valid -- and Deriso has shown that Kimmerer's assumption of a proportional relationship between OMR reverse flow and salvage of juveniles is not supported empirically -- Kimmerer still concluded that the impact of export losses on the overall population were vastly outweighed by mortality at a later life stage. (*Id*. at 25) Thus, like Bennett, Kimmerer concluded that project export effects had little impact on the population (as measured by the FMWT): "This [i.e., proportional loss of delta smelt from project entrainment] <u>would have made little difference to fall abu</u>ndance in the context of the approximately <u>50-fold variation in summer-fall survival</u> (Figure 17), and would be difficult to detect through correlation." See also *id.* ("despite substantial variability in export flow in years since 1982, <u>no effect of export flow on subsequent midwater trawl abundance is evident</u>."). Kimmerer also found that his estimates of proportional losses for salmon caused by the exports were *significantly less than the proportional losses of salmon caused by commercial fishing. (Id*. at 24)

Kimmerer did recommend that export controls be imposed to protect delta smelt "even though export effects are relatively small." (*Id.* at 25). But this was his policy recommendation based simply on his pragmatic belief that exports could be easily manipulated. (*Id*) It was not based on any scientific conclusion that exports were having a population-level adverse impact, and it failed to consider or balance any countervailing societal interest in permitting exports that have no discernable adverse effect on fish populations.

Grimaldo (2009)[9] examined the relationship between salvage of three fish species including delta smelt, and various environmental and flow characteristics. Leaving aside concerns about Grimaldo's use of absolute salvage instead of "normalized" salvage data, the authors found that sometimes flow and sometimes non-flow variables corresponded with salvage patterns for different fishes with no across-the-board "flow-explanation" for salvage. Moreover, the authors

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[8] Kimmerer 2008. Losses of Sacramento River Chinook Salmon and Delta Smelt to Entrainment in Water Diverions in the Sacramento-San Joaquin Delta, *San Francisco Estuary and Watershed Science* 6(2), 1-27.

[9] Grimaldo, Lenny F., Ted Sommer, Nick Van Ark, Gardner Jones, Erika Holland, Peter B. Moyle, Bruce Herbold,and Pete Smith, 2009. Factors Affecting Fish Entrainmentinto Massive Water Diversions in a Tidal Freshwater Estuary: Can Fish Losses be Managed? *North American Journal of Fisheries Management* 29:1253-1270.

did not address whether salvage – whatever its correlates –was having a population-level effect. (*Id.* at 1265 ("Our study does not address whether entrainment represents a large source of mortality for delta smelt"); 1266 ("Our study was not designed to address the most important management issue: whether these water diversions have population-level effects."). The authors also noted that "[t]he degree to which water exports have population-level effects in delta smelt is poorly understood"; that "the extent to which entrainment losses affect delta smelt population dynamics is unclear"; and that "[m]odeling studies by Bennett (2005) indicate that effects of exports on delta smelt growth and survival are very difficult to detect." (*Id.*)[10]

We note that these characterizations of effects as "poorly understood," "unclear," and "difficult to detect" are not consistent with published and unpublished studies finding no important, statistically significant effects of entrainment on subsequent abundance (Kimmerer 2008, Bennett 2005, Manly and Chotkowski 2006, Manly 2006 a and b)[11].

Like Kimmerer 2008, Grimaldo et al recommended certain management actions to protect delta smelt. But neither of the recommendations of Kimmerer or Grimaldo were based on increased scientific understanding derived from their reported studies. Instead, the management recommendations were based on the idea that among all the factors affecting abundance, Kimmerer thought that manipulating exports was simply the most feasible means of influencing abundance even though export effects were small. (Kimmerer 2008 at 25). And for Grimaldo et al., controlling project operations was justified because it addressed the "most directly observable" source of mortality, not necessarily the one that was most significant or likely to provide biological benefits. (Grimaldo et al 2009, at 1266.)

Finally, some have misconstrued various studies, and mistakenly believed that they showed that entrainment has a population-level effect. Their misunderstanding involves either a failure to appreciate that <u>flows were not being tested as an independent variable</u> for significance in the study but were incorporated into models for other purposes; or that a <u>relationship between flows and salvage was assumed</u> for purposes of generating other parameters; or that a population-level effect of OMR flows was merely a <u>hypothesis</u> rather than a relationship established by empirical evidence. (See Deriso Decl. 4, ¶¶ 3-24; Manly Decl. 3, ¶¶ 3-11.) (discussing misinterpretation of various studies).

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[10] Grimaldo et al also referenced other studies and evidence indicating that salvage impacts on population appeared to be negligible. (*Id.* at 1263 (exports played no major role in the salvage of littoral and demersal fishes and "[t]his result was somewhat surprising given that millions of age-0 littoral and demersal fishes are salvaged each year;" moreover, further study of littoral and demersal fishes may "show why the abundance of these species has increased in recent years (Brown and Michnuik 2007) despite large removal by the water diversions."); id at 1266 (referencing Kimmerer 2001 who found that export effects on the striped bass population were "small and sporadic."). The 2008 Delta Smelt Biological Opinion also stated that "currently published analyses of long-term associations between delta smelt salvage and subsequent abundance <u>do not support the hypothesis that entrainment is driving population dynamics year in and year out</u>." (Declaration of Dr. Bryan Manly in Support of Plaintiffs' Motion for Summary Judgment, dated, November 13, 2009, ¶ 6 (quoting Biological Opinion). (Emphasis added).

[11] Manly BFJ. 2006a. Review of Analyses Presented at the Environmental Water Account Meeting December 7-8, 2005. Western EcoSystems Report. Version dated 19 July 2006; Manly BFJ. 2006b. Review of Searching for Effects of State and Federal Exports on Delta Smelt Abundance. Western EcoSystems Technology report to the San Luis and Delta- Mendota Water Authority. Version dated, 7 September 2006; Manly BFJ., Chotkowski M., 2006. Two new methods for Regime Change Analyses. Archive fur Hydrobiology 167: 593-607.

Dr. Richard Deriso conducted modeling and statistical analyses of entrainment impacts in connection with the ongoing Endangered Species Act (ESA) litigation regarding the 2008 Delta smelt and 2009 salmon Biological Opinions (BiOps).[12] Dr. Deriso confirms that entrainment of delta smelt has not had a statistically significant adverse population-level effect on that species. (See Deriso Decl. 1; Declaration of Dr. Richard B. Deriso, dated November 13, 2009 ("Deriso Decl. 2"); Supplemental Declaration of Dr. Richard B. Deriso in Support of Motion for Interim Relief/Preliminary Injunction, dated December 7, 2009 ("Deriso Decl. 3"); Reply Declaration of Dr. Richard B. Deriso in Support of Motion for Interim Relief/Preliminary Injunction, dated January 26, 2010 ("Deriso Decl. 4"); Declaration of Dr. Richard B. Deriso in Support of Metropolitan Water District's Joinder in Motion for Temporary Restraining Order, dated February 1, 2010 ("Deriso Decl. 5").

Dr. Deriso used a Ricker stock recruitment model which is a quantitative, life-cycle fish population model. According to Dr. Ray Hilborn, Professor of Aquatic and Fisheries Sciences at the University of Washington,[13] such quantitative life-cycle modeling tools are well-accepted in the scientific community; are commonly employed in ESA recovery planning and in formulating Biological Opinions, and form the basis for management of sustainable fisheries throughout the world. See Declaration of Dr. Ray Hilborn, dated October 9, 2009 ("Hilborn Decl. 1"), ¶¶ 6, 10; Declaration of Dr. Ray Hilborn in Support of Plaintiffs' Motion for Summary Judgment ("Hilborn Decl. 2"); ¶¶ 4, 8-10, 17, 20, 25-27.) Ample empirical data about the Delta is available for use in quantitative life-cycle fish population models. (Hilborn Decl. 1; ¶12; Hilborn Decl. 2, ¶¶5, 28.) As noted previously, Bennett 2005 also identified fish population models as the best way to evaluate the impacts of entrainment on fish populations relative to other sources of mortality. Professor Hilborn similarly concluded that the only acceptable scientific method for evaluating entrainment impacts, given the availability of empirical data that can be used in such models, is through use of quantitative fish population modeling (i.e., stock recruitment or life stage models). (Hilborn Decl. 1, ¶¶ 6-13; Hilborn Decl. 2, ¶¶ 4-5, 33.)

There are at least three reasons why life cycle quantitative models should be used. First, any analysis of population-level effects must scrutinize and account for density dependent effects, different mortalities between different life stages, and "bottlenecks" between life stages. Life cycle models permit this type of analysis but other types of investigations, like those that focus solely on one life stage or one stressor, do not. (See Hilborn Decl. 1, ¶¶14-17.) For example, mortality to juveniles because of entrainment may have little impact on the overall adult population if other stressors (due to limited food supply, predation or pollutants) produces a "bottleneck" that otherwise limits the number of juveniles who become adults. (See above, pp. 19-21 (discussing Bennett 2005).) Investigations that only look at sources of mortality from one stressor, and then draw conclusions about the impact of that mortality on the overall population are flawed. For example, Feyrer's analysis of the impact of Fall X_2 looked only at effects of fall X_2 on abundance of subsequent summer juveniles. Feyrer's conclusion that Fall X_2 correlates with later abundance ignores a "bottleneck" between the juvenile life stage and the subsequent

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[12] Deriso's education, professional experience and publications are described in the Declaration of Dr. Richard Deriso in Support of Metropolitan's Motion to Allow Expert Testimony, dated July 30, 2009 ("Deriso Decl. 1) and in Exhibits A and B to that declaration.

[13] Professor Hilborn was retained by certain CVP contractors in connection with the ESA litigation regarding the 2008 Delta Smelt BiOp.

adult stage. (Hilborn Decl. 2, ¶¶ 29-30) Kimmerer estimated that there was a 50-fold variation in survival between the juvenile and adult stages due to other sources of mortality such as predation or pollutants. (Deriso Decl. 3, ¶¶ 31-33) and correlations involving spring prey density result in fall X_2 being insignificant to summer abundance. Thus, analyses like Feyrer's that look only at one stressor or one life change are an unsound basis for any conclusions about overall population impacts.

Second, there is a scientific consensus that multiple factors are causing fish population declines in the Bay-Delta. Therefore, methodologies that best permit analysis of multiple factors to determine their respective importance and magnitude are appropriate. Life stage models do this. They are well-suited to evaluating not just the effects of project entrainment but also the impacts of other sources of mortality (food supply, predation, pollutants, etc). (See Hilborn Decl.2, ¶ 9 (noting that quantitative models "allow[] analysis of the <u>relative importance</u> of <u>competing impacts</u> on the abundance of the population.") (Emphasis added); see also Bennett 2005, p. 41 ("<u>Population modeling</u> may be the best way to evaluate the potential impacts of water export operations <u>relative to other sources of mortality</u>.") (Emphasis added)

Finally, as noted by Hilborn, "[c]omplex ecosystems are characterized by non-linear relationships where a small change in one component may result in a large change in another, or conversely where a large change in one component may result in little if any change in another." (Hilborn Decl. 2, ¶ 7.) Because biological relationships may be complex and non-linear, they are best investigated using quantitative tools, methods and data that are more likely to reveal the true nature of the relationships, than by investigation through non-quantitative or "conceptual" and "holistic" approaches.

Using a Ricker stock-recruitment model, Dr. Deriso looked at the relationship between adult and juvenile delta smelt normalized salvage and OMR flows, and the corresponding impact of those variables on the population growth rate. (Deriso Decl. 2, ¶¶ 71-76). Deriso also conducted a weight-of-the-evidence approach using Akaike AC scores to test the relationship between abundance, and both OMR and normalized salvage. He again concluded that normalized salvage or OMR flows did not have a statistically significant effect on the population growth rate of delta smelt. (Deriso Decl. 3, ¶¶ 18-21.)

Deriso also investigated the relationship between juvenile delta smelt normalized salvage and OMR flow in the Spring, and the population growth rate. He concluded that there was no correlation between Spring OMR flows and the juvenile normalized salvage; in fact, normalized salvage was much lower at -7500 cfs than at -500 cfs. (Deriso Decl. 3, ¶26). Indeed, much of what was driving high salvage was simply high abundance instead of high OMR flows; i.e., when more fish are in the population, salvage is higher. (Deriso Decl. 3, ¶¶ 18-19). (See also Grimaldo et al 2009 at 1265-1266 (noting relationships between salvage and population size).

Deriso also investigated the impact of OMR flow and export-to-inflow (E/I) ratios upon the "take index" for winter-run and spring-run Chinook salmon. The "take index" consists of the raw numbers of fish salvaged divided by some measure of overall population or abundance. (Deriso Decl. 5, ¶ 5.) Thus, a take index represents salvage "normalized" in relation to abundance. In testing the relationships between OMR and E/I ratios and salvage, Deriso consistently found that

there was no statistical evidence that OMR flows or E/I ratios were having any significant effect on normalized salvage of Chinook salmon. (Deriso Decl. 4, ¶¶ 6-12.)

Finally, for the past four years (2006-2009), OMR reverse flows have been significantly lower than in previous years. During the two most recent years (2008 and 2009), OMR reverse flows were severely limited under the interim remedy adopted by Judge Wanger in the ESA litigation, and under the new delta smelt and salmon BiOps. Yet, despite these low OMR flows and severe OMR flow restrictions, there has been no improvement in delta smelt population abundance. Given the one-year life span of most delta smelt, the hypothesis that OMR flow limitations will benefit listed species has been tested in the real world in recent years, and there is no empirical support for it.

> a.   There is no empirical or statistical support for the notion that entrainment
>   has had an "episodic" impact on the populations of listed fish species

Despite the fact that their studies did not investigate whether entrainment was having a population-level effect, both Kimmerer 2008 and Grimaldo et al 2009 hypothesized that entrainment may have had an "episodic" impact on delta smelt population, and (in the case of Grimaldo et al) may have helped cause the POD. (Kimmerer 2008 at 25; Grimaldo et al 2009 at 1266.) However, this must be treated simply as a hypothesis, and it was not supported by the scientific investigation that was the subject of the articles which, in fact, disclaimed any intent to investigate whether entrainment was having a population-level effect. The authors pointed only to selective evidence that some years of high salvage corresponded with times of low abundance. But Bennett also identified years when high salvage was followed by significant increases in population abundance. (See Bennett 2005 at 38 (discussing 1999 salvage and subsequent increased abundance).

Dr. Bryan Manly, a bio-statistician, explained the statistical reasons why the "episodic" impact hypothesis fails. (See Declaration of Dr. Bryan Manly, dated October 9, 2009 ("Manly Decl.1"), ¶¶ 4-10; Declaration of Dr. Bryan Manly in Support of Plaintiffs' Motion for Summary Judgment, dated November 13, 2009 ("Manly Decl. 2"), ¶¶ 6-31; Declaration of Dr. Bryan Manly in Support of Plaintiffs' Motion for Interim Relief/Preliminary Injunction, dated January 11, 2010 ("Manly Decl. 3"), ¶¶ 8-11. Rather than looking at just selected years and concluding that entrainment could have "episodic" population-level impacts, Manly looked at all of the years that Kimmerer evaluated, and assumed that Kimmerer's percentage reductions in delta smelt population in those years were accurate. Manly then determined whether those percentage population reductions had any statistical relationship to subsequent delta smelt abundance. (Manly Decl. 1, ¶¶ 7-8; Manly Decl. 2, ¶¶ 9-14; Manly Decl. 3, ¶¶ 10-11. Manly concluded that there was no statistical relationship between Kimmerer's estimates of the percentages of the population being entrained, and subsequent population abundance. Instead, abundance varied in a pattern that had no relationship to whether a large or small percentage of the population had been entrained previously. (Manly Decl. 1, ¶ 8; Manly Decl. 2, ¶¶ 14-29, 31.; Manly Decl. 3, ¶ 11.) According to Manly, one possible explanation for the lack of a statistical relationship was that Kimmerer's estimates of the percentage of the population that was entrained – which were "mechanically" constructed by Kimmerer through a series of assumptions – were much higher than had actually occurred. (Manly Decl. 1, ¶ 9; Manly Decl. 2, ¶ 30.) In any event, there is no

statistical support for the "episodic" population impact theory based on the actual data on entrainment and population abundance.

Deriso also has explained that the notion that entrainment can have an "episodic" effect that simply is masked from statistical analyses is fallacious: "even an 'episodic' effect should be reflected in the population growth rate if it has somehow impacted the population." (Deriso Decl. 4, ¶ 31.) Tellingly, despite the supposed "masking effect" of high variation in population from year-to-year, Kimmerer detected a strong correlation between smelt abundance and zooplankton biomass. This illustrates that strong relationships (like abundance-zooplankton) are detectable despite supposed "masking effects." Thus, the fact that an abundance-OMR flow relationship is statistically undetectable indicates either that it is absent or is very weak, unlike that for zooplankton biomass. (Deriso Decl. 4, ¶ 18).

> 3. *The best available science does not support setting any quantitative or other OMR reverse flow standards*

Based on the best science available, there are several reasons why it would be inappropriate for the SWRCB to set any quantitative or other OMR reverse flow criteria in this proceeding. First, there is no statistically significant relationship between OMR reverse flows and normalized salvage, at least until very high levels of negative flows are reached. Moreover, there is no credible scientific evidence that OMR reverse flows are having any population-level effect on listed species at any level of OMR reverse flow. Also, instead of setting OMR reverse flows, the SWRCB should be endorsing and encouraging the use of full, life-cycle fish population models to investigate the impact of <u>all stressors</u> on listed populations, including flows, food supply limitations, pollutants, ammonium discharges, predators etc. The SWRCB should not reject the use of population modeling, statistical investigations or correlative studies in favor of so-called "mechanistic" or causal-based models in an effort to set some methodological "orthodoxy" that must be followed to understand Delta biological and hydrologic processes.

Finally, given the *de minimus* population-level and biological impacts of OMR reverse flows, and the vastly more significant impact of other sources of mortality -- including factors within the regulatory jurisdiction of the SWRCB like pollutant and ammonium discharges -- it is imperative that the SWRCB carefully balance the competing societal values in exports and water supply in making any judgments about OMR flow criteria.

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D.   Flows Adopted For Longfin Smelt

Abstract

Longfin smelt are one of the few estuarine species whose abundance is correlated with spring X_2. The California Fish and Game Commission established flow criteria aimed at keeping the location of X_2 in the spring at or near Suisun Bay. The Commission hypothesized that the location of X_2 influences the salvage of longfin smelt at the export pumps. Historical records show the export pumps salvage very few longfin smelt. For well over a decade, scientists have associated the decline in longfin smelt with the invasion of the Amur River clam (Corbula amurensis), which has created a food gap. Adding to the food gap, contaminant loading may be impacting the zooplankton favored by longfin smelt. In this respect, flows can mask the effects of contaminants via a dilution effect. Without addressing such underlying mechanisms, the use of flows as a management tool to improve population abundances of longfin smelt will likely fail.

Longfin smelt begin spawning in November, but most spawning is during February-April, with records extending into June (Moyle 2002). Peak hatching occurs in January or February (Kimmerer 2004). Optimum habitat for spawning includes submerged vegetation that can be used as a substrate for the adhesive eggs (Goals Project 2000). The pelagic, surface-oriented larvae move downstream with river flows to and beyond the low salinity zone (LSZ) where they feed on plankton. After metamorphosis, longfin smelt adopt a tidally-orientated vertical migration pattern and are found deeper in the water column (Kimmerer 2004). When high flows coincide with larval abundance, fish are transported primarily to Suisun and San Pablo Bays; when winter/spring flows are low, larval abundance is greatest in the western Delta and Suisun Bay.

