Proposed New Special Studies in support of 2011 Fall X2 Adaptive Management Experiment

Proposals recommended for funding:

Last Name	Affiliation	Proposal Title	Total Proposed Budget
Teh	UC-Davis	Estimation of survival, growth and reproductive fitness of delta smelt	$ 728,076
Parker	SFSU	Supplemental Nutrient and Phytoplankton Monitoring in Suisun Bay	$ 46,533
Schoellhamer	USGS	Suspended sediment and X2 in Suisun Bay and the Confluence during Fall, 1994-2011	$ 418,000
Thompson	USGS	Bivalve effects on the food web supporting delta smelt and Recruitment Patterns of Bivalves with Varying Freshwater Outflow	$ 123,375
Monismith	Stanford	Suisun Bay Hydrodynamics: Flows, Salt Fluxes and X2 dynamics during the 2011 IEP Fall X2 study	$ 463,000
Connon	UC-Davis	Old standards versus new approaches: defining the fundamental niche of delta smelt (*Hypomesus transpacificus*).	$ 72,400
Kendall	USGS	Residence Time as an Aid to Interpreting Nutrient Dynamics and Other Habitat Characteristics in the Suisun, SJR Confluence, and Cache Complex Regions	$ 126,560
Kendall	USGS	Enhanced fall habitat characterization using a multi-fingerprinting approach	$ 220,300
		Total proposed budget:	$ 1,977,944

Swee TEH, UC-Davis

Study Plan for Fall X2 Fish Sampling and for Estimation of Survival, Growth and Reproductive Fitness of Delta Smelt

A comprehensive methodology is described to optimize necropsies of fish for growth and health monitoring to support the information needs of the Fall X2 study. The target species is delta smelt, but age-0 striped bass, age-0 American shad and threadfin shad will be similarly processed to supplement information on growth and health of fishes within each study region (i.e., Suisun Bay region, Sacramento and San Joaquin river confluence region and the Cache Slough/Sacramento Deep Water Ship Channel region). The small size (ranging from 30 to 70mm in length) of these species during the Fall X2 sampling period requires the use of multiple approaches to evaluate their health, growth, and reproductive fitness. The fish species, as described in this study plan, will be collected by the ongoing IEP/DFG long-term fish monitoring surveys. No additional sampling will be conducted. An additional boat and operator will be needed for survey dates to allow Aquatic Health Program (AHP) staff to receive fresh fish directly from the fish monitoring staff. Otolith analyses (daily growth and salinity history) will be completed by James Hobbs and staff of the Interdisciplinary Center for Inductively Coupled Plasma Mass Spectrometry at UCD.

Approximate field sampling schedule is as follows and identifies sampling dates when surveys sample from regions of interest: Suisun Bay region, Sacramento and San Joaquin river confluence region and the Cache Slough/Sacramento Deep Water Ship Channel region.

Townet Survey August 23-26; Fall Midwater Trawl: survey 1 September 9, 12, 13 and 20; survey 2 October 6, 7, 10, 14; survey 3 November 10, 14, 15, 21; survey 4 December 8. 9, 12, 16; Spring Kodiak Trawl Survey: survey 1 January 10-13; and survey 2 February 7-10. Sampling for adult delta smelt will continue through May but these fish will not be processed to inform the deliverables described below. Instead, they will be processed during summer 2012.

It should be noted that AHP Staff will set up an onsite necropsy station on shoreline or a second boat but in either case the second boat will follow the long-term fish monitoring boat and after each successful tow transfer target fishes. This work will be coordinated with DFG Young Fish Monitoring Unit for Summer Townet and Fall Midwater Trawl field collections (Randy Baxter Supervisor) and the DFG Native Fish Sampling Unit for Spring Kodiak Trawl field collections (Bob Fujimura Supervisor).

1. Delta Smelt Processing Path (same for supplemental species except as noted below):

<u>1A. For delta smelt < 40mm in length*</u>

Because delta smelt are very sensitive to handling stress and usually do not survive for very long periods on the boat, fish that die during sampling and all those less than 40 mm FL will be immediately assigned

individual code numbers then frozen in liquid nitrogen. These fish will be processed upon arrival at the Aquatic Health Program (AHP) at UCD for weight (± 0.0001 gram) and length (± 1.0 mm FL) for measurements of condition index, otoliths extracted for analysis of daily growth and salinity history, RNA/DNA ratio to index recent growth, fatty acid analysis for nutritional status, and histopathologic and biochemical biomarkers for health evaluation.

1B. For delta smelt > 40 mm in length*

At each sampling site and depending on the number of smelt collected, 15 delta smelt, 15 age-0 striped bass, 15 age-0 American Shad, and 15 threadfin shad will be processed as outlined below.

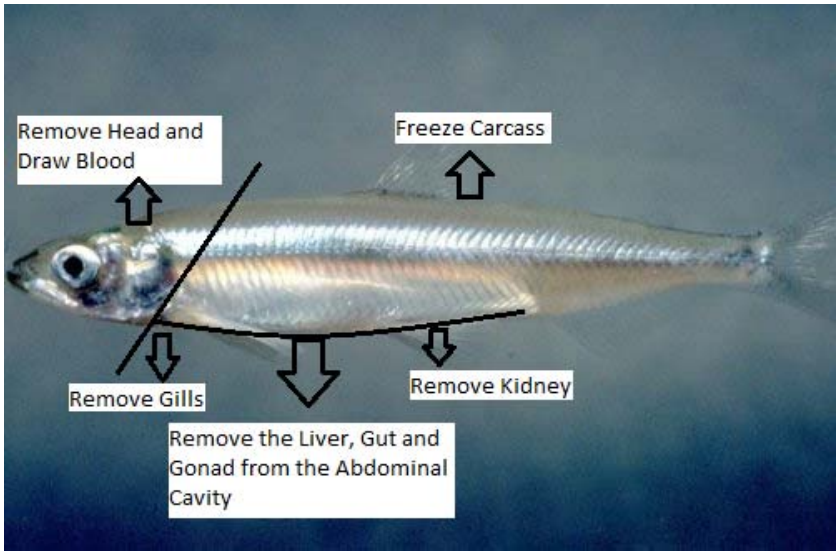
*Excess samples of delta smelt (all) and other fish species (n ≤ 20) will be frozen in liquid nitrogen and processed by the AHP

Fish processing steps are described below and are compatible for all fish species

1. Record fish number
2. Determine Condition factor
    a. Measure fish length in millimeters (± 1.0 mm)
    b. Weigh fish in grams (± 0.0001 g)
3. Determine gross health condition
    a. Check for external signs: fin erosion, skin ulcer, eye disorder, hemorrhage, parasites, tumors, skeletal deformities, and lesions
4. Remove head and transfer to James Hobbs for otolith removal and to preserve tissue for potential genetic analyses (latter not currently funded)
    a. Cut at a diagonal angle (see Figure 1)
    b. Draw Blood for hormone analysis to determine fish maturity and choriogenin and vitellogenin in males as indicators of exposure to endocrine disrupting chemicals (EDCs)
        i. Use a capillary tube to draw blood by making an incision from the caudal peduncle (for smaller fish), and by tapping the tube against an artery for larger fish
        ii. Place the filled capillary tube on ice
    c. Remove Gills
        i. Place the removed gills in a pre-labeled formalin jar for microscopic evidence of parasites, erosion or microscopic damage (histopathology)
    d. Place the head in 95% Ethanol
5. Remove the Liver, Gut Content and Gonad
    a. Make an incision beginning at the anus and cut anteriorly along the ventral surface to the head, making sure not to damage any internal organs (see Figure 1)
    b. Carefully remove visceral organs (including liver, gut and gonad) and place them in the same labeled formalin jar containing the gills
    c. Liver and gonad will be separated and weighed to determine hepatosomatic and gonadosomatic indices

    d. Liver and testis will be processed for histopathology and for immunohistochemistry to determine P450, choriogenin, and vitellogenin biomarkers
    e. Ovary will be staged grossly as indicator of sexual maturity and processed histologically for fecundity and maturity evaluation
    f. Gut will be transferred to Randy Baxter for potential gut content analysis
6. Remove Kidneys
    a. Aseptic isolation for bacteria by inoculating kidney portions onto general media (blood agar)
    b. Place kidneys on ice and examine for coloration, nodules, and amount of mesentery fat
    c. Store in buffered antibiotic and antifungal solutions or both for virus isolation using specific cell lines (Note: we have developed specific cell lines for delta smelt and threadfin shad)
7. Freeze Fish Carcass to determine nutritional status (fatty acid/promixate analysis) and for growth rate (RNA/DNA analysis)
    a. Wrap the carcass remains in a pre-labeled aluminum foil sheet (labeled with fish number and date) and place the wrapped remains in the designated liquid nitrogen dewar.
8. Record all measurements, observations and notes on the provided Microsoft excel data sheet

Figure 1 Major sites of dissection for delta smelt. Process will be the same for all species



2. Relevance of studies at UC Davis, Aquatic Health Program

Results from our analyses will provide two measures of fall growth (otolith daily increments in collaboration with James Hobbs and RNA/DNA ratio) and the biological effects of key environmental stressors in delta smelt and other at-risk species across the three contrasting habitats (Cache slough complex, Confluent of Sacramento River, Suisun Bay/Chipps Island) in the San Francisco Estuary (SFE). Outcomes will also provide estimates of delta smelt 'first spawn' fecundity that can be related to fall growth, fish size and salinity history, which in turn should be able to distinguish fish rearing in the Suisun

region rearing from those rearing in confluence or Cache Slough/Deep Water Ship Channel Regions, even after all have migrated upstream. This study will advance our current understanding of cause-effect relationships of 2011 Fall outflow manipulation on delta smelt and will provide a baseline fish health index for delta smelt and the other species included in these studies in the SFE Delta.

3. Expected Results

- Comprehensive measurements of biological effects due to key stressors that affect the overall health of delta smelt and at-risk species. These measurements include 1) Otolith growth rate, 2) Condition factor and organo-somatic indices, 3) RNA/DNA for growth rate indices, 4) Blood plasma hormonal analysis for gonad maturity, physiology, and endocrine disrupting effects, 5) Histopathology as indicators of contaminant and endocrine disruptor exposure and effects, 6) Isolation and identification of pathogens/diseases using specific cell lines for virus isolation, 7) Fatty acid/proximate* analyses to determine fish nutritional status. Finally, analyses of condition and ovarian-somatic indices, gonad maturity, hormonal changes, liver and ovarian histopathology, and fecundity will be integrated to evaluate reproductive fitness of fish.

*Note: Proximate analysis is a good indicator of the energy content of tissue and will be determined by measuring the moisture, protein and ash in fish samples. This analysis will be conducted only if large quantity of tissue mass will be available.

- Measurements of vital rates, notably growth and reproductive fitness and potential correlations to ameliorate 2011 fall outflow and water quality.
- Baseline fish health for predicting trends and patterns of fish health over time that may be altered due to emerging risk factors and varying effects of multiple man-made and environmental stressors affecting the Delta and its fishery resources.

4. Deliverables

The followings are deliverables for study plan of 2011 Fall X2 fish sampling and growth and reproduction fitness of delta smelt (Year 1).

1. Fish sampling and processing – August 2011 to February 2012
2. Otolith and tissue analyses – August 2011 to February 2012
3. Quarterly reports – November 30, 2011 and February 29, 2012
4. Draft Final Report April 30 2012
5. Final Report – May 31, 2012
6. Revised Fall X2 study plan, develop adult smelt reproductive fitness study plan, presentation and and preparation of manuscripts – May 2012 to August 31, 2012.

A revised study plan for 2012 Fall X2 study will be developed based on the outcomes of 2011 Fall X2 study. In addition, this study plan will address sampling to be conducted in winter 2012 and winter 2013 (Years 2 and 3) on processing and analyses of adult delta smelt reproductive fitness will also be developed to evaluate the potential combination of asynchronous or group synchronous spawning of delta smelt based on the fluctuation of environmental conditions in the three contrasting habitats (Cache slough complex, Confluent of Sacramento River, Suisun Bay/Chipps Island). It is postulated that individual smelt will perform asynchronous spawning, i.e., spawning small batches of egg throughout

the reproductive season when environmental condition are adequate but will perform group synchronized spawning during high spring flow when environmental condition is excellent to ensure the survival of their offspring.

Alex PARKER-San Francisco State University

Proposal to IEP (USBR) In Response to "Adaptive Management of Fall Outflow for Delta Smelt Protection and Water Supply Reliability" Plan (Fall Outfall Report):
Supplemental Nutrient and Phytoplankton Monitoring in Suisun Bay

August 10, 2011

PI: Alex Parker, RTC, San Francisco State University
Co-PIs: Richard Dugdale (mass spectrometry and data analysis), Frances Wilkerson (admin. and data analysis), RTC, SFSU
Project title: Understanding phytoplankton response to X2 management of fall outflow - A supplement to funded study: influence of elevated ammonium on phytoplankton physiology in the SFE/Delta during fall.
Total budget: $46,533
Study duration: One year. The Fall Outflow Report indicates that studies should provide data by spring 2012 suggesting 1 year. However, this proposed project could be repeated in fall 2012. This would add similar costs for 2012 as proposed for 2011.

Priority research topic and questions addressed and relevance to the IEP investigations

We propose to supply data and analysis concerning inorganic nutrients, phytoplankton composition and phytoplankton carbon and nitrogen production rates in the low salinity zone during September to November 2011, to assess the predicted qualitative and quantitative outcomes of X2 management as summarized in Table 1 of the Fall Outflow Report (FOR). As such, the proposal directly addresses the IEP investigation of how management of flow will affect bottom-up drivers of delta smelt abundance and health (Fig 13, FOR, IEP 2011).

The FOR describes a conceptual model that distinguishes between interacting dynamic and stationary (geographically fixed) abiotic habitat components that affect delta smelt, their predators, and their food resources in the river channels of the western Delta and in Suisun Bay during fall. The dynamic habitat components are associated with different fall outflow regimes, while the stationary habitat components are associated with the specific physical structure of the low salinity zone when it is located near the confluence of the Sacramento and San Joaquin Rivers or in Suisun Bay. Our proposed study will provide dynamic abiotic (nutrient concentrations) and biotic (phytoplankton biomass and species composition) habitat components and supply mechanistic rate measurement data to help explain the food web consequences of changing X2 and flow.

Project description background and conceptual model

The **conceptual model** of our currently funded IEP (USBR) work is ammonium (NH_4) suppression of phytoplankton nitrate (NO_3) uptake and primary production, influencing the occurrence and timing of phytoplankton blooms in the northern SFE and the Sacramento River (Wilkerson et al. 2006; Dugdale et

al. 2007; Parker et al. subm.). The present situation in Suisun Bay is that productivity and chlorophyll biomass is low. Grazing by *Corbula amurensis* is suspected to be the causal agent in holding chlorophyll concentrations to low levels and thereby maintaining the Suisun Bay ecosystem in an NH_4 based, low productivity condition in summer and fall. The fall Suisun condition is represented by the mean nutrient and chlorophyll values published in Wilkerson et al. (2006; Tables 1 and 2); high NO_3 (30.7 µmol L^{-1}) with NH_4 at 6 µmol L^{-1} (> 4 µmol L^{-1} suppression threshold for bloom formation) and low chlorophyll (1.6 µg L^{-1}). Phytoplankton N uptake is primarily NH_4 uptake (86%) and primary production is low, 55.6 µg C L^{-1} d^{-1}. Elevated NH_4 (due to low flows in fall or sediment flux) can exacerbate this situation.

Increased flow, according to Jassby (2008, his Fig 10) could decrease chlorophyll in Suisun Bay as occurred in 1980, or increase it as in 2000. We hypothesize the following effects of increased flow as proposed for fall 2011.

<u>Case 1</u>: Flow increased, diluting Sacramento River NH_4 to ≤ 4 µmol L^{-1} before it enters Suisun Bay. Requires flows of ca. 800 m^3 s^{-1} (28,000 cfs) at present NH_4 discharge by Sacramento Regional WTP (~15 tons NH_4-N d^{-1} (Dugdale et al. submitted)).

Physiological effect: phytoplankton NO_3 uptake enabled, primary productivity increases.
Biomass effect: increased chlorophyll concentrations and proportion of diatoms.

<u>Case 2</u>: Flow increased (e.g. 11,400 cfs = 320 m^3 s^{-1} as in Table 1, FOR) but not sufficient to reduce NH_4 to threshold level (i.e. > 4 µmol L^{-1}).

Physiological effect: phytoplankton remain in NH_4 uptake mode, NO_3 not used, lower NH_4 concentration results in lower NH_4 uptake and reduced primary production.
Biomass effect: reduced chlorophyll concentration, diatom proportion not increased.

<u>Case 3</u>: Flow increased, X2 moves downstream and overlaps with Suisun Bay resulting in increased turbidity (Kimmerer, unpubl.).

Physiological effect: reduced NH_4 uptake, NO_3 not used, low primary production.
Biomass effect: reduced chlorophyll concentration, diatom proportion not increased.

<u>Case 4</u>: Flow increased and dilutes some unidentified toxicant(s).

Physiological effects: NH_4 uptake increased, possibly reducing NH_4 to the threshold allowing NO_3 uptake, increased primary productivity.
Biomass effects: increased chlorophyll, amount depending on proportion of NH_4 or NO_3 used.

In all cases increased flow will decrease residence time in Suisun Bay likely lowering chlorophyll concentrations. Most of the effects of increased flow on phytoplankton biomass and primary production are negative except when flow is sufficiently high as to: a) dilute NH_4 to below the suppression threshold concentration for NO_3 uptake (Case 1) and b) reduce (hypothetical) phytoplankton toxicity (Case 4).

This study would supplement Task 1 of our current study to address the two **questions**

Q1. What are the rates of primary production and phytoplankton NO_3 and NH_4 uptake in Suisun Bay during the fall period and how is this related to X2.
Q2. How does increased flow (low X2) impact the NH_4 concentration and turbidity in Suisun Bay and affect phytoplankton production and chlorophyll concentration?

The study will include **one task:** supplemental station work on existing IEP and Delta Science Program-funded research cruises and two additional sampling cruises of Suisun Bay during fall 2011 (October 25 and November 1) (Table 1).

The task **objectives** are to:

1.1 Provide a comprehensive dataset of Suisun Bay inorganic nutrient chemistry, phytoplankton biomass (as chlorophyll, flow cytometry, microscopy counts) during September-November.

1.2 Quantify pelagic primary production (using ^{13}C tracer) and phytoplankton NH_4 and NO_3 uptake (using ^{15}N tracers) along longitudinal transects in the Sacramento and San Joaquin Rivers.

1.3 Evaluate the relationships between river flow, NH_4 concentration, primary production and phytoplankton N uptake in Suisun Bay.

Approach

We propose to add one to seven stations in the lower Sacramento River and Suisun Bay to each of the currently scheduled research cruises in September and October 2011 (Table 1) and add two additional cruises in late October and November (Table 1, **BOLD**). Only two of our current cruises are funded to make measurements in Suisun Bay (Fall Habitat 2, Fall Habitat 4). Seven additional stations (US649, US2, US3, US4, US5, US6, US7) will be added to the Delta Science Program-funded Nutrient Ratios (Glibert) cruises. One additional station will be added to the Microcystis (Parker) cruises. Through this proposal **a total of 36 additional stations will be occupied in the low salinity zone/ Suisun Bay during fall 2011.**

We will use the RV Questuary outfitted with a Seabird CTD/Rosette and underway data acquisition systems. At each station we will collect surface samples for water chemistry (NO_3, NO_2, NH_4, urea, PO_4, $Si(OH)_4$) and phytoplanton biomass and rates. Phytoplankton biomass will be assessed by size-fractionated chlorophyll collected onto GF/F filters (nominal pore size 0.7-µm) and 5-µm pore size nuclepore filters. Size spectra of the phytoplankton community will be assessed using a CytoSense flow cytometer. We will also collect phytoplankton samples for identification by an outside contract (EcoAnalysts or Cigdem Alemdar). Primary production and phytoplankton N uptake will be measured using ^{13}C /^{15}N (NH_4 and NO_3) tracer methods during 24-hr incubations.

