# EXHIBIT A: ATTACHMENT 7
# FINAL PROJECT REPORT
# 16 April 2007 - 31 March 2012

**FINAL TECHNIAL REPORT**
**CALFED SCIENCE PROGRAM PROJECT NUMBER: 1039**
**PROJECT TERM: 4/16/2007-331/2012**
**PROJECT TITLE:** Do low phytoplankton growth rates signal the "bad" habitat conditions in Suisun Bay driving the pelagic organism decline with amendment Comparison of nutrient sources and phytoplankton growth and species composition in two rivers: their roles in determining productivity and food web conditions in Suisun Bay and the Delta (Two-Rivers)

**DATE:** 20 July 2012

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***Funding Source:*** CALFED Science Program
***Project Location:*** San Francisco Bay/Delta
***Brief Description of Project:***

This project studies the anomalous low phytoplankton productivity in Suisun Bay by comparing Suisun Bay phytoplankton growth and nutrient uptake rates with those in Central San Francisco Bay, the Delta and the Sacramento and San Joaquin Rivers and using "grow-outs" to evaluate physiological response of the phytoplankton to changing conditions. The amendment was to compare nutrient sources and phytoplankton growth and species composition in the two source rivers for Suisun Bay and to evaluate their roles in determining productivity and food web conditions in Suisun Bay and the Delta

***Primary Objective to be Achieved:***

To assess the anomalous Suisun habitat ("Bad Suisun") in context of the Delta, upstream (into the Sacramento and San Joaquin Rivers) and downstream (a more oceanic condition in Central Bay). This will be accomplished by measuring gradients of bulk constituents (e.g. phytoplankton abundance as chlorophyll, nutrient concentration) and using experimental grow-outs/enclosures to optimize growth conditions of natural phytoplankton and evaluate physiological response of the phytoplankton to changing conditions. The amendment (added as Task 6) used the results from Rio Vista, that riverine ammonium from the Sacramento River might be impacting Suisun Bay productivity negatively with the primary objective to determine how nutrient and phytoplankton community composition differ between the San Joaquin and Sacramento Rivers ("Two Rivers") and how these influence conditions downstream in the Delta and Suisun Bay?

**BUDGET SUMMARY (**All tasks should exactly match those identified in the project Scope of Work.)

You should have received this from SFSU campus. Everything was expended by March 31 2012.

# FINAL TECHNICAL REPORT

This final project report comprises the following sections:

A. History of the project- since there were complications due to a stop work order and and an ammendment and two no cost extensions, this is necessary (Page 3)
B. Highlights of the findings of the project (Page 4)
C. Text describing technical progress (Page 6).
D. A list of the published reports and those in preparation-pdfs sent earlier (Page 18)
E. Table of data collected (Page 25)
F. Prior cumulative reports (Page 26)

## A. HISTORY/TIMELINE OF THE PROJECT

2007: Initiation of Grant #1039 Do low phytoplankton growth rates signal the "bad" habitat conditions in Suisun Bay driving the pelagic organism decline? (shortened name Bad Suisun).
Contract Date: 4/16/2007-4/15/ 2010
2008: Semiannual report 1 submitted: 2/11/2008
2009: Stop Work Order due to State budget 12/18/ 2008- 6/30/2009
Semiannual report 2 submitted: 3 March 2009
Amendment to add the "Two Rivers" supplemental research: 3/11/2009 with no time extension
Money not added into agreement until June 2009 due to stop work order and rebudgeting of funds.
2010: Field sampling initiated, for Amendment (Task 6: Two Rivers)
Two Rivers 10-1 cruise in April 2010; Two Rivers 10-2 cruise in August 2010
4/12/2010: No cost extension (NCTE): given to extend the award until 6/30/2011 to accommodate second field sampling and spring cruise as proposed.
The Two Rivers and NCTE were revised (w/ the rebudget) into the same agreement
2011: Two Rivers 11-1 cruise in April 2011
6/30/ 2011: No cost extension: given to extend award until 12/31/11 for nutrient and N15 analyses from the spring cruise
11/17/2011: No cost extension: given to extend award until 3/31/12 so that the phytoplankton enumeration (consultant charges) could be completed.

The "Bad Suisun" portion had 5 tasks and then for simplicity the Amendment "Two Rivers" was added as Task 6.

## B. HIGHLIGHTS OF THE PROJECT

6 published manuscripts; 4 manuscripts to be submitted (tbs); 3 masters theses; 2 IEP newsletters; 56 presentations supported by this project

- Characterized events leading to a spring phytoplankton bloom in Suisun Bay (1) phytoplankton N demand satisfied by $NH_4$ but with low biomass-specific and depth-integrated $NH_4$ uptake rates due to high turbidity and poor irradiance. $NO_3$ uptake is low or near zero during this period due to $NH_4$ inhibition. (2)With improved irradiance conditions (via increased water transparency, water column stability or seasonal increase in irradiance), phytoplankton $NH_4$ uptake rates and biomass increase causing water column $NH_4$ concentrations to decrease. (3) Once $NH_4$ decreases to < 4 μmol $L^{-1}$ phytoplankton $NO_3$ uptake is enabled. With continued phytoplankton growth, $NH_4$ concentration is further reduced to ≤ 1 μmol $L^{-1}$ and biomass-specific $NO_3$ uptake rates accelerate resulting in a rapidly developing bloom nourished by $NO_3$. (Parker et al. 2012, ECSS; Mar. Poll. Bull.; Dugdale et al. 2012 ECSS; Wilkerson et al. tbs; Dugdale et al. modeling. tbs) )
- Elevated $NH_4$ can result in reduced primary productivity (counter-intuitive response) and leaves $NO_3$ unused and exported from the ecosystem. (Dugdale et al. 2012 ECSS)
- For high levels of carbon uptake (primary productivity), high rates of $NO_3$ uptake need to occur (Parker et al. 2012 ECSS).
- In addition to $NH_4$, some contaminant other than elevated $NH_4$ may restrict bloom formation through depressed $NH_4$ uptake rates. $NH_4$ uptake in Suisun Bay is 50% lower than in Central Bay (Dugdale et al. 2012 ECSS; Parker et al. 2012 Mar Poll. Bull)
- Experimental enclosures were used to classify the "condition" of the water and phytoplankton. Unstressed cells (e.g. those from Central Bay) show Type-I response with chlorophyll accumulation within 72 hours after collection ($NH_4$ drawdown to 1 μmol $L^{-1}$ in 24 hours, peak in $NO_3$ uptake after 48 hours and the peaks in carbon uptake by 72 hours). Suisun Bay cells typically show a delayed response (more stressed), Type-II with chlorophyll accumulation at 96 hours ($NH_4$ drawdown to 1 μmol $L^{-1}$ in 72 to 96 hours, peak $NO_3$ uptake after 96 hours if at all and with incomplete $NO_3$ drawdown). Type-III shown by water collected at Rio Vista (very poor condition) with a greater lag in phytoplankton response with no $NH_4$ drawdown to 1 μmol $L^{-1}$ and no appreciable $NO_3$ uptake, C uptake or chlorophyll accumulation (Parker et al. 2012 ECSS; Wilkerson et al. tbs; Dugdale et al. modeling tbs).
- Suisun Bay "condition" is part of a continuum with upstream. Suisun phytoplankton displayed a suboptimal condition compared to Central Bay, but not compared to upstream; i.e. Rio Vista and the Sacramento River (Parker et al. 2012 Mar. Pol. Bull; Wilkerson et al. tbs).
- Rio Vista data collected during Bad Suisun showed the importance of Sacramento River as a source of $NH_4$ and the Two Rivers project showed that SRWWTP was a point source of $NH_4$ (and potentially contaminants) (Parker et al. 2012 ECSS, 2012 Mar Poll Bull;

Kress, 2012) that impacted primary production and phytoplankton blooms in the Sacramento River and Suisun Bay

- Herbicides "stress" SFE phytoplankton. Diuron and imazapyr were show to affect phytoplankton physiology-diuron with acute and chronic effects on photosynthesis and imazapyr with chronic effects. Both herbicides appeared to negatively impact diatoms compared to other phytoplankton in the community(Blaser et al. 2011 IEP; Blaser 2011; Blaser et al. tbs).
- Modeling efforts determined three criteria from the interactions of river flow and $NH_4$ discharge for bloom development in Suisun Bay: (1) Loading Criterion: $NH_4$ loading must not exceed the capacity of the phytoplankton to assimilate the inflow of $NH_4$, (2) Concentration Criterion: $NH_4$ must be $\leq 4$ μmol $L^{-1}$ to enable phytoplankton $NO_3$ uptake, (3) Washout Criterion: the dilution rate of phytoplankton biomass set by river flow must not exceed the phytoplankton growth rate to avoid "washout".(Dugdale et al. 2012 ECSS)
- Two Rivers data showed that the dominant forms of DIN (dissolved inorganic nitrogen) differ in the two rivers feeding Suisun Bay; typically the Sacramento River is dominated by $NH_4$ and the San Joaquin by $NO_3$, but this not always so e.g. very high flow spring 2011 Sacramento River dominated by $NO_3$(Kress, 2012; Kress et al. 2012 IEP; Kress al. tbs).
- Two Rivers project showed typically the Sacramento River to be dominated by small flagellates and the San Joaquin by centric diatoms. This reversed during the high flow April 2011 conditions. (Kress, 2012; Kress et al. 2012 IEP; Kress al. tbs).
- Two Rivers project showed that the Fluoroprobe was a useful realtime approach to evaluating phytoplankton community-displaying similar trends as microscopy (the gold standard for enumeration). (Kress, 2012; Kress et al. 2012 IEP; Kress al. tbs).
- Importance of flow for bloom initiation shown by all data. Modeling showed that flow of 800-1100 $m^3s^{-1}$ required for blooms. Two Rivers data showed in April 2011 high flow changed nutrients and phytoplankton characteristics of Sacramento and San Joaquin Rivers (Dugdale et al. 2012 ECSS; Kress 2012; Kress et al. tbs)
- Two Rivers project collected first samples for pelagic nitrification rates in Sacramento River to compare with calculated values (Parker et al. 2012 Mar. Poll. Bull.)
- Modeling showed Suisun Bay ecosystem to have two major productivity modes- a high-productivity condition fueled by $NO_3$ uptake and a low-productivity mode, fueled only by $NH_4$. When $NH_4$ and flow (400-4000 $m^3s^{-1}$) were varied a sharp boundary between the two modes appeared (Dugdale et al. modeling tbs).
- Modeling showed that at high $NH_4$ concentrations, the maximum flow for the high productivity mode was only 600 $m^3s^{-1}$ and an increase in flow to 700 $m^3s^{-1}$ drove the system into the low productivity mode. In the model, at low $NH_4$ concentrations the modeled maximum flow allowing high productivity mode increases to about 1600 $m^3s^{-1}$. (Dugdale et al. modeling tbs).
- The model results were consistent with the observation of Ball and Arthur (1979) who showed flows of <700 $m^3s^{-1}$ were required for bloom occurrence in Suisun Bay at the $NH_4$ concentrations observed in the early 1970's (Dugdale et al. modeling tbs).

## C. TEXT DESCRIBING TECHNICAL PROGRESS..

For this final report an overall approach is taken to describe the accumulated technical progress made, rather than using the Task structure since the Tasks overlapped when synthesizing the results. At the end of this report the cumulative progress (from all prior progress reports) by task of the individual tasks up till December 2011 is given.

### Introduction

Chlorophyll decline, lack of blooms in Suisun Bay and the POD

Prior to 1987, phytoplankton blooms occurred regularly in spring and summer in the Suisun Bay (northern San Francisco Estuary (SFE). For example, Ball and Arthur (1979) reported mean chlorophyll concentrations of 30 - 40 $\mu g\ L^{-1}$ in spring and 40 - 100 $\mu g\ L^{-1}$ in summer from 1969 to 1979. Diatoms were the dominant phytoplankton functional group. Phytoplankton blooms of this magnitude are now rare (Jassby, 2008), in spite of increasing inorganic nutrient concentrations delivered to Suisun Bay by the Sacramento River (Parker et al., 2012c). The zooplankton consumer trophic level is now food-limited (Müeller-Solger et al., 2002; Kimmerer et al., 2005). The lack of blooms has likely contributed to deleterious bottom-up impacts on estuarine fish by lowering the quantity and quality of food for the pelagic food web.

The decline in chlorophyll concentrations began in the early 1980's and blooms became rare after 1987, coincident with the introduction of *Potamocorbula amurensis* (Alpine and Cloern, 1992; Jassby et al., 2002). The appearance of *P. amurensis* has been considered the major factor in the disappearance of phytoplankton blooms in Suisun Bay (Alpine and Cloern, 1988: Kimmerer and Orsi, 1996). However any role of *Potamocorbula* in eliminating phytoplankton blooms during spring could only be minor as clam biomass is low during that season (Greene et al., 2011). The lack of spring phytoplankton blooms in Suisun Bay suggests some other causal agent may suppress phytoplankton activity.

Possible causes of low productivity and chlorophyll in Suisun Bay: "Bad" Suisun?