The petition to the California Fish and Game Commission (CFGC) recommending listing the longfin smelt (*Spirinchus thaleichthys*) as an endangered species argued that the fish required specific environmental conditions (freshwater flow, water temperature, salinity) and habitat types within estuaries for migration, spawning, egg incubation, rearing, and larval and juvenile transport from spawning to rearing habitats (Bay Institute 2007). It further noted that the decline of longfin smelt coincided with increases in Delta water exports, particularly during the sensitive winter and early spring periods when adult longfin smelt and their larvae are concentrated in the freshwater and the LSZ.

Subsequently, the CFGC while considering protection of longfin smelt under the California Endangered Species Act, adopted emergency flow criteria to address entrainment at the SWP and CVP pumps. These criteria limited OMR flows to between -750 and -5,000 cfs when longfin smelt spawning was detected (CFGC 2008).

CFGC hypothesized that the location of X_2 influences the location of adult spawning. Specifically, that the location of X_2 could determine the distance adult fish migrate into the Delta to spawn, and the closer the spawners are to the south Delta, the more vulnerable they and their offspring are to entrainment by the CVP and SWP pumps. CFGC further noted that the highest

and most consistent salvage of adult longfin smelt occurs when X_2 is upstream of 70 km and little salvage occurs when X_2 is below 60 km. The fish were hypothesized to suffer from risk of entrainment from December-July (CFGC 2008). Baxter et al. (2008) likewise considered winter- and spring-time entrainment as an important stressor because spawners and larvae are surface-oriented and concentrated in the general vicinity of the export facilities at this time.

Notwithstanding these hypotheses, the Interagency Ecological Program reports salvage of all fish entrained at the SWP and CVP fish salvage facilities. Salvage for 1990-2008 as reported by the IEP demonstrates that the SWP and CVP entrain very few longfin smelt (see Figure 8), except for the anomalous 2002.

The early work by Jassby et al. (1995) demonstrated a relationship between the average January through June X_2 and longfin smelt abundance.
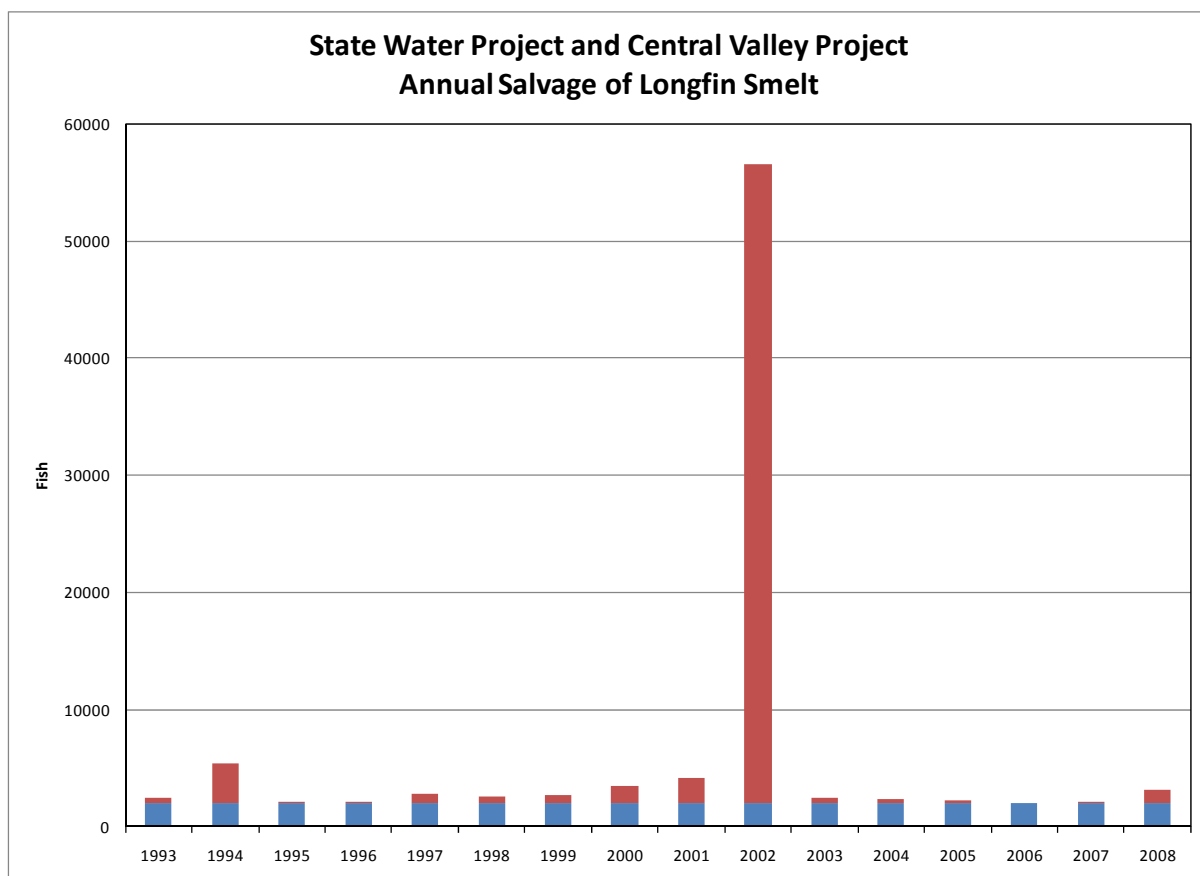

FIGURE 8. State and federal salvage of longfin smelt. Except for 2002, longfin smelt salvage has historically been very low. Red indicates the State Water Project; blue indicates the Central Valley Project.

However, Kimmerer (2002) reported a four-fold decline in the X_2-fish abundance relationships after 1987, presumably due to declines in the availablility of prey items following the Amur River clam invasion. Corroboration of the decline is found in Kimmerer et al. (2009), which also reported that the mechanisms responsible for the X_2 relationship are still unknown.

Rosenfield and Baxter (2007) found that survival between age-1 and age-2 fish declined between the pre- and post-drought periods (pre-1987 and post-1994). They found no evidence that, following the drought, longfin smelt were consistently absent from particular sites in the estuary where they had occurred before the drought. Rather, they attributed the decline in the average number of sites where age-2 longfin smelt were detected to a decline in population density toward a threshold of (non)detectability. They also concluded that food limitation is consistent with their finding of reduced age-1 productivity and the reduction in age-2 recruitment. Hobbs et al. (2006) further documented poor growth and condition of longfin smelt in the south channel region of Suisun Bay.

Food limitation may be driven by contaminant loading, one contaminant being ammonia/um concentrations. Glibert (in preparation) and Fullerton (unpublished data) have found trophic linkages of elevated ammonium concentrations with the phytoplankton assemblage in the San Francisco estuary. Longfin abundance in relation to X_2 may therefore be tracking a dilution effect, whereby diluted levels of ammonium, reflected by downstream X_2, lead to trophic changes favorable to longfin smelt.

Even if X_2 were kept in or near Suisun Bay all year, the conditions in Suisun Bay are currently unfavorable for the recovery of longfin smelt populations because of the lack of prey. A closer look at the possible mechanisms responsible for the longfin-X_2 relationship reveals that longfin declines are likely due to a change in trophic relationships in the Delta, and that current low food availability for longfin may be driving population declines. A narrow focus on the location of X_2 as a management tool is not likely to recover longfin populations, but should rather be considered in the context of a suite of measures designed to benefit fish populations. Major foodweb effects of the Amur River clam and contaminants cannot be overcome simply by adjusting flows and reducing exports.

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E.   Toxics/Contaminants

Abstract

Contaminant loads in the Bay-Delta have been steadily increasing, both from agricultural and urban sources. Pyrethroid pesticides have been found throughout the Delta's watershed; ammonia/um loadings, primarily from the Sacramento Regional Wastewater Treatment Plant, have increased significantly. These loadings have been shown to affect the lower trophic levels. The SWRCB should address these loadings at their sources rather than mask their effects by requiring higher flows.

There are numerous lines of evidence indicating that a significant shift in the pelagic food web has occurred in the Delta; this has been identified as a potentially significant factor in the POD (Baxter et al. 2008). We are unaware of any clear lines of evidence that manipulating manageable flows will restore the food web, especially if other factors, such as nutrient inputs and invasive clam populations, are not addressed. First, primary productivity and phytoplankton biomass as measured by chlorophyll-*a* (chl-*a*) is among the lowest of all estuaries studied and dropped even lower in the 1980s (Jassby et al. 2002). Declines in several zooplankton species have followed the chl-*a* declines. Laboratory experiments suggest that Delta-wide chl-*a* levels are now low enough to limit zooplankton abundance (Müeller-Solger et al. 2002). Second, the Delta's algal species composition has shifted from diatoms to smaller and lower quality species such as flagellates, cryptophytes and cyanobacteria (Lehman 2000, 2005, 2010; Jassby et al. 2002; Sommer et al. 2007) and to invasive macrophytes such as *Egeria densa* (Sommer et al. 2007; Nobriga et al. 2005). Jassby (2008) states,

> A decrease in percentage of diatom biovolume occurred during 1975–1989, caused by both a decrease in diatoms and an increase in green algae, cyanobacteria, and flagellate species biovolume (Kimmerer 2005; Lehman 1996), i.e., probably in the direction of declining nutritional value per unit biomass. In principle, the total nutritional value of a community could decrease even as its biomass increases. Moreover, changes in size, shape, and motility of species comprising the phytoplankton community could also affect their availability as food particles for crustacean zooplankton and other consumers.

Given that such shifts in phytoplankton have altered the microbial ecology of the Delta, of major concern is the question of the extent to which flow affects phytoplankton, whether in quantity or quality. Flow may affect phytoplankton directly, as different phytoplankton have greater or lesser tolerance for turbulence. Diatoms, in general, tolerate high flow better than flagellates, and low flow, quiescent or stratified conditions are generally preferred by cyanobacteria and flagellates. Flow may also affect phytoplankton indirectly through the solutes, nutrients or particles that are carried with the flow. These, in turn, affect both quantity and composition of nutrients and light available to phytoplankton. These indirect effects also differentially impact different phytoplankton groups with potential cascading results on food quality.

A path analysis approach (Figure 9) provides the conceptual framework to evaluate the possible mechanisms responsible for food quality and quantity. There are four major paths to

phytoplankton: nitrogen and phosphorus levels, residence time, turbidity or light availability, and Amur River clam abundance. While not an exhaustive list, the major effects of flow are captured.
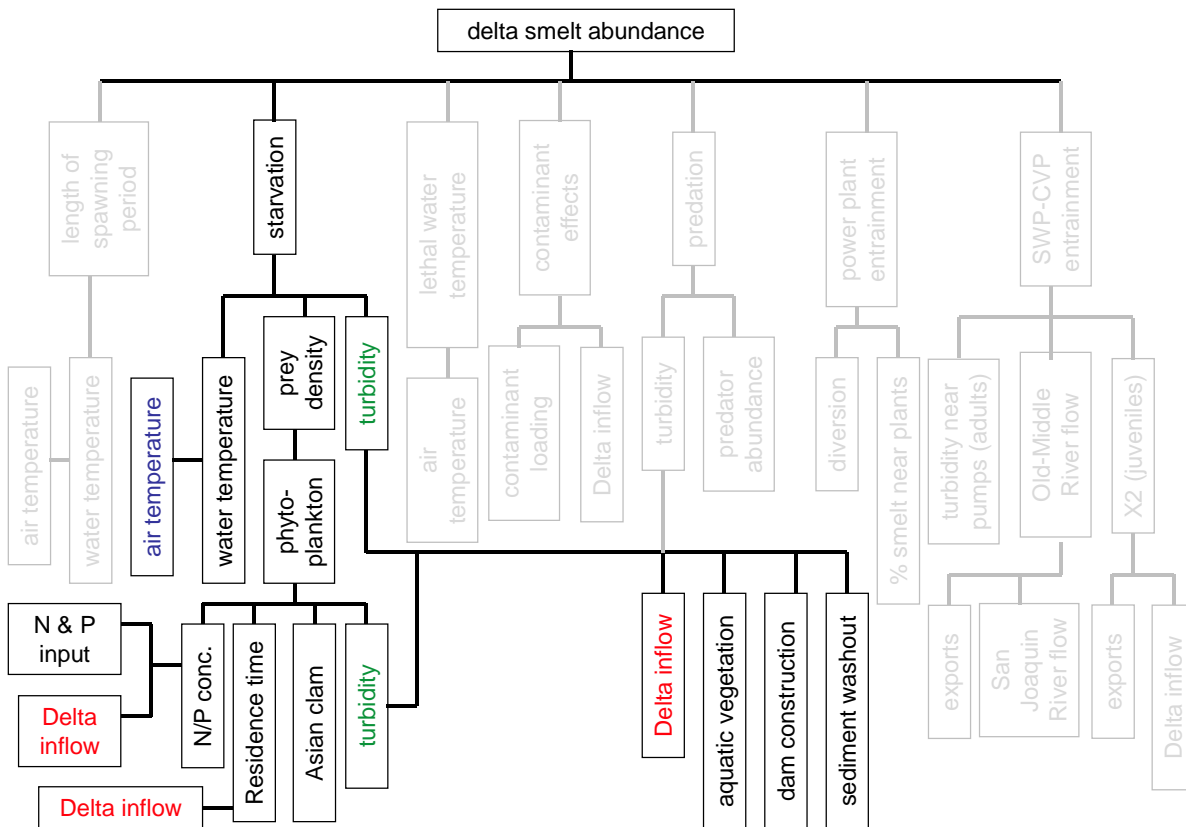
Simplified hierarchy – food path

FIGURE 9. Simplified hierarchical path analysis related to food resources for Delta smelt

1. *Turbidity path*

Algal productivity in the San Francisco Estuary is often described as light limited (Wilkerson et al. 2006; Cloern 1999). While total suspended solids are related to river inflow due to increased scouring during higher flows, total suspended solids have been declining, resulting in the equivalent of about 25% increase in photic zone depth (Jassby 2002). This increase in photic zone depth should increase primary productivity and Jassby (2002) speculates that the recent decline in productivity may have been even worse without this increase in clarity. Regardless, lower, rather than higher, flows would be required to increase clarity and reduce light limitation.

2. *Amur River clam path*

The drop in chl-*a* levels in the San Francisco estuary is attributed to the invasion of the Amur River clam *C. amurensis* (Jones et al. 2009; Jassby 2008; Feyrer et al. 2003). It has been

suggested that flow could be used to control *C. amurensis* distribution and density; however, the relationship between flow and *C. amurensis* is not a simple one. Parchaso and Thompson (2002) report: "Although the spatial extent of *Corbula* increases under low flow conditions, the reproductive season is shorter and fewer individuals were reproductive in dry years compared to wet years at Mallard Island and Suisun Bay stations." *C. amurensis* are also able to re-colonize quite rapidly following high flow events (Thompson 2007; see Figure 10). Therefore, higher flows cannot be used to reliably control Amur River clam abundance or grazing rates.
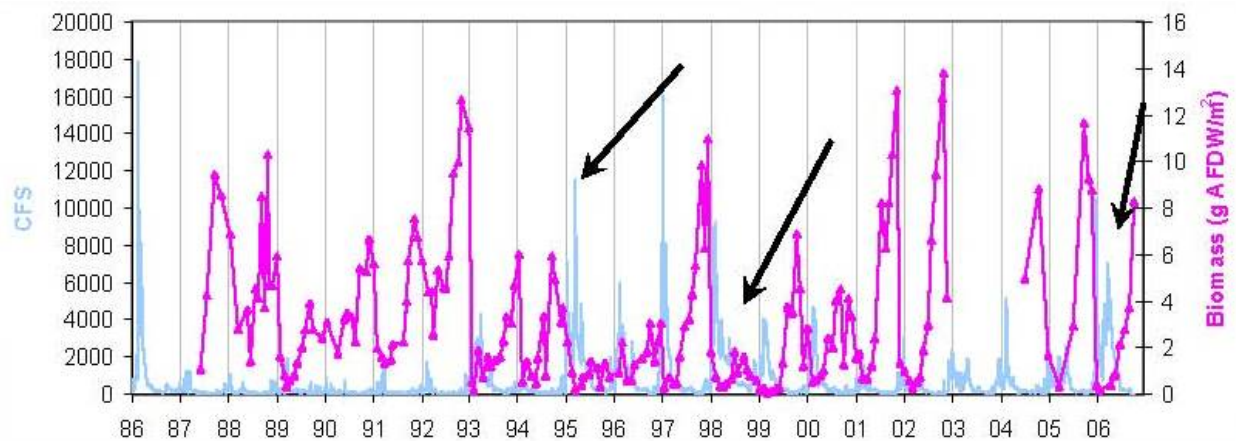

FIGURE 10. *Corbula amurensis* **biomass in Grizzly Bay and flow rate. From Thompson 2007**.

3. *Residence time path*

Residence time affects phytoplankton growth rates by determining the amount of time available for phytoplankton biomass to accumulate before being dispersed. Flow rate is the biggest determinant of residence time. Kimmerer (2002) found no correlation between X_2 position and summer or spring chlorophyll levels. Jassby (2002) found that, although river inflow is an important factor in year-to-year variability of winter chl-*a,* neither inflow nor other hydrological variables show a long-term trend during 1975–1995. In fact, inflow obfuscates the trend, which becomes more obvious when the effects of inflow are removed." Lower flows and higher residence time in 2000-2006 is related to a small increase in chl-*a* levels in the Delta, though not in Suisun Bay, during this time period (Jassby 2008).

4. *Nutrient input path*

Possibly more disruptive to the base of the estuary's foodweb is the shift that has occurred in algal species composition from dominance by diatom and green alga species to dominance by cryptophytes and flagellates and, in the last decade, increasing occurrence and magnitude of harmful algal blooms of *Microcystis aeruginosa* (Lehman 2000, 2005, 2010; Jassby et al. 2002; Sommer et al. 2007). The shift in algal species composition may be explained, at least in part, by the ratio of nitrogen and phosphorus inputs to the system. Nutrient inputs and river concentrations have changed as population has grown and treatment processes have changed (Jassby 2008, Van Nieuwenhuyse 2007). Van Nieuwenhuyse (2007) observed a significant decrease in phosphorus discharges to the Sacramento River from the Sacramento Regional

Wastewater Treatment Plant in 1993 (Figure 11). Also apparent in this figure, though not mentioned in his paper, is an increase in nitrogen load in 1987 and again beginning around 1999 (open circles in figure (b)). Van Nieuwenhuyse (2007) relates the drop in phosphorus to a drop in chl-*a* concentration; however, these changing nutrient loads and ratios can also explain some of the observed algal species changes.