Budget (Table 2)

We are requesting $15,541 for sample collection and analysis/consumables costs, and an additional $9600 for phytoplankton analysis (Ecoanalysts or Cigdem Alemdar; 36 samples for new stations and 12 samples for rapid analysis of Suisun Bay stations collected during Fall Habitat 2 and 4). $2000 is requested in ship costs (2 days) and $12,462 in data analysis / management time (1 mo Parker, 0.3 mo ea. Dugdale and Wilkerson). $1000 is requested for in-state travel costs and to attend the IEP workshop in spring 2012. The IDC rate based on the previous agreement between IEP (USBR, DOI) and the CSU Cooperative Agreement and is 17.5%.

Deliverables

Data will be made available to the IEP as a progress report by April 2012 and presented at a meeting of the Estuarine Ecology Team or other IEP forum (spring 2012 IEP Workshop). Following more careful

analysis, data will be written up as part of a peer reviewed manuscript.

Table 1: Current and proposed transects of the low salinity zone (Suisun Bay) made by Dugdale / Parker Group Fall 2011

Date	**PI**	**Project**	**Current Stations**	**Proposed Additional Stations**
Sept 6	Glibert	Nutrient Ratios	Sacramento R to US657	US649. US2, US3, US4. US5, US6, US7 (7 stations)
Sept 8	Parker	*Microcystis*	D12, US657, Franks tract, Mildred Island, Old River, Mokelumne River	US4
Sept 12	Glibert	Nutrient Ratios	Sacramento R to US657	US649. US2, US3, US4. US5, US6, US7 (7 stations)
Sept 19	Parker	*Microcystis*	D12, US657, Franks tract, Mildred Island, Old River, Mokelumne River	US4
Sept 28	Parker	Fall Habitat-1	Sacramento R to US649	US4
Oct 5	Parker	Fall Habitat-2	San Joaquin R. Stockton to US7	
Oct 12	Parker	Fall Habitat-3	Sacramento R. to US649	US4
Oct 19	Parker	Fall Habitat-4	San Joaquin R. Stockton to US7	
Oct 25	***Proposed***			***US657, US653, US649. US2, US3, US4. US5, US6, US7 (9 stations)***
Nov 25	***Proposed***			***US657, US653, US649. US2, US3, US4. US5, US6, US7 (9 stations)***

Table 2. Proposed budget

Approved: _____

Leroy Morishita, VP for Administration and Finance

Initial: Agnes-Wong Nikerson, InterimAssoc. VP for Fiscal Affairs and Controller

ORSP Proposal No.:		
Cost Sharing?:	☑ No	☐ Yes
Dean:		
Chair:		
ORSP:		
Deviation from negotiated IDC?:	☑ No	☐ Yes
Comment:		
SFSU Required to Institutionalize this program?	☑ No	☐ Yes

INSTITUTION: **San Francisco State University**
PROJECT DIRECTOR: **Alexander Parker**
TITLE: **Supplemental Nutrient and Phytoplankton Monitoring**
SPONSOR: **Dept of Interior**
DURATION: **1 year (9/1/11-8/31/12)**

				Total Requested Y1
PERSONNEL				
Principal Investigator, Richard Dugdale				
	$123,900	Calendar Year Salary		
	$10,325	Per Month		
	2%	RRT		$ 2,478
	39.29%	Fringe Benefits		974
Co-PI, Frances Wilkerson				
	$91,200	Academic Year Salary		
	$7,600	Per Month		
	3%	RRT		2,736
	50%	Fringe Benefits		1,373
Co-PI, Alex Parker				
	$51,036	Calendar Year Salary		
	$4,253	Per Month		
	1.0	Months (100% Time/Effort)		4,253
	62%	Fringe Benefits		2,648
Research Technician, Adam Pimenta				
	$38,000	Calendar Year Salary		
	$3,167	Per Month		
	1.3	Months (100% Time/Effort) Y1-3		3,958
	51%	Fringe Benefits		2,019
Hrly, TBN				
	$13.50	Per Hour		
	240	Hours		3,240
	10.0%	Student Fringe Benefits		324
Total Salaries				16,665
Total Benefits				7,337
Total Salaries and Benefits				**24,003**
TRAVEL				
Local Meeting IEP Workshop				500
Field Work Travel (Local)				500
Subtotal Travel				**1,000**
SUPPLIES COSTS				
Materials and Supplies (Disposable Lab Supplies)				3,000
SubtotalSupplies Costs				**3,000**
Other				
Boat time				2,000
EcoAnalyst - Plankton ID services				9,600
Other Direct Costs Subtotal				**11,600**
Total Direct Costs				**39,603**
Indirect Costs			17.5%	**6,930**
Total Costs				**$46,533**
Modified Total Direct Cost Base (MTDC)				*39,603*

Literature Cited

Dugdale, R. C., Wilkerson, F. P., Hogue, V.E., Marchi, A., 2007. The role of ammonium and nitrate in spring bloom development in San Francisco Bay. Estuarine, Coastal and Shelf Science 73: 17-29.

Dugdale, R. C., Wilkerson, F. P., Parker, A.E., Marchi, Taberski, K. Decreased anthropogenic ammonium enables spring blooms in an urbanized estuary. Estuarine, Coastal and Shelf Science *In review, June 2011*

IEP 2011. Draft Plan: Adaptive Management of Fall Outflow for Delta Smelt Protection and Water Supply Reliability.

Jassby, A., 2008. Phytoplankton in the upper San Francisco Estuary: recent biomass trends, their causes and their trophic significance. *San Francisco Estuary and Watershed Science*, 6: 1-24. http://www.escholarship.org/uc/item/71h077r1

Parker, A.E., F.P. Wilkerson, R.C. Dugdale. Elevated ammonium concentrations from wastewater discharge depress primary productivity in the Sacramento River and the northern San Francisco Estuary. Marine Pollution Bulletin. *In review, May 2011*

Wilkerson, F. P., Dugdale, R. C., Hogue, V. E., Marchi, A., 2006. Phytoplankton blooms and nitrogen productivity in San Francisco Bay. Estuaries and Coasts 29: 401-416.

David Schoellhamer-US Geological Survey

I. Principal Investigator: David Schoellhamer, USGS California Water Science Center, dschoell@usgs.gov

II. Co-Investigators: Brian Bergamaschi, Maureen Downing-Kunz, Jacob Fleck, Tara Morgan, Greg Shellenbarger, and Scott Wright, USGS California Water Science Center.

III. Project title: Suspended sediment and X2 in Suisun Bay and the Confluence during Fall, 1994-2011

IV. Budget: FY2012: $285,000, FY2013: $133,000

V. Study duration: We are proposing a two year study. The first year (FY2012) includes data collection, initial analysis, and preparation for a presentation at the Bay/Delta Science Conference. The second year (FY2013) is for writing and reviewing a journal article.

VI. Priority research topic and questions addressed and overall relevance to the IEP investigations: This project would study the relation between X2 and suspended-sediment concentration in Suisun Bay and the Sacramento-San Joaquin River confluence during Fall, defined in the adaptive management plan as September and October. Specific research questions are:

1) Does X2 position affect suspended-sediment concentration?
2) Did sudden clearing beginning in water year 1999 alter suspended-sediment transport processes?

3) Is the confluence or Suisun Bay more turbid? What effect do the spring/neap tidal cycle, X2 position, and sudden clearing of Suisun bay beginning in water year 1999 have on the turbidity distribution?
4) How does turbidity in Suisun Bay and the confluence compare to turbidity in the Cache Slough complex?
5) How is the quality of suspended sediment affected by resuspension and the passage of X2?

VII. Overall project purpose: Determine how X2 affects turbidity in the Fall in Suisun Bay and the confluence and whether/how Fall turbidity has changed since 1994.

VIII. Project background and conceptual model. The USGS California Water Science Center has collected extensive data and written several publications on suspended-sediment transport in Suisun Bay. Turbidity is primarily determined by suspended-sediment concentration (Ganju et al. 2007, Schoellhamer et al. in press). We began continuously monitoring suspended-sediment concentration (SSC) at Mallard Island in 1994 (Buchanan and Morgan 2011). Beginning in water year 1999 there was a step decrease in SSC in Suisun Bay probably because the threshold from transport to supply regulation was crossed as the anthropogenic erodible sediment pool was depleted (Schoellhamer 2011). In 1995 we continuously measured SSC and hydrodynamic parameters at 11 sites in Suisun Bay in summer and fall. These data and data from monthly USGS water quality cruises were used to quantify three estuarine turbidity maxima in Suisun Bay at the Benicia Bridge, Garnet Sill, and during neap tides in the low salinity zone (Schoellhamer 2001). In 1999 we continuously measured SSC and hydrodynamic parameters at seven sites in Suisun Bay from Fall 1999 to spring 2000. These data described suspended-sediment dynamics in Suisun Cutoff (Brennan et al. 2002) and floodtide pulses in Grizzly Bay (Warner et al. 2003). The low salinity zone (LSZ) was located in Suisun Bay in Fall 1995 and in the confluence in fall 1999, providing historical data sets for comparison to 2011. Instrument deployments in 1996 and 1997 did not include Fall and were used to describe sediment transport in Honker Bay (Ruhl and Schoellhamer 2004). We also operate a meteorological station near the mouth of Honker Bay. These studies show that SSC, and thus turbidity, is controlled by a complex mix of tidal, wind, density, and fluvial forcing. In the fall, fluvial inputs are small, wind is decreasing, and fine sediment has been winnowed from the bed, so SSC is typically less than other seasons. Because 2011 is a wet year, longitudinal and vertical density gradients will be greater in Fall than during dry years and gravitational circulation and stratification will be greater than is typical. Given space and time limitations, readers are referred to the adaptive management plan and the publications cited above for a conceptual model.

IX. Estimated number of all FESA and CESA-listed fishes that would be captured by the field component of your study: none

X. Project description: We intend to present results at the 2012 Bay/Delta Science Conference and to write one or more journal articles on sediment transport. Additionally we will collaborate with other investigators by sharing data, results, and analysis.

Task 1: Collect turbidity and suspended sediment data: In September and October 2011 we will deploy two instrument packages to measure velocity, salinity, turbidity, SSC, and particle size in Suisun Cutoff (a deep channel) and Grizzly Bay (shallow subembayment) where we collected data in Fall 1995 and Fall 1999. Task 6 would deploy a third package on Garnet Sill that measures these

and additional sediment quality parameters. An instrument package used for our Delta sediment study will be deployed in Suisun Cutoff to measure near-bottom quantities (Monismith and Stacey would collect water column measurements here). The Grizzly Bay package at site GS will include a wave gage. If Drs. Monismith and Stacey are conducting their proposed salt flux study, we will rent six conductivity-temperature-depth-turbidity (CTDT) instruments to deploy with their instruments throughout Suisun Bay and the confluence. This would improve spatial coverage of turbidity monitoring and our ability to perform tasks 3, 4, and 5. Collaborating with them costs $40,000 in FY2012 and $33,000 in FY2013 which is included in our part IV budget.

Task 2: Does X2 position affect suspended-sediment concentration?

We will analyze Fall 1994-2011 SSC at Mallard Island to determine whether X2 affects interannual variability. Data from 1999 when the LSZ was in the confluence will be compared to 2011 data when the LSZ will be in Suisun Bay.

Task 3: Did sudden clearing beginning in water year 1999 alter suspended-sediment transport processes?

We will compare 1995 and 2011 data from Suisun Cutoff and Grizzly Bay (and salt flux sites) to determine whether tidal advection of suspended sediment or resuspension by tidal currents and wind waves changed.

Task 4: Is the confluence or Suisun Bay more turbid? What effect do the spring/neap tidal cycle, X2 position, and sudden clearing of Suisun Bay beginning in water year 1999 have on the turbidity distribution?

We will analyze Mallard Island salinity and SSC data from 1994-2011. Mallard Island is at the boundary of the confluence and Suisun Bay. During a tidal cycle, we can assume that higher salinity water is from Suisun Bay and lower salinity water is from the confluence. Thus salinity can be used as an indicator of whether water comes from the Bay or confluence, which allows daily geographic binning of our 15-minute SSC data assuming tidal advection dominates and resuspension is tidally symmetric. Rank sum tests on the two daily SSC bins would determine whether they are statistically different. Daily X2, tide range, wind, and SSC bins would be compared. Historical synoptic data and data collected in Fall 2011 would be used to verify results.

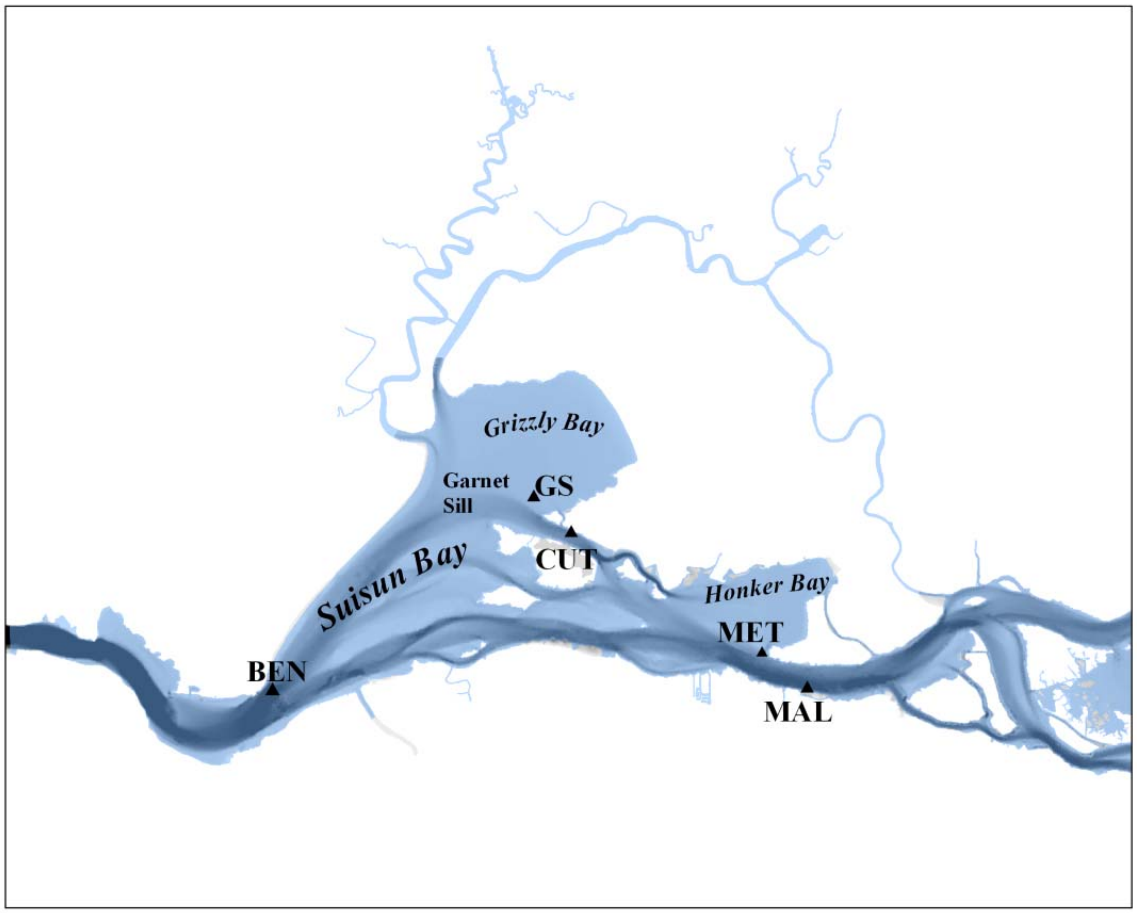
Task 5: How does turbidity in Suisun Bay and the confluence compare to turbidity in the Cache Slough complex?

In the fall, delta smelt are found in the LSZ and in Cache Slough. We have been collecting turbidity and SSC data in the Cache Slough complex since 2008 (IEP2010-132). Fall 2008-2010 SSC will be compared to Mallard Island SSC when the LSZ was in the confluence. Turbidity and SSC from the Cache Slough complex and the LSZ will be compared for Fall 2011 when the LSZ will be in Suisun Bay.

Task 6: How is the quality of suspended sediment affected by resuspension and the passage of X2?

The ecological effects of suspended sediment may be beneficial or deleterious, depending on its' source and behavior in suspension. There are 3 general properties that are significant: particle size distribution (PSD), relative proportion of biogenic material, and contaminant loading. PSD is important because it affects the turbidity (smaller particles cause more turbidity), settling rates, and grazing size class for zooplankton. The relative proportion of biogenic material (phytoplankton, detritus, and exopolymeric material – which has been reported in abundance at X2) can affect the formation of flocs in suspension as well as the grazing of the particles. Contaminant loading is largely determined by source. We have shown that the size class and contaminant loading in suspended sediment material is significantly different than in bed sediments, and varies tidally (Bergamaschi et al. 2001). Also, suspended particles and flocs were shown to contain 5X higher mercury contamination on ebb tide than flood tide in Browns Island (Bergamaschi et al. 2011). We propose to characterize the particle quality at Garnet Sill in Grizzly Bay in situ as well as tidal sampling across multiple tidal cycles. Data will be integrated with turbidity and hydrodynamic data collected by others to develop a conceptual model of how resuspension and salinity variation alter PSD and contaminant transport through Grizzly Bay, with particular attention to the association of contaminants with grain sizes actively grazed by zooplankton. Cost is $125,000.

Map



References

Bergamaschi, B. A., J. A. Fleck, B. D. Downing, E. Boss, B. Pellerin, N. K. Ganju, D. Schoellhamer, W. Heim, M. Stephenson, and R. Fujii. 2011. Methyl mercury dynamics in a tidal wetland quantified using in situ optical measurements. Limnology and Oceanography 56: 1355-1371.

Bergamaschi, B. A., K. M. Kuivila, and M. S. Fram. 2001. Pesticides associated with suspended sediments entering San Francisco Bay following the-first major storm of water year 1996. Estuaries 24: 368-380.

Brennan, M.L., Schoellhamer, D.H., Burau, J.R., and Monismith, S.G., 2002, Tidal asymmetry and variability of bed shear stress and sediment bed flux at a site in San Francisco Bay, USA, in Winterwerp, J.C. and Kranenburg, C., ed., Fine Sediment Dynamics in the Marine Environment: Elsevier Science B.V., p. 93-108.

Buchanan, P.A., and Morgan, T.L., 2010, Summary of Suspended-Sediment Concentration Data, San Francisco Bay, California, Water Year 2007: U.S. Geological Survey Data Series 476, 30 p. http://pubs.usgs.gov/ds/476/

Ganju, N.K., Schoellhamer, D.H., Murrell, M.C., Gartner, J.W., and Wright, S.A., 2007, Constancy of the relation between floc size and density in San Francisco Bay, in Maa, J.P.-Y., Sanford, L.P., and Schoellhamer, D.H., ed., Estuarine and Coastal Fine Sediments Dynamics: Elsevier Science B.V., p. 75-91.

