Conceptual Model of Ammonium Utilization at the Base of the Delta Food Web

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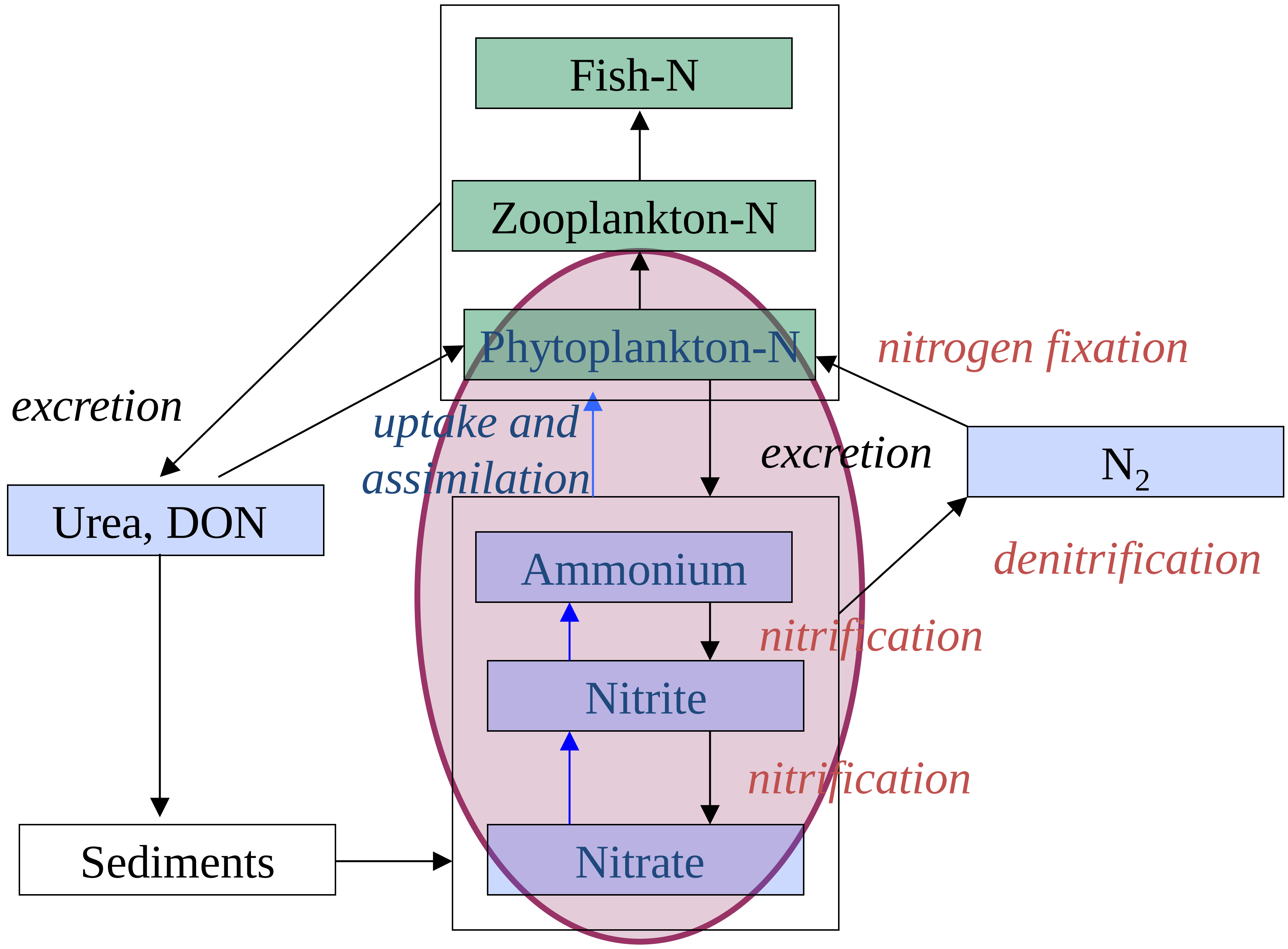
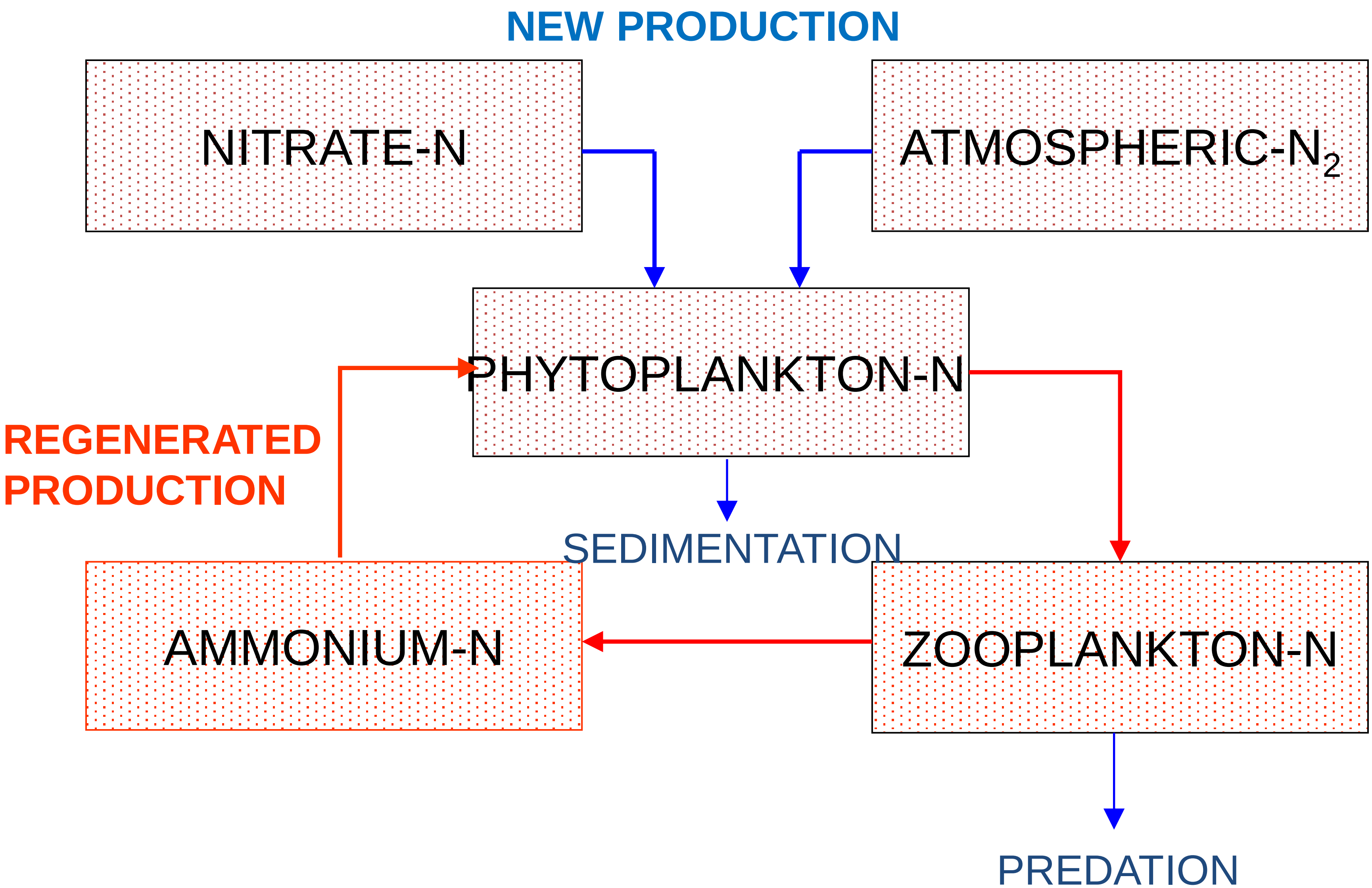
Outline

1. Background: nitrogen cycle in the ocean
2. Background data from San Francisco Bay
3. Physiological and experimental basis for effect of ammonium on nitrate uptake by phytoplankton
4. River Transects
5. Suisun Bay spring bloom studies
6. Suisun Bay conceptual model
7. Suisun Bay NH_4/NO_3 model
8. Nutrient stoichiometric ecosystem model
9. SMORE salmon model
10. COSiNE model

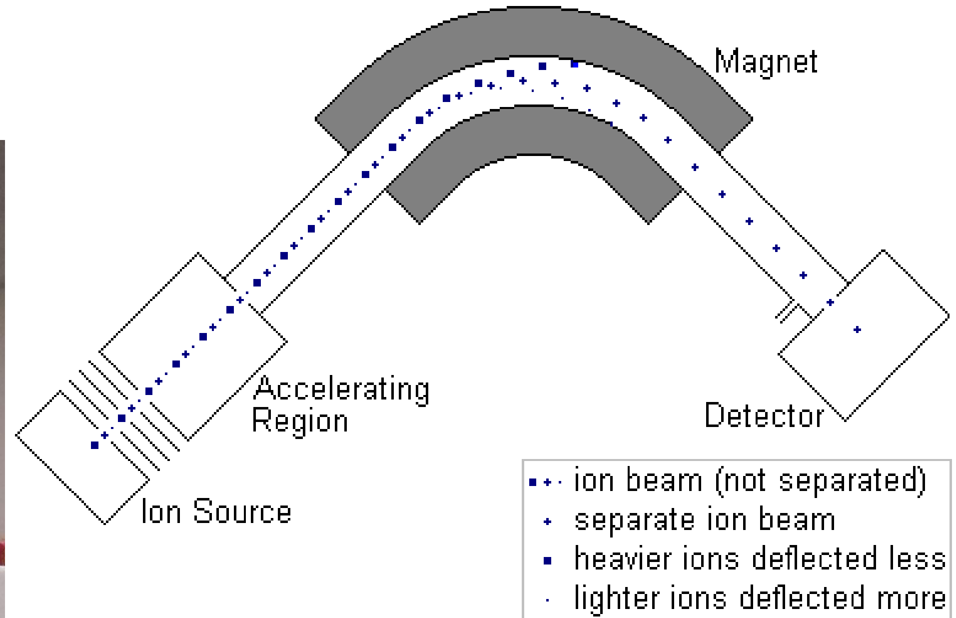
Aquatic Nitrogen Cycle



New and Regenerated Production

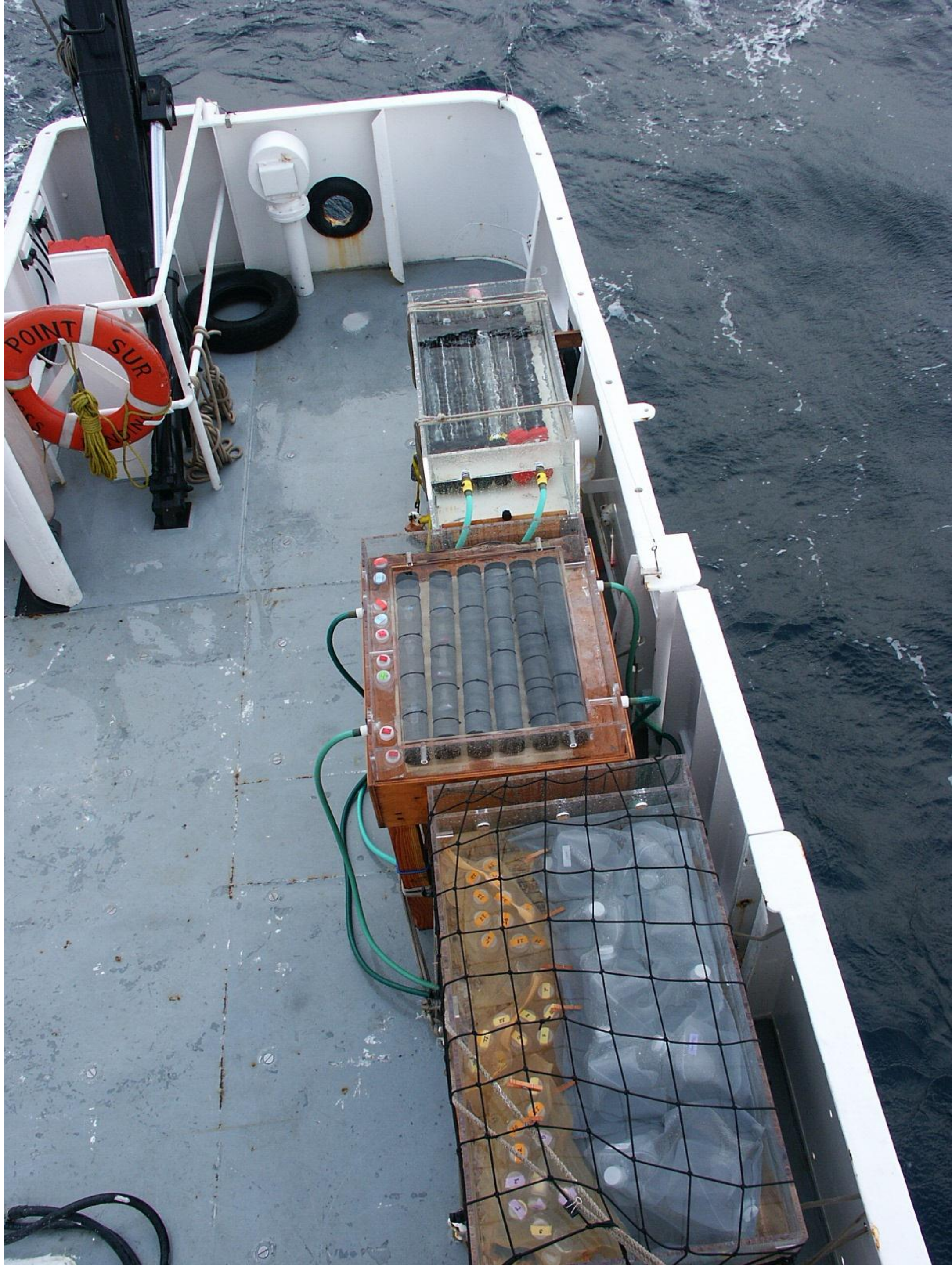


Use of tracers: can track new and regenerated production with N15 labeled nitrate and ammonium measured with mass spectrometry



sample
water

Incubate water sample containing phytoplankton with 15N labeled nitrate or ammonium, or 13C bicarbonate (C fixation)



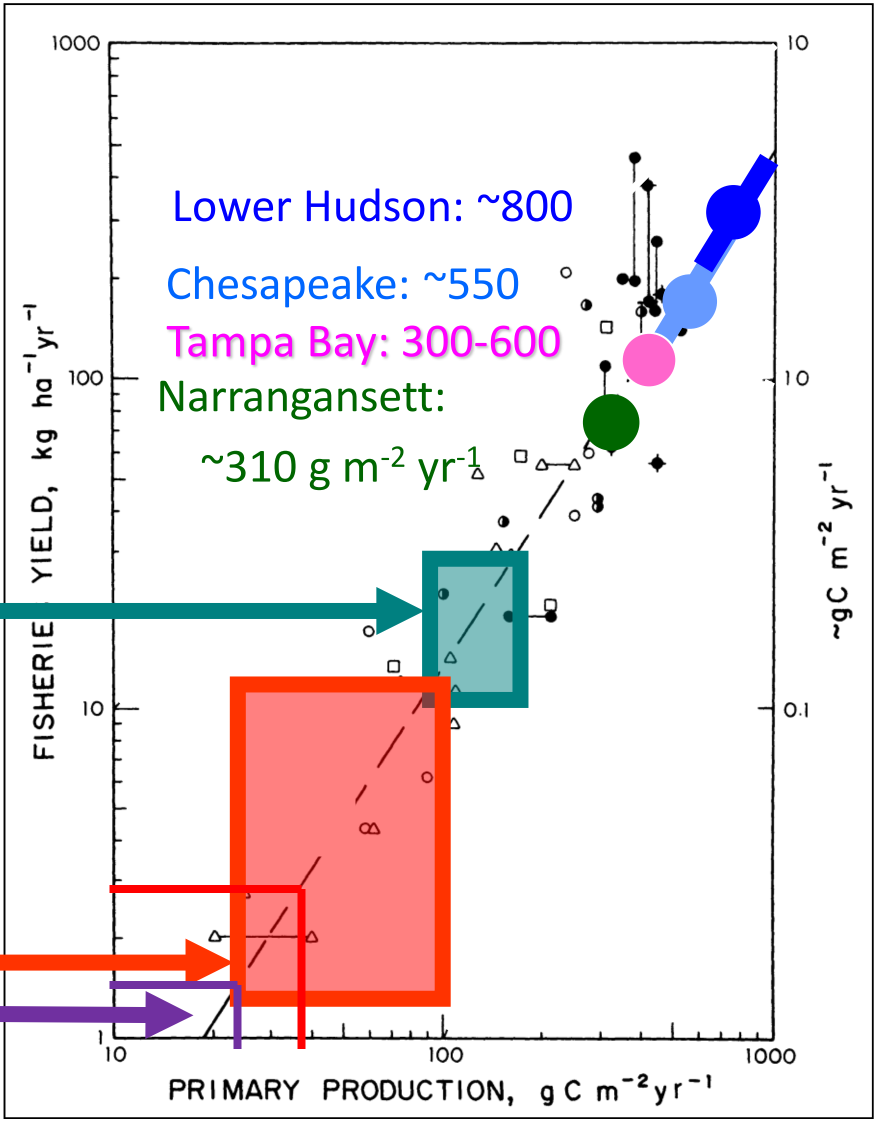
Filter out the phytoplankton

San Francisco Estuary

The conventional wisdom for nutrients and primary productivity by phytoplankton in the San Francisco estuary is that:

- Nutrients don’t matter as light is limiting, and nutrients are always in excess
- The composition of the DIN pool is unimportant since nitrate and ammonium can be used equally-worldwide
- *Corbula amurensis* (Asian clam) invasion was responsible for the collapse of the primary productivity in Suisun Bay in 1987