When we first submitted the research proposal to CALFED (now Delta Science Program) in 2006 we had noticed that Suisun Bay phytoplankton productivity was lower than that of Central and San Pablo Bay and only one spring bloom (in 2000) had been observed since 1999. We proposed that something anomalous about Suisun Bay (possibly ammonium ($NH_4$) or some other contaminant such as herbicides) was the cause. We assumed that productivity in the rivers supplying water and phytoplankton to Suisun Bay would have a more typical phytoplankton response and resemble San Pablo phytoplankton. So our scientific questions were

1. Is the "bad" habitat for phytoplankton in Suisun Bay an anomalous condition or part of a continuum between freshwater and oceanic systems?
2. What drivers contribute to the low phytoplankton growth rate in Suisun Bay and how well can the phytoplankton recover when these are removed or changed?
3. If Suisun and Delta phytoplankton are encouraged to grow in near natural conditions (i.e.in experimental enclosures), how do the phytoplankton respond?

4. Can an adaptive management approach be identified to alleviate the diminished food sources linked to the pelagic organism decline (POD)?

One suspected driver identified was $NH_4$ since a feature of the 2000 bloom in which 30 μg $L^{-1}$ chlorophyll was measured, was a decline in $NH_4$ concentrations to ~1 μmol $L^{-1}$ (Wilkerson et al., 2006), suggesting a possible role for $NH_4$ as the missing causative agent. Ammonium concentrations increased in the northern SFE and in Suisun Bay prior to the clam invasion, coincident with human population (Jassby, 2008; Glibert et al., 2011),

The likely mechanism for $NH_4$ impact is inhibition of phytoplankton $NO_3$ uptake by $NH_4$ (e.g. Pennock, 1987; Dugdale et al 2007; Parker et al 2012c). The lack of access to $NO_3$ limits primary production (Parker et al. 2012a, c) and the buildup of chlorophyll, i.e. blooms, since $NO_3$ is by far the largest component of the inorganic N pool, about 80% in Suisun Bay. The increased $NH_4$ may have also resulted in deleterious changes in the food web structure, e.g. diatoms replaced by cryptomonads and flagellates, large zooplankton replaced by smaller species (Glibert 2010; Glibert et al., 2011).

Another driver considered was herbicides used in the watershed that may inhibit photosynthesis of the phytoplankton. In particular we (Sarah Blaser, MSc student) focused on how additions of diuron (used widely for clearing rights-of-ways, such as freeways, parking lots etc. in addition to agricultural applications) and a new chemical imazapyr (used to control invasive plants in restoring wetlands) impact SFE phytoplankton productivity.

These considerations were developed in Grant 1039.

<u>Original hypotheses proposed for Bad Suisun portion</u>

1. Suisun is an anomalous ecosystem in the midst of a normal transition. i.e. something is wrong in the locality of Suisun. Phytoplankton condition and growth rates will be greater both upstream and downstream.
2. Water with native phytoplankton sampled from Suisun Bay and enclosed in experimental mesocosms to stimulate growth will show a less than optimal response compared to water sampled from upstream and downstream.

These hypotheses were falsified. Our comparative experimental enclosures showed the "bad condition" to start in the Sacramento River. Phytoplankton in enclosures filled with Rio Vista water had a more delayed response than those from Suisun and were unable to take up $NH_4$ or use $NO_3$ and accumulate chlorophyll after 5 days. Typically Suisun Bay phytoplankton showed an intermediate response compared with Central Bay and Rio Vista phytoplankton. In one situation when ambient $NH_4$ was lower than usual for Suisun Bay, chlorophyll accumulation and nutrient drawdown occurred at same time scale as Central Bay.

3. Physiological drivers specific to Suisun Bay are toxic or inhibitory to phytoplankton nutrient uptake and primary productivity rates. These may be local sources of unknown toxicity to phytoplankton (perhaps agricultural sources of chemicals, $NH_4$ at high concentrations). These drivers are dissolved within the water column and will inhibit growth of phytoplankton inoculated to the water.

As will be described in the Results below, both $NH_4$ and herbicides dissolved in the water can be inhibitory to phytoplankton productivity and uptake rates but these are likely not specific to Suisun Bay and be of local origin. Both field data and modeling showed the source of $NH_4$ to be upstream from Sacramento Regional Waste water Treatment Plant.

4. Enclosing water in mesocosms will cause a phytoplankton community change to more resistant species that will likely be fast growing opportunistic diatoms.

In most of the mesocosms (enclosures) when phytoplankton were identified, diatoms tended to be the major contributor to the chlorophyll that accumulated. At the end of most mesocosm experiments , larger cells dominated the community as measured by the percentage of chlorophyll in the larger cell sizes (i.e. > 5 µm diameter)

5. Reducing the Suisun Bay ”bad” driver by dilution will allow Suisun Bay phytoplankton to thrive and improve lower trophic levels feeding the Delta food web .

Modeling efforts showed that increased river flow would dilute the $NH_4$ arriving in Suisun Bay and allow the phytoplankton to access $NO_3$ and grow.

The ammendment “Two Rivers” built upon the data collected in “Bad Suisun” that indicated that the low productivity condition occurred in the Sacramento River and might be due to elevated $NH_4$. The San Joaquin River has lower anthropogenic $NH_4$ and a natural experiment to compare nutrients, productivity and phytoplankton was developed. The following supplemental questions to those of the “Bad Suisun” project were.

1. How do differences in nutrient and phytoplankton community composition between the San Joaquin and Sacramento Rivers influence conditions downstream in the Delta and Suisun Bay?
2. How do phytoplankton growth rates and community structure respond to the differences in nutrient concentrations in the San Joaquin River vs. the Sacramento River, resulting from the differences in wastewater treatment?

**Approach**

To assess the anomalous Suisun habitat (“Bad Suisun”) in context of the Delta, upstream (into the Sacramento and San Joaquin Rivers) and downstream (a more oceanic condition in Central Bay), gradients of bulk constituents (e.g. phytoplankton abundance as chlorophyll, nutrient concentration) and experimental grow-outs/enclosures were used to measure ambient conditions and evaluate the physiological response of the phytoplankton. During the spring of 2007 and 2008, seven sets of experimental enclosure experiments were conducted using water collected from Central Bay (the “healthy control”), Suisun Bay, Rio Vista and in the lower San Joaquin River. In all cruises, the station data collected showed higher$NH_4$ concentrations in the Sacramento River sampled at Rio Vista compared to all the other sites. Nitrate was higher at the San Joaquin site compared to the other locations. Chlorophyll was typically higher in Central Bay.

As a continuation for the “Two Rivers”, three cruises were conducted moving the study further into freshwater to characterize the Sacramento and San Joaquin rivers. Two cruises were conducted in spring (2010, 2011) and one cruise was conducted in summer 2010. Cruises were

aimed at measuring nutrients, nutrient uptake and phytoplankton community structure in the rivers and Suisun Bay. All of the data, "Bad Suisun" and "Two Rivers" has been complied into master data files for analysis.

**Results**

*"Bad Suisun" cruise data*

A short summary for the data collected during the 7 cruises of "Bad Suisun" (Table 1) show that chlorophyll at most locations was low in spring 2007 and 2008 (1-3 µg $L^{-1}$), that Rio Vista had the highest $NH_4$ concentration that decreased going seaward and that Suisun Bay typically the highest $NO_3$ concentrations. The highest chlorophyll recorded was 10.7 µg $L^{-1}$ in Central Bay and was accompanied by low $NH_4$ (1.1 µmol $L^{-1}$). This water was used to fill enclosures s that a range of $NH_4$, $NO_3$ and chlorophyll conditions were supplied as initial conditions.

Table 1 Surface data collected during "Bad Suisun" project 2007-2008

| Cruise | Date | Location | $NO_3$ (µmol $L^{-1}$) | $NH_4$ ( µmol $L^{-1}$) | Chl (µg L-$^{1}$) |
|---|---|---|---|---|---|
| BS1 | 4/4/2007 | RioVista | 21.25 | 14.6 | 2.1 |
| | | Suisun Bay | 36.04 | 3.9 | 2.7 |
| BS2 | 4/23/2007 | RioVista | 28.8 | 7.5 | N/A |
| | | Suisun Bay | 35 | 6.3 | N/A |
| | | Central Bay | 24.6 | 4.4 | 3.6 |
| BS3 | 6/26/2007 | RioVista | 19.2 | 9.0 | 2.7 |
| | | Suisun Bay | 43.7 | 3.8 | 2.7 |
| | | Central Bay | 24.1 | 7.6 | 3.6 |
| BS4 | 7/17/2007 | RioVista | 14.3 | 7.0 | 3.9 |
| | | Suisun Bay | 29.96 | 3.9 | 2.3 |
| | | Central Bay | 21.58 | 4.7 | 3.6 |
| BS5 | 3/12/2008 | RioVista | 33.78 | 16.2 | 1.1 |
| | | Suisun Bay | 42.23 | 8.7 | 1.0 |
| | | Central Bay | 22.67 | 5.0 | 2.9 |
| BS6 | 4/21/2008 | RioVista | 25.73 | 15.4 | 1.4 |
| | | Suisun Bay | 42.31 | 4.4 | 1.6 |
| | | Central Bay | 16.96 | 1.1 | 10.7 |
| BS7 | 5/13/2008 | RioVista | 37.11 | 18.2 | 1.4 |
| | | Suisun Bay | 37.95 | 6.6 | 2.4 |
| | | Central Bay | 17.71 | 3.9 | 3.4 |

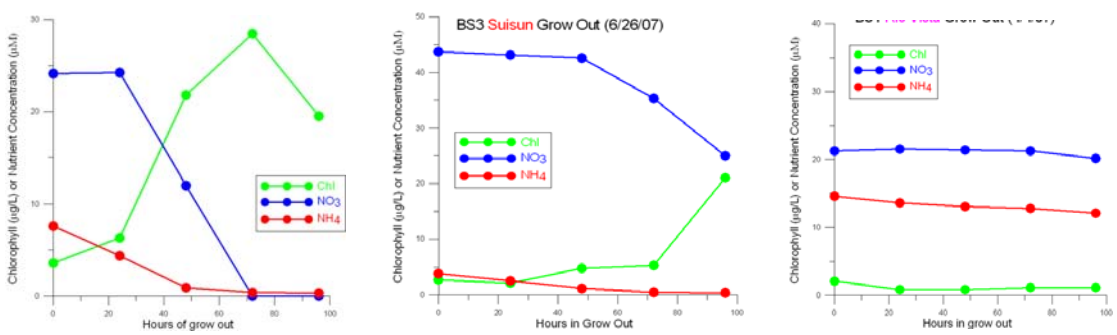
*"Bad Suisun" enclosures*

The enclosure experiments were designed to examine phytoplankton – nutrient interactions during favorable light conditions. During this study (as in our other enclosure studies) there was a predictable sequence of events over a 96-hour incubation period. First, phytoplankton N demand is satisfied by available $NH_4$ as would be predicted by classical $NH_4$

inhibition of $NO_3$ uptake. Second, as $NH_4$ concentrations are reduced to below an inhibitory concentration, phytoplankton access $NO_3$ with rapid $NO_3$ uptake, in excess of $NH_4$ uptake rates, realized within 24 hours of $NH_4$ depletion. Third, carbon assimilation rates increase to balance high $NO_3$ uptake rates, leading to an increase in biomass (quantified as changes in chlorophyll, POC, PON and cell number). Fourth, $NO_3$ becomes depleted within 96 hours (assuming $NH_4$ has been exhausted during that time) regardless of the initial $NO_3$ concentration. The time scale for each of these events changes with the type of water used.

The enclosure data was classified according to the "condition" of the water. The timescale for Central Bay phytoplankton (Type-I) is for $NH_4$ drawdown to 1 µmol $L^{-1}$ in 24 to 48 hours, a peak in $NO_3$ uptake after 48 hours with $NO_3$ drawdown to 1 µmol $L^{-1}$ by 72 hours and the peaks in carbon uptake and chlorophyll accumulation after 72 hours. Type II response has each event drawn out, with $NH_4$ drawdown to 1 µmol $L^{-1}$ in 72 to 96 hours, peak $NO_3$ uptake after 96 hours if at all and with incomplete $NO_3$ drawdown. The maximal carbon uptake and chlorophyll accumulation occurs at 96 hours. This is characteristic of Suisun Bay phytoplankton in enclosures. Finally type III, typical of Rio Vista enclosures, there is even greater lag in phytoplankton response with no $NH_4$ drawdown to 1 µmol $L^{-1}$ and no appreciable $NO_3$ uptake. The enclosures also showed that for high levels of carbon uptake, $NO_3$ uptake needs to occur. The carbon uptake tracked that of $NO_3$ in all experiments, rather than with $NH_4$ uptake.

Figure 1. Example of Type-I, Type-II and Type-III phytoplankton response – showing $NH_4$ decrease (red), then $NO_3$ decrease (blue) and then chlorophyll accumulation (green). Slower response by Type-II and Type-III.