Fig. 4. Mean summer nutrient discharge from the Sacramento regional wastewater treatment facility: (*a*) total P discharge from the facility (solid circles) and total P load in the Sacramento River at Freeport ~100 m upstream from the facility's outfall (open diamonds); (*b*) discharge of effluent from the treatment facility (broken line) and the effluent's total P concentration (solid circles) and total N concentration (open circles, right axis); and (*c*) total N discharge from the facility (solid circles), total N load (tonnes (t)·day^{-1}) in the Sacramento River at Freeport (open diamonds), and mean summer discharge at Freeport (broken line, right axis). Effluent total P was not measured in 1996. Broken vertical line marks the beginning of the period of reduced phosphorus discharge from the wastewater facility (1994–2005).
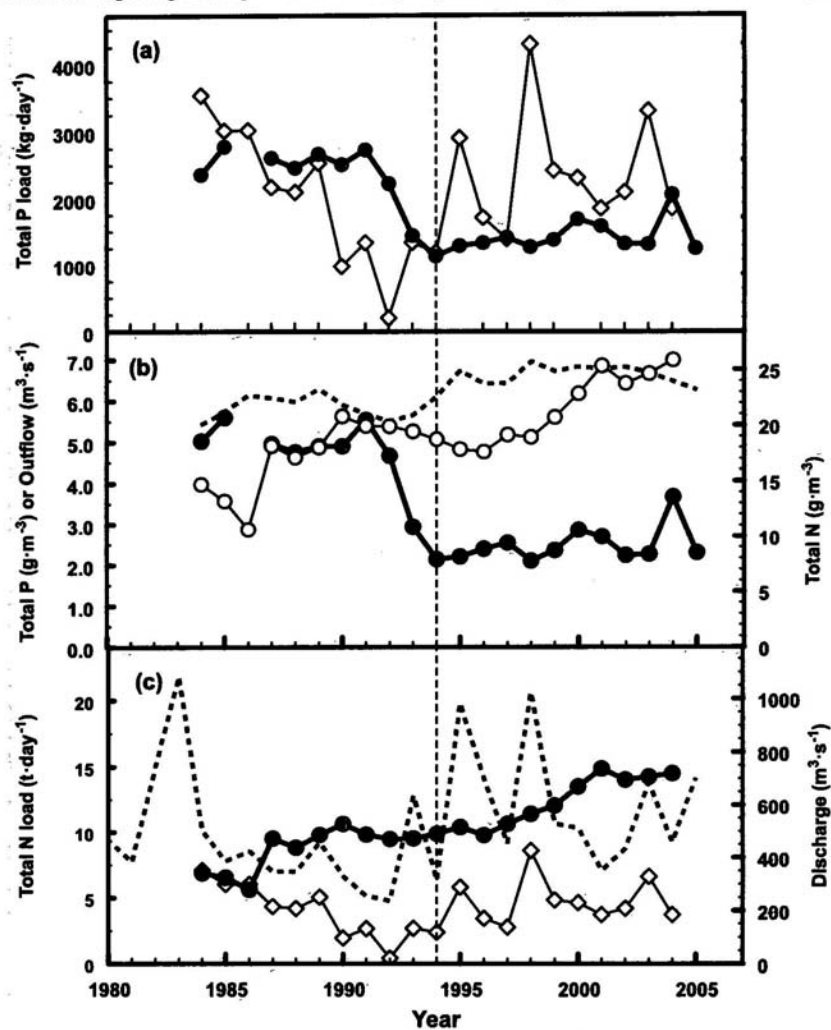

FIGURE 11. Nutrient loads from the treatment plant compared to loads in the Sacramento River upstream of the treatment plant. From Van Nieuwenhuyse 2007.

There is ample evidence from the literature recognizing that different phytoplankton groups have different nutritional preferences with respect to nutrients (Dyhrman 2008; Heil et al. 2007). As described above, flow can affect the proportion of major nutrients, especially during major storm events as different nutrients are delivered from different sources.

The form of nutrients available is also important, particularly for phytoplankton quality. While flow can affect the rate of transformation from one form to another, nutrient form is much less affected by flow than concentration. The recent increase in *Microcystis* blooms may be attributed to shifts in the nutrient forms in the Delta. Cyanobacteria have been shown to preferentially use chemically reduced forms over nitrate in many studies. Chemically reduced nitrogen not only includes ammonium, but also urea and dissolved organic nitrogen. This evidence comes from:

1. Measurements of enzyme activities in the cells – enzymes that process these forms of nitrogen. Cyanobacteria have been shown to have some of the highest measured rates of urease, for example, relative to all phytoplankton species tested, and among cyanobacteria, *Microcystis* rates are the highest (C. Solomon, Gallaudet Univ, unpub. data).

2. Directly determined rates of nitrogen uptake using isotope tracer techniques. These rates show that cyanobacteria use reduced nitrogen forms and, in many cases, avoid the chemically oxidized forms (e.g. Glibert et al. 2004).

3. Direct growth studies. These studies based on growth measurements in the laboratory demonstrate that growth rates of *Microcystis* can be significantly higher on urea than on nitrate (e.g., Berman and Chava 1999). Meyer et al. (2009) state: "Compared to NO_3- and N_2 (via fixation) as N sources, NH_4+ produces the highest growth and primary production rates for *Microcystis aeruginosa* and other cyanobacteria (*Aphanizomenom flos-aquae* and *Anabaena flos-aquae*) in laboratory studies (Ward and Wetzel 1980)".

In the 1990s it was recognized that diatoms may have a nutritional requirement for, and under some circumstances even a preference for, nitrate (e.g., Lomas and Glibert 1999a, b). Moreover, diatoms show no evidence of nitrate uptake saturation under very high nitrate conditions, in contrast to the generally accepted saturating uptake kinetic relationships that are used to describe the relationship between nutrients and uptake rate. Thus, cyanobacteria grow particularly well on ammonium while their competitors, such as diatoms, do not.

Moreover, retrospective analysis of the data in the Delta system further demonstrates that at very high ammonium concentrations (i.e., > 200 ug L^{-1}), phytoplankton functional groups such as flagellates, cryptophytes and diatoms are outcompeted by cyanobacteria (Glibert unpub. data). Thus, even though *Microcystsis* may have a broad capability for using different forms of nitrogen to support their physiological demands for nitrogen, they have a greater capacity to take up and metabolize reduced forms of nitrogen compared to other functional groups and may have higher growth rates under reduced nitrogen compared to nitrate and thus may outcompete other phytoplankton groups at very high ammonium levels. Lehman (2010) concedes: "Recent increases in ammonium concentration in the western delta may give a competitive advantage to *Microcystis* which rapidly assimilates ammonium over nitrate."

Further evidence that the form of nutrients matters comes from studies by Dugdale et al. (2007). In grow out experiments and time series plots in Central, San Pablo and Suisun Bays, they show that "bloom levels of chlorophyll are evident only when NO_3 uptake occurs and that NO_3 uptake only takes place at lower ambient NH_4 concentrations". They conclude that ammonium concentrations greater than 4 umol L^{-1} inhibits nitrate uptake by diatoms and thus bloom formation. Lomas and Glibert (1999a) describe the threshold for inhibition of nitrate uptake at approximately 1 umol L^{-1}. As discussed previously, this level of ammonium is almost always exceeded in the Delta.

There is also some evidence that the increase in aerial coverage by the invasive aquatic plants *Egeria densa* and *Eichhornia crassipes* may also be attributed to the ratio of nutrient inputs to the system. Feijoo et al. (2002) experimentally found that *E. densa* absorbed more nitrogen from water when it was present in the form of ammonium than when it was as nitrate. Reddy and Tucker (1983) measured growth and nutrient uptake rates in microcosm experiments with *E. crassipes* and found highest productivity when nitrate and ammonium were added in equal amounts.

Based on these physiological studies and a retrospective analysis of phytoplankton species composition during different nutrient regimes in the Delta system, it is clear that nitrogen and phosphorus inputs are likely more important to algal species composition than flow.

As numerous studies have demonstrated, agricultural and municipal runoff and municipal effluents discharged into the Sacramento-San Joaquin Rivers and Delta are often toxic to aquatic organisms. Each year approximately 20 to 42 million pounds of pesticides are applied in the Sacramento and San Joaquin River watersheds, respectively, which does not even account for the significant urban usage for landscaping, home gardens, and pest management (USFWS 2008, p. 5).

Pesticides are applied throughout the year, with heavy use occurring in the wet winter months. However, the higher seasonal winter outflow does not necessarily eliminate toxicity from these pesticides as they enter the Delta waterways. Orlando et al. (2004) state:

> …previous studies have shown that the first significant rainfall (greater than 12.7 mm/day or 0.5 in/day) and subsequent runoff following the winter application of dormant-spray pesticides is accompanied by a rise in the detected concentrations of these same pesticides in downstream surface waters (Kuivila and Foe, 1995; Kratzer, 1997; Dubrovsky, and others, 1998). Studies have also shown these pulses of multiple pesticides to be acutely toxic to the aquatic invertebrate *Ceriodaphnia dubia* (Foe and Conner 1991; Kuivila and Foe, 1995).

The USFWS also recognized the negative impact of high flow and pesticides: "[p]esticide detections in streams and other waterways are generally highest following pulse inputs from high flows after rain events, and frequently exceed California Fish and Game's water quality criteria to protect aquatic life [citations omitted] (USFWS 2008, p. 5). When toxic concentrations spike after high flow events, there is no single pesticide that dominates the system; rather, a complex mix of chemical compounds are washed into the Delta (USFWS 2008, p.5).

Toxic concentrations of pesticides have been identified in surface waters in and around the Delta on many occasions. For example, "[i]n the 1980s, rice pesticides caused fish kills in the Sacramento River (due to molinate), taste problems in drinking water (due to thiobencarb), and toxicity to invertebrates in the Colusa Basin Drain and the Sacramento River (due to carbofuran, methyl parathion, and malathion)." (Kuivila and Hladik 2008.) In 1993, toxicity caused by chlorpyrifos was identified at Paradise Cut and in 1994 toxicity resulting from chlorpyrifos and malathion was identified at French Camp Slough (Kuivila and Hladik 2008).

While the use of the organophosphates diazinon and chlorpyrifos has been reduced in agriculture and eliminated from urban use, pyrethroid pesticides have largely taken their place (Weston et al. 2010; Amweg et al. 2006). In addition, there has been a significant shift to more toxic pyrethroid pesticides in the last decade (Figure 12). In 2008 and 2009, pyrethroids were found in all but one of the thirty-three urban runoff samples collected from locations serving Sacramento, Stockton and Vacaville (Weston et al. 2010). The testing determined that 88% of these samples were toxic, causing death or inability to swim in the aquatic test species *Hyalella azteca*. The study concluded that this toxicity was likely caused by the pyrethroid concentrations in the water.
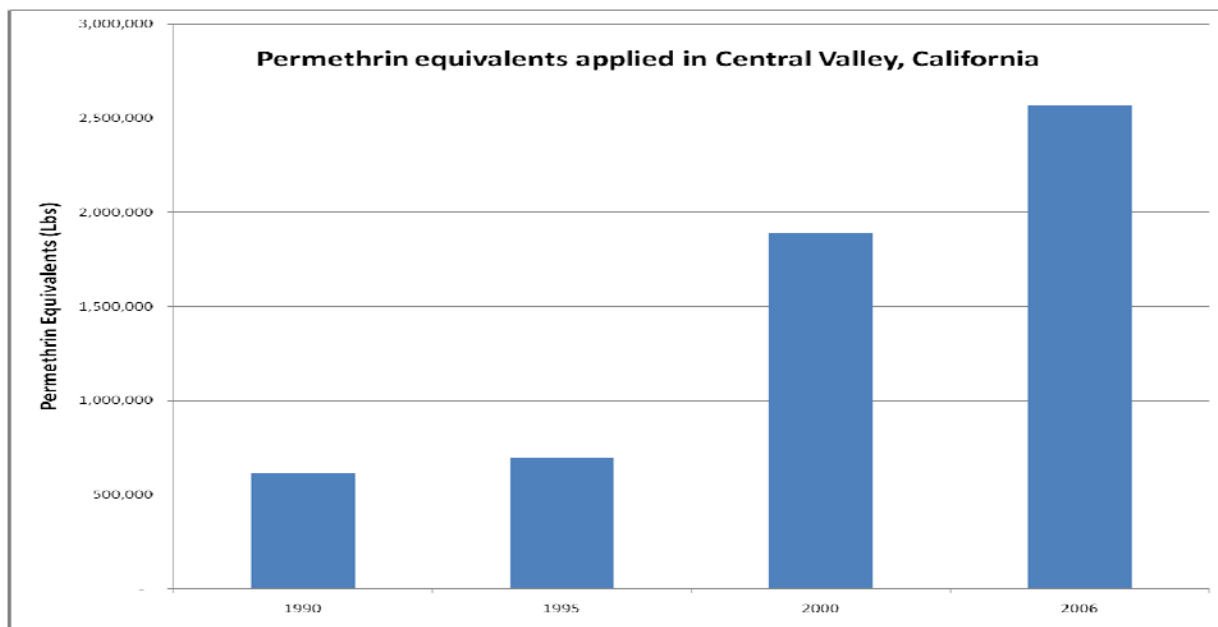

FIGURE 12. Permethrin equivalents applied in Central Valley, California. Pounds of pyrethroid applied were obtained from the Department of Pesticide Regulation DPUR database and converted to permethrin equivalents using the methods described in Amweg et al 2006.

Urban wastewater dischargers are also a major conduit for pyrethroids entering the Delta. (Weston et al. 2010) collected water samples from wastewater treatment plants in Sacramento, Stockton and Vacaville in 2008 and 2009, and identified significant toxicity:

> Mortality was observed in 22% of POTW [publicly owned treatment works] final effluent samples, and mortality or inability to swim was seen in 44% of samples. In every sample of Sacramento POTW effluent, at least 70% of organisms were dead or unable to swim. Similar conditions were observed occasionally at Vacaville (33% of samples), though

never at Stockton. When proportions of dead or non swimming individuals are compared with pyrethroid toxicity units across all plants, there is a significant correlation ($r=0.48$, $p<0.05$), driven by the fact that Sacramento usually had relatively high levels of toxicity and pyrethroids.

And:

> Given the high effluent volume discharged from some POTWs, and the fact that discharge occurs even in dry weather, POTWs can be a significant source of pyrethroids. The Sacramento facility, for example, has an average dry weather flow of 480 million L/d, and a peak wet weather flow of 902 million L/d. A rough approximation of its loading based on the median total pyrethroid concentration in the three dry weather and three wet weather sampling events (18.2 and 14.2 ng/L, respectively), would be 9 g/d in the dry season and 13 g/d in the wet season. While further study is necessary to refine these estimates, they do indicate large POTWs can be significant pyrethroid sources on a mass basis. The Stockton and Vacaville facilities, with substantially lower flow rates, produce loadings an order of magnitude smaller.

The toxic conditions in the Delta are not limited to the water column. Pyrethroids and other pesticides that have been, and are being, discharged into the Delta have accumulated in sediments. Higher flows will not necessarily provide relief from these toxic conditions, as high flow events disperse the contaminated soil throughout the Delta and/or churn up the soil and re-suspend the contaminated particles, thereby heightening the exposure of aquatic species to these pesticides.

Toxic concentrations of pesticides have been identified in the sediments of waterways throughout the Delta. Kuivila and Hladik (2008) report: "In a study of the San Joaquin River and its tributaries (Pereira and others 1996), chlorpyrifos, DCPA, and dicofol were detected. More pesticides were detected in a study of bed sediments at six input sites to Yolo Bypass (Smalling et al. 2005, 2007), including carbaryl, chlorpyrifos, DCPA, metolachlor, molinate, napropamide, oxyfluorfen, thiobencarb, and trifluralin."

The concentrations of pesticides found in the sediment are high enough to be toxic to aquatic species. Pyrethroid residues have been found in the sediment of creeks that drain the City of Sacramento and Curry Creek, which is in a residential suburb of the City of Roseville (Amweg et al. 2006). The results showed that "…12 of the 15 creeks tested were toxic on at least one sampling occasion, and sediment pyrethroid concentrations were sufficient to explain the observed toxicity in most cases. The pyrethroid bifenthrin, due to its high concentrations and relative toxicity as compared to other pyrethroids, was likely responsible for the majority of the toxicity at most sites. Cypermethrin, cyfluthrin, deltamethrin and λ-cyhalothrin also contributed to toxicity at some locations." (Amweg *et al.* 2006; *see also*, Weston *et al.* 2005)

Sediment toxicity has also been identified in agricultural creeks throughout the Delta watershed, covering a 10 county area. Weston et al. (2004) analyzed creek sediments for the occurrence of 26 pesticides, including 5 pyrethroids, 20 organochlorides, and 1 organophosphate. Toxicity tests were completed using the amphipod *H. azteca* and for some samples *Chironomus tentans.* "Forty-two percent of the locations sampled caused significant mortality to one test species on at

least one occasion. Fourteen percent of the sites (two creeks and four irrigation canals) showed extreme toxicity (>80% mortality) on at least one occasion. Pyrethroid pesticides were detected in 75% of the sediment samples...." (Weston *et al.* 2004). The primary source of the toxicity was determined to be pyrethroids and, to a lesser extent, organochlorines (endrin and endosulfan).

Species of concern in the Delta are coming into contact with these pesticides (see e.g.,Thompson et. al. 2007). It is also evident that the mix of pesticides in the Delta are in concentrations that are likely to cause adverse effects to these species, either through direct toxicity or by indirect toxic effects that may change the prey or competitors of an organism, affecting food supply and habitat availability (Thompson et al. 2007). Pesticide toxicity can affect aquatic species in numerous ways, including interruption, blocking, or interference with specific cellular functions, such as the increased production of highly reactive molecules, macrophage disruption, enzyme induction, interference with nerve synapses, hormone receptors, or immunoreceptors (Thompson *et. al.* 2007; Clifford et al. 2005; Whitehead et al. 2004).

The impacts of exposure may also be transferred from one generation to the next. In a recent study of striped bass, Ostrach et al. (2008) determined there is:

> ...clear evidence of maternal transfer of xenobiotics and their adverse effects on larval striped bass in the San Francisco Estuary. Chemical analysis of unfertilized eggs from Sacramento River-collected striped bass indicated that maternal transfer of biologically significant lipophilic compounds occurred in all 21 females in this study. Contaminants found in these eggs include PCBs, PBDEs, current-use pesticides, legacy pesticides, and their degradation products. Our results indicate that pesticides not in use for decades, such as DDT and its degradation products are still persistent in the estuary and are being made bioavailable by recycling through the food chain to apex predators. Furthermore, our results show that these contaminants are being transferred to their progeny in biologically relevant levels.

Cullon et al. (2008) also describe transfer of PCBs to apex predators.

As the USFWS has recognized: "[p]esticides are of particular concern to delta smelt because their spawning season (February-June) corresponds with the rainy season in the Central Valley, and with peak application to orchards, alfalfa, and rice (USFWS 2008, p.6). Kuivila and Moon (2004) confirmed in a multiple year study from1998 to 2000 that delta smelt may experience prolonged exposure to pesticides and may be experiencing some of the effects of toxicity. Specifically, Kuivila and Moon (2004) analyzed 202 water samples from delta smelt spawning and nursery habitat for 28 pesticides during April-June of 1998-2000. They detected 23 pesticides, with metolachlor detected in 95% of samples, molinate in 74%, and thiobencarb in 61%. All samples had detectable concentrations of at least two pesticides and up to 14 different pesticides. In 1999 and 2000, the highest densities of delta smelt co-occurred with the highest total concentrations of pesticides. Kuivila and Moon estimate that delta smelt were exposed to multiple pesticides for a minimum of 2-3 weeks, and exposure occurred during the larval and juvenile life stages which are particularly sensitive. They conclude: "[a]lthough the measured concentrations were well below short-term (96-h) LC50 values for individual pesticides, the combination of multiple pesticides and lengthy exposure duration could potentially have lethal or

sublethal effects on delta smelt, especially during early larval development." (Kuivila and Moon 2004)

Based on how pervasive pesticides are throughout the Delta, Chinook salmon, steelhead and green sturgeon are similarly exposed and are likely being affected. This magnitude of exposure to pesticides in the Delta, even if short in duration, may be enough to cause chronic or sublethal effects in these species. A recent study evaluated the effect of short-term exposures of pesticides on Chinook salmon. Baldwin et al. (2009) determined that pesticides affect physiology and behavior, thereby reducing the somatic growth of juvenile Chinook salmon, and by extension, subsequent size dependent survival when animals migrate to the ocean and overwinter their first year. The results:

> …indicate that short-term (i.e., four-day) exposures that are representative of seasonal pesticide use may be sufficient to reduce the growth and size at ocean entry of juvenile Chinook. The consequent reduction in individual survival over successive years reduces the intrinsic productivity (lambda) of a modeled ocean-type Chinook population.