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



1976 – 1987

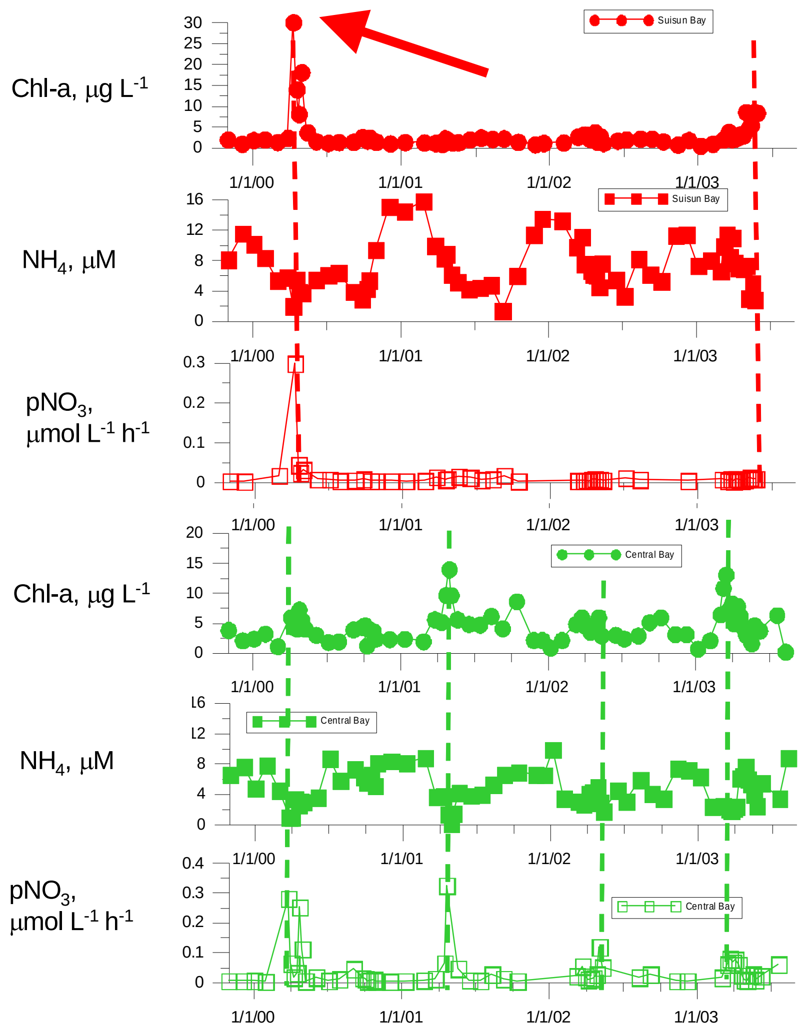
San Francisco Estuary Low-Salinity Zone

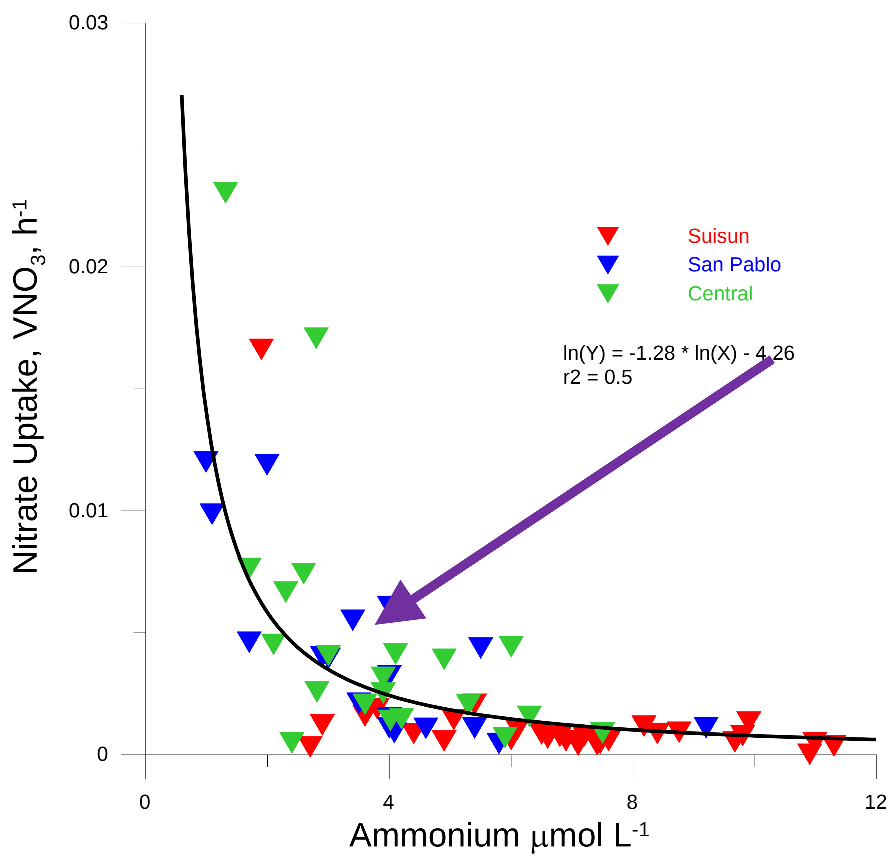
1988 - 2002

2002 on

Adapted from Nixon 1988 by Cloern, Parker and others

We observed in Suisun in 2000, that spring blooms happen when NH_4 is low

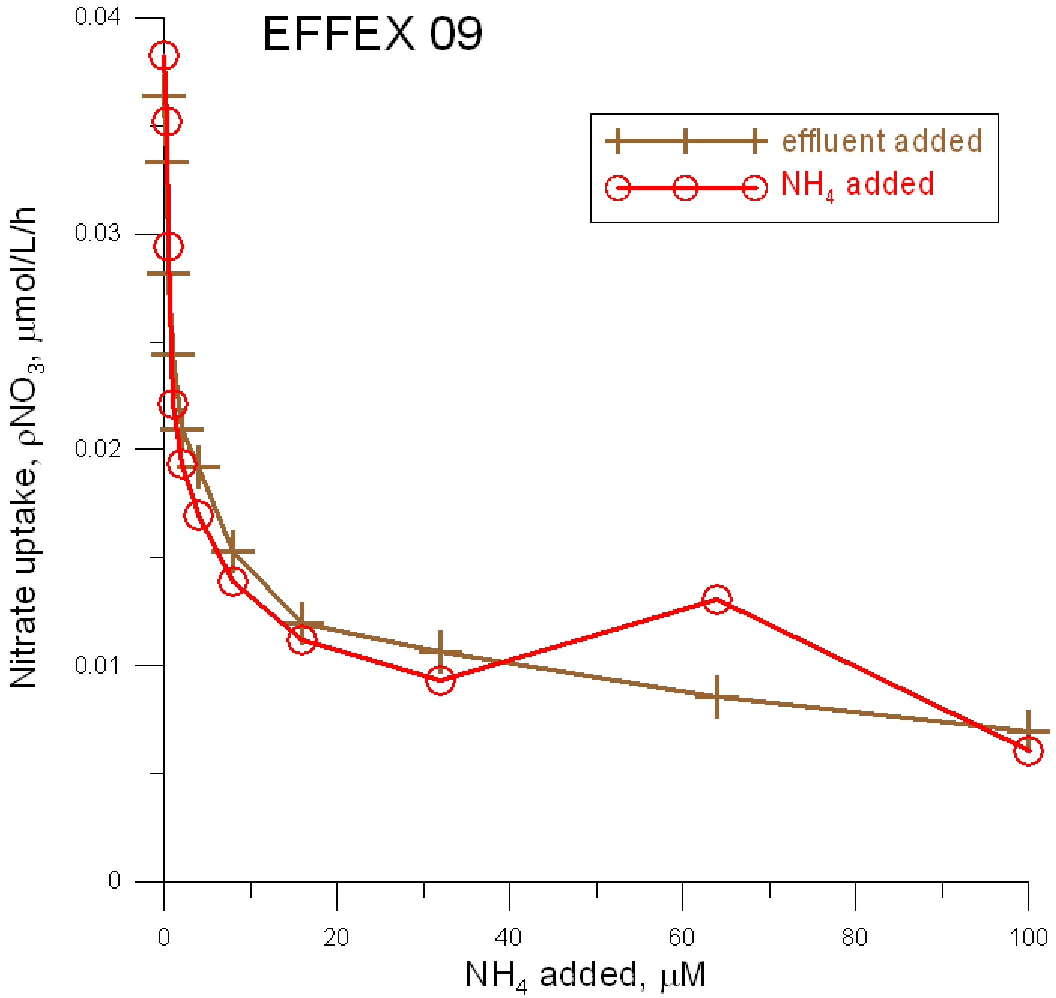




Chl accumulation (dotted line) with low NH_4
Phytoplankton need to access NO_3.

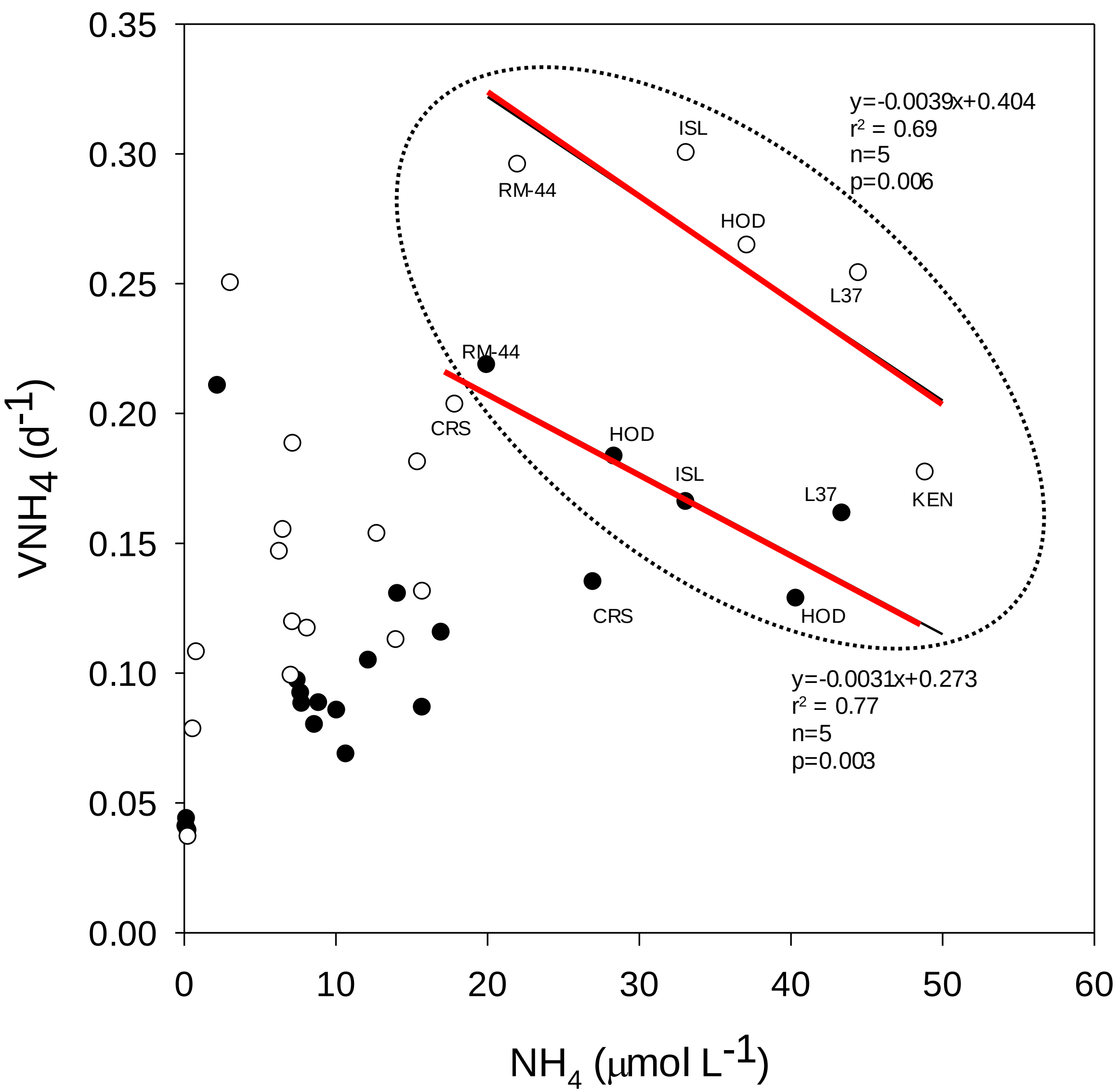
Nitrate uptake increases, once NH_4 is below an inhibitory concentration

The same relationship occurs with dilutions of effluent or NH_4Cl

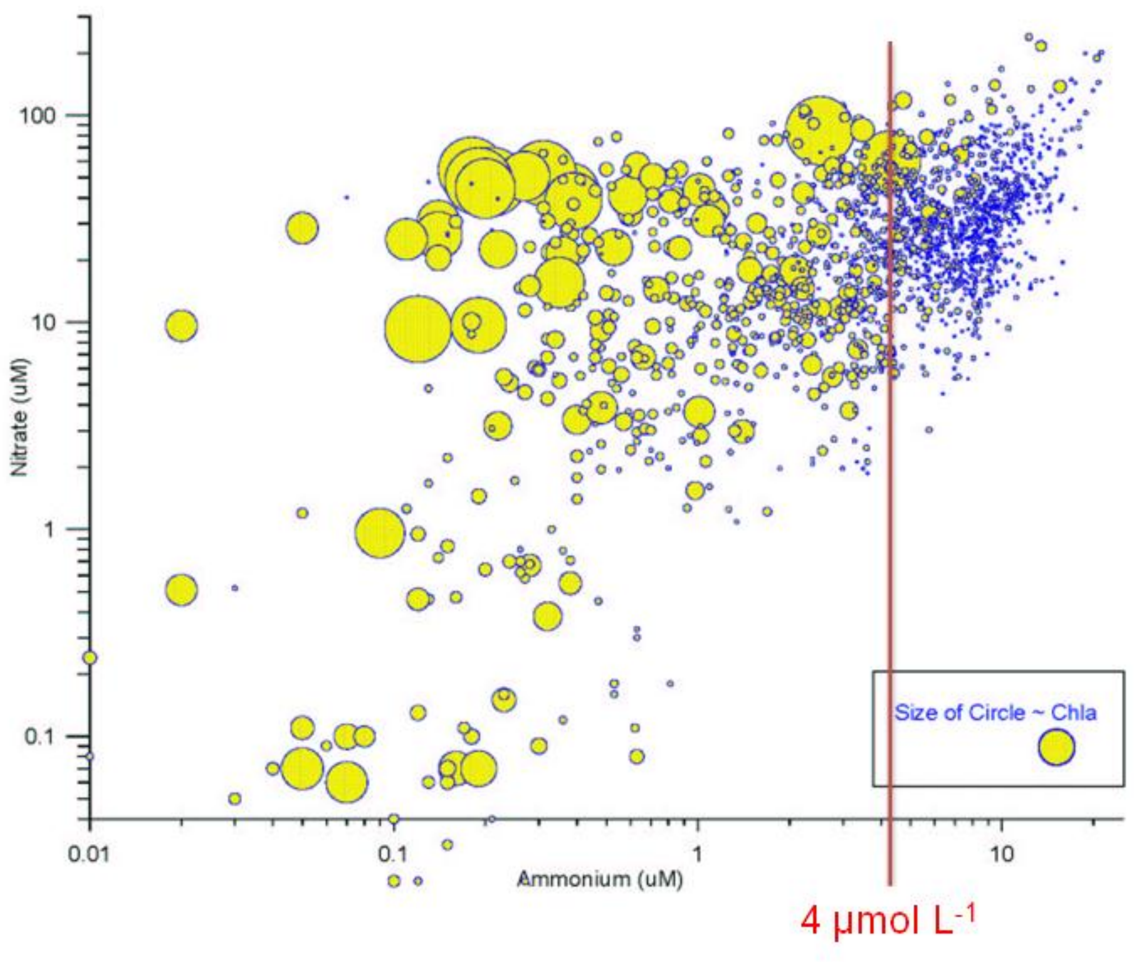


nitrate uptake decreases with high NH_4 whether NH_4 is in effluent or alone

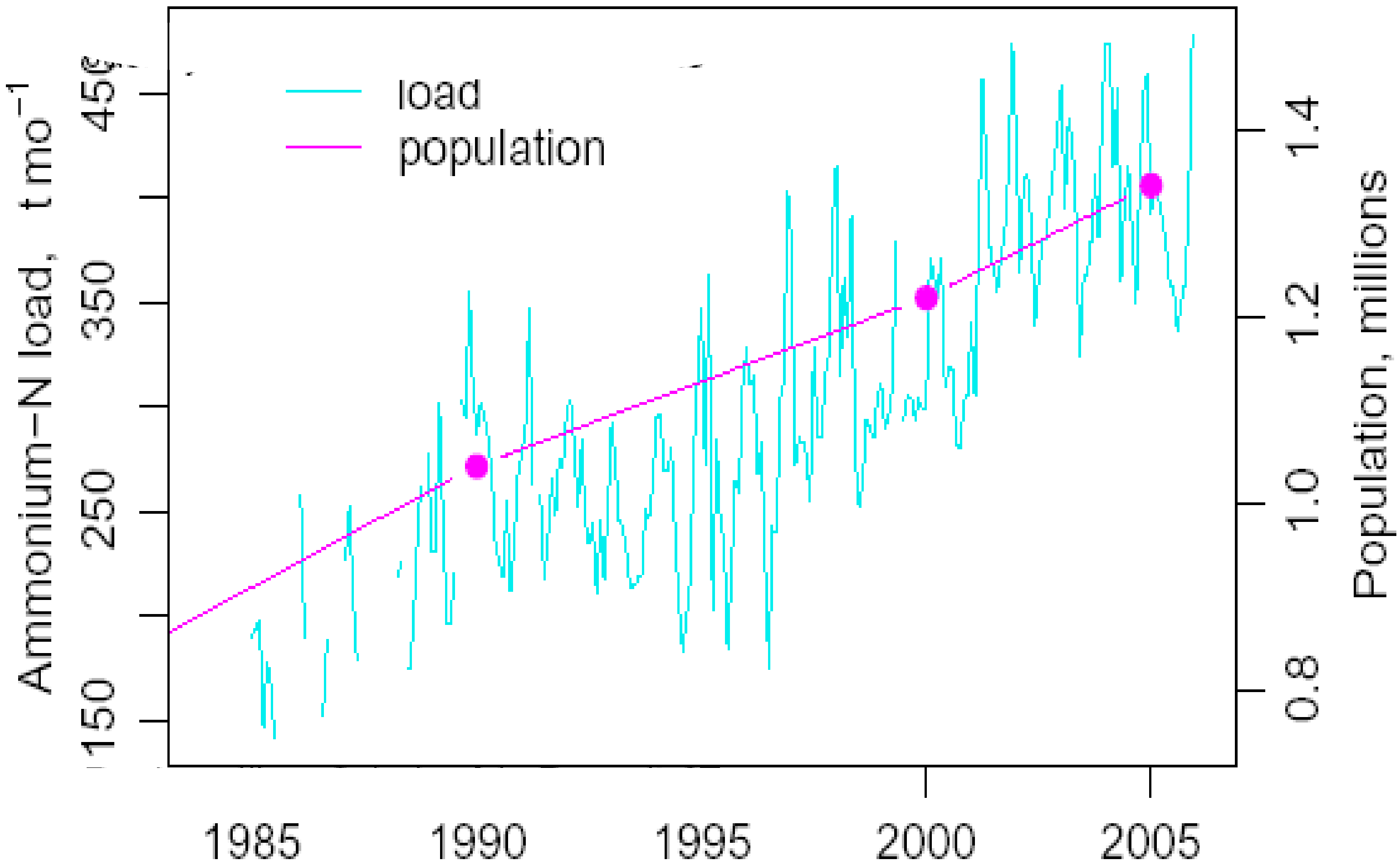
High NH_4 can result in decreased NH_4 uptake



Cloern Data for SFE – more chlorophyll (bigger circles) with less ammonium (NH_4)