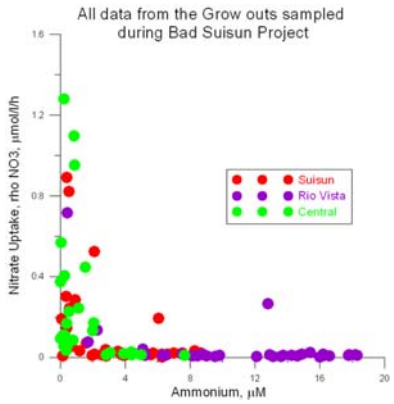



These enclosure data, along with our other prior results) were used to predict the events leading to a spring phytoplankton bloom in SFE. In early spring, phytoplankton N demand in Suisun Bay is satisfied by $NH_4$ but with low biomass-specific and depth-integrated $NH_4$ uptake rates due to high turbidity and poor irradiance (Parker et al., 2012b). $NO_3$ uptake is low or near zero during this period due to $NH_4$ inhibition. With improved irradiance conditions (via increased water transparency, water column stability or seasonal increase in irradiance), phytoplankton $NH_4$ uptake rates and biomass increase causing water column $NH_4$ concentrations to decrease. Once $NH_4$ decreases to < 4 µmol $L^{-1}$ phytoplankton $NO_3$ uptake is enabled. With continued phytoplankton growth, $NH_4$ concentration is further reduced to ≤ 1 µmol $L^{-1}$ and biomass-specific $NO_3$ uptake rates accelerate resulting in a rapidly developing bloom nourished by $NO_3$. However, if residence time is too low to allow the phytoplankton to assimilate the

inflowing $NH_4$, as may happen with high river flow conditions or if there is very elevated $NH_4$ inflow, the production processes are only $NH_4$-based. $NO_3$ is unused and exported from the ecosystem (i.e. to the Pacific Ocean). Reduced primary production is a counter-intuitive result of elevated $NH_4$; the $NH_4$ paradox.

We also observed $NH_4$ inhibition of $NO_3$ uptake in the grow-out experiments above ~1 µmol $L^{-1}$ $NH_4$, $NO_3$ uptake was relatively low and uniform, whereas below $NH_4$ of 1µmol $L^{-1}$ $NO_3$ uptake increased (Figure 2). These findings are consistent other results for the northern SFE including the station time series analysis presented in Wilkerson et al (2006) and Central Bay enclosures presented in Dugdale et al (2007).

Figure 2. $NO_3$ uptake by phytoplankton plotted versus $NH_4$ showing that $NO_3$ uptake is greater at low $NH_4$ concentrations. It also shows how uptake at Rio Vista (purple) is mostly very low and accompanied by high $NH_4$.



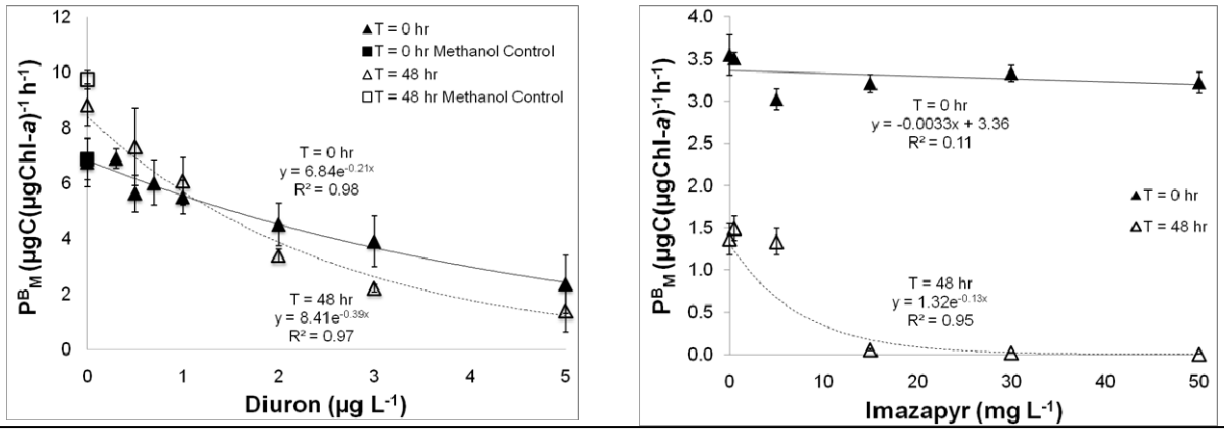

The enclosure data also showed that for high levels of carbon uptake (primary production), high rates of $NO_3$ uptake need to occur. This was also observed in enclosures filled with Suisun Bay water by Parker et al. (2012 ECSS). Finally $NH_4$ uptake by phytoplankton in Suisun Bay was 50% lower than in Central Bay indicating that something was affecting $NH_4$, likely some other contaminant.

*Herbicide effects on SFE phytoplankton*

Experiments were made with SFE water to which additions of either diuron or imazapyr we added and the response of primary production and phytoplankton community composition were monitored. Both herbicides are used widely in the northern estuary-diuron for clearing "rights-of-way" such as freeways and imazapyr is used for eliminating invasive weeds in restoration wetland sites. Results from five diuron experiments using SFE phytoplankton showed a decrease in carbon assimilation number (primary production) during both acute (0 hrs) and chronic (48 hrs) exposure. Diuron has been measured at concentrations up to 2.14 µg $L^{-1}$ in the northern SFE, suggesting that at times in the northern estuary diuron concentrations may be sufficient to negatively impact phytoplankton productivity. Results from three imazapyr experiments showed no difference in carbon assimilation after acute exposure, but in chronic exposure experiments, carbon assimilation declined by up to 80% (compared to the control). Imazapyr concentrations up to 4.2 mg $L^{-1}$ have been measured in the SFE in waters directly adjacent to sites of application during the first tidal flush after application, but this likely dilutes rapidly with time from application. Imazapyr is less likely to have impact on SFE phytoplankton

at the current application concentrations. In all studies diatoms were affected more strongly that flagellates or cyptomonads

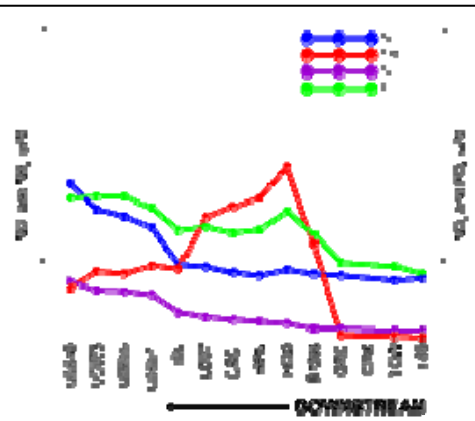
Figure 3. Assimilation number ($P^B_M$, carbon productivity) response to additions of either diuron (left panel) or imazapyr (right panel). Solid symbols show acute response and open symbols show chronic response after 48hours. Decreased productivity with diuron immediately and after 48 hours. Decreased productivity after 48 hours with added imazapyr




*Sacramento River as a source of $NH_4$*

The "Bad Suisun" cruises (Table 1) indicated that elevated $NH_4$ occurred at Rio Vista and that the high $NH_4$, low chlorophyll condition was not localized to Suisun Bay- falsifying our originally hypothesis. Rio Vista phytoplankton showed lower productivity than those in Suisun Bay. Consequently transects were made going upstream from Rio Vista to above the City of Sacramento during the Two Rivers project task and confirmed observations made by Jassby (2008) and ourselves in 2009 (funded by State Water Contractors; Parker et al. 2012 Mar. Pol. Bull) that the $NH_4$ source was Sacramento Regional Wastewater Treatment (SRWTP) plant near Freeport (Figure 4). $NH_4$ decreases going downstream from the SRWTP for various reasons including phytoplankton uptake and nitrification. Although not funded as part of this study, we did use the shiptime from the Two Rivers portion to make incubations with $^{15}N$ to be able to measure pelagic nitrification rates In the future

Figure 4. $NH_4$ (red line) increases at location of SRWTP between Garcia Bend and RM44



The SRWTP currently discharges 15 tons N $d^{-1}$, largely as $NH_4$, to the inland Delta of the SFE and to Suisun Bay, a 3-fold increase from 5 tons N $d^{-1}$ in 1987. Elevated $NH_4$ from sewage effluent has been implicated in reducing primary productivity in other pelagic systems - e.g. along the California coast (MacIsaac et al., 1979), the Delaware Estuary (Yoshiyama and Sharp, 2006), the Scheldt Estuary (Cox et al., 2009), Wascana Creek, Canada (Waiser et al., 2010), and the inner bay of Hong Kong Harbor (Xu et al., 2010), and is likely contributing to the low productivity in the river and Suisun Bay.

*Sacramento River vs San Joaquin River: nutrients and phytoplankton*

The "Two Rivers" task showed that the dominant forms of DIN (dissolved inorganic nitrogen) differed in the Sacramento River (dominated by $NH_4$) and the San Joaquin (by $NO_3$), except in April 2011 (a very high flow condition), $NO_3$ dominated in both Sacramento and San Joaquin rivers. (Figure 5)(Kress, 2012; Kress et al. 2012 IEP; Kress al. tbs). In both rivers a large part of the DIN entering the river comes from the WTP- either SRWTP discharging $NH_4$-N or the Stockton WTP with advanced secondary treatment that discharges mostly $NO_3$-N. Table 2 shows the differences in flow during the cruises with extremely high flow in 2011

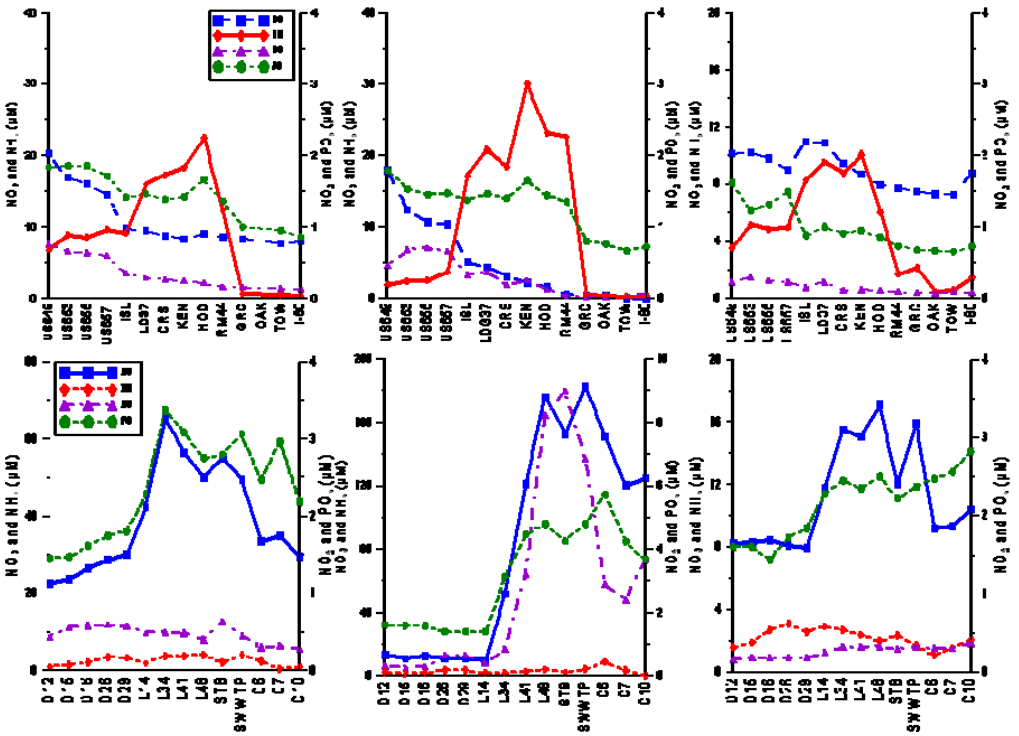


Figure 5. Upper Panels: Nutrient concentrations in Sacramento River with $NH_4$ (red) dominating DIN pool in April & August 2010 (left and center) and $NO_3$ (blue) in April 2011(right panel).
Lower Panels: Nutrient concentrations in San Joaquin River with $NO_3$ (blue) dominating

Chlorophyll concentrations were greater in the San Joaquin than the Sacramento rivers (Kress, 2012). As described in Glibert et al. (2011) and Glibert (2010), differences in the dominant form

Table 2. Differences in physical parameters between Sacramento and San Joaquin

| | Flow ($m^3/s$) | Secchi (m) | Temperature (°C) | EC (µS/cm) |
|---|---|---|---|---|
| **Sacramento River** | | | | |
| **April-10** | 575 @Freeport (4/26/10) | 0.55±0.05 (0.50-0.60) | 16.72±0.30 (16.10-17.20) | 176.31±36.0 (145.0-242.0) |
| **August-10** | 42 @Freeport (8/25/210) | 1.44±0.51 (0.60-2.10) | 21.4±0.43 (20.90-22.20) | 456±1045 (136-4079) |
| **April-11** | 1107 @Freeport (4/19/211) | 0.71±0.13 (0.50-0.90) | 14.80±0.80 (14.1-16.5) | 122±29.30 (98-182) |
| **San Joaquin River** | | | | |
| **April-10** | 158 @Vernalis (4/26/10) | 0.94±0.36 (0.50-1.40) | 17.15±0.33 (16.70-17.60) | 300.6±29.43 (270.0-367.0) |
| **August-10** | 34 @Vernalis (8/26/10) | 1.24±0.59 (0.45-2.75) | 23.4±1.48 (21.70-25.30) | 599±445 (221-1756) |
| **April-11** | 728 @Vernalis (4/20/11) | 1.04±0.31 (0.70-1.50) | 16.6±0.37 (16.0-17.3) | 125±33.88 (124-172) |

of DIN may affect phytoplankton communities with $NO_3$ favoring diatoms and N reduced forms, i.e. $NH_4$ favoring flagellates, cryptomonads and cyanobacteria. April and August 2010 data support this hypothesis. The Sacramento River was dominated by $NH_4$ and also by small flagellates (red/orange in Figure 6) while the San Joaquin River, with high $NO_3$ was dominated by centric diatoms (purple) and chlorophytes (green). This changed during the high flow April 2011 conditions. (Kress, 2012) with more diatoms (34% of total cells) in Sacramento than during other seasons and more cryptophytes (yellow) in the San Joaquin River than other seasons.