Ruhl, C.A., and Schoellhamer, D.H., 2004, Spatial and Temporal Variability of Suspended-Sediment Concentrations in a Shallow Estuarine Environment: San Francisco Estuary and Watershed Science. v. 2, no. 2, article 1. http://repositories.cdlib.org/jmie/sfews/vol2/iss2/art1

Schoellhamer, D.H., 2001, Influence of salinity, bottom topography, and tides on locations of estuarine turbidity maxima in northern San Francisco Bay, in McAnally, W.H. and Mehta, A.J., ed., Coastal and Estuarine Fine Sediment Transport Processes: Elsevier Science B.V., p. 343-357. URL: http://ca.water.usgs.gov/abstract/sfbay/elsevier0102.pdf

Schoellhamer, D.H., 2011, Sudden clearing of estuarine waters upon crossing the threshold from transport- to supply-regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999: Estuaries and Coasts.

Schoellhamer, D.H., Wright, S.A., and Drexler, J.Z., in press, Conceptual Model of Sedimentation in the Sacramento – San Joaquin River Delta: San Francisco Estuary and Watershed Science.

Warner, J.C., Schoellhamer, D.H., Ruhl, C.A., and Burau, J.R., 2004, Floodtide pulses after low tides in shallow subembayments adjacent to deep channels: Estuarine, Coastal and Shelf Science, v. 60, no. 2, p. 213-228.

Jan Thompson-US Geological Survey

Principal Investigator: Jan Thompson, US Geological Survey, Menlo Park, CA
Co-Investigator: Karen Gehrts, California Department of Water Resources; Francis Parchaso, US Geological Survey, Menlo Park, CA
Project title: **Bivalve effects on the food web supporting delta smelt and Recruitment Patterns of Bivalves with Varying Freshwater Outflow**
Total budget: $64,625 (year 1) $58,750 (year 2)

Study duration: The lab work will take at least a year to complete (GRTS sample for 2012 will not be available until late summer/early fall) This proposal is written as a two year proposal to allow for synthesis of the data.
Priority research topic: Food web effects on delta smelt population dynamics

> **Research question**: How do *Corbula amurensis and Corbicula fluminea* affect the food web supporting Delta Smelt, and how is their success and distribution affected by flow variability in fall?

Overall project purpose: Determine if the bivalves *Corbula amurensis* and *Corbicula fluminea* can limit the availability of phytoplankton and zooplankton to other members of the foodweb by (1) limiting transport of phytoplankton and zooplankton into the LSZ from the upstream Delta and (2) by limiting production of phytoplankton and zooplankton within the LSZ.

PROJECT BACKGROUND AND CONCEPTUAL MODEL
The POD conceptual models recognize that food limitation may be contributing to the decline of Delta Smelt. The questions of how food has changed during the POD years and the factors responsible for those changes have not been resolved. We know that the variability in salinity decreased in late summer and fall during the POD and that Delta Smelt are mostly in the low salinity zone (LSZ) during this period. There are several components of the LSZ food web that might be affected by this change in salinity. We will (1) concentrate here on the response of two species of benthic bivalves and how their change in biomass and grazing rate in space and time may reduce phytoplankton, copepods, bacteria, and microzooplankton, and (2) examine how fall freshwater outflow influences the successful recruitment of these bivalves at several locations where long term data is available.

The distributions of *Corbula amurensis* (*Corbula* hereafter) and *Corbicula fluminea* (*Corbicula* hereafter) are dependent on the salinity distribution at the time their larvae are available for settlement, the number of adults present in the area of settlement, and the environmental stresses on the population post-settlement. Field data that was analyzed as part of an ongoing HSG study shows that these bivalves overlap within the LSZ region (Figure 1) which is consistent with laboratory studies on the juvenile/larval salinity tolerances for both species (Nicolini and Penry 2000, McMahon 1999). It is also apparent in Figure 1 that *Corbula* was a larger presence in the LSZ than *Corbicula* during this time period, and that the pattern is reversed upriver of the LSZ. We will examine both species of bivalve as previous field (Thompson et al 2008, Lopez et al. 2006) and modeling (Lucas et al 2002, Lucas et al 2009) work has

shown that both bivalves can limit phytoplankton biomass in the bay and delta. In addition, experimental work has shown zooplankton nauplii and ciliates can be filtered out of the water column by *Corbula* in the bay (Kimmerer et al 1994, Greene in press). *Corbicula* can filter fast-moving ciliates (Scherwass et al 2001) and glochidia (Scherwass et al 2005) but there have been no experiments on their ability to filter copepod nauplii. Thus, *Corbula* may limit food supplies in the LSZ, but it will primarily be *Corbicula* that will consume phytoplankton and zooplankton as it is transported towards the LSZ. When we examine the water column turnover rate of the two bivalves in the May 2010 GRTS data (Figure 2) we see that both bivalve species are capable of turning over the water column in excess of 10 times per day at many locations. Thus both species have the potential of reducing pelagic food sources.

Because Delta Smelt feed on zooplankton (mostly calanoid copepods, Nobriga 2002) throughout their lives, any direct reduction in zooplankton through filtration by bivalves or indirect reduction in zooplankton due to food limitation needs to be examined. Thus, this project will concentrate on the effect of bivalve grazing on phytoplankton and zooplankton within the LSZ, within the tidal dispersion zone of the LSZ, and upstream of the LSZ as shown by the distribution of stations in Figures 1 and 2.

We know from prior work by the USGS (Figure 3) that extremely wet years resulted in reasonably large populations of *Corbicula* in Suisun Bay and Grizzly Bay. In 1984 and 1985 the presence of *Corbicula* sometimes coincided with a smaller than normal phytoplankton biomass. Thus as stated in the Draft Plan, it is important to understand how the populations of clams have responded to freshwater flow in the past (p. 60 M5) as part of our background information. We are fortunate to have monitoring samples available that will allow us to answer some basic questions about biomass and grazing rate of the two species at several locations at the monthly time scale (previous HSG work has focused on examining the bivalves in GRTS, the spatially intensive sampling). In many cases as explained below we will be filling in missing data as some of this work has been done as part of other projects. Some of this data is available at stations sampled by the USGS but we stopped sampling our monthly stations in 2007 and 2008 so it is not sufficient for present needs.

There is also a stated interest in the Draft Plan to understand how recruitment of the two species is effected by freshwater flow in fall and how changes in fall recruitment might be reflected in population changes into the next year. This data is available from the same monitoring station data and does not require further processing if the bivalves are measured as stated above. The USGS has examined recruitment of *Corbula* in Grizzly Bay from 1988-1999 in the past (Figure 4) and we can see that the only years to have fall outflow in excess of the proposed 2011 outflow (Figure 5) resulted in two very different recruitment patterns. The 1995 event was followed by a wet winter that resulted in a reduction of the population for two years, whereas the wetter fall, 1998, was followed by a dry year and a dry fall in 1999 which resulted in a large population of recruits followed by high biomass. Thus we will also be able to explore how the fall increase or decrease in bivalves resulting from controlled freshwater flow result in a corresponding increase or decrease in spring bivalve biomass in the same area.

FESA and ESA-listed fishes to be captured: None

PROJECT DESCRIPTION

This project augments an ongoing DWR EMP monitoring study with additional laboratory work done on existing samples. DWR currently does a spatially intensive benthic sampling study in spring and fall (GRTS) that can be used to answer some of our basic questions related to the spatial extent of the species following the fall experiment. Task deliverables are shown in Table 1 and division of labor and budget is shown in Table 2. The methods are similar for the tasks and are shown after the tasks

Task 1: Estimate *Corbula* and *Corbicula* biomass and grazing rate during the spring and fall (2012 GRTS) following the fall flow experiment in 2011 to note the lag effects of the higher outflow. This is a compliment to present work. It would be a waste not to see the effect of the increased flow on populations in spring and fall of the following year.
Q1 How do the grazing rates of *Corbicula fluminea* and *Corbula amurensis* vary with longitudinal location and depth in the Delta and the LSZ following an increase in flow in fall?

Task 2: Estimate biomass and grazing rate of *C. amurensis* and *C. fluminea* at DWR monitoring stations for period since 1995. We pick 1995 because it was the first year with fall flows above the 2011 levels (Figure 5) and thus we will examine 14 low flow and the 2 high flow periods. To fulfill this time period we will do these estimates at D7 (2008 -2012), D41a (2008-2012), D4 (2011-2012), D16 (1995 -2012), D24 (1995-2012), D28A (2011-2012).
Q2 What has been the "normal" population biomass pattern of both species with varying fall outflows?

Task 3: Examine size frequency data from data acquired in #2 above to determine recruitment periods and relative success of recruitment for each bivalve species relative to freshwater outflow. This requires examining the time series of the smallest clams measured in Task 2.
Q2 How does recruitment of *Corbula* and *Corbicula* respond to varying fall outflows?

Methods for all tasks: Measuring bivalves: USGS will measure the bivalves to the nearest mm using an image analyzer and calipers (for the larger animals). This is a technique the USGS has used for over 20 years. Bivalves will be returned to DWR for archiving. Biomass estimates will be based on relationships between length and dry tissue weight that will be done by DWR and the USGS during each field sampling using the standard techniques described in Thompson et al. (2008).
Estimating grazing rates: Grazing rates will be calculated using the method described in Thompson et al (2008) for *Corbula* and in Lopez et al (2006) for *Corbicula*. Pumping rates will be adjusted for temperature and values will be provided as the highest possible rates (pumping rates not adjusted for concentration boundary layer) and as low rates (corrected for concentration boundary layer and reduced feeding period). These values should bracket the range in values needed for model studies. Grazing rates will be produced following the completion of each collection period.

Feasibility: All of the methods have been done before by Thompson of the USGS and Gehrts of DWR. J. Thompson has published several papers using these techniques.

Table 1. Deliverables for Tasks. Spring 2012 deliverables highlighted.

	Year 1	Year 2
Progress reports Spring 2012 Deliverables – biomass, grazing rate and recruitment data at D7, D41a, D4, D28A through 2011	X	X
Talks at EET or other IEP forums	X	X
Talks/posters at national meetings		X
Talks/posters at CALFED Science Conference or State of the Estuary		X
IEP newsletter articles submitted		X
Published papers submitted		Probably beyond year 2

Table 2. Task and Budget by Year.

	Person	Budget	Contingencies
GRTS Year 1			
1. May 2012 measured	USGS Tech	$15,000	
GRTS Year 2			
2. Sept 2012 measured	USGS Tech	$15,000	
3. 2012 Biomass & Grazing Rate calculated	USGS Thompson, Parchaso	$5,000	Contingent on 1 & 2
Monitoring Station Data Year 1			
4. Bivalve Measure D7, D41a 2008-2011	USGS Tech	$35,000	
5. Bivalve Measure D4, D28A - 2011	USGS Tech		
6. Bivalve Measure D24, D16- 1995-2011	USGS Tech		
Monitoring Station Data Year 2			
7. Measure all stations 2012	USGS Tech	$25,000	
Monitoring Station Data Year 1-2			
8. Biomass, Grazing Rate and Recruitment analyzed as available; synthesized in year 2	USGS : Thompson & Parchaso DWR: Gehrts	$5,000 $5,000	Contingent on 4, 5 & 6

TOTAL: Year 1: $55,000+9625 (17.5% OH) = $64,625

TOTAL: Year 2: $50,000+8750 (17.5% OH) = $58,750

Literature Cited

Kimmerer WJ, Gartside E, Orsi JJ. 1994. Predation by an introduced clam as the likely cause of substantial declines in zooplankton of San Francisco Bay. Mar Eco Prog Ser 324:207-218

Kraemer L R and Galloway ML. 1986. Larval development of *C. fluminea fluminea* (Muller) (Bivalvia: C. flumineacea): an appraisal of its heterochrony. American Malacological Bulletin 4: 61-79.

Lopez CB, Cloern JE, Schraga TS, Little AJ, Lucas LV, Thompson JK, and Burau JR, 2006, Ecological values of shallow-water habitats: implications for restoration of disturbed ecosystems , Ecosystems 9: 422-440

Lucas LV, Cloern JE, Thompson JK, and Monsen NE, 2002, Functional variability of habitats in the Sacramento-San Joaquin Delta: restoration implications: Ecological Applications, v.12, no. 5, p. 1528-1547

Lucas LV, Thompson JK, Brown LR. 2009. Why are diverse relationships observed between phytoplankton biomass and transport time?. Limnol. Oceanog. 54(1):381-390

McMahon RF. 1999. Invasive characteristics of the freshwater bivalve *C. fluminea fluminea*. Nonindigenous Freshwater Organisms: Vectors, Biology, and Impacts. R. Claudi and J. H. Leach. New York, Lewis Publishers: 315-346.

Nicolini MH, Penry DL, 2000. Spawning, fertilization, and larval development of *Potamocorbula amurensis* (Mollusca: Bivalvia) from San Francisco Bay, California. Pacific Science, 54:377-388.

Nobriga ML 2002. Larval delta smelt diet composition and feeding incidence: environmental and ontogenetic influences. Calif Fish Game 88:149-164

Scherwass A, Eimer A, and Arndt, H. 2001. Selective influence of filter-feeding benthic bivalves (*C. fluminea* sp., *Mytilus* sp.) on planktonic ciliates. Verh. Int. Verein. theor. angew. Limnol.: 27, 3315-3318.

Scherwass, A., Arndt, H. 2005. Structure, dynamics and control of the ciliate fauna in the potamoplankton of the river Rhine. Archiv für Hydrobiologie: 164(3), 287-307

Thompson JK, Koseff JR, Monismith SG, Lucas LV, 2008. Shallow water processes govern system-wide phytoplankton bloom dynamics: A field study. J Mar Syst 74:153-166

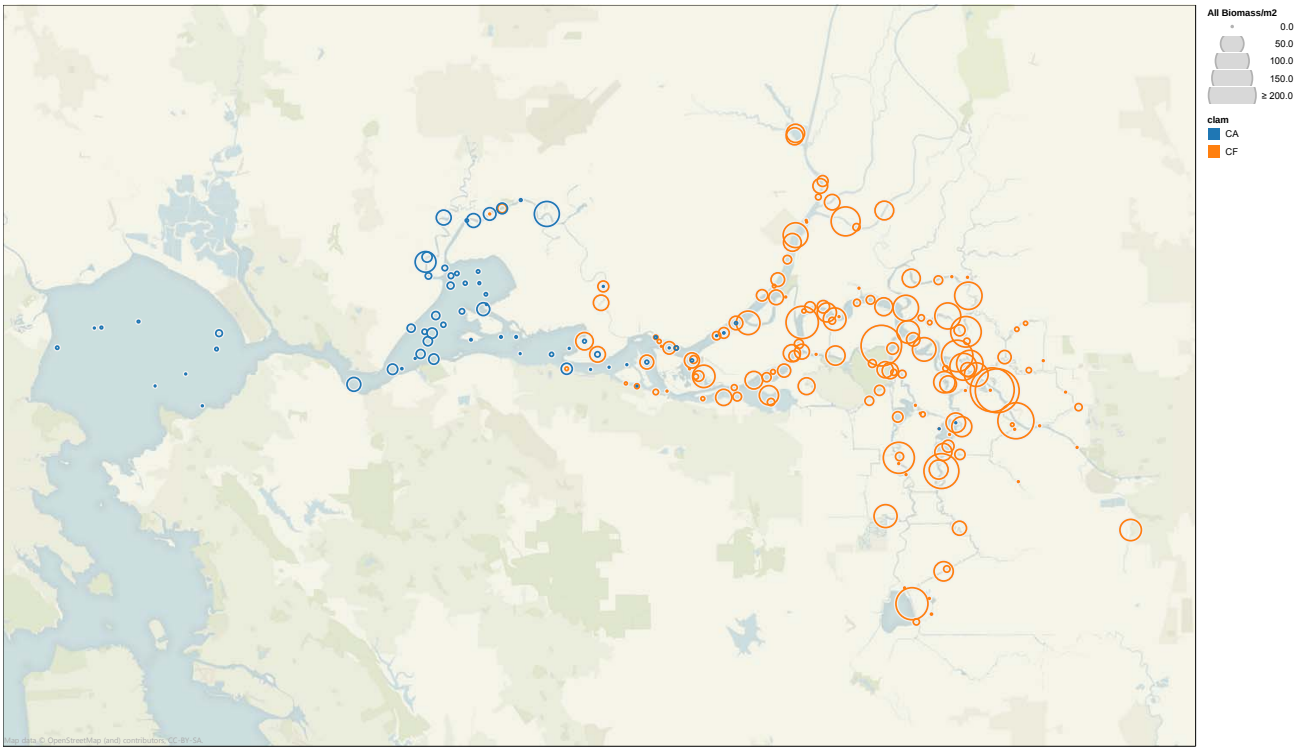


Figure 1. Biomass (g AFDW m^{-2}) of *Corbula* (blue) and *Corbicula* in May 2010. Based on the GRTS sampling in that month.

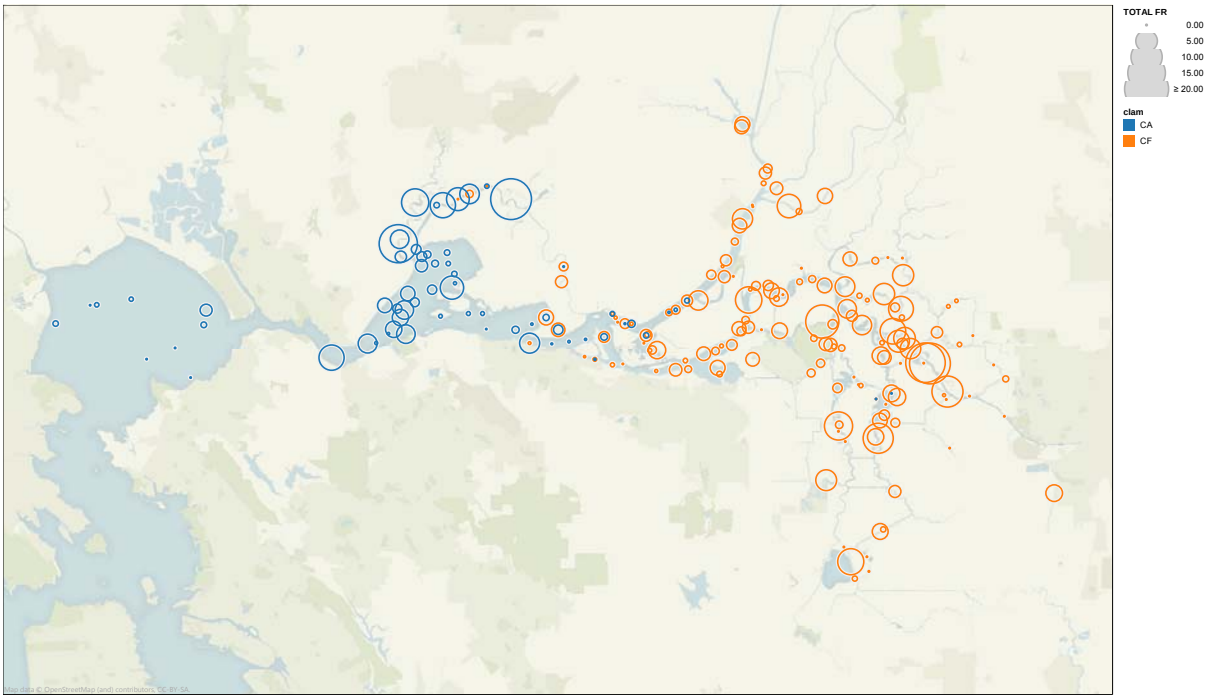


Figure 2. Water column turnover rate (day^{-1}) for *Corbula* (blue) and *Corbicula* in May 2010. Based on the GRTS sampling in that month.