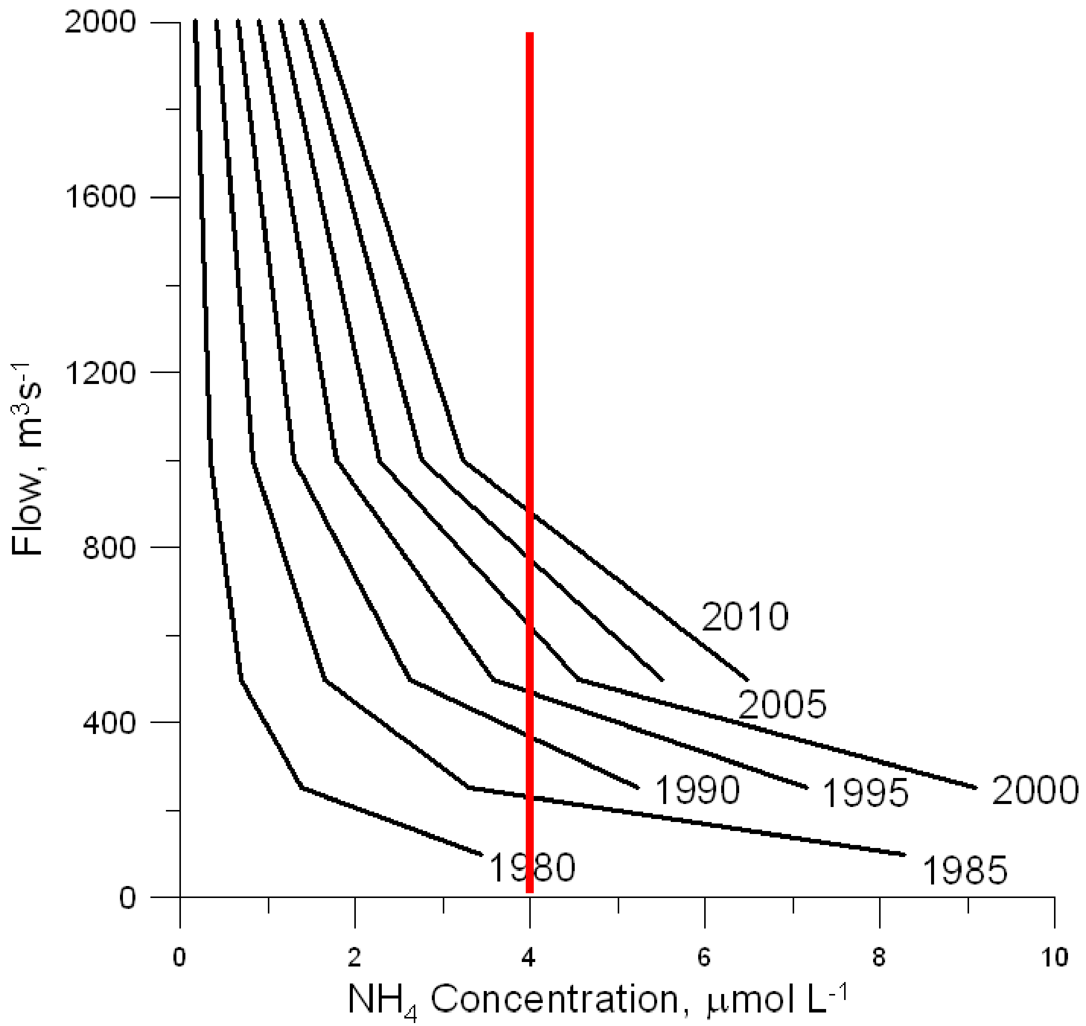


Ammonium loading has increased into Sacramento River along with population



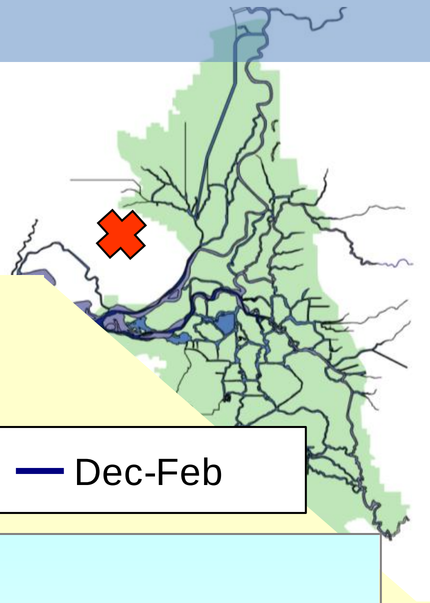
Jassby 2008

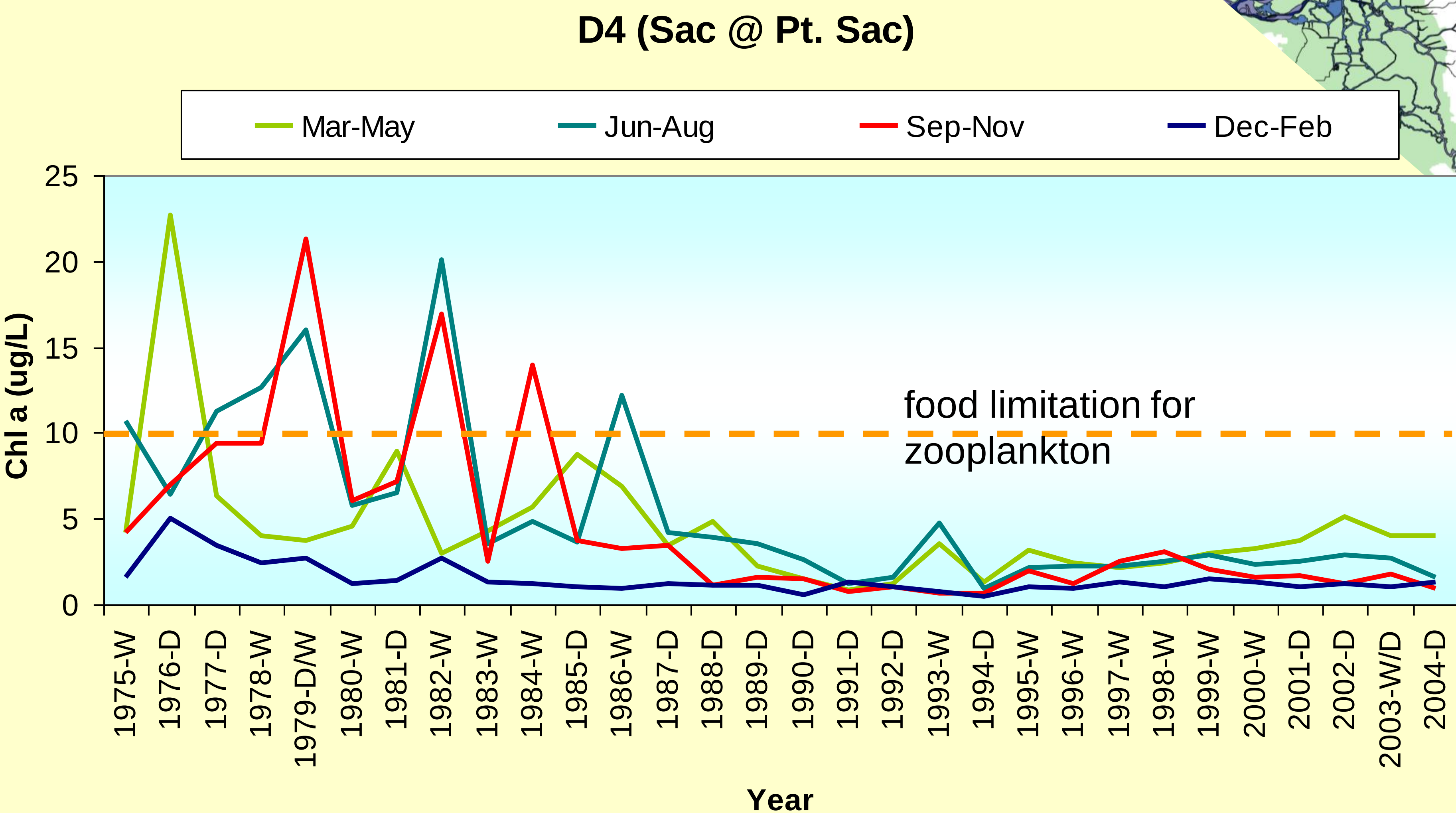
NH_4 concentrations at Suisun Bay calculated from SRWWTP discharge in different years



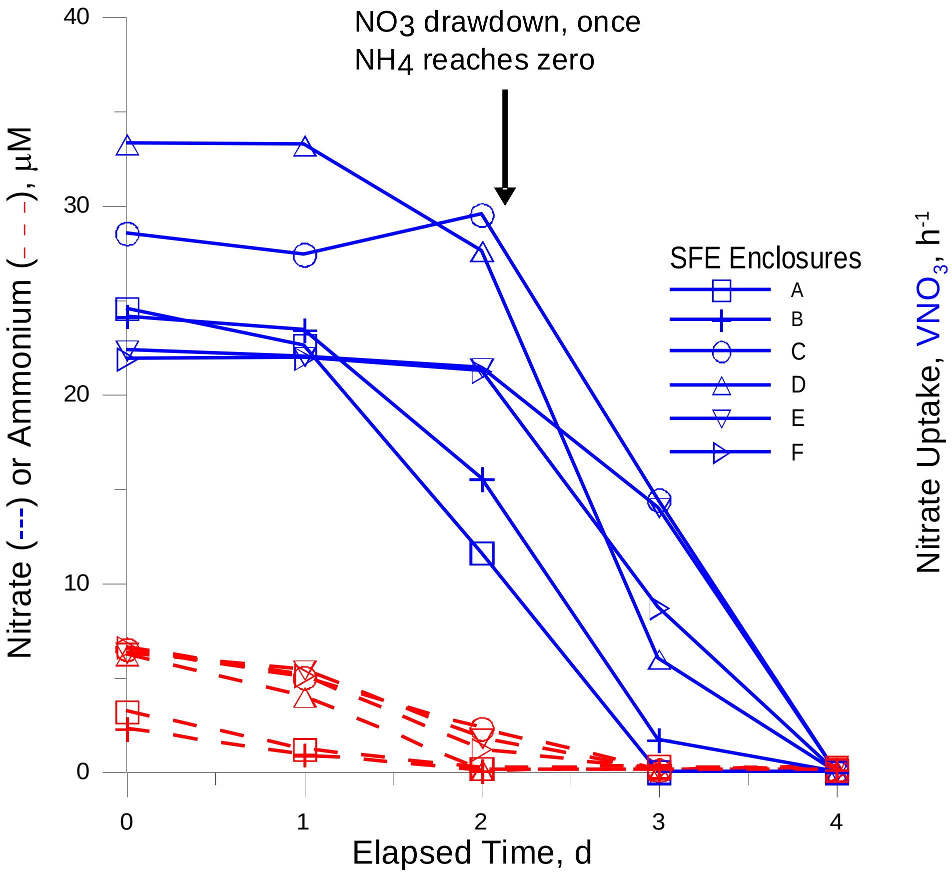
As the discharge increases, the flow needed for 4 µmol L^{-1} (ie blooms) increases)

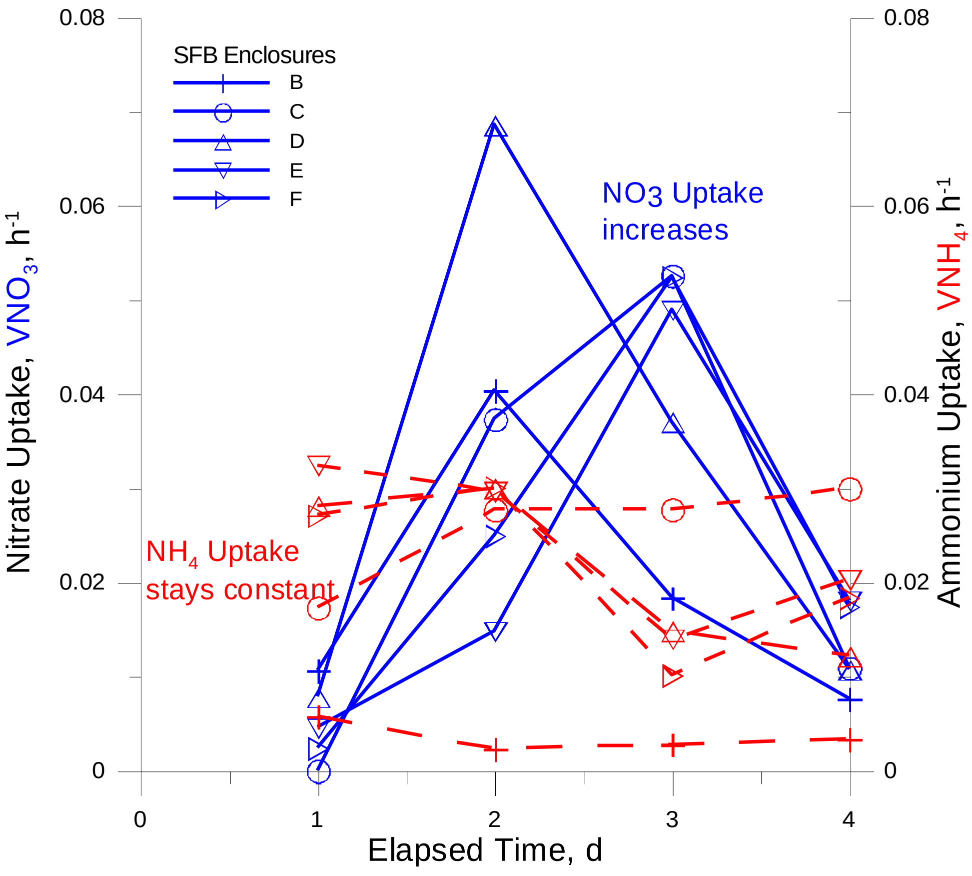
In Suisun Bay, chlorophyll decreasing





Central Bay Enclosure Experiments





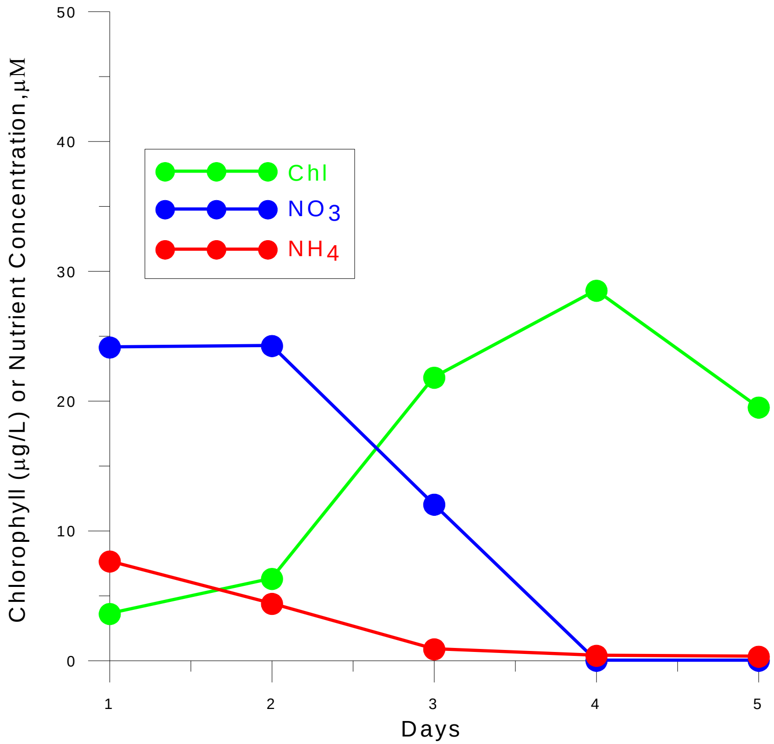
Nitrate drawdown starts once NH_4 is reduced below inhibitory values

Nitrate uptake exceeds ammonium uptake

Dugdale et al. 2007

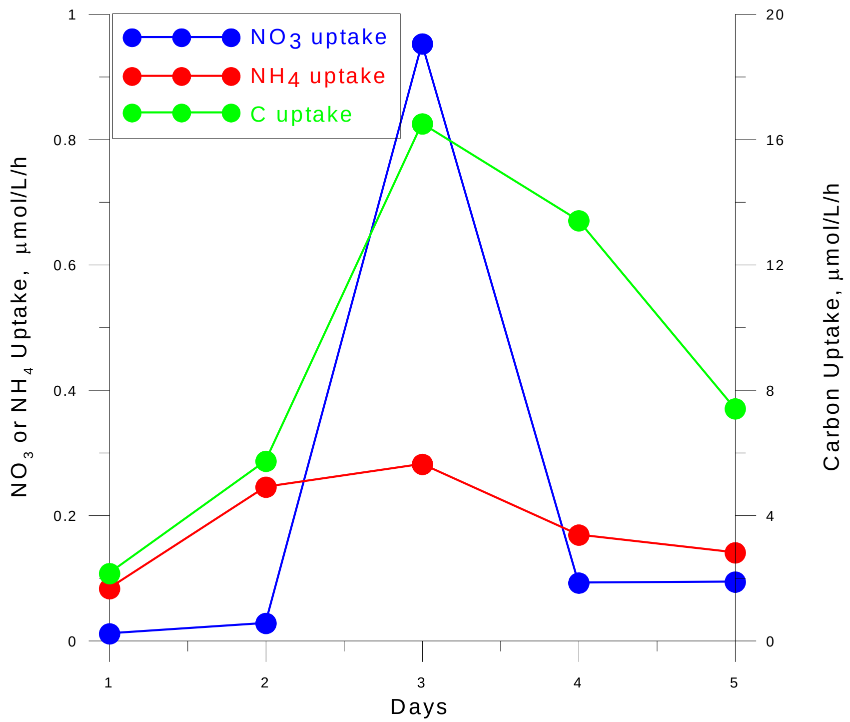
Chlorophyll accumulation and phytoplankton productivity in Central Bay enclosures

Nutrient drawdown and chlorophyll



NH_4 decreases, then when NH_4 ~4 µm, NO_3 drawdown starts on Day 2 and chlorophyll biomass increases

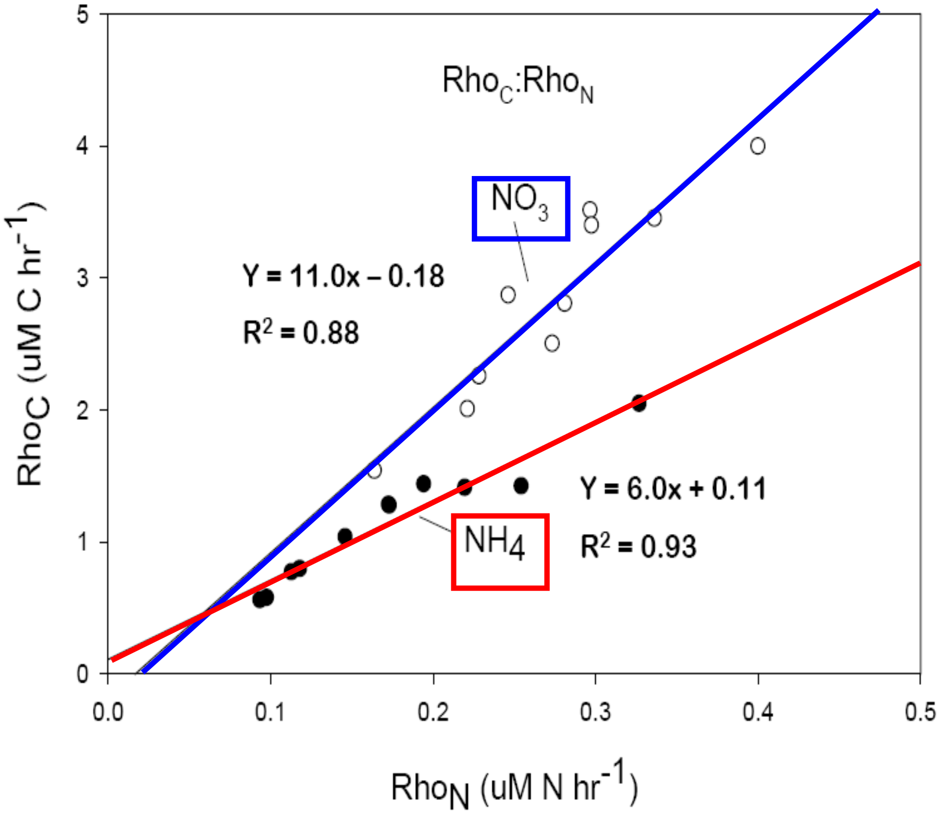
Nutrient uptake and C fixation



NO_3 uptake is greater than NH_4 uptake. C uptake tracks NO_3 uptake.

