Ammonium, phytoplankton productivity and spring blooms in San Francisco Bay/Delta

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CALFED Bay-Delta Program

Outline

- Need primary productivity (i.e. algae) for healthy food web and fish. Low primary productivity is a problem in SFE/Delta.

- Nutrients (and light) are required for primary productivity. SFE has abundant nutrients. The conventional wisdom for SFE is that nutrients don't matter as they are always in excess.

- In most estuaries, high nutrients result in bad unhealthy conditions: eutrophication, low oxygen, harmful algal blooms etc. No such problems in SFE at present.

- Conventional wisdom is wrong: the kind of DIN (dissolved inorganic nitrogen) matters, nitrate (NO_3) or ammonium (NH_4). High NH_4 affects the amount of primary production and the dominant type of phytoplankton (algae): good (diatoms) or bad (e.g. cyanobacteria or dinoflagellates).

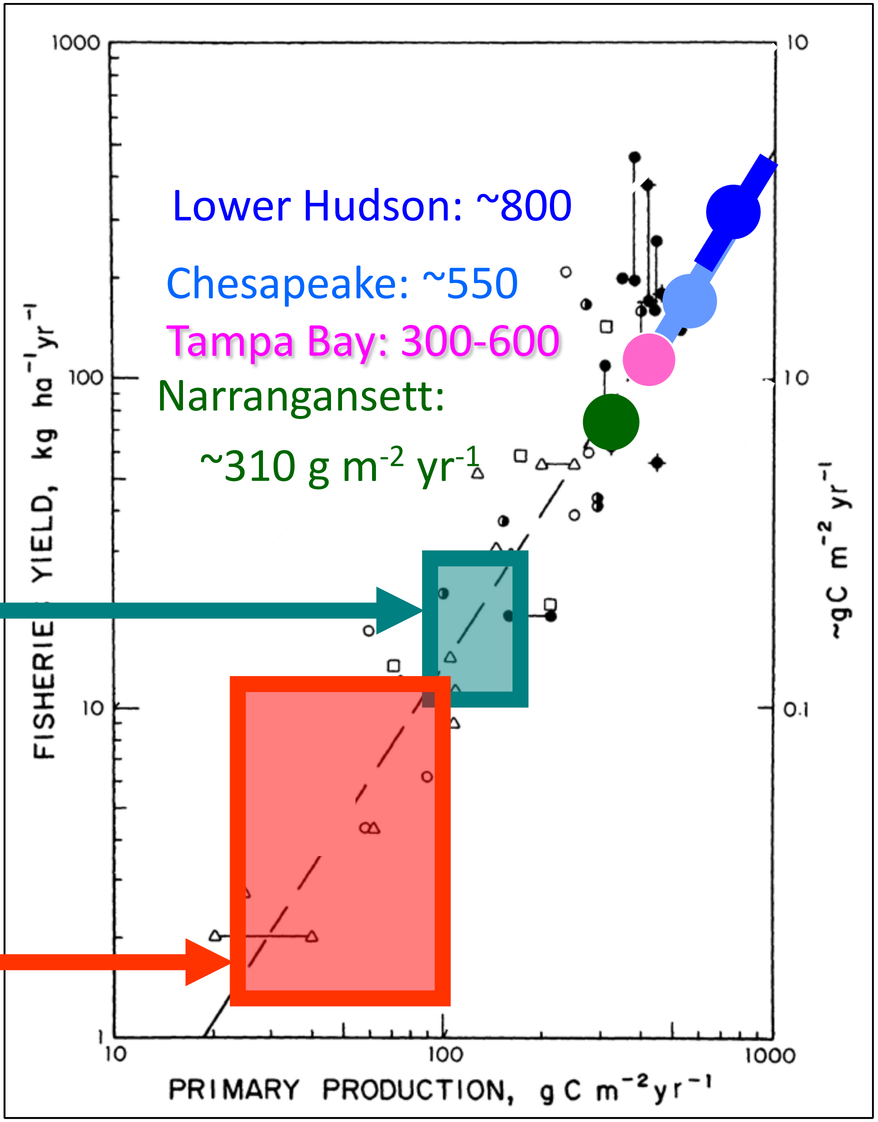
- Solutions/Next Steps

Primary productivity is the foundation of a healthy estuary
Fishery yield directly related to primary production

1976 – 1987

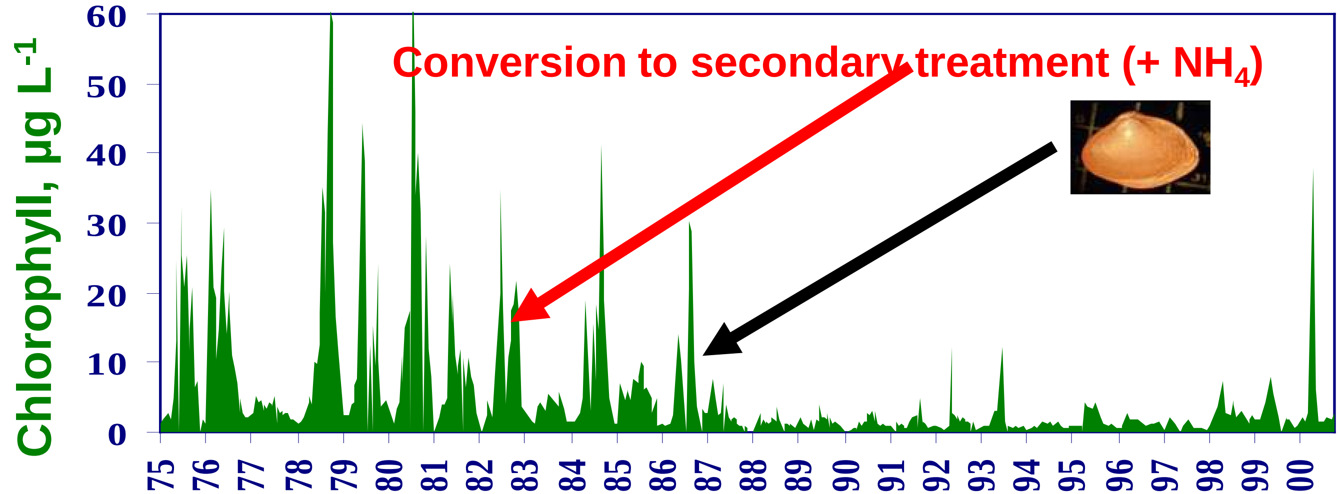
San Francisco Estuary Low-Salinity Zone

1988 - 2002

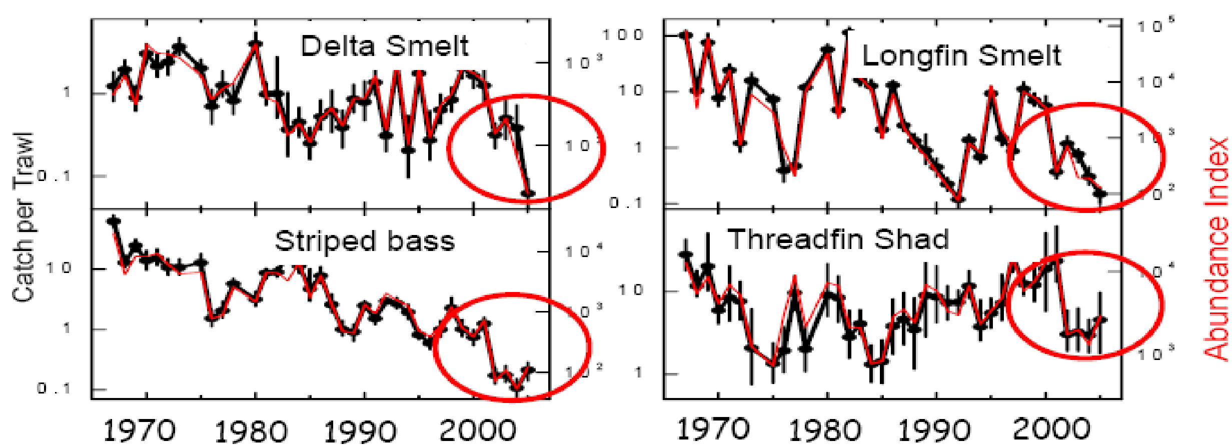


Adapted from Nixon 1988 by Cloern, Parker and others

In SFE since 1987, historical decline of phytoplankton (diatom dominated) blooms, followed by introduction of invasive *Corbula* and the POD



Pelagic Organism Decline

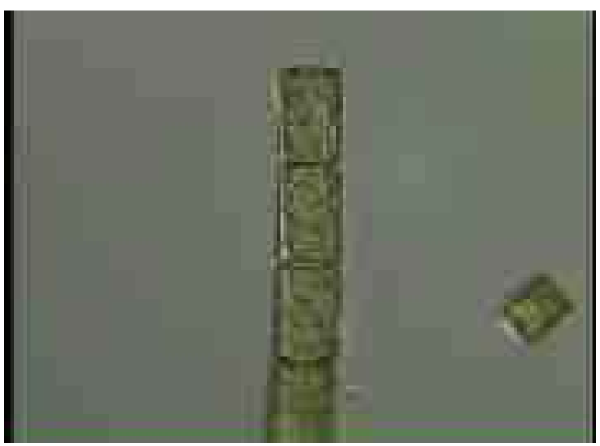


Source: Kimmerer and Nobriga (2005); Sommer et al. (2007)

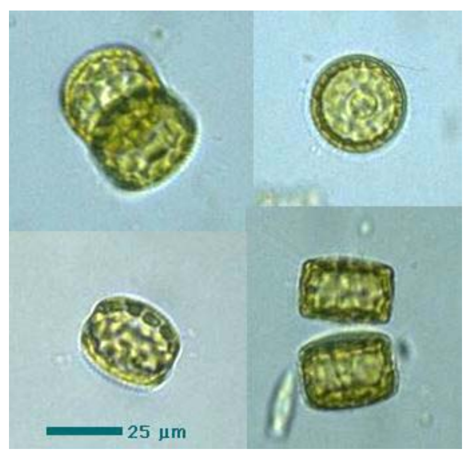
Diatoms: one type of phytoplankton
"Workhorses of the Sea" and of Estuaries

- Evolved and adapted to a high nitrate, low ammonium environment

- Can take up all nitrate in 3-5 days (***as long as ammonium is low)***



Melosira sp.



Cyclotella sp.