Baldwin et al. (2009) concluded: "…exposures of common pesticides may place important constraints on the recovery of ESA-listed salmon species…" This is consistent with the NMFS biological opinions, which have determined that a whole range of pesticides commonly used in the Delta and its watershed are likely to cause jeopardy and adverse modification of the critical habitat for Chinook salmon and steelhead species in California and other western states (NMFS 2008; NMFS 2009). The potential for the mixtures of pesticides in the Delta to cause direct and/or indirect effects is therefore well established, and may be in fact causing jeopardy to multiple species; however, the toxicity that is evident in the Delta cannot be minimized by simply increasing flow. The SWRCB should address the actual problem – the complex mix of pesticides that continue to be released into the Delta – rather than simply masking the problem by directing the water projects to increase Delta outflow.

There is a diverse array of toxic metals that are being discharged into the Delta each year. One of the more pervasive metals, which is likely having a profound impact on aquatic species throughout the food web, is copper. The use of copper in the Delta watershed is extensive, originating from fertilizers, aquatic weed control agents, industrial point and nonpoint discharges, acid mine drainage, wastewater treatment plant effluent, urban runoff (motor vehicles, residential use), and marinas (USFWS 2008, p.3). The relationship between copper toxicity in the Delta and flow is the same as described for pesticides. High flow events are linked to high discharges of copper out of the upper tributaries and smaller sloughs into the Delta. The highest concentrations of copper in the Delta generally occur during high flow events, indicating that additional increases in flow would not be an effective response to the existing widespread copper contamination problem in the Delta.

Copper is highly toxic to many aquatic species throughout the food web, including microbes, algae, invertebrates, and many fish species, especially in early life stages. USFWS (2008) states: "[e]xposure of metals, even at low concentrations often measured in the environment, can exert toxic effects, such as changes in feeding, growth, and swimming behavior, on aquatic organisms, especially on sensitive early life stages." Copper also affects the olfactory mechanism of many fish species (Tierney *et al.* 2009; Raloff 2007; Sandahl et al 2007). The olfactory system

conveys critical information to fishes, enabling activities such as mating, locating food, discriminating kin, avoiding predators and homing. In a review of studies on contaminant effects to fish olfactory systems, Raloff (2007) cited one researcher that noted, "pesticides and copper at concentrations similar to those in the environment knock out olfactory communication in every species tested to date." In another study, Coho salmon olfactory neuron activity was reduced after 30-minutes exposure to 1 μg^{-L} atrazine (Raloff 2007).

The effects of copper are seen at concentrations that exist in the Delta. Sandahl et al. (2007) observed a 40% reduction in olfactory response in juvenile Coho salmon exposed to 2 μg^{-L} dissolved copper for only 3-hours. This loss in olfactory sensitivity led to a failure to initiate predatory avoidance behaviors in response to chemical alarm cues. In laboratory studies with 3-month old delta smelt, Werner (2008) calculated the 7-day lethal LC50 concentration at 24.7 μg^{-L} copper. Teh (2009) calculated the 96-hour LC10 and LC50 for *Eurytemora affinis* at 1.42 μg_{-L} and 3.48 μg^{-L} copper, respectively.

The copper concentrations in the Delta frequently exceed these levels.

> The Sacramento River Watershed Program has detected copper as high as 21.5 μg^{-L} in the Colusa Basin Drain, and 18.9 μg^{-L} in the Sacramento River near Hamilton City [citation omitted]. The Department of Water Resources' Environmental Monitoring Program (EMP) detected up to 478 μg^{-L} total copper and 149 μg^{-L} dissolved copper, average 27 μg^{-L} and 16 μg^{-L}, respectively (n=42 and 25) in Suisun Bay between 1975 and 1993 [citation omitted]. Between 1975 and 2002, total copper concentrations averaged 13 μg^{-L} in the San Joaquin river and 10 μg^{-L} in the Sacramento River (n=114 and 202, respectively) [citations omitted]. Concentrations in Mosher Slough and Duck Creek have been reported as high as 500 μg^{-L} and 670 μg^{-L}, respectively [citations omitted]. (USFWS 2008, p.3)

There is evidence that protected species, like the delta smelt, are coming into contact with these elevated concentrations of copper. A recent study measured copper levels in delta smelt and determined that: "[c]oncentrations of copper in delta smelt in the Sacramento River have been measured at 6.5 mg^{-KG} (wet weight), which is over 32 times higher than normal background concentrations (Bennett et al. 2005)." (USFWS 2008, p.3.) It appears that delta smelt are accumulating copper in their tissues, suggesting repeated exposure and possible chronic effects.

A class of emerging contaminants the SWRCB should consider in its proceedings are endocrine disrupting compounds (EDCs), which have the potential to disrupt reproductive endocrine system function in aquatic organisms in the Delta. There has been increased interest in EDCs in recent years and many studies have documented the occurrence and effects of EDCs in surface water, including in the Delta.

Municipal wastewater treatment plant effluents can be significant sources of EDCs (Kidd et al. 2007; Huang and Sedlak 2001). EDCs present in treated wastewater effluent can interfere with fish maturation and reproduction (Jobling et al. 1998). Exposure of fish populations to low concentrations of such compounds, similar to those levels found downstream of wastewater treatment plants, can have significant effects. One of the more potent synthetic estrogens found in surface waters is 17 alpha-ethinyl estradiol (EE2), a biologically persistent analogue of

estradiol that is widely used in oral contraceptives. In a multi-year field study, Kidd et al. (2007) showed that chronic exposure of fathead minnows to 5-6 ng^{-L} of 17 alpha-ethinyl estradiol (EE2) led to rapid population failure of this species from the experimental lake.

Other sources of EDCs include pesticides. Studies by Moore and Waring (2001) demonstrated that the pyrethroid cypermethrin reduced the fertilization success in Atlantic salmon after a 5-day exposure to 0.1 μg^{-L}. In a study on bluegill sunfish, Tanner and Knuth (1996) found delayed spawning and reduced larval survival after two applications of 1 μg^{-L} esfenvalerate. Results of a study performed by Werner et al (2002) suggest that dietary uptake of esfenvalerate (21 mg^{-kL}) may lead to a decrease in fecundity in adult medaka (*Oryzias latipes*) and a decrease in the percentage of viable larvae. Studies have shown that pyrethroid pesticides may also cause endocrine disruption in aquatic invertebrates, which are an important component of the food web.

Several recent studies have documented endocrine disruption in Bay-Delta fish. One of the biomarkers of EDCs is intersex fish, fish with both male and female reproductive organs. A recent histopathological evaluation of delta smelt for the POD found 9 of 144 maturing delta smelt (6%) collected in the fall were intersex males (Bennett et al. 2008). One of the biomarkers of EDCs is intersex fish, fish with both male and female reproductive organs. This study provides evidence that delta smelt are being exposed to EDCs. Brander et al. (2008) observed choriogenin induction in male silversides from Suisun Marsh. Riordan (2008) reported endocrine disruption in male fathead minnows following in-situ exposures below the Sacramento Regional Wastewater Treatment Plant. Lavado et al. (in press) conducted studies in 2006 and 2007 to evaluate the occurrence and potential sources of endocrine disrupting compounds in Central Valley waterways. In their study, estrogenic activity was repeatedly observed at 6 of 16 locations in the Bay-Delta watershed, including in water from the Lower Napa River and Lower Sacramento River in the Delta. Further studies are needed to identify the compounds responsible for the observed estrogenic activity and their sources.

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F.   Prey/Prey Density

Abstract

This section identifies important prey for pelagic fish, especially delta and longfin smelt, presents data on trends in prey density, discusses different ways to measure prey density, relates prey density to abundance of delta and longfin smelt, analyzes the relationship between prey density and river flow, and presents data on the effects of turbidity on larval feeding success for delta smelt and on distribution of adult delta smelt. Major conclusions drawn from this section are that significant declines in density of desirable prey for pelagic fish have occurred, that these declines are especially pronounced in the western part of the estuary, generally at and west of the confluence of the two rivers, and that declines in prey density, especially in spring, are strongly associated with declines in abundance of delta and longfin smelt to record low levels. Influences of flow on prey density are evident in western sub-regions, probably due to dilution of phytoplankton-inhibiting ammonium by river flow. Significant decreases in turbidity (increases in Secchi depth) have occurred in the San Joaquin River part of the estuary. These increases suggest that adult delta smelt are less likely to move into that part of the estuary than in years past and if they do move into that part of the estuary and spawn, their larvae are less likely to survive because of impairment of feeding success due to less turbid waters.

1.   Introduction

Food availability has been identified as an important factor affecting recent declines in abundance of pelagic fish (Bennett 2005, Baxter 2008, Kimmerer 2008). This section examines trends in prey density and how those trends relate to abundance of pelagic fish and to river flow. Particular attention is directed at delta smelt, the most important pelagic fish because of its status as a threatened species, its recent record low abundance, and its effect on operation of the SWP and CVP.

2.   Important Prey For Pelagic Fish

Declines in abundance have occurred for several pelagic fish, delta smelt (*Hypomesus transpacificus*), longfin smelt (*Spirinchus thaleichthys*), threadfin shad (*Dorosoma petenense*), and age-0 striped bass (*Morone saxatilis*). (Baxter 2007) The following zooplankton have been identified as important prey species for these pelagic fish (Slater 2009; Slater pers. comm.):

- *Eurytemora affinis*
- *Pseudodiaptomus forbesi*
- *Mysids*
- *Amphipods*
- *Limnoithona tetraspina*
- *Other cyclopoids*
- *Sinocalanus doerrii*
- *Acartiella sinensis*
- *Tortanus species*

- *Harpacticoid copepods*
- *Rotifers*
- *Cladocerans*

Eurytemora and *Pseudodiaptomus* are particularly important to delta and longfin smelt. Lott (1998) found that delta smelt strongly select for *Eurytemora*, *Pseudodiaptomus*, and *Limnoithona*, although results for *Limnoithona* are suspect because the 20 mm survey zooplankton gear is not efficient for the small *Limnoithona*, so selectivity for *Limnoithona* was probably overestimated. Nobriga (2002) concluded from diet studies that use of *Eurytemora* and *Pseudodiaptomus* by delta smelt was related to densities of those zooplankton in surrounding waters, whereas use of other zooplankton was not related to densities in surrounding waters. Sullivan (2009) suggested that although larval fish consume *Limnoithona*, high densities of *Limnoithona* later in the year could be contributing to abundance declines. Slater reported that longfin smelt feed heavily on *Eurytemora* in spring (Slater 2008).

> *3.   Zooplankton Data Sources*

Data used in this analysis are derived from the Interagency Ecological Program Monthly Zooplankton Survey and the 20 mm Survey. The Monthly Zooplankton Survey has sampled at stations shown in Figure 13 since 1972. This survey samples for meso-zooplankton with a Clarke-Bumpus net and for micro-zooplankton, such as Limnoithona, with a siphon pump. The 20 mm survey has sampled since 1995 at stations shown in Figure 14, but only with a Clarke-Bumpus net, so this survey is not efficient at capturing micro-zooplankton. Even though both surveys sample with a Clarke-Bumpus net, densities of zooplankton, such as *Eurytemora* and *Pseudodiaptomus*, are not the same and one must be adjusted to be comparable with the other. Because the Monthly Zooplankton survey samples for micro-zooplankton, data from that survey will be used in this paper unless otherwise stated.
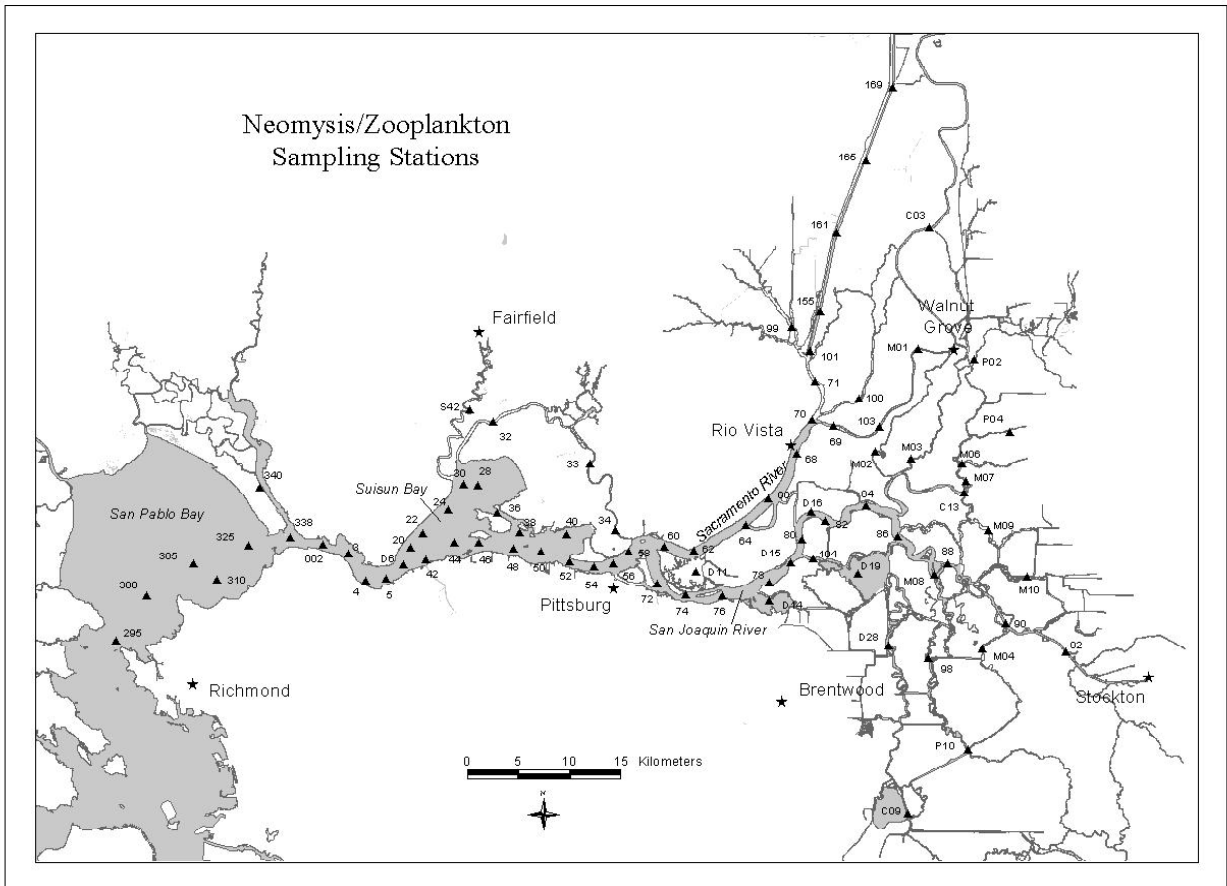
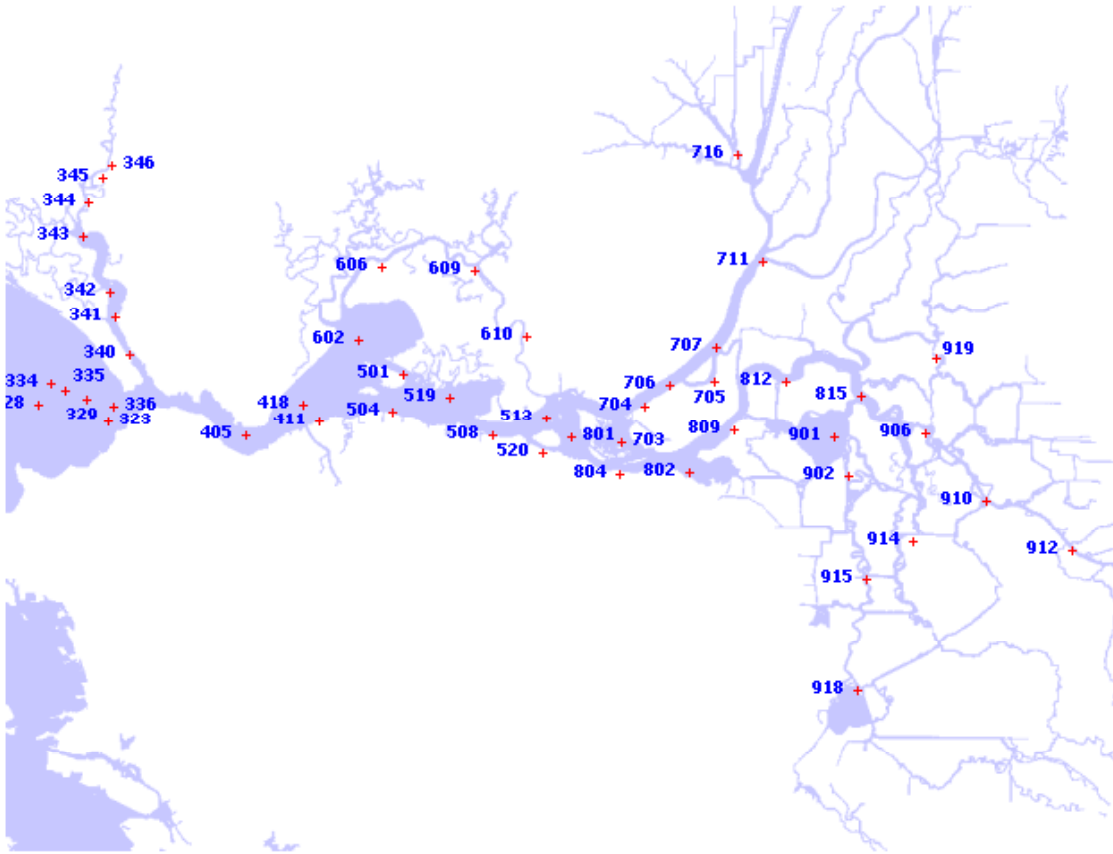FIGURE 13. Monthly zooplankton survey stations.

FIGURE 14. 20-mm survey stations.

4. *Trends in prey density*

Introduction. This section describes changes in densities of important prey species. There are a number of ways that prey densities can be measured, from estuary-wide averages at one extreme to densities weighted by the relative abundance of fish at the other. This section describes trends in prey density first in terms of estuary-wide averages, then regional averages, then weighted by the relative abundance of fish. Seasonal patterns are presented. Examples of correlations between prey density and abundance of delta and longfin smelt are presented. Relationships between prey density and flow are also presented.