June 2007

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)

Required sequence for bloom formation in SFE

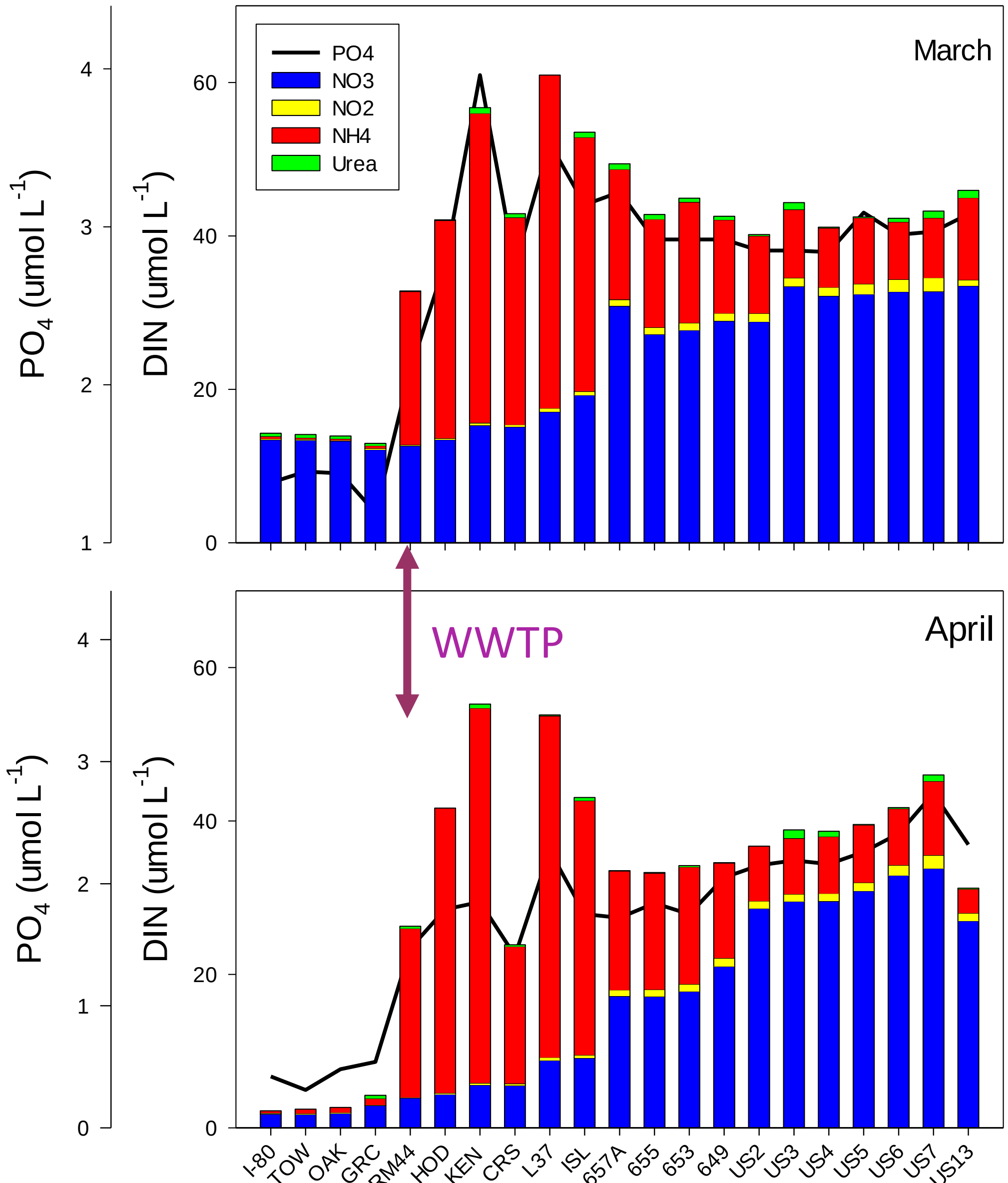
1) Phytoplankton biomass buildup by uptake of NH_4 (e.g. from improving irradiance, better water column stability)

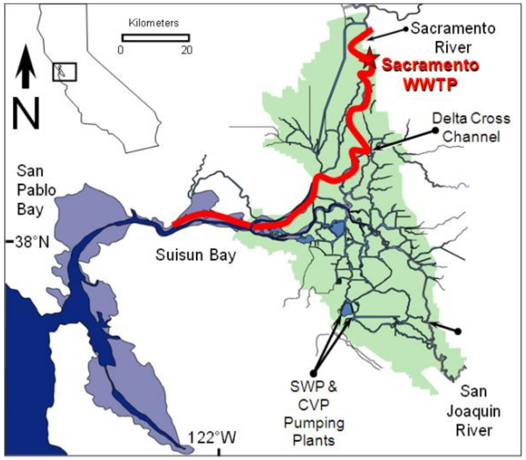
2) NH_4 concentrations decline to below 4 μmol L^{-1}

3) Nitrate (NO_3) and NH_4 uptake produce rapid bloom of chlorophyll

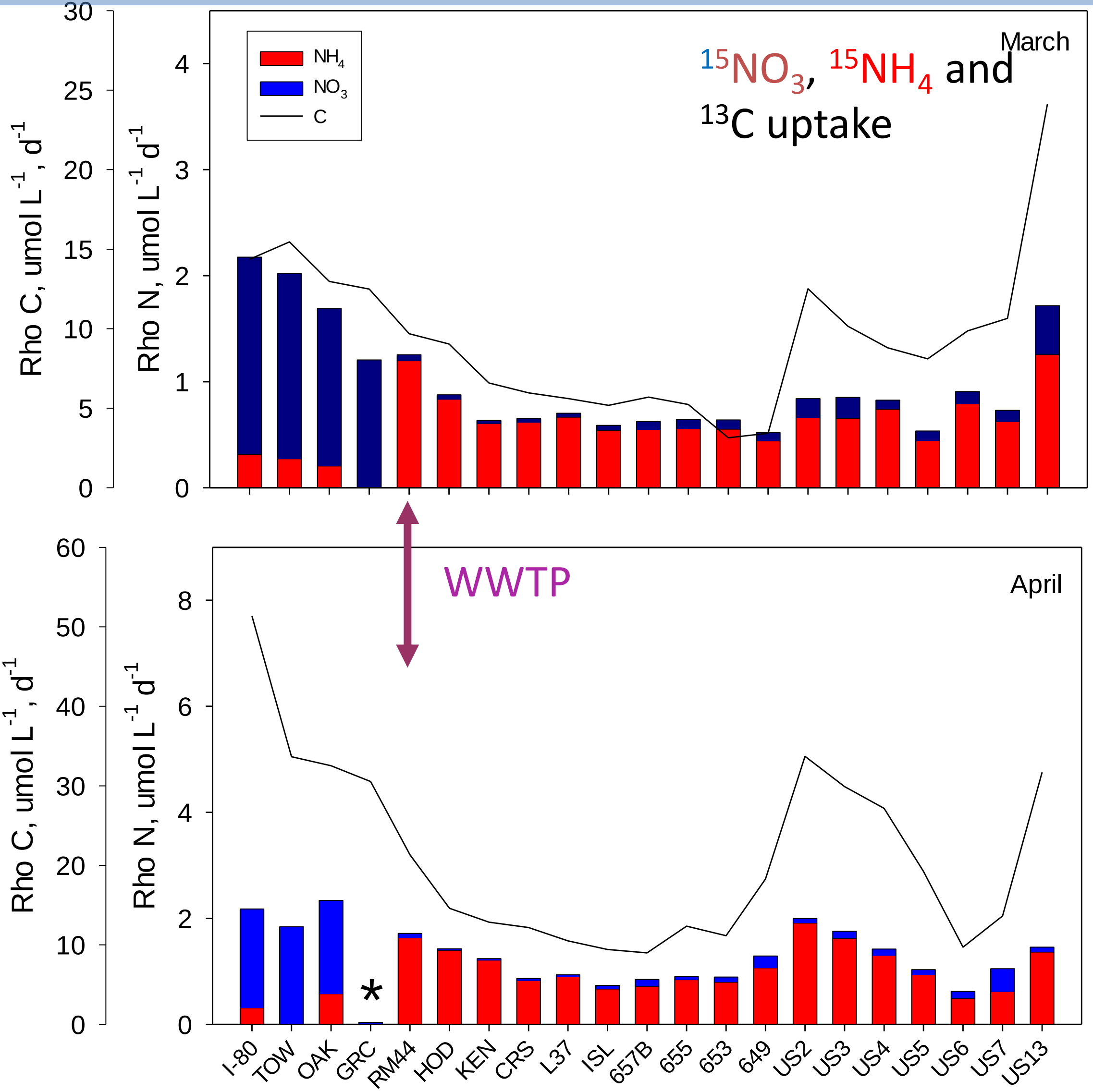
River Transects

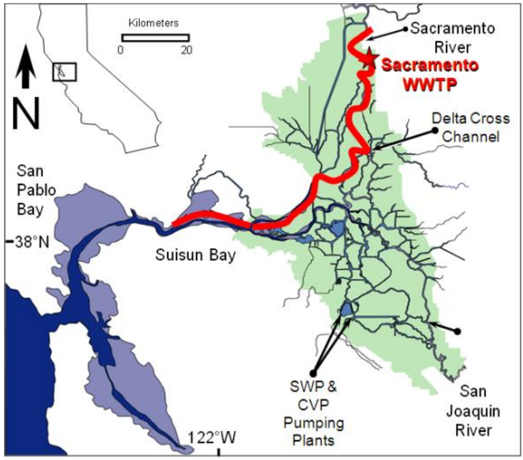
Change in contribution of NO_3 and NH_4 to total DIN as go downstream



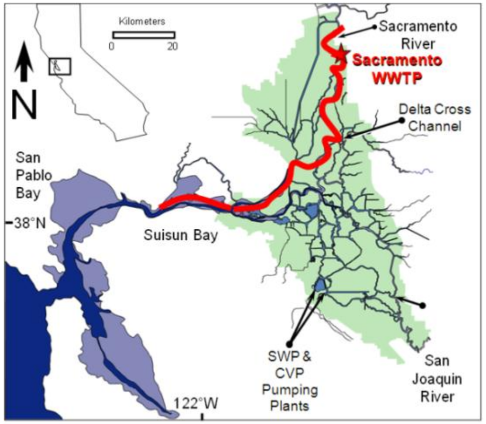


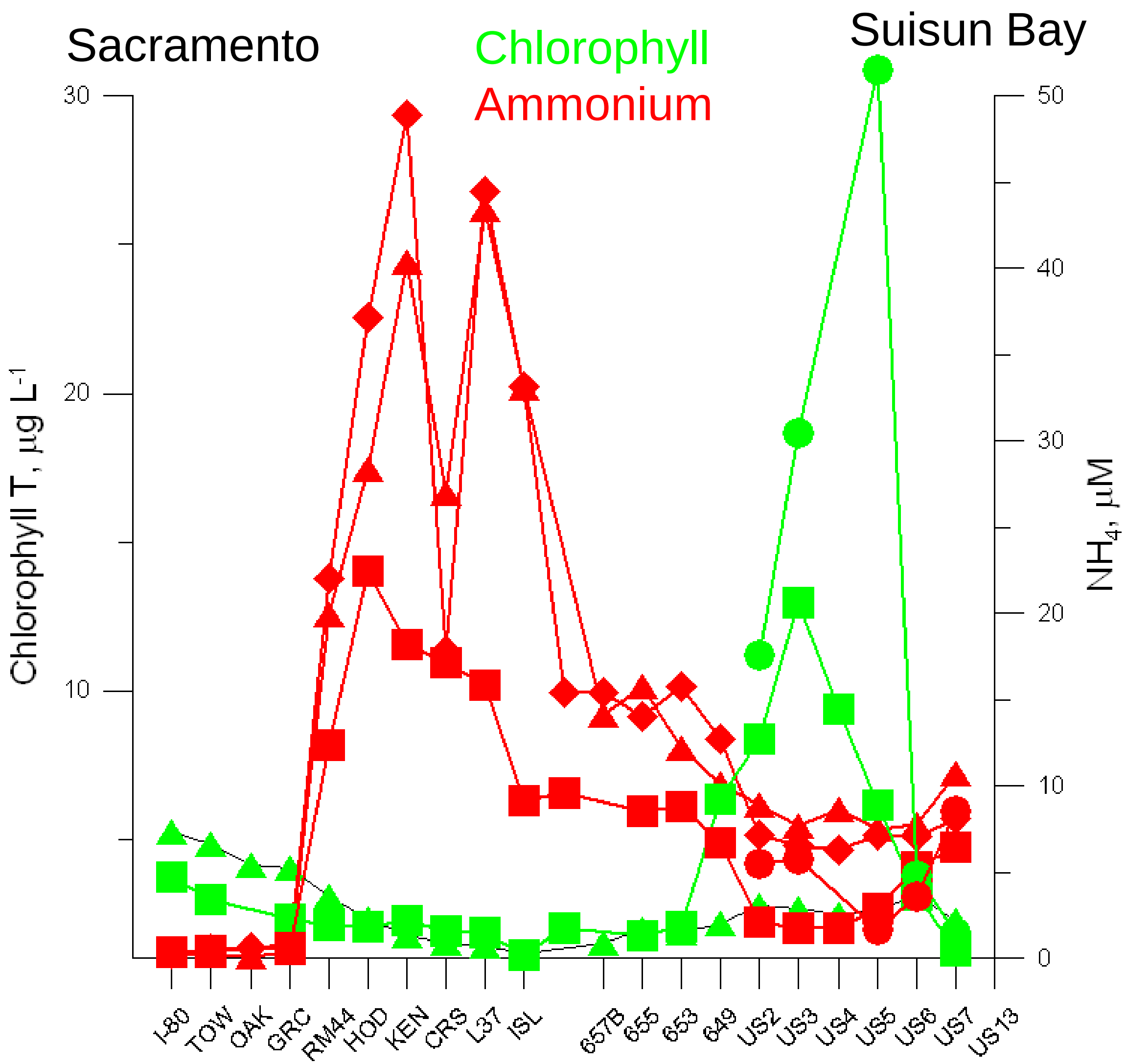
Shift from uptake of NO_3 to NH_4 uptake system with low primary productivity (C uptake) downstream of WWTP