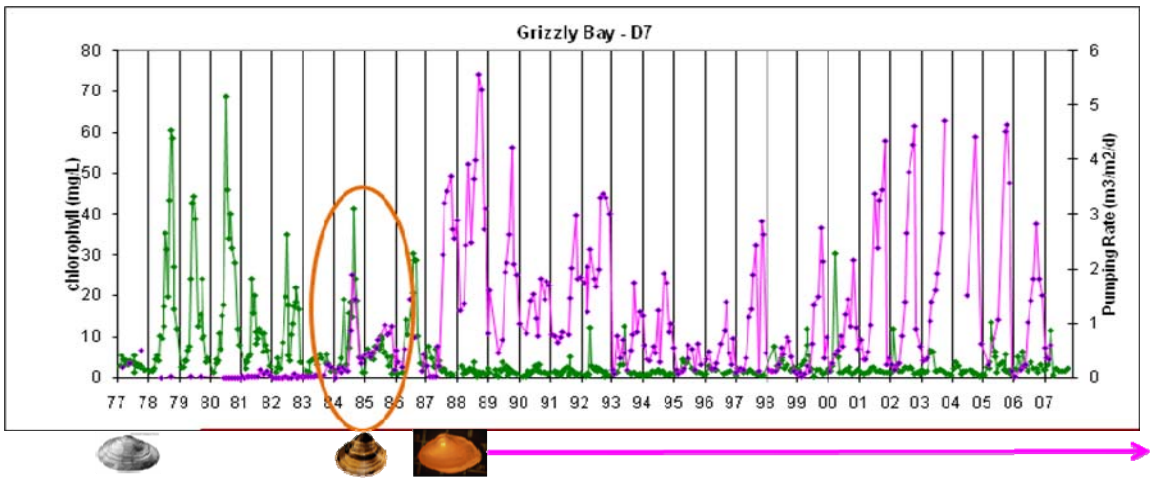


Figure 3. Bivalve grazing rate at D7 (DWR long term monitoring station) in Grizzly Bay. Note that before Corbula invaded in 1986, both *Mya arenaria* and *Corbicula* occurred with sufficient biomass to possibly affect the phytoplankton biomass. Data based on analysis by USGS during CALFED LSZ Delta Smelt study and USGS Priority Ecosystems Study.

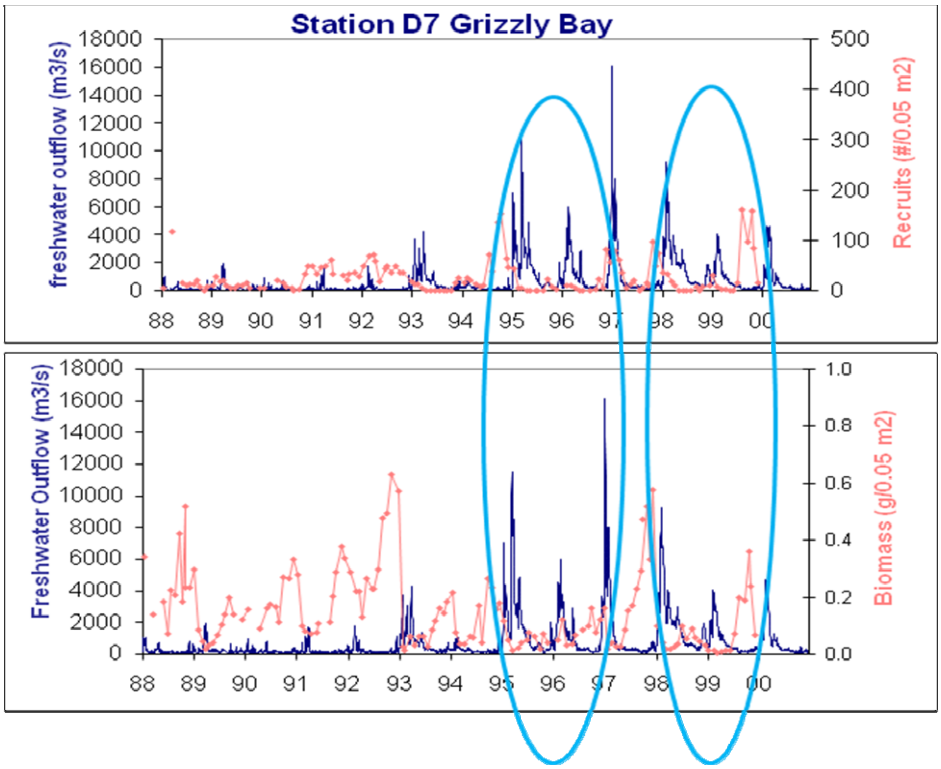


Figure 4. Corbula recruit abundance, total population biomass in Grizzly Bay between 1988 and 1999 (Station D7, DWR samples) plotted with net delta outflow. Note that the wet period in 1995 had a larger effect than the much larger outflow in 1998 because the years following 1995 were wet and the years following 1998 were relatively dry. Data based on analysis by USGS during CALFED LSZ Delta Smelt study and USGS Priority Ecosystems Study.

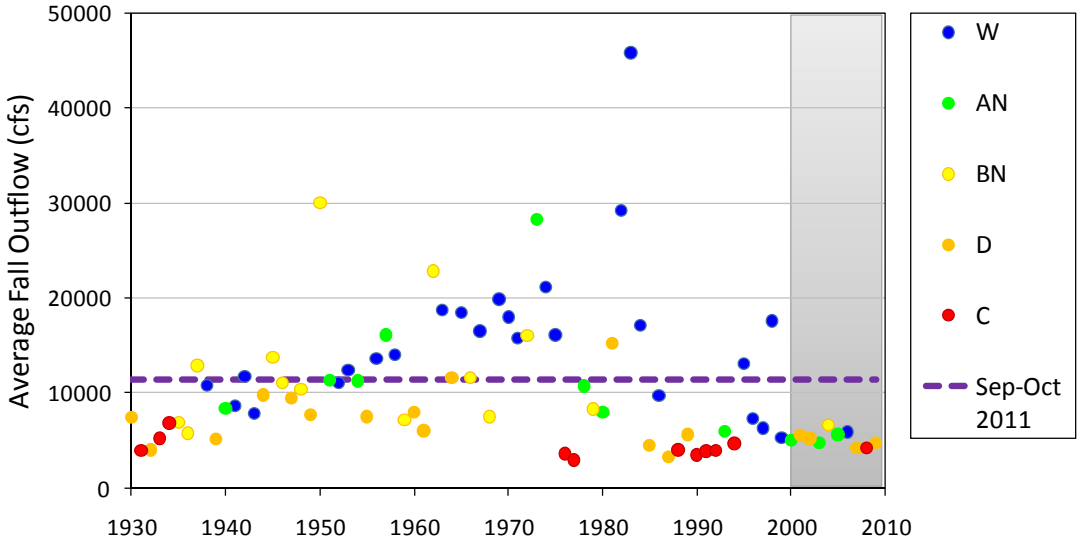


Figure 5 (from Draft Plan Figure 18.) Time series of average daily net Delta outflow index in the fall (cfs, September – November) from 1930 to 2009. The shaded area shows the POD period. Symbols: water year type of the preceding spring for the Sacramento valley (W: wet, AN: above normal, BN: below normal, D: Dry, C: critically dry). Dashed purple line: projected average daily net Delta outflow level for September and October 2011. (Data source: Dayflow (http://www.water.ca.gov/dayflow/). Graphic: A. Mueller-Solger, unpublished.)

Stephen Monismith-Stanford University

I. **Principal Investigator:** Stephen Monismith, Stanford University.
II. **Co-Principal Investigator:** Mark Stacey, UC Berkeley, co-principal investigator.
III. **Title:** Suisun Bay Hydrodynamics: Flows, Salt Fluxes and X2 dynamics during the 2011 IEP Fall X2 study
IV. **Total budget:** $463,000 (year 1: $350,000; year 2: $113,000 – based on 25% overhead as with Delta Science projects)
V. **Study duration:** Two years. The first year would focus on the deployment and basic data processing of the data, aiming to produce a data set useable by the Bay/Delta community. The second year would be devoted to more detailed analysis of the data we would acquire.
VI. **Priority topic:** Understanding how flow affects the physical environment in Suisun Bay and the Western Delta, i.e., the physical dynamics of the LSZ up and downstream of X2.
VII. **Overall project purpose:** (1) Develop an accurate picture of the flows and salt field in Suisun Bay during the IEP field program that can be used to interpret other biological/sediment data and to calibrate/verify the UNTRIM and other modeling that might get done; (2) Use this data along with the USGS 1995 and 1999 Suisun Bay studies and other data to develop a new/refined picture of circulation and mixing in Suisun Bay that can be used to help understand how inflow variability affects the physical environment there.
VIII. **Project background and conceptual model:**
Much of the utility of X2 as a flow metric that can be used to connect water project operations as well as fundamental hydrologic variation to ecological variations in the Bay/Delta depends on the fact that many aspects of the physical environment vary systematically with X2. This includes basic physical variables like salinity, which to first approximation is a function of the distance from the Golden Gate relative to X2, as well as dynamic processes like periodic stratification and gravitational circulation that are important to ecosystem function. Indeed, the original genesis of the X2 standard was the conceptual model that there would be increased primary production in Suisun Bay if the presumed Estuarine Turbidity Maximum (ETM), roughly co-located with X2, was located in Suisun Bay opposite the shallow waters of Grizzly and Honker Bays such that combination of gravitational circulation and lateral mixing by tidal motions (presumably) would lead to enhanced residence time for phytoplankton cells and hence higher standing stocks of phytoplankton biomass.
Since the early 1990s our understanding of the physics of Suisun Bay has improved markedly, most notably we now know that the low salinity zone (LSZ) stratifies and de-stratifies tidally downstream of X2 such that strength of gravitational circulation varies strongly through the tidal cycle and is stronger the farther X2 is downstream. Moreover, while the basic salt balance described by the classical Hansen and Rattray model sets the positioning of salt field in the estuary, the upstream salt flux due to gravitational circulation also intensifies dramatically as X2 moves downstream such that the dependence of X2 on Net Delta Outflow (NDO) is much weaker than might be expected in the absence of stratification.

However, several important aspects of the hydrodynamics of Suisun Bay have only received cursory attention. Firstly, high-resolution computations made using the 2D circulation code, TRIM2D showed how energetic eddies can form in the presence of strong horizontal shear in tidal flows due to differences in depths between channels and adjacent shoals. These eddies and the overall straining of salinity field by spatial variations in tidal currents appeared to horizontally mix Suisun Bay within several tidal cycles. Secondly, observations of flows in Suisun Bay made using ADCPs in 1993 and 1995 show important aspects of the flow that do not readily fit into simple analytical framework of a 2D channel-like estuary: In particular there appears to be a mean clockwise circulation around the Ryer/Roe Island complex in the center of Suisun Bay, meaning that in Suisun Cut the mean, depth-averaged flow is upstream. How this influences the transport of salt, organisms, connectivity of different habitats in the shallow portions of Suisun Bay, or even residence time in Honker and Grizzly Bays remains to be determined. Finally, a further complication to circulation and transport in Suisun Bay are the rectified tidal flows in Montezuma Slough that exist when the Suisun Marsh tide gate is operated. Anecdotally, these are thought to be ca. 2,000 to 3,000 cfs, a significant fraction of the likely NDO in autumn and early winter. How the delivery of freshwater at the top of Grizzly Bay affects the Suisun Bay salinity field as well as the physical connection of Suisun Marsh with Suisun Bay is likewise unclear.
It is fair to note that many of these issues can (but have not yet) be (been) addressed through 3D hydrodynamic modeling using unstructured grid codes like UNTRIM or SUNTANS. However, these models are only as good as their calibrations and so we believe that calibration requires a high quality synoptic data set that can be used to critically assess model skill. Moreover, simply modeling observed flows is not the same as understanding how they work and so the integrated use of models and observations offers the best approach for untangling the complicated physics of Suisun Bay.

IX. **Project description:**

PIs: Monismith and Stacey will have joint responsibility for both tasks;

Questions: Our project is aimed at addressing the following questions:

a. Does X2 respond to Delta outflow increases in the same manner as it responds to decreases in outflow? Does the rate at which X2 changes with flow depend on the absolute flow level?

b. With what accuracy can salinities in the shallows of Honker and Grizzly Bay be predicted from knowledge of X2 in the main channel?

c. What is the effect on Suisun Bay salinities of rectified flows through Montezuma Slough due to operation of the Suisun Marsh gates?

d. What are patterns of horizontal transport in Suisun Bay?

e. Does X2 position influence fluxes between Honker and Grizzly Bays and their adjacent channels?

The tasks below really represent year 1 and year 2 efforts and so might more usefully be combined into a single task. Please note that the second task is moot if the first task is not supported.

a. **Task 1**: *Autumn 2011 Field program*

Timeline: This task would run from September 1, 2011 to August 31, 2013.

Approach: We propose a set of current and salinity meter deployments throughout Suisun Bay. As shown on the attached figure, from October 1 to November 15 (approx.) we would deploy 9 TRDI ADCPs (3@600 KHz and 6@1200 KHz) each with top and bottom CTDs, as well as 2 Sontek ADV/CTD Hydra instruments as well

as 2 additional CTDs in the shallows in Grizzly and Honker Bays from upstream of the confluence of the two rivers to near Benecia. Including existing DWR and USBR salinity monitoring stations and USGS UVMs, this would give thorough coverage of the salinity and velocity fields throughout Suisun Bay, allowing a number of quantities to be direct computed or estimated:

- X2 (with bottom salinities)
- Residual barotropic flows
- Residual and tidally varying stratification and gravitational circulation
- Salt fluxes

In particular, the array is designed to allow us to partition mass and salt fluxes among the various main flow paths through Suisun Bay as well as assessing the degree to which salinities measured in the main channel are reflective of salinities in Suisun Bay's shallow side embayments.

All instruments would be deployed from the RV Shana Rae and would be positioned with so as to ensure safe recovery of all instruments as well as yielding truly representative measurements of the region in which the mooring is placed. Following recovery, all data from the array would be "packaged" for use by other groups participating in the overall Fall X2 study.

Interaction with existing monitoring surveys or other studies: We would make use of existing monitoring data to gain a more detailed map of salinities throughout Suisun Bay. The data we would collect could readily be integrated with other biological sampling as with basic water quality surveys like that done by the USGS Bay program. We have had brief discussions with Dave Schoellhamer's USGS group concerning his and our plans and it is clear that our proposed work and his could effectively be integrated with his focus on sediments and ours on salt and flows being entirely complementary. Both PIs have extensive experience working in interdisciplinary groups doing estuarine and ocean science.

Feasibility: Both PIs have carried out deployments of this kind in energetic tidal flows, although in this case there is somewhat more risk to our instruments because of various ongoing activities in Suisun Bay, notably sand dredging and fishing. There is also the issue of burial: in the past, instruments in the northern reach of the Bay have been buried by sand waves requiring commercial divers to recover them. We will try to work to identify safe locations, likely nearer to shore than we would prefer, and plan on using steel cable for all moorings.

Deliverables: Data report plus archived physical data; Presentations to IEP agencies as desired. We would ultimately prepare at least one archival journal publication from this data, although this cannot be done in 1 year.

Budget: $350,000 (Stanford: $185,000; UC Berkeley $165,000 – both predicated on 25% overhead rate as done for the Delta Science program)

b. **Task 2**: *Analysis of Autumn 2011 Field program*

Timeline: This task would run from June 1, 2012 to August 31, 2013.

Approach: Monismith and Stacey would carry out the detailed analysis of data collected in Autumn 2011, aiming to address the questions detailed above. This would include retrospective analysis of the 1995 and 1999 USGS Suisun Bay study datasets.

Feasibility: Both PIs have extensive experience with analysis of estuarine hydrodynamic data.

Deliverables: We would plan on producing one or more archival journal (e.g. J. Phys. Ocean.) publications as well as giving one or more presentations at national meetings

like the 2012 Fall AGU meeting in San Francisco or the 2012 CERF meeting.
Budget: $113,000 (Stanford: $68,000; UC Berkeley $45,000 – both predicated on 25% overhead rate as done for the Delta Science program)

Richard Connon-UC Davis

I. Principal Investigator and Affiliation

Dr. Richard E. Connon, Research Scientist, Department of Anatomy, Physiology and Cell Biology, School of Veterinary Medicine, UC Davis.

II. Name of Co-Investigators

Dr. Nann A. Fangue, Assistant Professor, Department of Wildlife, Fish, and Conservation Biology, UC Davis.

Dr. Joan C. Lindberg, Director, Fish Conservation and Culture Laboratory, Department of Biological and Agricultural Engineering, UC Davis.

III. Project Title.

Old standards versus new approaches: defining the fundamental niche of delta smelt (Hypomesus transpacificus).

IV. Total Budget:

$72,400.

V. Study Duration.

This study will be integrated into an ongoing Delta Stewardship Council funded project (DSC #201015533) to Dr. Connon, entitled "Physiological mechanisms of environmental tolerance in delta smelt (*Hypomesus transpacificus*): from molecules to adverse outcomes". As such the project will end on June 30th, 2014. The total duration depends on when funds would be available but is likely to be approximately 30 months.

VI. Priority research topic and questions addressed and overall relevance to the IEP investigations.

This research directly relates to the ongoing IEP investigations. It seeks to establish the fundamental niche for three delta smelt life stages, based on the interactions of turbidity, salinity and temperature, as determined by stress levels and performance.

VII. Overall project purpose.

We seek to integrate assessments on the effects of turbidity on Delta smelt physiological performance and stress response along with concurrent studies on salinity and temperature that are being conducted by the PIs.

VIII. Project Background and conceptual model.

Background: Delta smelt population declines have been attributed to entrainment, loss of habitat, competition with and predation from introduced species, and poor water quality (Sommer et al., 2007), along with other complex factors potentially affecting aquatic species throughout the Bay-Delta system (Brown et al., 2009). Presence, abundance and distribution of fish species is thus attributed fundamentally to habitat quality and suitability. Salinity and turbidity, along with water temperature have been shown to be amongst the main physicochemical factors determining the distribution of delta smelt in the Sacramento-San Joaquin estuary (Feyrer et al., 2007; Nobriga et al., 2008). Further investigations have indicated that there is a greater probability of observing delta smelt in areas of relatively low salinities and higher turbidity (Feyrer et al., 2007; 2010). Habitat suitability can also be assessed by measuring performance parameters such as stress levels, swimming behavior, and feeding ability with suitable habitat allowing for optimal performance. Behavior as well as prey capture ability would be suitable indicators of performance. Methods exist, both old and novel, to measure such parameters, and a full assessment of optimal performance at a range of turbidity, salinity and temperature variables can readily be conducted. In addition, plasma hormone and metabolites (cortisol, glucose, lactate, and total amino acids) can be assessed (Pottinger, 2010), along with stress transcriptomic assessments on the hypothalamus-pituitary-interrenal (HPI) axis activation that for example, controls cortisol production (Aluru and Vijayan, 2009).

We propose to measure organismal stress parameters, in conjunction with feeding ability to determine the fundamental niche of delta smelt within the context of turbidity, salinity and temperature. This approach is similar, for example, to one used to define the fundamental niche for *Daphnia magna*, by assessing population growth rates over a matrix of pH and calcium; (Fig. 1), (Hooper et al., 2008).

Conceptual model: Studies have shown that delta smelt require turbidity for successful feeding, and it has been hypothesized that low turbidity may increase vulnerability to predation. However, delta smelt may seek high turbidity zones for refuge that are greater than the optimal turbidity requirement for feeding. Proportions of organic and inorganic materials will further impact performance, and must also be assessed where possible. Salinity and temperature will have further effects on delta smelt's performance ability (effects relating to salinity and temperature are being investigated in DSC #201015533). The optimal fundamental niche, as determined turbidity, salinity and temperature, can be assessed not only through preferential condition trials, but it can also adequately be conducted by measuring performance within these conditions. By assessing organismal stress, using both old and new techniques, along with feeding ability, the fundamental niche for delta smelt can be defined; thus establishing suitability thresholds for larval, juvenile and adult stages.