Estuary-wide average prey density. Monthly zooplankton stations were grouped into sub-regions shown in Figure 15 and average density was estimated for each month for each sub-region. Estuary-wide average density was estimated for each month as the water-volume-weighted averaged over all sub-regions. Data was available for sub-regions from Suisun Marsh and Bay to the west to the lower Sacramento River and east-southeast Delta to the east. Figure 22 shows estuary-wide average densities for the most important prey species for pelagic fish, with the exception of amphipods, for which data from the surveys are available but not yet processed for trend analysis.
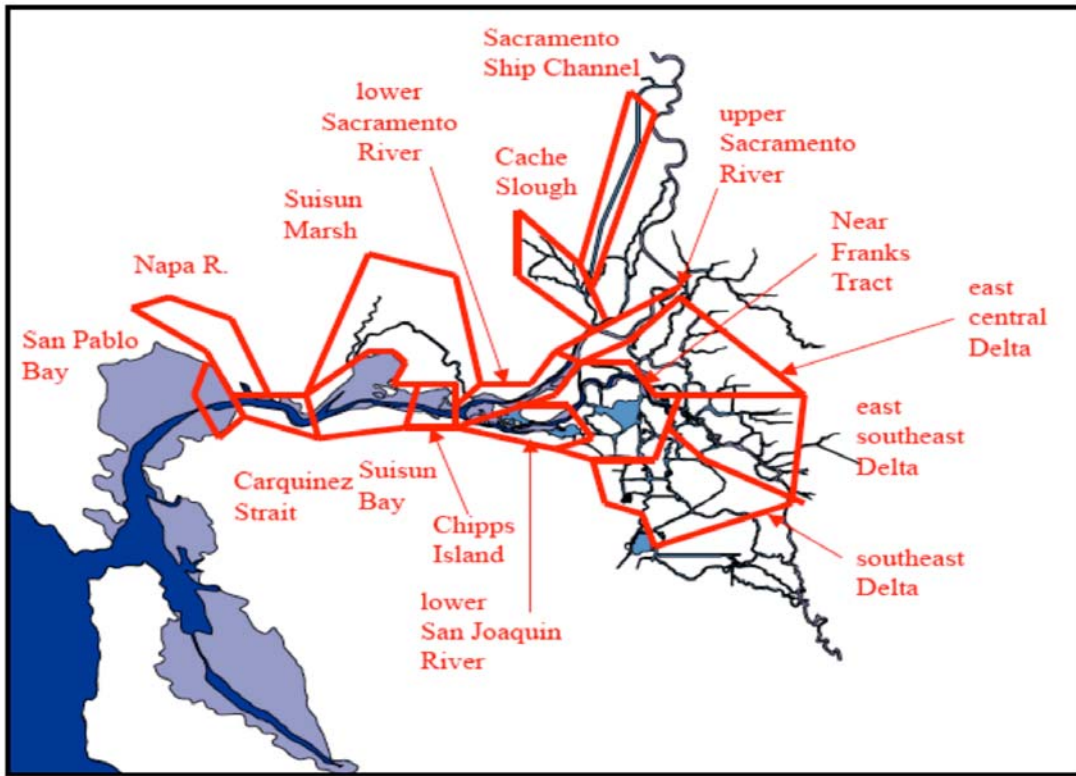
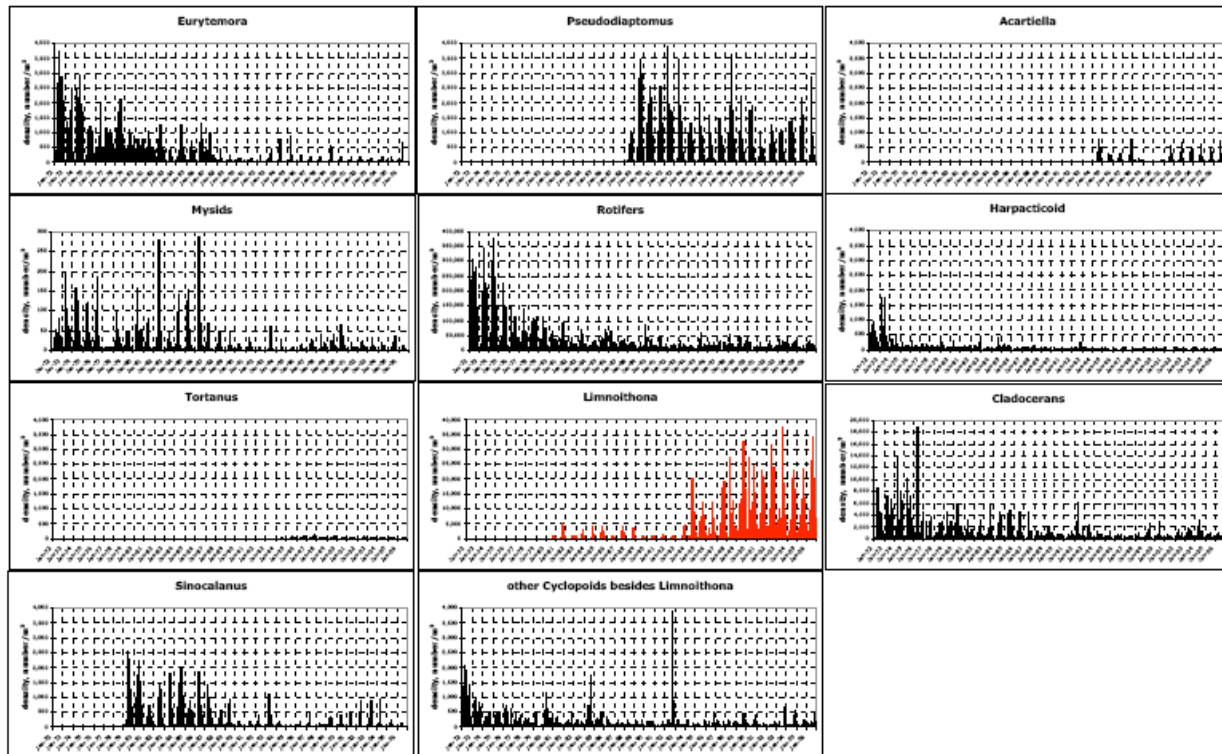FIGURE 15. Sub-regions of Bay-Delta estuary.

FIGURE 16. Estuary-wide (Suisun Marsh to southeast Delta) density of important prey species of zooplankton. Red identifies Limnoithona, suspected of impairing feeding success. Note y-axis scales for Limnoithona, rotifers, mysids, and Caldocerans.

Figure 17 shows marked declines or consistently low densities for all important, desirable prey species except *Pseudodiaptomus*. The density of *Limnoithona*, which is thought to impair feeding success, has increased greatly. Successive introductions of species, which appear as sharp rises in density from zero, are also shown for *Pseudodiaptomus*, *Acartiella*, *Tortanus*, *Limnoithona*, and *Sinocalanus*. All dominant zooplankton are aliens, including Eurytemora which was introduced with striped bass (Orsi 2001).

5. *Regional and seasonal trends in prey density*

There have also been important changes in prey density within areas of the estuary, as opposed to estuary-wide. Furthermore, different prey species are important for different life stages and, therefore, at different times of the year. Bennett concluded that food limitation is important in summer (Bennett 2005), and Mongan and Miller have presented correlations between spring prey density and subsequent abundance (Miller and Mongan). Therefore, these two seasons appear to be most important with respect to problems with food availability.

Spring and summer prey density trends in different part of the estuary. Figure 18 shows trends in average prey density for April-June and July-August for sub-regions of the estuary for the most important prey species.
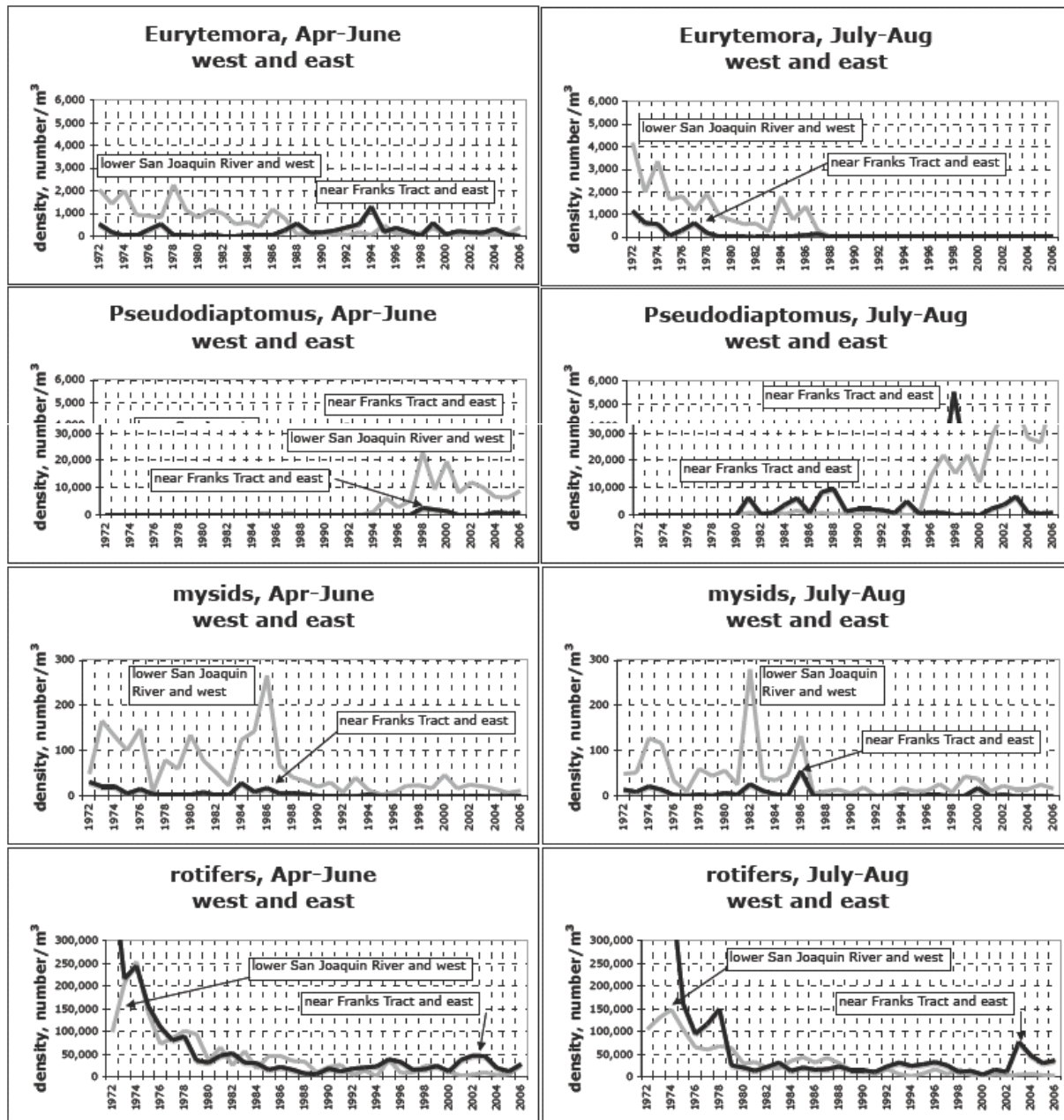
FIGURE 17. Spring and summer average density of selected prey species in the western part of the estuary (Suisun Marsh to the lower San Joaquin river) and eastern part (near Franks Tract to the east-southeast Delta).

Figure 19 shows that *Eurytemora*, a key prey species in spring, is now somewhat higher in the eastern part of the estuary than the western part, whereas prior to 1988 the opposite was the case. *Eurytemora* densities are now essentially zero in summer. *Pseudodiaptomus* is also higher in the eastern part than the western part of the estuary, especially in summer. *Limnoithona* occur at very high densities in spring and even higher in summer. *Limnoithona* is about 1/10 the size of *Eurytemora* and *Pseudodiaptomus* but occurs at densities more than an order of magnitude higher. Mysid shrimp density likewise dropped sharply in the western part of the estuary after the late 1990s, in both spring and summer, and is now essentially zero in the eastern part of the estuary. Rotifers show a sharp decline in both parts of the estuary beginning in the 1980s, although increases in density have occurred in the eastern part of the estuary in recent years.

Prey densities are now generally higher at or east of Franks Tract, albeit lower than in the past. *Pseudodiaptomus* is now a key prey species in spring and summer, replacing *Eurytemora* after the mid-1980s.

> 6.   *The spring food gap*

Eurytemora and *Pseudodiaptomus* are key prey species for delta and longfin smelt in spring. These two species now have a pronounced pattern of density increases and decreases each year as shown in Figure 19 for the lower Sacramento River sub-region, which typically has a high percentage of delta smelt in all seasons (for example, see http://www.dfg.ca.gov/delta/data/20mm/CPUE_map.asp?syear=2009 and http://www.dfg.ca.gov/delta/data/skt/DisplayMaps.asp).
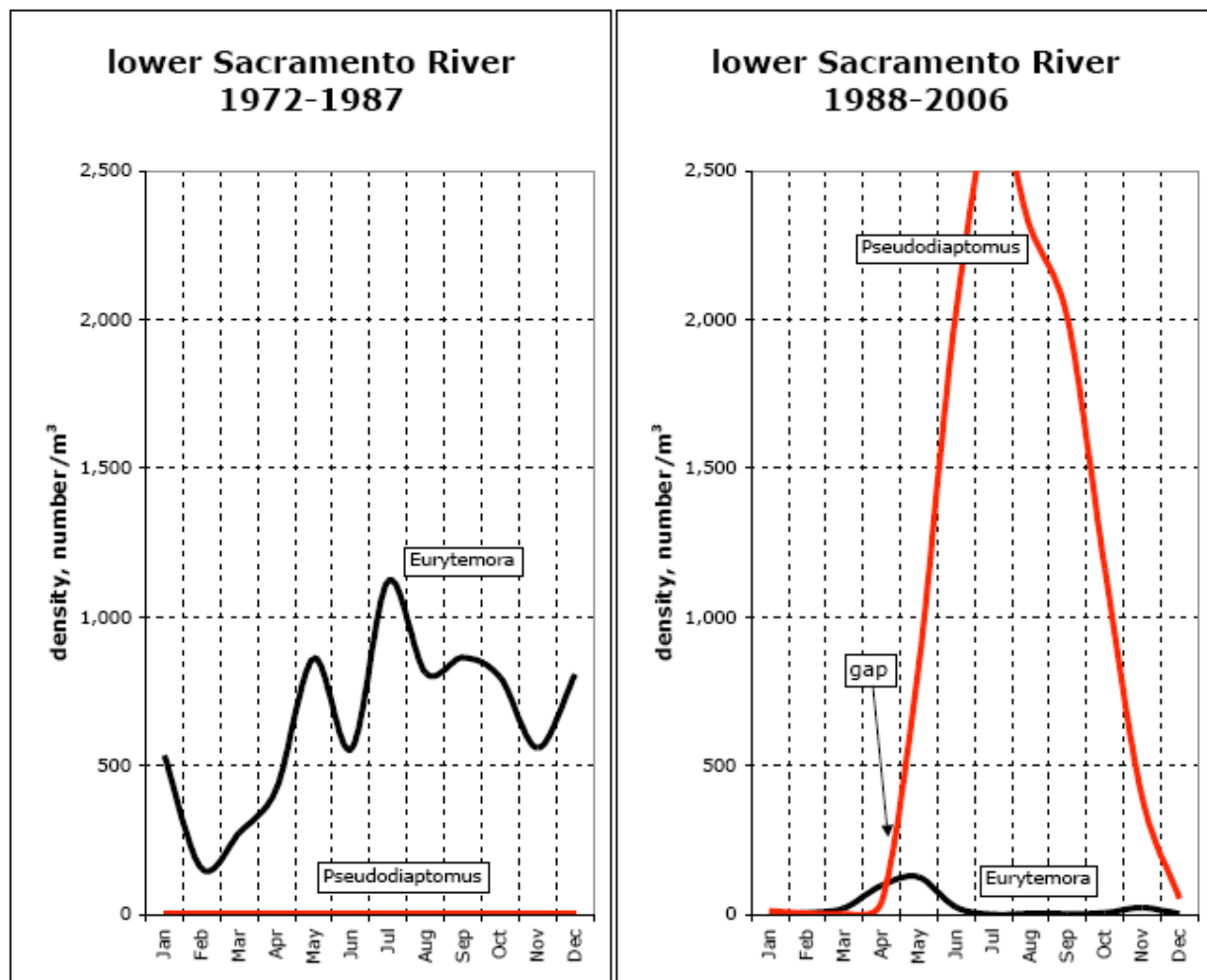
FIGURE 18. Annual patterns of density increases and decreases for *E. affinis* and *P. forbesi* in the lower Sacramento River sub-region.

The pattern for 1988-2006 is typical for other sub-regions as well. Each year, *Eurytemora* densities rise from approximately zero in early spring before falling to approximately zero in May or June. *Pseudiaptomus* densities rise from approximately zero later in spring and fall to zero late in the calendar year; therefore, each spring, there is a gap when the sum of *Eurytemora* and *Pseudodiaptomus* densities are at their minimums. If this gap is too low, survival of smelt larvae that hatch before this gap occurs will be low.

7. Co-occurrence of delta and longfin smelt and prey

Prey species are not relevant to fish if the fish and prey do not co-occur, both temporally and spatially. Therefore, a more refined measure of prey density can be developed by weighting prey density at each sampling station or in each sub-region by the proportion of smelt at each station or sub-region. One way to do this is to average prey density only over those stations or sub-regions at which delta smelt were caught in a particular survey. A better estimate can be made by weighting the prey density at each station or in each sub-region by the proportion of fish at the station or in the sub-region. Figure 19 shows time trends in *Eurytemora* and *Pseudodiaptomus* in spring and summer using different methods of accounting for co-occurrence with delta smelt. Note that the three measures of prey density in spring all show large declines in the recent years of low abundance of delta smelt.
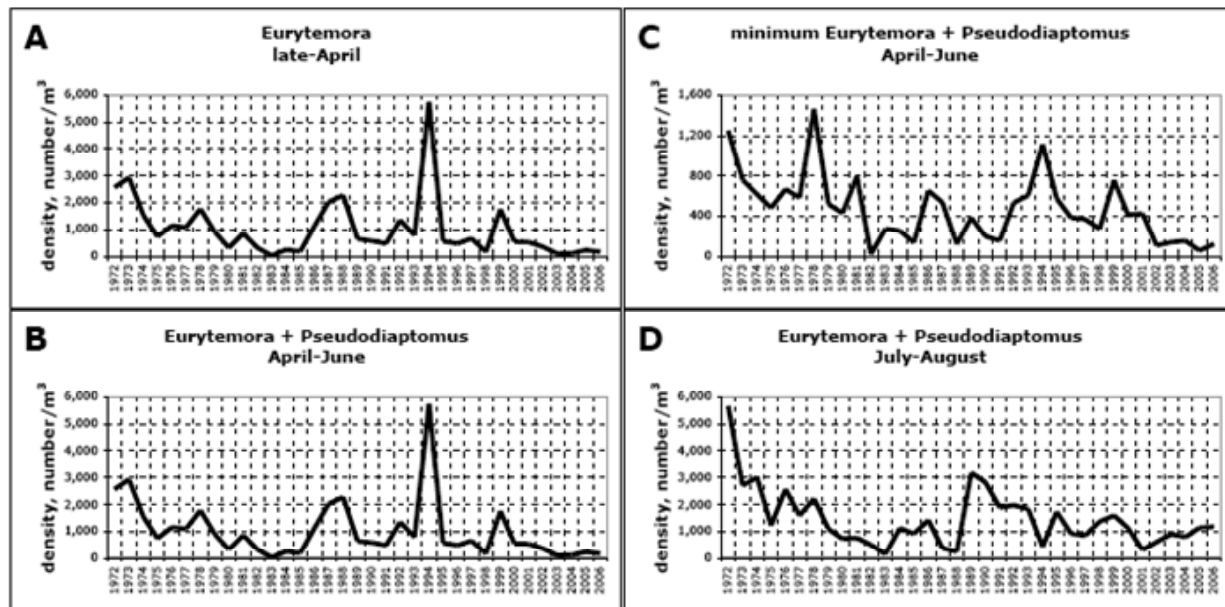

FIGURE 19. Densities of *Eurytemora* and *Pseudodiaptomus* weighted by occurrence of delta smelt. A: *Eurytemora* density in late April averaged over sub-regions where delta smelt are typically found in late April. B: *Eurytemora* plus *Pseudodiaptomus* densities averaged April-June over sub-regions where delta smelt are typically found in April-June. C: April-June minimum of sum of *Eurytemora* plus *Pseudodiaptomus* densities weighted by proportion of delta smelt at each station. D: *Eurytemora* plus *Pseudodiaptomus* densities averaged over July-August over sub-regions where delta smelt are typically found in July-August.

8.   *Abundance of delta and longfin smelt related to prey density*

Prey density directly affects abundance of fish in general and delta and longfin smelt in particular. That is, as described in the summary of the written testimony, prey density is one of the factors at the top of the effects hierarchy. Therefore, it is appropriate to test the relationship of abundance to prey density.