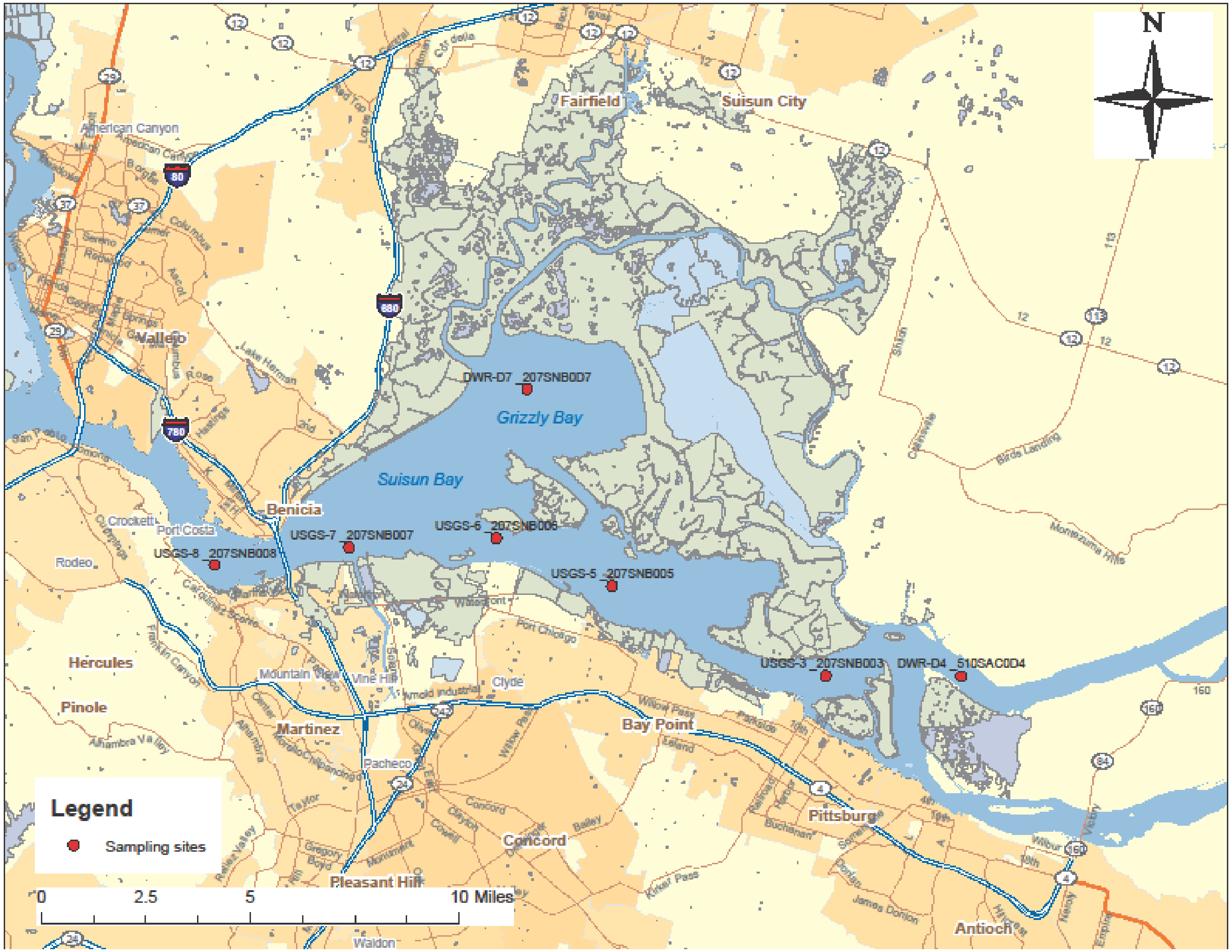
Patterns downstream





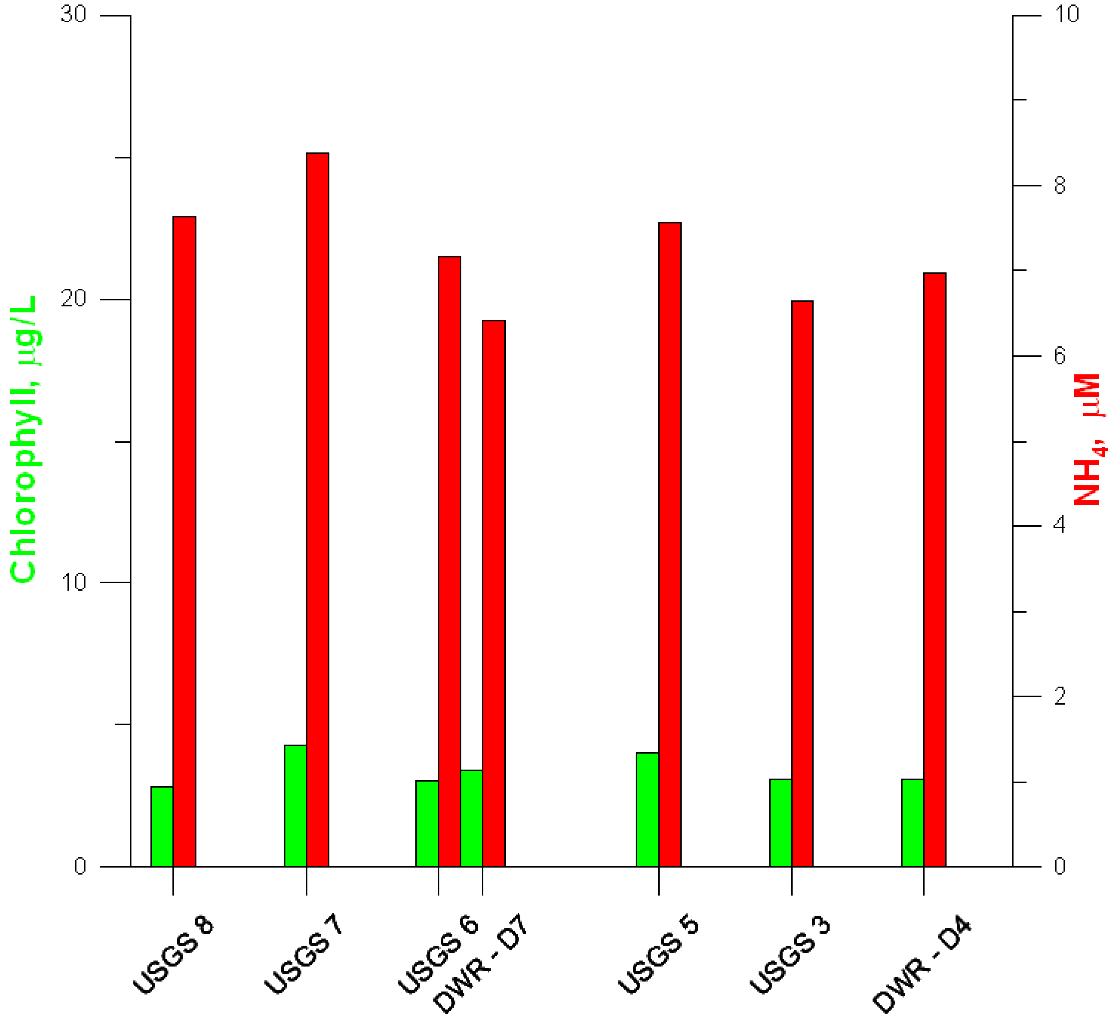
Spring transects sampled in 2009 and 2010

Suisun Bay spring bloom studies 2010 and 2011



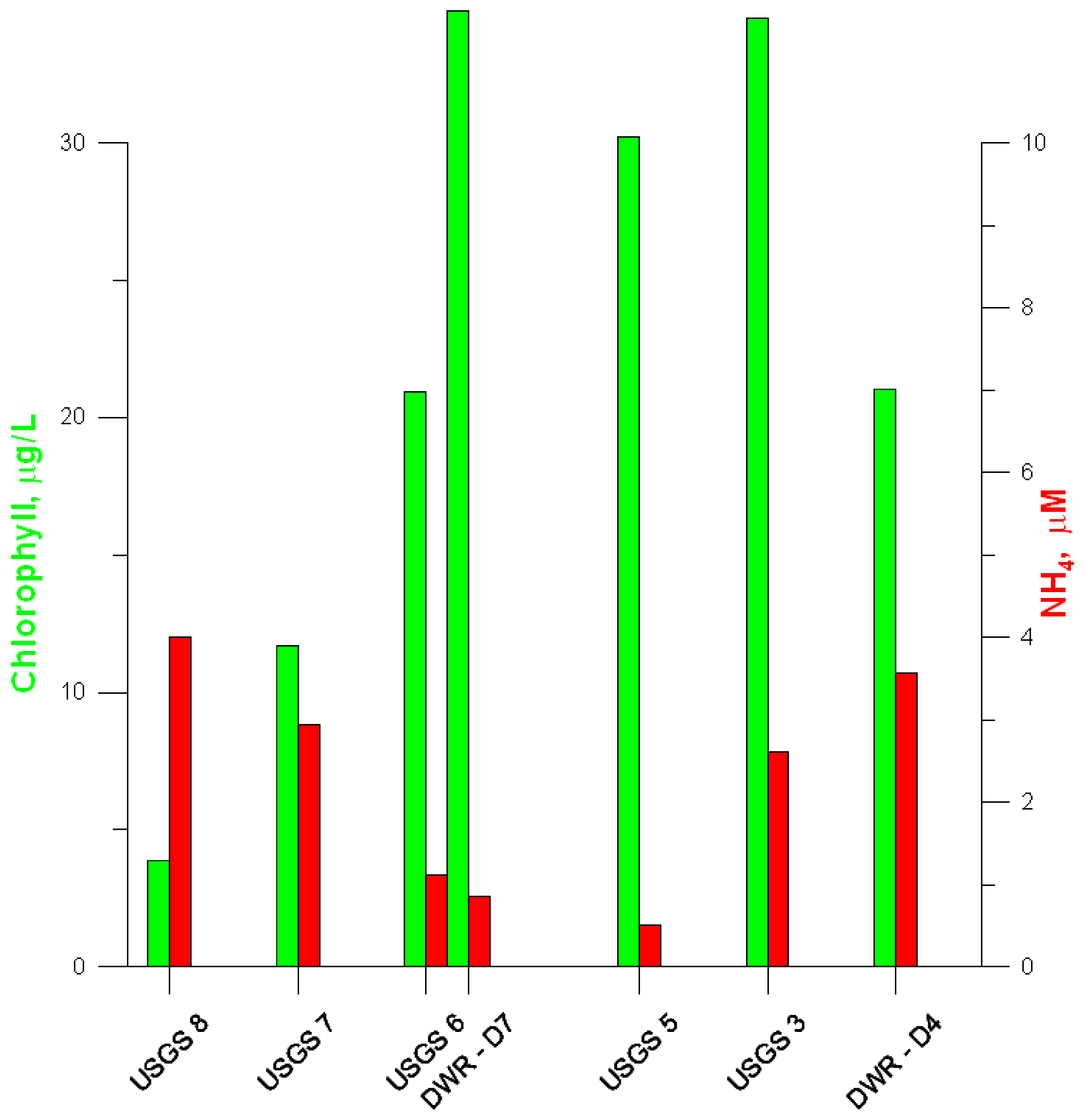
Sponsored by San Francisco Regional Water Quality Control Board, Karen Taberski

With high NH_4 concentrations, there was low chlorophyll



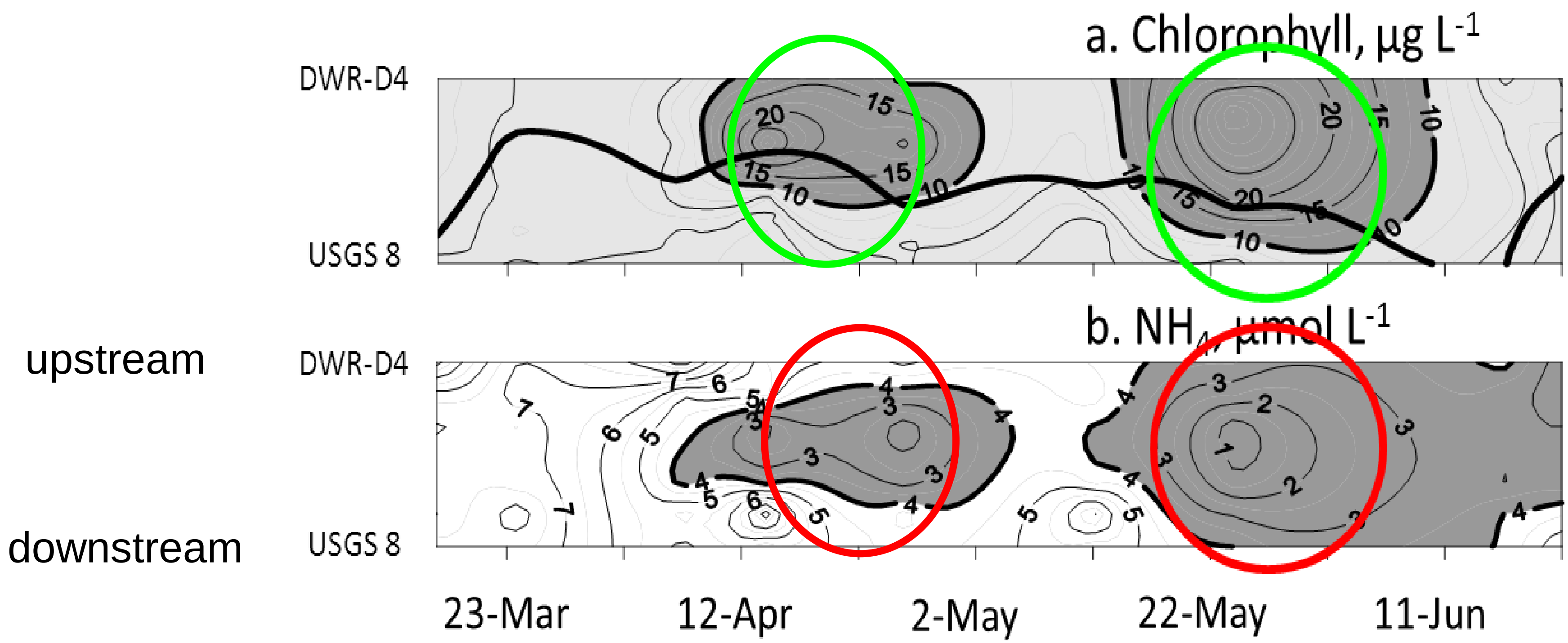
March 24 2010

Phytoplankton Blooms in 2010 occurred with low NH_4 concentrations - as in 2000

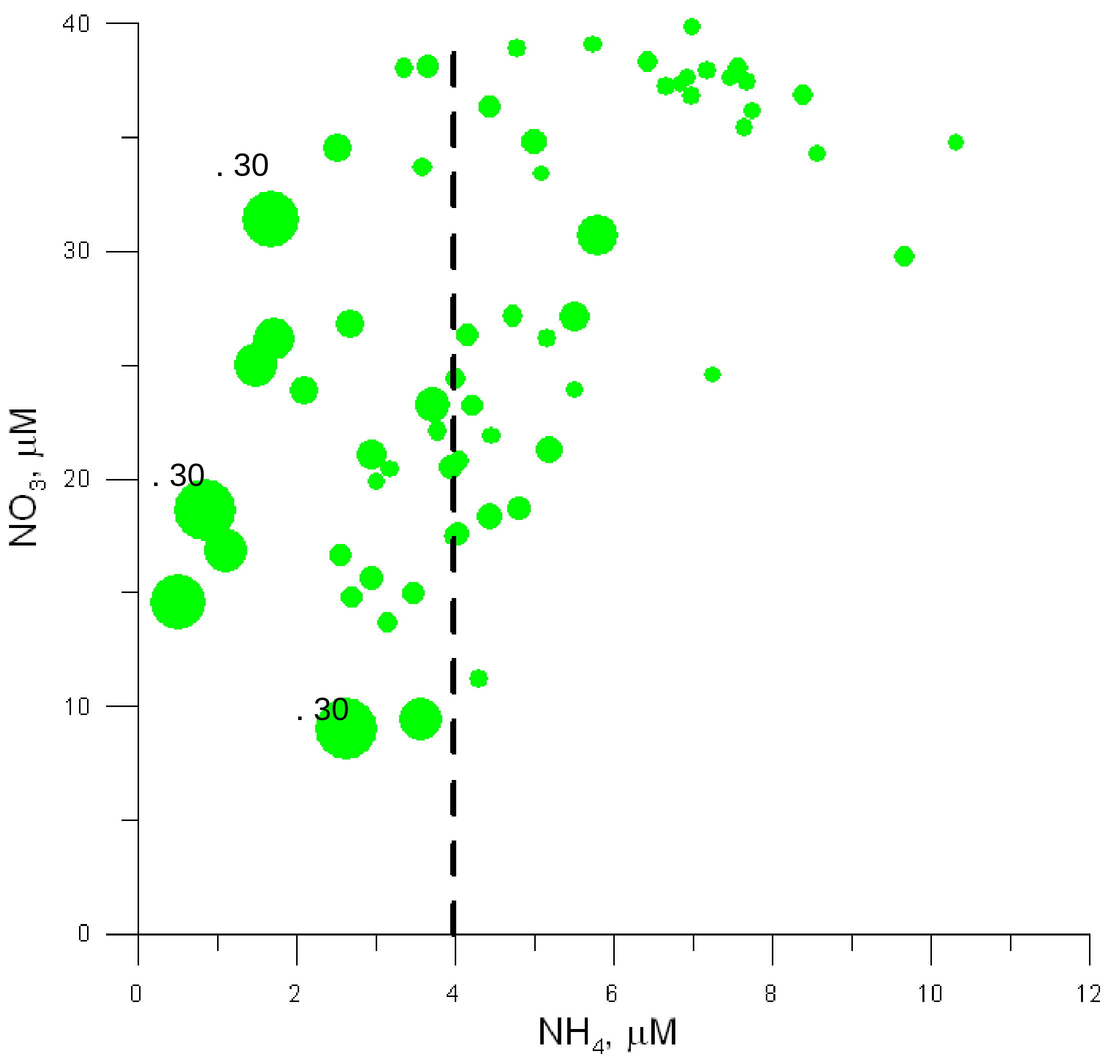


May 24 2010

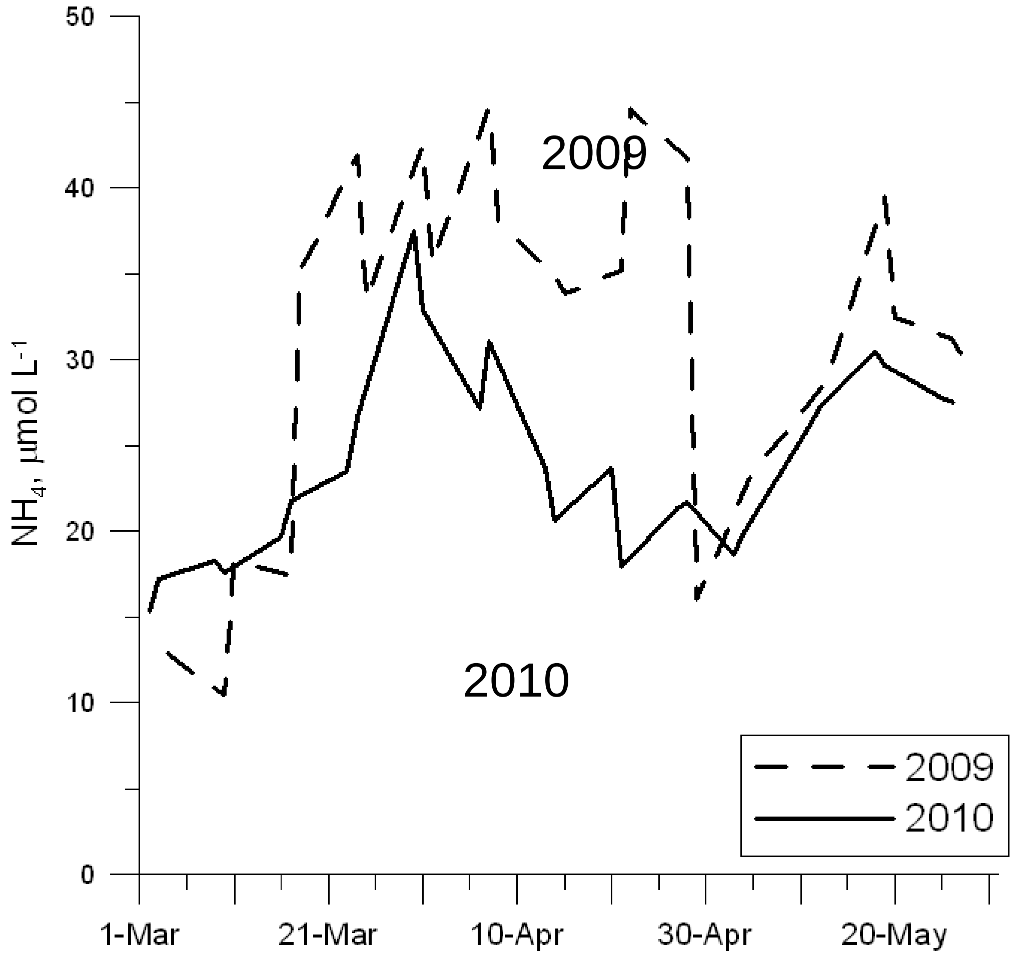
In Suisun Bay, blooms where $NH_4 < 4$ µmol L^{-1} in 2010



At the height of the bloom NH_4 was < 4 µmol L^{-1} with high chlorophyll concentrations (~ 30 µg L^{-1}); about 20 µmol L^{-1} NO_3 was drawndown



We calculated that in 2010 there was a decline in NH_4 in Sac R near the SR WTP due to increased flow and a decline in NH_4 discharge



SR WTP later explained that they had reduced NH_4 discharge by 12% due to changes in treatment practices !