IX. Estimated number of all FESA and CESA-listed fishes that would be captured by the field component of your study.

None. Delta smelt will be obtained from Dr. Lindberg at FCCL.

X. Project description:

1. Task title: Effect of turbidity, salinity and temperature on stress and performance on delta smelt.

2. Investigator(s) responsible for carrying out the task: Richard Connon, Nann Fangue and Joan Lindberg.

3. Specific questions the task seeks to address: Do previously identified turbidity, salinity and temperature requirements correspond with low stress levels and optimal performance within the fundamental niche of delta smelt?

4. Approach and methods: Approach and methods for salinity and temperature are highlighted in DSC #201015533. Detailed below are additional studies incorporating turbidity effects:

A) Based on data from prior studies conducted by Dr. Lindberg, larvae, juveniles, and adult delta smelt will be exposed to a range of turbidity levels (comprised of algal and inorganic particles) and allowed to acclimate for 24 hours. *Test 1.* Each delta smelt will then be fed with *Artemia franciscana*, for a period of three minutes, after which they will be euthanized and snap frozen. Prey capture will be quantitatively assessed using existing *A. franciscana* 18s Ribosomal RNA sequences and quantitative PCR; indicative of total biomass consumed. *Test 2*. after 24 hours acclimation to a range of turbidity levels, stress will be induced by agitating the water in each vessel. Recovery levels at each turbidity level will be assessed over time, with fastest recovery as an indication of best turbidity level. Samples will be taken at regular intervals over a six hour period, and plasma hormone and metabolite analyses will be performed (as described by Pottinger, 2010), along with genomic assessments (Aluru and Vijayan, 2009), to quantify stress levels at each condition.

B) Turbidity, salinity and temperature variables will be investigated jointly, maintaining one parameter constant (at pre-established optimum) and conducting a 5 x 5 matrix exposure for the other two. Stress and feeding assessments will be performed as summarized above.

5. Interaction with existing monitoring surveys or other studies: There is a direct link with this proposal, studies previously conducted by Dr. Lindberg, and an ongoing DSC project # 201015533. Other studies, to out knowledge, do not take into account stress measurements in delta smelt in order to assess optimum conditions. Further links will be established during the project.

6. Feasibility: Feasibility of this project is extremely high, as qPCR assay for Artemia 18S determination, genomic assessment for stress using microarrays (in development) and qPCR assays for transcription assessments are readily available. All participants are highly qualified to perform the proposed research.

7. Deliverables (e.g. report(s), journal publication(s), IEP newsletter article(s), presentation(s): Overall deliverables are included in DSC #201015533. Additional deliverables include at least one publication on the fundamental niche of delta smelt as it relates to turbidity and one publication on stress assessments in delta smelt.

8. Budget: Total $72,400. Direct costs $57,920, plus $14,480 indirect costs (25%). Funds are requested for a Junior Specialist (49%); $42,920 over 30 months (no benefits), and supplies and materials; $15,000.

9. If you are proposing a multi-year study, please give a task schedule: Year 1 (12 months): Optimization of techniques for delta smelt, determination of baselines, and optimum turbidity

assessments; determined by stress and feeding. Preliminary stress and feeding assessments will be conducted on larval delta smelt by April 2010. Year 2 and 3 (18 months): Determination of fundamental niche for delta smelt; larvae, juveniles and adults and prepare results for publication.

10. If applicable, number of delta smelt specimens required by task. Indicate life stage (larval, juvenile and adult) and hatchery or wild origin: Approximately 1,000 specimens will be required for each life stage; totaling 3,000 individuals. Numbers are additional to concurrent project #201015533.

References

Aluru, N., Vijayan, M.M., 2009. Stress transcriptomics in fish: a role for genomic cortisol signaling. Gen Comp Endocrinol 164, 142-150.

Brown, L.R., Kimmerer, W., Brown, R., 2009. Managing water to protect fish: a review of California's Environmental Water Account, 2001-2005. Environmental management 43, 357-368.

Feyrer, F., Newman, K., Nobriga, M., Sommer, T., 2010. Modeling the effects of future freshwater flow on the abiotic habitat of an imperiled estuarine fish. Estuaries and Coasts 34, 120-128.

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

Hooper, H.L., Connon, R., Callaghan, A., Fryer, G., Yarwood-Buchanan, S., Biggs, J., Maund, S.J., Hutchinson, T.H., Sibly, R.M., 2008. The ecological niche of Daphnia magna characterized using population growth rate. Ecology 89, 1015-1022.

Nobriga, M.L., Sommer, T.R., Feyrer, F., Fleming, K., 2008. Long-Term Trends in Summertime Habitat Suitability for Delta Smelt (Hypomesus transpacificus). San Francisco Estuary and Watershed Science, 6(1) 6.

Pottinger, T.G., 2010. A multivariate comparison of the stress response in three salmonid and three cyprinid species: evidence for inter-family differences. Journal of Fish Biology 76, 601-621.

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

Figures.

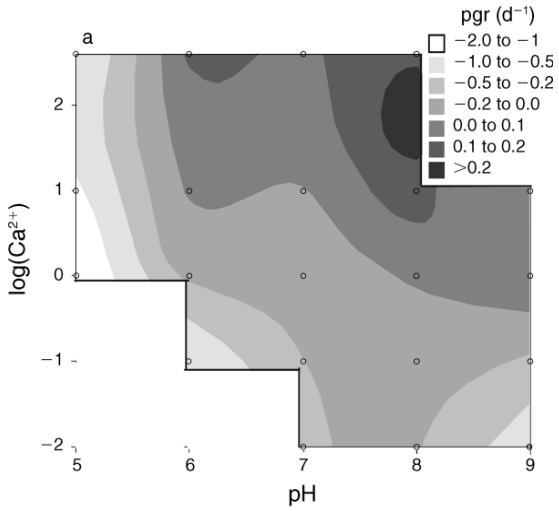


Fig. 1. Population growth rate (pgr) contours plotted against nominal Ca^{2+} and pH concentrations. Open circles represent Ca^{2+} x pH treatments. Population growth rate contours were generated from the raw data (n = 42 Daphnia populations) on a 5 x 5 grid with seven contours at specified values of pgr using Minitab 14. The minimum and maximum contour levels reflect the measured pgr range of -1.87 to 0.23. Measurements were not made in the areas in the top right and bottom left corners (after Hooper et al, 2008).

Carol Kendall-US Geological Survey

I. Principal Investigator: Carol Kendall (US Geological Survey), ckendall@usgs.gov

II. Co-Investigators:

Marianne Guerin, Resource Management Associates (RMA)
Megan Young, Steve Silva, and Tamara Kraus (US Geological Survey)

Guerin's Role in Project and the Relation to other IEP Projects: This project is linked to Kendall's two 2010 IEP projects. Under a range of historical flow conditions 01/1990 – 12/2011, Guerin will use RMA 2-dimensional models to calculate metrics defining transport time scales such as residence time, exposure time, and/or age of a water parcel in the Suisun region, the SJR Confluence region and the Cache Complex region; and, to calculate the volume of water encompassing the low salinity zone (LSZ), the location of X2, as well as other abiotic variables. Residence time and RMA modeled volumetric percentages of source waters will be used to help interpret the sources and determine the fate of nutrients and organic matter at the times and locations of previously generated and evaluated isotope and nutrient data (see: Figure 1, and Tables 1 and 2), plus proposed new data generated during fall 2011 as part of a new Kendall IEP2011 proposal.

Roles of other Co-Investigators: All of the investigators will be involved in the interpretation of data and modeling results and the preparation of written documentation.

III. Project title: Residence Time as an Aid to Interpreting Nutrient Dynamics and Other Habitat Characteristics in the Suisun, SJR Confluence, and Cache Complex Regions

IV. Total budget: $126,560 (includes USGS overhead of 38%)

V. Study duration: 1 year (Preliminary results should be available spring 2012).

VI. Priority research topic and questions addressed:

Two IEP priority research topics are addressed: habitat effects (**Topic 1**) and food web effects (**Topic 2**) on delta smelt population dynamics. The focus on habitat effects is the quantification of abiotic variables such as residence time within the study area and their effect on nutrient dynamics (**Question 1C**). The focus on food web effects is at the level of nutrients and primary productivity (**Question 2C**). This proposal supports the research priority from the "CALFED Science Program Issue Summary" on the role of ammonium: Use models to explore the transport of ammonia/um within the Delta and effects on the amount of, type of, and growth of algae, the base of the Delta food web. This proposal also directly addresses one of the goals (p.19) of the DRAFT Fall Adaptive Management (A.M.) Plan to "…to increase understanding about the effects of adjusting Fall outflow on the physical and biological environment, how those effects propagate through the ecosystem…" by establishing metrics of hydrodynamically-linked abiotic variables (residence time, X2 location, volume of LSZ, …) using well-documented models. By analyzing these variables in conjunction with nutrient and isotopic data, we will be establishing "…how these effects propagate through the ecosystem…" in terms of the base of the food web.

VII. Overall project purpose:

The purpose of this project is to investigate how seasonal and spatial changes in freshwater flow, particularly in the fall, and the volumetric percentages of water from different sources -- Sacramento R., San Joaquin R., Yolo Complex, Sac Regional Wastewater Treatment Plant (SRWTP), *etc.*--affect the temporal and spatial variations in the sources, transport, and sinks of ammonium (denoted here as NH4), nitrate (denoted here as NO3), chlorophyll, and organic matter (particulate and dissolved organic matter, denoted here as POM and DOM) in the Cache Complex, the Suisun Region, and the Confluence Region. In specific, we propose to take advantage of several large sets of <u>existing</u> chemical and isotopic data, plus new chemical and isotopic data from samples collected fall 2011 and analyzed as part of Kendall's proposed IEP2011 studies, to ask questions about how the residence time of waters, the position of X2 (the location of the 2 ppt isohaline), and the volume of water defining the LSZ (average daily salinity conditions of 1-6 ppt) affects constituents important to the base of the delta smelt and other foodwebs in the Cache Complex, the Suisun Region and the Confluence Region, especially in the fall.

VIII. Brief Description of Project Background

Background: Ecosystem productivity in the Delta is influenced by the time scales for nutrient transport entering the system, from upstream sources and from sources within the Delta such as agricultural returns or wastewater effluent. Nutrients are also transported between different habitat types with variable nutrient characteristics. If the growth rate of primary producers in nutrient-rich habitats matches transport time scales, the efficiency of nutrient utilization may be optimized (Cloern, 2007), and if mismatched, nutrients may be underutilized. Thus, knowledge of transport time scales of the constituents in Delta waters can help define the local productivity characteristics of the ecosystem.

Of the metrics that are frequently used to define transport time scales, we focus on residence time, exposure time, and age of a water parcel in this proposal. Residence time is defined herein as the cumulative amount of

time a parcel of water is contained within a specified domain (defined elsewhere as exposure time). These metrics have been defined and redefined in the literature (Monsen *et al*., 2002; Lucas *et al*., 2006; Olivera and Baptista, 1997; Abdelrhman, 2005; Jouon *et al*., 2006; Bilgili *et al*., 2005; Chen, 2007; Wang *et al*., 2004). In a given domain, residence time varies spatially and temporally with flow conditions, tidal cycle, and other conditions (*e.g*., wind velocity). However it is defined, residence time is a critical component in understanding nutrient dynamics, habitat suitability for aquatic species, exposure to toxic constituents and other factors such as the transport of pelagic plankton (Monsen *et al.,* 2002).

For example, quantifying the time scales for the exchange of nutrients between the Sacramento River and the Cache Complex region can increase our understanding of the primary productivity regime and the exchange of nutrients on pertinent time scales, from tidal to seasonal (Lehman *et al.*, 2009). Our isotopic analyses and preliminary mass balance calculations (Kendall *et al.*, 2010b) indicate this area may act as a significant sink of nutrients. Figure 2 is an example of how nutrient concentrations evolve in samples collected at various distances downstream of SRWTP, as indicated by large shifts in isotopic ratios at Rio Vista and the confluence. By including residence times, volumetric source percentages and net flows calculated in RMA models in our analysis, we will be able to better estimate how much of the NH4 loss and NO3 gain is due to nitrification *vs.* dilution, additions of nutrients from the tributaries, or changes in net flow. Figure 3 illustrates the differences in Sacramento River and Cache Complex slough samples under high and low flow conditions along several transects. Differences in nutrient concentrations and downstream nitrification trends in the mainstem and sloughs such as these will be evaluated using residence time and volumetric percentages to determine the likely cause of these trends.

Numerical models can generate information to assess hydrodynamic effects -- for example, net flow, stage, transit time, residence time, and dilution -- at any spatial and temporal density. Tables 1 and 2 indicate potential data collection times and sites (see Figure 4 and Figure 5) where we will use model calculations to interpret data. Model results will be used to produce spatial maps of metrics such volume of water in specified concentration ranges (*e.g.*, such as ranges specifying the LSZ), residence time and/or water depth. Spatial maps can be visualized in contour plots, such as those shown in Figure 1 illustrating RMA model calculations of exposure time in the Delta. RMA has implemented four different methods for measuring the "residence time" concept, supported by spatial visualization.

In summary, by using RMA historical model output in the study area in combination with isotopic and nutrient data, we hope to clarify the linkages among different sources and sinks of nutrients and organic matter (including phytoplankton and DOM) in the 3 main fall smelt habitats (Cache, Confluence, and Suisun regions) discussed in the DRAFT Fall A.M. Plan using residence time calculations. RMA models will also be used to calculate metrics quantifying residence time in user-defined areas for a range of historical flow conditions in the period 1990 – 2011 (this period has a wide range of Water Year Types for both Sacramento and San Joaquin watersheds). In addition, the volume of the LSZ will be calculated, along with X2 position (and other pertinent abiotic variables), to investigate the relationship with residence time on a range of potential Delta outflow rates, with a focus on fall outflow (although LSZ volume and X2 have been calculated elsewhere, using RMA models for all variables assures an internally consistent set of calculations and assumptions).

IX. Estimated number of FESA and CESA fish captured in study: None

X. Brief Description of Project

Feasibility and Relevance: The information produced by the tasks described in the proposal, such as the analysis of residence time relationships in specific regions of the Delta under historical flow conditions, has long been considered an important aid in understanding nutrient and food web dynamics in the Delta. However, combined data analysis and modeling projects such as the one described here, have not historically been funded despite their value in the synthesis of data into metrics that can be used to specify habitat objectives. This is reflected in the current DRAFT Plan (p.46): "The greater hydrodynamic complexity in the Suisun region likely produces a greater variety of residence times and tidal excursions ….. but detailed studies about these interactions are currently lacking". The approaches and methods described below have been demonstrated using RMA models in previous Delta projects (Franks Tract, BDCP, Discovery Bay, *etc*.).

Task 1 – Select a range of hydrodynamic conditions in the period 1990 – 2011 in which to investigate: the relationship between residence time in the Cache Complex, the Suisun Region and the Confluence Region, the volume of the LSZ and outflow conditions, particularly in the fall; and, the relationship between residence time and other modeled variables (e.g., X2 and volumetric percentages), and the available isotopic and nutrient data. The output of this task will be specific months and years during which these relationships will be investigated (Guerin, $7,000).
Task 2 – Develop RMA 2-D historical models for the range of conditions defined in Task 1 (~80 % of Task cost estimate). Models will also be used to calculate residence time, net flow, volume of the LSZ, volumetric percentages, and the location of X2 at a minimum (~20 % of cost estimate) (Guerin $13,200; RMA staff $5,200).
Task 3 – Produce spatial maps of residence time (or, exposure time or age) and of the LSZ for the conditions defined in Task 2 using RMA models (Guerin $23,100; RMA staff $6,500).
Task 4 – Prepare quarterly reports, presentations at local workshops, documentation with results relating metrics of abiotic variables with nutrient and isotopic data, and the relationship of residence time with fall outflow conditions; produce one journal article. (Kendall, $0 (in kind); Young, Kraus, and/or Schmidt, $28,000; Guerin, $7,000).
Task 5– Project management (Kendall, $0 (in kind); Young $13,000; Guerin, $0).

References

Abelrhman, M.A. (2005) Simplified modeling of flushing and residence time in 42 embayments in New England, USA, with special attention to Greenwich Bay, Rhode Island. Estuarine, Coastal and Shelf Science 62: pp. 339 – 351.

Biligili, A. J.A. Proehl, D.R. Lynch, K.W. Smith,. M.R. Swift (2005) Estuary/ocean exchange and tidal mixing in a Gulf of Maine estuary: A Lagrangian modeling study. Estuarine, Coastal and Shelf Science 65: pp. 607 – 624.

Chen, X.J. (2007) Averaged two-dimensional trajectory model for estimating transport time scales in the Alafia River Estuary, Florida. Estuarine, Coastal and Shelf Science 75: pp. 358 – 370.

Cloern, J.E. (2007) Connectivity and ecosystem productivity: Implications from a simple model. The American Naturalist. 169(1): E21-E33.

Kendall, C., Silva, S.R., Young, M.B., Guerin, M., Kraus, T., and Parker, A.E., (2010b). Stable isotope tracing of nutrient and organic matter sources and biogeochemical cycling in the Sacramento River, Delta, and Northern Bay. U.S. Geological Survey Open-File Report 2011-XX, preliminary draft.

Lehman, P. W. S. Mayr, L. Mecum. C. Enright. (2009) The freshwater tidal wetland Liberty Island, CA was both a source and a sink of inorganic and organic material to the San Francisco estuary. Aquatic Ecology. 0(0) pp. 1-14.

Lucas, L.V., D.M. Sereno. J.R. Burau. T.S. Schraga. C.B. Lopez. M.T. Stacey. K.V. Parchevsky. V.P. Parchevsky. (2006) Intertidal variability of water quality in a shallow tidal lagoon:Mechanisms and Implications.. Estuaries and Coasts, 29(5), pp. 711-730.

Monsen, N.E., J.E. Cloern, L.V. Lucas. (2002) A comment on the use of flushing time, residence time, and age as transport time scales. Limnology and Oceanography 47(5):pp. 1545-1553.

Oliveira, A. and A. M. Baptista. (1997) Diagnostic modeling of residence times in estuaries. Limnology and Oceanography 33(8):pp. 1953 – 1946.

Wang, C.F., M.H. Hsu, A.Y. Kuo. (2004) Residence time of the Danshuei Estuary, Taiwan. Estuarine, Coastal and Shelf Science 60: pp. 381 - 393.