May 2010 bloom diatoms in Suisun

Redfield Ratio:
In addition to requiring light for an energy source, phytoplankton need the basic nutrients in this ratio

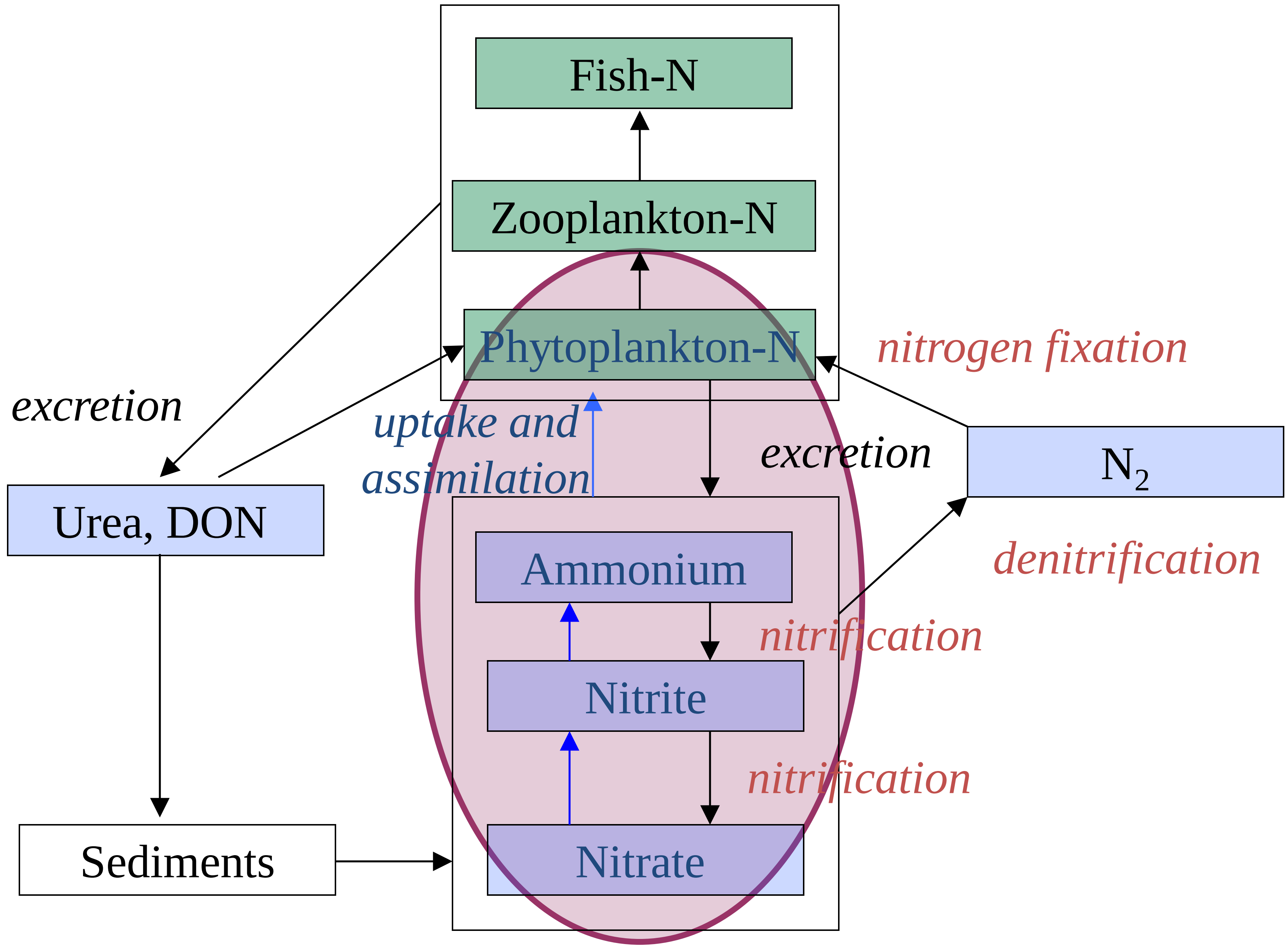
Redfield Ratio is C:N:P = 106:16:1, molar units,

In addition diatoms need Si in about the ratio 1Si:1N

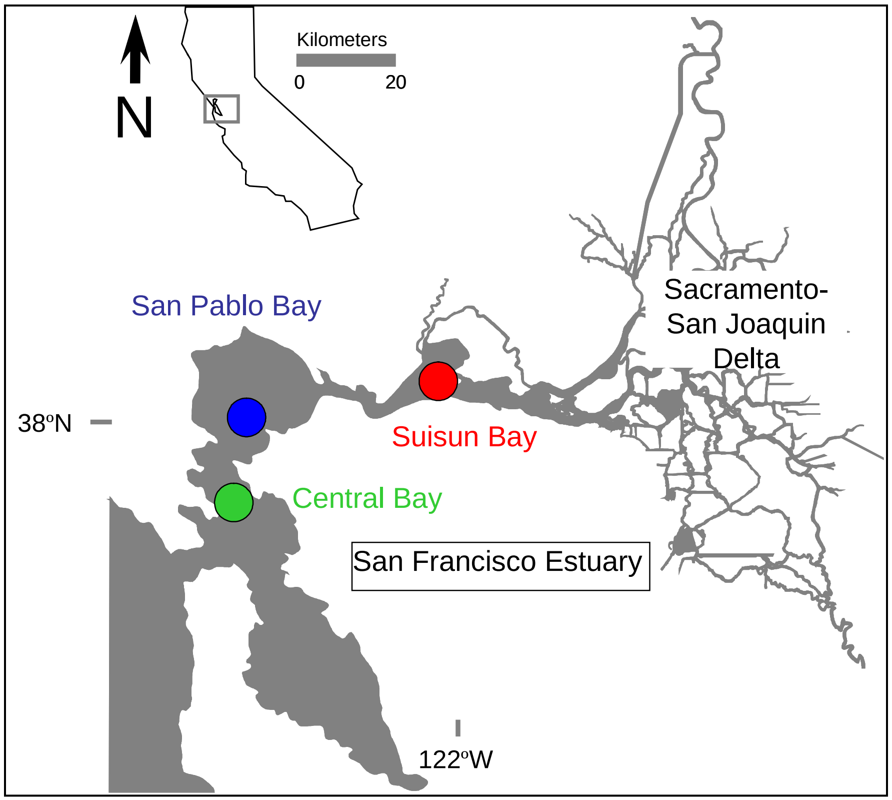
Mean nutrient concentrations in Suisun Bay in spring (Wilkerson et al., 2006)

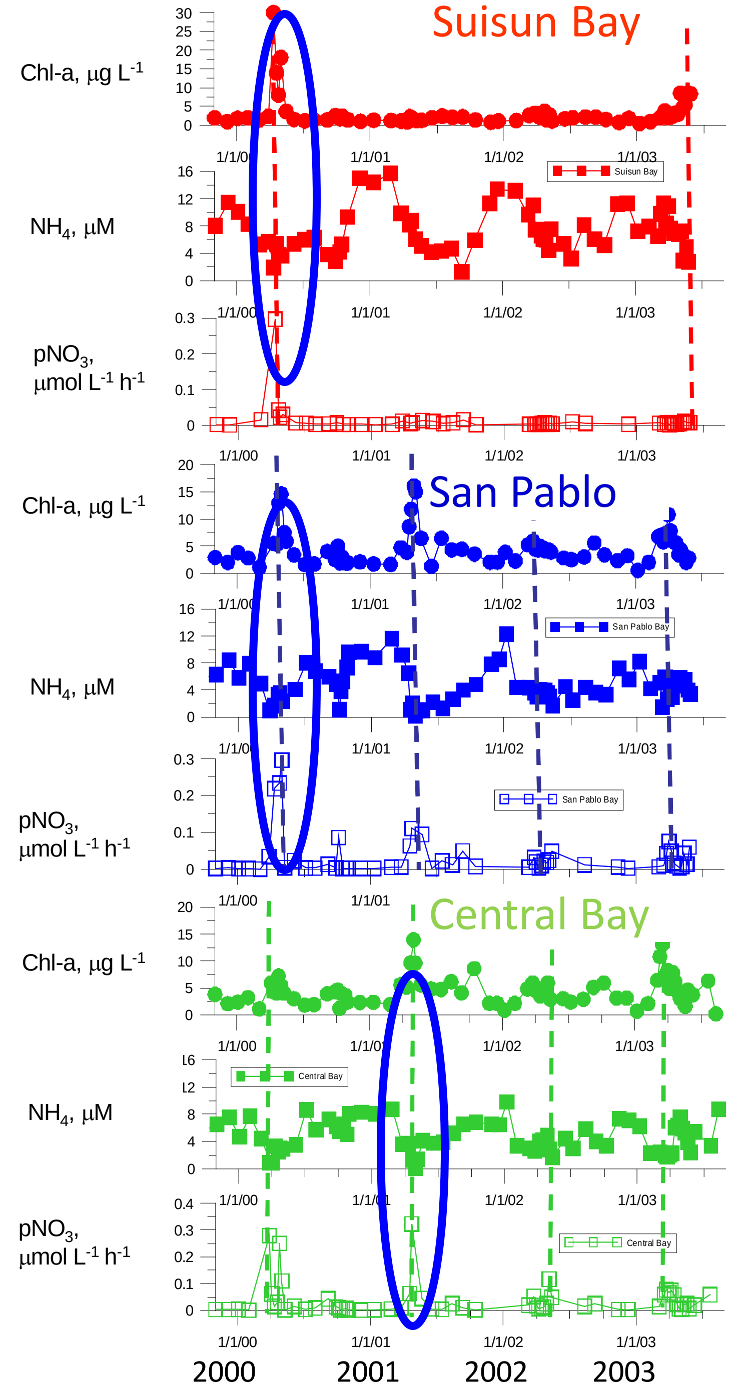
	$\mu mol\ L^{-1}$	
NO_3	27.5	
NH_4	6.8	
PO_4	2.7	
$Si(OH)_4$	264.6	(lots of silicate)
N:P	13:1	not far from Redfield