Criteria for phytoplankton to bloom in Suisun Bay (i.e. chlorophyll > 10 µg L^{-1}), assuming adequate light

1) Loading of ammonium must not exceed capacity of the phytoplankton population to take it up (or NH_4 concentration will increase)

2) The inflowing concentration of ammonium must be close to 4 µmol L^{-1}

3) Flow must be less than the washout rate; i.e. basin dilution no greater than phytoplankton growth rate

Simplified basin model for NH_4 criteria for blooms

NH_4 input from rivers
1) NH_4 per day, tons N d^{-1}
2) Concentration µmol L^{-1}

Flow, $m^3 d^{-1}$

Surface area 1.7x10^8 m^2
Volume 9.9x$10^8$$m^3$

Loading NH_4 input from rivers / surface area

Phytoplankton uptake=VNH_4 * biomass
as N or chl

NH_4 outflow=
NH_4 input from rivers minus
phytoplankton uptake

Comparing NH_4 loading with phytoplankton capacity to take up NH_4

Range of loadings to Suisun Bay (from SacRegional WTP, corrected for nitrification)

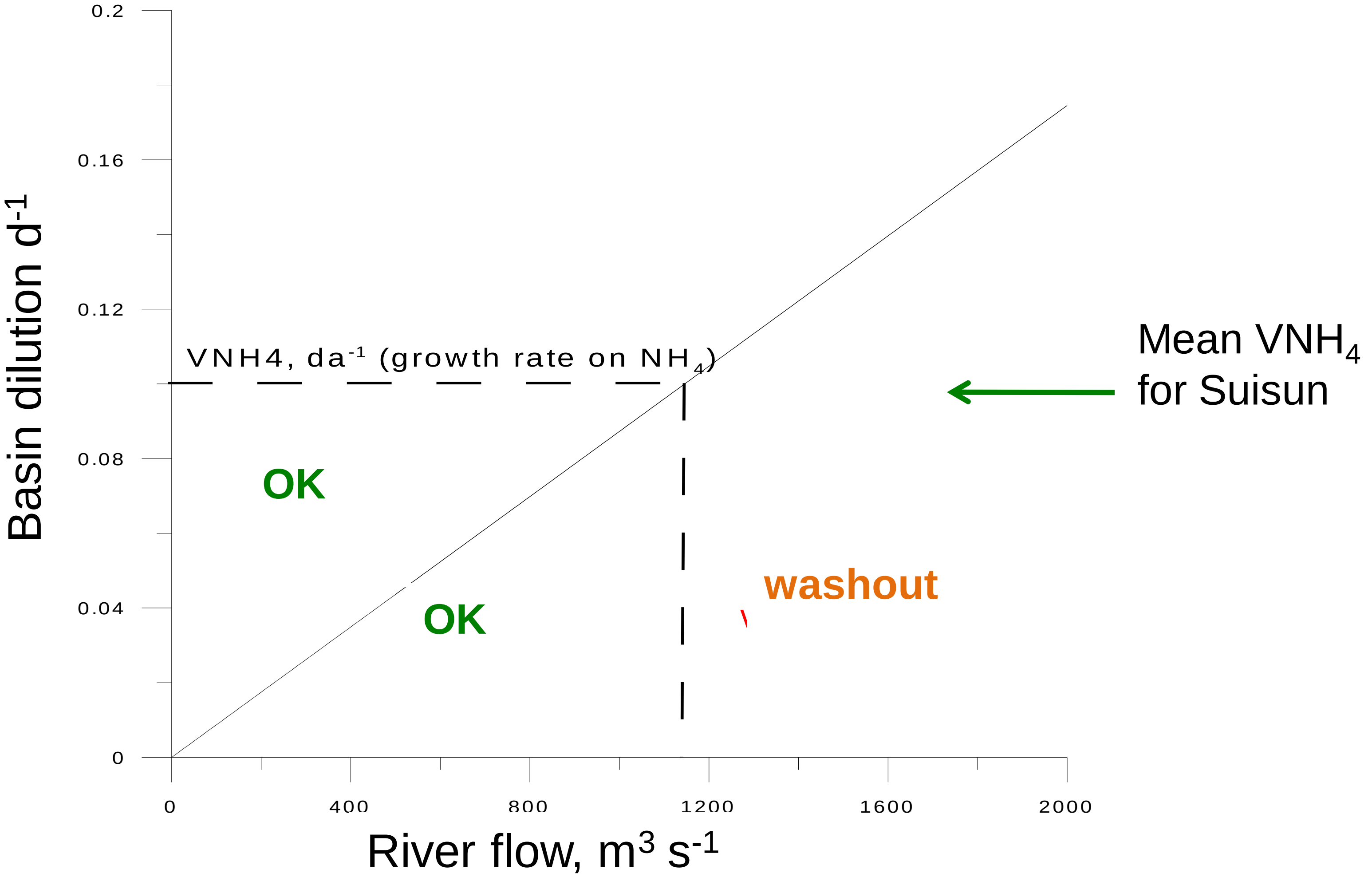
tons N day^{-1}	*mmolm^{-2}d^{-1}*
5 (ca 1980)	0.53
10	1.05
15 (present)	1.58

Range of phytoplankton uptake in Suisun Bay (from Wilkerson et al. 2007)

mmolm^{-2}d^{-1}
0.49-1.2

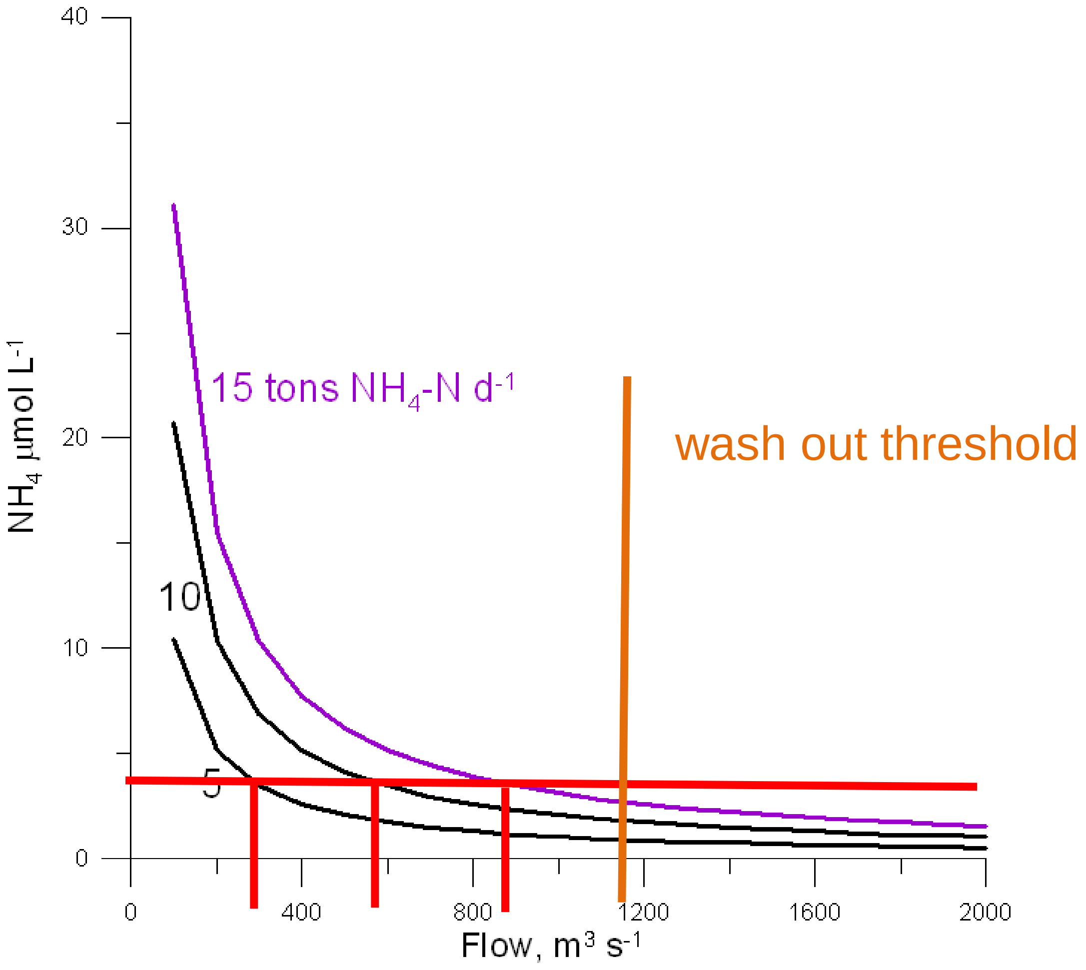
Loading must be less than phytoplankton uptake capacity (or NH_4 concentration will increase)

Comparing basin dilution with phytoplankton growth rate on NH_4



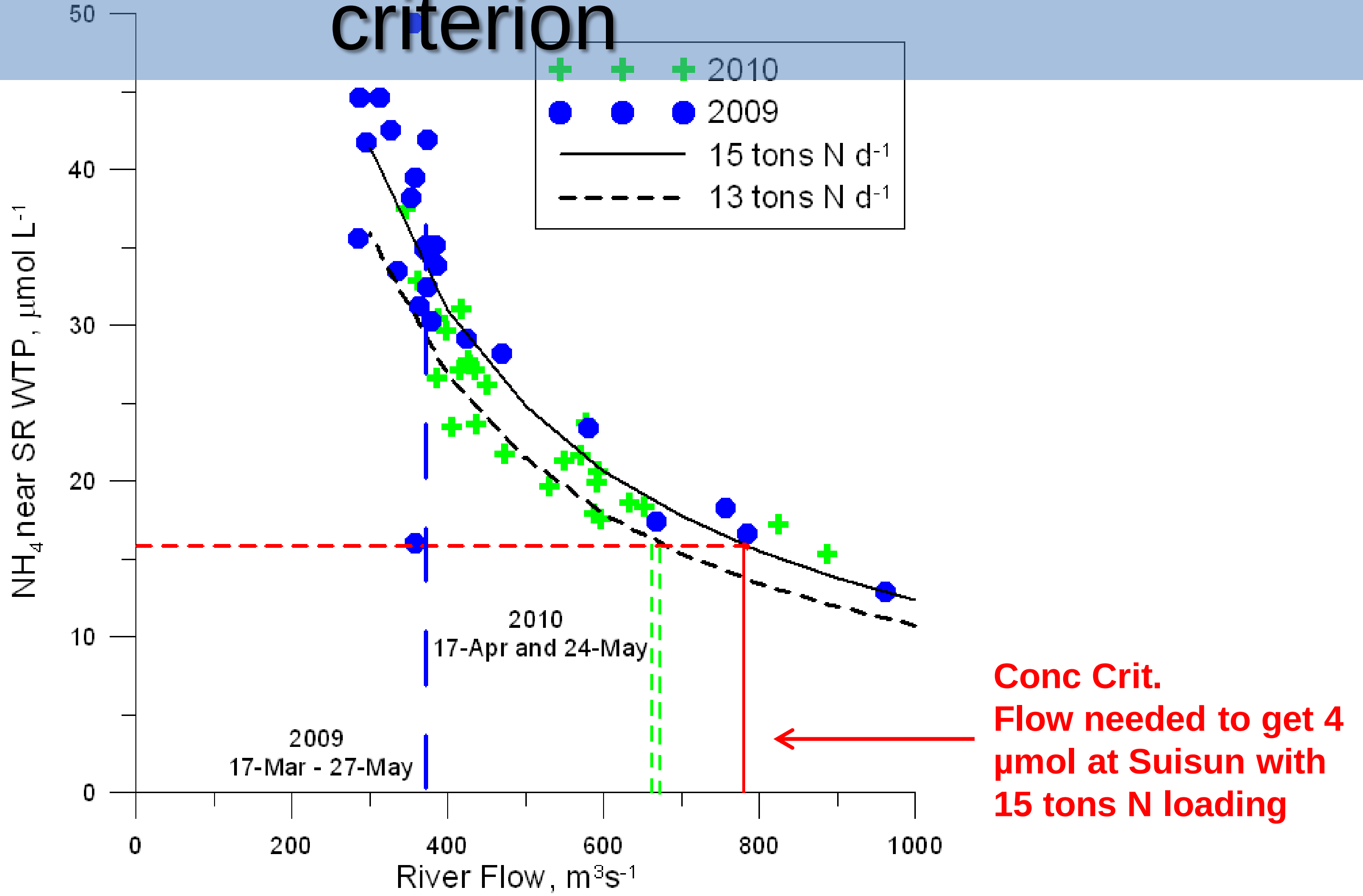
Basin dilution no greater than phytoplankton growth rate (or will washout)

Threshold flows required for 4 µmol L^{-1} NH_4 at Suisun with different NH_4 loading (5-15 tons d^{-1})



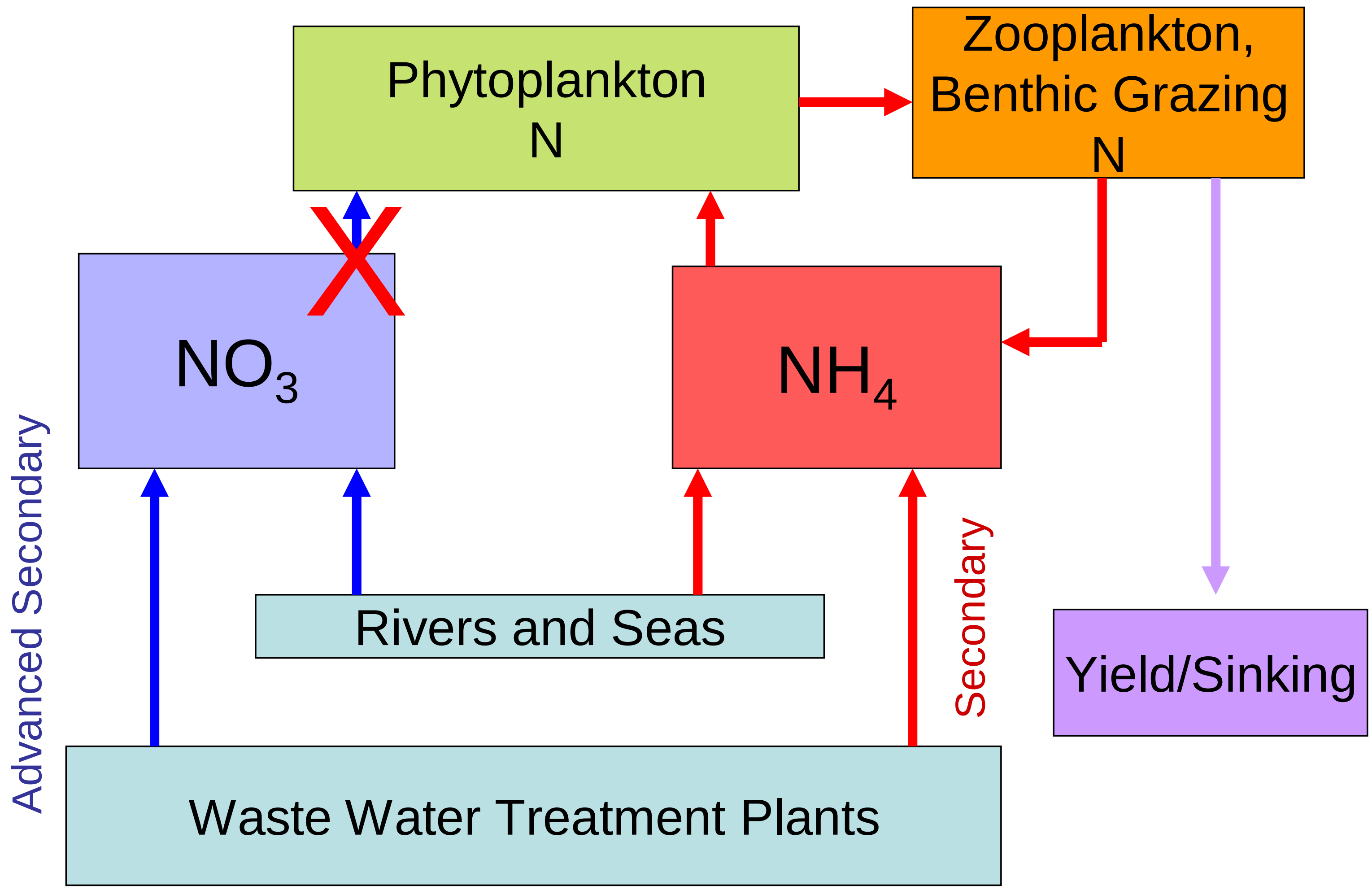
With increasing loads the flow window gets smaller.
With 15 tons N loading, flows need to be between ~825 and ~1100 m^3 s^{-1}

NH_4 in the river at the WTP vs. river flow with curves showing relationship for different N loadings with the 4 µmol L^{-1} concentration criterion



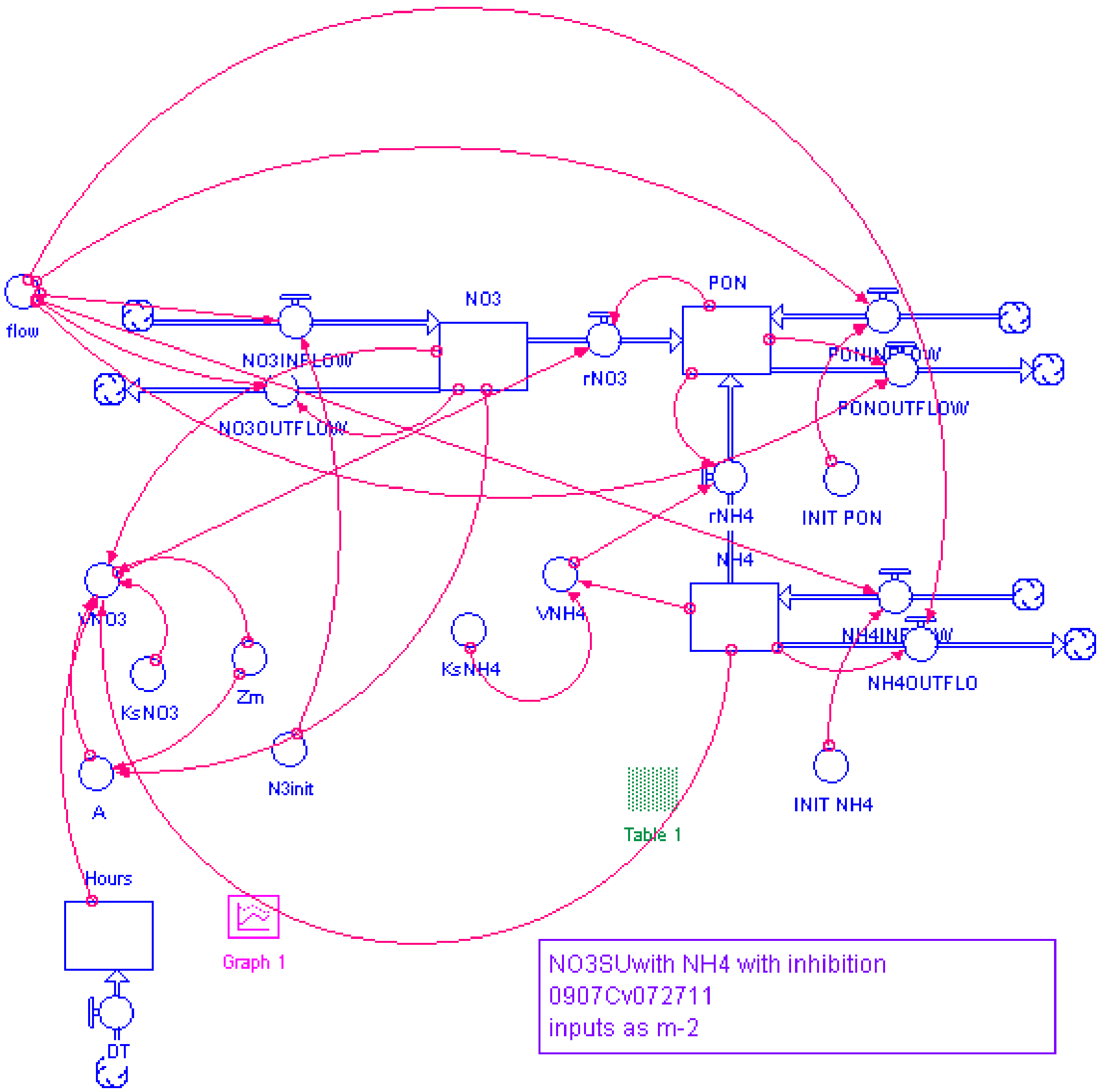
Flow during 2010 blooms was sufficient to meet the concentration criterion of 4 µmol at Suisun with ~13 tons N loading.
Flow too low in 2009