Table 1. Transect dates and data types

Transect Dates	PI and Program	Isotope samples *	SR-Cache-Delta samples +	Chemistry (includes measured values and ones calculated by difference) #
Monthly $	USGS Polaris	No °	0-0-9	For details see: http://sfbay.wr.usgs.gov/access/wqdata/
3/26-27/09	Dugdale SWC	Yes	10-2-13	NO3, NO2, NH4, PO4, urea, DIC, silica, Chl-a, Pheo, POC, PON, EC, T, uptake rates (C, NO3, NH4), OBS, T, etc.
4/23-24/09	Dugdale SWC	Yes	10-3-12	
3/9/09	Parker WB	No	7-0-1	NO3, NO2, NH4, PO4, urea, DIC, silica, Chl-a, Pheo, Chl 5u, POC, PON, EC, T, uptake rates (C, NO3, NH4), flow cytometer, SCUFA, T, etc.
4/6/09	Parker WB	No	7-0-1	
5/8/09	Parker WB	No	7-0-1	
3/16-17/09	Foe WB	No	5-4-4	NO3, NO2, NH4, TN, DON, TP, TDP, PO4, DOC, Chl-a, Pheo, EC, pH, DO, NTU, T, etc.
3/30-31/09	Foe WB	No	5-4-4	
4/13-14/09	Foe WB	No	5-4-4	
4/27-28/09	Foe WB	No	5-4-4	
5/11-12/09	Foe WB	No	5-4-4	
5/26-27/09	Foe WB	Yes	5-4-4	
6/8-9/09	Foe WB	Yes	5-4-4	
6/22-23/09	Foe WB	Yes	5-4-4	
7/14-15/09	Foe WB	Yes	5-4-4	
8/3-4/09	Foe WB	Yes	5-4-4	
9/28-29/09	Foe WB	Yes	5-4-4	
10/20-21/09	Foe WB	Yes	5-4-4	
11/9-10/09	Foe WB	Yes	5-4-4	
12/7-8/09	Foe WB	Yes	5-4-4	
1/25-26/10	Foe WB	Yes	5-7-4	
2/22-23/10	Foe WB	Yes	5-7-4	
4/26/10	Dugdale 2Rivers	Yes	22-0-4	NO3, NO2, NH4, PO4, urea, DIC, silica, Chl-a, Pheo, POC, PON, EC, T, uptake rates (C, NO3, NH4), OBS, T, etc.
8/25/10	Dugdale 2Rivers	Yes	16-0-4	
4/19/11	Dugdale 2Rivers	Yes	15-0-4	
4/15/10	Kendall Sloughs	Yes	4-3-0	NO3, NO2, NH4, TN, DON, TP, TDP, PO4, DOC, Chl-a, Pheo, EC, pH, DO, NTU, T, etc.
4/19/11	Kendall Sloughs	Yes	5-7-0	
5/10/11	Kendall Sloughs	Yes	5-7-0	
6/9/11	Kendall Sloughs	Yes	5-7-0	

7/20/11	Kendall Sloughs	Yes	5-7-0	
8/18/11	Kendall Sloughs	Yes	5-7-0	
9/?/11 [ϕ]	Kendall Sloughs	Yes	5-7-0	

NOTES:

* Isotope analyses include NH4-δ^{15}N; NO3 δ^{15}N and δ^{18}O; DOC-δ^{13}C; POM δ^{13}C, δ^{15}N, δ^{34}S, C:N, C:S; and water δ^{18}O and δ^{2}H; also DIC-δ^{13}C on recent Slough project samples.

[+] Sites are divided into the categories "SR" (I-80 to Isleton), "Cache" (tributaries and sloughs in the Cache/Yolo Complex), and "Delta" (Rio Vista downstream to Martinez). Hence, 4-2-4 means 4 sites in the SR, 2 in the Complex, and 4 in the Delta. Foe sites and "Dugdale 2 Rivers" sites sampled on the San Joaquin River are not included in this table. Polaris cruises include 10 sites downstream of Martinez to near Angel Island.

[#] This is a list of the chemistry data we have access to; other data may be available.

[$] Data are site-dependent; for example, nutrient data are only available for a subset of sites.

° We only have limited isotope data for Polaris cruises 2009-2011; however, we have almost monthly isotope data for 8/06-5/08 (and not-yet-analyzed samples for 7/08, 11/08, 5/09, and 4/11).

[ϕ] We are proposing to continue and expand the slough sampling September through at least December as part of another 2011 IEP proposal.

Table 2. Dates of transects in the SJR DWSC and SF Bay where we have piggybacked isotope samples onto routine IEP-EMP and RMP cruises. Dates from different cruises have been lined up so the months match. [+]

SJR DWSC sites *RV San Carlos* cruises *	SF Bay/Delta *RV Polaris* cruises [#]	Water Year type of the preceding spring for the Sacramento Valley
08/09/06	08/15/06	wet
09/07/06	09/12/06	wet
09/19/06		wet
10/05/06	10/17/06	wet
11/06/06	11/14/06	wet
11/20/06	12/12/06	wet
	01/09/07	
	02/06/07	
	03/06/07	dry
	04/03/07	dry
06/28/07		
07/12/07	07/19/07	dry
07/26/07		dry
08/10/07		dry
08/23/07		dry
09/25/07	09/11/07	dry
10/11/07		dry
10/25/07	10/23/07	dry
11/09/07	11/14/07	dry
11/26/07		dry
12/12/07	12/11/07	dry
	02/12/08	
	03/11/08	critically dry
	05/06/08	critically dry
	07/17/08	critically dry
	11/18/08	critically dry
	05/19/09	dry
	04/19/11	wet
	08/16/11	wet

Notes:

[+] Samples 8/06 to 5/08 were collected and analyzed as part of Kendall's CALFED PIN700 project.

* Some of these sites were sampled 3 times 4/10, 8/10, and 4/11 for isotopes as we piggybacked on the "Dugdale 2 Rivers" project; these SJR samples have not yet been analyzed for isotopes.

[#] Samples collected after 5/08 have not yet been analyzed for isotopes. As part of this proposal, we plan new monthly Polaris cruises September through December 2011.

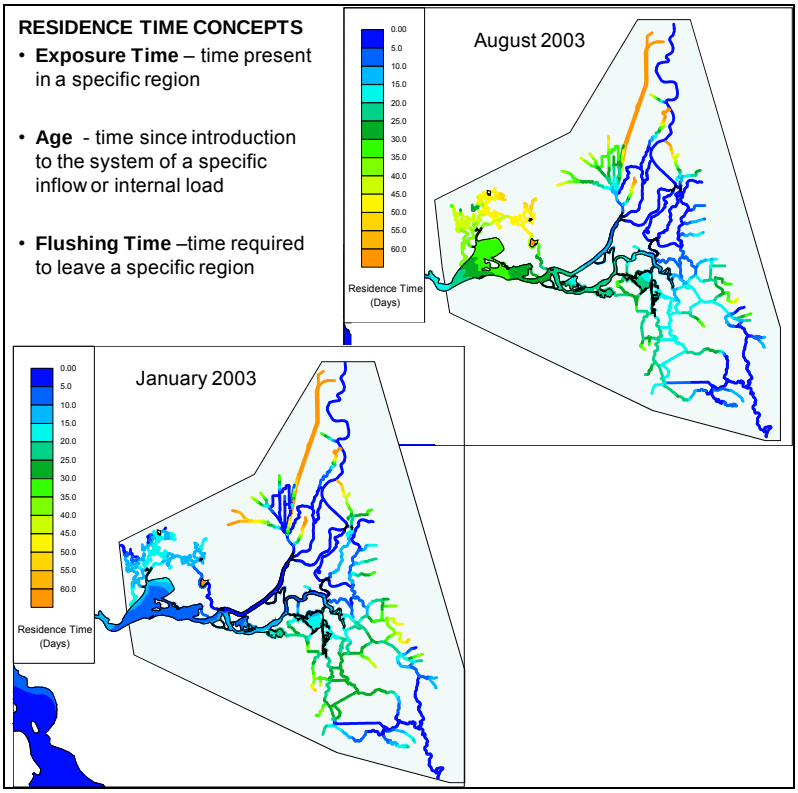


Figure 1. Residence time and other measures of transport time scales can be calculated in RMA models – these figures show the metric exposure time in the Delta area upstream of Martinez in January and August of 2003. Residence time is much greater in Suisun Bay and in Suisun Marsh in August vs. February, as expected.

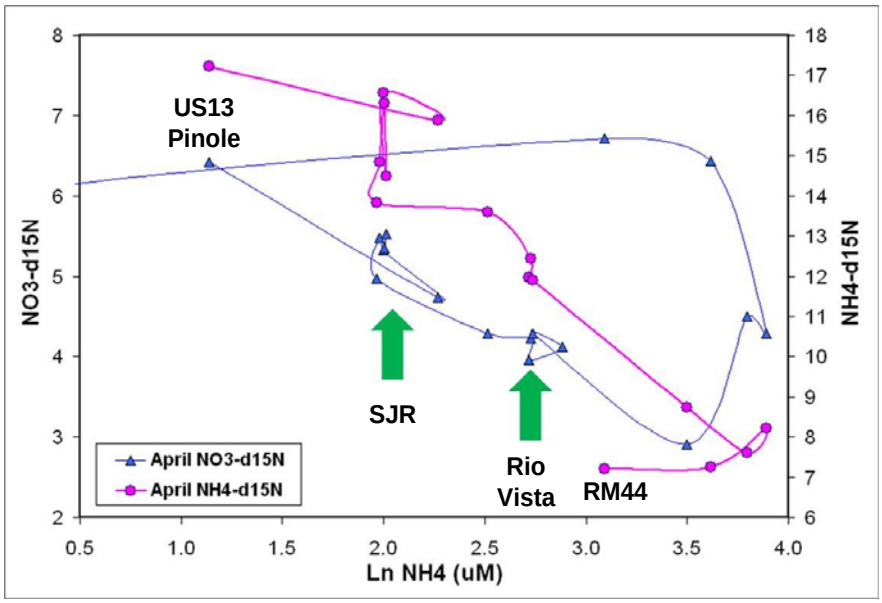
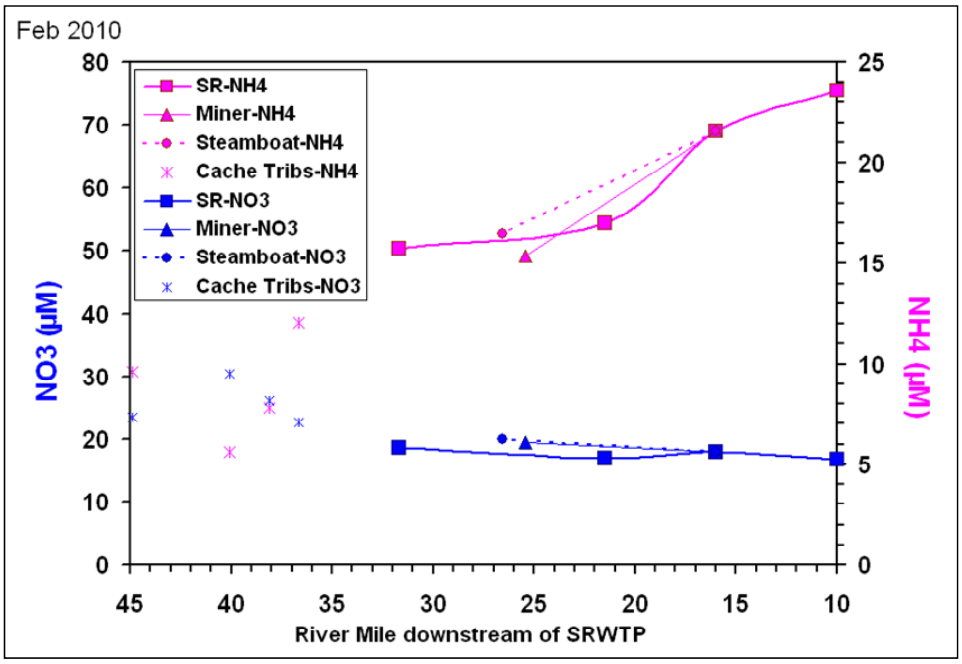


Figure 2. This plot clearly illustrates the cycling and mixing of nutrients at Rio Vista (where nutrients are derived from the Sac River, Cache Complex, and western Delta) and near the confluence of the Sacramento and San Joaquin Rivers (SJR in plot) – possibly indicating increased residence time of waters in upstream or nearby open water areas.



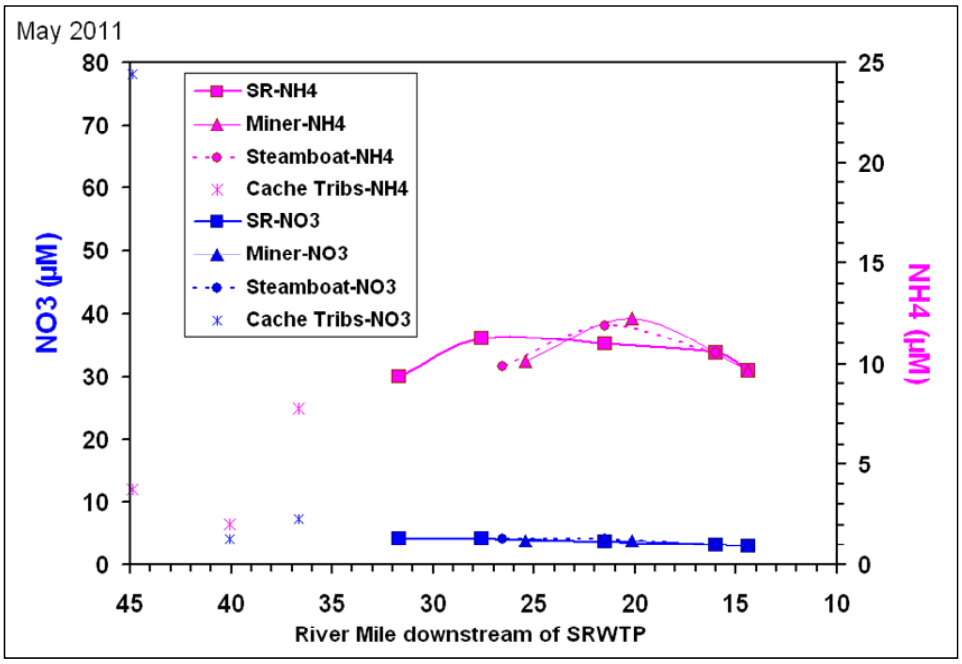


Figure 3. The figures above show concentrations at 4 types of sites: mainstem, Miner Slough, and Steamboat Slough (lines connect sites along these 3 transects), and samples from 4 other separate and unrelated Cache/Yolo slough sites previously sampled by Chris Foe.

The Feb. 2010 samples (upper plot) were collected at very high flow (Yolo Bypass flooded) and show high nutrient concentrations and similar downstream nitrification trend along mainstem and sloughs. Samples collected at lower

flows and nutrient concentrations in May 2011 (lower plot) show a more gradual nitrification trend downstream, although slightly different in the mainstem and sloughs (probably because of differences in travel times and residence times). The nitrification trend seen in the transects (symbols connected by lines) continues downstream for the other unrelated slough sites, with increasing changes in NH4 and NO3 proportional to increasing distance downstream. It appears that RM is a rough proxy for extent of nitrification and hence residence time of the nutrients. Actual residence times would allow the improved differentiation of changes in nutrients due to residence-time dependent nitrification vs dilution, additions from other sources, and other nutrient sinks.

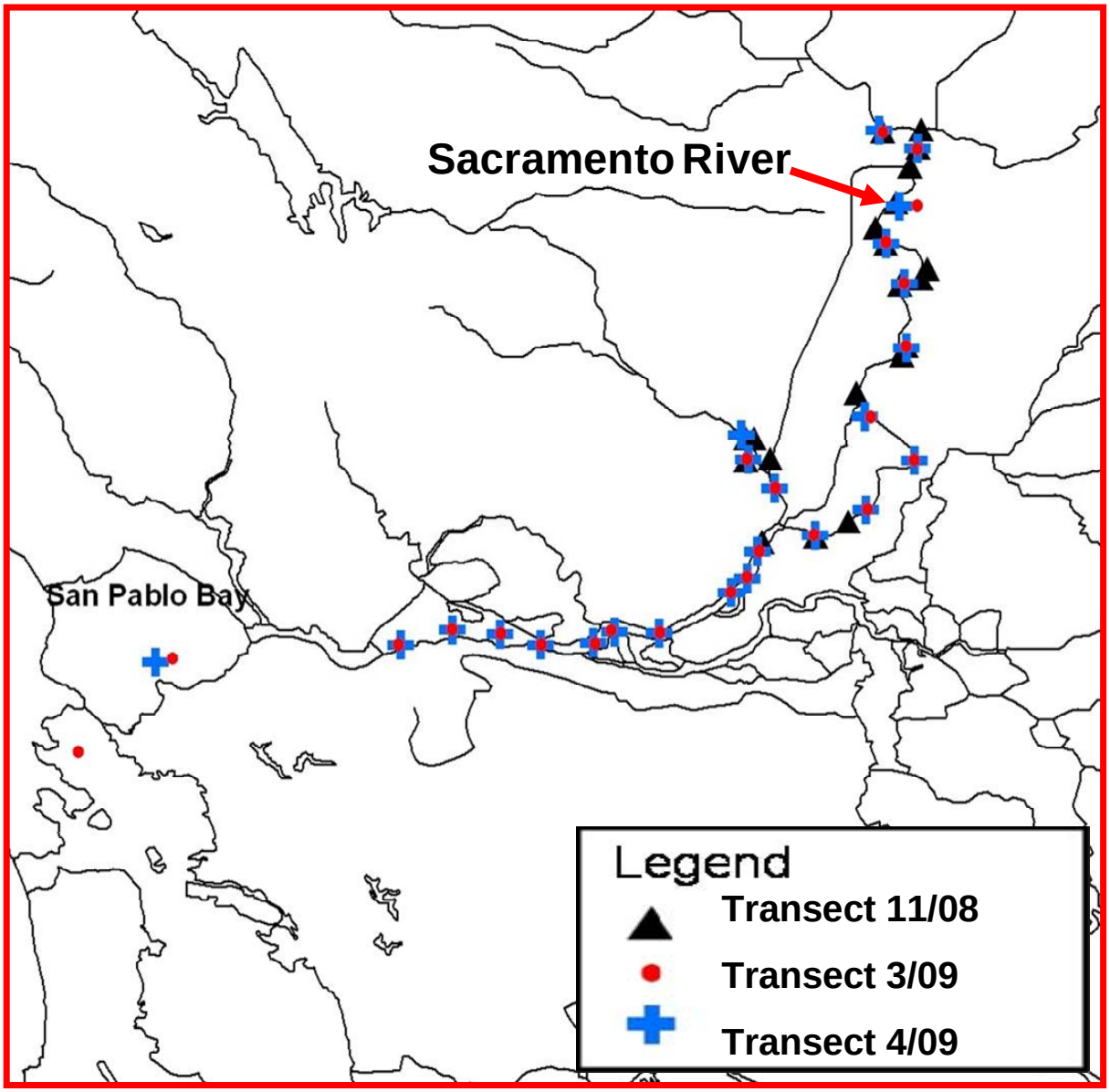


Figure 4 Example of sampling density for three transect dates - samples were collected from ~25 sites from each of 3 transects in the Sacramento River and Delta 11/08, 3/09 and 4/09. The latter two transects piggybacked on sampling by the Dugdale Team.