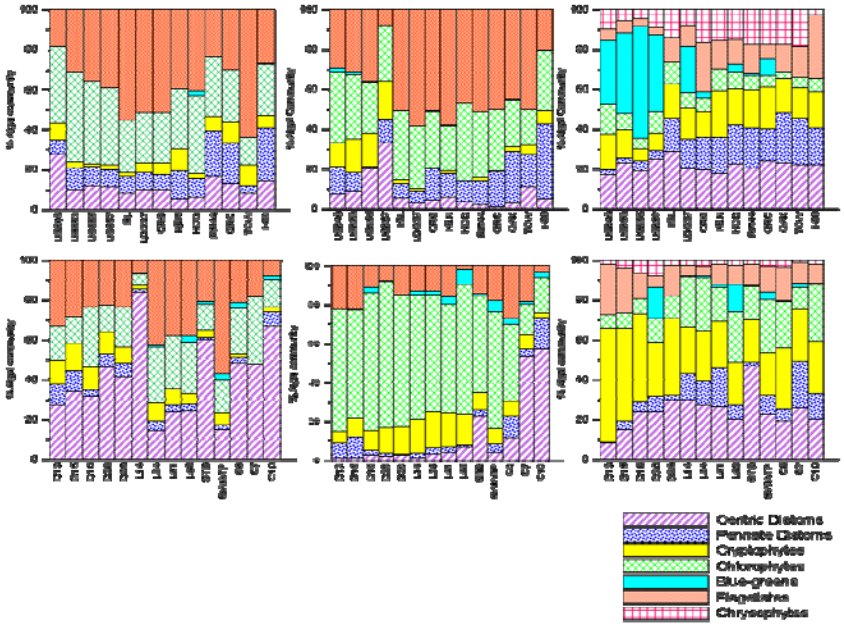



Figure 6. Microscopic enumeration of phytoplankton functional groups. Upper panels: Sacramento R. showing dominance of flagellates in April and August 2010 (left and center panels). Lower panels: San Joaquin R. showing the dominance of centric diatoms in April and August 2010 (left and center panels)

*Comparison of different approaches to evaluate phytoplankton communities*

Another aspect of this project was to use a variety of approaches, in addition to microscopy, to evaluate changes or difference in phytoplankton community. We used size fractionated chlorophyll-a measurements- assuming that the smaller (<5 µm cells) would be mostly the flagellates and >5 µm cells, diatoms and cryptomonads. We used flow cytometry onboard to provide more size fractionation of the community and also a bbE Fluoroprobe, a fluorospectrophotometer, that was plumbed into the vessel's water flow through an intake located approximately 1m below the water surface (Kress et al. 2012). The FluoroProbe gave an *in vivo / in situ* horizontal profile of chlorophyll and accessory pigments and provided "fluorescent fingerprints" of algae in four different taxonomic groups: 1) green (containing chlorophyll-*a*, *b*); chlorophytes), 2) brown algae (containing fucoxanthin or peridinin; diatoms, chrysophytes, dinoflagellates), 3) blue-green (with phycocyanin; cyanobacteria) and 4) cryptophytes (with phycoerythrin). Although each approach provided a specific aspect, there was overlap between trends provided by the different techniques. For qualitative uses, the Fluoroprobe was an effective, easy to use, effective realtime approach to evaluating phytoplankton community (Kress et al. 2012 IEP). Table 3 gives an example.

Table 3. A comparison of approaches used to evaluate phytoplankton community structure during April 2010 cruise

| | Sacramento R. | San Joaquin R. |
|---|---|---|
| Abundance-all methods | Less | More |
| Size fractionated Chl-a<br>Chl-a in cells >5-µm | 66% | 78% |
| Flow cytometer<br>Fluores. Particles 5-50-µm | 44% | 64% |
| Fluoroprobe<br>Dominant fluorescent group | green | brown |
| Microscopy<br>Dominant functional group | flagellates | centric diatoms |

*Importance of flow for phytoplankton productivity and functional group*

The April 2011 data illustrated how important high flow conditions can be in changing the nutrient and phytoplankton conditions. River flow dilutes nutrients and affects the proportion of $NO_3$ and $NH_4$ in the two rivers. This will affect the phytoplankton communities (Glibert et al. 2011). The high river flow in 2011 and subsequent decrease in the peak $NH_4$ concentration in

Sacramento River due to dilution compared to the peaks in 2010 may explain the increase in phytoplankton biomass compared to 2010.

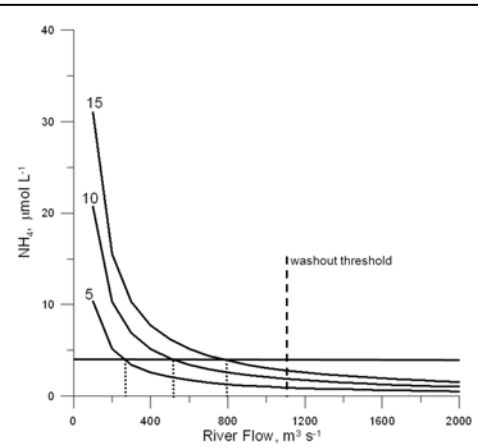
In the Sacramento River during spring 2011 the increase in phytoplankton abundance as well as the change to a dominance of diatoms may be attributed to the increased flow causing more flood and drainage events into the Sacramento River's floodplains. During a study on the effect of inundation of the main floodplain of the Sacramento River, the Yolo Bypass, Lehman (2007) showed the floodplain to be a good source of high quality food to the main river during flood and drainage events and that the dominant phytoplankton group in the floodplain was the diatom *Cyclotella*. This was the diatom species that dominated in the Sacramento River in our "Two Rivers" task in 2011.

The increase in flow in 2011 was far greater in the San Joaquin River compared to the Sacramento River; flow was roughly 4.5-fold greater in the spring 2011 compared to 2010. This presumably resulted in flushing of phytoplankton downstream and insufficient residence time for chlorophyll accumulation, as described by Jassby (2005) who described that with a peak flow of 650 $m^3s^{-1}$ (an 'extreme wet' event), chlorophyll was <10 µg $L^{-1}$ (Jassby 2005). The peak flow recorded in April 2011 was 730 $m^3s^{-1}$ and the chlorophyll concentrations were <4 µg $L^{-1}$, lower than usual for the San Joaquin River.

*Modeling and flow*

Since the point source of $NH_4$ is on a river, flow will modulate the concentration and spatial distribution. As part of Task 5 of "Bad Suisun", a simple conceptual box model was constructed to understand the interactions of river flow, $NH_4$ discharge, river flow and bloom initiation of spring blooms in Suisun Bay. The model has three criteria; 1) $NH_4$ loading to Suisun Bay must not exceed the capacity of the phytoplankton to assimilate the inflow of $NH_4$, 2) the $NH_4$ concentration must be ≤ 4 µmol $l^{-1}$ to enable phytoplankton $NO_3$ uptake, 3) the dilution rate of phytoplankton biomass set by river flow must not exceed the phytoplankton growth rate to avoid "washout". These criteria were determined for Suisun Bay; with sufficient irradiance and present day discharge of 15 tons $NH_4$-N $d^{-1}$from the SRWTP (upstream wastewater treatment plant). The loading criterion requires phytoplankton $NH_4$ uptake to exceed 1.58 mmol $m^{-2}$ $d^{-1}$; the concentration criterion requires river flow > 800 $m^3s^{-1}$ at the SRWTP for sufficient $NH_4$ dilution and the washout criterion requires river flow at Suisun Bay <1100 $m^3$ $s^{-1}$ (Figure 7) In spring 2010 these criteria were met and there was a bloom. Other years flow was too low (<800 $m^3s^{-1}$) or discharge too high or flow was too high (>1100 $m^3$ $s^{-1}$).

Figure 7. $NH_4$ concentration of inflowing river water at the entrance to Suisun Bay as a function of river flow at point of discharge and three effluent discharge levels (5, 10 and 15 tons $NH_4$-N $d^{-1}$). The 3 dotted vertical lines show the river flow that will result in $NH_4$ = 4 µmol $L^{-1}$ at Suisun Bay for each of three discharge levels. The dashed vertical line shows the river flow threshold at which the phytoplankton population washes out.



Further modeling efforts built a "Stella" model to describe the interaction of $NH_4$ and $NO_3$ uptake in enclosures of SFE water from Central Bay, Suisun Bay and the Sacramento River and run for sensitivity analysis to input parameters. Slight changes in parameters were made to tune the model to match the trends observed in a series of enclosures of Central Bay water published by Dugdale et al. (2007). The model was then run with initial input variables (concentrations of $NH_4$, $NO_3$, and phytoplankton as particulate organic nitrogen PON) taken from an independent set of enclosures from different regions of the SFE (including "Bad Suisun" enclosure data) and Sacramento River, with good qualitative agreement.

The model was then run to simulate a fully-mixed Suisun Bay, essentially running in a chemostat-like mode, and showed a transition from a high-productivity condition fueled by $NO_3$ uptake to a low-productivity condition fueled only by $NH_4$. In this model, when $NH_4$ and flow (400-4000 $m^3s^{-1}$) were varied a sharp boundary between the two modes appeared (Dugdale et al. modeling tbs). The Stella model also showed that at high $NH_4$ concentrations (10 µmol $L^{-1}$), the maximum flow that would allow for the high productivity mode was only 600 $m^3s^{-1}$ and an increase in flow to 700 $m^3s^{-1}$ drove the system into the low productivity mode. In the model, at low $NH_4$ concentrations the modeled maximum flow allowing high productivity mode increased to about 1600 $m^3s^{-1}$. (Dugdale et al. modeling tbs). The model results were consistent with the observation of Ball and Arthur (1979) who showed flows of <700 $m^3s^{-1}$ were required for bloom occurrence in Suisun Bay at the $NH_4$ concentrations observed in the early 1970's (Dugdale et al. modeling tbs). These results confirm our conclusion that the present-day SFE is in a chronically low productivity mode, except for rare blooms when $NH_4$ concentrations fall to very low levels allowing access of the phytoplankton to $NO_3$.

## D. LIST OF ALL PUBLICATIONS AND PRESENTATIONS RESULTING OR PREPARED DURING GRANT 1039

*Publications that use data collected during the grant*

Blaser, S., Parker, A.E., Wilkerson, F.P. ms being finished, to be submitted (tbs) Sept 2012. The effect of diuron and imazapyr herbicides on phytoplankton carbon and nitrogen assimilation and community composition. *Aquatic Toxicology.*

Blaser, S., Parker, A.E., Wilkerson. F.P. 2011. Diuron and imazapyr herbicides impact estuarine phytoplankton carbon assimilation: evidence from an experimental study. *IEP Newsletter* 24 (3): 3-11.

Blaser, S.B. 2011 Effect of diuron and imazapyr herbicides on phytoplankton in the San Francisco Estuary in an experimental study. MSc thesis, SFSU.

Dugdale, R., Wilkerson, F., Parker, A and Marchi, A. 2012 Accepted. River flow and ammonium discharge determine spring phytoplankton blooms in an urbanized estuary. *Estuarine, Coastal and Shelf Science*

Dugdale, R.C., Wilkerson, F.P., Hogue, V.E., Parker, A.E. Suisun Bay phytoplankton productivity modeled as a simple flow through system. Ready to be submitted July 2012, *Environmental Modeling and Assessment*.

Kress, E. Parker, A.E., Wilkerson. F.P., Dugdale, R.C ms being finished, to be submitted Sept 2012. ms being finished, Phytoplankton abundance and community structure in the Sacramento and San Joaquin Rivers. *Estuaries and Coasts.*

Kress, E. Parker, A.E., Wilkerson. F.P., Dugdale, R.C. 2012. Assessing phytoplankton communities in the Sacramento and San Joaquin Rivers using microscopic and indirect analytical approaches. *IEP Newsletter* 25 (3).