Simplified Estuarine N Cycle



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

Suisun Bay NH_4/NO_3 model to describe NH_4 and NO_3 interactions



Basic Equations

NH4 uptake,
Michaelis Menten
$VNH_4 = V_{maxNH4} * NH_4/(NH_4 + K_S)$

NO_3 uptake,
1)Acceleration kinetics
$VNO_3 = NO_3(i) + A*t$
$A = 4 \times 10^{-5} * NO_3 + 4 \times 10^{-5}$
2) Inhibition by NH_4,
$VNO_3 * \exp^{-5.59*NH4}$

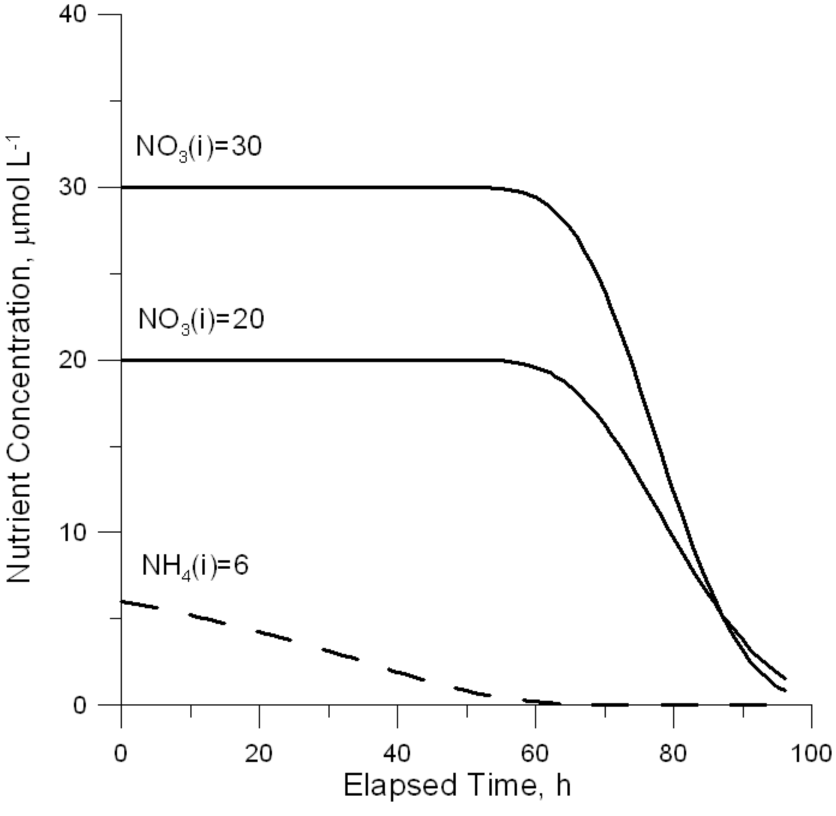
Model can be run in 3 modes:

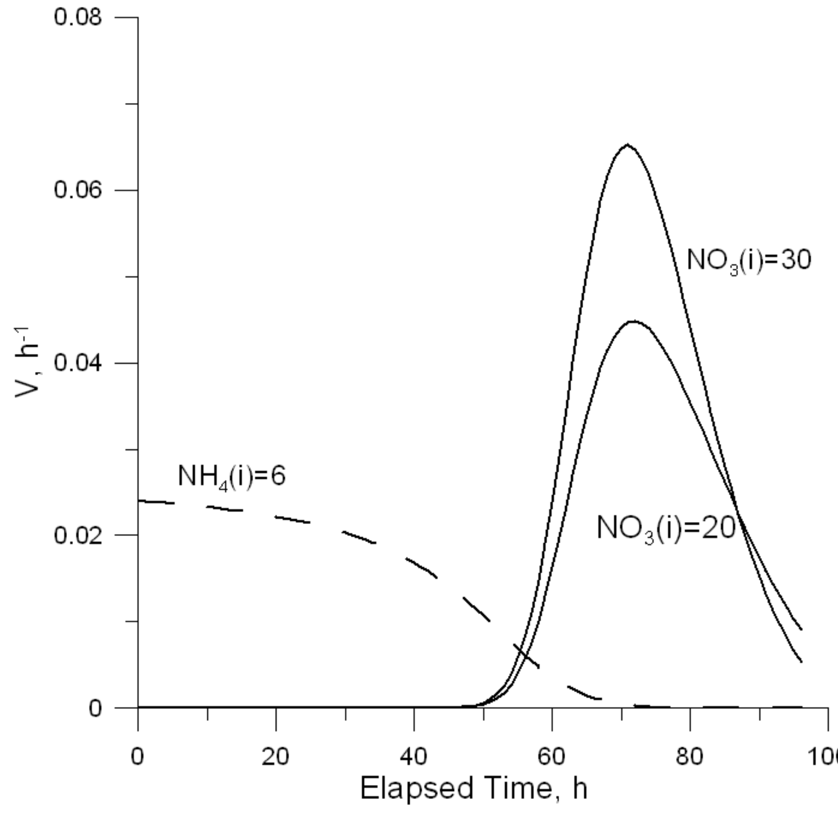
1) Flow set to 0, simulates enclosure experiments

2) Flow set to proportion of volume, simulates a fully mixed bay

3) Flow set to proportion of volume, inputs are as surface area integrated values, Simulates fully mixed bay with phytoplankton productivity restricted by irradiance

1) Flow set to 0, simulates enclosure experiments

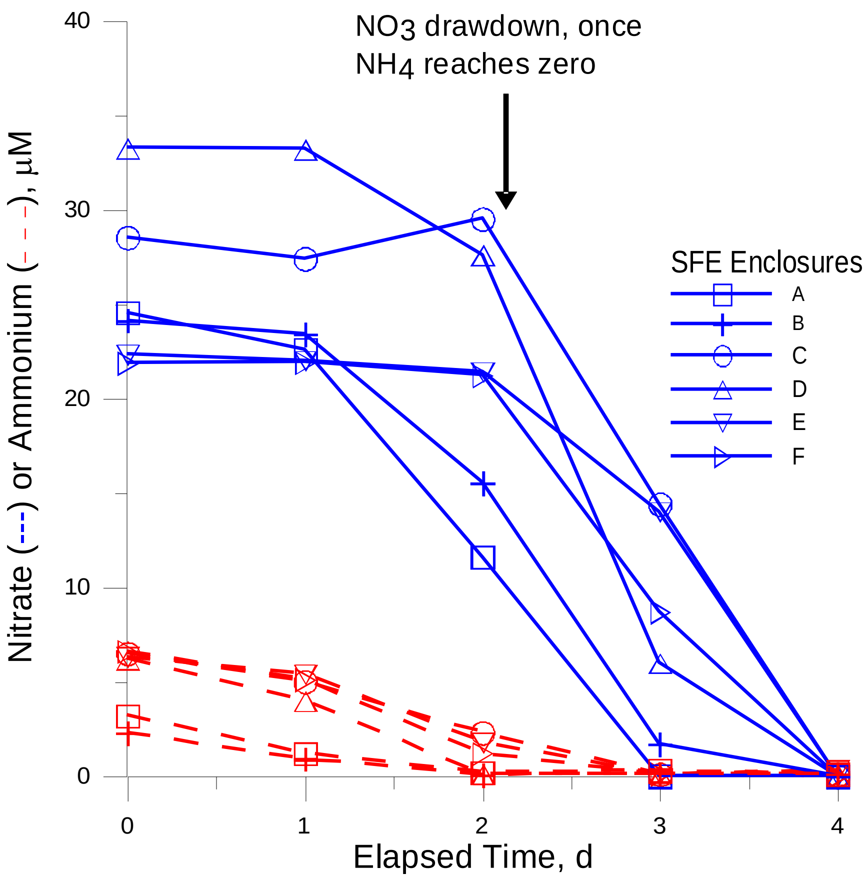


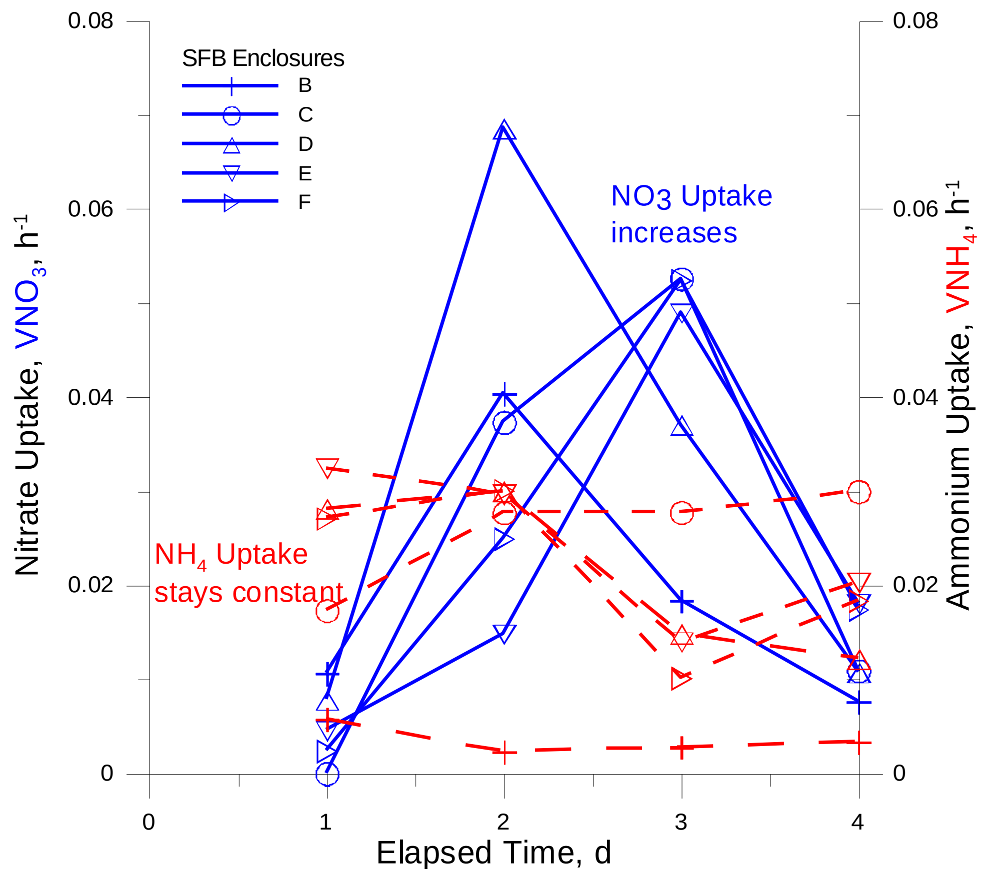


Nitrate drawdown starts once NH_4 is reduced below inhibitory values

Nitrate uptake exceeds ammonium uptake

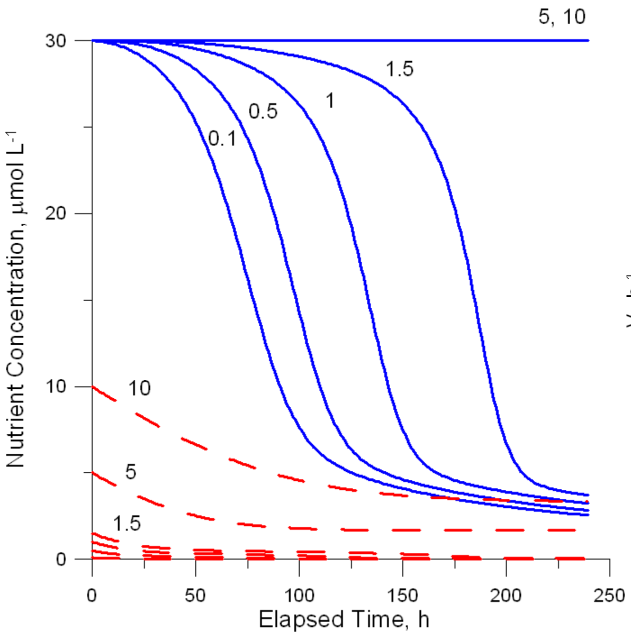
Central Bay Enclosures



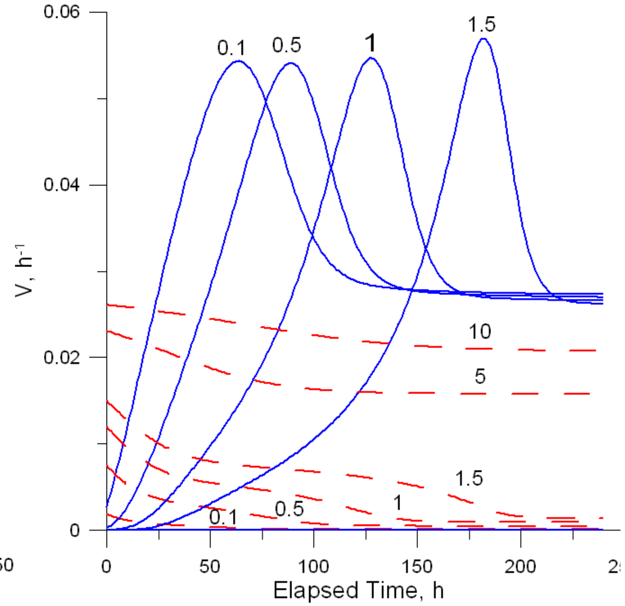


Dugdale et al. 2007

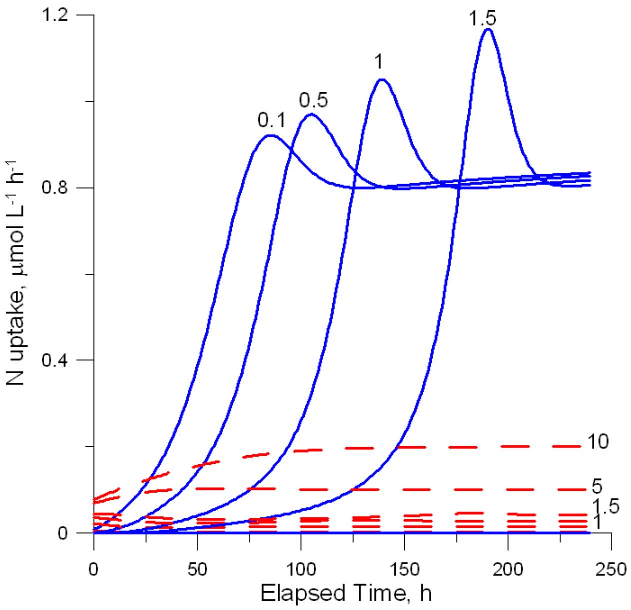
2) Flow set to proportion of volume, simulates a fully mixed bay