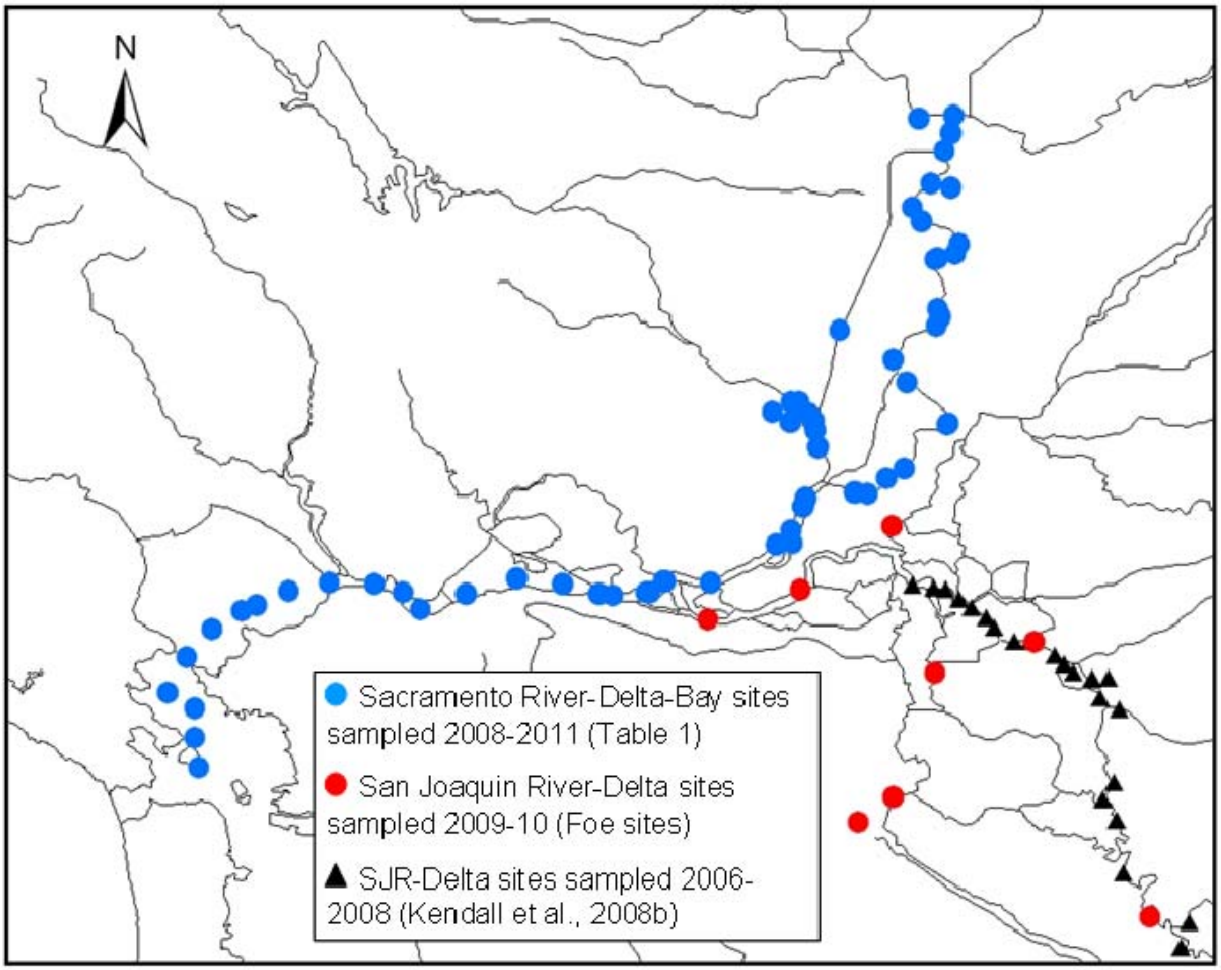


Figure 5 Sampling map of data available for analyses detailed in Table 1 and Table 2.

Carol Kendall-US Geological Survey

I. Principal Investigator: Carol Kendall (US Geological Survey), ckendall@usgs.gov

II. Co-Investigators:

Megan Young, Steve Silva, and Tamara Kraus (US Geological Survey)
Marianne Guerin, Resource Management Associates (RMA)

Roles of Co-Investigators: USGS team members share responsibility for data management, overseeing the laboratory analyses and QA/QC, and statistical analysis of the data. Guerin and I have submitted a proposal for augmented USBR funding for DSM2 modeling (net flows, stage, travel time, vol source %) to support our current IEP projects, and a separate IEP2011 proposal for RMA modeling (calculations for the location of X2 and residence times, and 2-dimensional results such as contour plots of residence time, salinity distribution, and net flows) to support

both our ongoing IEP2010 projects and this proposed IEP2011 project. Co-investigators will share the responsibility for interpretation of the data and preparation of deliverables.

III. Project title: Enhanced fall habitat characterization using a multi-fingerprinting approach

IV. Total budget: $220,300 (for the entire set of 5 proposed tasks, which includes 38% USGS overhead)

V. Study duration: 1 year (preliminary results available spring 2012)

VI. Priority research topics and questions addressed:

Two priority research topics are addressed: habitat effects (**Topic 1**) and food web effects (**Topic 2**) on delta smelt population dynamics. We will focus on quantification of the effects of abiotic variables such as net flow, turbidity, and residence time within the study area -- and the effects of these variables on nutrient and organic matter dynamics (**Research Question 1C**). In specific, we have assembled a set of tasks that focus on different habitat-quality-oriented issues and questions raised in the Draft Fall Outflow Plan (PLAN) including: How can applications of water (and nutrient and organic matter) "fingerprinting" tools, which includes DSM2 source vol%, aid habitat characterization investigations? How has nutrient and sediment loading affected the quality and abundance of aquatic food sources in major smelt habitats? How important is the role of turbidity as a substrate for bacterial and microalgal growth, source of adsorbed P, source of DOM for bacteria, and other biogeochemical reactions such as adsorption of excess NH4, etc – and how does sediment quality vary among the important fall smelt habitats? How much of the smelt association with high turbidity is a function of the nutrient sources and sinks and organic matter quality associated with the sediments, or differences in the source of the sediments?

VII. Overall project purpose:

The purpose of this project is to extend and enhance our ongoing IEP-funded investigations in the Sacramento River, western Delta, and northern Delta (Figure 1) by (1) piggybacking the collection of samples for chemical and isotopic analysis starting in mid-August from the 3 main fall smelt habitats (Suisun Bay, SJR Confluence, and Cache Complex) onto various monitoring programs, and (2) by combining the new targeted data with our existing dataset for these habitat areas to address questions about why these habitats are favorable for smelt in the fall. This project is intended to build on the findings in the in-progress papers that will be completed this fall and winter with earlier SWC and IEP2010 funding. These projects and papers focus on the determination of the (1) spatial and temporal changes in biogeochemical processes and the contributions of different sources of nutrients, organic matter, and phytoplankton (for transects in Tables 1 and 2); and, (2) effect of seasonal variations in flow on the spatial and temporal variations of sources and processes for the above transects and others sampled 1990-2011.

The combination of intensive chemical and isotopic data for recent years with a range of fall flows (Tables 1 and 2) with the longer-term dataset for 1990-2010 with more oscillations in flow as reflected in X2 values (Fig. 1) and chemical measurements (eg., Fig. 5), provides a means for testing hypotheses about habitat characteristic at various temporal and spatial scales.

In specific, we will (1) continue our ongoing "slough sampling study" past the planned end in August 2011, continue our sampling of Suisun, Confluence, and adjacent sites via the USGS *RV Polaris* cruises, and attempt to piggyback on other monitoring programs that will be sampling relevant sites this fall in these 3 smelt habitats; (2) analyze these new samples for some of same suite of isotopic measurements currently being used; (3) analyze these samples for the same suite of chemical measurements as Foe's NH4 monitoring project (if similar or sufficient chemistry is not already being covered by another program); and (4) combine the new dataset with the datasets generated, assembled, and interpreted as part of our IEP and SWC projects (Tables 1 and 2, plus chemical data from Polaris sites 1990-2011, plus the DSM2 and RMA-based hydrological modeling that we sincerely hope will finally be funded) to write one or more new journal-intended papers. If funding for Guerin is available from the augmented USBR funding request and the new IEP2011 proposal, we will be able incorporate information about how the residence time of waters, the position of X2, and the volume of water defining the LSZ affect nutrients, organic matter, and phytoplankton important to the base of the delta smelt and other foodwebs in Suisun Bay, the Confluence, and the Cache Complex, especially in the fall.

VIII. Project background and conceptual model:

Background: Our USGS Isotope Tracers Project specializes on piggybacking multi-isotope ecosystem studies on large-scale monitoring programs (Kendall et al., 2010a). Our first successful SJR study (Kratzer et al, 2004) led to continued isotope studies in the SF Bay (Wankel et al. 2006) and SJR (Kendall et al., 2008a), and extension of these studies to the SJR DWSC, the Delta, and northern SF Bay (Kendall et al., 2008b). We were subsequently invited to apply our multi-approach to POD studies in 2009, which resulted in a successful SWC-funded pilot study (Kendall et al., 2010b). We later extended our investigations of sources and sinks of nutrients and organic matter as part of an IEP 2010 project. Table 3 lists the interpretive values of our normal suite of isotope fingerprinting tools.

Conceptual Model: The authors of the PLAN "hypothesize that degradation of habitat is the fundamental cause of delta smelt decline…. Both abiotic and biotic aspects of habitat suitability have declined over time." However, the X2-habitat curve approach (Fig. 1) only explains about 25% of the variance in smelt presence-absence, despite the strong long-term association between smelt occurrence and salinity and turbidity (Feyrer et al. 2010). Biotic drivers such as aquatic biogeochemical processes (e.g., nitrification, adsorption on and off of sediments), bioavailability of dissolved and particulate organics (DOM and POM), and temporal

changes in nutrient and phytoplankton sources -- that have been the focus of our current SWC & IEP studies – have received much less attention than other "animal" biotic drivers and abiotic drivers in recent POD-related paper and in the PLAN since the Sobczak et al. (2002) study. We hypothesize that combining different "fingerprinting" approaches **[**i.e., our detailed set of chemical and isotopic data and findings from our ongoing IEP studies with hydrological driver data (including data from DSM2 and RMA models) and the proposed new studies focusing on this "wet-year" fall**]** is likely to provide a novel and improved characterization of the interplay of biotic and abiotic drivers responsible for creating suitable fall smelt habitats.

IX. Estimated number of all FESA and ESA-listed fishes captured: None.

X. Brief project description:

Feasibility: Our isotope lab will be finished with analyses of ~95% of the samples from our IEP2010 projects in September 2011, leaving us with a full staff and all-working instruments to immediately start processing new samples as they are received. By the time these new samples are analyzed, we will have completed drafts of papers on the earlier SWC and IEP studies and will be ready to incorporate our new findings and interpretations into the additional papers planned for this new IEP project.

Below is a list of various research tasks that we think would contribute significantly to our understanding of the biotic and abiotic drivers and characteristics of major fall smelt habitats. We have listed the first 4 tasks in order of perceived "best bang for the buck."

Task 1: Continued collection of monthly ebb-tide samples from our "Slough sampling mini-project" (Table 1 and Figure 2), which includes 5 major Sacramento River sites sampled previously as part of Foe and/or Dugdale cruises (we believe it is important to continue sampling at these sites to maintain our multi-year linkage of data in the sloughs and delta with mainstem sources of nutrients and organics), plus 7 sites in the Cache Complex. These samples will be analyzed for (1) about the same suite of field and chemical measurements (at Dahlgren's lab at UCD) as the Foe project, and (2) the same isotopic analytical suite used in our SWC and IEP 2010 projects (Table 3). We would like to augment this plan with samples from the new Cache Complex sites fish monitoring sites (p.54 of PLAN), either by asking these two programs to collect 3L of water from each site for us, or by having us collect samples at these sites during our monthly sampling of the other sloughs – or both! **Budget:** 4 trips x 16 sites, one where 6 Cache sites are sampled at both ebb and flood tide. ($77,208)

Task 2: Continued collection of monthly samples of Suisun, Confluence, and adjacent sites on the *RV Polaris* (Table 2 and Fig.3) and analysis for our normal suite of isotope tools plus the addition of a single set of test samples for SO4 concentration and isotopes (Table 3). **Budget:** for 4 trips x 14 sites ($53,500)

Task 3: Provide a more detailed spatial and temporal map of the quality and source of suspended sediments in important fish habitats this fall by piggybacking the collection of 1L

water "grab" samples on as many of many fish monitoring programs listed in the PLAN as are willing to participate. Samples would be filtered and archived pending discussions with partners about their interests. We will use an iterative adaptive management approach to decide priorities for analysis for POM and DOC isotopes (Table 3) from the total set of archived samples. Other archived samples can be analyzed later if the initial results show correlations with fish abundance, turbidity, or other habitat characteristics. If we find interested partners, we could use some of these funds to analyze benthic sediments for sediment isotopes (at half the cost per sample). **Budget:** 200 samples ($27,600)

Task 4: Conduct some preliminary field assessments of whether other N cycling processes besides nitrification and algal uptake (that have been the main focus of our ongoing studies and those of the Dugdale group) might be important sources and sinks of nutrients in fall smelt habitats. Figure 6 shows that there is a significant discrepancy between the NH4 lost and NO3 gained between adjacent downstream sites, suggesting that there may be some important sinks for NH4 besides nitrification and the minor NH4 uptake by algae. Reviewers of previous proposals have encouraged us to investigate this topic, especially in shallow wetlands. Candidates for investigation include denitrification, adsorption of NH4 on suspended and benthic sediments, and bacterial uptake of NH4, and macrophyte uptake. **Budget:** 4 1-day studies in the Cache Complex or Suisun (depending on boat availability and interest by partners), plus nutrient and gas concentration measurements (~$20,000).

Task 5: Project management, prepare presentation or brief report about preliminary results in spring 2012, prepare quarterly reports, provide presentations at state workshops, and prepare one or more journal-intended paper. **Budget:** 3 months salary for Young, Kraus, and/or Schmidt to assist Kendall with this task; no salary requested for Kendall (in kind contribution). ($42,000)

References:

Feyrer, F, Newman, K, Nobriga, M, Sommer, T. (2010). Modeling the effects of future freshwater flow on the abiotic habitat of an imperiled estuarine fish. Estuaries and Coasts 34:120-128.

Kendall, C., Young, M.B., Silva, S.R. (2008a). A Multi-Isotope Tracer Approach to Understanding Organic Matter and Nutrient Source Dynamics in the San Joaquin River, Task 7 in: Stringfellow, W.T. et al. (Eds), San Joaquin River Up-Stream DO TMDL Project, Final Report (unpublished).

Kendall, C., Young, M.B., and Silva, S.R. (2008b) Determination of Sources of Organic Matter and Nutrients in the San Joaquin River, final interpretive report for the PIN700 project, September 2008, 470p (unpublished).

Kendall, C., Young, M.B., and Silva, S.R. (2010a). Applications of stable isotopes for regional to national-scale water quality and environmental monitoring programs. Chapter 5. In: West JB, Bowen GJ, Dawson T, Tu KP (Eds) Isoscapes: Understanding Movement, Pattern, and Process on Earth through Isotope Mapping. Springer Pub., p. 89-112.

Kendall, C., Silva, S.R., Young, M.B., Guerin, M., Kraus, T., and Parker, A.E., (2010b). Stable isotope tracing of nutrient and organic matter sources and biogeochemical cycling in the Sacramento River, Delta, and Northern Bay. Intended as USGS Open-File Report, now likely will be incorporated in future papers.

Kratzer, C.R., Dileanis, P.D., Zamora, C., Silva, S.R., Kendall, C., Bergamaschi, B.A., and Dahlgren, R.A. (2003). Sources and transport of nutrients, organic carbon, and chlorophyll-a in the San Joaquin River upstream of Vernalis, California, during summer and fall, 2000 and 2001, USGS WRI 03-4127. online: http://water.usgs.gov/pubs/wri/wri034127/

Sobczak, W.V., Cloern, J.E., Jassby, A.D. and Muller-Solger, A.B., (2002). Bioavailability of organic matter in a highly disturbed estuary: The role of detrital and algal resources. Proceedings of the National Academy of Sciences of the United States of America, 99(12): 8101-8105.

Wankel, S.D., Kendall, C., Francis, C.A. & Paytan, A. (2006) Nitrogen sources and cycling in the San Francisco Bay Estuary: A nitrate dual isotope approach. Limnol. Oceanogr., 51: 1654-1664.

Table 1. Transect dates, programs, locations, and measurement types. [¥]

Transect Dates	PI and program	Isotope samples *	SR-Cache-Delta samples [+]	Chemistry (includes measured values and ones calculated by difference) [#]
Monthly [$]	USGS Polaris	No [°]	0-0-9	See: http://sfbay.wr.usgs.gov/access/wqdata/
3/26-27/09	Dugdale SWC	Yes	10-2-13	NO3, NO2, NH4, PO4, urea, DIC, silica, Chl-a, Pheo, POC, PON, EC, T, uptake rates (C, NO3, NH4), OBS, T, etc.
4/23-24/09	Dugdale SWC	Yes	10-3-12	
3/9/09	Parker WB	No	7-0-1	NO3, NO2, NH4, PO4, urea, DIC, silica, Chl-a, Pheo, Chl 5u, POC, PON, EC, T, uptake rates (C, NO3, NH4), flow cytometer, SCUFA, T, etc.
4/6/09	Parker WB	No	7-0-1	
5/8/09	Parker WB	No	7-0-1	
3/16-17/09	Foe WB	No	5-4-4	NO3, NO2, NH4, TN, DON, TP, TDP, PO4, DOC, Chl-a, Pheo, EC, pH, DO, NTU, T, etc.
3/30-31/09	Foe WB	No	5-4-4	
4/13-14/09	Foe WB	No	5-4-4	
4/27-28/09	Foe WB	No	5-4-4	
5/11-12/09	Foe WB	No	5-4-4	
5/26-27/09	Foe WB	Yes	5-4-4	
6/8-9/09	Foe WB	Yes	5-4-4	
6/22-23/09	Foe WB	Yes	5-4-4	
7/14-15/09	Foe WB	Yes	5-4-4	
8/3-4/09	Foe WB	Yes	5-4-4	
9/28-29/09	Foe WB	Yes	5-4-4	
10/20-21/09	Foe WB	Yes	5-4-4	
11/9-10/09	Foe WB	Yes	5-4-4	
12/7-8/09	Foe WB	Yes	5-4-4	
1/25-26/10	Foe WB	Yes	5-7-4	
2/22-23/10	Foe WB	Yes	5-7-4	
4/26/10	Dugdale 2Rivers	Yes	22-0-4	NO3, NO2, NH4, PO4, urea, DIC, silica, Chl-a, Pheo, POC, PON, EC, T, uptake rates (C, NO3, NH4), OBS, T, etc.
8/25/10	Dugdale 2Rivers	Yes	16-0-4	
4/19/11	Dugdale 2Rivers	Yes	15-0-4	
4/15/10	Kendall Sloughs	Yes	4-3-0	NO3, NO2, NH4, TN, DON, TP, TDP, PO4, DOC, Chl-a, Pheo, EC, pH, DO, NTU, T, etc.
4/19/11	Kendall Sloughs	Yes	5-7-0	
5/10/11	Kendall Sloughs	Yes	5-7-0	
6/9/11	Kendall Sloughs	Yes	5-7-0	
7/20/11	Kendall Sloughs	Yes	5-7-0	
8/18/11 [φ]	Kendall Sloughs	Yes	5-7-0	

NOTES:

[¥] 2009 is considered a dry year, and 2010 is considered a below normally wet year (see Fig. 1).

[+] Sites are divided into the categories "SR" (I-80 to Isleton), "Cache" (tributaries and sloughs in the Cache/Yolo Complex), and "Delta" (Rio Vista downstream to Martinez). Hence, 4-2-4 means 4 sites in the SR, 2 in the Cache Complex, and 4 in the Delta. Foe sites and "Dugdale 2 Rivers" sites sampled on the San Joaquin River are not included in this table. Polaris cruises include 10 sites downstream of Martinez to near Angel Island.

* Isotope analyses include NH4-δ^{15}N; NO3 δ^{15}N and δ^{18}O; DOC-δ^{13}C; POM δ^{13}C, δ^{15}N, δ^{34}S, C:N, C:S; and water δ^{18}O and δ^{2}H; also DIC-δ^{13}C on recent Slough project samples and 2006-2007 Polaris samples.

This is a list of the chemistry data we have access to; other data may be available.

$ Data are site-dependent; for example, nutrient data are only available for a subset of sites.

° We only have limited isotope data for Polaris cruises 2009-2011; however, we have almost monthly isotope data (all but NH4-δ^{15}N) for 8/06-5/08 (and not-yet-analyzed samples for 7/08, 11/08, 5/09, 4/11, and soon 8/11). We are proposing to continue monthly Polaris isotope sampling 9/11-12/11 as part of this proposal.