Figure 20 shows the relationship between the FMWT index of sub-adult delta smelt abundance and the previous July co-occurrence of delta smelt and the sum of *Eurytemora* and *Pseudodiaptomus* densities. In this case, the sum of *Eurytemora* and *Pseudodiaptomus* densities in each sub-region in July was weighted by the relative abundance of delta smelt each sub-region in July and compared to the subsequent FMWT index.   Note that, prior to 1989, *Pseudodiaptomus* densities were zero and after that year *Eurytemora* densities were zero.
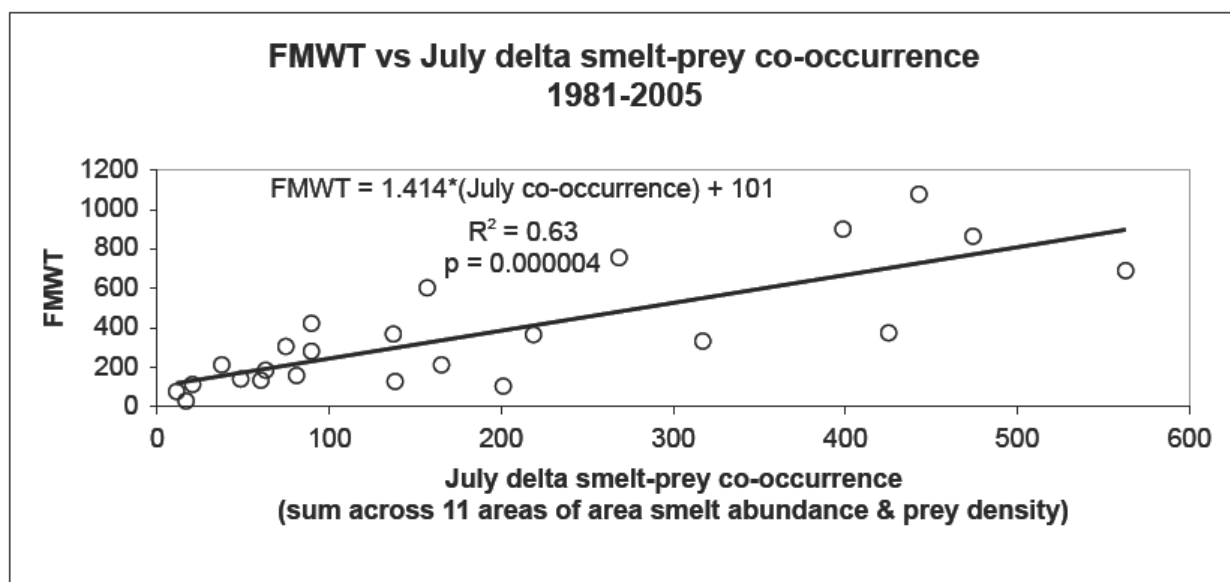

FIGURE 20. Relationship between the co-occurrence of delta smelt and prey (*Eurytemora* plus *Pseudodiaptomus*) in July and the subsequent FMWT index of sub-adult abundance.

Figure 20 indicates a strong relationship between summer prey density and subsequent fall abundance of delta smelt. Similar graphs result when other calanoid copepods are included along with *Eurytemora* and *Pseudodiaptomus*.

Figure 21 shows results of a multiple linear regression of the FMWT index against late-April *Eurytemora* densities, adjusted to account for the proportion of delta smelt at each sampling station, and the previous FMWT index as a measure of the number of larvae-juveniles present in late-April. Similar results are obtained for analyses in mid-April and mid-May. Data from the 20-mm survey were used. This figure indicates that spring densities of *Eurytemora* are strongly determinative of subsequent abundance since and before the recent sharp decline in abundance of delta smelt.

Figure 22 shows the same analysis for longfin smelt with the same conclusion, that spring densities of *Eurytemora* are strongly determinative of subsequent abundance since and before the recent sharp decline in abundance of longfin smelt. Data from the 20-mm survey were used.
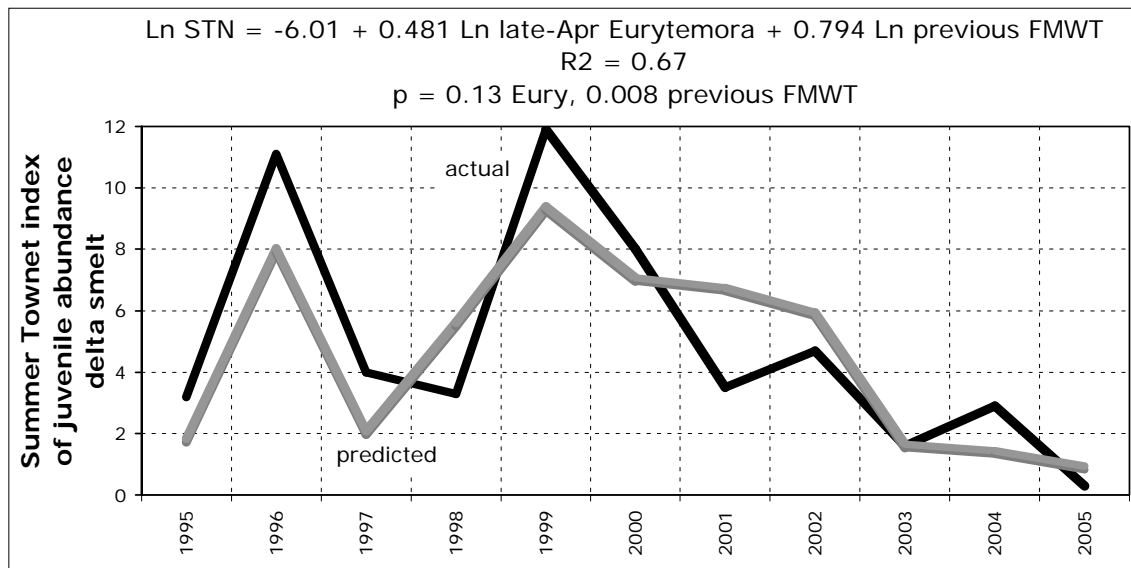

FIGURE 21. Actual Summer Townet index (STN) for delta smelt and predicted STN from multiple linear regression of STN vs. previous late-April *Eurytemora*, weighted by the proportion of delta smelt at each *Eurytemora* sampling station, and previous FMWT.
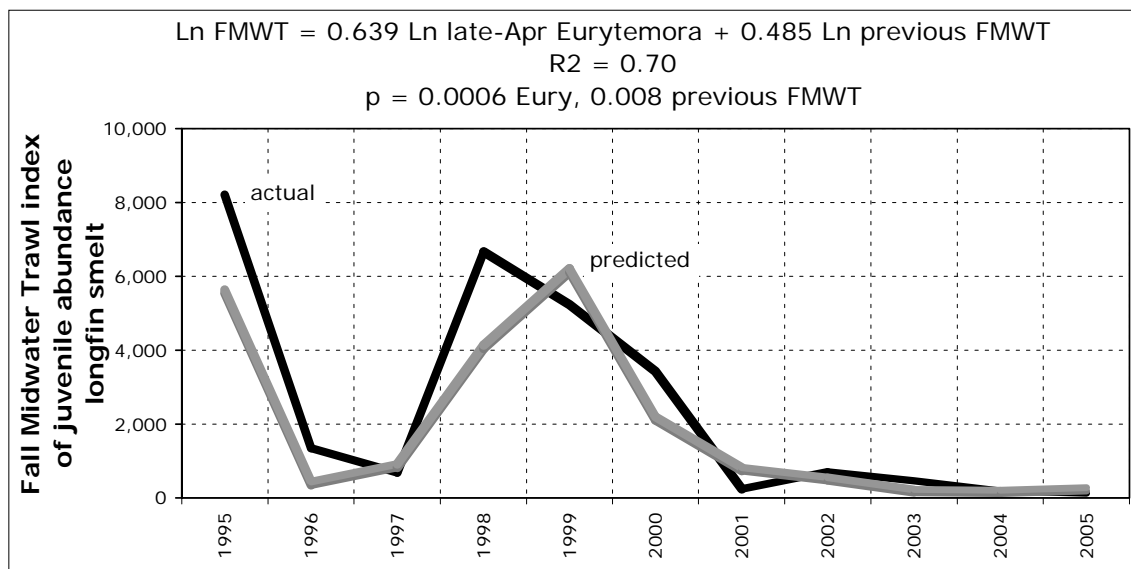

FIGURE 22. Actual FMWT index for longfin smelt and the FMWT predicted from the correlation equations resulting from multiple linear regression of FMWT vs. previous late-April *Eurytemora*, weighted by the proportion of longfin smelt at each *Eurytemora* sampling station, and previous FMWT

Figure 23 shows an even more striking relationship between the FMWT index of delta smelt and the previous April-June minimum of the sum of Eurytemora and Pseudodiaptomus densities for recent years. The years 1995-2005 are shown because for those years, station-by-station delta smelt and prey density data are available from the 20 mm Survey. These are the data from Figure 25C and measure the spring food gap. Note that this gap appears to be such a strong predictor of subsequent fall abundance that previous abundance need not be accounted for. In other words, this figure suggests that regardless of the previous fall abundance, the spring food gap largely determines subsequent abundance, at least in the last decade or so.
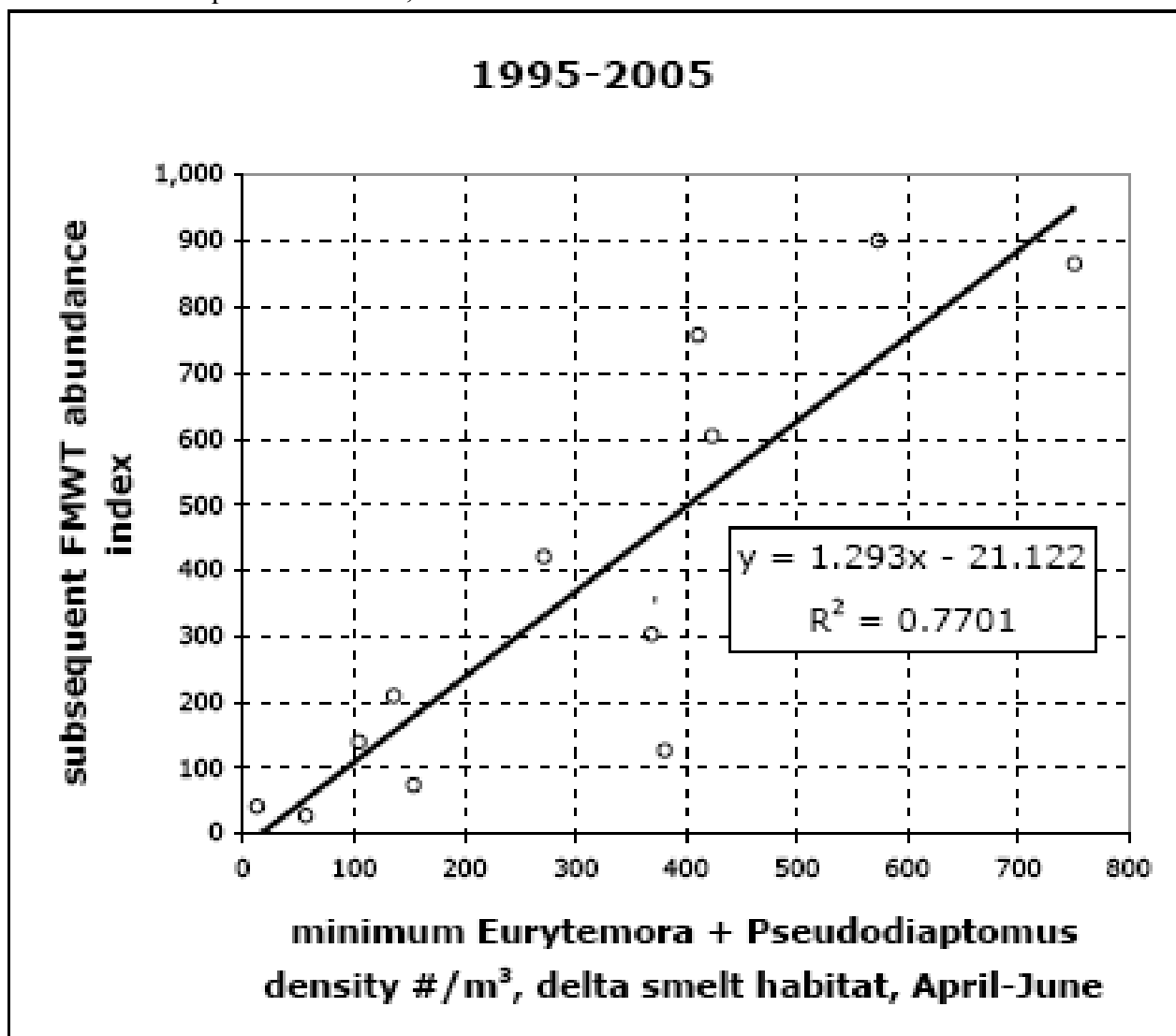

FIGURE 23. Relationship of the FMWT index of sub-adult abundance for delta smelt to the previous April-June minimum of the sum of *Eurytemora* and *Pseudodiaptomus* densities, weighted by the proportion of delta smelt at each stations for each 20-mm survey.

These are several examples of strong relationships between prey density and subsequent abundance of delta and longfin smelt. Nevertheless, these relationships indicate that prey density is a strong determinant of subsequent abundance of both delta and longfin smelt. They also suggest that the more carefully the measure of prey density is specified, the better the

relationships. If prey density is specified with regard to prey selectivity, seasonal importance, and the co-occurrence or overlap of smelt and prey, correlation analysis yields remarkably strong associations between prey density and subsequent abundance.

9.   *Relationship of prey density to flow*

Figures 24 and 25 show the relationship between *Eurytemora* and *Pseudodiaptomus* densities in the eastern and western parts of the estuary and Delta outflow for April-June (the time of the year when prey density seems to be most important – see correlations above). It is clear from Figure 30A that factors other than flow caused the large decline in *Eurytemora* densities in the late 1980s. Figure 24B shows a positive relationship between *Eurytemora* densities and flow beginning in 1990 in the west, but the relationship is created by three years (1995, 1998, and 2006) when spring outflows ranged from 75,000 to 100,000 cfs, well outside the limits of managed flow. It is likely that this relationship can be explained by the dilution of ammonium that can occur as a result of these extreme river flow events. The opposite relationship is seen for the eastern part of the estuary, near and east of Franks Tract, where the influence of Sacramento River ammonium is much weaker. There, *Eurytemora* densities in spring tend to be higher when outflow is low. No relationships between *Pseudodiaptomus* densities and flow are evident.
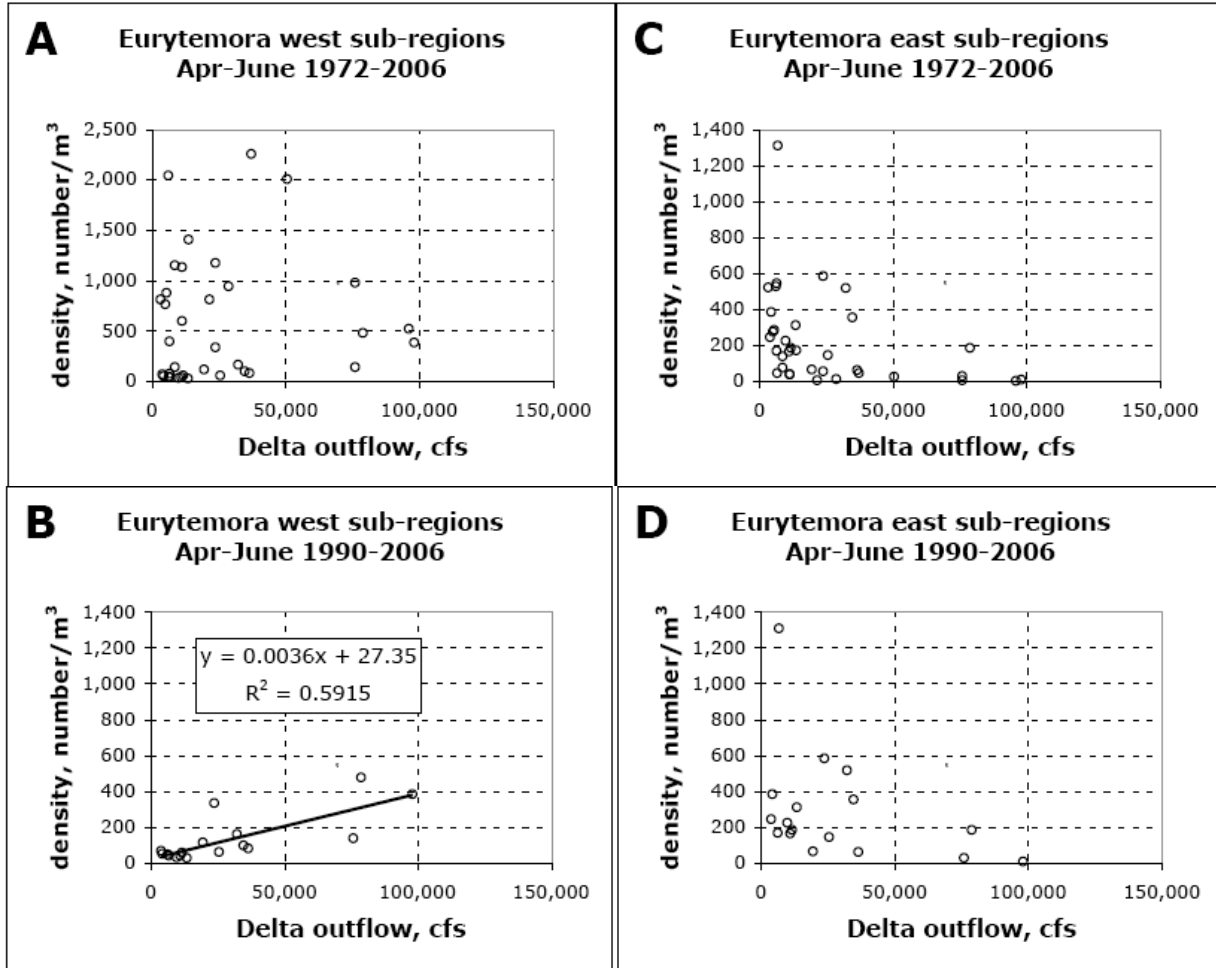
FIGURE 24. The relationship between average *Eurytemora* densities in April-June and Delta outflow, averaged over those same months. A: Western sub-regions (lower San Joaquin River and west) 1972-2006. B: Western sub-regions 1990-2006. C: Eastern sub-regions 1972-2006. D: Eastern sub-regions 1990-2006.
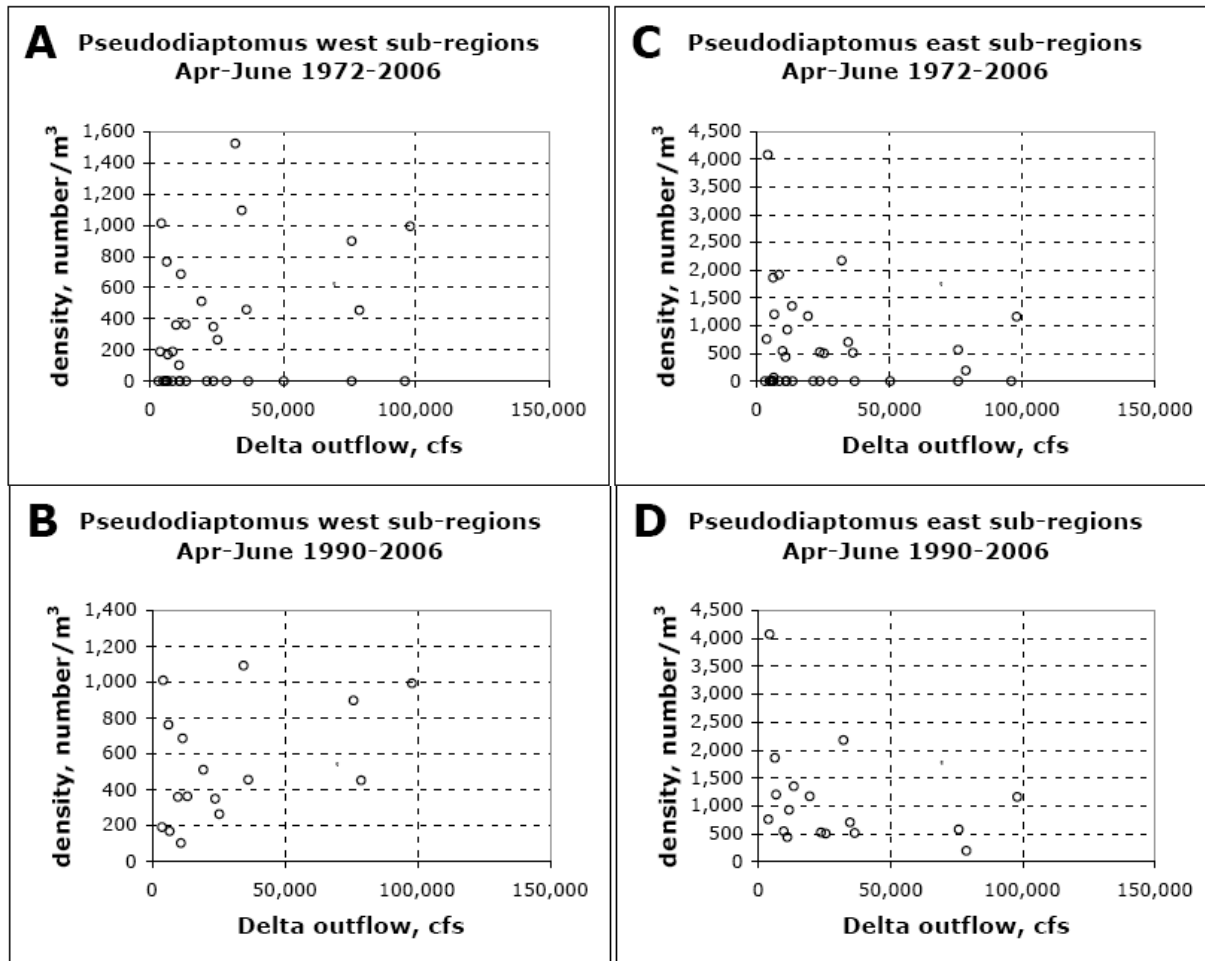
FIGURE 25. The relationship between average *Pseudodiaptomus* densities in April-June and Delta outflow, averaged over those same months. A: Western sub-regions (lower San Joaquin River and west 1972-2006. B: Western sub-regions 1990-2006. C: Eastern sub-regions 1972-2006. D: Eastern sub-regions 1990-2006.