Kress, E. Phytoplankton abundance and community structure in the Sacramento and San Joaquin Rivers. 2012. MSc thesis, SFSU.

Parker, A.E., Hogue, V.E., Wilkerson, F.P. and Dugdale, R.C. 2012. The effect of inorganic speciation on primary production in the San Francisco Estuary. *Estuarine, Coastal and Shelf Science.* 104: 91-101.

Wilkerson, F.P., Dugdale, RC., Parker, A.E., Hogue, V.E., March, ms being finished, to be submitted Oct 2012. A. Characterization of phytoplankton responses to changing nutrient regimes in San Francisco Bay. *Marine Ecology Progress Series*.

*Publications prepared while personnel were partially supported by the grant*

Brooks, M.J., Fleishman, E., Brown, L.R., Lehman, P.W., Werner, I., Scholz, N., Mitchelmore, C., Lovvorn, J.R., Johnson, M.L., Schlenk, D., van Drunick, S., Drever, J.I., Stoms, D.M., Parker, A.E., Dugdale, R.C., 2011. Life histories, salinity zones, and sublethal contributions of contaminants to pelagic fish declines illustrated with a case study of San Francisco Estuary, California, USA. *Estuaries and Coasts.* 35: 603-621. doi 10.1007/s12237-011-9459-6

Dugdale, R.C, F. Wilkerson, AE. Parker, Al Marchi, K. Taberski 2012 Accepted . River flow and ammonium discharge determine spring phytoplankton blooms in an urbanized estuary. *Estuarine and Coastal Shelf Science*.

Kimmerer, W.J., Parker, A.E., Lidström, U.E. and Carpenter, E.C. 2012. Short-term and interannual variability in primary production in the low-salinity zone of the San Francisco Estuary. *Estuaries and Coasts* (2012) 35:913–929, DOI 10.1007/s12237-012-9482-2

Kleckner, A 2009. The role of an invasive bivalve, Corbula amurensis, in the Suisun Bay nitrogen cycle. SFSU Masters thesis.

Parker, A.E., Al M. Marchi, Jan Davidson-Drexel, Richard C. Dugdale, Frances P. Wilkerson. 2010. Effect of ammonium and wastewater effluent on riverine phytoplankton in the Sacramento River, CA. Technical Report for the California State Water Resources Board

Parker, A.E., Dugdale, R.C. and Wilkerson, F.P. 2012. Elevated ammonium concentrations from wastewater discharge depress primary productivity in the Sacramento River and the Northern San Francisco Estuary. *Marine Pollution Bull*. 64: 574-586. doi:10.1016/jmarpolbul.2011.12016.

Parker, A.E., Kimmerer, W.J. Lidström, U.U. 2012. Reevaluating the generality of an empirical model for light-limited primary production in the San Francisco Estuary *Estuaries and Coasts* (2012) 35:930–942, DOI 10.1007/s12237-012-9507-x

*Presentations that used data collected during the grant*

**2007**

Dugdale, R.C. F. Wilkerson, .A. Parker, V. Hogue, A. Marchi, A. Kleckner, J. Fuller, K. Lew First the “Bad Suisun” and now the “Dead Delta” ? The collapse of primary production in the Delta .RTC Seminar Series, December 2007

Dugdale, R.C., Sharp, J.H., Wilkerson, F., Parker, A.E.DIN is an inadequate descriptor for evaluating nitrogen based effects on estuarine ecosystems. Estuarine Research Federation Meeting Providence, RI. November 2007

Dugdale, R. C., Wilkerson, F., Parker, A. E., Hogue, V., Marchi, A., Kleckner, A., Fuller, J. The declining ecosystem health of the northern San Francisco Bay-Delta may be linked to poor phytoplankton productivity. Biennial State of the Estuary Conference, Oakland, CA 2007

Wilkerson, F., Hogue V, Parker AE, Dugdale RC, Marchi A, Kleckner A, Fuller J. Anomalously low phytoplankton productivity in northern San Francisco Estuary. Estuarine Research Federation Meeting Providence, RI. November 2007

Parker, A. E., Dugdale, R.C., Wilkerson, F. Bad Suisun: Exploring the role of anthropogenic NH4 in determining primary production in the northern San Francisco Estuary. Contaminants Workgroup meeting, June 15, 2007 UC Davis

Dugdale, R., Wilkerson, F., Parker, AE, Marchi, A., Hogue, V., Lew, K. Do Low phytoplankton growth rates signal the "bad" habitat conditions in Suisun Bay driving the pelagic organism decline., Interagency Ecological Program Science Meeting, Pacific Grove, CA. 2007

**2008**

Dugdale, R.C., Parker, A.E., Mueller-Solger, A., Wilkerson, F., Marchi, A., Hogue V.E. Origins of high nutrients and low productivity conditions in Suisun Bay, and the Sacramento and San Joaquin Rivers. Interagency Ecological Program Science Meeting, Pacific Grove, CA. 2008

Wilkerson, F; Parker, A; Hogue, V; Marchi, A; Dugdale, R, 2008 (March) Influence of the San Francisco outflow on the productivity of the Gulf of the Farallones, AGU Ocean Sciences Meeting, Orlando For special session: Structure and Function of River Plumes in Coastal Margins

Dugdale, RC. October 2008. Effects of ammonium on phytoplankton growth and consequences for the POD. 2008. CALFED Science Conference, Sacramento

Dugdale, R.C. November 2008 Nitrate, ammonium and phytoplankton blooms in San Francisco Estuary, San Francisco Bay regional Water Quality Board, Oakland, CA.

Dugdale, R.C. November 2008 Phytoplankton Blooms, nitrate, and ammonium, from upwelling to estuary, USGS, Menlo Park, CA.

Parker, A.E., Lidstrom, U., Hogue, V.E., Wilkerson, F., Dugdale, R.C. 2008 Food limitation and the pelagic organism decline: quantifying carbon supply from heterotrophic bacteria to the food web of Suisun Marsh and the northern San Francisco estuary Interagency Ecological Program Science Meeting, Pacific Grove, CA.

Dugdale, R. A. Parker, A. Mueller-Solger, F. Wilkerson, A.Marchi, V. Hogue. March 2008. Origins of high nutrients and low productivity conditions in Suisun Bay, and the Sacramento and San Joaquin Rivers. IEP, Asilomar, CA.

Wilkerson, F.P., R. Dugdale, A.Parker, A.Marchi, V.Hogue. 2008. Influence of the San Francisco Outflow on the productivity of the Gulf of the Farallones. Ocean Sciences, Orlando FL.

R Dugdale participated in NCEAS Workshop Potential role of contaminants in declines of pelagic organisms in the upper SFE, CA (Jan 2008, Santa Barbara)

**2009**

Parker, A.E. , Dugdale, R.C. Wilkerson., F.P., Marchi, A. 2009. Primary production in the northern San Francisco Estuary: recent insights from carbon and nitrogen productivity studies. American Association for the Advancement of Science Western Region Meeting, San Francisco, CA

Parker, A.E. 2009. Effect of wastewater treatment plant effluent on algal productivity in the Sacramento River: transect results. Interagency Ecological Program Ammonium Summit, Rancho Cordova, CA

Parker, A.E. 2009. Transport and fate of ammonium supply from a major urban wastewater treatment facility in the Sacramento River, CA. 9$^{th}$ Biennial State of the Estuary Conference, Oakland, CA

Parker, A. E. Dugdale, R. C., Foe, C., Wilkerson, F. P., Marchi, A., Davidson-Drexel, J., Blaser, S., Fuller, J. 2009. Transport and fate of ammonium supply from a major urban wastewater treatment facility in the Sacramento River, CA. Coastal and Estuarine Research Federation Conference, Portland, OR

Marchi, A., Parker, A.E., Dugdale, R.C., Wilkerson, F.P. 2009. Long-term trends in nutrient and chlorophyll-a concentrations in the San Francisco Estuary, CA: interannual perturbations in freshwater flow. Coastal and Estuarine Research Federation Conference, Portland, OR

Dugdale, R., Wilkerson, F., Parker, A.E., Marchi, A. Fuller, J. 2009. Suppression and modulation of primary productivity by anthropogenic$NH_4$ inputs in the San Francisco Bay and delta. California Estuarine Research Society Annual Meeting, Bodega, CA.

Dugdale, R.C., Parker, A.E., Marchi, A., Wilkerson, F.P. 2009. Anthropogenic ammonium inputs have contributed to reduced primary production in San Francisco Bay. ASLO Aquatic Sciences Meeting, Nice, France

Parker, A.E. 2009. The relative importance of external organic carbon and in situ primary production for the foodweb of the San Francisco Estuary, USA. ASLO Aquatic Sciences Meeting, Nice, France

**2010**

Blaser, S.,Wilkerson, F., Parker, A. E. 2010. Effect of Diuron and Imazapyr Herbicides on Phytoplankton in the San Francisco Estuary. 6TH biennial Delta Science Conference, Sacramento, CA

Kendall, C., Silva, S., Young, M., Guerin, M., Parker, A.E., Foe, C. 2010. seasonal and spatial variation in water chemistry and isotopes in the Sacramento River, Delta, and eastern San Francisco Bay. 6TH Biennial Delta Science Conference, Sacramento, CA

Kendall, C., Silva, S., Young, M., Kraus, T., Guerin, M., Parker, A.E., Foe, C. 2010. Causes of seasonal and spatial variation in water chemistry in the sacramento river, delta, and eastern san francisco bay and their effects on chlorophyll levels. 6TH Biennial Delta Science Conference, Sacramento, CA.

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Kress, E., Parker, A.E., Wilkerson, F., Mueller-Solger, A. 2010. Nutrient loading effects on phytoplankton community structure and biomass in the Sacramento and San Joaquin Rivers. 6TH Biennial Delta Science Conference, Sacramento, CA

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Parker, A.E., Dugdale, R.C., Wilkerson, F., Marchi , A. 2010. Biogeochemical processing of anthropogenic ammonium in the Sacramento River and the northern San Francisco Estuary: consequences for the pelagic organism decline Species. 6TH Biennial Delta Science Conference, Sacramento, CA

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Blaser, S., Wilkerson, F.P., Parker, A.E. 2011. Diuron Herbicide Impacts Estuarine Phytoplankton: Evidence from an experimental study. 10th Biennial State of the Estuary Conference, Oakland, CA

Kress, E., Parker, A.E., Wilkerson, F. P., Dugdale, R.C., Mueller-Solger, A. 2011. Assessing phytoplankton communities in two urbanized rivers with contrasting inorganic nitrogen speciation. Coastal and Estuarine Research Federation Biennial Conference, Daytona Beach, FL.

Wilkerson, F.P., Parker, A.E., Dugdale, R.C., Marchi, A., Blaser, S., Taberski, K. 2011. Balance between different contributions to the DIN pool in determining phytoplankton blooms in San Francisco Estuary. Coastal and Estuarine Research Federation Biennial Conference, Daytona Beach, FL.

Parker, A.E. 2011. Increased reliance on microbial loop processes in the low salinity zone of the San Francisco Estuary. Coastal and Estuarine Research Federation Biennial Conference, Daytona

Blaser, S., Wilkerson, F.P., Parker, A.E. 2011. Effect of Diuron and Imazapyr herbicides on phytoplankton in the San Francisco Estuary in an experimental study. Coastal and Estuarine Research Federation Biennial Conference, Daytona Beach, FL

Parker, A.E., Dugdale, R.C., Wilkerson, F.P., Kress, E., Marchi, A. 2011. Contrasting nutrient environments in the Sacramento and San Joaquin Rivers: implications for the phytoplankton community. IEP Workshop at the 45th Annual Conference of the California-Nevada Chapter of the American Fisheries Society, Folsom, CA.

Dugdale, R.C., Wilkerson, F.P., Parker, A.E., Marchi, A., Blaser, S., Taberski, K. 2011. Diatom blooms observed in Suisun Bay during spring 2010; how did ambient nutrients play a role? IEP Workshop at the 45th Annual Conference of the California-Nevada Chapter of the American Fisheries Society, Folsom, CA.

Wilkerson, F.P. Dugdale, R.C., Parker, A.E., Marchi, A., Blaser, S. 2011. Anthropogenic nutrient enrichment in San Francisco Estuary/Delta: water quality impacts on pelagic food webs and productivity. ASLO Aquatic Sciences Meeting, San Juan, Puerto Rico.

Parker, A.E., Mueller-Solger, A., Kress, E., Wilkerson, F. 2011. Phytoplankton Community Characterization Using Flow Cytometry and Submersible Spectrofluorometry in the Eutrophic Northern San Francisco Estuary Delta, CA. ASLO Aquatic Sciences Meeting, San Juan, Puerto Rico.