[ϕ] We are proposing to continue and expand the "slough sampling project" through at least December as part of this proposal.

Table 2. Dates of transects in the SJR DWSC and SF Bay where we have piggybacked isotope samples onto routine IEP-EMP and RMP cruises. Dates from different cruises have been lined up so the months match. [+]

SJR DWSC sites *RV San Carlos* cruises *	SF Bay/Delta *RV Polaris* cruises [#]	water year type of the preceding spring for the Sacramento valley
08/09/06	08/15/06	wet
09/07/06	09/12/06	wet
09/19/06		wet
10/05/06	10/17/06	wet
11/06/06	11/14/06	wet
11/20/06	12/12/06	wet
	01/09/07	
	02/06/07	
	03/06/07	dry
	04/03/07	dry
06/28/07		
07/12/07	07/19/07	dry
07/26/07		dry
08/10/07		dry
08/23/07		dry
09/25/07	09/11/07	dry
10/11/07		dry
10/25/07	10/23/07	dry
11/09/07	11/14/07	dry
11/26/07		dry
12/12/07	12/11/07	dry
	02/12/08	
	03/11/08	critically dry
	05/06/08	critically dry
	07/17/08	critically dry
	11/18/08	critically dry
	05/19/09	dry
	04/19/11	wet
	08/16/11	wet

Notes:

[+] Samples 8/06 to 5/08 were collected and analyzed as part of Kendall's CALFED PIN700 project.

* Some of these sites were sampled 3 times 4/10, 8/10, and 4/11 for isotopes as we piggybacked on the "Dugdale 2 Rivers" project; these SJR samples have not yet been analyzed for isotopes.

[#] Samples collected after 5/08 have not yet been analyzed for isotopes. As part of this proposal, we plan new monthly Polaris cruises September through December 2011.

Table 3. The value of different "isotope fingerprinting tools" for the determination of biogeochemical processes and sources of waters, nutrients, and organic matter.

Tracer type	Interpretive Value for Processes and Sources
Particulate organic matter (POM) $\delta^{15}N$, $\delta^{13}C$, $\delta^{34}S$, C:N, C:S	Information about the source of C, N, and S and the biogeochemical reactions that cycle them; Quantify algal *vs* terrestrial contributions to biomass; Evaluate role of algal-based foodwebs, contributions of marine sources of POM & nutrients; Quantify contributions of organic matter from Sac River, Cache Complex, and Bay sources to adjacent ecosystems.
Nitrate $\delta^{18}O$ and $\delta^{15}N$	Quantify nitrate from different sources (fertilizer, wastewater, wetlands, etc); Role of algae and degree of recycling; Evidence for denitrification or assimilation.
Ammonium $\delta^{15}N$	Quantify NH_4 from different sources (fertilizer, wastewater, wetlands, etc); Role of algae and degree of recycling; Evidence for nitrification or assimilation.
Water $\delta^{18}O$ and $\delta^{2}H$	Ideal conservative tracers of water sources and mixing; useful for quantifying flow contributions from different tributaries and groundwater.
Dissolved organic carbon (DOC) $\delta^{13}C$	Information on sources of DOC; evidence for degradation of organic matter; quantify algal vs terrestrial contributions to DOC.
* Sulfate $\delta^{34}S$ and $\delta^{18}O$ (new isotope measurement proposed for use in this proposal)	Quantify sulfate from different sources (upper Sacramento River, marine, wastewater, sulfate reduction in the wetlands, etc), and source of phytoplankton that incorporates the S during growth (upper Sacramento River, Cache Complex, marine, or estuarine).

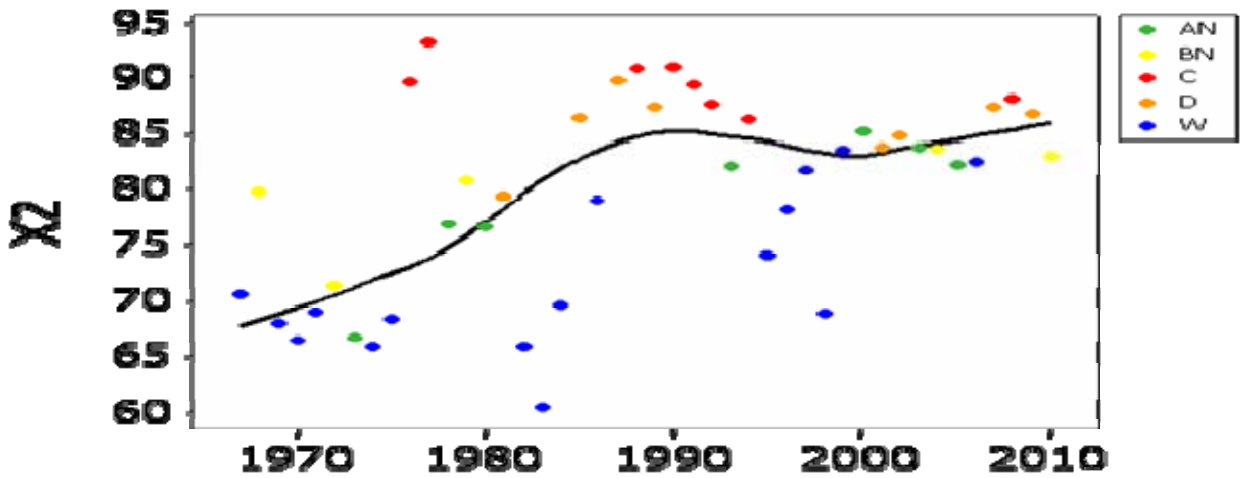


Figure 1. Time series of average fall X2 (km, September – November) since 1967. Symbols: water year type of the preceding spring for the Sacramento valley (W: wet, AN: above normal, BN: below normal, D: Dry, C: critically dry). A LOESS smooth is fitted to the data. (Fig 7 of PLAN; from F. Feyrer, unpublished).

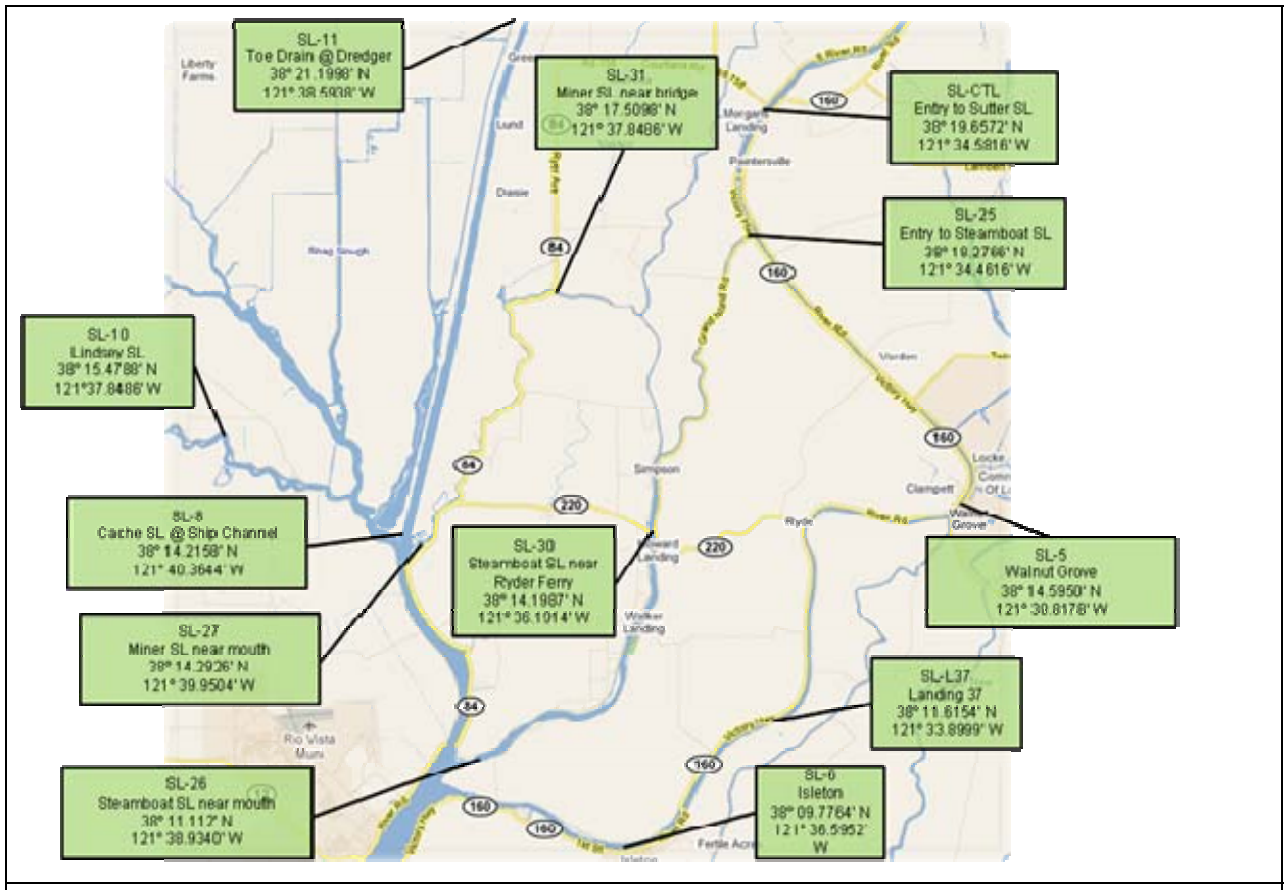


Figure 2. Map of sites sampled as part of the "Slough sampling mini-project"; see Table 1.

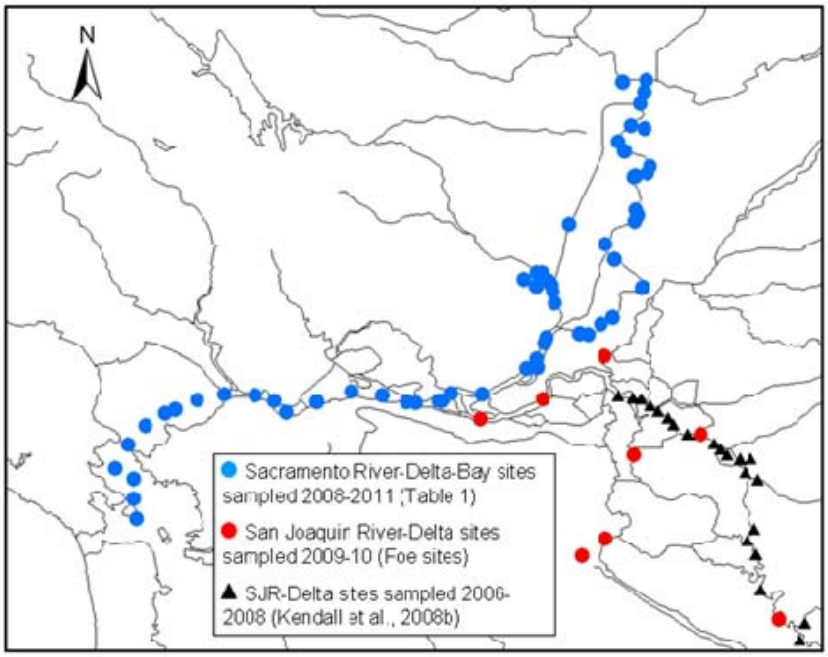


Figure 3. Map showing sites sampled in the transects listed in Tables 1 and 2.

	t-Test				PAIRED t-Tests					
					TRANSECT DATA			FOE DATA		
Parameter+	# River samples	# Trib samples	P value^	Trib vs. River	# Tribs	P value^	Trib vs. River	# Tribs	P value^	Trib vs. River
NO3-δ^{15}N	3	25	0.181	T>R	9	0.001	T>R			
NO3-δ^{18}O	3	25	0.895	NS	9	0.034	T>R			
NH4-δ^{15}N	2	17	0.004	T>R	3	0.066	T>R			
H2O-δ^{18}O	3	25	<0.000	T>R	9	0.002	T>R			
H2O-δ^{2}H	3	25	0.017	T>R	9	0.010	T>R			
POM-C:N (at)	3	25	0.148	NS	9	0.057	T>R			
POM-δ^{13}C	3	25	0.030	T<R	9	0.007	T<R			
POM-δ^{15}N	3	25	0.601	NS	9	0.367	--			
POM-δ^{34}S	10	22	<0.000	T<R	5	0.022	T<R	8	0.001	T<R
DOC-δ^{13}C	3	25	0.319	NS	9	0.027	T<R			
DOC	19	25	0.001	T>R	9	0.004	T>R	16	<0.000	T>R
DON	16	16	0.131	NS				16	<0.000	T>R
DIC	2	5	0.063	NS	5	0.026	T>R			
NO3 + NO2	19	25	<0.000	T>R	9	0.083	T>R	16	<0.000	T>R
NO3	18	21	0.002	T>R	5	0.157	T>R	16	<0.000	T>R
NO2	18	21	0.001	T>R	5	0.026	T>R	16	0.001	T>R
PO_4	18	21	<0.000	T>R	5	0.133	T>R	16	<0.000	T>R
NH_4	19	25	<0.000	T<R	9	<0.000	T<R	16	<0.000	T<R
Si(OH)4	2	5	0.705	NS	5	0.221	--			
chla	14	17	<0.000	T>R	9	0.068	T>R	16	0.001	T>R
Sp. Cond.	19	25	<0.000	T>R	9	0.024	T>R	16	0.001	T>R

Figure 4. Statistical comparisons between waters from the SR @ Isleton and the Cache Complex tributaries (tribs), where statistics in orange are significant at $p < 0.05$ and ones in yellow at $p<0.1$. Thus, most measured constituents showed statistically significant differences between these two major water sources, indicating that isotopes and chemistry can be used to estimate % sources.

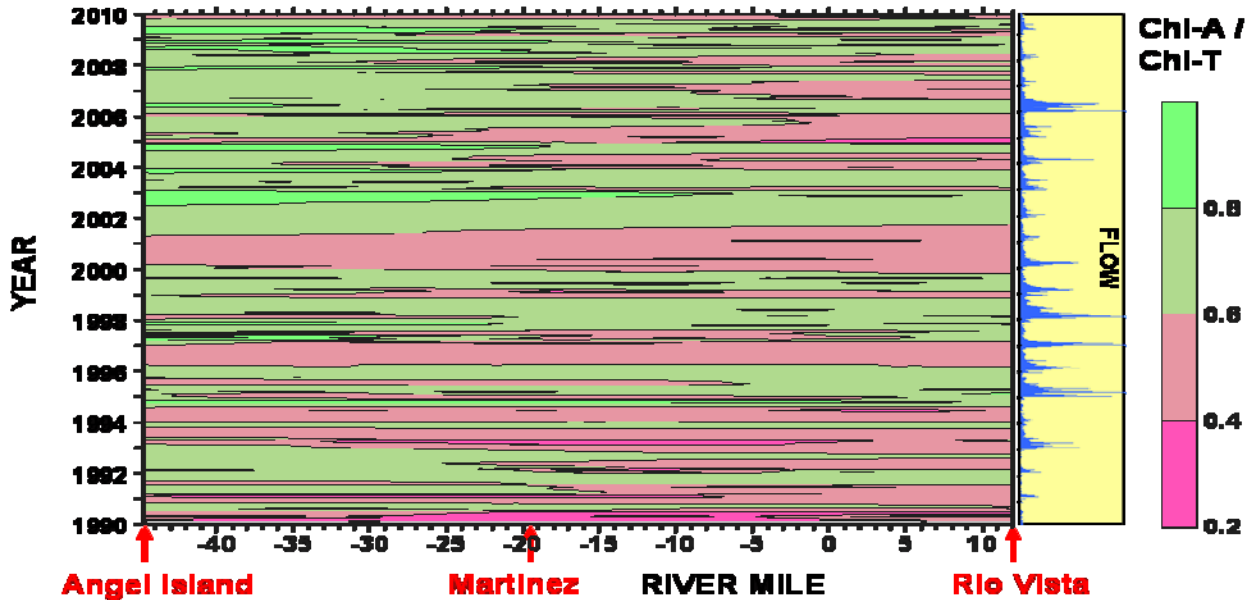


Figure 5. This plot shows 20 years of chlorophyll ratio data from Polaris sites; see http://sfbay.wr.usgs.gov/access/wqdata/. Note that chlorophyll ratios appear to be generally higher (more fresh) since 2001 than many previous years, especially at downstream sites. There are many years (e.g., 2000-2001) when almost all the algae appear to be "old". These years correspond to a range of water-year types (Fig. 1) and show temporal changes in the quality of a major food source that might be related to other temporal and spatial changes in habitat characteristics.

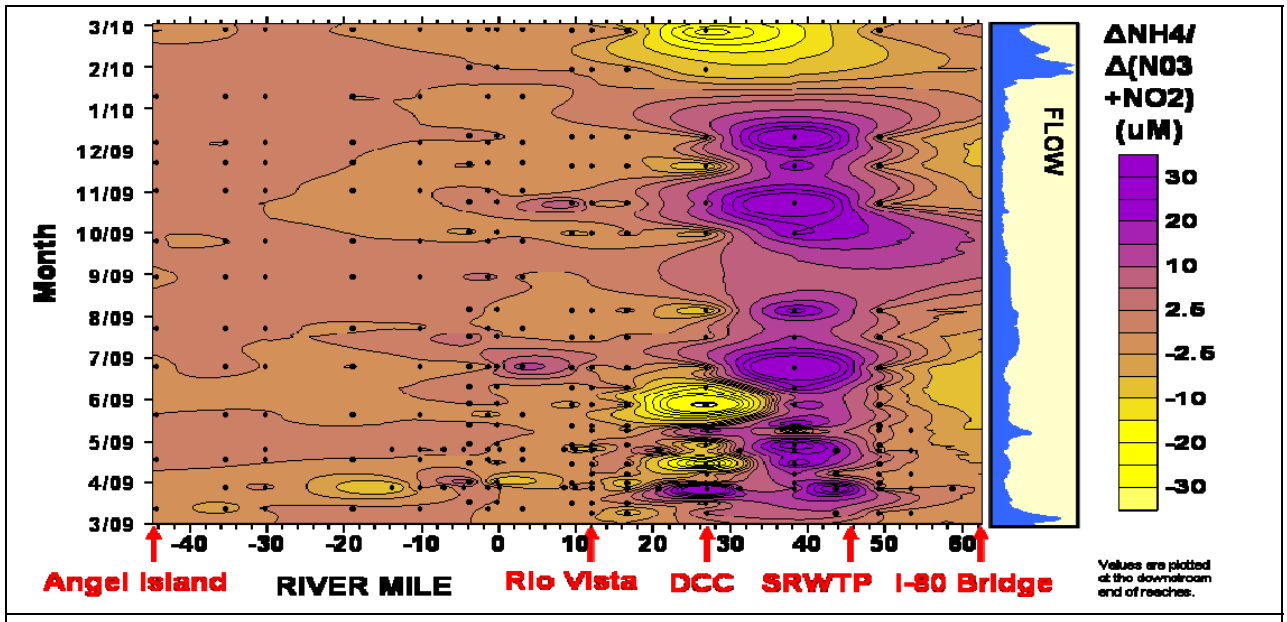


Figure 6. The downstream differences (Δ) in NH4 concentrations between adjacent sites, divided by the differences (Δ) in NO3+NO2 concentrations between adjacent sites, show that changes in NH4 concentration are NOT mirrored by changes in NO3+NO2 concentrations – when the data are examined in detail. The ratio should be ~1 if nitrification was the dominant NH4 sink. What are the main causes of the NH4 losses? Other NH4 sinks?