10.   The relationship of turbidity to delta smelt feeding success

Lindberg (2006) reported that feeding success of larval delta smelt in the presence of adequate food is impaired if turbidity is too low. Feeding success is impaired at turbidities less than 20 NTU (Secchi depth greater than 33 cm). Turbidity measurements are only available beginning in the 1990s, but all surveys for fish and other aquatic species routinely measure Secchi depth because measurement is so easy. Combining all data from those surveys produces more than 80,000 Secchi depth measurements beginning in the 1960s. These data were averaged by month for the sub-regions, as shown in Figure 15. Figure 26 shows trends in Secchi depth for sub-regions of the estuary.
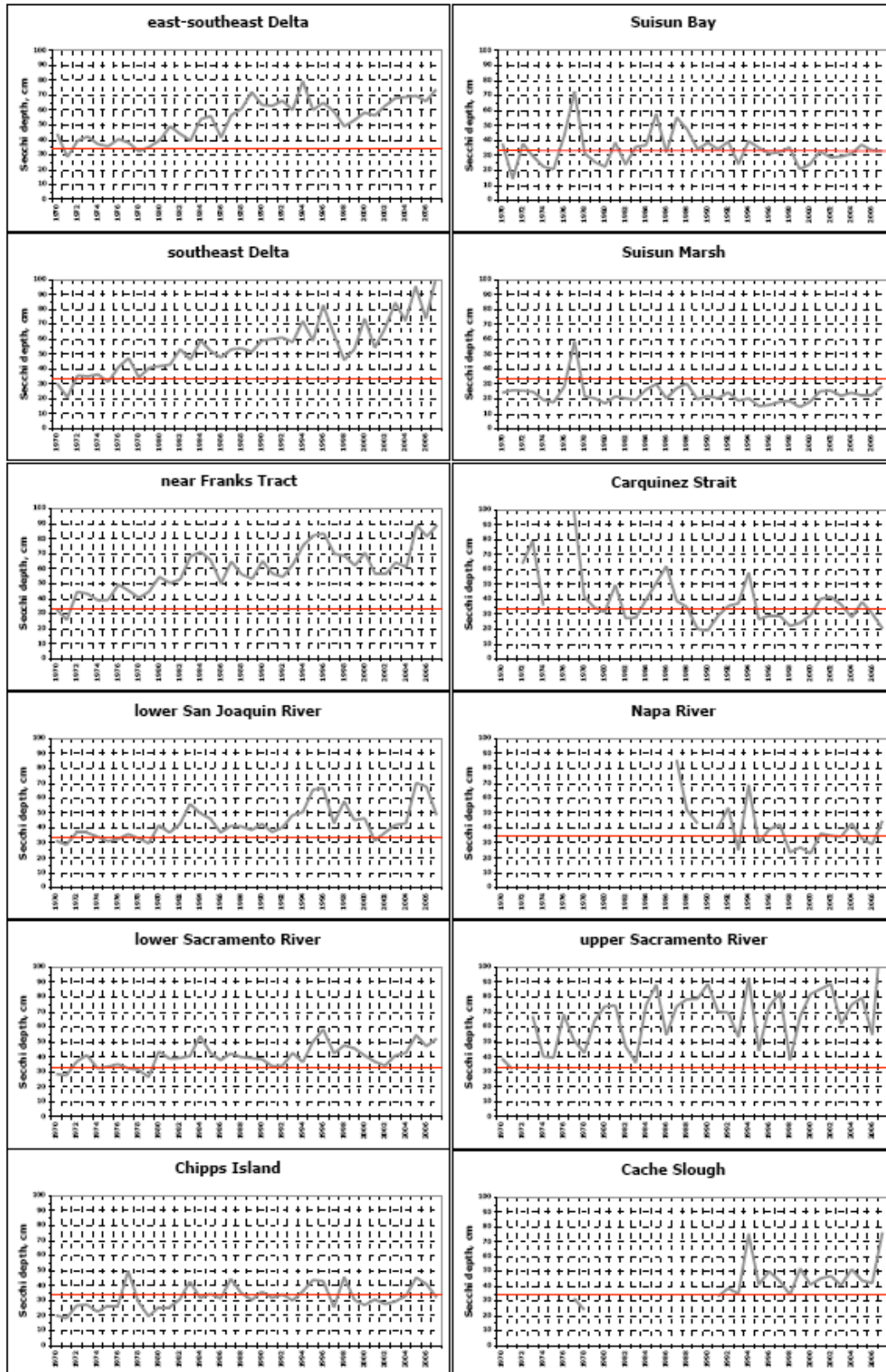
FIGURE 26. Trends in April-June average Secchi depth for sub-regions, with red line showing Secchi depth above which larval feeding success is impaired

These data show that Secchi depths have increased (turbidity decreased) markedly in the eastern part of the estuary, that is, in the San Joaquin part of the Delta. Secchi depths there are now well above the level of 33 cm at which larval feeding success is impaired. Mild increases are evident in the lower Sacramento River and Chipps Island, but not in Suisun Bay, Suisun Marsh or areas to the west, areas where Secchi depth is generally not in the range that impairs larval feeding success. These trends, in combination with Lindberg's findings that larval feeding success is more impaired as Secchi depth increases above 33 cm, indicate that increasing clarity of water is likely having significant adverse effects on larval feeding success in the San Joaquin River part of the Delta.

> 11.   *Distribution of adult delta smelt*

Adult delta smelt prefer turbid water. As Moyle (2002) states: "... individual fish apparently hang out in the water column and rely on their small size and transparency to hide them from predators in turbid water." Analysis of the relative density of adult delta smelt caught in the Spring Kodiak Trawl produced the data shown in Figure 27, which shows that 90% of adult delta smelt are found in water with Secchi depth less than 55 cm.
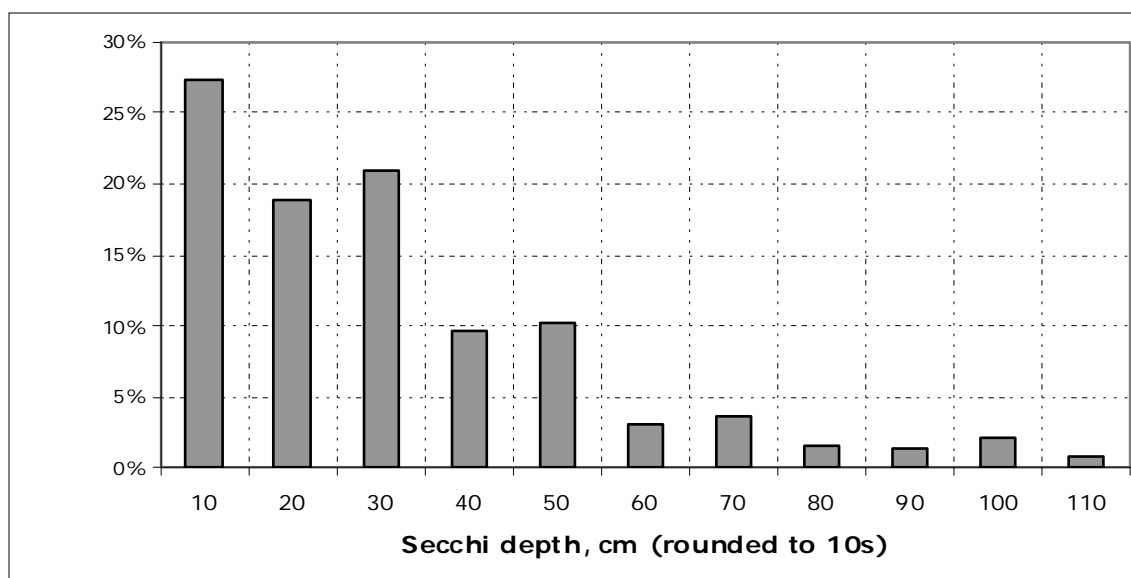

FIGURE 27. Preference of adult delta smelt for waters with various Secchi depths. Data from Spring Kodiak Trawl.

Figure 28 shows Secchi depth averaged over December through March for various sub-regions.
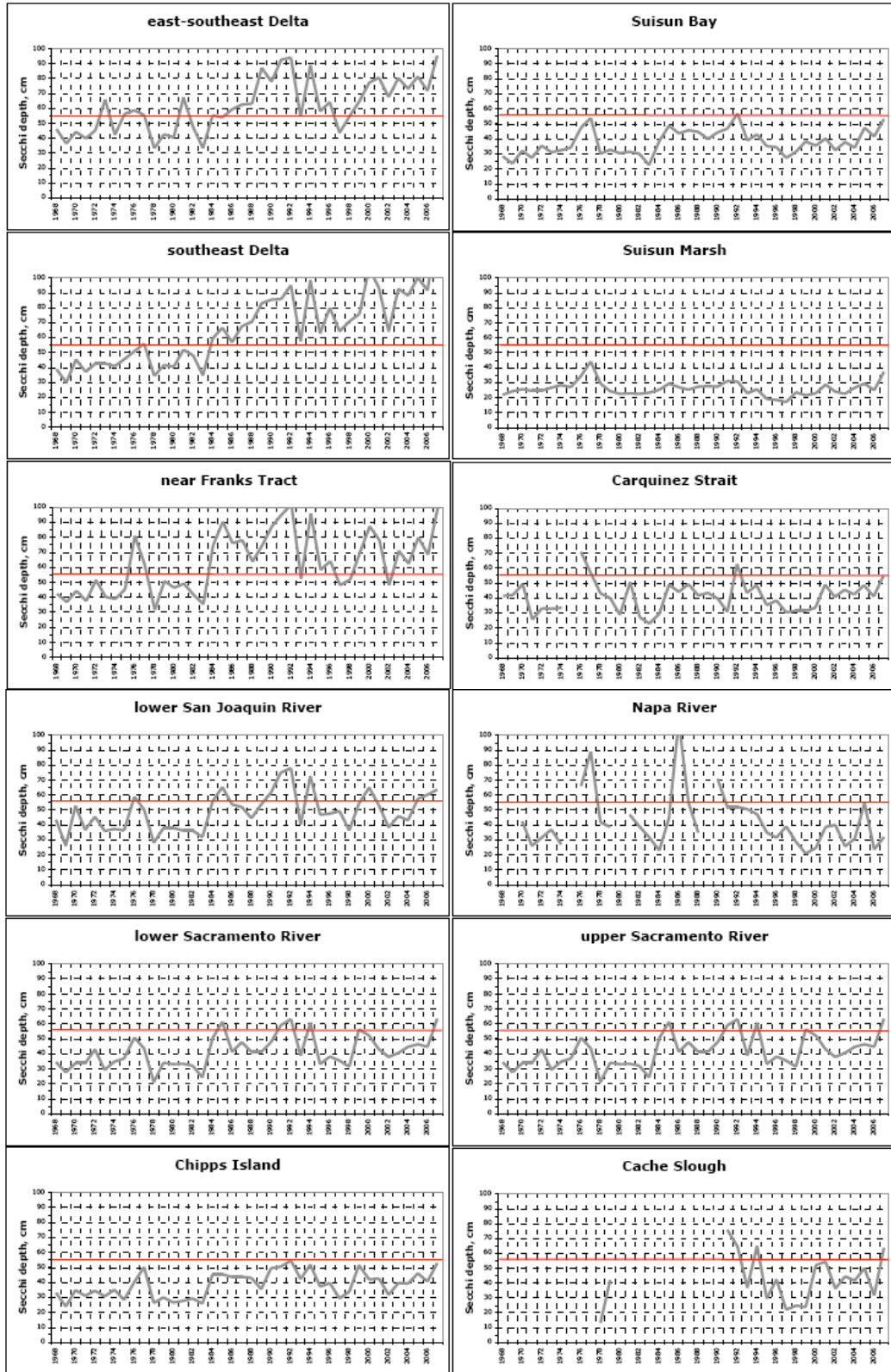
FIGURE 28. Average Secchi depth for December-March for sub-regions. Red line shows Secchi depth below which 90% of adults are typically found.

These data indicate that adult delta smelt are now less likely to move into the San Joaquin River part of the Delta in winter, preferring, instead, more turbid waters of the lower Sacramento River and sub-regions upstream and west of there. Figure 29 compares average December-March Secchi depth in the southeast Delta and the lower Sacramento River and shows that even when Secchi depths fall below 55 cm in the southeast Delta, Secchi depths in the lower Sacramento River are usually even lower and more preferable to adult delta smelt.
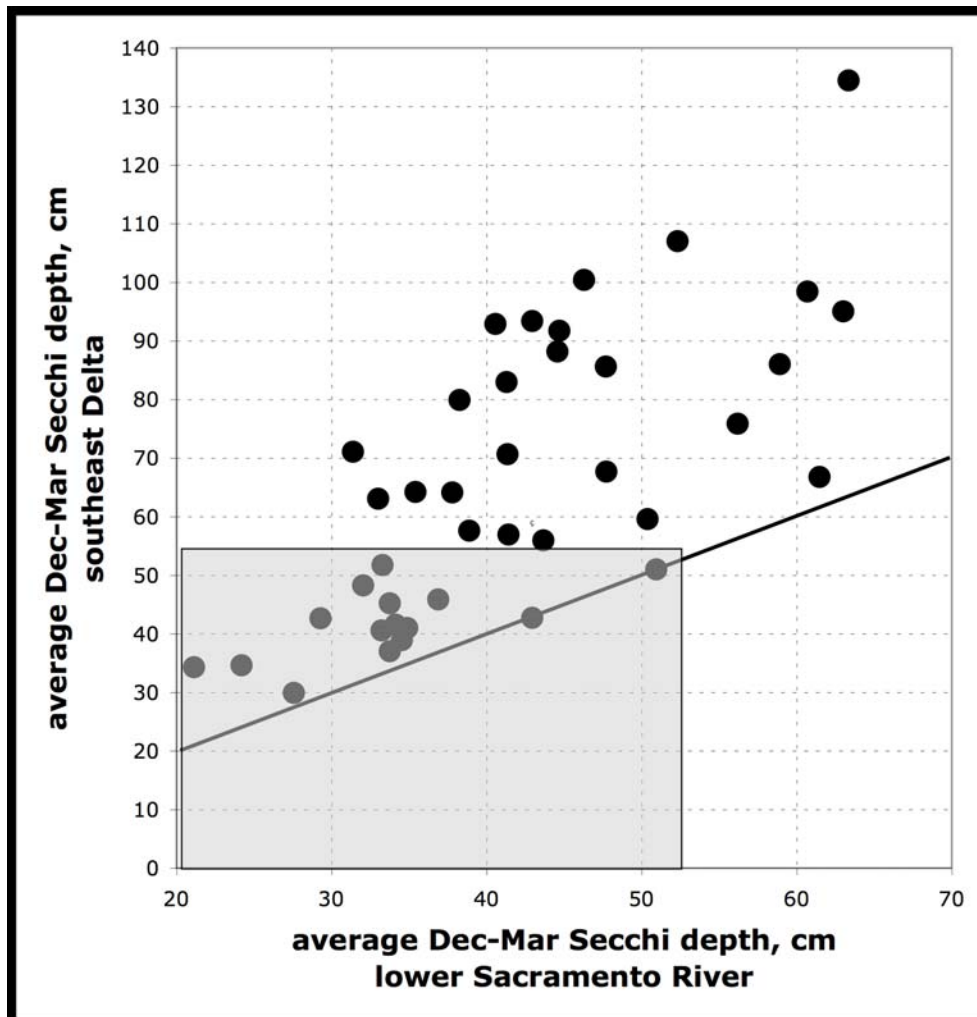

FIGURE 29. Comparison of Dec-Mar average Secchi depth in the southeast Delta and lower Sacramento River sub-regions. Shaded area shows Secchi depths at which 90% of adult delta smelt are found in the Spring Kodiak Trawl. The line shows equal Secchi depths in both sub-regions.

12. Summary

These data indicate that adult delta smelt are now less likely to move into the San Joaquin River part of the Delta than in past years, and it they do move into that part of the Delta and spawn, the resulting larvae are less likely to survive, because of impaired feeding success.

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Wanger O. Interim remedial order following summary judgment and evidentiary hearing ((Doc. No. 560) issued December 14, 2007 in *NRDC v. Kempthorne* (E.D. Cal. Case No. 1:05-cv-1207-OWW GSA).)

The zooplankton metadata is contained in files that can be requested from April Hennessy at DFG: ahennessy@delta.dfg.ca.gov

G.   Non-Native Species

Abstract

Invasive species now comprise the majority of the biomass in the Bay-Delta. Infestations of non-native phyto and zooplankton, exotic plants, fish, and mollusks have combined to create an ecosystem that has become hostile to native species. These species have affected the clarity of the water, devastated the foodweb, provided habitat for an exploding population of predators. Impacts on abundances of native species has been negative and dramatic. These ecosystem-level stressors cannot be reversed simply by changing flows

The fish of the central Delta are dominated by non-native species (Grimaldo et al. 2002; Feyrer and Healey 2003). Bennet and Moyle (1996) hypothesized that the dominant non-native species were better adapted to the altered water quality and habitat conditions existing in the Bay-Delta. The precipitous decline in native fishes has created considerable concern among state and federal agencies who have responded with restoration programs and regulatory actions.