Blaser, S.,Wilkerson, F., Parker, A. E. 2010. Effect of Diuron and Imazapyr Herbicides on Phytoplankton in the San Francisco Estuary. 6TH Biennial Delta Science Conference, Sacramento, CA

Kendall, C., Silva, S., Young, M., Guerin, M., Parker, A.E., Foe, C. 2010. Seasonal and Spatial Variation in Water Chemistry and Isotopes in the Sacramento River, Delta, and Eastern San Francisco Bay. 6TH biennial Delta Science Conference, Sacramento, CA

Blaser, S. Effect of diuron and imazapyr herbicides on phytoplankton in the San Francisco Estuary in an experimental study. Master Defence, SFSU.

**2012**

Blaser, S. Wilkerson, F.P., Parker, A.E., Dugdale, R.C. 2012. Effect of Diuron and Imazapyr herbicides on phytoplankton in the San Francisco Estuary in an experimental study. Delta Science Conference, Sacramento, CA

Dugdale, R.C., Wilkerson, F.P., Parker, A. E. 2012. New and regenerated productivity: an oceanographic concept applied to the San Francisco Bay Delta to understand phytoplankton response to improved irradiance and nitrate versus ammonium supply. Delta Science Conference, Sacramento, CA

Wilkerson F.P. Parker, A.E., Dugdale, R.C., Pimenta, A, Blaser, S., Kress, E., Buck, C. 2012. The rise in fall of northern estuary phytoplankton during the FLaSH study. Delta Science Conference, Sacramento, CA

Blaser, S., Wilkerson, F.P., Parker, A.E. 2012. An experimental study of Diuron and Imazypr herbicide effects on phytoplankton assemblages in the San Francisco Estuary. Interagency Ecological Program Conference, Folsom, CA

Wilkerson, F.P., Parker, A.E., Dugdale, R.C. 2012. Nutrient and phytoplankton distributions during the Fall Low Salinity Habitat (FLaSH) Study in Suisun Bay. Interagency Ecological Program Conference, Folsom, CA

Dugdale, R.C., Parker, A.E. 2012. The effect of ambient light on phytoplankton nutrient uptake in San Francisco Estuary. Interagency Ecological Program Conference, Folsom, CA

Kress, E., Parker, A.E., Wilkerson, F.P., Dugdale, R.C. 2012. Assessing phytoplankton communities in the Sacramento and San Joaquin Rivers using microscopic and indirect analytical approaches. Interagency Ecological Program Conference, Folsom, CA

Wilkerson, F., Dugdale, R., Parker, A., Marchi, A., Blaser, S., Taberski, K. 2012. Altered San Francisco Estuary: how waste water treatment practices negatively influence the pelagic food web AGU/TOS/ASLO Ocean Science Meeting, Salt Lake city, UT.

Dugdale, R., Parker, A. E. 2012. Anthropogenic ammonium ecosystem effects: from river to estuary to coastal ocean. AGU/TOS/ASLO Ocean Science Meeting, Salt Lake city, UT.

Kress, E. Phytoplankton abundance and community structure in the Sacramento and San Joaquin Rivers. 2012. Masters Defence, SFSU.

## E. DATA COLLECTED FOR PROJECT 1039

| | **Bad Suisun cruises 2008-2008** | **Bad Suisun enclosures 2010-2011** | **Two Rivers cruises 2010-2011** |
|---|---|---|---|
| Temperature/salinity | 26 | | 104 |
| Nutrients ($NO_3$, $NH_4$, $PO_4$, Si) | 26 | 112 | 112 |
| Chl-*a* (5µm>X, X<5µm) | 26 | 112 | 112 |
| urea | 26 | | 112 |
| $NO_2$ | | | 112 |
| Secchi / PAR | 26 | | 112 |
| $^{13}C/^{15}NH_4$ uptake | 26 | 112 | 112 |
| $^{13}C/^{15}NO_3$ uptake | 26 | 112 | 112 |
| Dissolved inorganic carbon | 26 | 112 | 112 |
| FluoroProbe | | | 100 |
| CytoSense | | 112 | 70 |
| Microscope counts | | Collected but not preserved well | 112 |

## F. CUMULATIVE PROGRESS REPORTS THAT WERE SUBMITTED LISTED BY TASK

**TASK 1:**
Task 1 is the mandatory administrative Project Management task. Management concerning the amendment "Two Rivers" was included in Task 6.

***From Prog Rep 3 (4/16/07-12/31/11)***
Between Dec 2008 and 2011, this task did the administrative work to deal with the stop work-order (12/31/08-6/30/09) and paperwork involved with adding the Amendment and rebudgeting. This task also arranged for two no-cost extensions to the project as a result of the no cost extension and start of the amendment which resulted in loss of an entire field year.

***From Prog Rep 2 (1/1/08-12/31/08)***
Between January and December 2008, we continued collaborations with Anke Mueller Solger. Data from the project was presented at the IEP Conference in Asilomar in March 2008, the Ocean Sciences Meeting in Orlando in February 2008, and in the NCEAS Workshop "Potential role of contaminants in declines of pelagic organisms in the upper SFE, CA" (Jan 2008, Santa Barbara). R Dugdale and F Wilkerson participated in a workshop/scoping session for a potential SFE environmental report card, organized by NCEAS at RTC, SFSU. R.Dugdale gave a talk at thje CALFED Science Meeting in October 2008 and a talk to the San Francisco Bay Regional Water Qulaity Board.on this project. We (Alex Parker and Dick Dugdale) also participated in Contaminants meetings led by Karen Larsen in Sacramento. We also prepared a proposal for a grant extension for the CALFED project to include more detailed studies of the two rivers as the data collected indicated since they too showed some reduced phytoplankton health.

***From Prog Rep 1 (4/16/07-12/31/07)***
This involved administrative efforts to set up the contract and accounting at SFSU, set up personnel costs. Under this task we initiated collaborative discussions with Anke Mueller Solger at DWR. We presented preliminary data collected at an EET (informal IEP workgroup) meeting and at ERF 2007 in Providence- poster by Wilkerson et al.

**TASK 2 and TASK 3:**
Although separated in the proposal these tasks (Task 2 Suisun Habitat Description and Task 3 Experimental Manipulations) are combined in the project.

***From Prog Rep 3 (4/16/07-12/31/11)***
Between Dec 2008 and now all the nutrient, chlorophyll, DIC, flow cytometry, and physiological uptake data were analyzed in the laboratory; ie mass spectrometry, fluorometry etc. With the stop work order most samples had to be preserved until the work order ended. The data were entered into master data sheets for both the field sampling and the experimental enclosures. These data were synthesized and presented at numerous conferences including the Ammonium Summit held in August 2009. In addition a masters student started studies on herbicide effects on phytoplankton production and community structure to examine if herbicides could contribute to declining productivity condition in the northern estuary.

***<u>From Prog Rep 2 (1/1/08-12/31/08)</u>***

Water was collected simultaneously in Suisun Bay, and at locations in the two rivers, San Joaquin and Sacramento and in Central Bay and along with CTD, DIC, nutrients, chlorophyll, physiological uptake rates by the phytoplankton are measured (Task 2). The water is then held for up to 5 days and monitored for changes in biomass and physiological rates (Task 3). Sampling was carried out using the RV Questuary and the R/V Polaris.

In 2008 we completed an additional 3 sets of grow-out experiments (see below, Bad Suisin 5, 6 and 7) in addition to measuring parameters at the 4 collection sites to collect water used for the grow-outs.

| **Date** | **Experiment Name** | **Grow-out 1** | **Grow-out 2** | **Grow-out 3** | **Grow-out 4** |
|---|---|---|---|---|---|
| 3/12/08 | Bad Suisun 5 | Rio Vista (Sac), 38º 8.9'N, 121º 41.3'W | Eight-Mile Rd (San Joaq), 38º 2.3'N, 121º 29.3W | Suisun Bay, 38º 2.1'N, 122º 5.8'W | RTC Seawall, 37º 53.8'N, 122º 25.5'W |
| 4/21/08 | Bad Suisun 6 | same | same | same | same |
| 5/13/08 | Bad Suisun 7 | same | same | same | same |
| | | | | | |

Seventy samples in 2008 were analyzed using the AutoAnalyzer for concentrations of nitrate, silicate, and phosphate, seventy for dissolved inorganic carbon, 70 for spectrophotometric measurements of ammonium. 70 for extracted chlorophyll, 70 for particulate nitrogen and particulate carbon., Phytoplankton uptake of 13C, 15N-nitrate and 15N-ammonium were also measured using mass spectrometry at all stations in all enclosure (grow-outs) – 70 samples. uptake rates. Urea samples are still waiting to be analyzed. However the data from 2007 suggested urea was not a significant contributor to the DIN pool (typically 0.3 µM, max measured was in Central Bay, at 1 µM).

*From Prog Rep 1 (4/16/07-12/31/07)*

Four such samplings were completed in 2007; Bad Suisun 1 (4/03/07), Bad Suisun 2 (04/23/07), Bad Suisun 3 (06/26/07) and Bad Suisun 4 (07/16/07). Data was collected in Suisun Bay and usually at Rio Vista (Sacramento R) and in the lower San Joaquin, with Central Bay for comparison and showed that Suisun consistently had higher nutrients than the other locations with higher DIC than the river stations. Preliminary uptake rates suggest a decreasing trend in productivity into the rivers. The experimental grow-outs also support this with little drawdown of nutrients or DIC in the rivers (almost net heterotrophic sometimes) compared to Central Bay.

| Date | Experiment Name | Encl #1 | Encl #2 | Encl #3 | Encl #4 |
|---|---|---|---|---|---|
| 4/3/07 | Bad Suisun 1 | Rio Vista 38º 08.9' N 121º 41.3' W | Sta 649 38º 3.7N 121º 48.0'W | "5 psu" 38º 05.5N 122º 00W | |
| 4/23/07 | Bad Suisun 2 | "0.5 psu" 38º 03.7N 121º 48.6W | "2 psu" 38º 02.8N 121º 55 W | "5 psu" 38º 05N 121º 59.7W | "SW" 37º 53.8' N, 122º 25.5' W |
| 6/26/07 | Bad Suisun 3 | Rio Vista 38º 08.9' N 121º 41.3' W | "San" 38º 02.3N 121º 29.3W | "5 psu" 38º 04.4N 121º 58.4W | "SW" 37º 53.8' N, 122º 25.5' W |
| 7/16/07 | Bad Suisun 4 | Rio Vista 38º 08.9' N 121º 41.3' W | "San" 38º 02.3N 121º 29.3W | "5 psu" 38º 02.6N 121º 55.3W | "SW" 37º 53.8' N, 122º 25.5' W |

In 2007 Seventy samples were analyzed for concentrations of nitrate, silicate, phosphate, ammonium, urea, dissolved inorganic carbon (DIC), chlorophyll (in large and small cells) particulate nitrogen, particulate carbon, 13C uptake rates, 15N-nitrate and 15N-ammonium uptake rates.

**TASK 4 and TASK 5:**

***From Prog Rep 3 (4/16/07-12/31/11)***

Since Dec 2008 till now, for Task 4 Dr Carpenter trained two graduate students in phytoplankton identification using light microscopy. For Task 5 Dr Dugdale has developed a series of models- a simple flow box model to predict when and how spring chlorophyll blooms can develop in Suisun Bay. Another more complex ecosystem model using STELLA was constructed that includes the ammonium/nitrate interactions and phytoplankton growth responses from Tasks 2 and 3 results. This model shows two steady state conditions- one in low and the other high ammonium conditions.

*From Prog Rep 2 (1/1/08-12/31/08)*

These tasks have just begun. Dr Carpenter has started to prepare algal samples for microscopy. Dr Carpenter has provided algal counts for the 2008 cruises and an additional set of samples taken on a DWR cruise and we are starting to compare that data with the preliminary Fluoroprobe data that was collected by Dr. Anke Mueller Solger. Dr Dugdale has initiated a simple model to simulate the nutrient interactions in the grow-out experiments

**TASK 6 TWO RIVERS**

***From Prog Rep 3 (4/16/07-12/31/11)***

This Task covers the Amendment-"Two Rivers". This Task actually commenced in spring 2010 due to paperwork delays and rebudgeting when Anke Muller Solger took the Lead Scientist position at IEP and we changed her part of the budget to cover both a graduate student and

personnel to operate the bbE fluoroprobe and collect phytoplankton samples on cruises and start phytoplankton ID work in addition to a phytoplankton ID consultant. Since then we have carried out three cruises (Table) that each consist of 2-3 day cruises covering 14 stations in the Sacramento R starting above Sacramento, passing the Sacramento waste water treatment plant (WWTP) down to the confluence at USGS 649; 14 stations down the San Joaquin R. (including 3 "car" sampled stations) starting at above Stockton to Suisun and 6 stations in Suisun and 1 in San Pablo Bays. In addition to CTD profiles, bbE fluorprobe and flow cytometry were used on board to characterize the size structure and major pigmentation of the phytoplankton communities. Samples were collected for nutrients (nitrate, ammonium, silicate, phosphate, nitrite, urea), chlorophyll, phytoplankton ID, picoplankton abundance, and 13C and 15N-NO3 and 15N-NH4 uptake. In addition we also incubated samples for measuring pelagic nitrification rates (funded by IEP-another project).