Simplified Aquatic Nitrogen Cycle



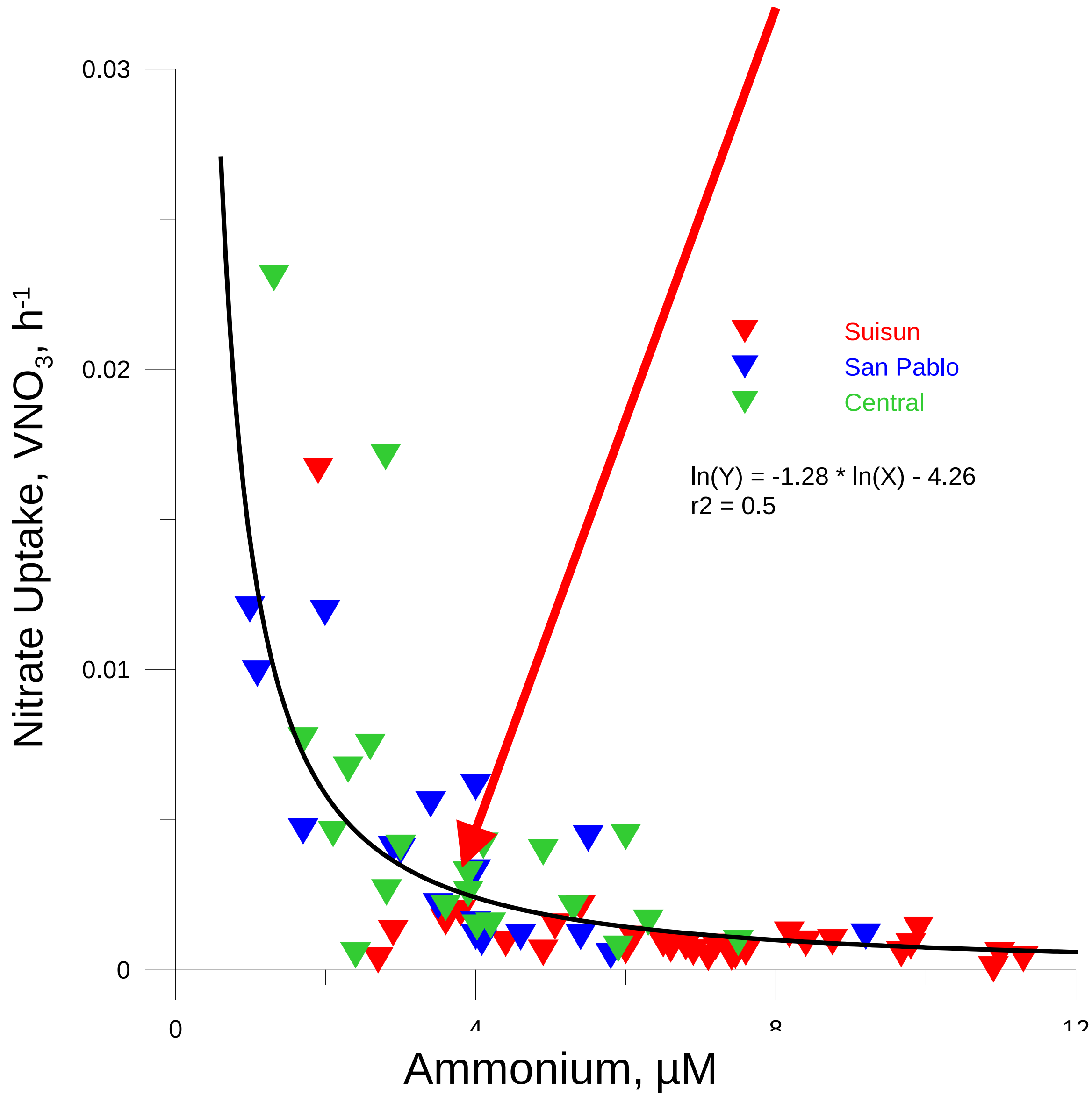
Monthly measurements made from 2000-2003



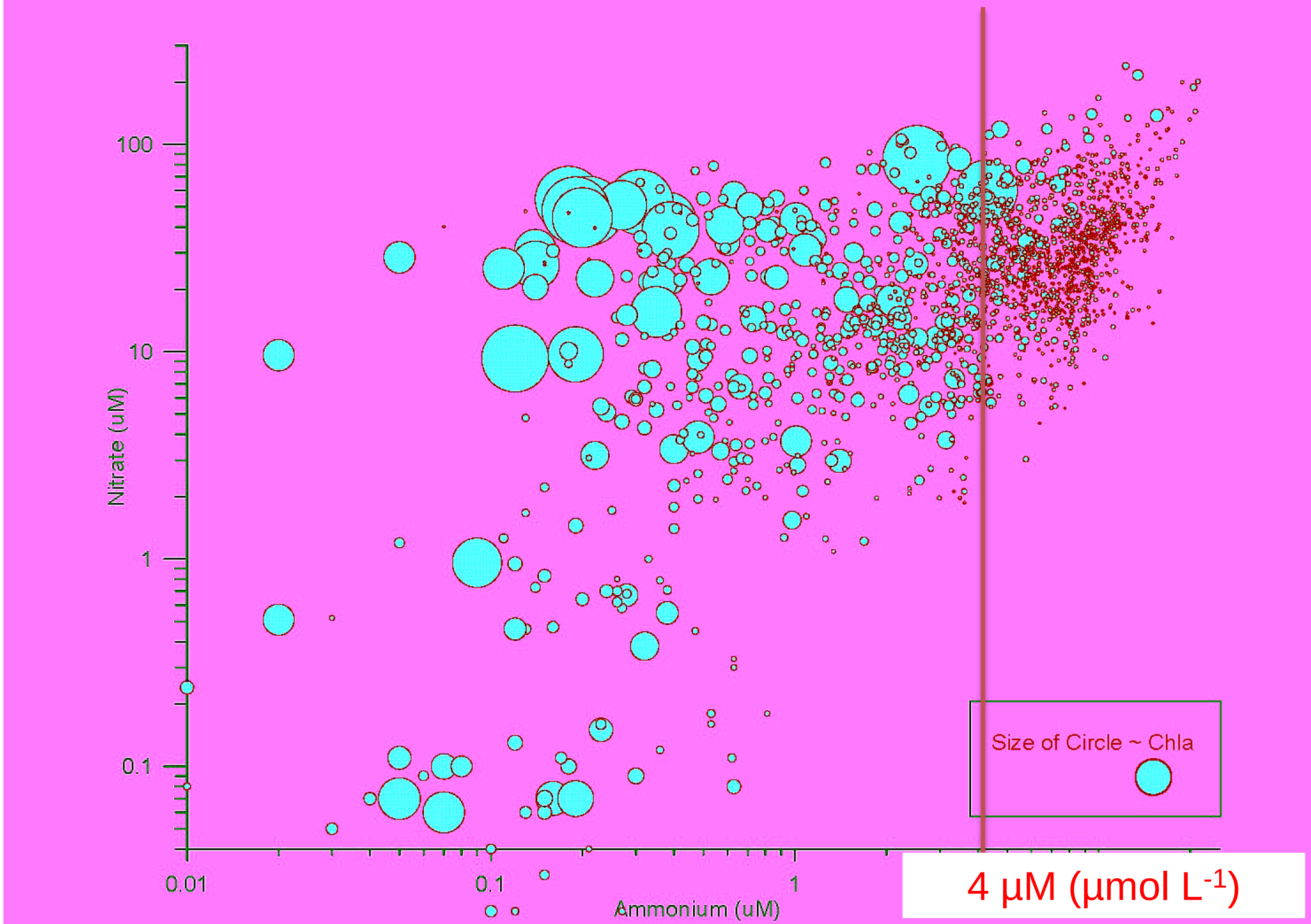


- **Chlorophyll increases occur when NH_4 is low and results from nitrate uptake by the phytoplankton**

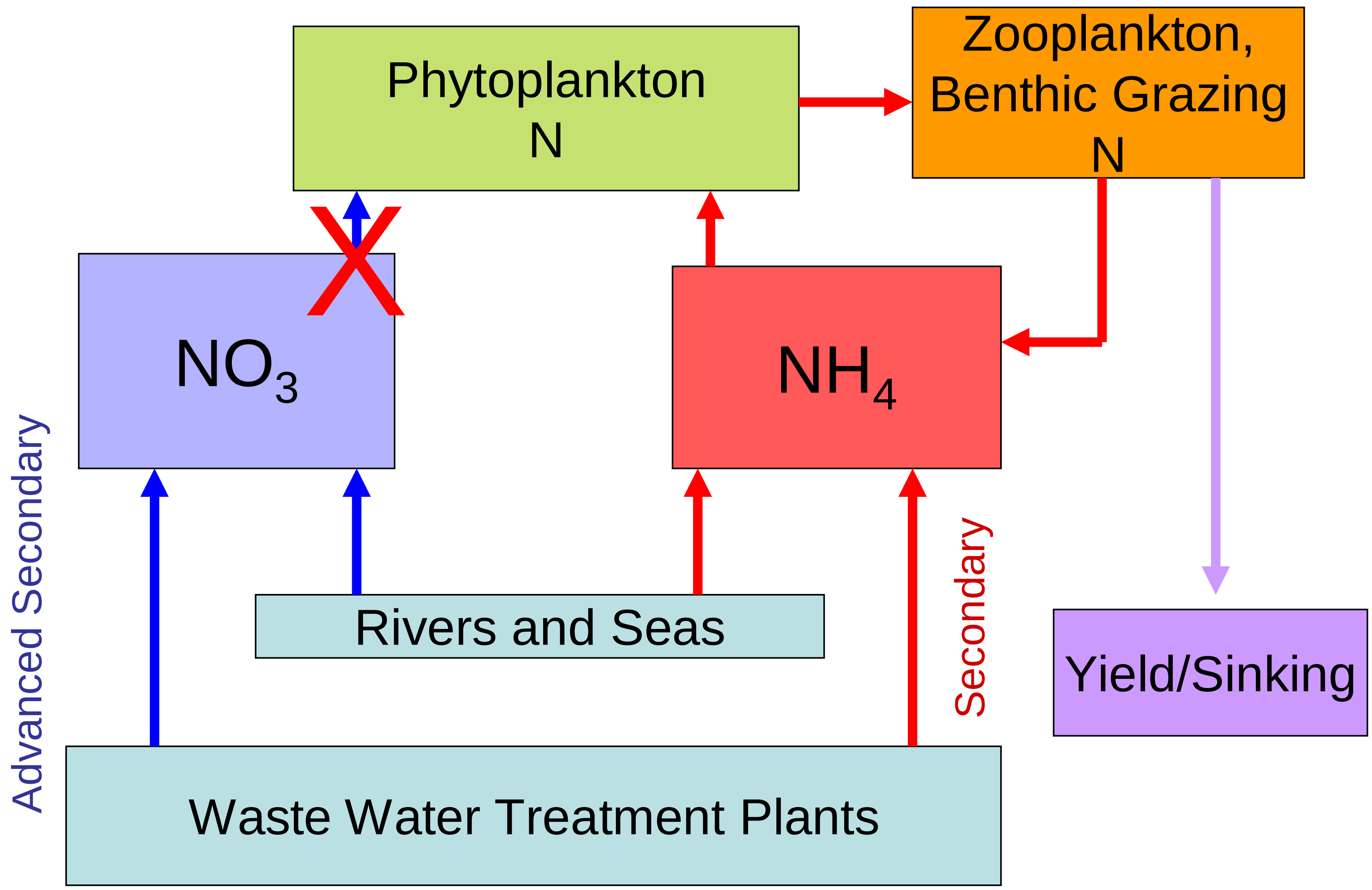
Nitrate uptake increases, once ammonium (NH_4) is below an inhibitory concentration (~4 µmol L^{-1})