Although there is a long list of non-native species present in California, the following species have made a disproportionate impact or have the capability to severely impact ecosystem dynamics: Brazilian waterweed, water hyacinth, Asiatic and Amur River clams, striped bass, black bass, centrarchids, and silversides. General descriptions and impacts to native fish are reviewed below.

    1.   Plants

Introduced invasive aquatic plants are understood to have a negative impact on the native Delta ecosystem. Waterweeds displace native plants, reduce dissolved oxygen levels, block light, and deposit silt at a higher than normal rate. Community-level effects of invasive macrophytes include reductions in native plant abundance and diversity and in habitat or prey availability for native fish (Madsen 1997; Killgore and Hoover 2001; Toft et al. 2003). The primary example of problematic weeds in the Delta and Suisun Marsh are *Egeria densa* and *Eichhornia crassipes*.

E. densa (Brazilian waterweed) is a shallow water, submerged aquatic plant from South America. It was introduced into the Bay-Delta about 40 years ago and now infests about 12% of its area. It may grow rooted in sediments or free-floating, and can form surface mats that block light penetration. The plant reproduces vegetatively by fragmentation. It interferes with boating and recreation, degrades habitat for native fish and waterfowl, and provides cover for predators such as centrarchid fishes.

E. crassipes (water hyacinth) is an attractive floating plant that is extremely prolific, making mats of vegetation up to 6 ft thick. It was introduced to the United States in 1884 as an ornamental and by 1904 it had invaded California. *E. crassipes* is often noted in the literature as one of the world's most problematic weeds (Gopal 1987; Cohen and Carlton 1995; Batcher 2000). Also introduced to the Delta from South America, the plant can double its size every 10 days and cover many acres. Recent surveys have found the plant covers approximately 4,000 acres of the Delta during the height of its growing season. CALFED (2000) reported water

hyacinth to increase sedimentation and accretion of organic matter, inhibit gaseous interchange with the air, reduce water flow and deplete oxygen, thus altering ecosystem processes that the native residents rely on.

Floating (FAV) and submerged (SAV) aquatic vegetation have degraded habitat for native fishes in the Delta. Delta regions dominated by macrophytes have been found to be primarily inhabited by assemblages of non-native, predatory fishes (Feyrer and Healey 2003; Grimaldo 2002; Nobriga et al. 2005). The vegetation is thought to influence fish communities through structuring mechanisms like competition and predation (Nobriga et al. 2005). FAV and SAV also increase water clarity (measured by Secchi depth) by trapping suspended sediments. Jassby et al. 2002), and Nobriga et al. (2005) found water clarity and SAV abundance co-varied in the Bay-Delta. The long-term trend of increasing Secchi depth has altered feeding success and predation patterns for native fish (Feyrer et al. 2007).

The rapid expansion of the aquatic weeds has improved the carrying capacity for centrarchids by providing structure and altering water clarity. While reduced turbidity is harmful to some Delta fishes, it improves foraging success among largemouth bass.

2. *Bivalves*

The Asiatic clam *Corbicula fluminea* was first collected in the United States in 1938 along the banks of the Columbia River near Knappton, Washington (Counts 1986). Since this first introduction, it is now found in 38 states and the District of Columbia. The Asiatic clam was thought to enter the United States as a food item used by Chinese immigrants, or it may have come in with the importation of the giant Pacific oyster, also from Asia. The dispersal mechanisms for the clam are not well understood. Problems with the clam include its prolific reproduction, extensive filter feeding (which increases water clarity and alters foodweb dynamics), and impacts to water systems by fouling.

The Amur River clam *C. amurensis* was first detected in the San Francisco Bay estuary in 1986 and now ranges from almost freshwater at Rio Vista through the brackish waters of Suisun Bay and Carquinez Strait to the saline waters of the central and south bay. It accounts for up to 95% of the living biomass in some shallow portions of the bay (Carlton et al. 1990; Nichols et al. 1990). The species may reach densities of up to $50,000m^{-2}$ (Peterson 1996), change food web dynamics, and increase contaminant transfer to higher food web levels (Stewart et al. 2004). In both non-flowing and flowing water, the clam exposes one-half to two-thirds of its shell above the sediment surface to facilitate planktonic feeding (Carlton et al. 1990) and has contributed to a persistent decline in plankton availability in the San Francisco Bay estuary (Jassby et al. 2002).

Bivalves impact native fish communities by altering natural physical conditions (i.e., water clarity) and food web dynamics (i.e., prey resource depletion). This in turn has caused fish population declines (Feyrer et al. 2003). They are voracious filter feeders; it is estimated that clams in the northern portion of San Francisco Bay have the capacity to filter the entire water column at least once and possibly more than twice in a single day (Thompson 2005).

3.   Fishes

Many different fish species have been deliberately introduced to the Bay-Delta. Overall, these fish share the traits of being generalists and opportunistic feeders. Some also have high fecundity and respond well to increases in water temperature and decreases in dissolved oxygen. The following details are provided for those categories of non-native fishes that may have the largest impact on native fish in the Delta due to their life history traits, predation rates, or reproductive capacity. Many of the introductions were purposeful for recreational fishing or stocking activities. Degrading conditions in terms of higher temperatures and more stable salinities may have facilitated the invasion, along with invasion by non-native plants.

Striped bass *Morone saxatilis* were introduced to the Delta from the East Coast initially in 1879, with additional introductions by the Fish and Game Commission in 1882. Within a few years, large numbers of striped bass were being commercially caught and sold. Commercial fishing was halted in 1935 to enhance the recreational fishery. Striped bass migrate to freshwaters to spawn and begin in the spring when the water temperature reaches 60°F (15.5°C). The spawning period extends from April to mid-June in open freshwater with moderate to swift current. Striped bass reach sexual maturity at 2-3 years (males) and 5 years (females), and are prolific, broadcast spawners. They have high fecundity and in favorable environmental conditions large populations can be established. Striped bass eggs are slightly heavier than water, so a moderate current is needed to suspend them while they develop. Warm water also increases development. Striped bass are voracious predators that feed on invertebrates and other fish. In the Delta and upriver areas, larger bass feed mainly on threadfin shad, young striped bass, juvenile salmon, delta smelt, and other small fish. In general, striped bass move downstream into brackish and salt water in the summer and fall after spawning in the spring, and some fish enter the ocean. They have been caught from Monterey to Bodega Bay.

Black bass refers to several species of *Micropterus* spp. that have all been introduced in California. Largemouth bass *Micropterus salmoides* were introduced from Illinois to Lake Cuyamaca (San Diego County) in 1891. They are now found throughout California waterways. There are two recognized subspecies: the northern subspecies *M. s. salmoides*, and the Florida subspecies *M. s. floridanus*. Largemouth bass is also documented as the dominant piscivore in SAV-dominated habitats with a larger per capita 'predatory influence' (Nobriga et al. 2005) supporting biotic structuring of habitat. Juvenile largemouth bass may be dispersed by tidal and river currents, but most remain closely associated with submerged vegetation along channel edges and in shallow portions of flooded agricultural tracts (Nobriga et al. 2005). In contrast to the availability of extensive striped bass datasets, less is known about Delta largemouth bass population dynamics. Recruitment success was historically low (Moyle 2002), but abundance of adult largemouth bass in the Delta has increased in the last decade (Brown and Michniuk 2007) and now supports a significant sport fishery. There is strong evidence that rapid increases in FAV and SAV habitat have facilitated population growth (Nobriga et al. 2005; Brown and Michniuk 2007). Smallmouth bass *Micropterus dolomieu* were first introduced into California in the Napa River in 1874 from Lake Champlain, New York. A second introduction occurred at Crystal Springs Reservoir (south of San Francisco), and provided ample supply for additional stockings. Spotted bass *Micropterus punctulatus* have also been introduced into California.

The inland silverside *Menidia beryllina* is a neotropical silverside native to eastern North America and may compete with delta smelt. It was introduced into California in 1967 to control the Clear Lake gnat *Chaoborus asticopus* in lakes and reservoirs of Alameda and Santa Clara counties. From there the fish spread into the San Francisco Bay and Central Valley, and have since become widespread across California. In some areas, they are the most abundant fish of any species. Moyle (2002) suggests that this fish may have contributed to the demise of the Clear Lake splittail, although the effect of the silversides introduction on California ecosystems has not been much studied.

Wakasagi *Hypomesus nipponensis* are pelagic plankton feeders found in open lakes, streams and reservoirs, and they are found in a wide range of temperatures (2-29°C) and salinities (0-29 psu). Copepods and insect larvae appear to make up the majority of their diet, and in contrast to the similar and more solitary delta smelt, they have been observed in large schools in the Bay-Delta. They are known to share habitat with the delta smelt and may occasionally hybridize, reducing delta smelt fitness. Most live for one to two years before spawning and dying. They generally spawn in April-May in shallow areas of gravel or sand.

The mechanisms by which introduced fish most often impact native fish communities is by predation or competition. Unlike native fish abundances, populations of predators are increasing and will likely continue to negatively impact native fish.

Juvenile salmonids generally emigrate during the early spring and summer, the same time as adult striped bass are beginning their freshwater spawning migrations. Striped bass are known to heavily prey upon juvenile salmonids (Nehlsen et al. 1991). Largemouth bass appear to have the greatest impact on near-shore fishes, including native fishes (Nobriga and Feyrer 2007), which they consume well into summer months. Incidence of piscivory is predominantly a function of size, with largemouth bass becoming piscivorous at smaller sizes than those of the native predator, Sacramento pikeminnow (Nobriga and Feyrer 2007).

Both theory and empirical data indicate that striped bass and other predators may at least limit the potential for recovery of juvenile salmonids, delta smelt, and other native fishes. This potential has been acknowledged by the USFWS (1996), the California Department of Fish and Game (CDFG 1999), and most recently by the Interagency Ecological Program, Pelagic Organisms Decline evaluation team (IEP 2008). Evidence is also mounting regarding the relationship between non-native plant invasions, habitat change, and benefits for some centrarchid populations (Nobriga et al. 2005; Feyrer et al. 2007).

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H.   Fall X$_2$

Abstract

The purported benefits to delta smelt of increased fall outflow are not supported by the best available science. The correlation is (1) weak, (2) relies on a single outlier year, 1999, and (3) excludes years before 1987. Moreover, the use of linear correlation for STN against FMWT and fall X$_2$ is biologically inappropriate. The fall X$_2$ hypothesis is a perfect example of the perils of focusing only on flow related relationships.

A fall X$_2$ requirement was included in the USFWS biological opinion for delta smelt (USFWS 2008), which has enormous water costs to the CVP and SWP. The requirement is premised on a published paper by Feyrer et al. (2007) and a draft 2008 manuscript also prepared by Feyrer et al. Feyrer et al. (2007) analyzed the relationship between occurrence of delta smelt in the fall and a so-called "Environmental Quality Index" (EQ) based on salinity, temperature and turbidity.[14] Interestingly, Feyrer et al. found no relationship between EQ as a whole and delta smelt abundance, although they claimed that delta smelt abundance was correlated with a single EQ component, salinity, measured in the fall. Feyrer et al. (2008) essentially repeated the previous analysis, adding two years of new data (2005 and 2006) and measuring salinity as X$_2$.

These papers coined the term "abiotic habitat" and purported that changes in "abiotic habitat" have led to declines in delta smelt abundances. There is no such thing as "abiotic habitat." Appropriate habitat for any species has numerous characteristics, some of which are "biotic" (e.g., consumable, such as oxygen and prey) and some of which are "abiotic" (i.e., not consumable, such as temperature and salinity).

What is more, the relationship in Feyrer et al. (2007) between fall X$_2$ and delta smelt abundance is driven by a single data point – 1999 – which, when removed, renders the correlation insignificant. Figure 30 shows the ratio of the summer smelt abundance index (STN) to the previous fall abundance index (FMWT) for the years 1987 - 2006. If Fall X$_2$ were a driver of smelt abundance the next summer, we would expect to see a relationship on the graph. There is a relationship, but it is very weak and only exists at all because of a single point – 1999 -- and even then only if the analysis excludes all years before 1987. Indeed, if the same graph is drawn, but for years prior to 1987, a strong line emerges, suggesting that low fall flows may actually benefit smelt (Figure 31). The explanation for low fall flow benefiting smelt before 1987, but showing no real relationship after 1987, may be that high dry year concentrations of pollutants have increasingly masked the benefits of low flow in recent years. If ammonium is controlled, the original relationship between smelt and fall flow might reemerge.

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[14]   Feyrer et al. (2007) defines EQ as being composed of three components: temperature, salinity, and turbidity. These components were chosen, not because they were thought to comprise all of the important factors affecting environmental quality for delta smelt, but because they were the factors measured in the FMWT and therefore readily available.
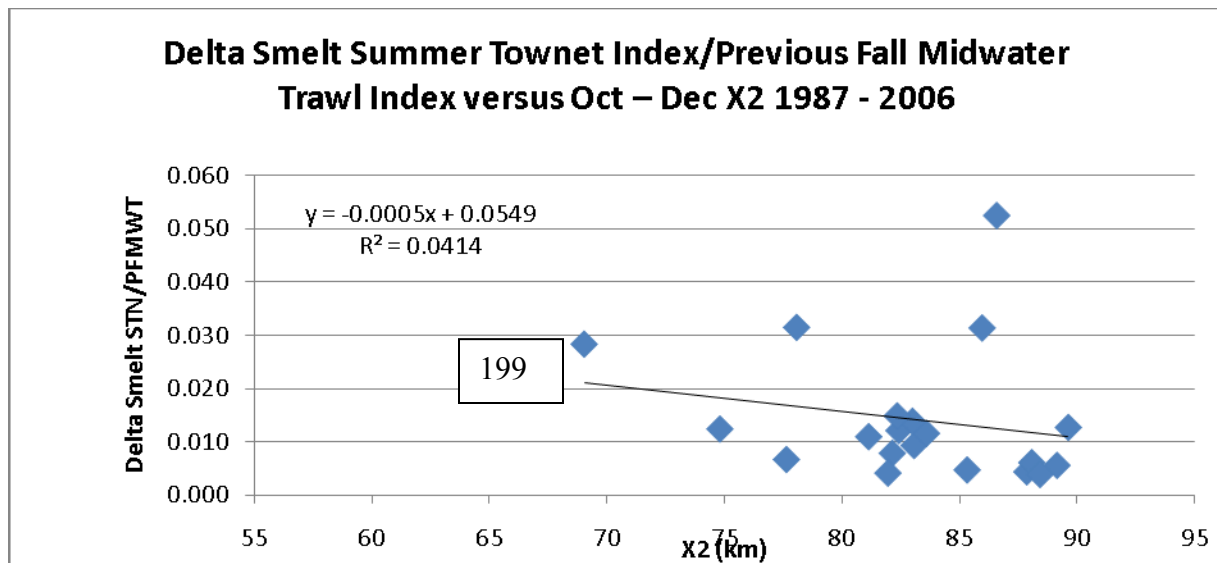
FIGURE 30. The Delta Smelt Summer Townet Index/Previous Fall Midwater Trawl Index versus Fall X_2 1987 - 2006.
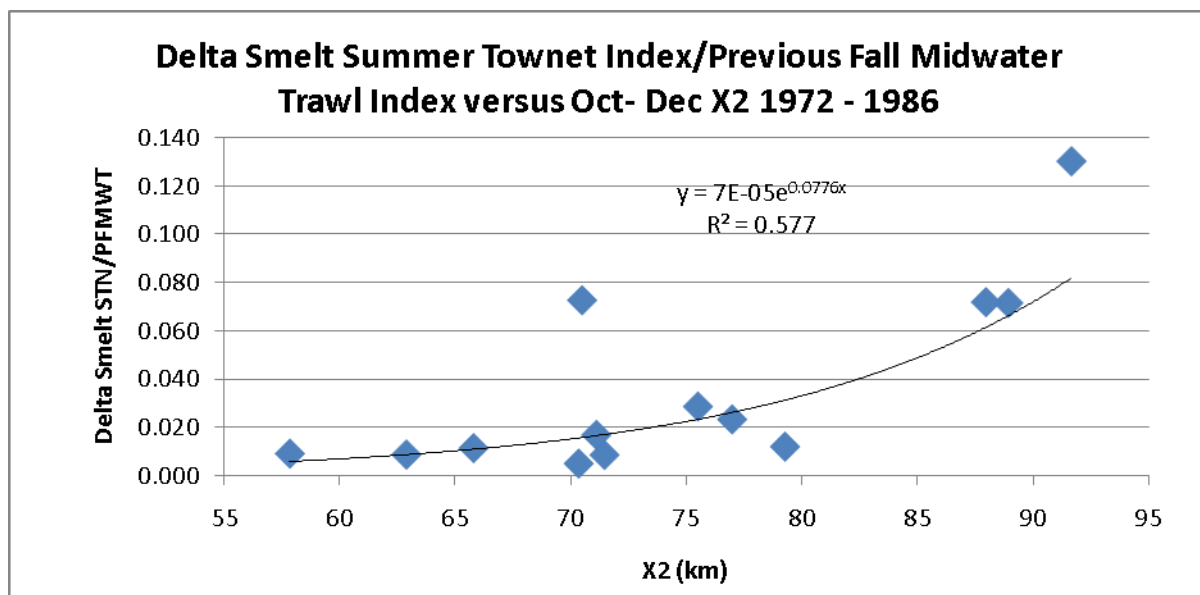

FIGURE 31. The Delta Smelt Summer Townet Index/Previous Fall Midwater Trawl Index versus Fall X^2 1972 - 1986.

Feyrer et al. hypothesized that the mechanism linking the relationship between fall X_2 and delta smelt abundance was habitat volume (Feyrer et al. 2007, p. 731; 2008, p. 16), although they also identified fall food availability, predation, and contaminants. Yet the abundance indexes for delta smelt all show that the species is at all-time lows. Therefore, the hypothesis is illogical; abundance levels are so low that there is likely an excess of habitat needed to support the current population.

Feyrer et al. (2007) even note that their analyses would likely be improved by "additional studies on the effects of food availability (p. 732)," yet, amazingly, Feyrer et al. (2008) did not do so.

Section F (above) explains that food limitation is, indeed, a major stressor on delta smelt populations. In fact, when food availability is added into the correlation, X_2 disappears altogether as an important factor.

Dr. Richard Deriso examined Feyrer et al. (2007, 2008) and concluded that these studies used the wrong model to demonstrate their purported relationship between fall X_2 and delta smelt abundance.[15] Feyrer et al. used a linear additive model, which produces the unfortunate result that zero adults in one year could still yield young in the next year, a result that is not biologically plausible. To explain, it is understood that a simple regression line (slope-intercept line) is described by the equation $Y=mx + b$, where m=the slope of the line, x=the independent value, and b=the y-axis intercept. Correspondingly, using a simple translation of Feyrer et al., if A (juveniles measured in TNS) = B (constant) + C (adults measured in FMWT) – D (Fall X_2), one can see that, if C were set at zero (no adult spawners), then B minus D could still produce a positive number. Their linear additive model also treats the X_2 as an additive factor, which has the implausible property of reducing the absolute numbers of juveniles by the same quantity for a given value of X_2 irrespective of the total population.

Instead of using a linear additive model, Feyrer et al. should have used a multiplicative stock-recruit model, such as the Ricker model (Hritonenko et al. 2005). A Ricker model is a multiplicative model as opposed to a linear additive model. As such, it avoids the implausible results noted above. When a Ricker model is used, there is no statistically significant relationship between fall X_2 and delta smelt abundance.

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[15] See Declaration of Dr. Richard B. Deriso in support of Metropolitan's motion to allow expert testimony, dated September 28, 2009.