Ammonium and Nitrate Drawdown



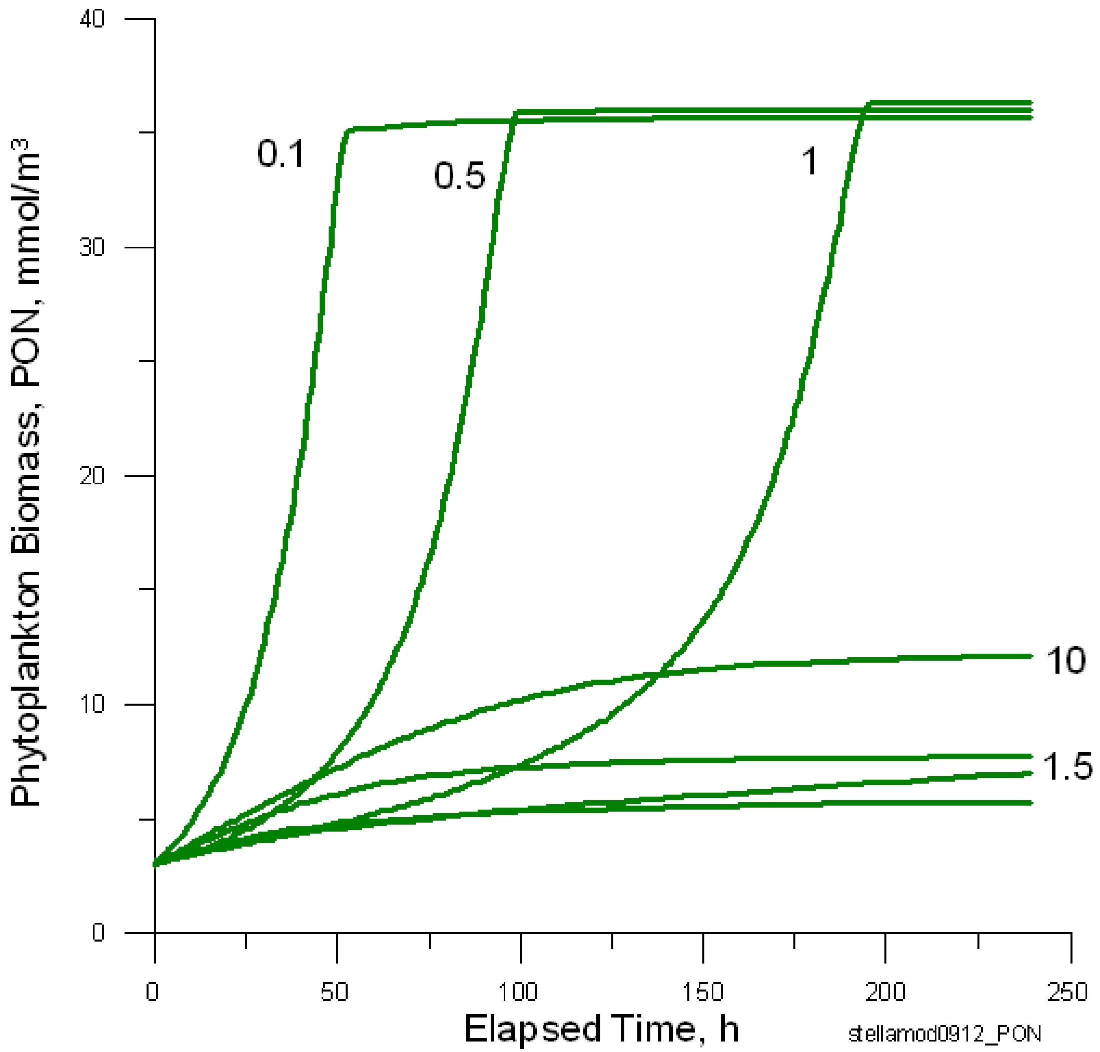
Growth on Ammonium and Nitrate



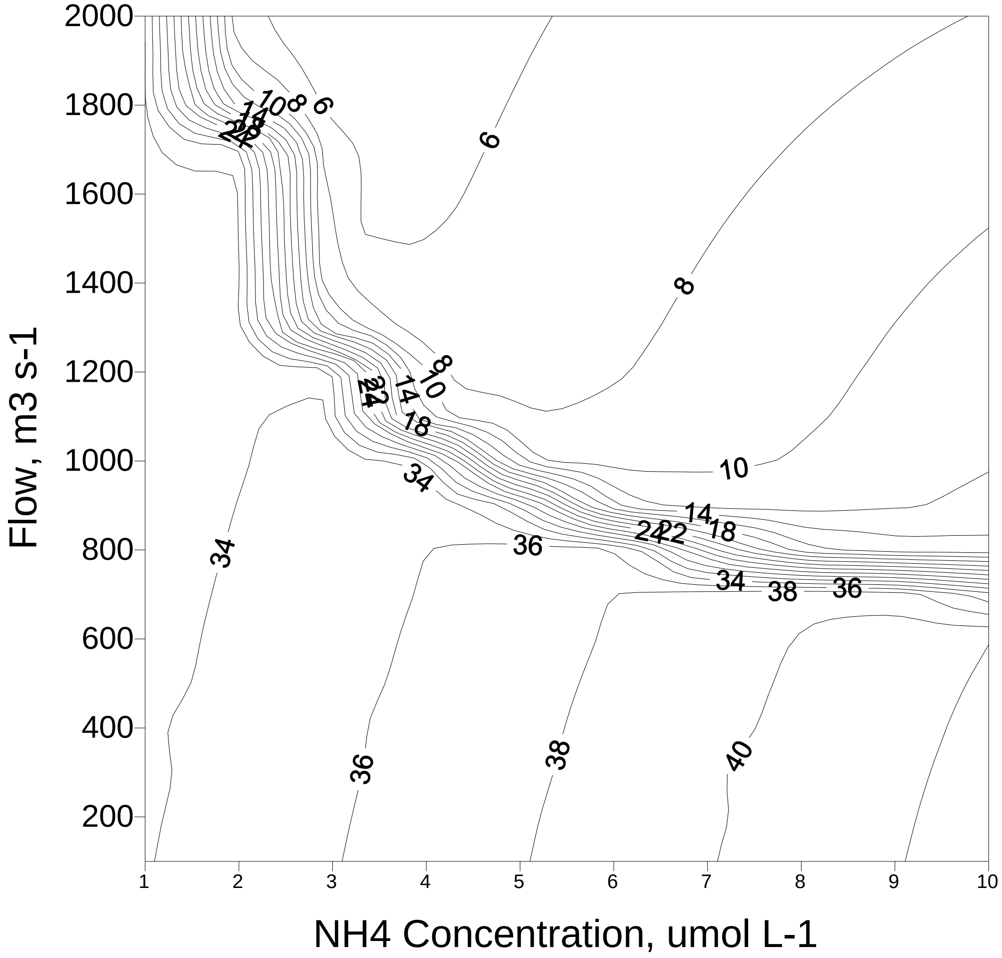
Ammonium and Nitrate Uptake

Numbers are increasing inflowing ammonium concentrations

2) Flow set to proportion of volume, simulates a fully mixed bay: two states of biomass accumulation

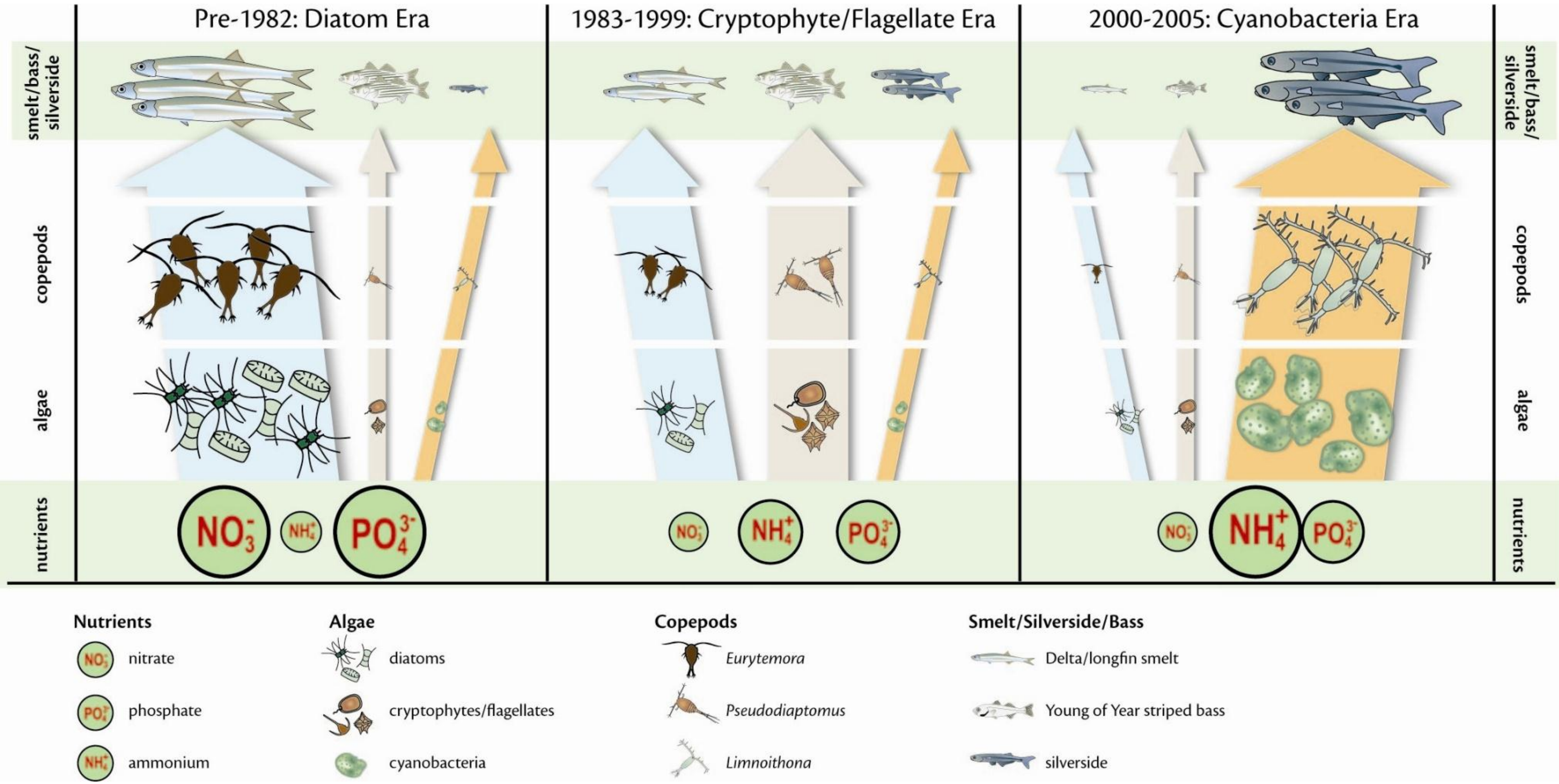


3) Flow set to proportion of volume, inputs are as surface area integrated values, simulates fully mixed bay with phytoplankton productivity restricted by irradiance



Sharp boundaries in biomass (the contours) at critical flow and NH_4 interactions

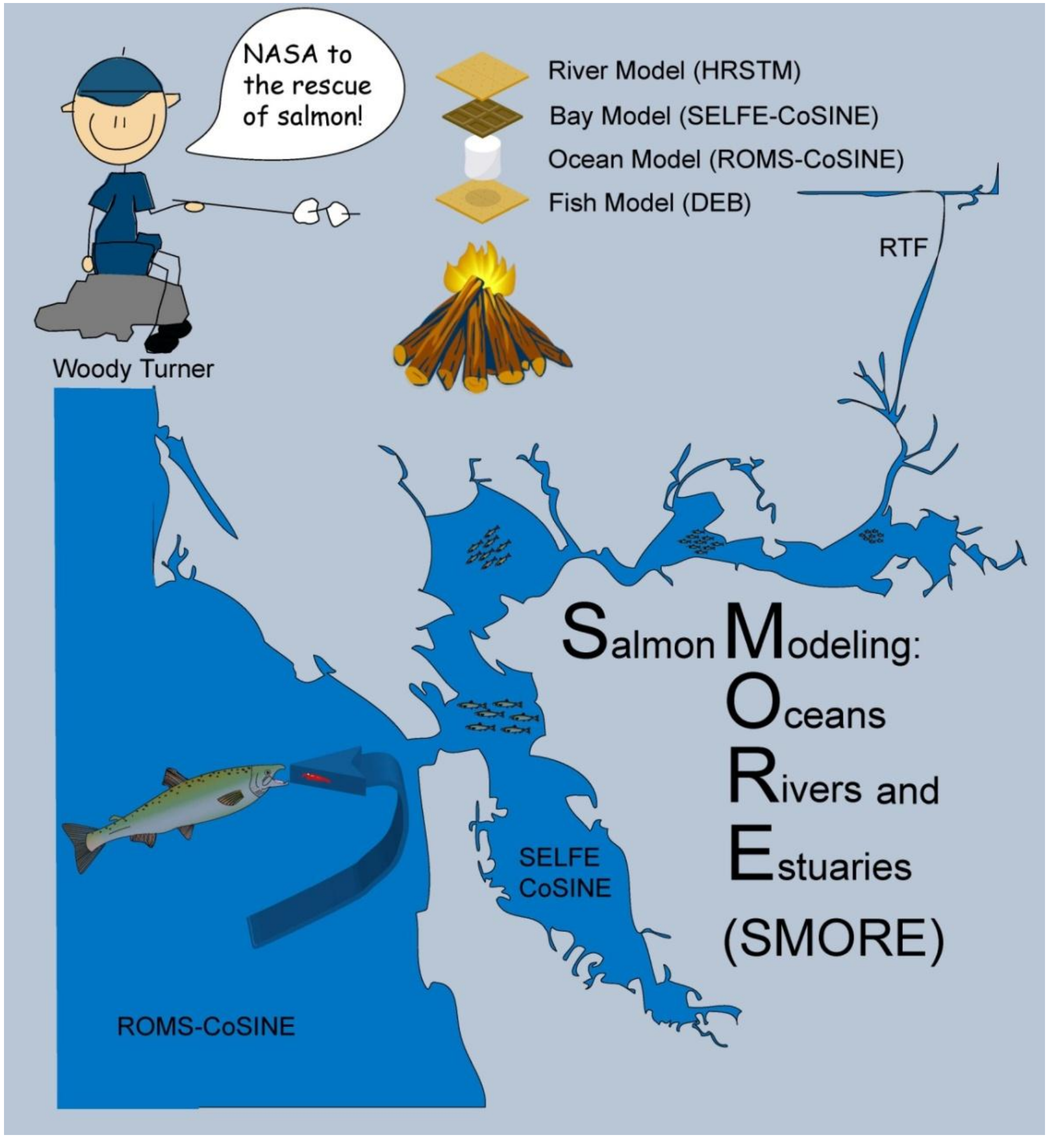
Nutrient stoichiometric model
With increasing NH_4 and decrease in PO_4, the phytoplankton and food webs have changed



Increasing contribution by NH_4

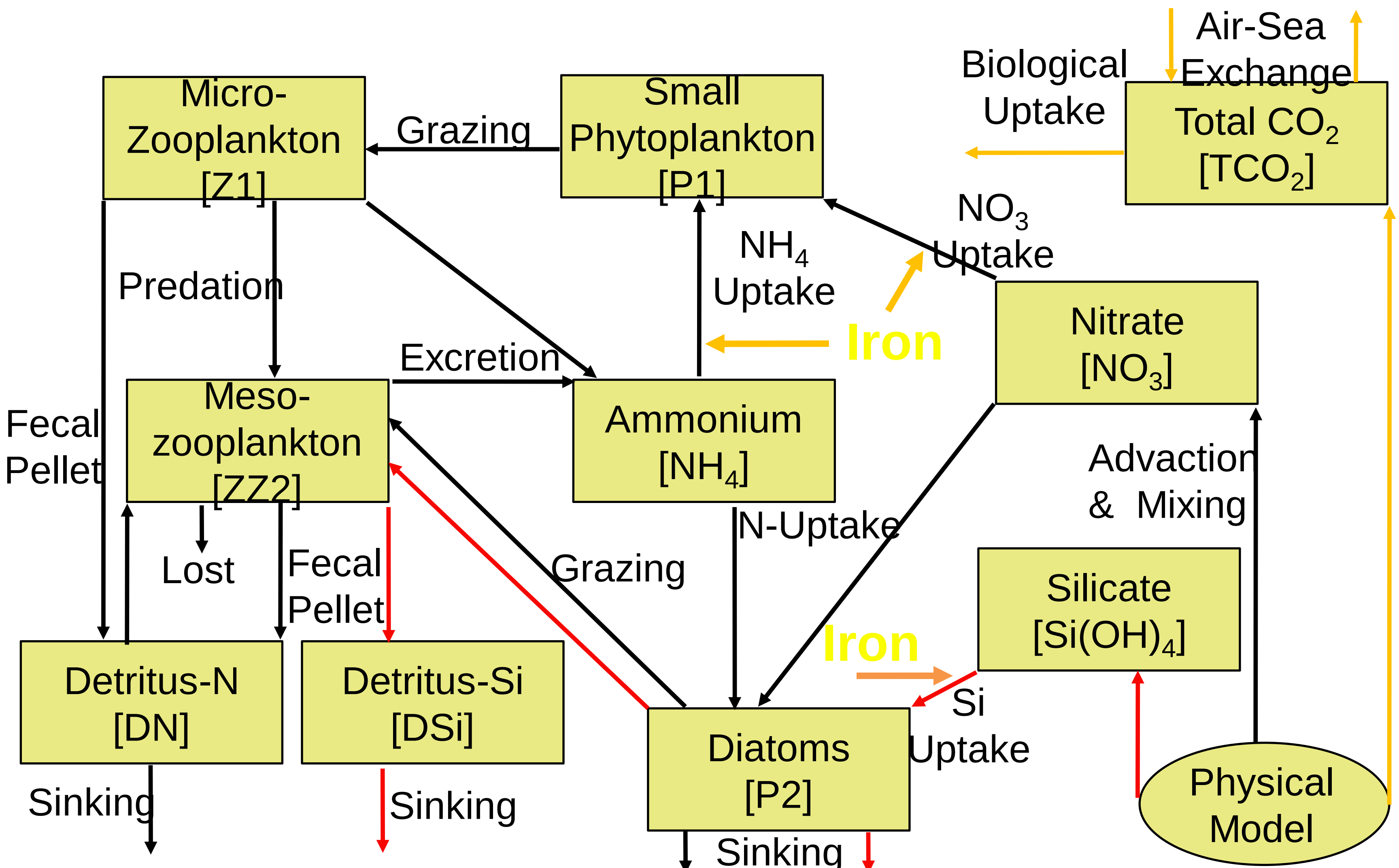
Glibert, 2010

SMORE salmon model: new project to combine a lot of models to simulate salmon success from egg to adult



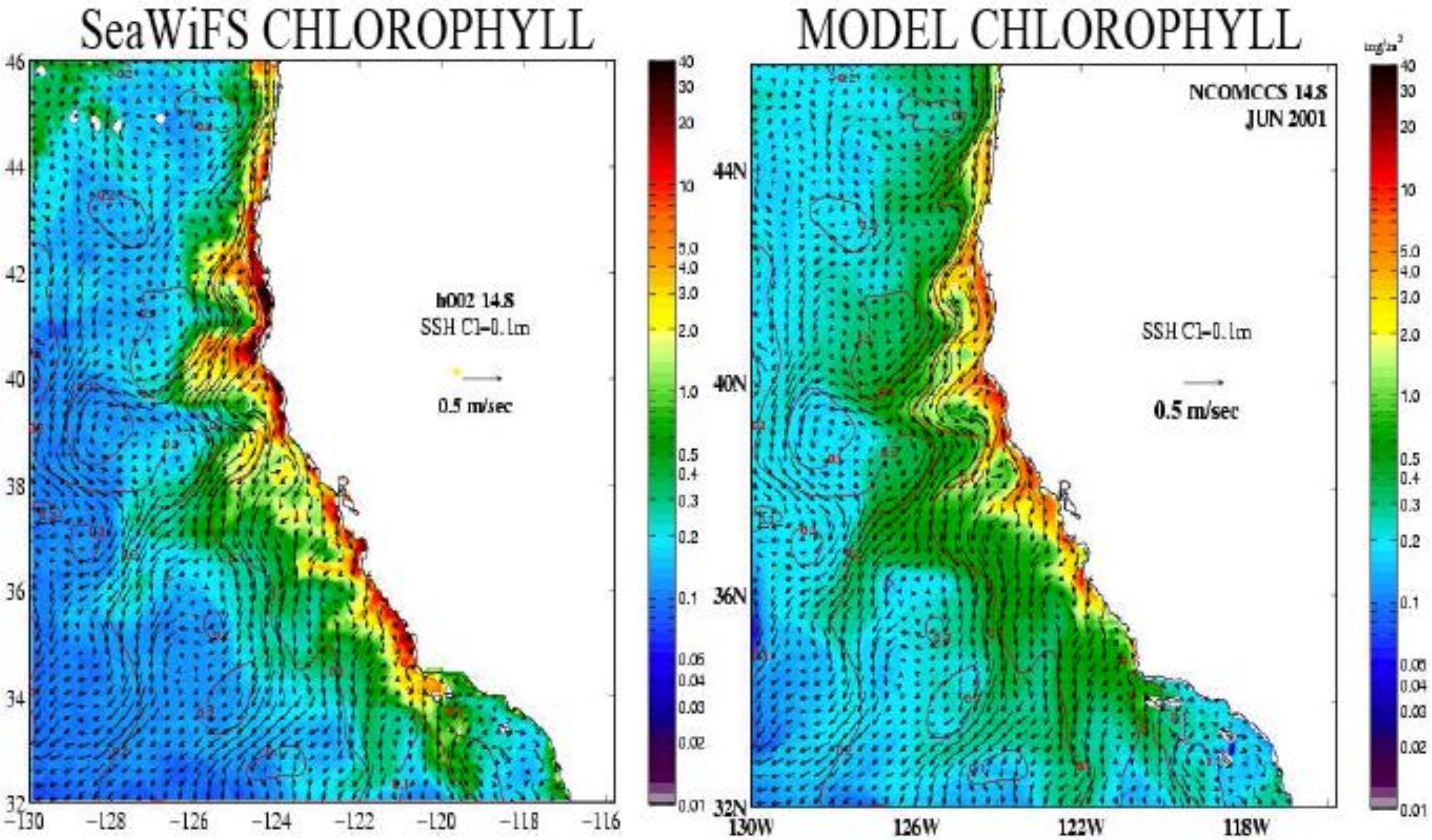
The lower trophic model to be used will be CoSiNE which will need to be modified for the estuary and rivers

Carbon, Silicate, Nitrogen Ecosystem Model* *CoSiNE,



Chai et al. 2002; Dugdale et al. 2002

Example of CoSiNE/NCOMCCS in Coastal Ocean



Chao, Chai and Dugdale

Acknowledgements

- Calfed/Delta Science Program
- InterEcological Agency
- State and Federal Water Contractors
- San Francisco Bay Regional Water Quality Board
- Central Valley Regional Water Quality Board

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