Two Rivers Cruises

| Cruise | Start Date | Sacramento Transect | San Joaquin Transect | Suisun/San Pablo Transect |
|---|---|---|---|---|
| TRP10-1 | 4/29/2010 | I80 to US649<br>14 stations | C10 to DWR12<br>14 stations | USGS2 to USGS 13<br>7 stations |
| TRP10-2 | 8/25/2010 | same | same | same |
| TRP11-1 | 4/19/2011 | same | same | same |

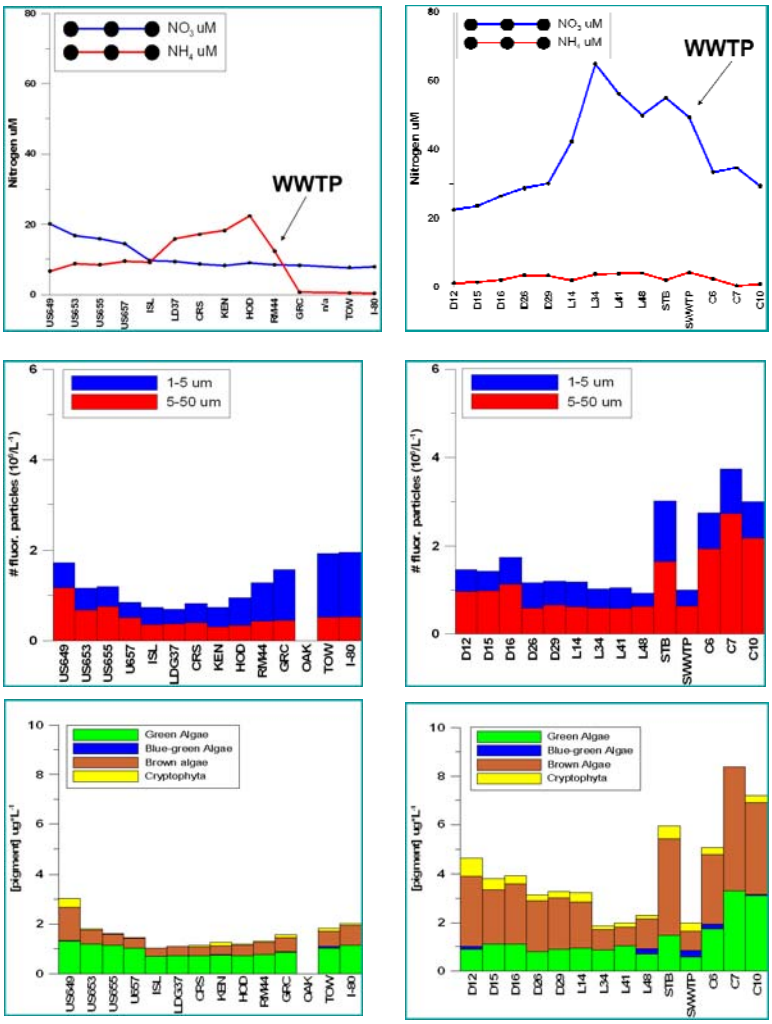
Laboratory analyses of these samples is almost complete except for some mass spectrometry of the 13C/15N uptake data and most of the phytoplankton ID. The data has been presented locally and nationally.

## A. PROJECT-WIDE STATUS

ACHIEVED OBJECTIVES, FINDINGS, AND CONTRIBUTIONS:

The enclosure data was classified according to "condition" of the water and this was described during the Ammonium Summit. We described the typical condition for central bay phytoplankton and showed how the chlorophyll accumulation and algal growth is extended in time when there is elevated ammonium conditions, extended from 72h in Central Bay, to 96h in Suisun Bay and > 100h in Rio We also showed that for high levels of carbon uptake, nitrate uptake needs to occur. The carbon uptake tracked that of nitrate in all experiments, rather than with ammonium uptake.

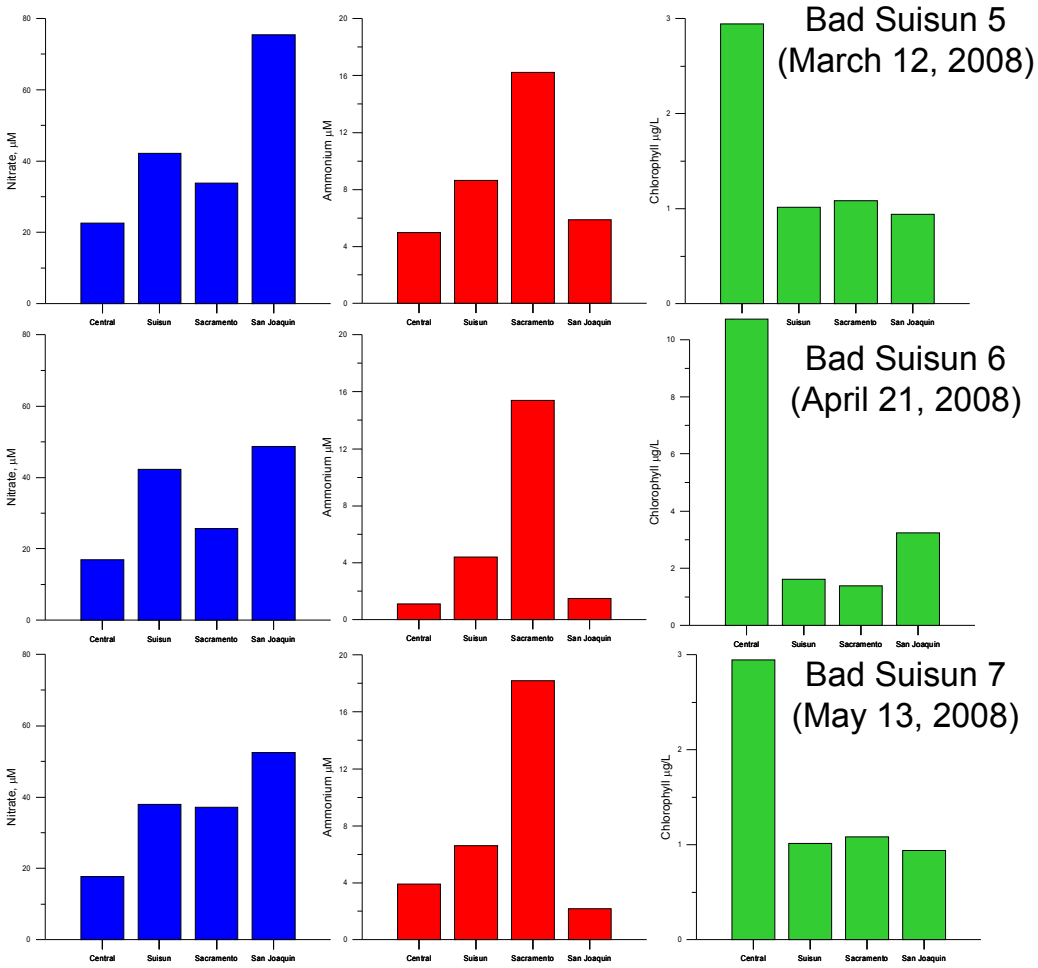
The Two river data showed as we had predicted a dominance of ammonium contributing to the DIN pool with its source at the WWTP and for nitrate in the San Joaquin River. Data from the first cruise, shown below shows more chlorophyll in the San Joaquin and different phytoplankton communities as elucidated by the different approaches: flow cytometry, bbe Fluoroprobe and microscope counts. These data all come from a poster recently presented by grad student Erica Kress at CERF (Coastal Estuarine Research Federation) meeting and part of her thesis.

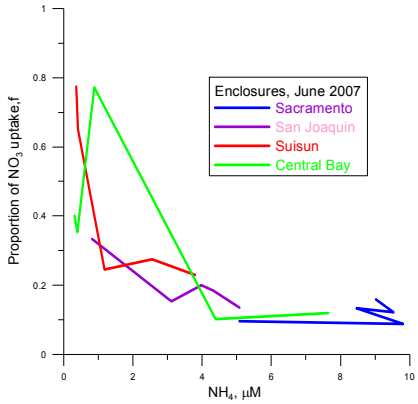



Left panel are transects along the Sacramento River (nutrients, flow cytometry and fluoroprobe) contrasting with the nitrate dominated San Joaquin transect (right panel) with more cells, larger in size and dominated by brown algae. Microscopy showed these brown algae to be centric diatoms

*From Prog Rep 2 (1/1/08-12/31/08)*

The station data collected in 2008 show clearly the higher $NH_4$ concentrations in the Sacramento River sampled at Rio Vista compared to the other sites. Nitrate was higher at the San Joaquin site compared to the other locations. Chlorophyll was always much higher in Central Bay. In BS7 the phytoplankton were dominated at Central Bay by the diatom *Skeletonema costatum*. Like in 2007 the DIC levels were lower at the river locations (data not shown). Nitrate and ammonium uptake in 2008 suggested that Suisun Bay had lower rates of nitrate and ammonium than other locations, both when measured per volume of water- probably because there was less phytoplankton biomass, but also when measured as a biomass specific rate showing these algae were physiologically less competent at uptake. The only substantial nitrate uptake measured was in Central Bay during BS6.




We took the results from both 2007 and 2008 Bad Suisun enclosures and station data and used coastal oceanographic approaches to evaluate the different SFBay/Delta/river ecosystem. This employed the application of f, a parameter used to assess the proportion of NO3 uptake compared to total DIN uptake ($NO_3$ plus NH4 uptake) in estuaries. High $NO_3$ uptake correlates with bloom formation and high primary production (C fixation). High f (= > 0.5, proportion of $NO_3$ uptake) occurs when $NH_4$ is low; ie. when $NH_4$ has been drawn down in the enclosures. Peak f in enclosures exceeds 0.5 in Central and Suisun Bays. In the Sacramento River $NH_4$ is never low enough for f to reach 0.5. In the San Joaquin River, the response in grow outs is delayed but f does increase (see Figure to left).

Mean initial data from the 7 Bad Suisun enclosures show two productivity patterns; low f, low $NO_3$ uptake ($\rho NO_3$) based production with low C uptake ($\rho C$)and chlorophyll (with blue highlighting) vs higher f, NO3 based production with high C uptake and chlorophyll.
The low f productivity pattern occurs in Suisun, Sacramento and San Joaquin stations

| | $NO_3$ | $NH_4$ | chl a | ρC | ρNO3 | ρNH4 | f |
|---|---|---|---|---|---|---|---|
| | µM | µM | µg/L | µg/l/h | µmol/l/h | µmol/l/h | |
| Central Bay | 23.40 | 4.4 | 4.37 | 309 | 0.051 | 0.076 | 0.41 |
| Suisun | 38.80 | 5.1 | 2.36 | 90 | 0.015 | 0.042 | 0.26 |
| Sacramento | 25.20 | 13.4 | 2.09 | 53 | 0.013 | 0.048 | 0.21 |
| San Joaquin | 44.30 | 3.5 | 2.55 | 71 | 0.020 | 0.054 | 0.27 |

Using this approach, in Central, San Pablo and South Bays where there is lower $NH_4$ concentrations, spring blooms tend to occur often, f shows $NO_3$ use and somewhat elevated primary production. Enclosures filled with water from these ecosystems show draw down of all NO3 in 5 days or less. In Suisun Bay, there is increased ambient $NH_4$ concentration, spring blooms are mostly absent but observed when there are unusually low $NH_4$ concentrations; low f, low $NH_4$ uptake rates and reduced primary production. Enclosures show slow draw down of $NH_4$ and delayed draw down of $NO_3$. At Rio Vista (Sacramento R), there are higher ambient $NH_4$ concentrations, low chlorophyll, low $NH_4$ uptake rates, extremely low primary production and in enclosures there is typically no drawdown of $NO_3$ within 5 days. The San Joaquin location sampled has lower $NH_4$ concentrations, elevated $NO_3$ concentrations, often low chlorophyll, low $NH_4$ uptake rates, and low primary production, although some enclosures show some $NO_3$ drawdown. Our San Joaquin location was selected as a place that could be sampled by car and may not be the most appropriate representative of the higher $NO_3$ San Joaquin waters.

***<u>From Prog Rep 1 (4/16/07-12/31/07)</u>***

We achieved our initial objectives by successfully completing 3 cruises with grow-out experiments to measure the gradients in productivity and nutrients and physiological response in the northern estuary and delta. The data collected during our 4 cruises in 2007 showed low phytoplankton productivity and poor food supply for higher trophic levels to occur both in northern SFB and also upstream of Suisun Bay at the San Joaquin and Sacramento river stations.