Cloern data for SFE – more algae (chlorophyll: bigger yellow circles) with less ammonium (NH_4)



Simplified Estuarine N Cycle

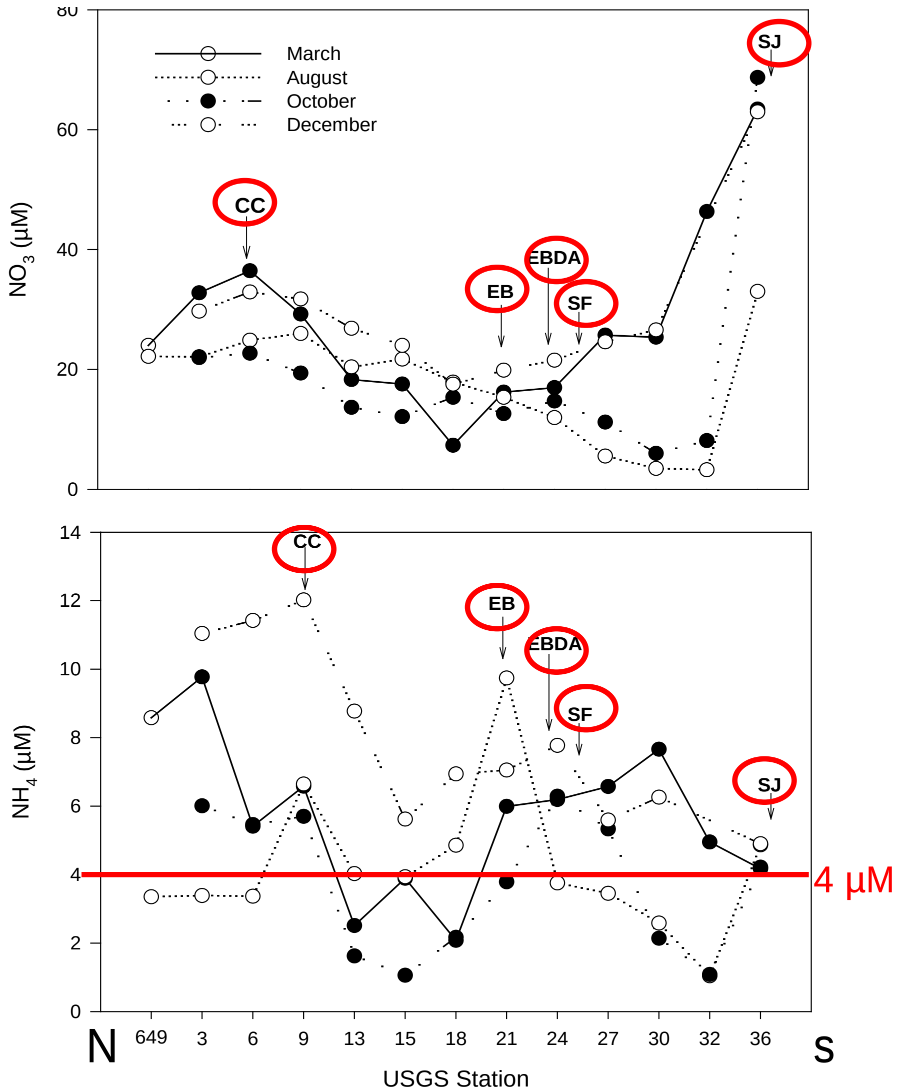


Cutting off phytoplankton access to NO_3 reduces potential phytoplankton biomass by 80%

Waste water treatment plants throughout the system supply NH_4 and NO_3

Nitrate

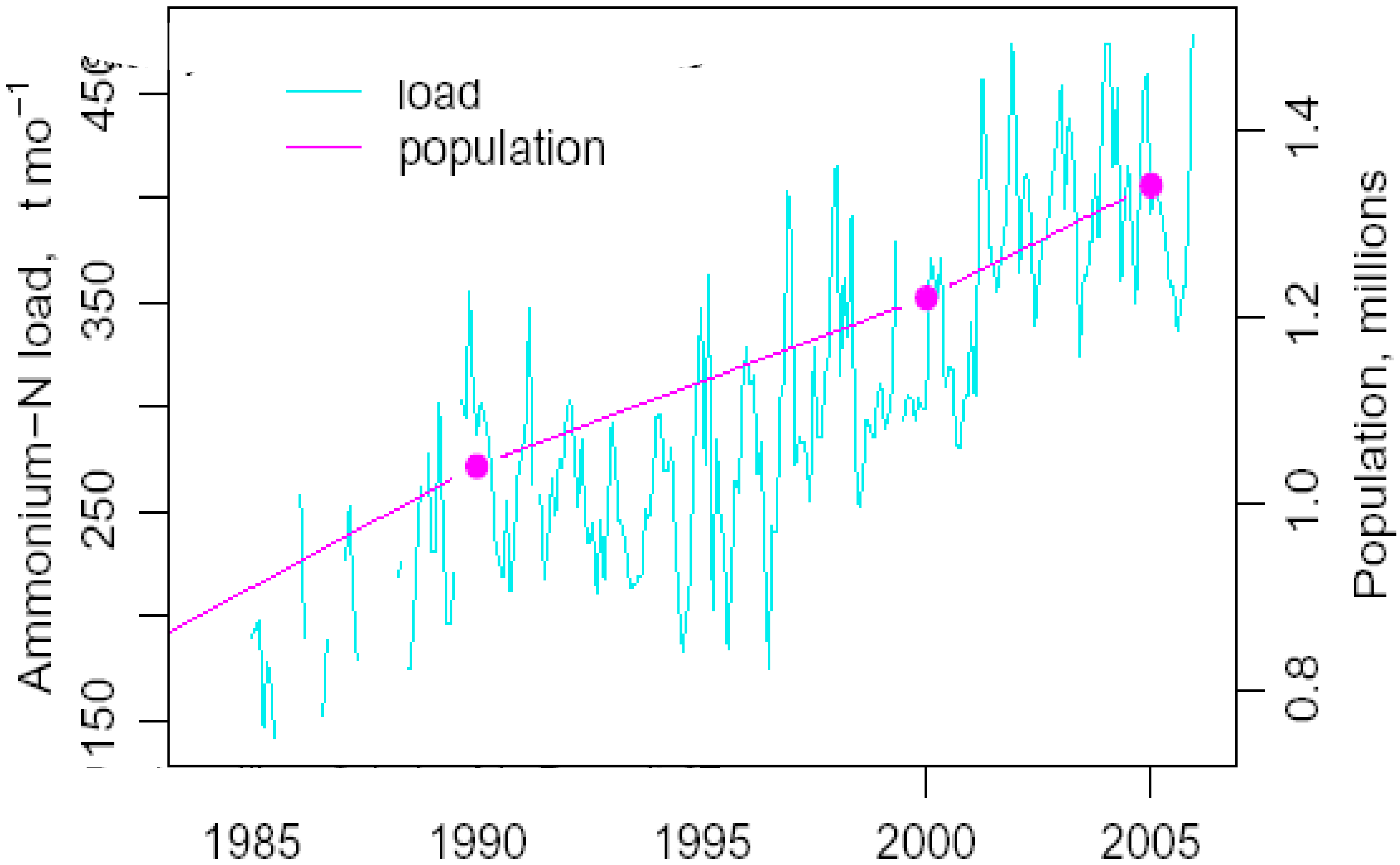
Ammonium



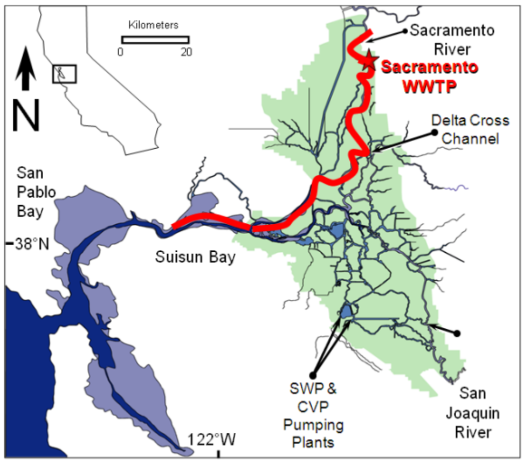
SFE 2005

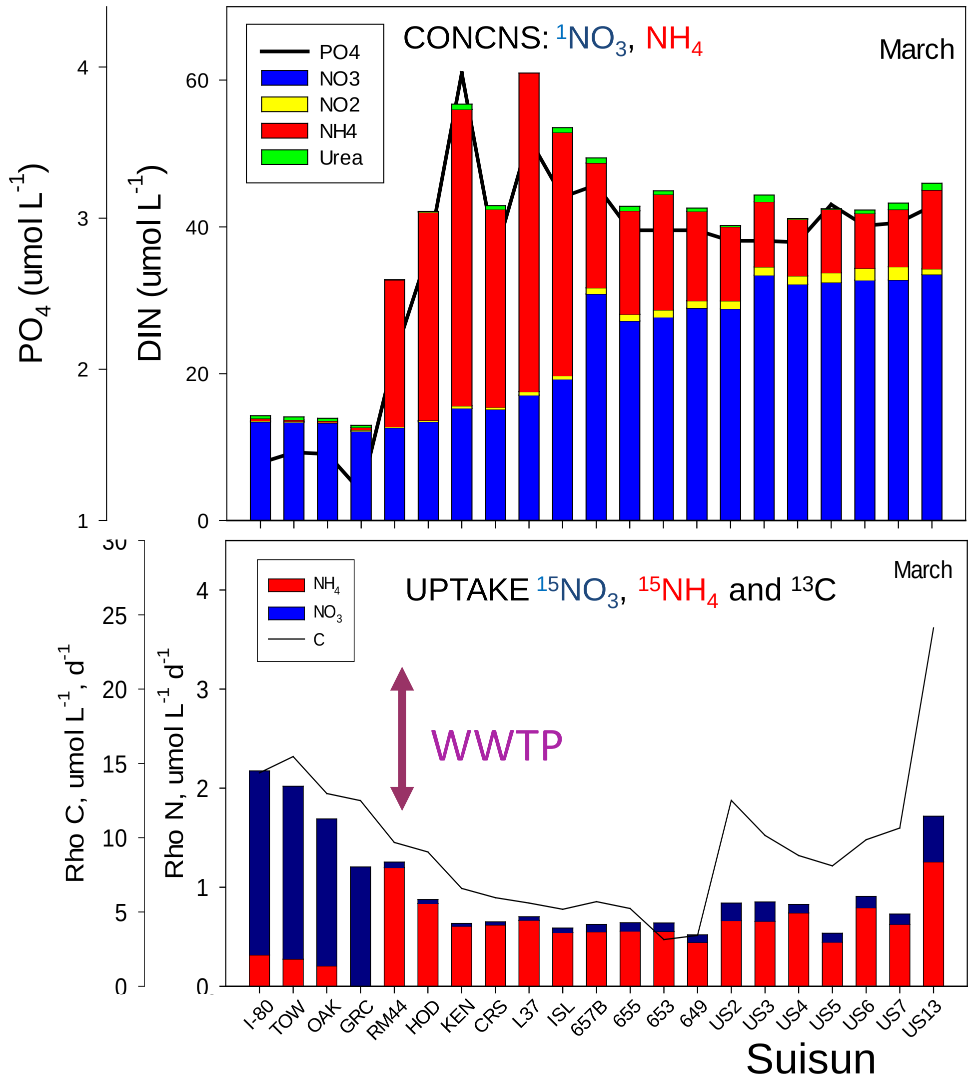
POWTs abbreviations: **CC** - Central Contra Costa, **EB** - East Bay MUD, **EBDA** - EBDA East Bay, **SF** - County and City of SF (southeast), **SJ** - San Jose/ Santa Clara WPCP

Ammonium loading has increased into Sacramento River (Jassby 2008) along with population

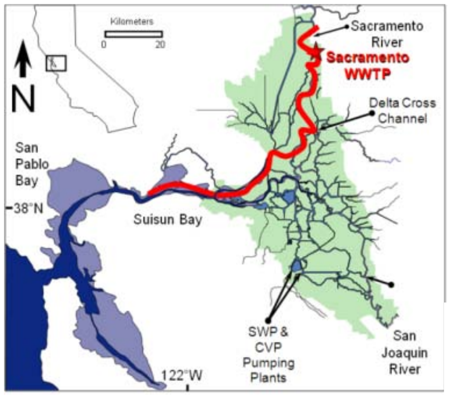


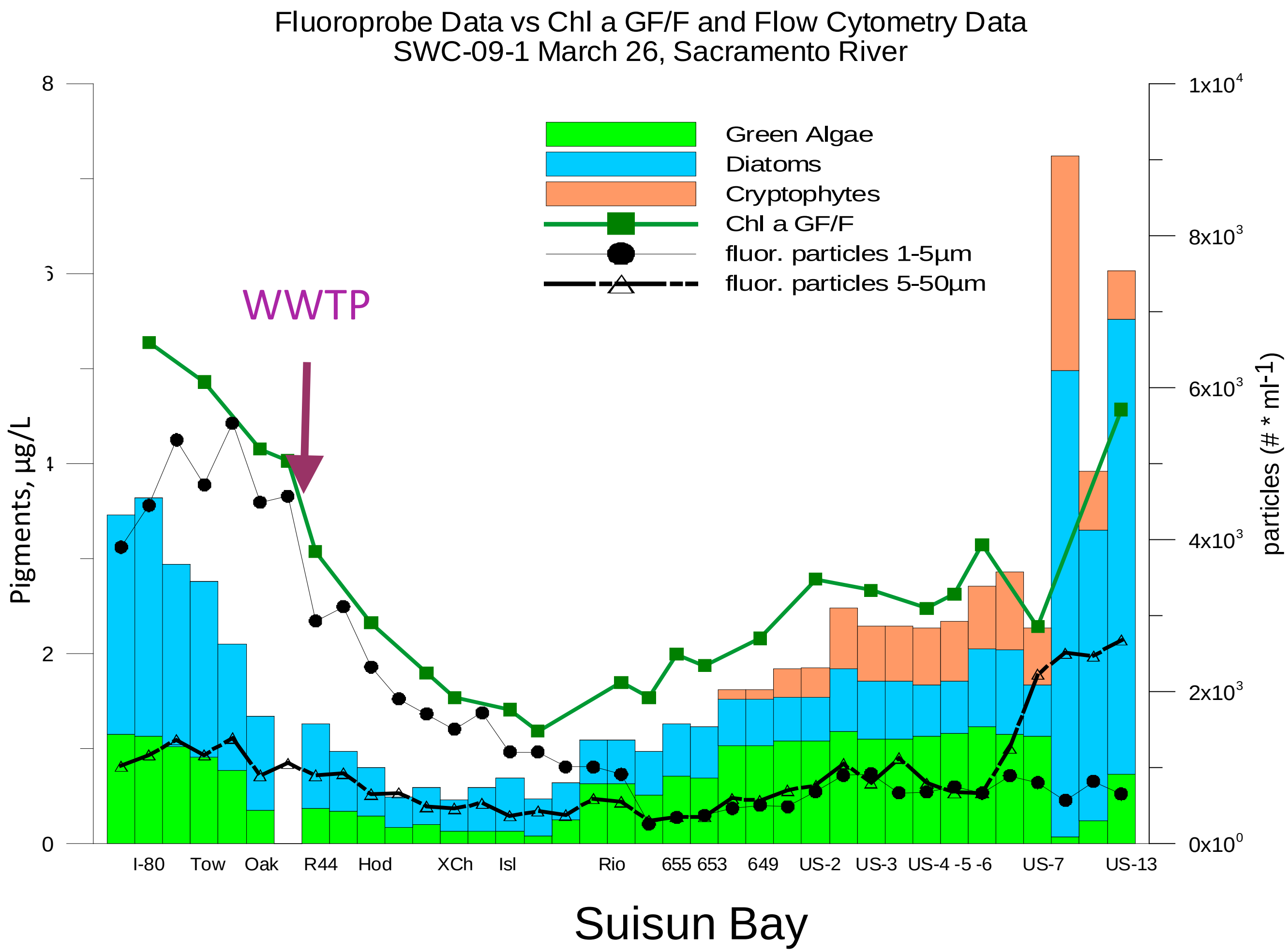
Downstream Sacramento River: shift from NO_3 dominated to NH_4 system (both concentrations and uptake) with low primary productivity (C uptake) downstream of WWTP





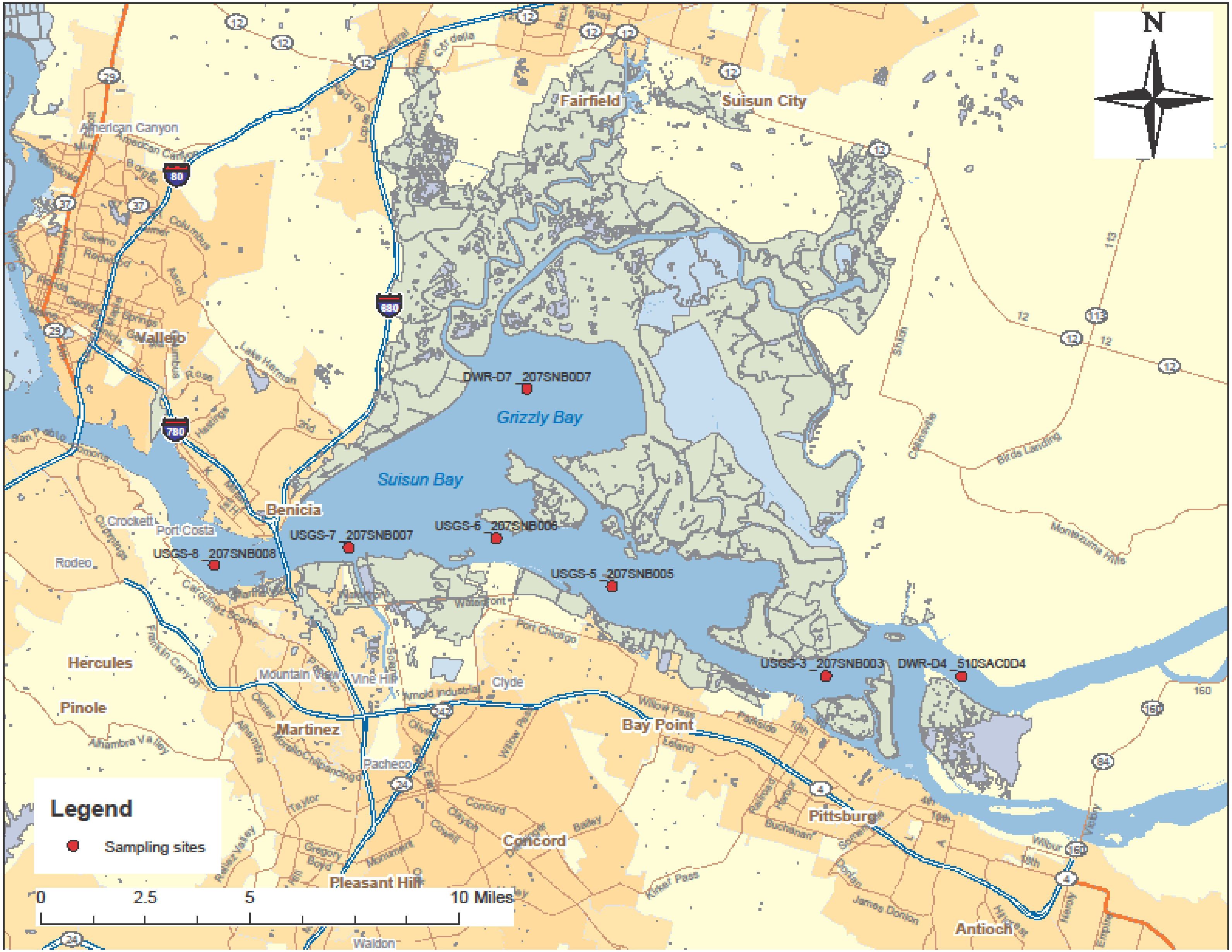
Downstream of WWTP, chlorophyll and diatoms decrease; in NO_3 dominated systems diatoms do well- upstream and Suisun Bay (March 2009)



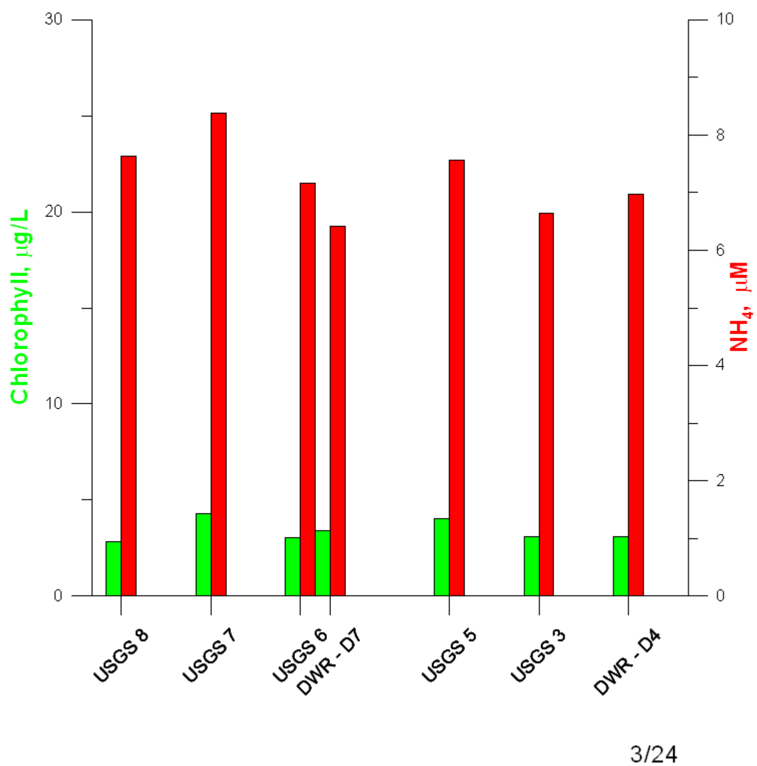


Pigments measured by Fluoroprobe, data courtesy of Anke Mueller Solger

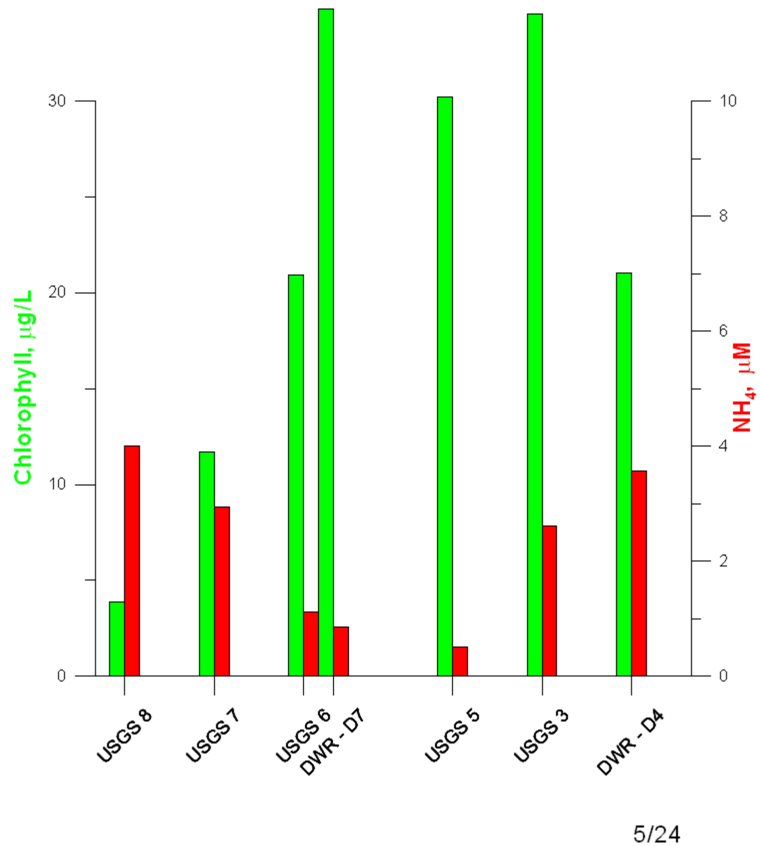
SFRWQCB sampling, March through June 2010



March: with high ammonium, low chlorophyll (algae)
May: with low ammonium, high chlorophyll

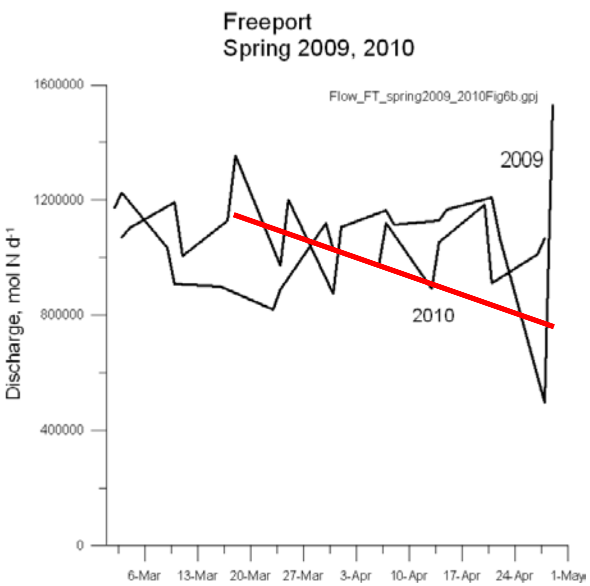


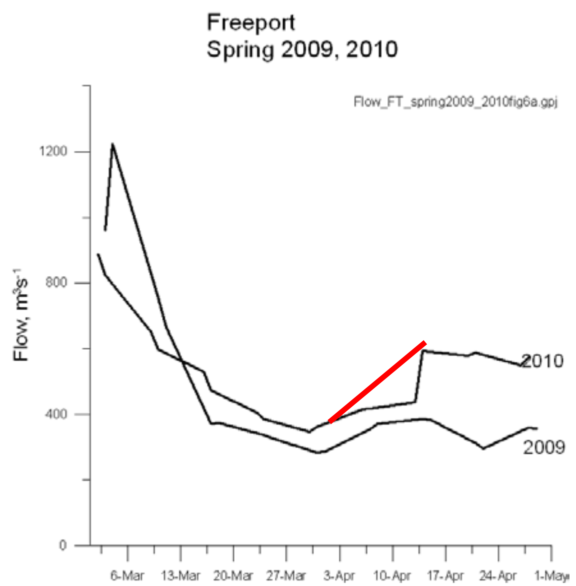
March 24 2010

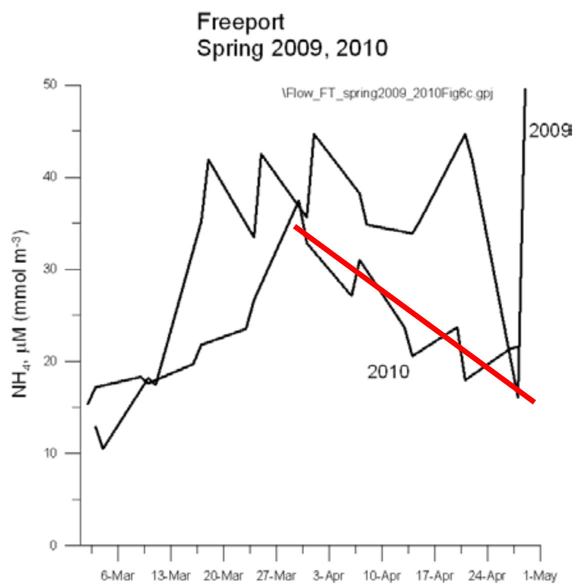


May 24 2010

Decline in discharge at SRWWTP and increase in flow resulted in declining NH_4 concentration

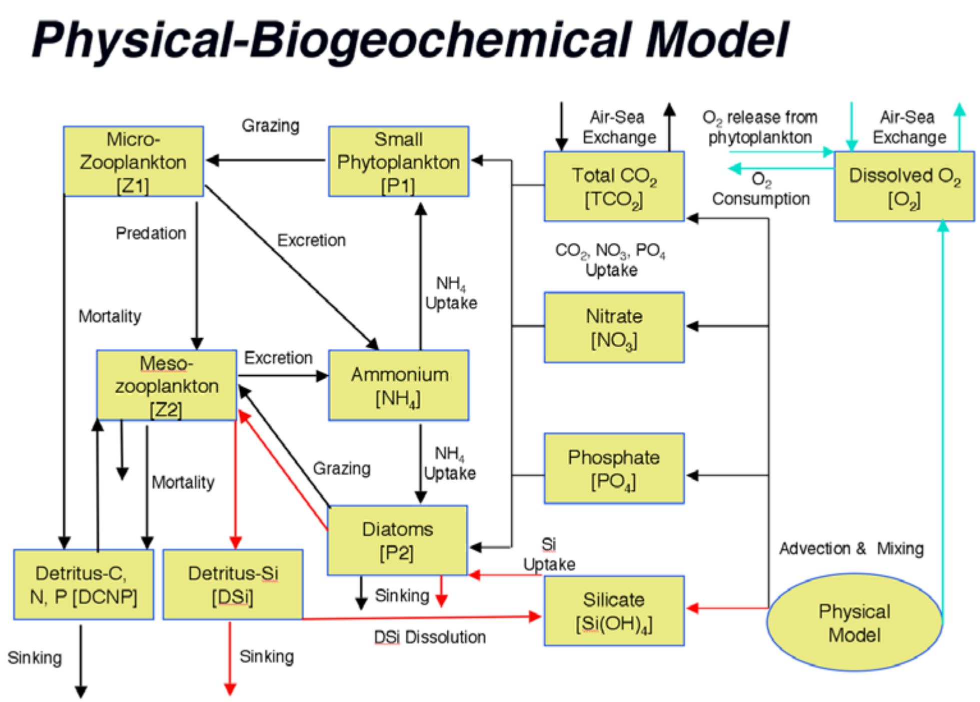






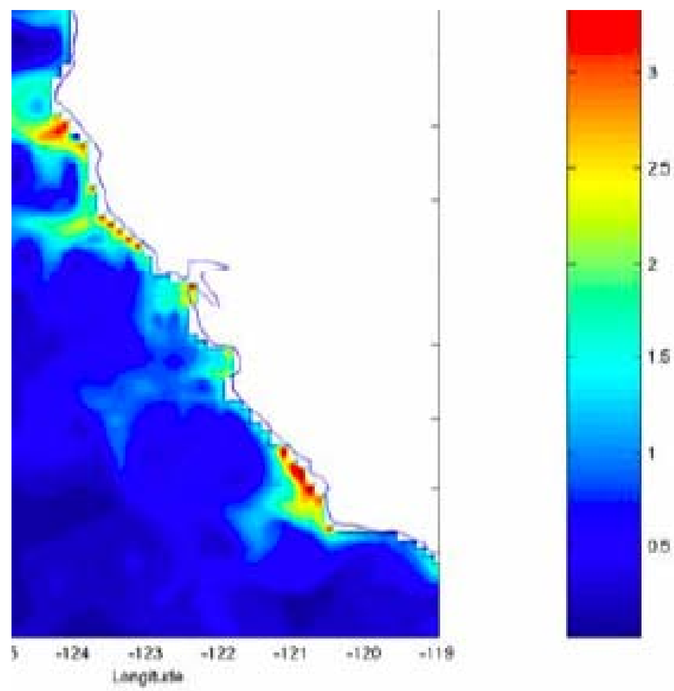
This resulted in a chlorophyll bloom in Suisun Bay in 2010

Urgent need is to develop a 3-D open source model for SFE/Delta for adaptive management purposes designed to accommodate new information; an example from coastal ocean.



CoSiNE Model- Carbon, Silicon, Nitrogen Ecosystem Model

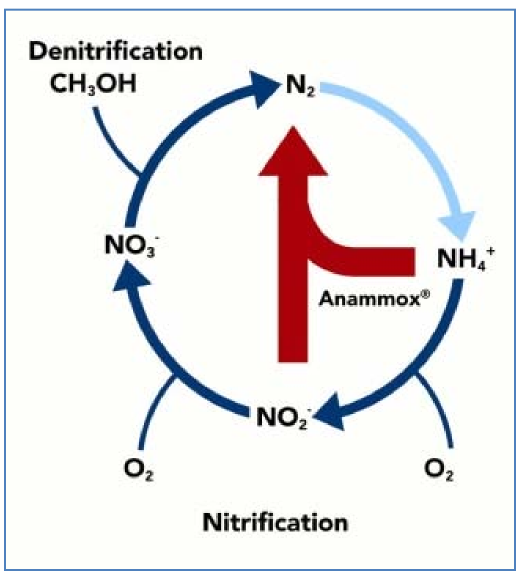
Chai et al. (2002)



Simulation of chlorophyll using 3km ROMS with CoSiNE model- West US Coast

Summary / conclusions / next steps

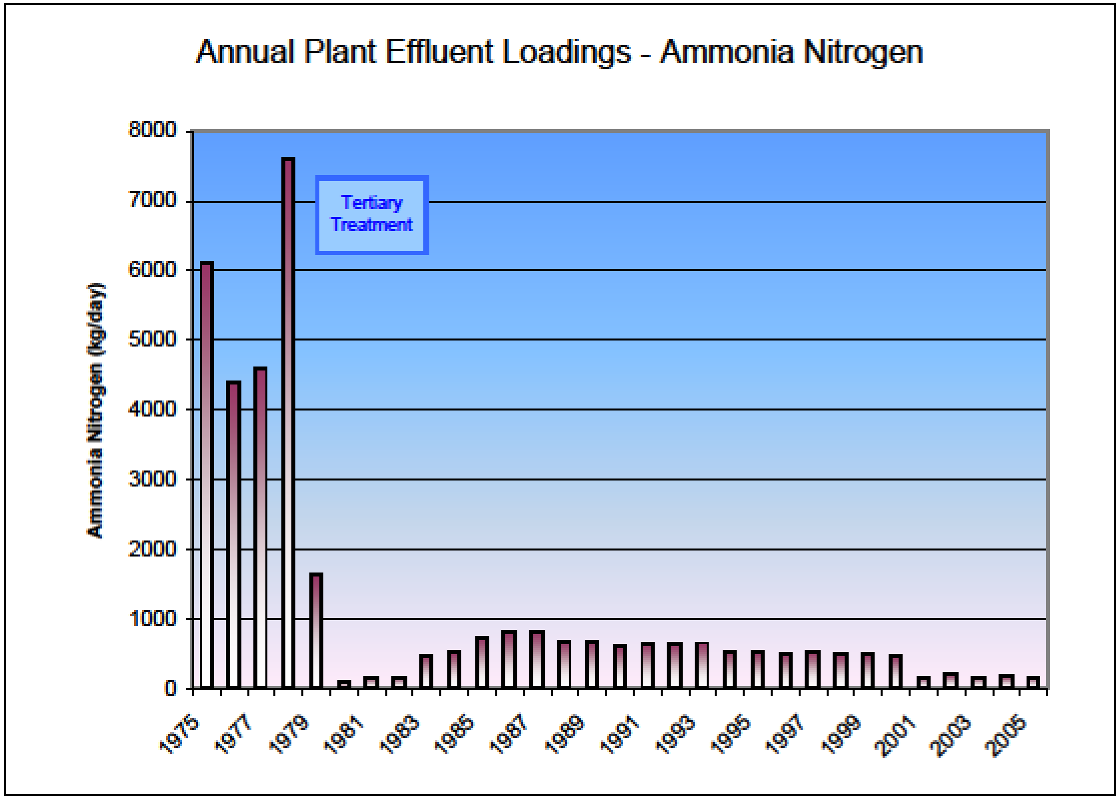
- Need to reverse the low productivity non-diatom regime
- Remove ammonium and maybe eventually nitrate (using Anammox?)
- Find and eliminate any toxins/herbicides
- Construct a modern open source 3-D model of the bay/delta for management purposes.



Possible solutions: Denitrification, conventional or Anammox

END

Year	KG/Day **Ammonia Nitrogen**
1975	6100
1976	4400
1977	4600
1978	7600
1979	1632
1980	103
1981	158
1982	163
1983	478
1984	514
1985	732
1986	807
1987	818
1988	676
1989	684
1990	604
1991	644
1992	640
1993	658
1994	541
1995	517
1996	490
1997	530
1998	487
1999	499
2000	464
2001	163
2002	204
2003	166
2004	176
2005	168



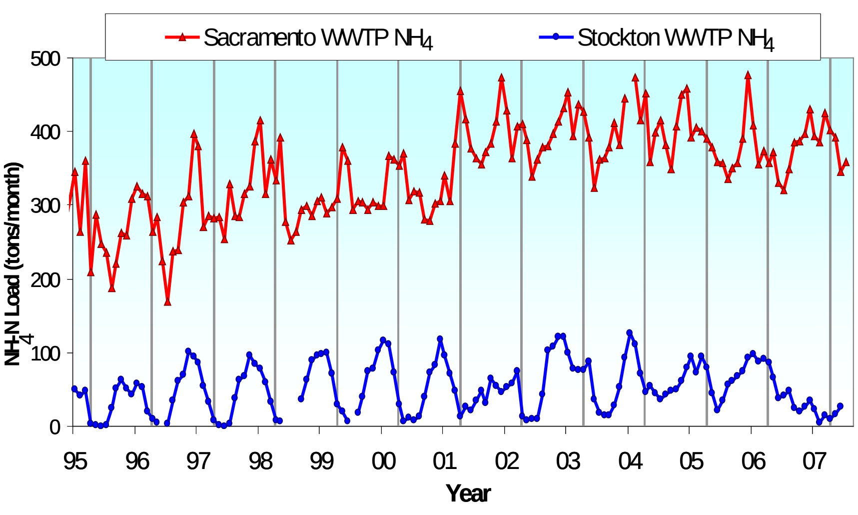
Increasing nitrogen inputs to SF Estuary

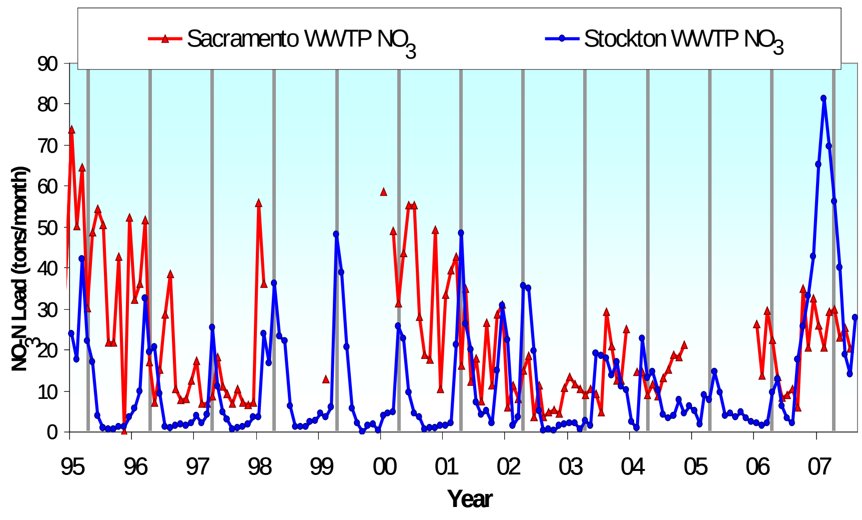
Manufactured N now = to natural nitrogen fixation,
A 100% perturbation of the Global Nitrogen Cycle

What form is it discharged?

Secondary = ammonium (e.g. Sac Regional WWTP)
Advanced Secondary = nitrate (Stockton, San Jose)

100,000 population = 1 Ton N/ day effluent
Sac Regional now discharges about 15 Tons N/day as ammonium
Plans to double output without changing treatment

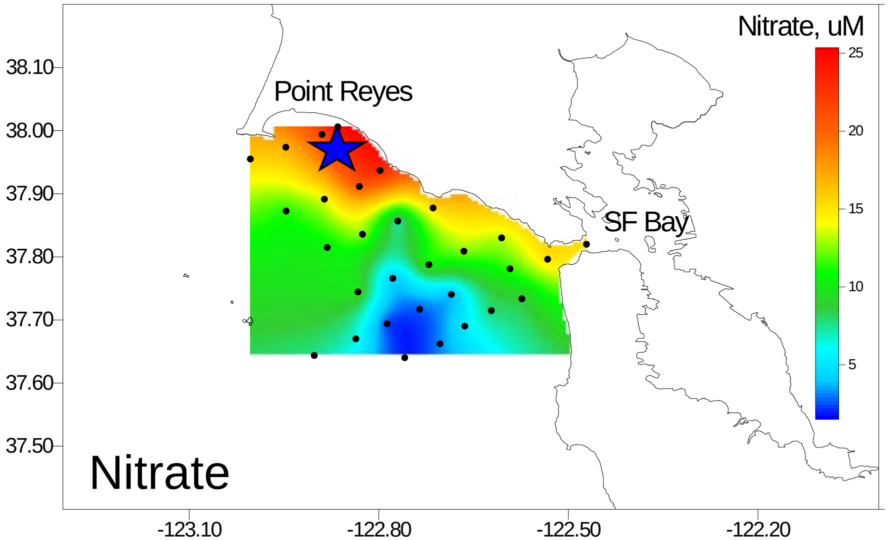


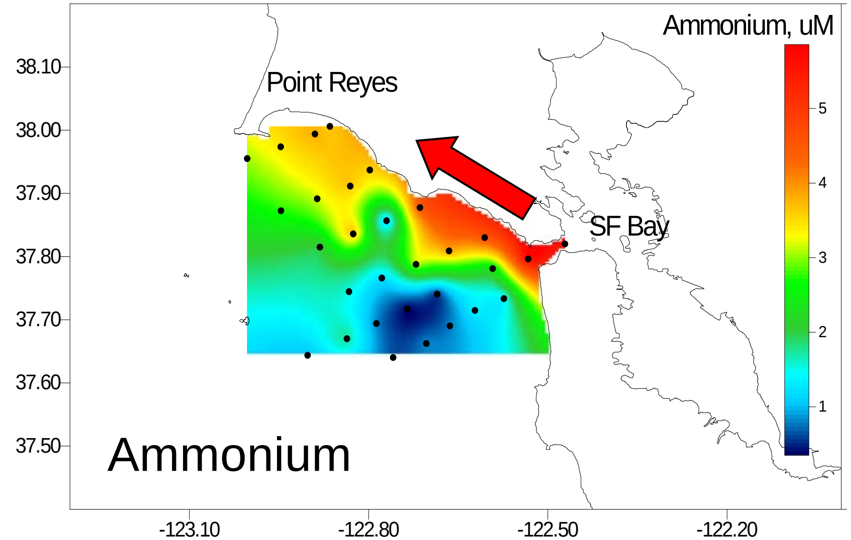


Concentration and loading declined substantially between 7 and 14 April 2010 allowing the bloom to develop in Suisun Bay

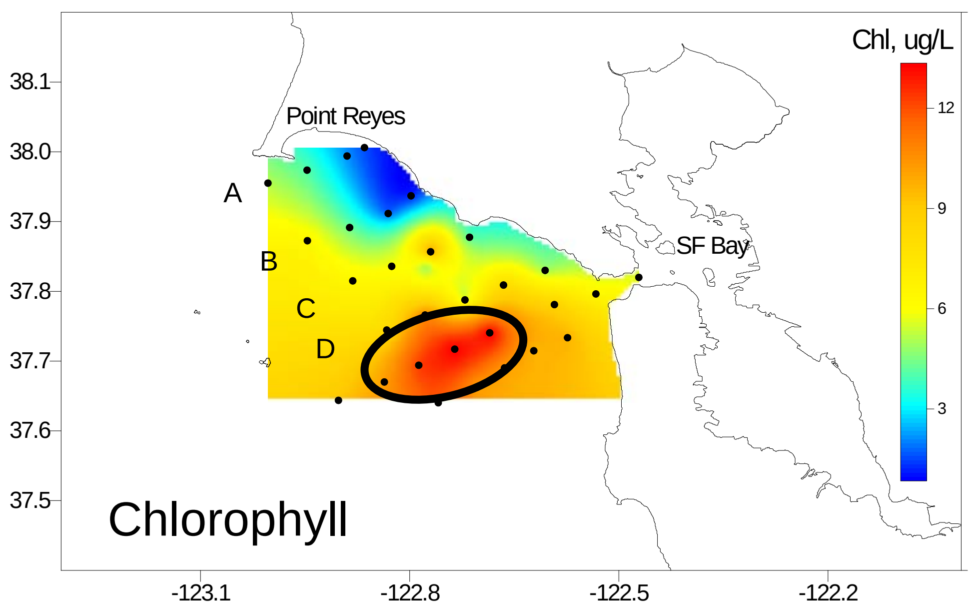
Date	Delta Flow $m^3 s^{-1}$	Concentration NH_4 at D4 mmol N m^{-3}	NH_4 Loading to Suisun mmol $m^{-2} d^{-1}$
17-Mar	496.9	10.31	2.61
24-Mar	283.3	6.97	1.01
7-Apr	616.9	9.66	3.04
14-Apr	633.5	5.5	1.77
26-Apr	765.3	5.18	2.02
12-May	617.3	4.43	1.39
24-May	639.7	3.56	1.16
16-Jun	595.5	4.29	1.30
21-Jun	280.9	2.69	0.38
mean			**1.63**
sd			**0.82**

Implications for the nearshore: estuary/ocean interactions



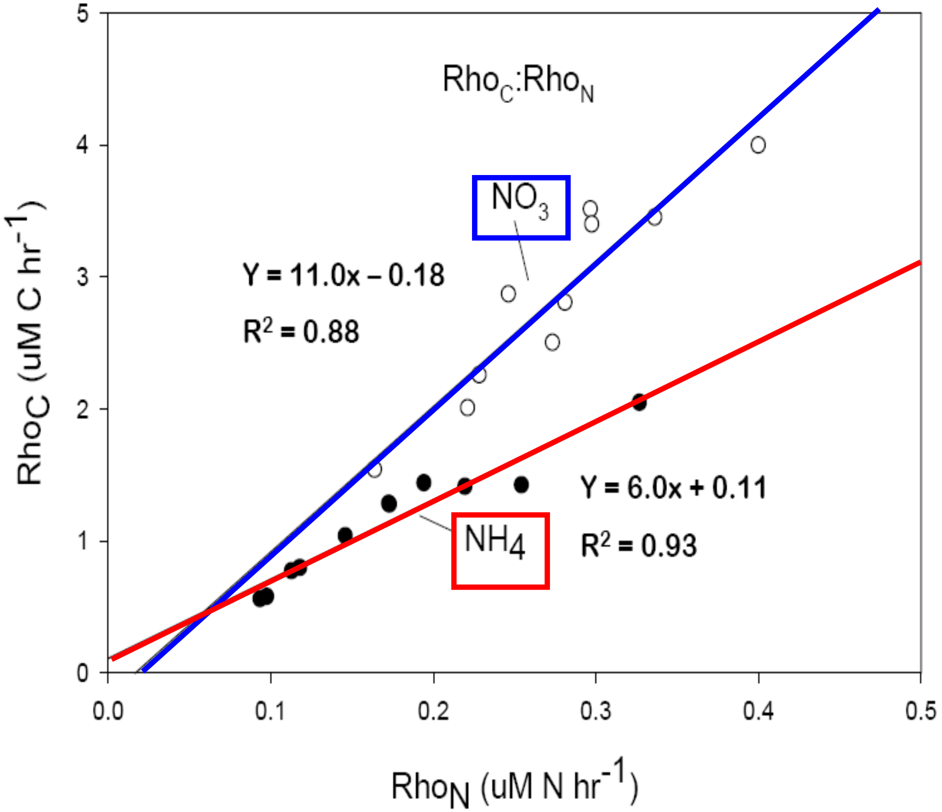


★ upwelling



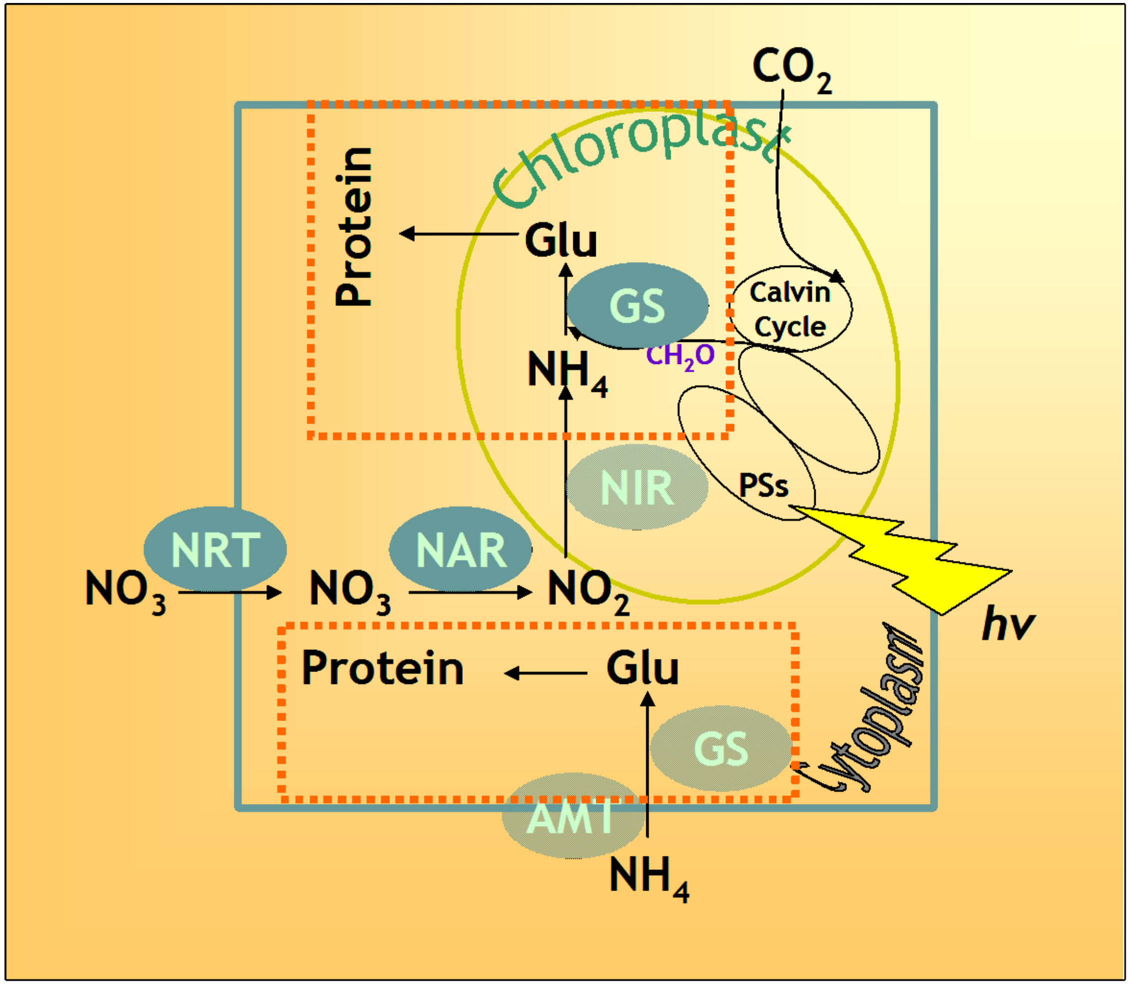
SF outflow, buoyant plume

Carbon fixation is greater when growth is on NO_3 vs NH_4



Carbon fixation (rho C) vs NO_3 or NH_4 (rho N) uptake in enclosures in the Delaware Estuary (from Parker, 2004)

Cellular transformations of nitrogen



NRT = nitrate transporter
NAR = nitrate reductase
NIR = nitrite reductase

AMT = ammonium transporter
GS = glutamine synthestase