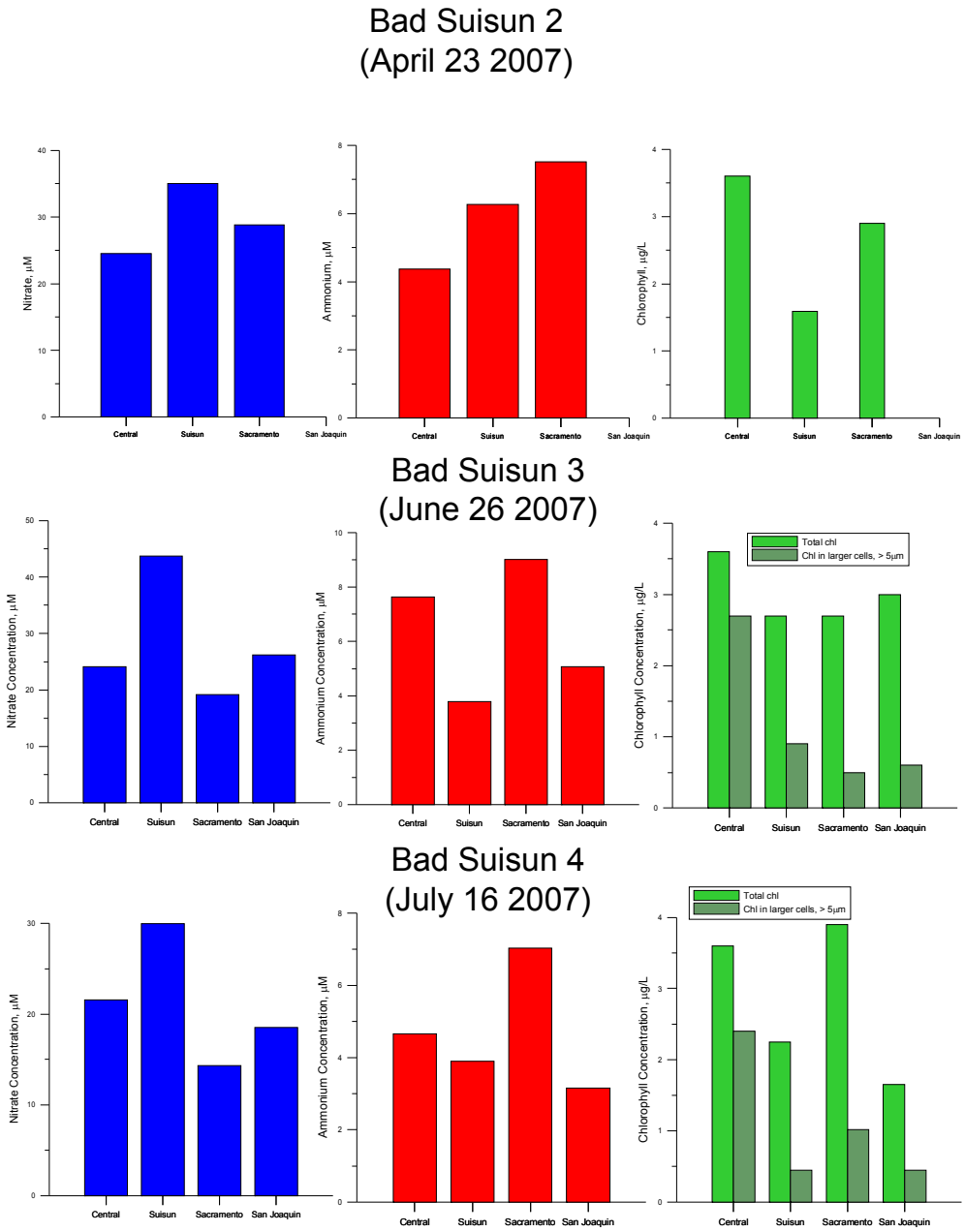



Fig. 1Nutrient and Chlorophyll Concentrations in Central, Suisun and Delta

Ambient conditions showed Suisun to consistently have higher nitrate than the other regions, and the Sacramento River to have higher ammonium than the other sampling sites (Fig. 1). Ambient chlorophyll concentrations tended to be higher in Central Bay where the chlorophyll was dominated by larger phytoplankton cells (with diameters > 5 µm).

The "bad" Suisun condition does not appear to be localized but part of a continuum upstream, In fact, one sampling (our first-Bad Suisun 1-on April 4 2007) showed Suisun Bay phytoplankton can have similar productivity and response in grow-outs to Central Bay phytoplankton and build biomass (Fig 2 b, a). The low productivity and chlorophyll accumulation in the rivers and Suisun (at times) is linked in part to high ambient $NH_4$ (Fig 2c,d,e), that results in low $NO_3$ uptake and C production (data not shown here).

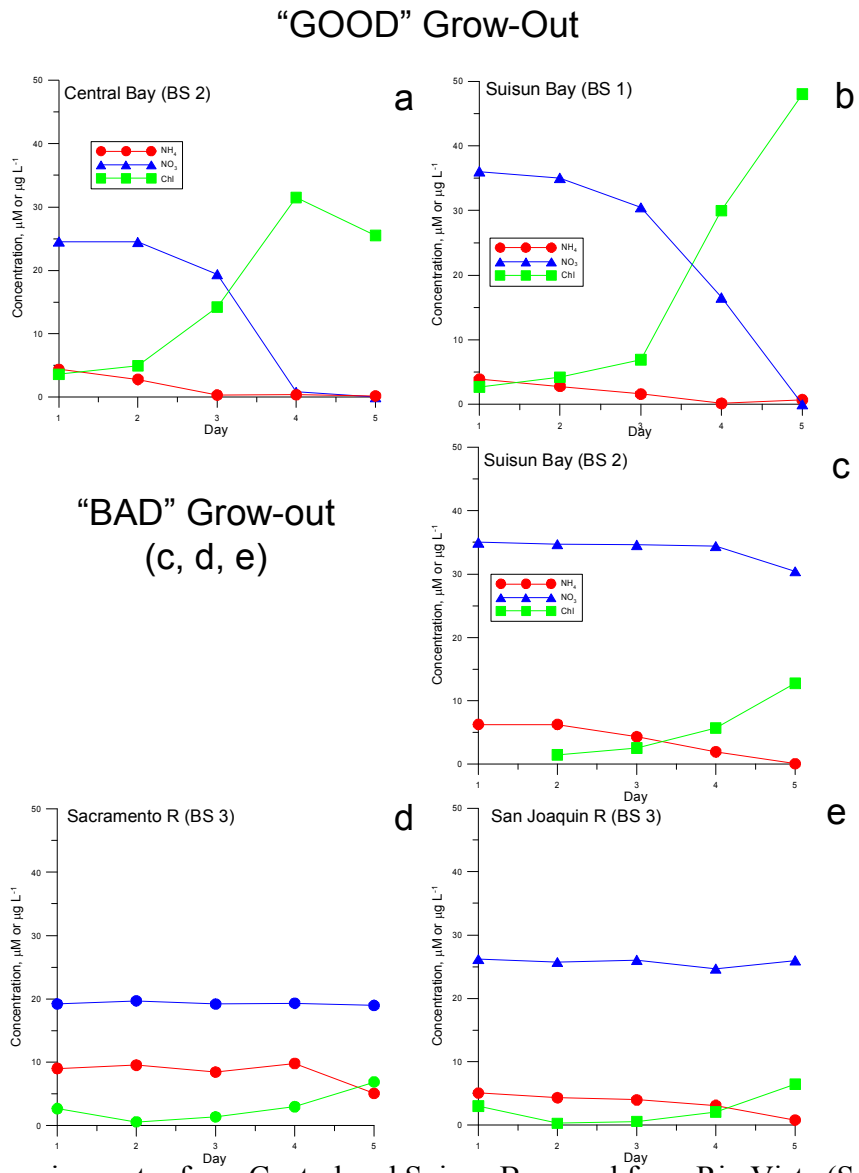



Fig 2 . Grow-outs using water from Central and Suisun Bays and from Rio Vista (Sac River) and 8-mile Slough (lower SJ River) showing "good" response (a,b) when $NO_3$ drawdown occurs and chlorophyll accumulates and "bad" response when ambient $NH_4$ is elevated and remains elevated, $NO_3$ is not drawn down and chlorophyll does not increase (c,d,e)..

However, the grow-outs carried out with water from the Sacramento and San Joaquin Rivers in June (BS3, Figs 2 d,e) showed almost no $NO_3$ drawdown and a small amount of $NH_4$ drawdown with little buildup of chlorophyll. It is important to note that our "San Joaquin" sampling took place in the lower San Joaquin in an area that often receives a large quantity of $NH_4$-rich Sacramento River water during the summer due to export pumping, open Delta Cross Channel gates, and low San Joaquin River inflows.

**C. PROBLEMS OR DELAYS ENCOUNTERED:**

Stop Order on Dec 14th.

***From Proq Rep 1 (4/16/07-12/31/07)***
An unanticipated university-wide salary increase meant that we used up our personnel budget sooner than expected which may mean that to be able to carry out our 2008 research we will need to request to either transfer some of our supplies budget to personnel or transfer personnel dollars from next years budget to this years. We have submitted a supplement proposal that includes personnel costs that could be used if it were funded and the budget made available before the next fiscal year.

**B. DELIVERABLES:**
Presentations Given using this Data (Jan 2008-Dec 2008)

Dugdale, RC. October 2008. Effects of ammonium on phytoplankton growth and consequences for the POD. 2008. CALFED Science Conference, Sacramento

Dugdale, R.C. November 2008 Nitrate, ammonium and phytoplankton blooms in San Francisco Estuary, San Francisco Bay regional Water Quality Board, Oakland, CA.

Dugdale, R.C. November 2008 Phytoplankton Blooms, nitrate, and ammonium, from upwelling to estuary, USGS, Menlo Park, CA.

Parker, A.E., Lidstrom, U., Hogue, V.E., Wilkerson, F., Dugdale, R.C. 2008 Food limitation and the pelagic organism decline: quantifying carbon supply from heterotrophic bacteria to the food web of Suisun Marsh and the northern San Francisco estuary Interagency Ecological Program Science Meeting, Pacific Grove, CA.

Dugdale, R. A. Parker, A. Mueller-Solger, F. Wilkerson, A.Marchi, V. Hogue. March 2008. Origins of high nutrients and low productivity conditions in Suisun Bay, and the Sacramento and San Joaquin Rivers. IEP, Asilomar, CA.

Wilkerson, F.P., R. Dugdale, A.Parker, A.Marchi, V.Hogue. 2008. Influence of the San Francisco Outflow on the productivity of the Gulf of the Farallones. Ocean Sciences, Orlando FL.

R Dugdale participated in NCEAS Workshop "Potential role of contaminants in declines of pelagic organsims in the upper SFE, CA" (Jan 2008, SB)

R Dugdale and F Wilkerson participated in workshop/scoping session for a potential SFE environmental report card.

Abstracts Prepared for Future Presentations

Abstract accepted by ASLO Ocean Sciences Meeting 2009
Special Session accepted at ASLO Ocean Sciences Meeting 2009
Abstract submitted to CAERS, 2009

*Previous Presentations (from Prog Report 1)*

Dugdale, R.C. F. Wilkerson, .A. Parker, V. Hogue, A. Marchi, A. Kleckner, J. Fuller, K. Lew First the "Bad Suisun"and now the "Dead Delta" ? The collapse of primary production in the Delta .RTC Seminar Series, December 2007

Dugdale, R.C., Sharp, J.H., Wilkerson, F., Parker, A.E.DIN is an inadequate descriptor for evaluating nitrogen based effects on estuarine ecosystems. Estuarine Research Federation Meeting Providence, RI. November 2007

Dugdale, R. C., Wilkerson, F., Parker, A. E., Hogue, V., Marchi, A., Kleckner, A., Fuller, J. The declining ecosystem health of the northern San Francisco Bay-Delta may be linked to poor phytoplankton productivity. Biennial State of the Estuary Conference, Oakland, CA 2007

Wilkerson, F., Hogue V, Parker AE, Dugdale RC, Marchi A, Kleckner A, Fuller J. Anomalously low phytoplankton productivity in northern San Francisco Estuary. Estuarine Research Federation Meeting Providence, RI. November 2007

Parker, A. E., Dugdale, R.C., Wilkerson, F. Bad Suisun: Exploring the role of anthropogenic NH4 in determining primary production in the northern San Francisco Estuary. Contaminants Workgroup meeting, June 15, 2007 UC Davis

Dugdale, R., Wilkerson, F., Parker, AE, Marchi, A., Hogue, V., Lew, K. Do Low phytoplankton growth rates signal the "bad" habitat conditions in Suisun Bay driving the pelagic organism decline., Interagency Ecological Program Science Meeting, PacificGrove, CA. 2007

Abstracts/Presentations Submitted
Dugdale, R.C., Parker, A.E., Mueller-Solger, A., Wilkerson, F., Marchi, A., Hogue V.E. Origins of high nutrients and low productivity conditions in Suisun Bay, and the Sacramento and San Joaquin Rivers. Interagency Ecological Program Science Meeting, Pacific Grove, CA. 2008

Wilkerson, F; Parker, A; Hogue, V; Marchi, A; Dugdale, R, Influence of the San Francisco outflow on the productivity of the Gulf of the Farallones, AGU Ocean Scinces Meeting, Orlando For special session: Structure and Function of River Plumes in Coastal Margins

PERSONNEL CHANGES: no changes

GRANT AGREEMENT MODIFICATIONS: none

NOTES / OTHER: