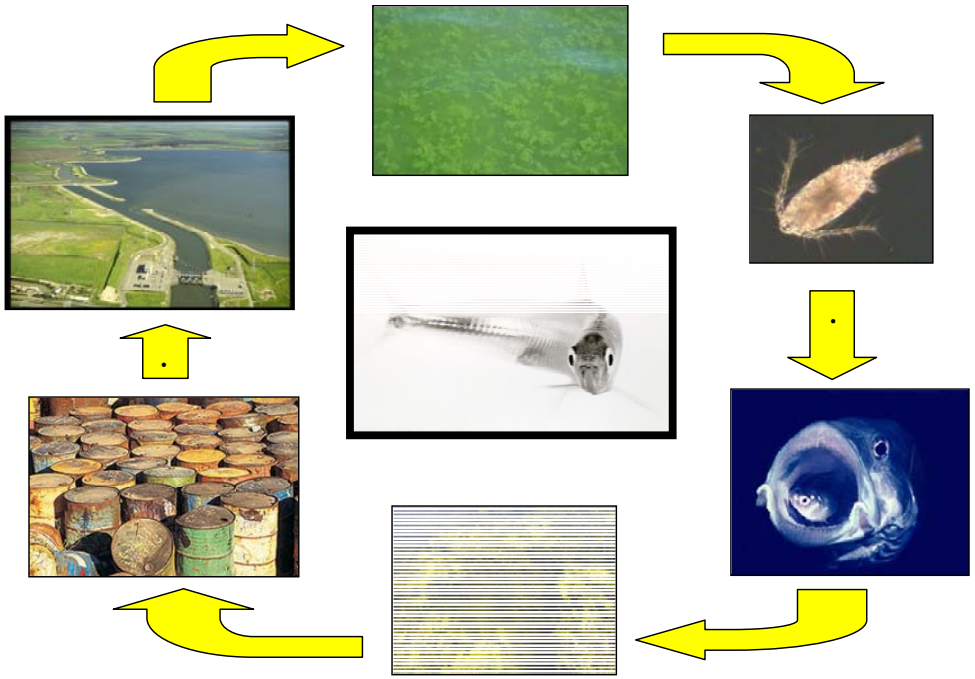
IEP, POD, and Ammonia/um Studies in the San Francisco Estuary – A Summary



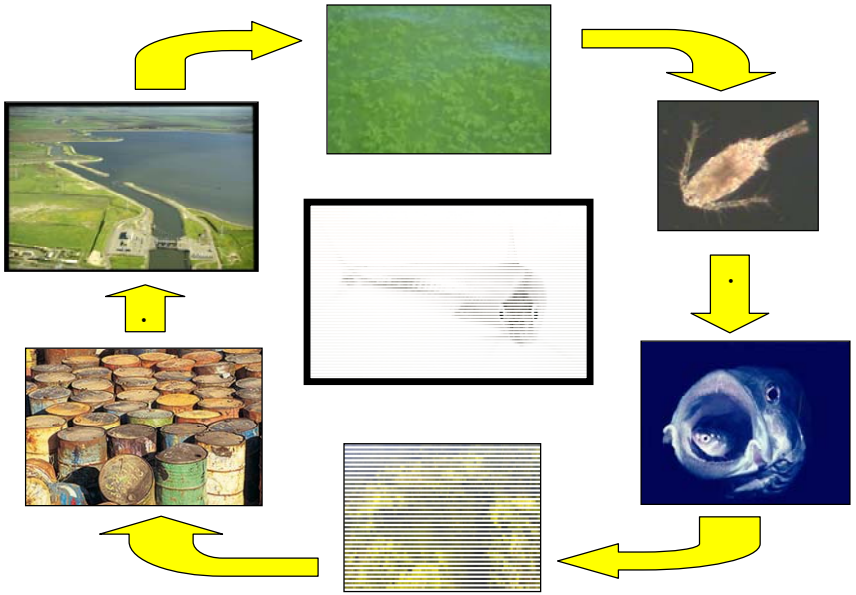
Anke Mueller-Solger

IEP Lead Scientist & POD Management Team

CALFED Science Program

Talk Outline:

1. IEP
2. POD
3. Ammonia/um Investigations



1. IEP: Interagency Ecological Program

- Founded in 1970
- 9 +2 member agencies
- http://www.iep.ca.gov/
- Monitoring & Studies
- Mission: "*Provide ecological information … for more efficient management of the San Francisco estuary.*"
- 2009 budget: ~$33 million
- Geographic focus on Delta & Suisun Bay

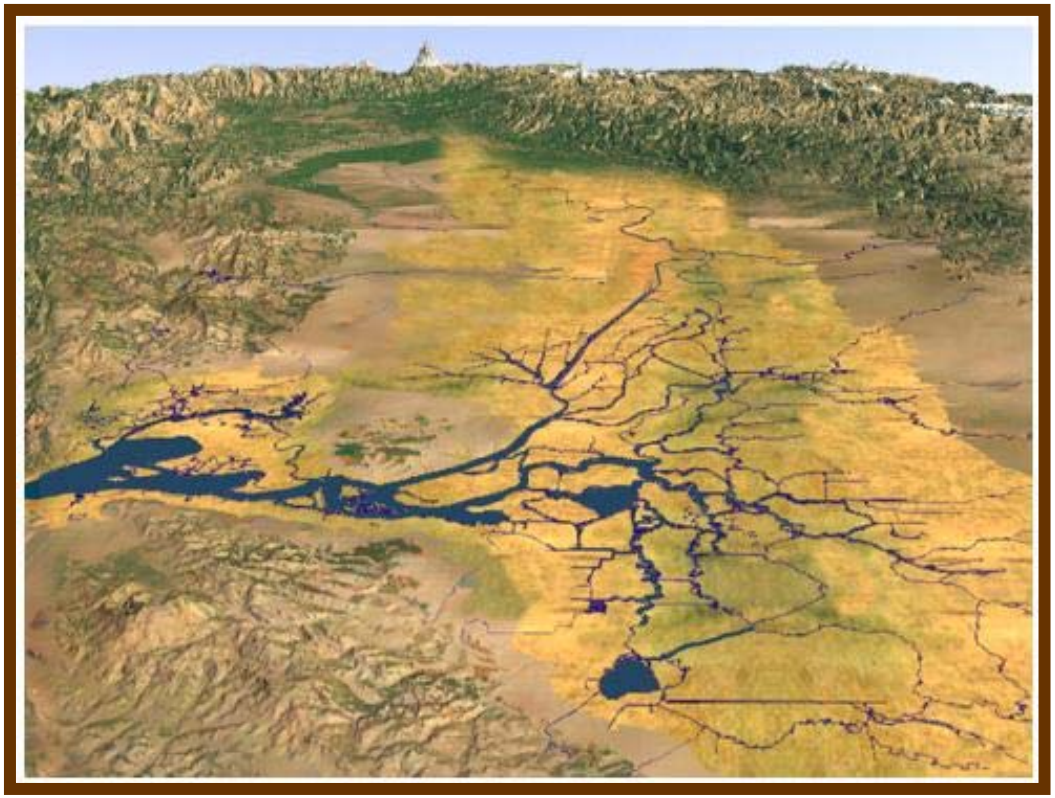
Why the Delta?

Interagency Ecological Program
Cooperative Ecological Investigations Since 1970

Important functions:

- Habitat (500+ species, crops, people)
- Hub for water conveyance & transportation
- Connection to ocean

Threatened & Degrading!



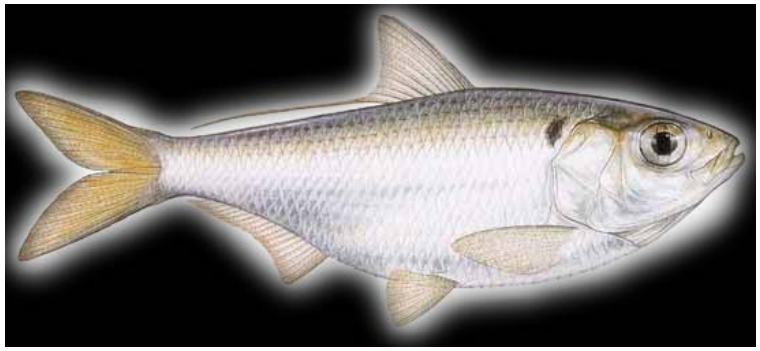
2. POD: Pelagic Organism Decline

Delta Smelt

Striped Bass

Longfin Smelt

Threadfin Shad



POD: Pelagic Organism Decline

Native

Delta Smelt

Striped Bass

Longfin Smelt

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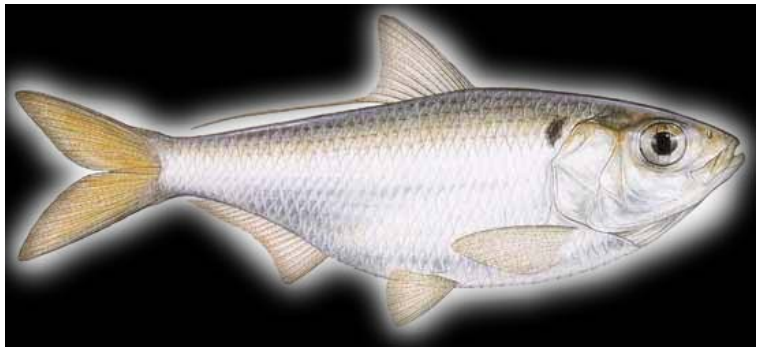


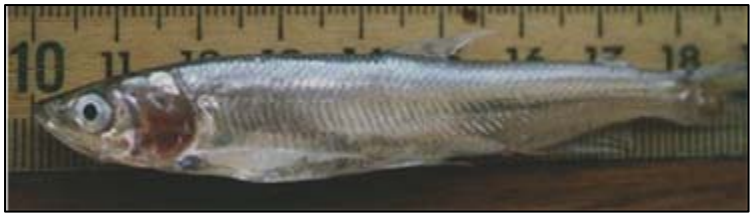
Just Last Week (March 4, 2009): CA Fish and Game Commission

Delta smelt

- ***Uplisted to Endangered***

Longfin smelt

- ***Listed as Threatened***



POD: Pelagic Organism Decline

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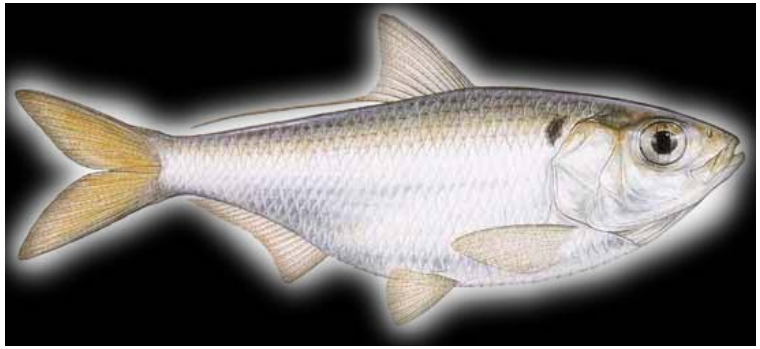
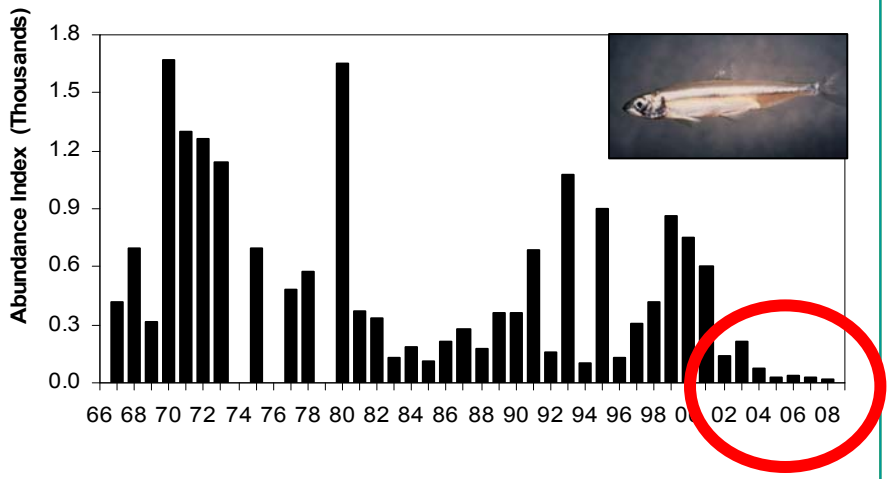


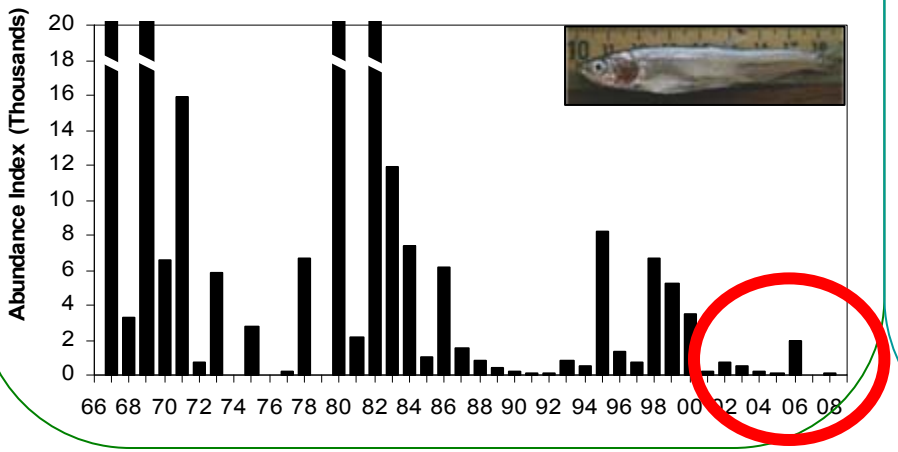
2. POD: Pelagic Organism Decline

Native

Delta Smelt

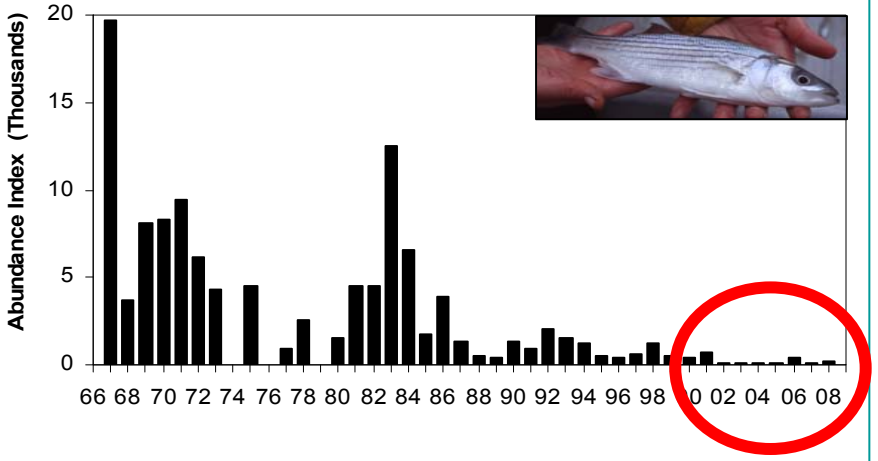


Longfin Smelt

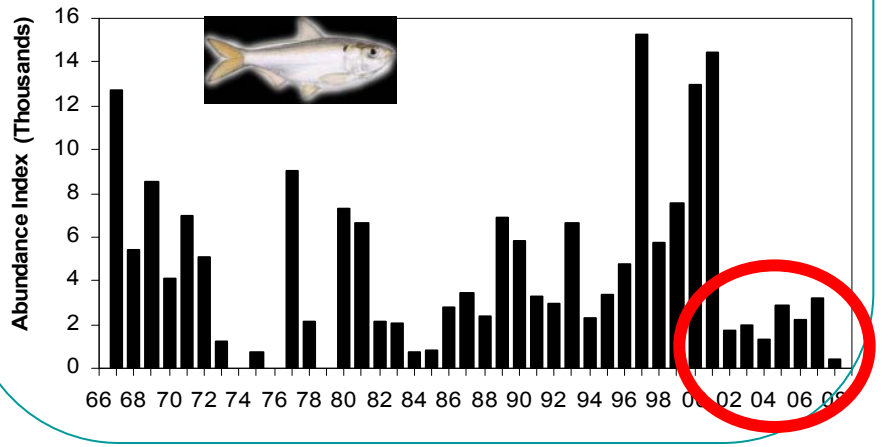


Non-Native

Striped Bass



Threadfin Shad

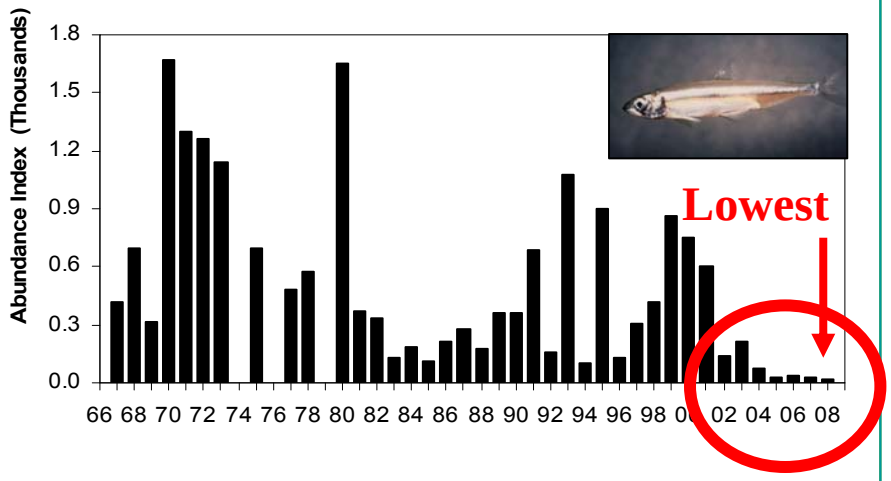


Source DFG 2008 Fall MW Trawl; No sampling 1974 and 1979

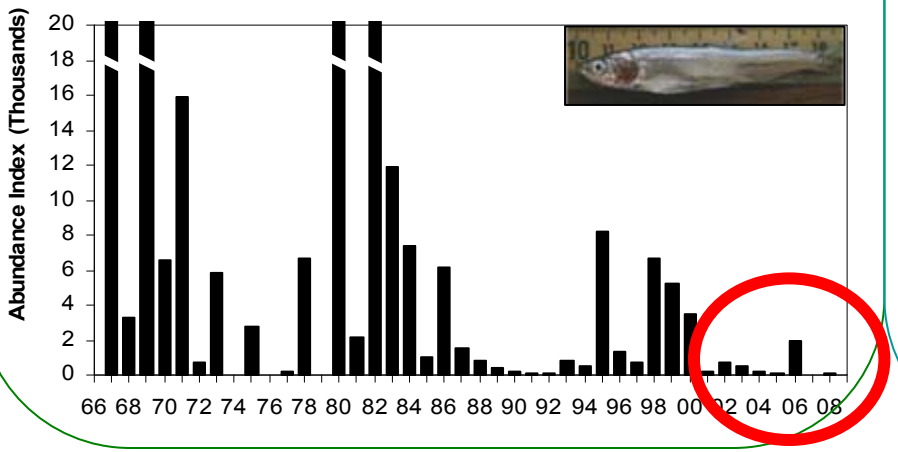
POD: Pelagic Organism Decline

Native

Delta Smelt



Longfin Smelt



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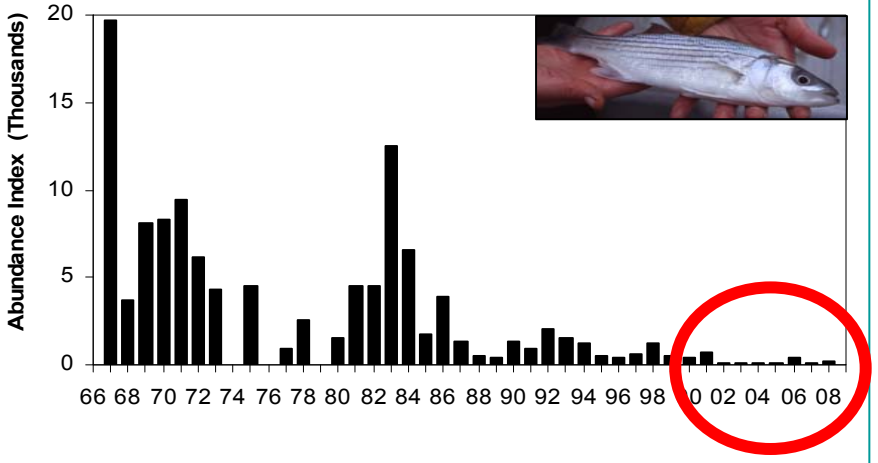

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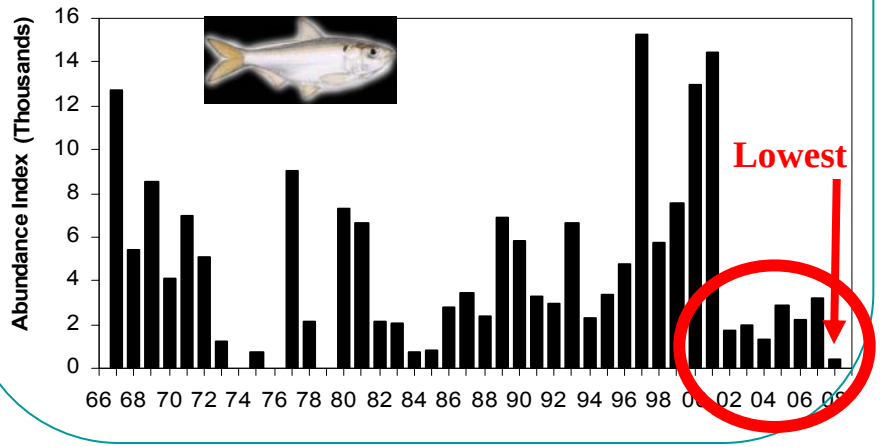


Source DFG 2008 Fall MW Trawl; No sampling 1974 and 1979

Public Spotlight

2005

Fish survey

Each year, scientists survey dozens of locations along the Delta, using a trawl net to capture a sampling of fish. The numbers at right are calculations of population density based on the average number of fish caught in a specified volume of water.

Copepods *Pseudodiaptomus forbesi* (all ages)

A type of zooplankton, copepods are usually 1 to 1.5 mm long and help form the bottom of the food chain in the Delta.

1,868

2004: 56

Source: California Department of Fish and Game

Delta smelt (all ages)

Typically living just one year, Delta smelt grow to about 4 inches.

1,673

414

2004: 74

Juvenile striped bass (up to 1 year old)

Striped bass grow to 18 inches, the legal minimum for anglers to keep, within three years and can grow to 4 feet and 70-plus pounds.

20,038

2004: 53

Sacramento Bee/Mitchell Brooks

DELTA DANGER

A decline in fish species and their food source is a reminder of a recurring worry in the West: A broad ecosystem collapse

By Matt Weiser
BEE STAFF WRITER

An unprecedented research effort is to make sense of an alarming plung Delta fish species. But some observers be a case of "too little, too late."

The $2 million research plan was pul in just five months by state and federal ter routine surveys in fall 2004 foun

Fortunes of a key Delta fish keep sinking

Members of Congress Seek Answers on Delta Fish Decline
by Dan Bacher *Thursday, May. 12, 2005 at 11:23 PM*
danielbacher@hotmail.com

Decline In Delta Forage Species Alarms Scientists

May 25, 2005
By Dan Bacher

Officials challenged over Delta smelt deaths

By Matt Weiser
BEE STAFF WRITER

The San Francisco Examiner

Opinion

Delta fish decline hints at water crisis

Viewpoint

By Los Angeles Times
Published: Wednesday, August 24, 2005 11:54 PM PDT

Delta smelt threatened

Delta smelt continue to decline, with the latest numbers from a June survey. The numbers are a measure of abundance relative to water volume, not an actual population count. The lowest numbers ever recorded for the native fish coincide with near-historic shipments of Delta water in three of the past five years.

62.5

32.5

12.1

No index

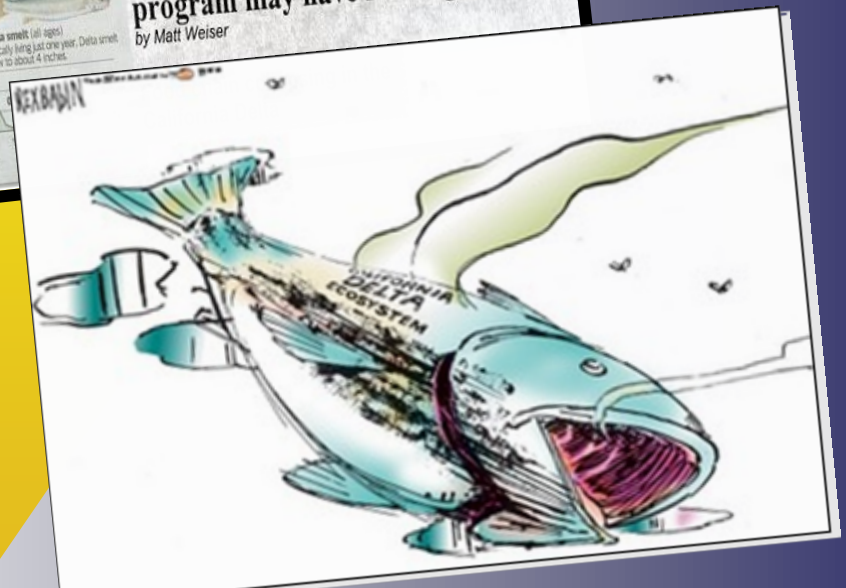
Delta smelt (all ages)
Typically living just one year, Delta smelt grow to about 4 inches.

Source: California Department of Fish and Game

WESTERN ROUNDUP - May 30, 2005

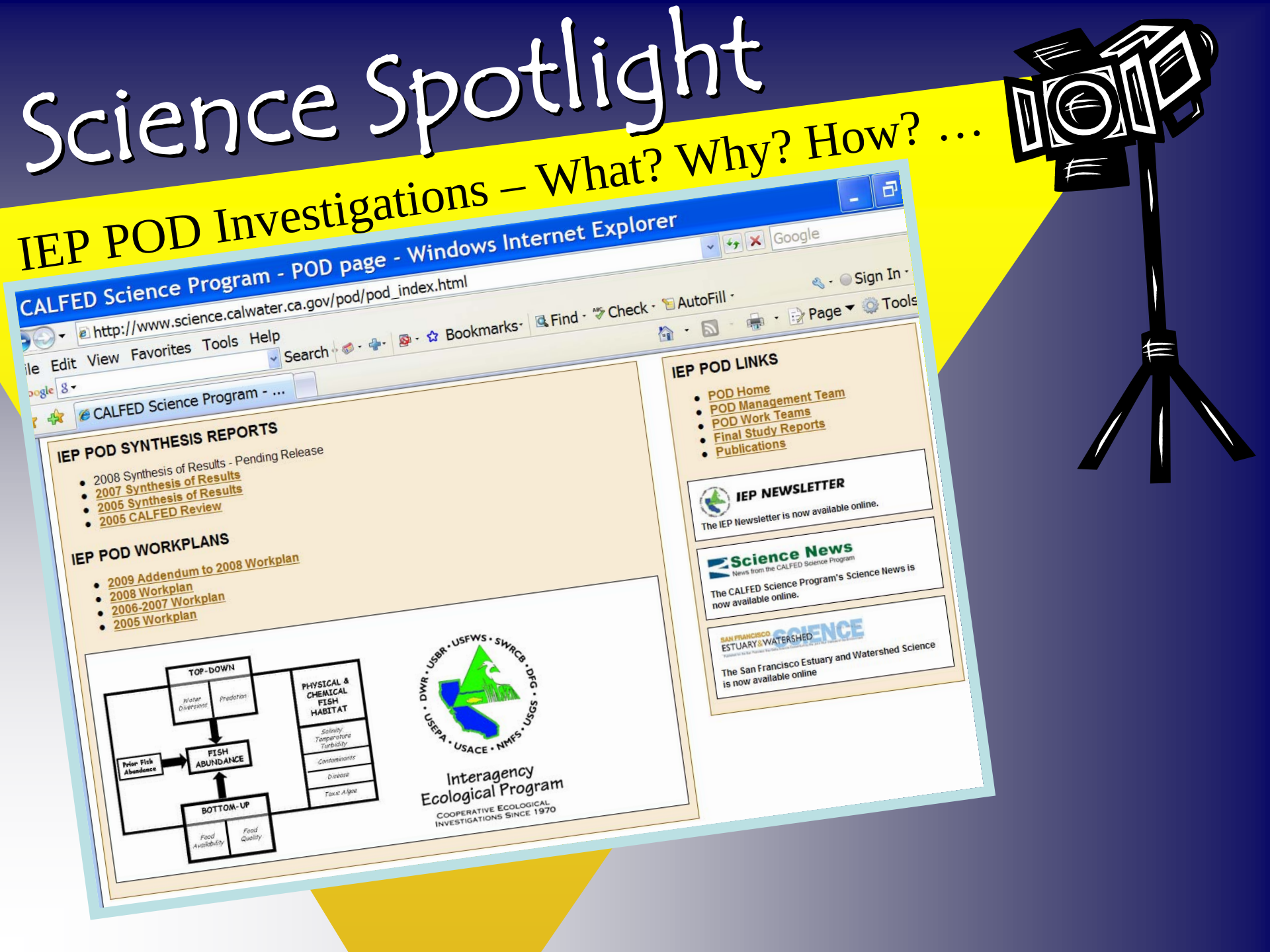
A massive restoration program may have nothing left to sav

by Matt Weiser



Science Spotlight

IEP POD Investigations – What? Why? How? …



Science Spotlight

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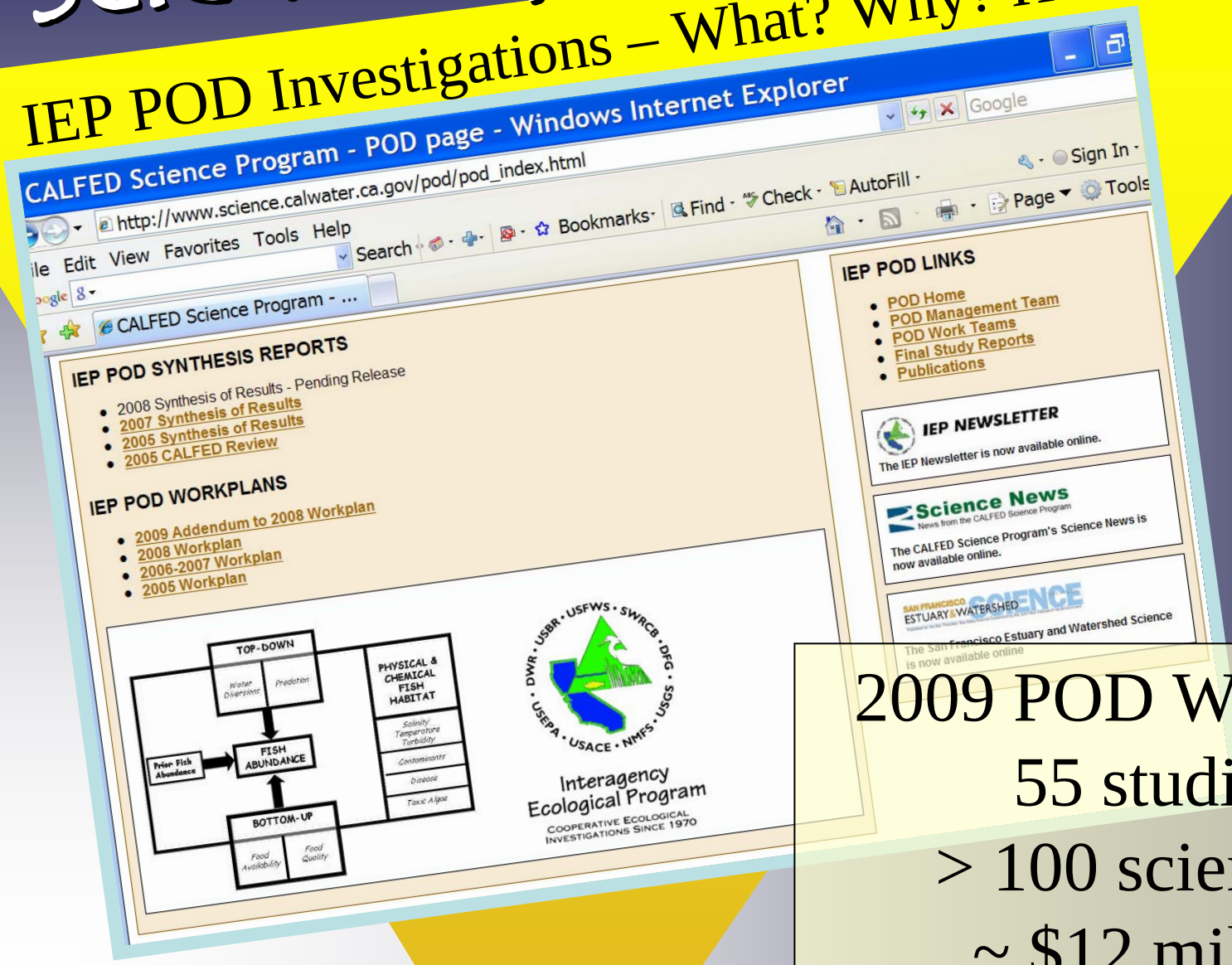
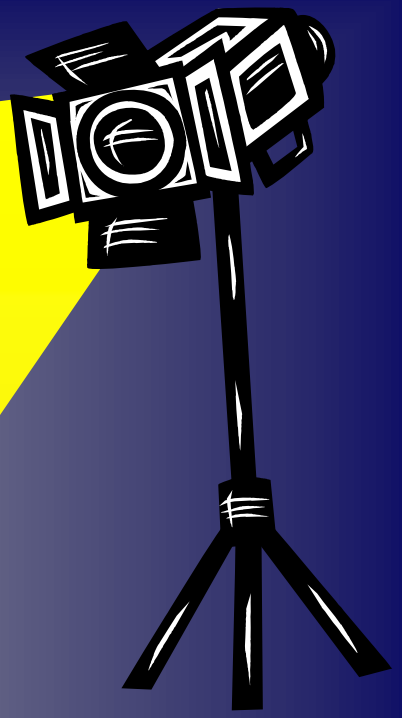




2009 POD Workplan:

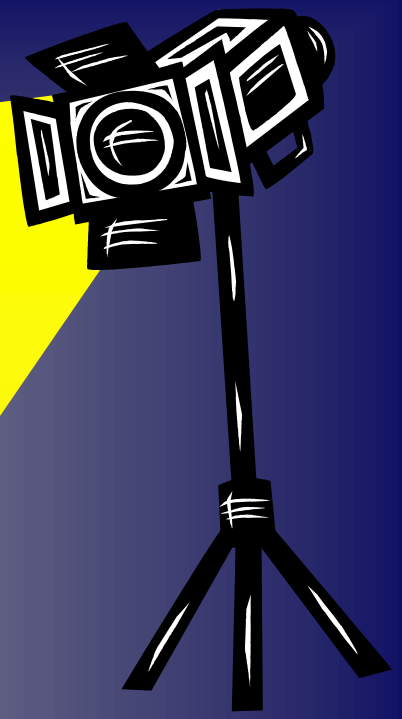
55 studies,

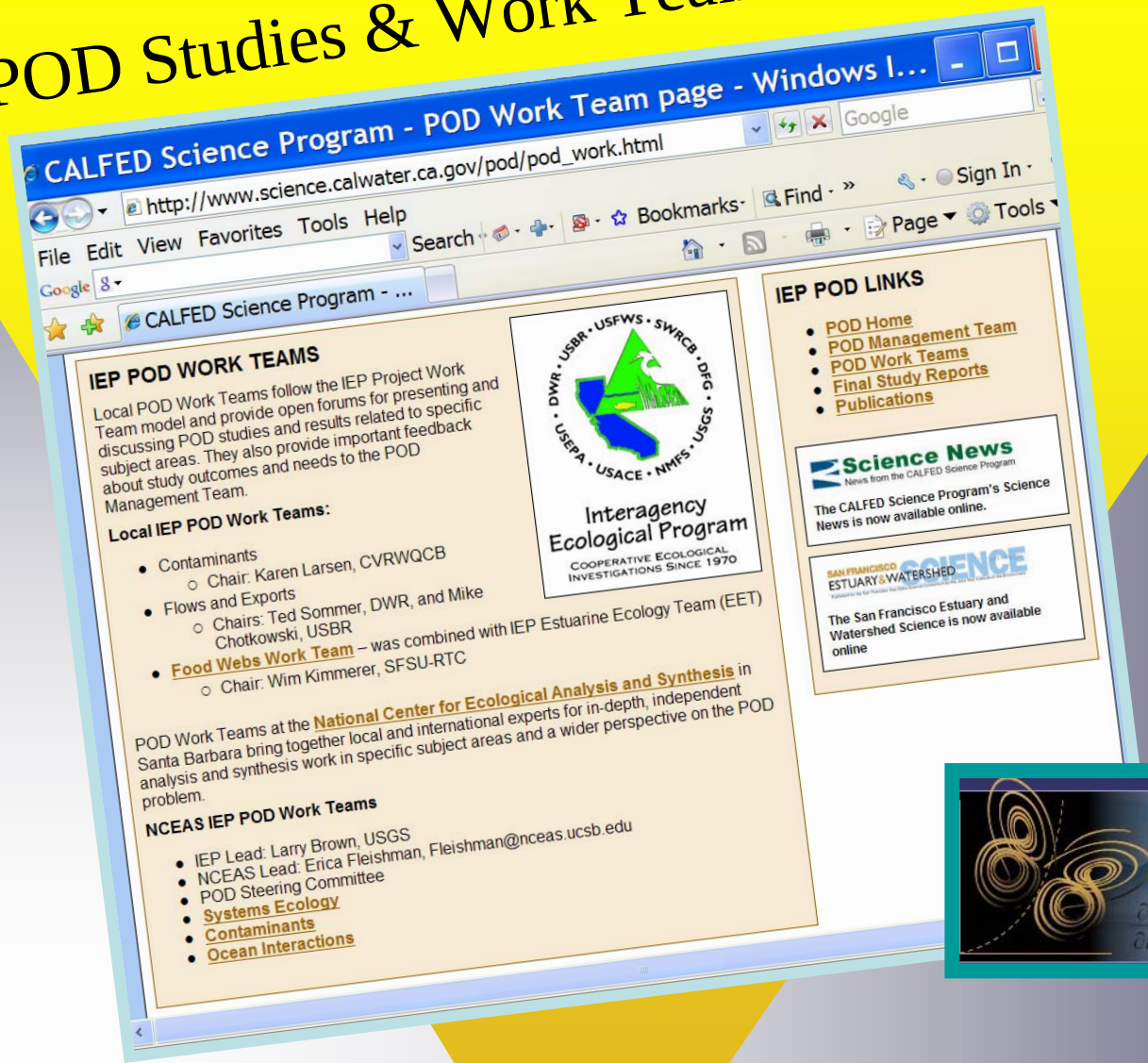
> 100 scientists,

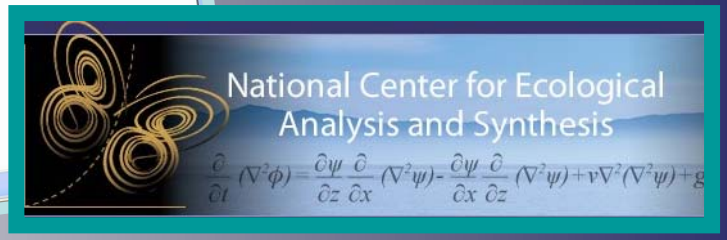
~ $12 million

Science Spotlight

POD Studies & Work Teams: Local & at NCEAS

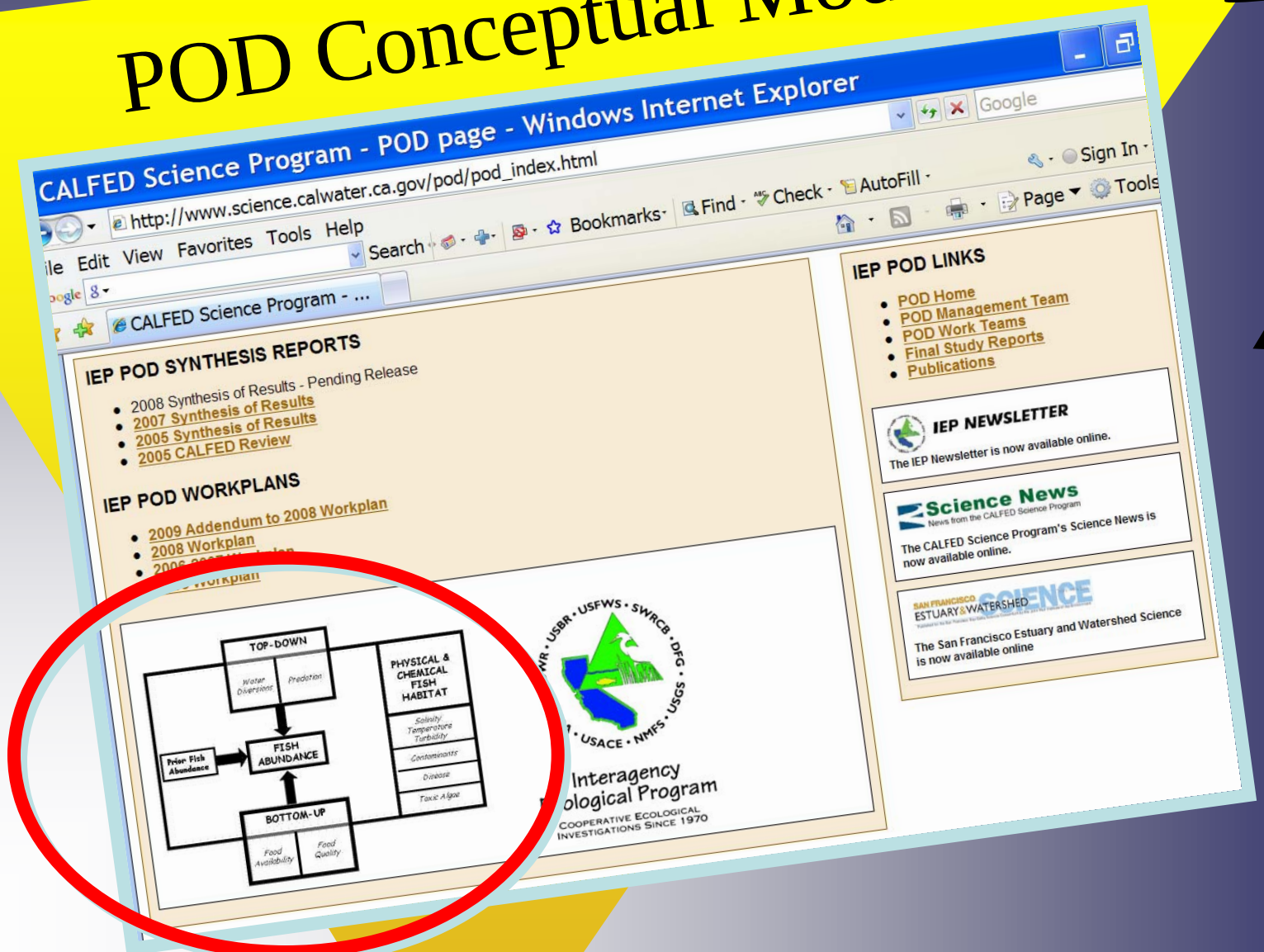


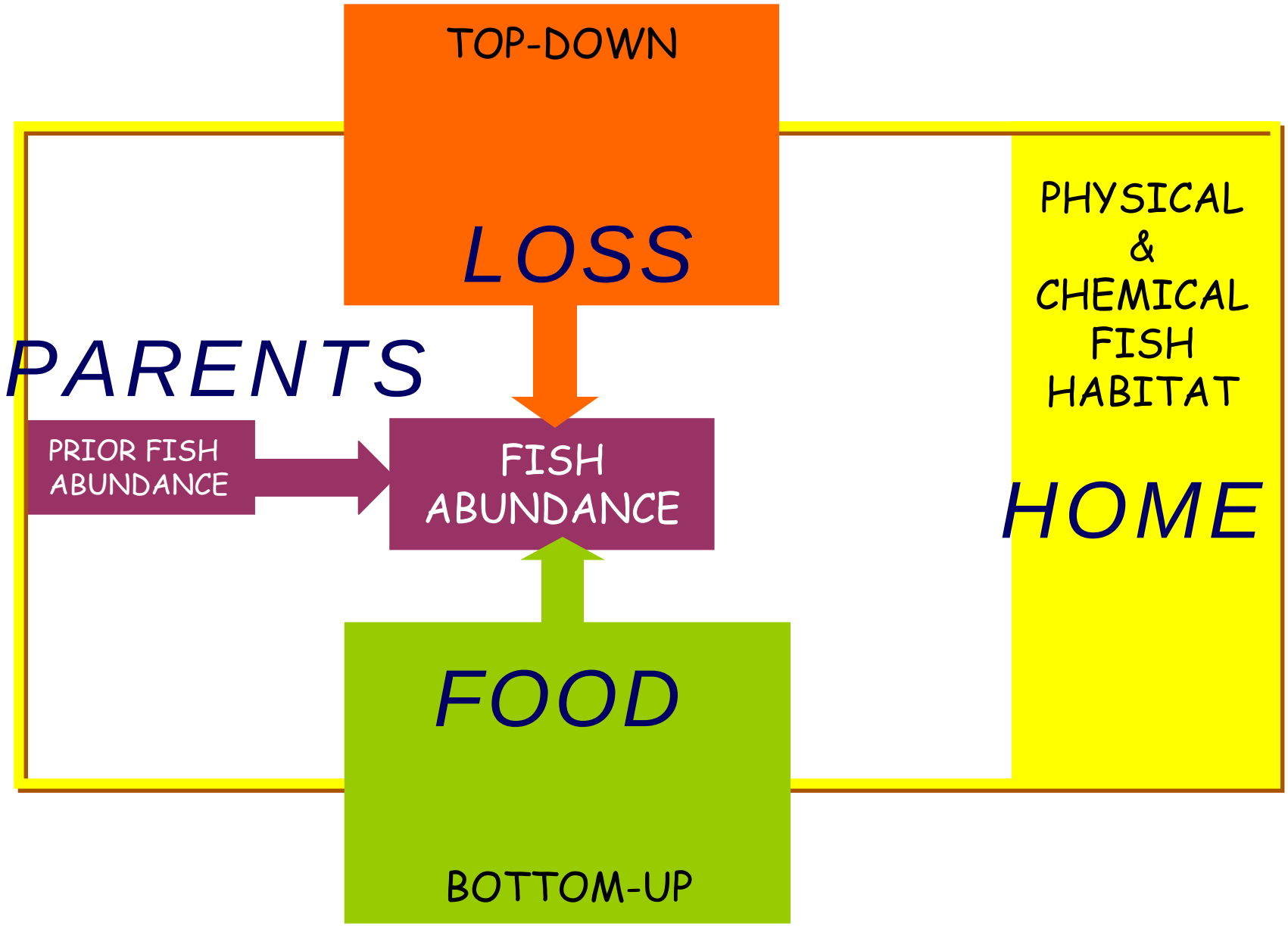


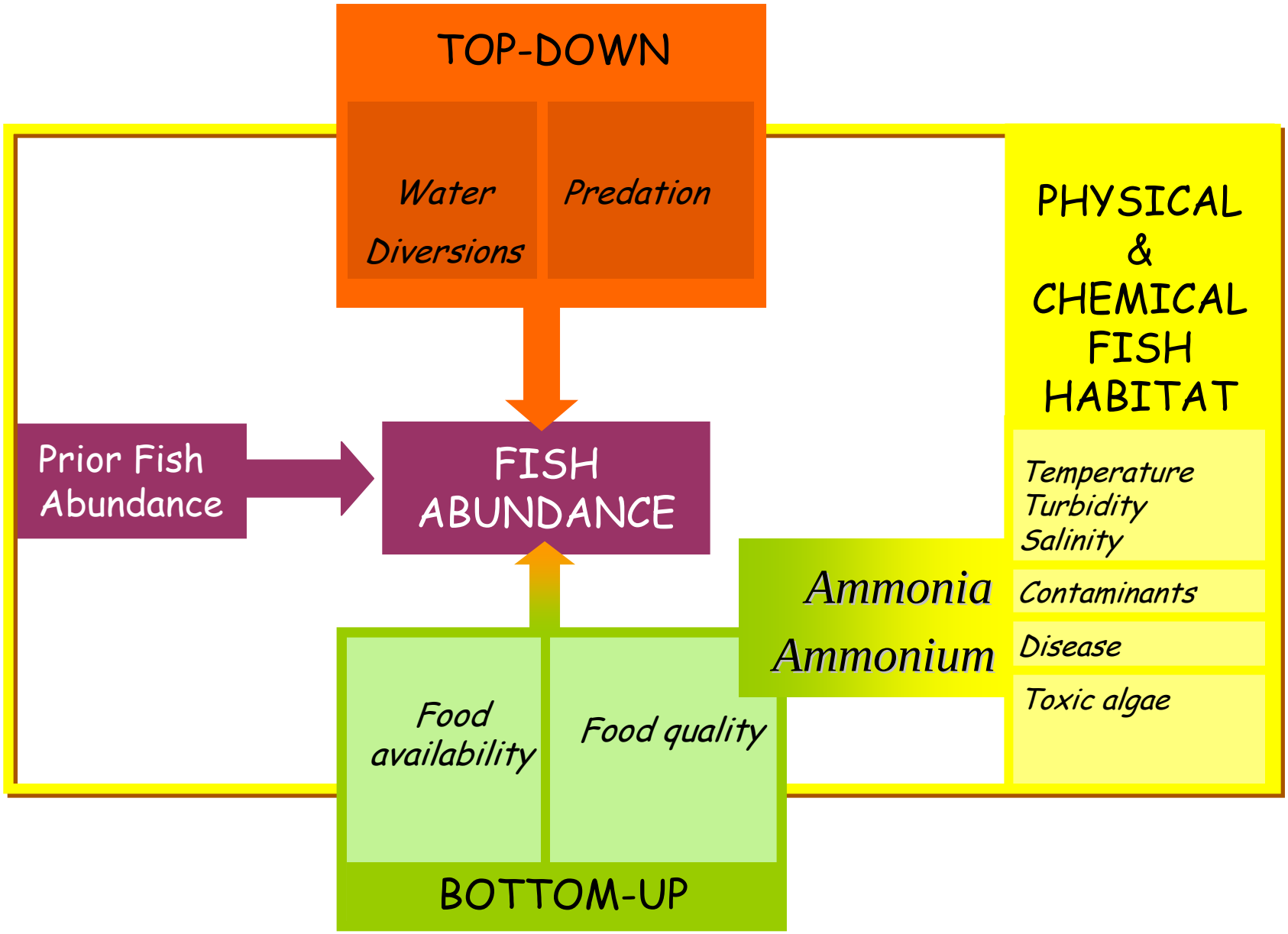


Science Spotlight

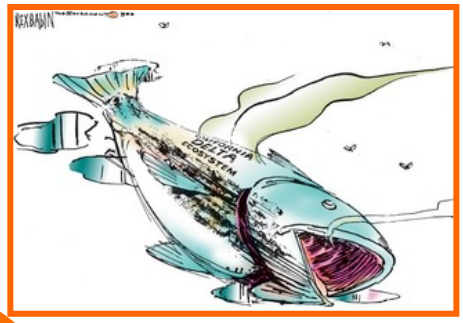
POD Conceptual Model

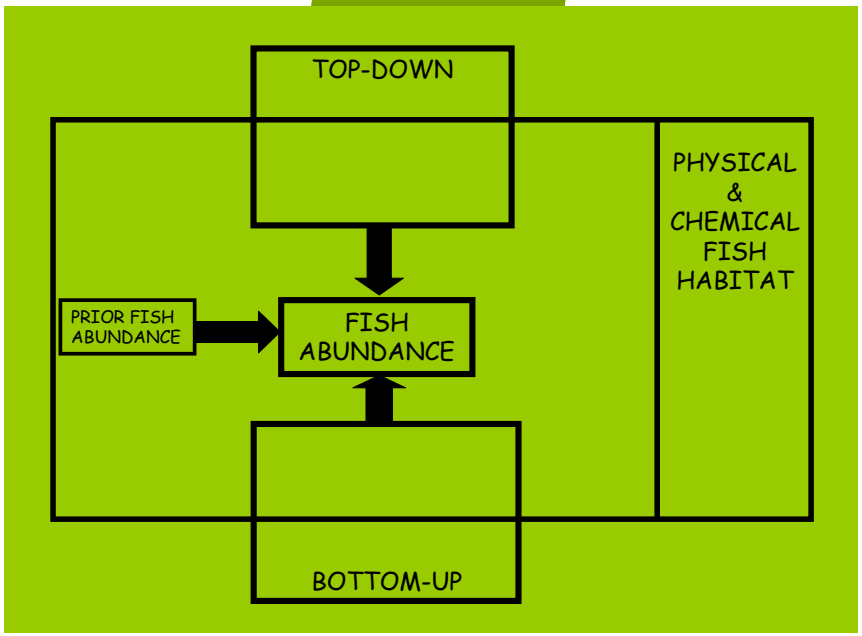


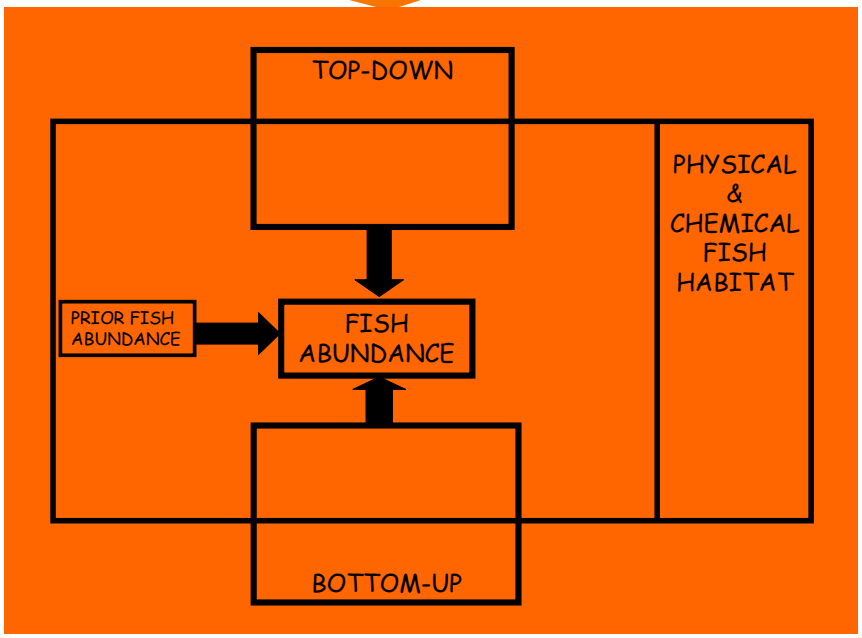

TOP-DOWN
LOSS
PARENTS
PRIOR FISH ABUNDANCE
FISH ABUNDANCE
PHYSICAL & CHEMICAL FISH HABITAT
HOME
FOOD
BOTTOM-UP


TOP-DOWN
Water Diversions
Predation
PHYSICAL & CHEMICAL FISH HABITAT
Temperature
Turbidity
Salinity
Contaminants
Disease
Toxic algae
Prior Fish Abundance
FISH ABUNDANCE
Ammonia
Ammonium
Food availability
Food quality
BOTTOM-UP

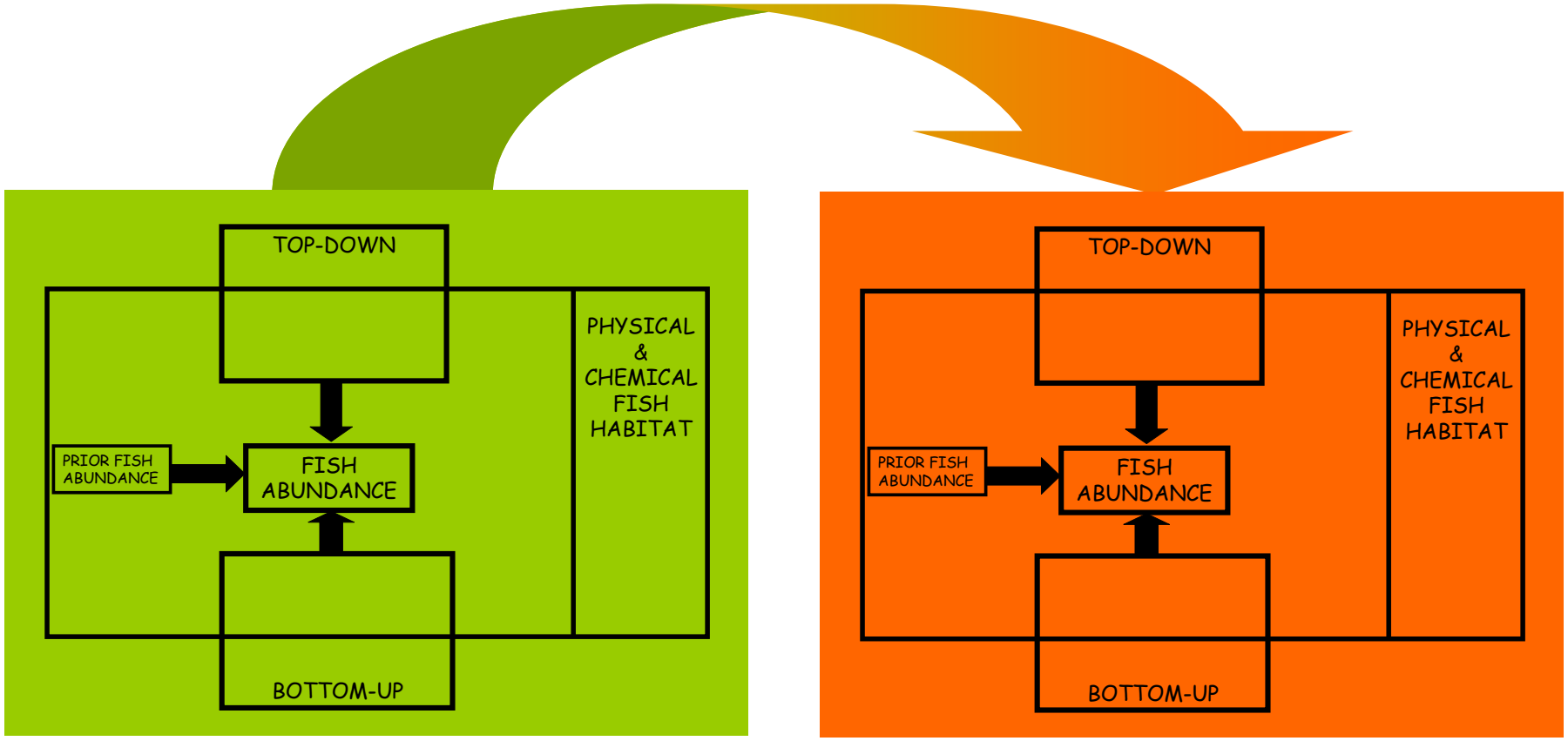
Emerging Story:
Regime Shift



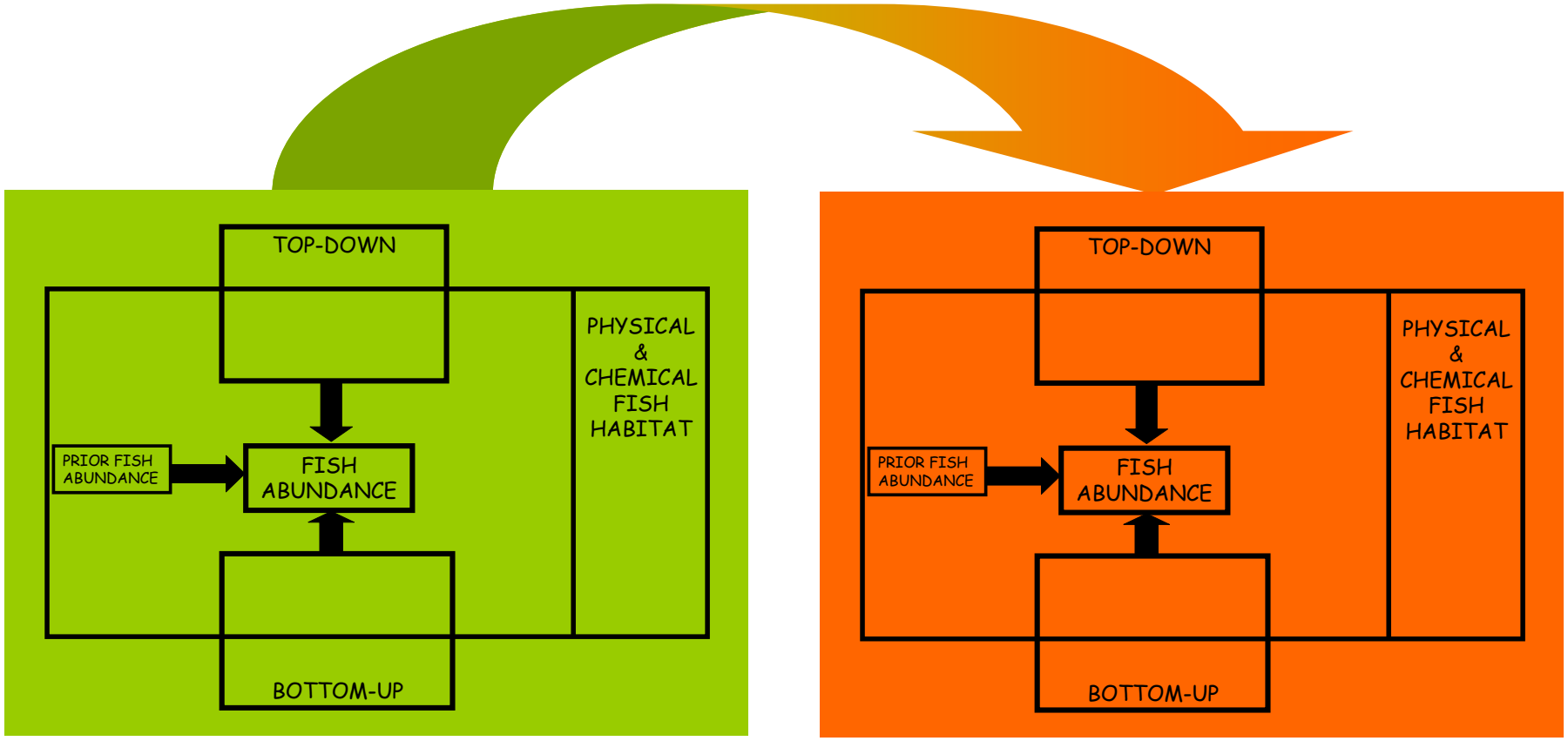




Many Causes, Many Consequences



Ammonia/um & the POD: Cause? Consequences?



Talk Outline:

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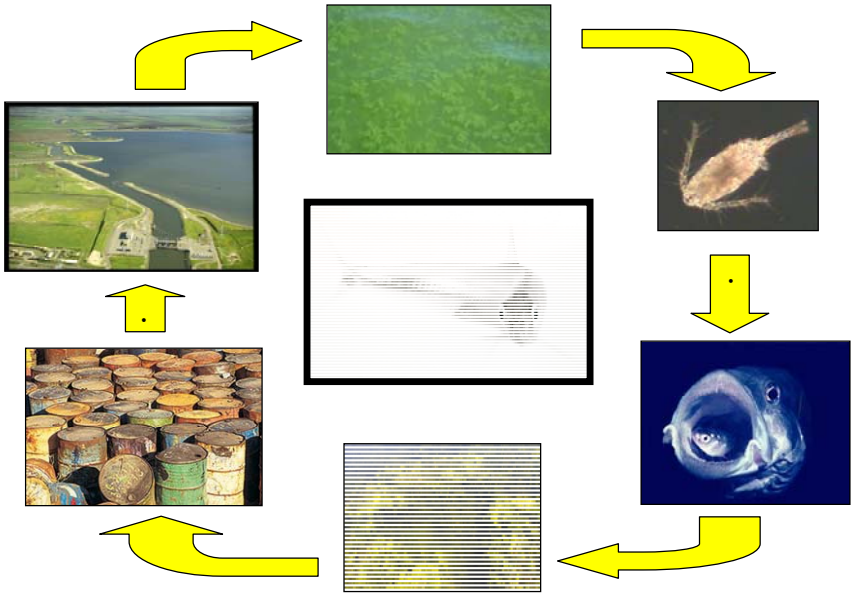
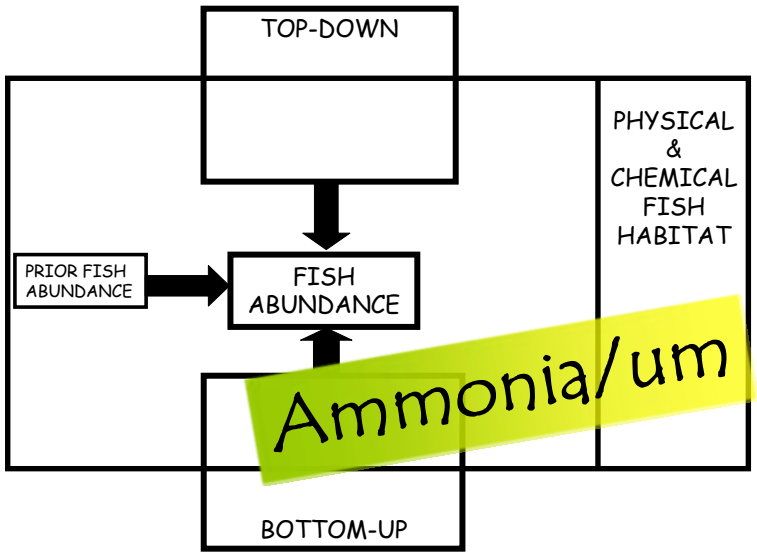
2. POD
3. Ammonia/um Investigations



3. Summary of Ammonia/um Investigations

- Many results are **preliminary**
- Many investigations are ongoing
- Results workshop in summer
- Background/summary report



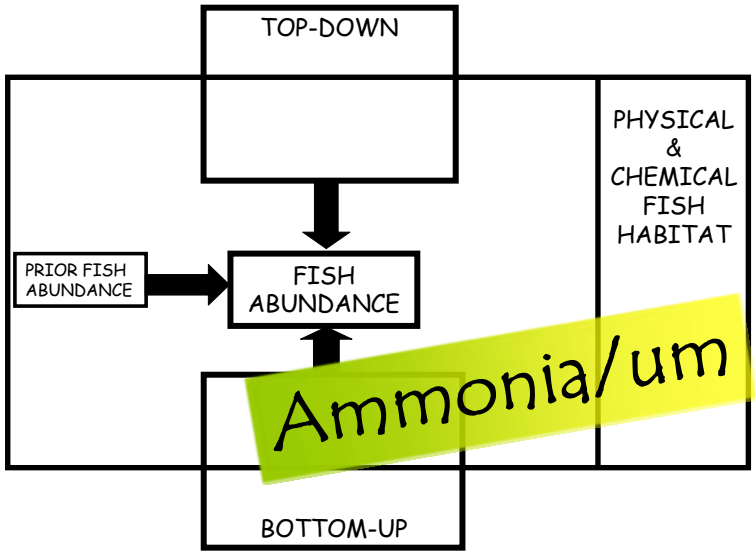
3. Summary of Ammonia/um Investigations

Topic Areas (*following report*):

A. Sources, concentrations, fate, transport

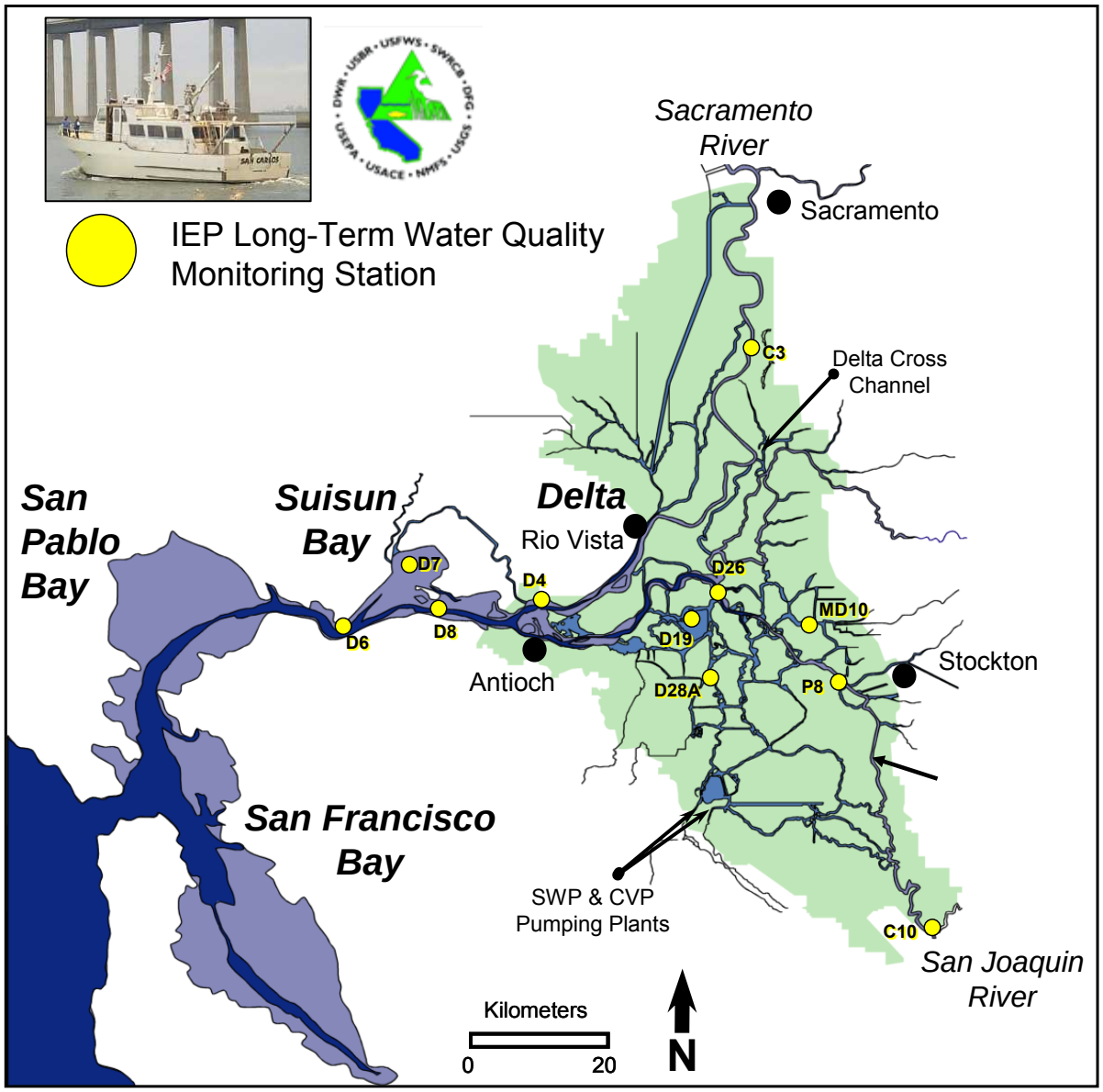
B. Food web effects

C. Toxicity to Delta fish and invertebrates



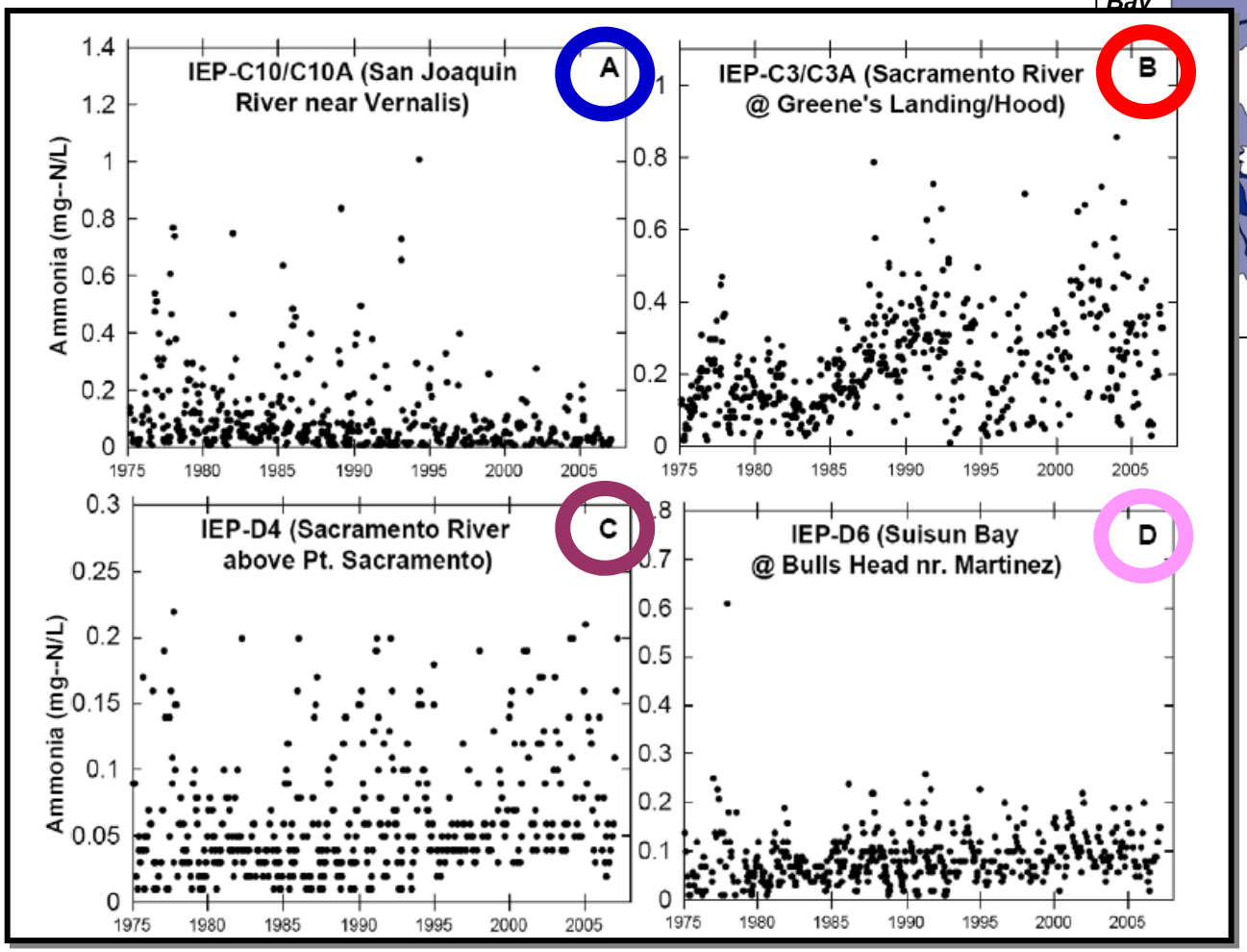
A. Sources, **concentrations**, fate, transport

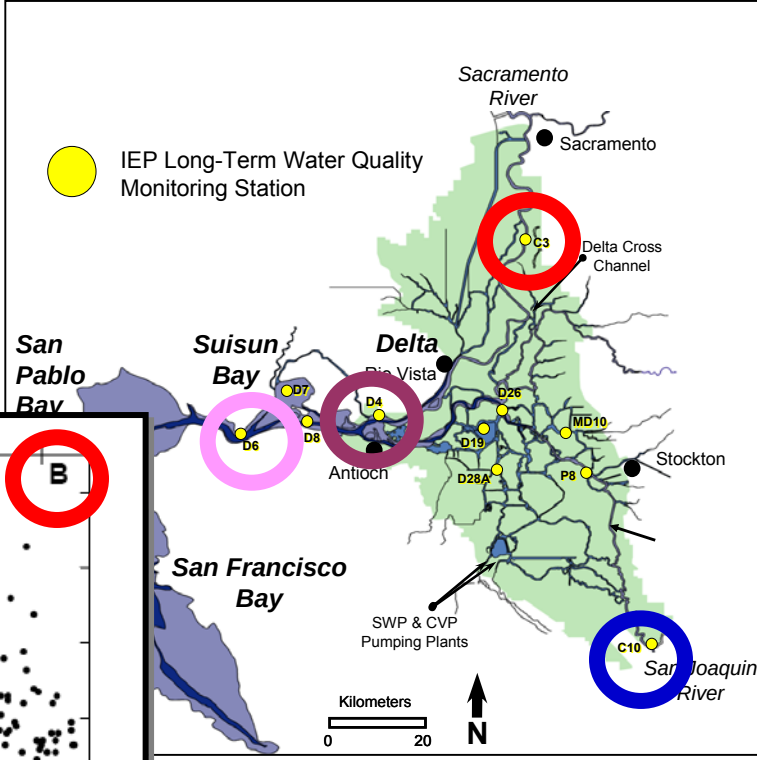
Fig. 1
In Report



Ammonium-N concentrations 1975-2008

Fig. 2



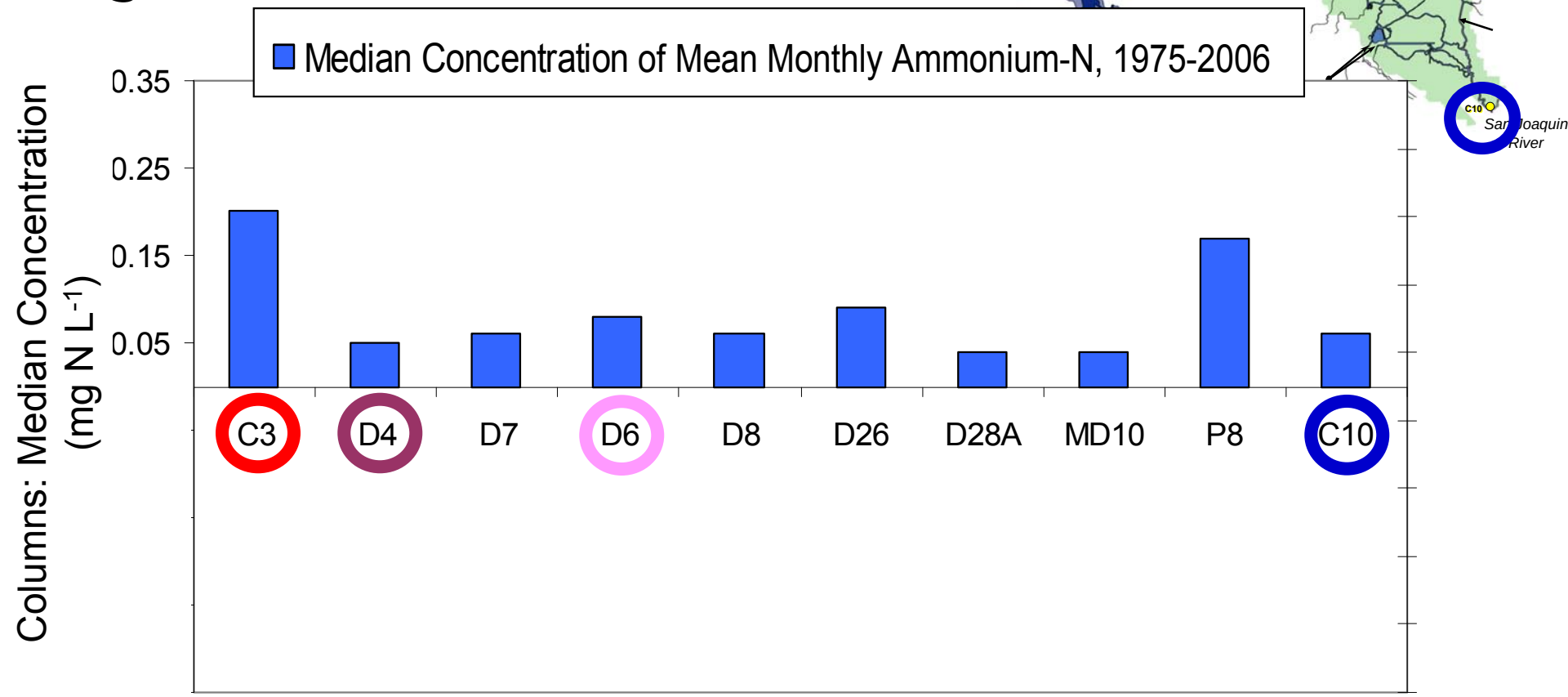


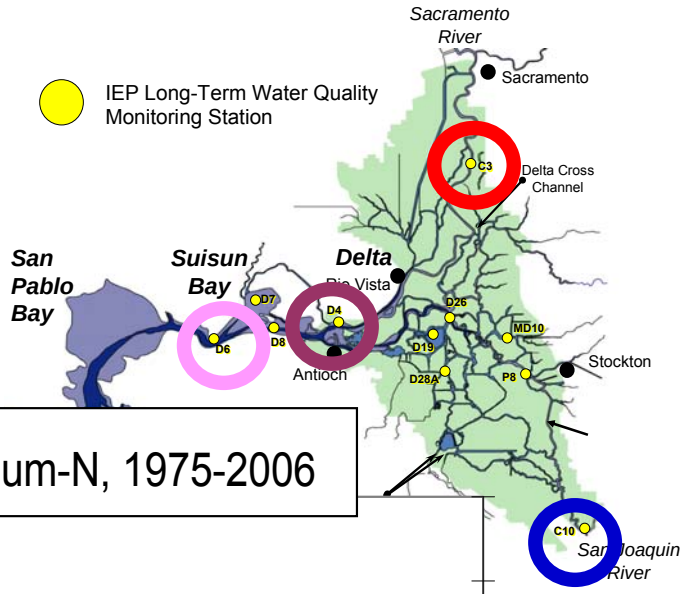
Different y-axis scales!

SRWTP Unpublished; IEP data available at bdat.ca.gov

Median ammonium-N concentrations 1975-2006

Fig. 3





A. Mueller-Solger unpublished;
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Median ammonium-N concentrations 1975-2006

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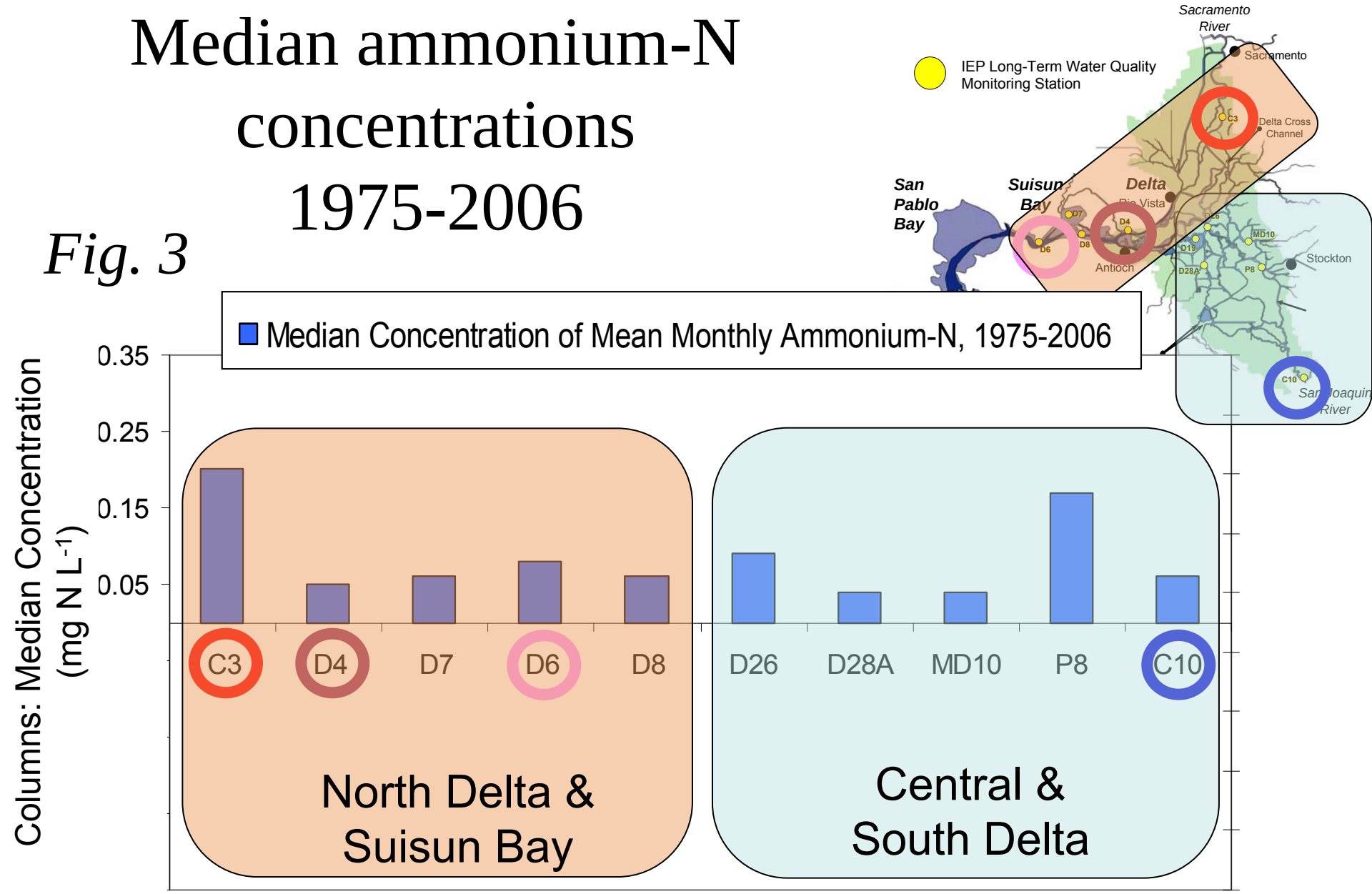

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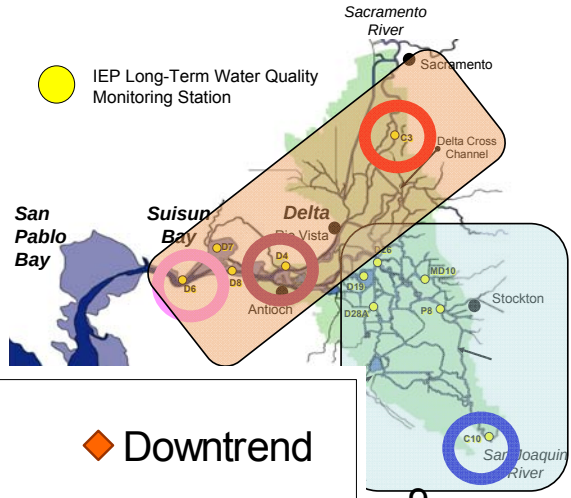
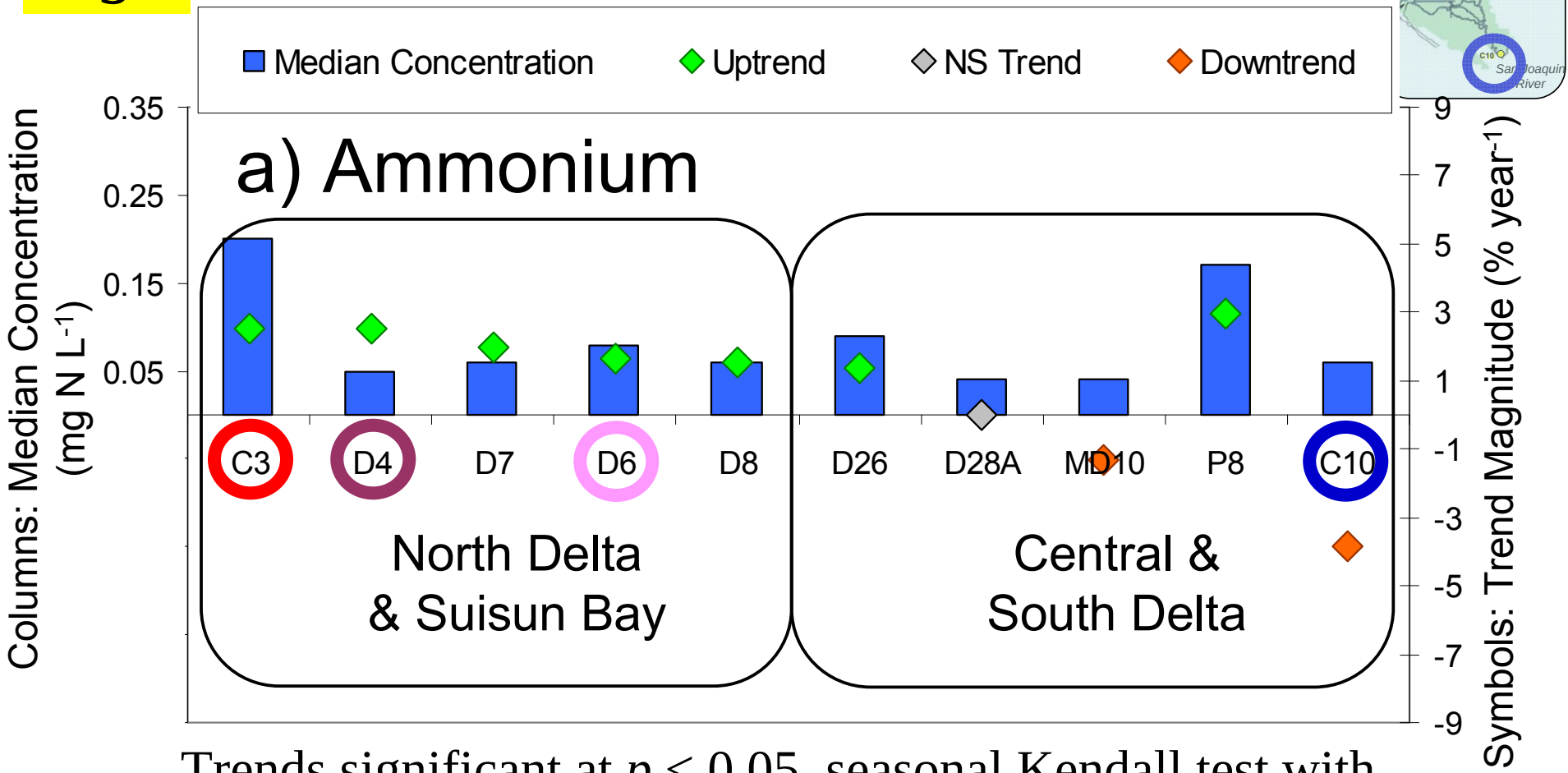
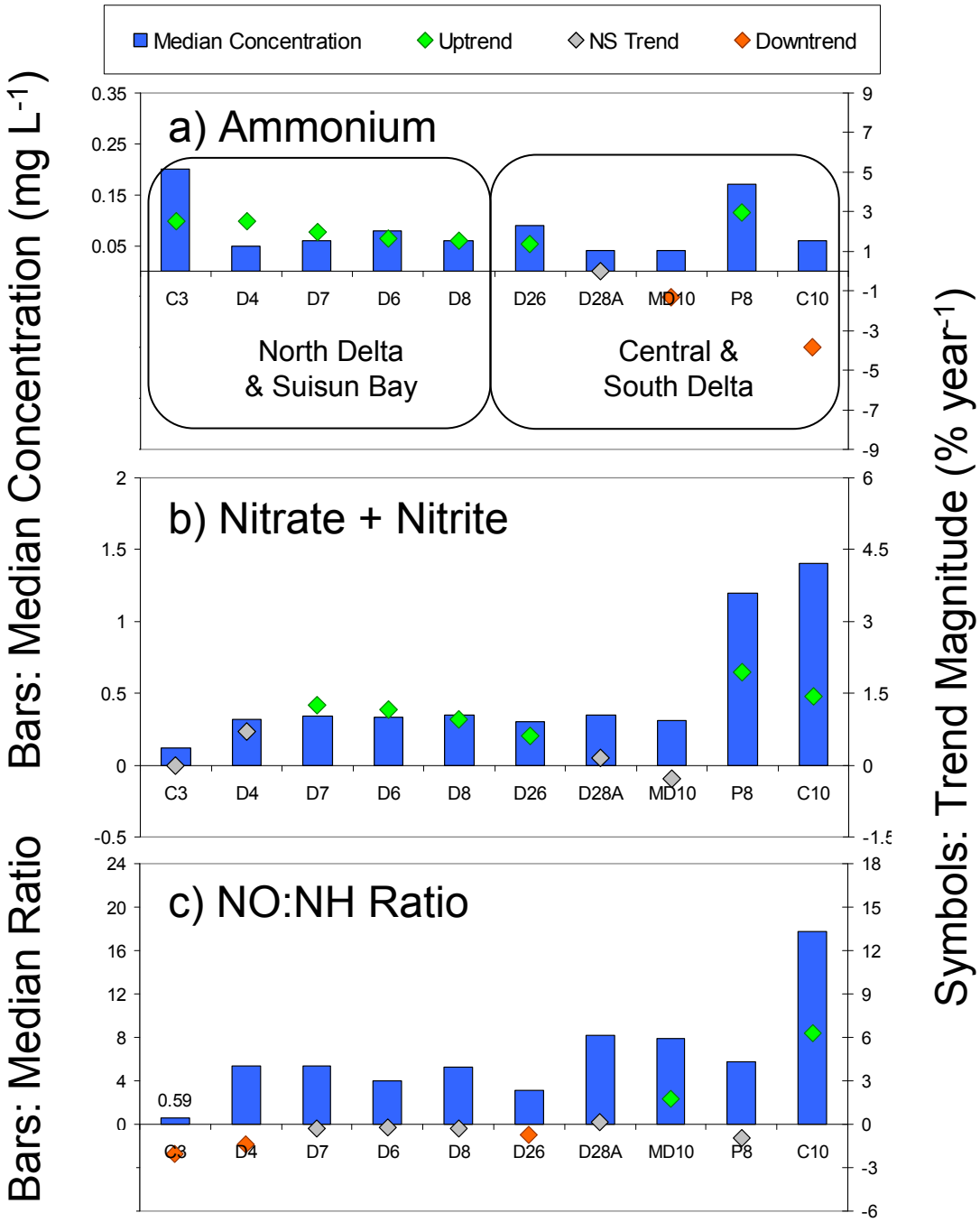
Median ammonium-N concentrations & **trends** 1975-2006

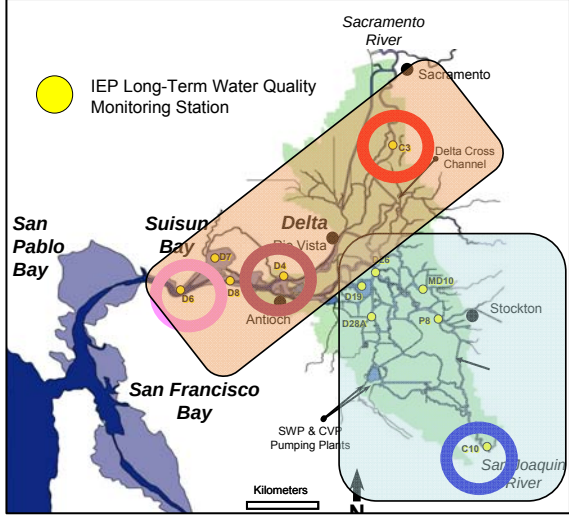
Fig. 3





Trends significant at $p < 0.05$, seasonal Kendall test with months as seasons and no flow adjustment





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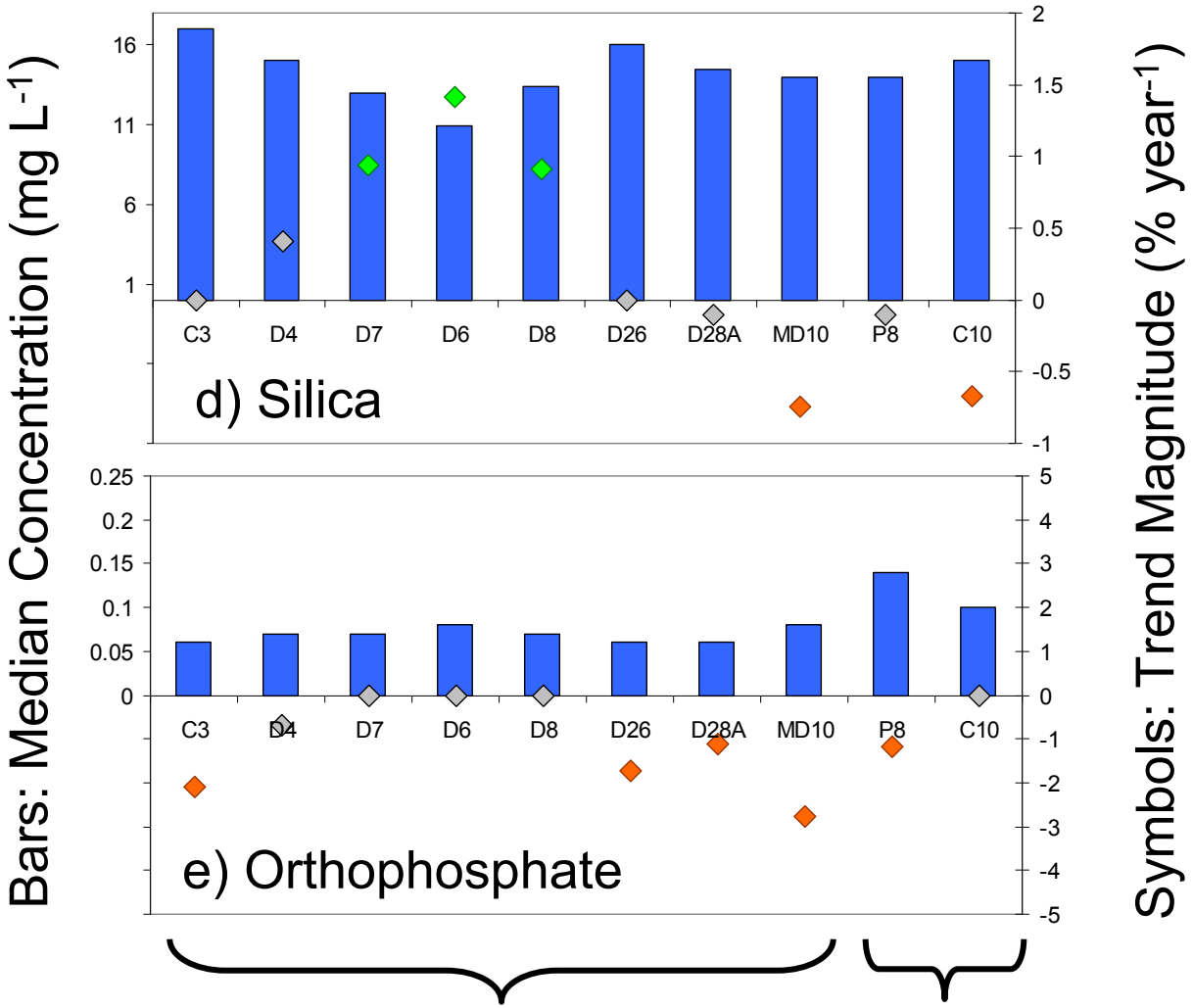

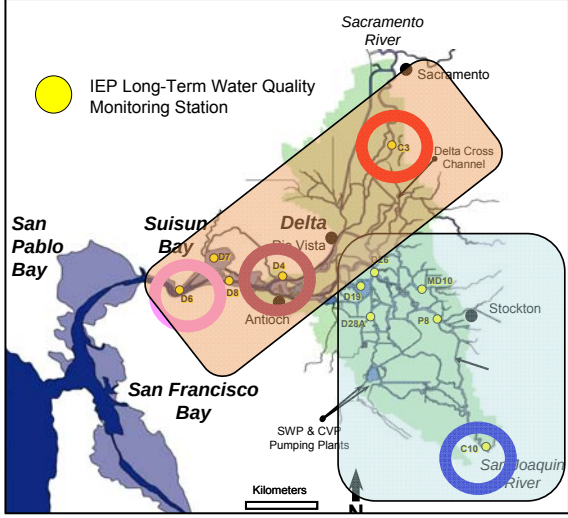

Fig. 3

A. Mueller-Solger unpublished;
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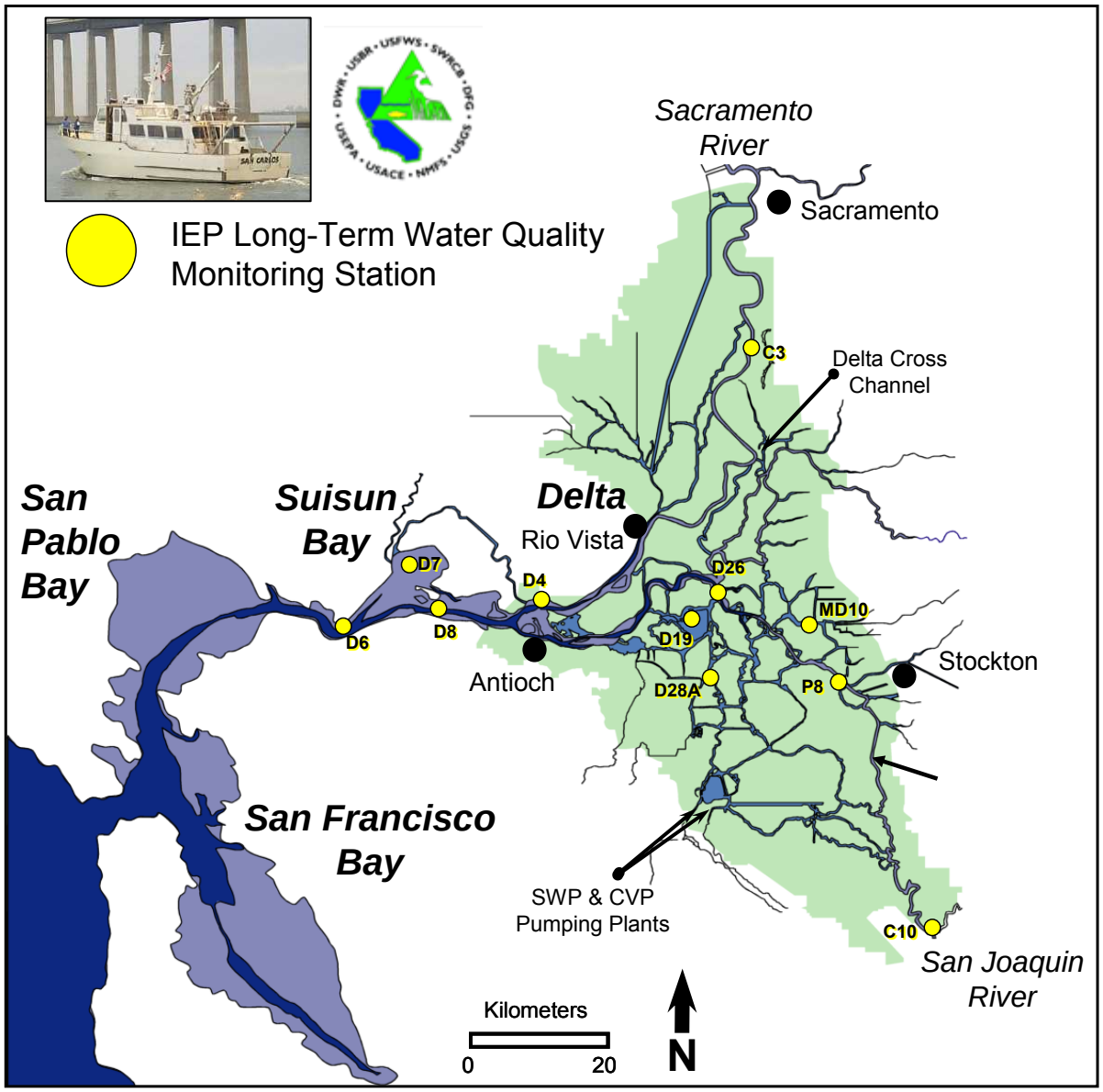
A. Sources, **concentrations**, fate, transport

Fig. 1

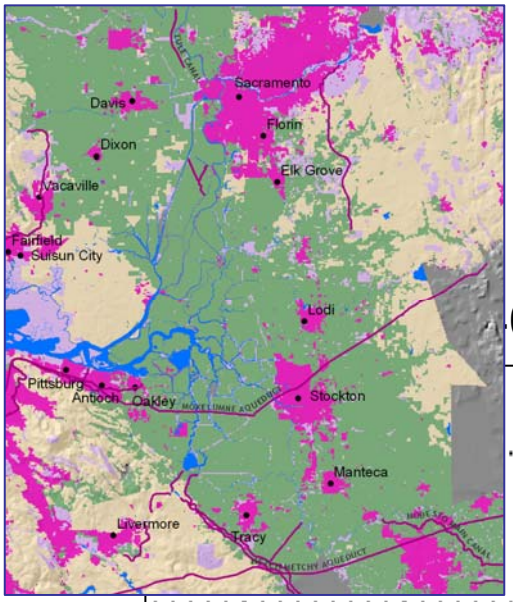


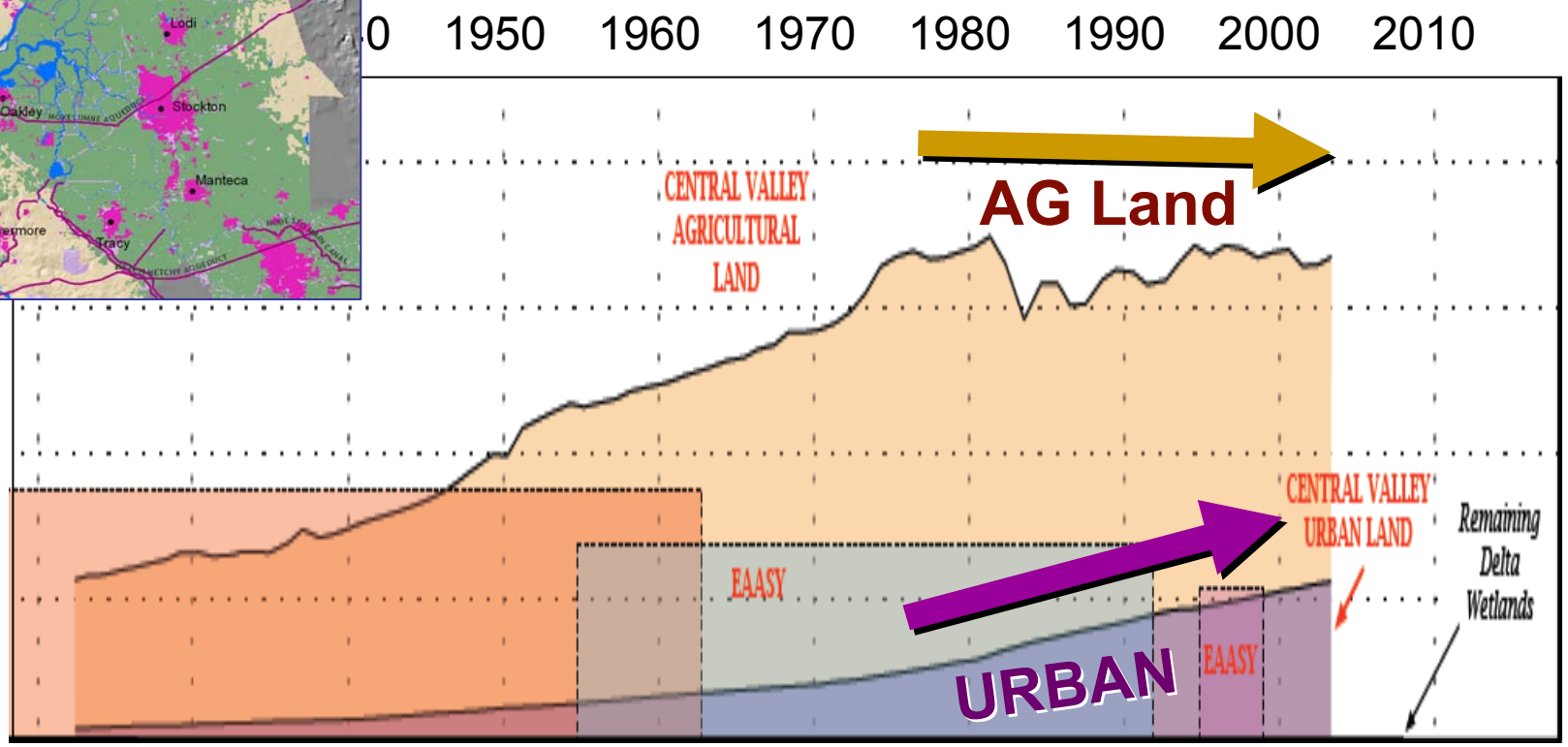
A. **Sources**, **concentrations**, fate, transport

Many sources:

- Wastewater treatment plants with secondary treatment
- Urban & agricultural run-off (fertilizers)
- Atmospheric depositions

The Central Valley is rapidly urbanizing



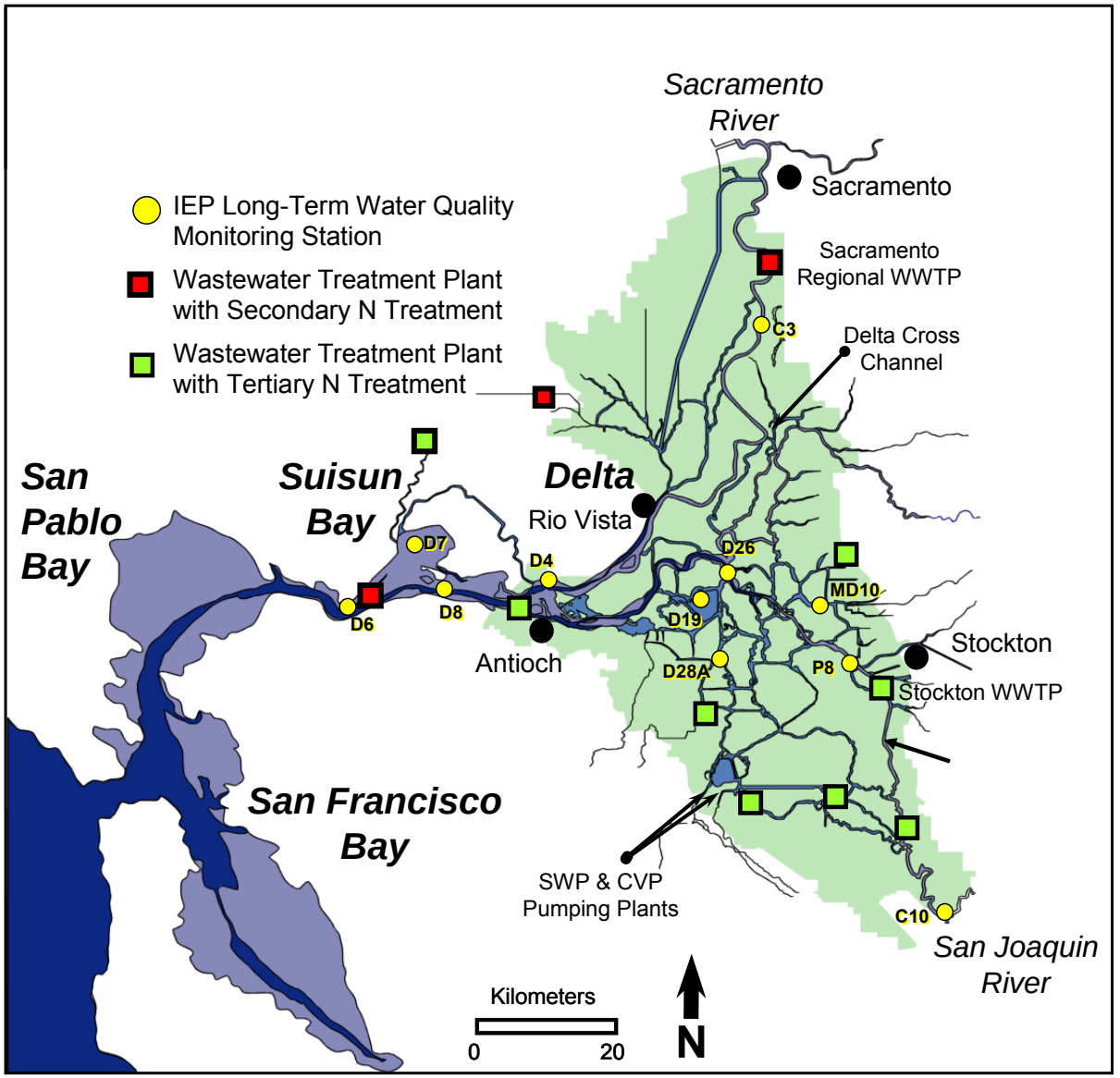


Dorian Fougères for CALFED, 2007

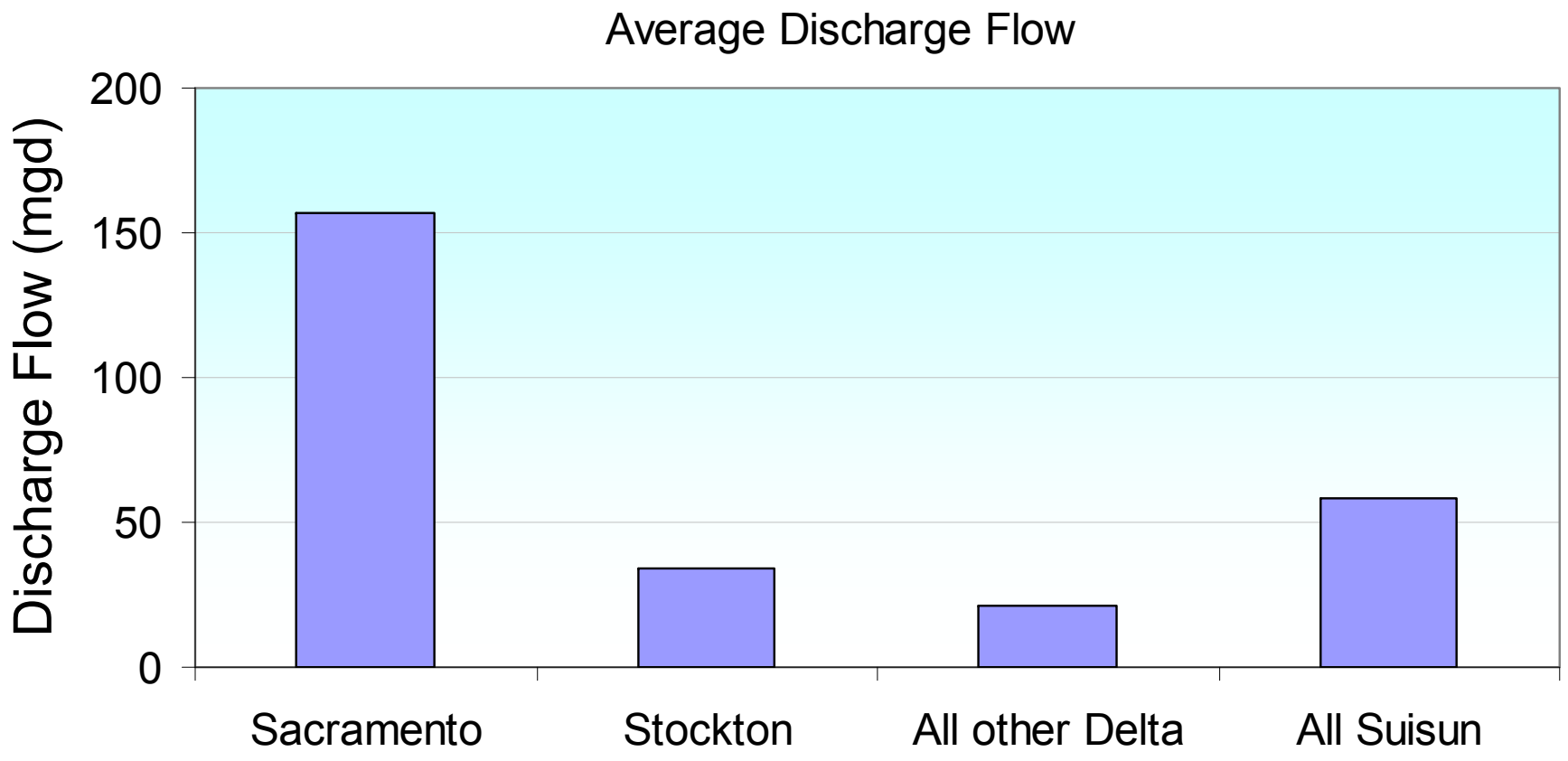
Jassby 2008: “Wastewater discharge is the dominant source by far of the river-borne ammonium load.”

Fig. 1

with WWTPs



Most wastewater discharge flow is from the Sacramento Regional Wastewater Treatment Plant (SRWTP)



Data: SWP Watershed Sanitary Survey 2006 Update & Jassby 2008

Jassby 2008:

- 2001-2005 average monthly SRWTP ammonium-N load: ~400 t mo^{-1}
- Increasing - “This probably reflected population increases…”

Fig. 5

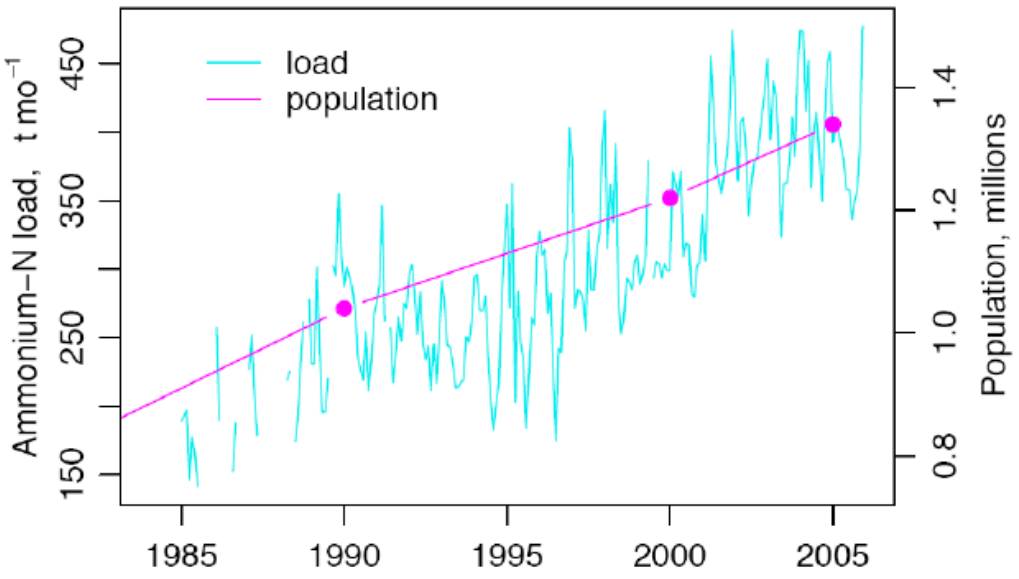
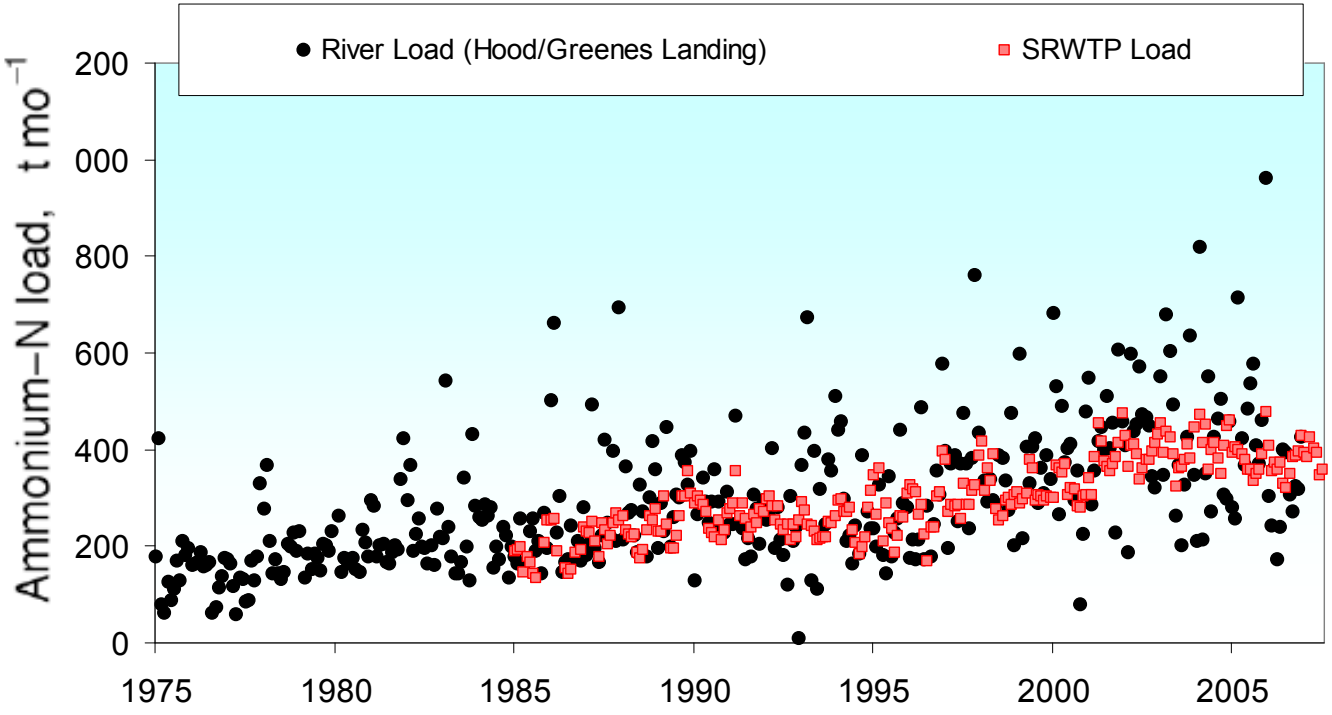
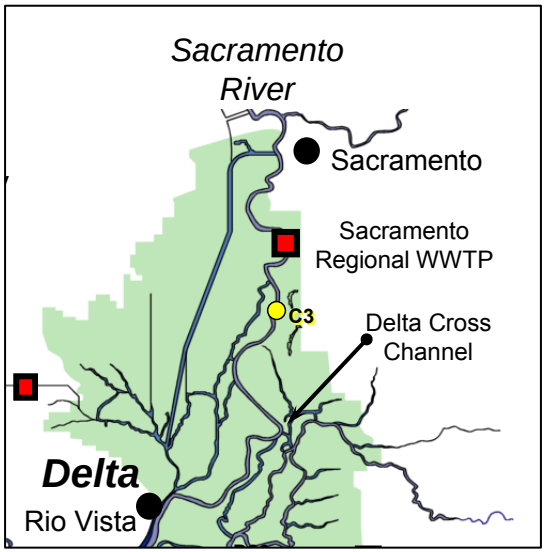


Figure 15. Monthly load of ammonium-N in wastewater from the County of Sacramento Regional Wastewater Treatment Plant. County population is also shown for comparison.

Jassby 2008:

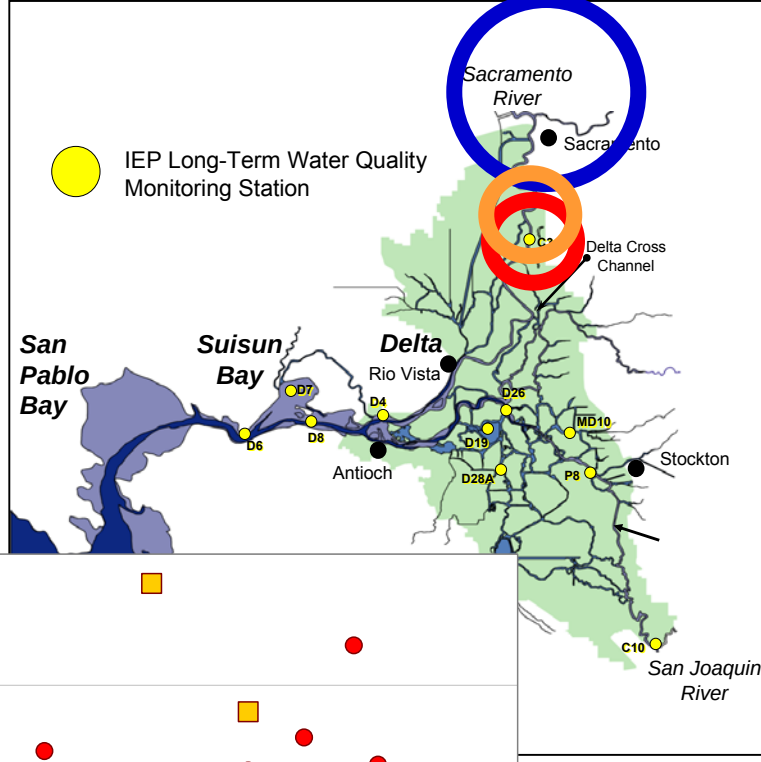
- 1985–2005 ammonium load from the SRWTP ~ 90% of the river ammonium load at C3

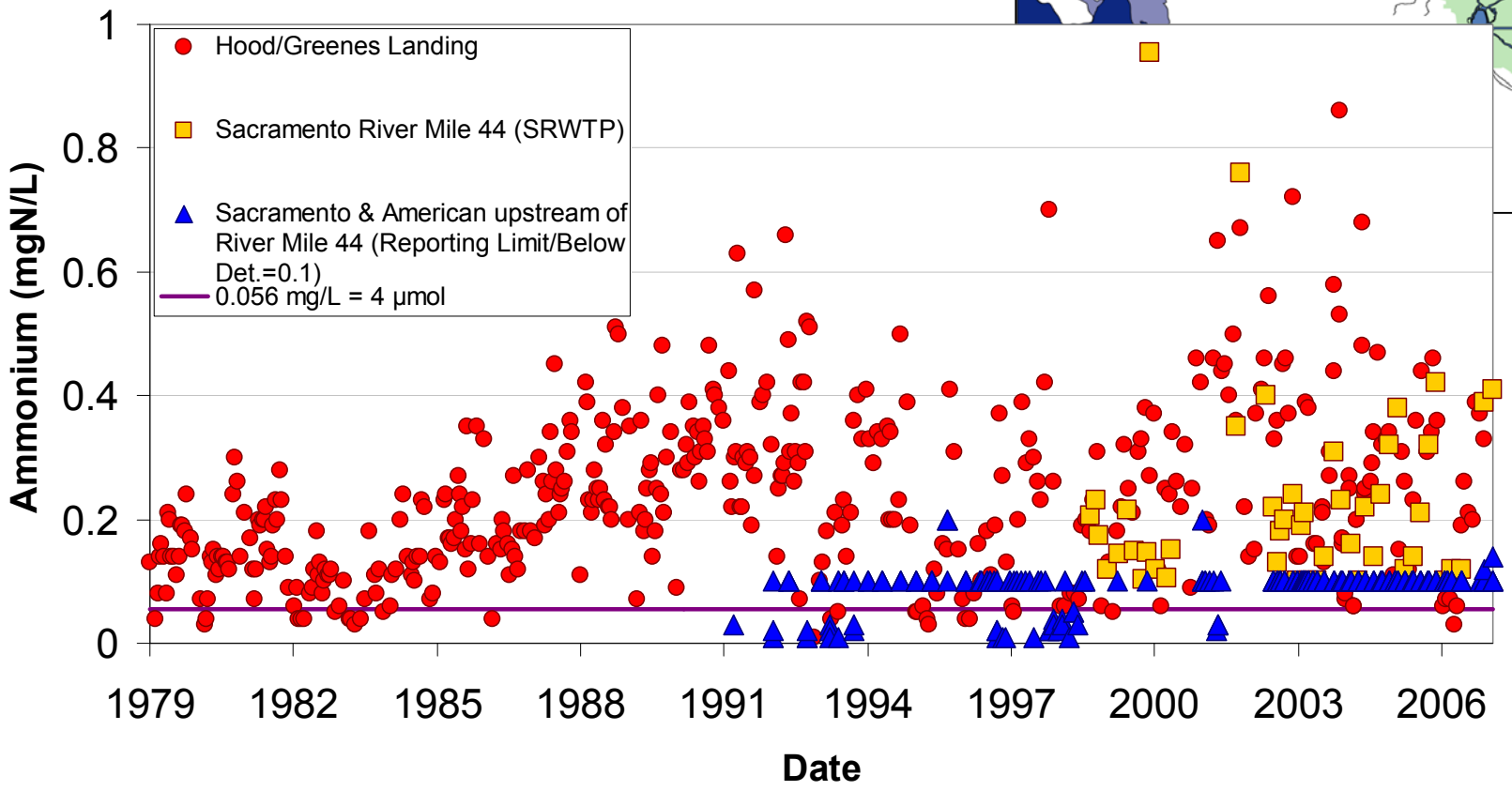




Data: IEP & SRWTP

Upstream Sacramento River ammonium concentrations are low

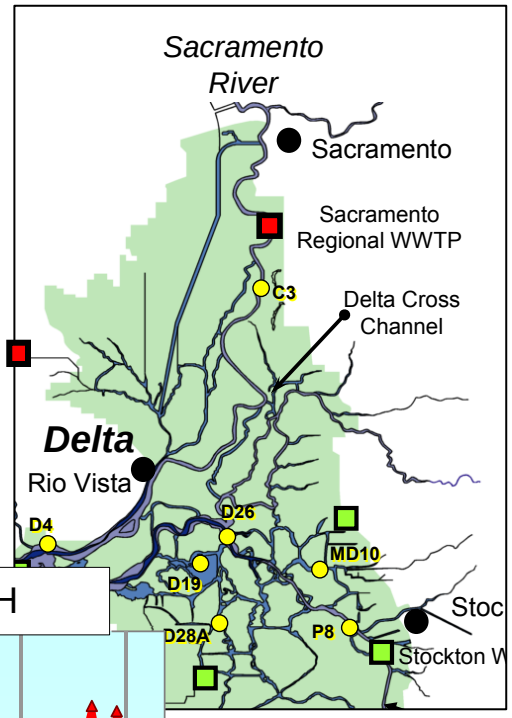


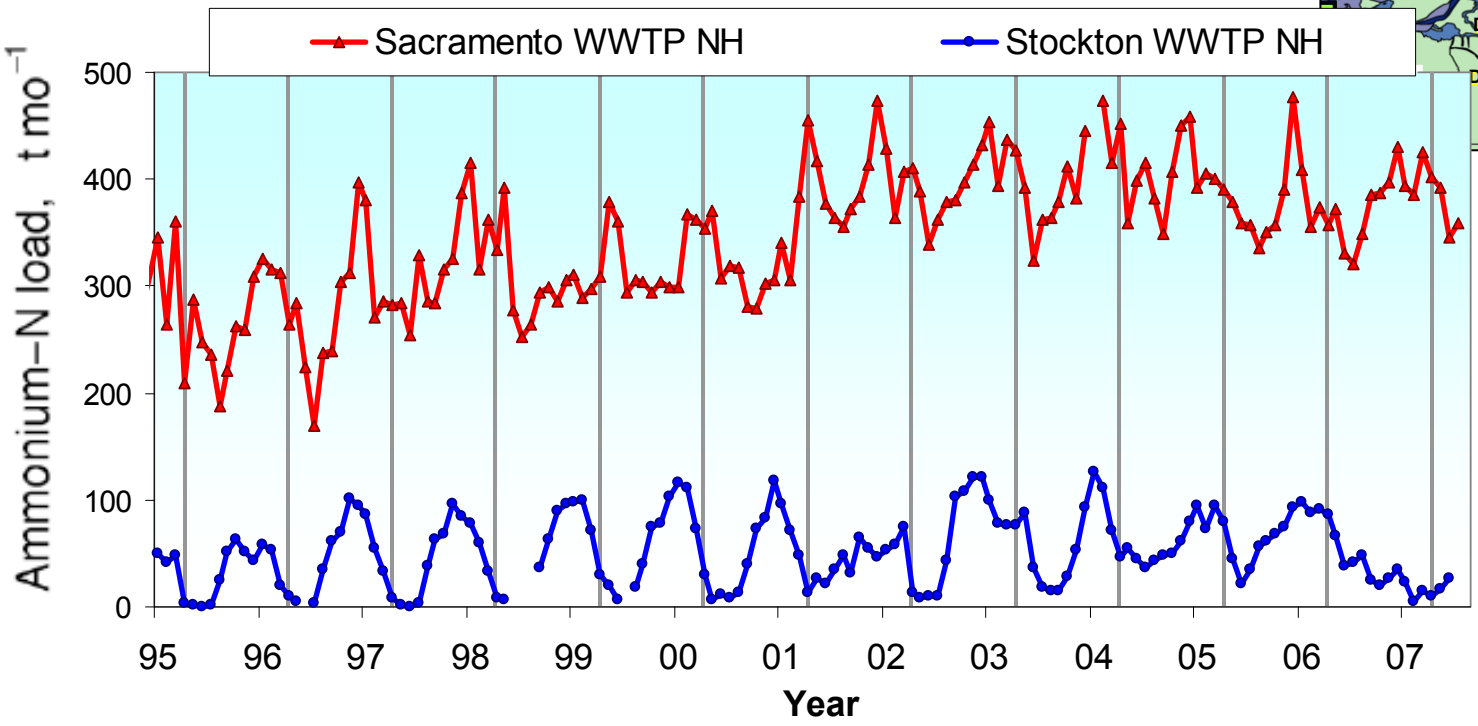


Data from BDAT, http://bdat.ca.gov/

Jassby 2008:

- Stockton ammonium loading also grew
  - Loads are much smaller than from SRWTP
  - Year-round nitrification starting in 2007
- Loads from other WWTPS are smaller, but “may be important locally”

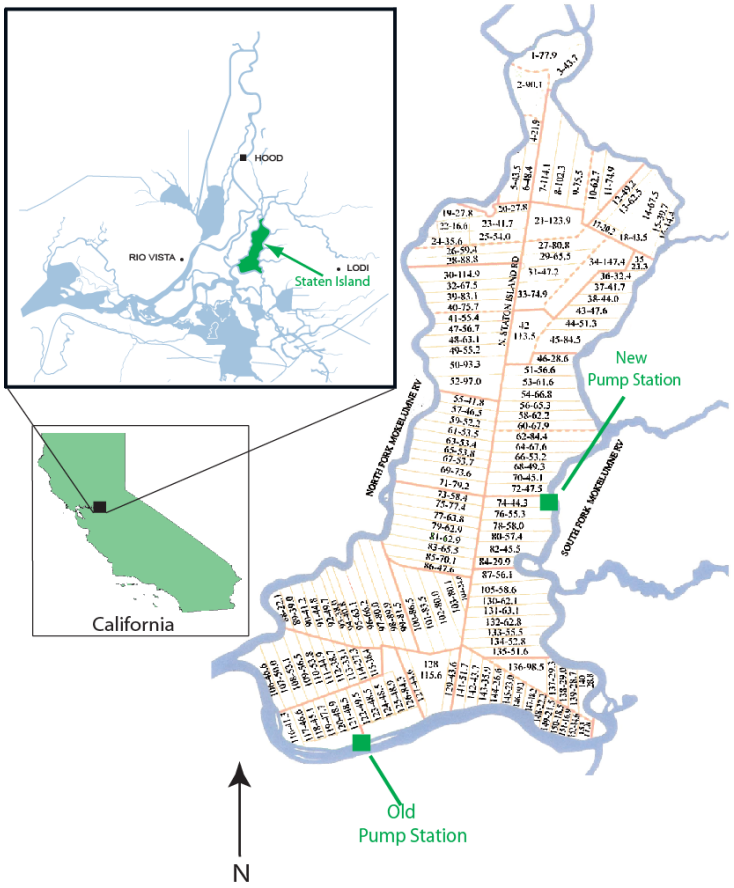


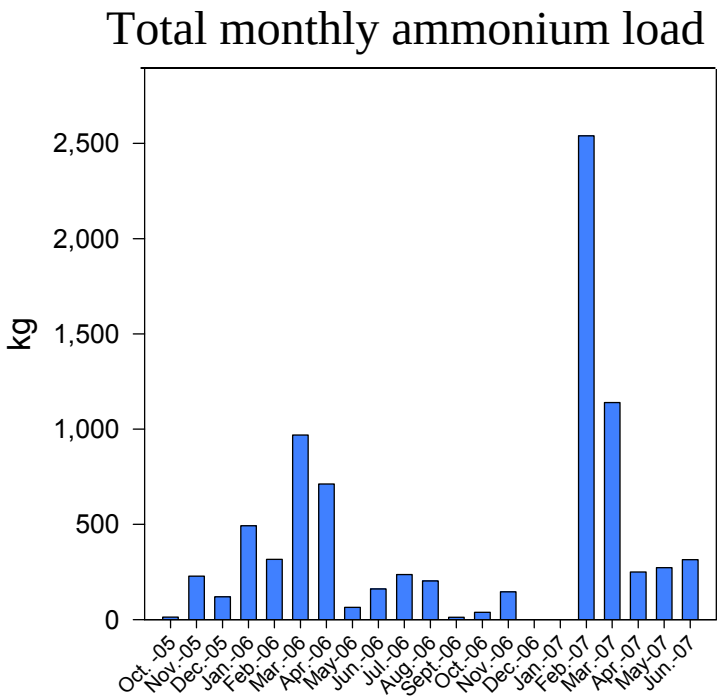


Data: SRWTP & Stockton WWTP

Agricultural loading?

- Staten Island - actively farmed Delta peat island
- WY 2006: up to 2.5 t mo^{-1} , total annual load = 3.5 t
  (Compare to ~400 t mo^{-1} from SRWTP)





From poster by Carol DiGiorgio et al, DWR, CALFED Science Conference 2008

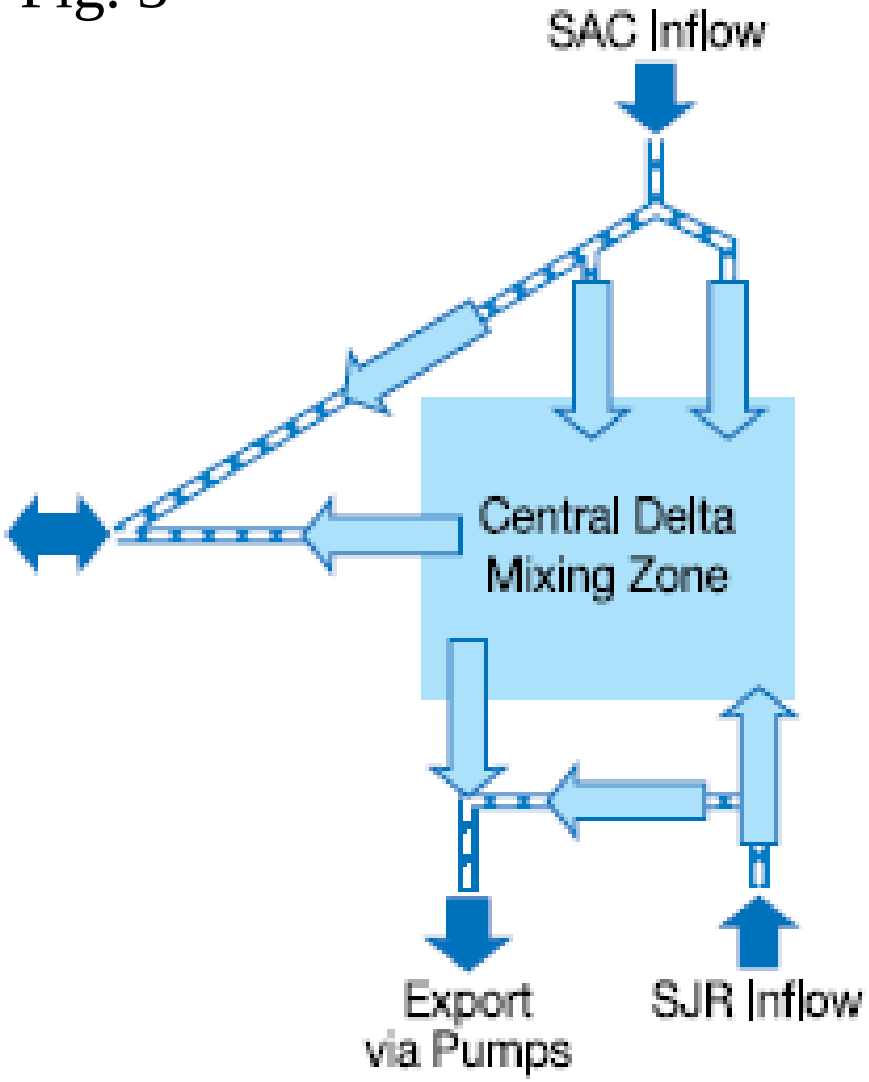
A. **Sources**, **concentrations**, fate, **transport**

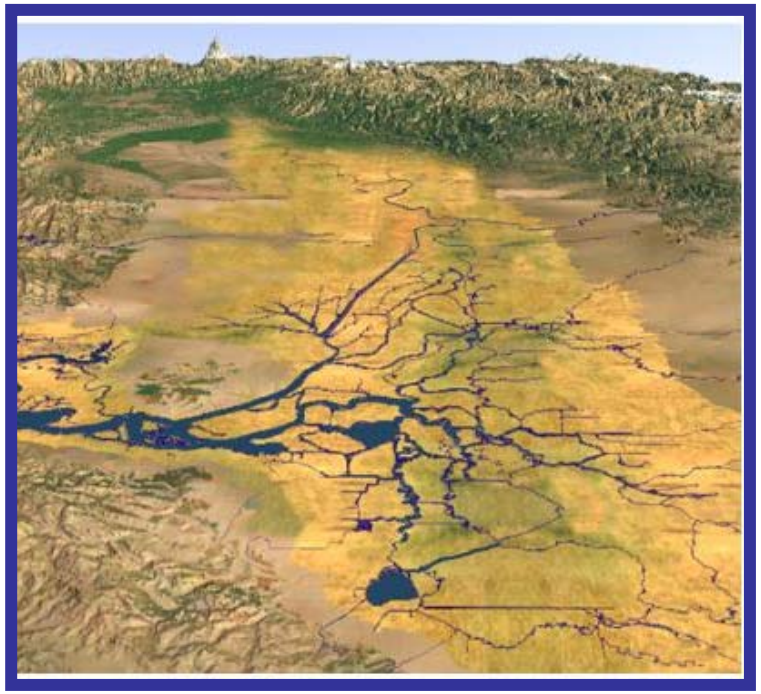
Monsen et al 2007:

- "… the **Delta is a mixing zone** of water from the Sacramento and San Joaquin Rivers, agricultural return water, and the San Francisco Estuary."
- "…the contribution of each source varies in response to natural **hydrologic variability and water diversions**."

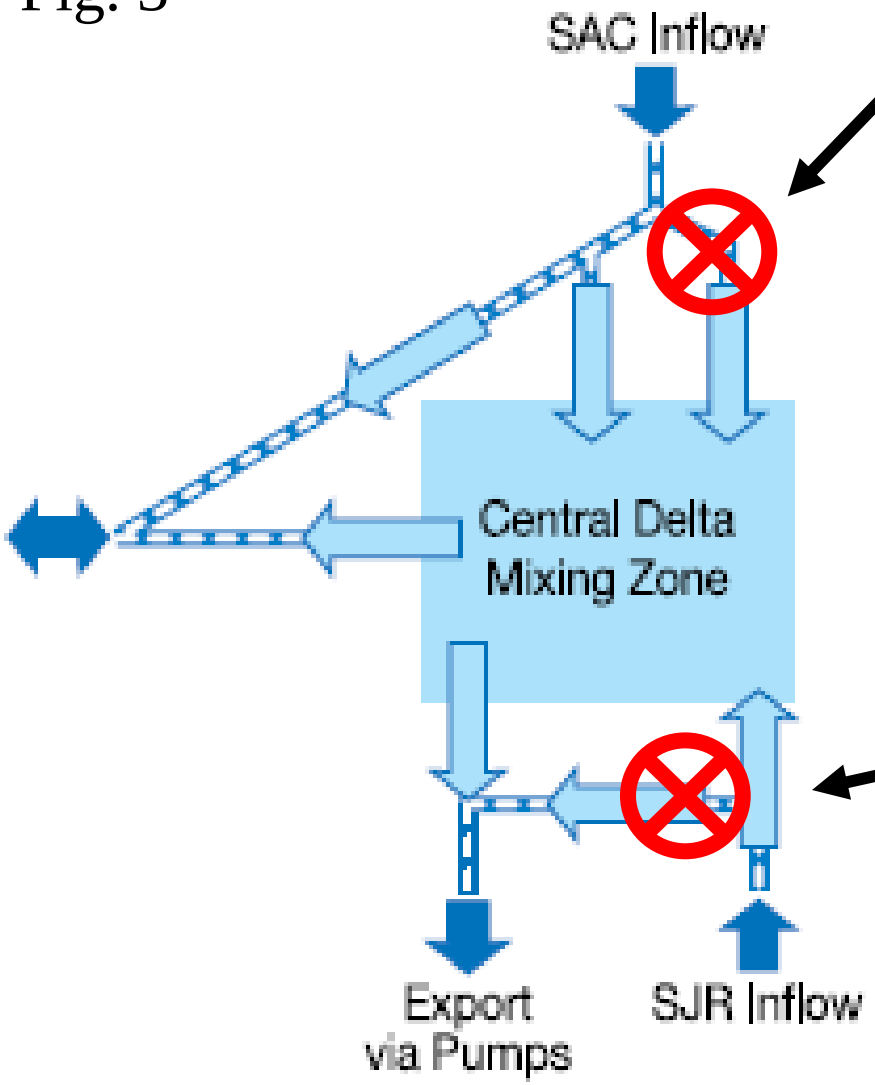
Monsen, Nancy E., James E. Cloern, and Jon R. Burau. Effects of Flow Diversions on Water and Habitat Quality: Examples from California's Highly Manipulated Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science. Vol. 5, Issue 3 [July 2007]. Article 2. http://repositories.cdlib.org/jmie/sfews/vol5/iss3/art2

Monsen et al 2007,
Fig. 3





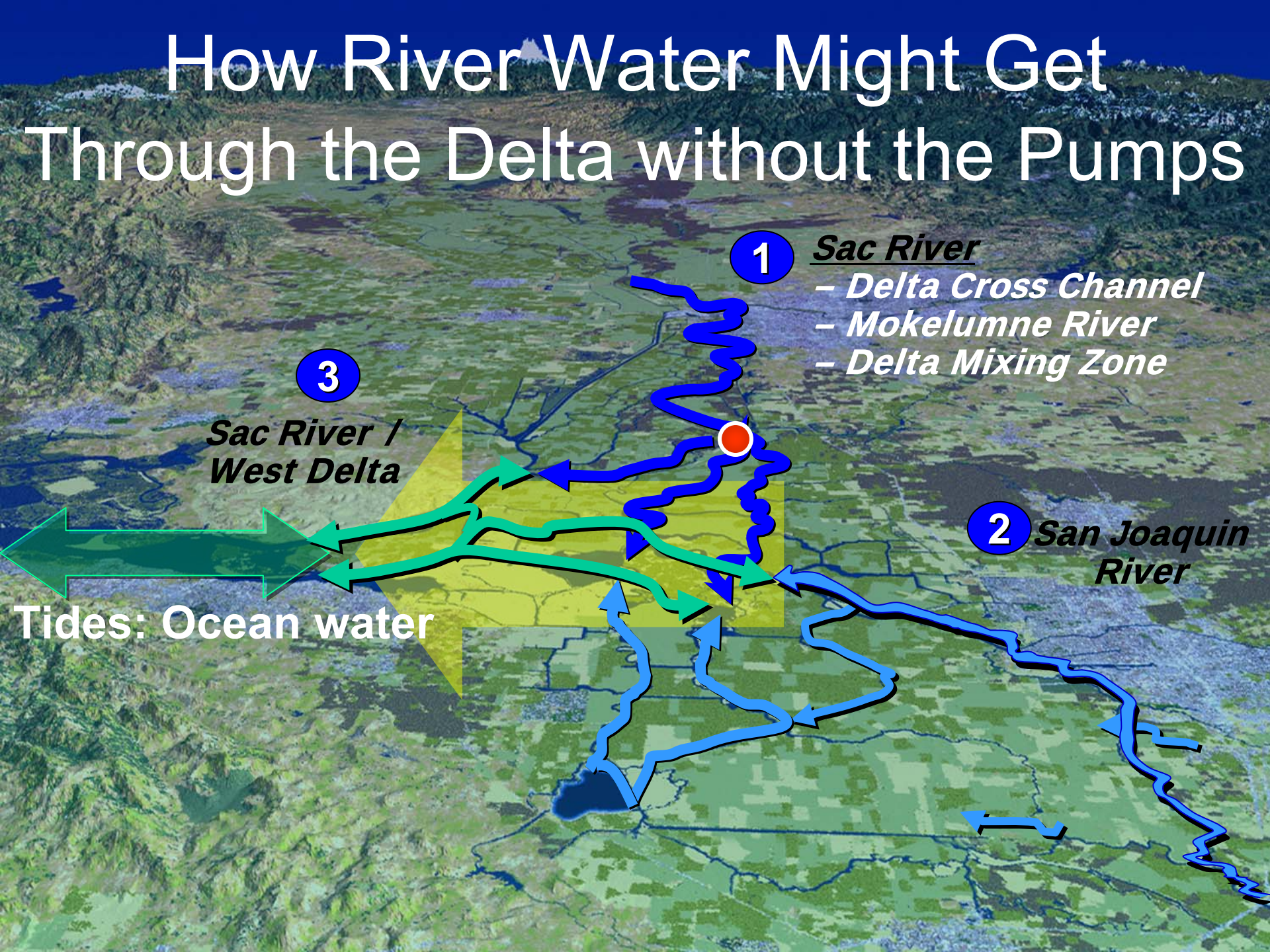
Monsen et al 2007,
Fig. 3



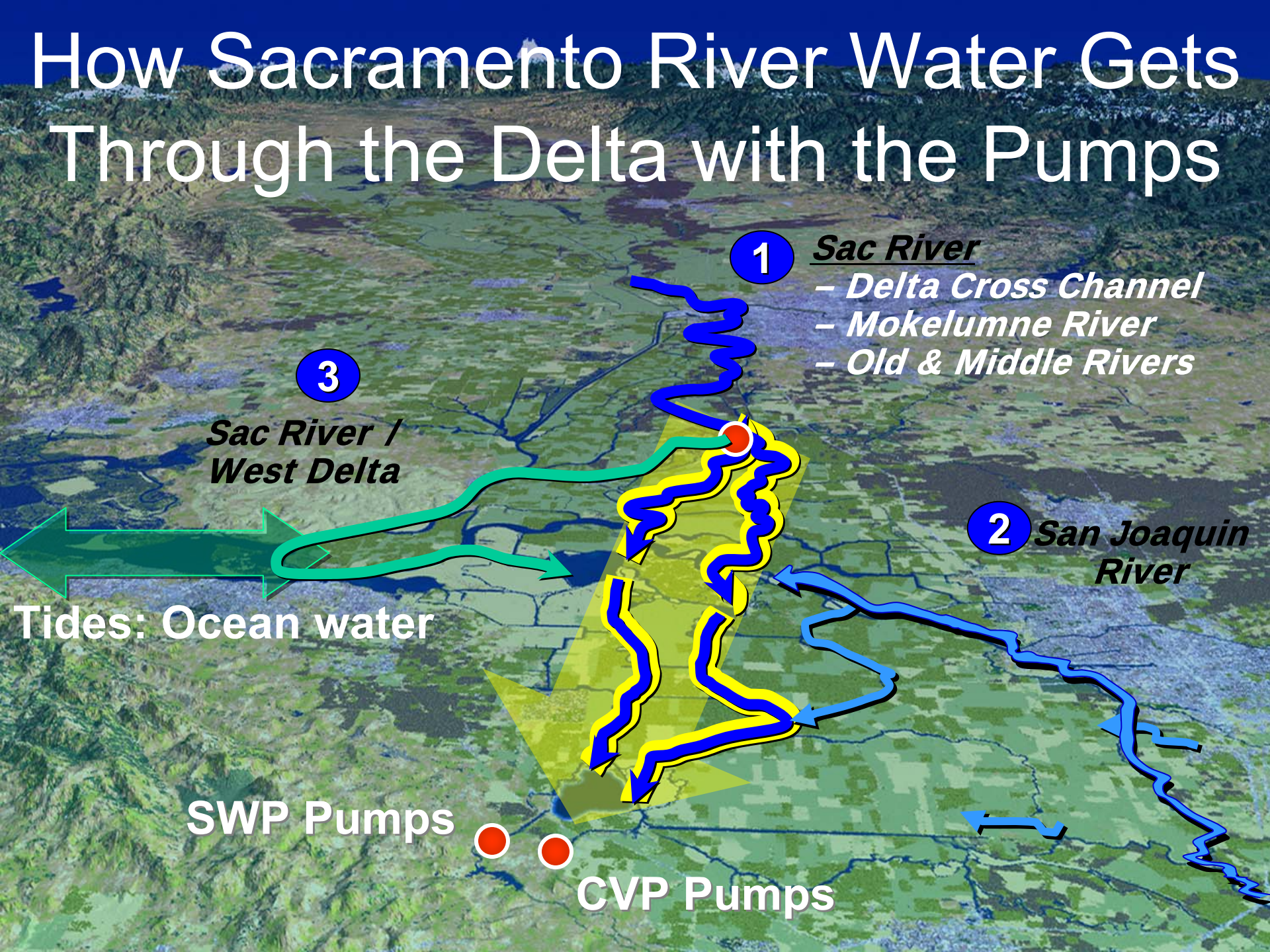
Delta Cross Channel

Head of Old River
Agricultural Barrier

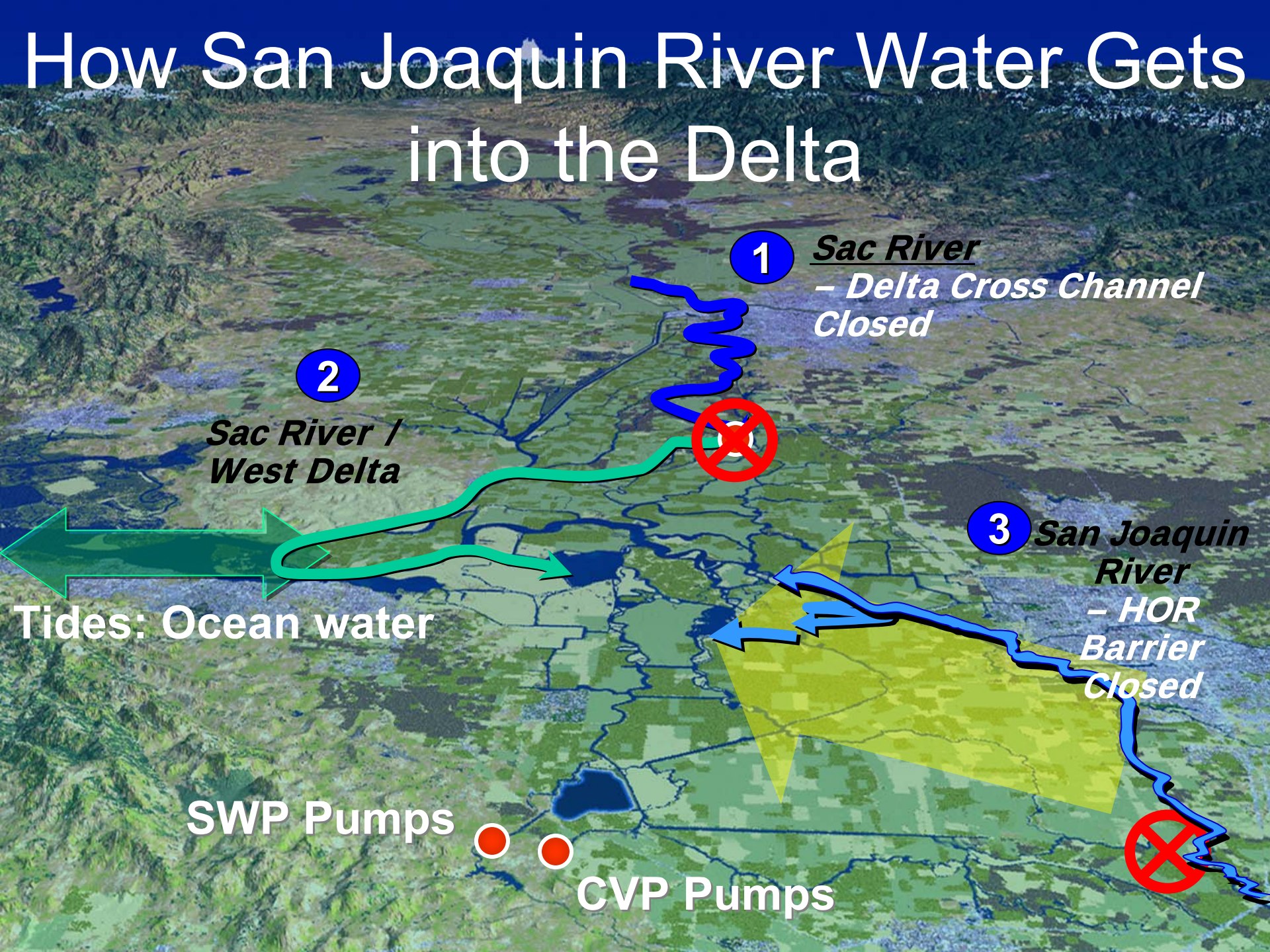
How River Water Might Get Through the Delta without the Pumps



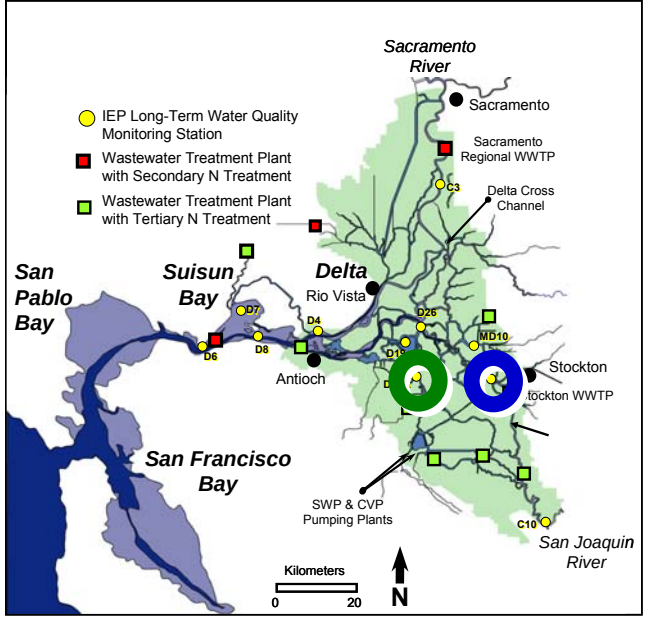
How Sacramento River Water Gets Through the Delta with the Pumps

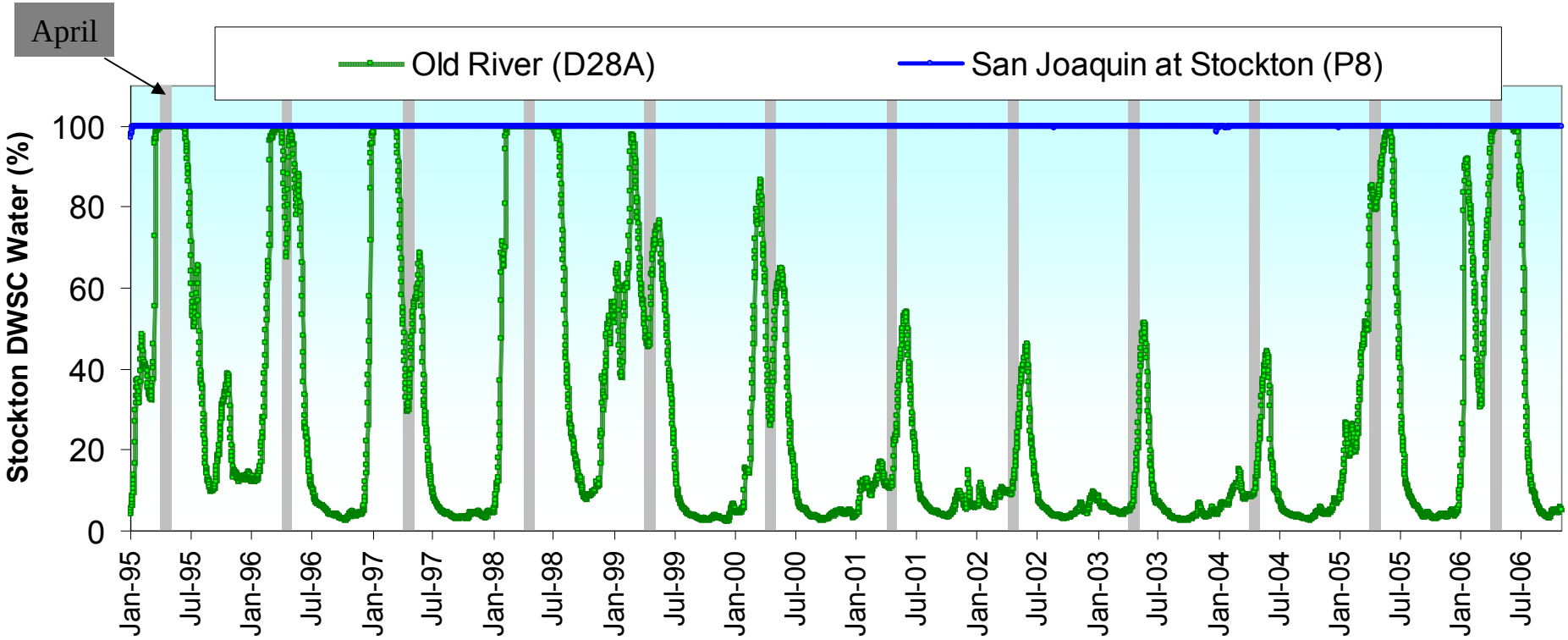


How San Joaquin River Water Gets into the Delta



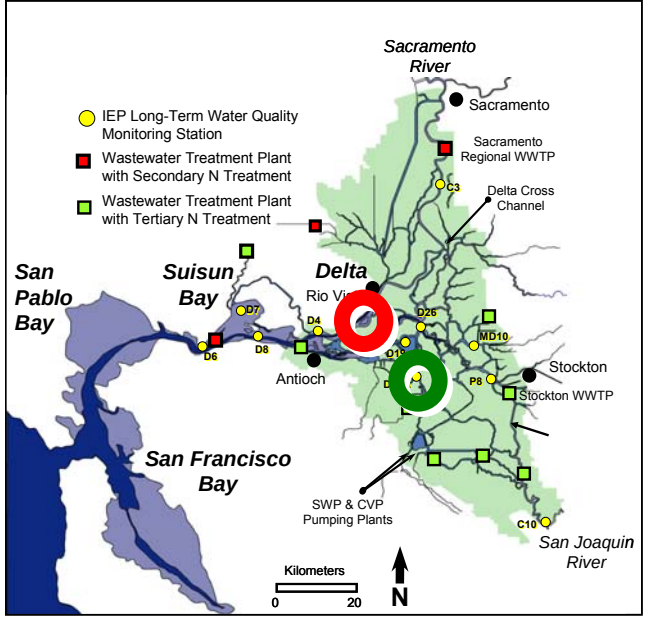
- Stockton ship channel water penetrates into the central Delta & Suisun Bay only in late winter/spring

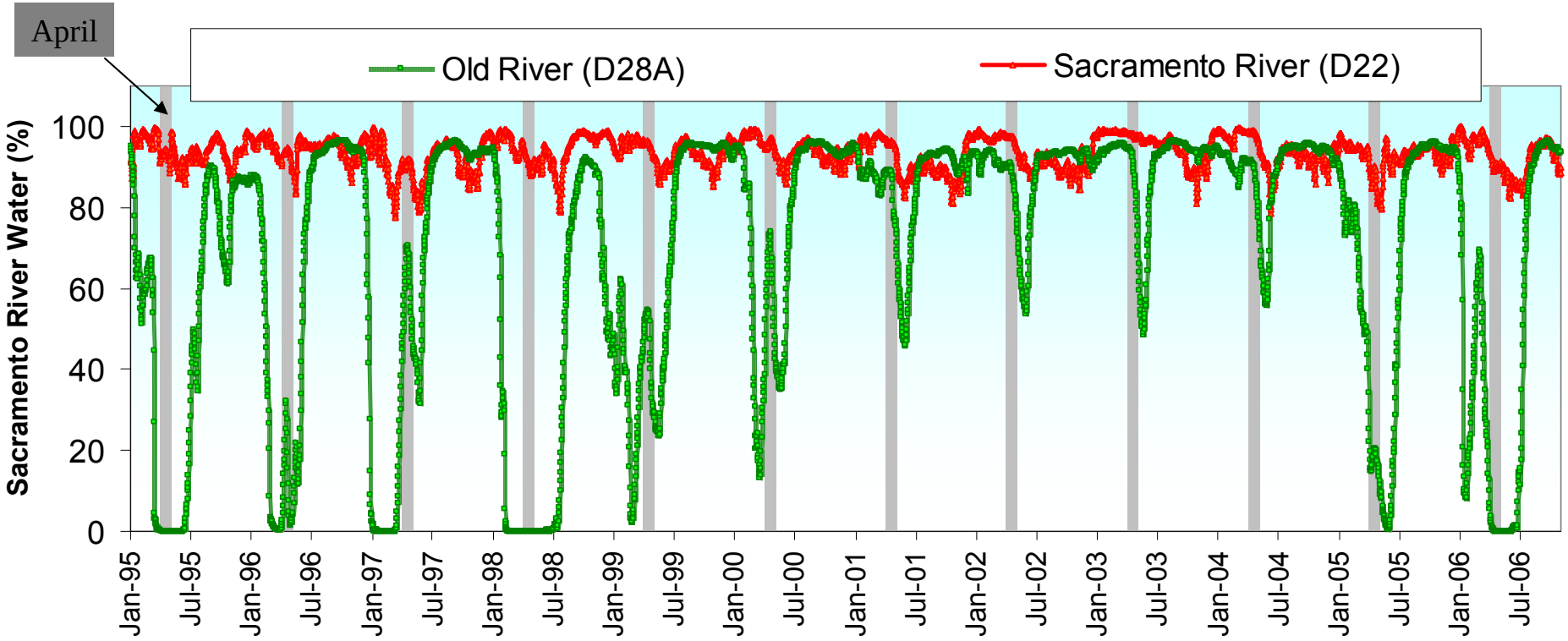




A. Mueller-Solger, unpublished; Volumetric source water "fingerprints" generated with DSM2 by Bob Suits, DWR

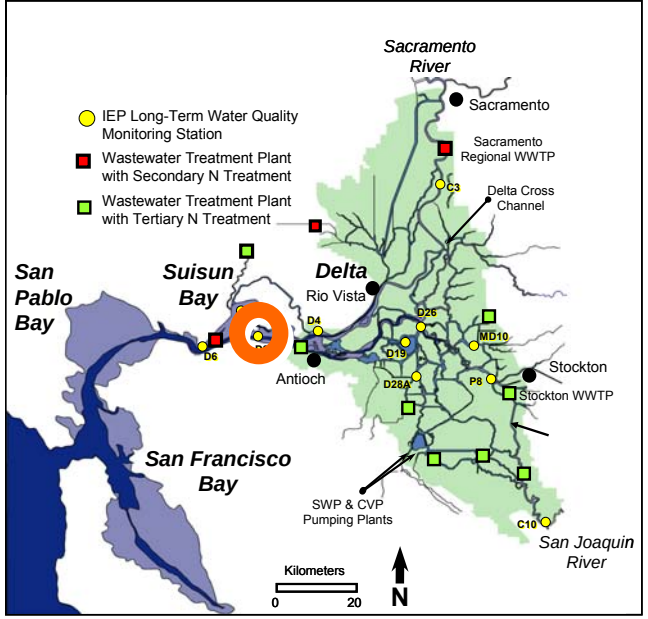
- Sacramento River is dominant water source in north & central Delta
- Seasonal differences
- Differences between (water) years

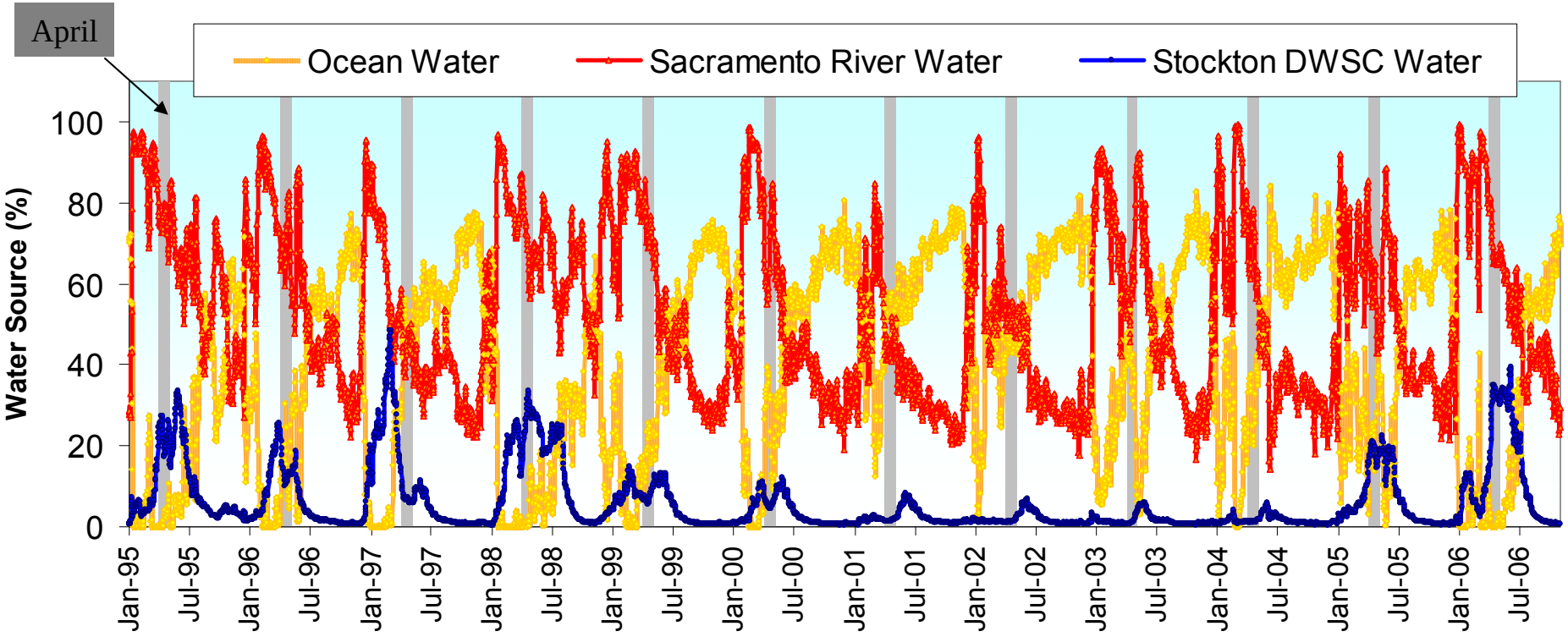




A. Mueller-Solger, unpublished; Volumetric source water "fingerprints" generated with DSM2 by Bob Suits, DWR

- Suisun Bay: Sacramento River water in winter & spring, ocean water in summer & fall



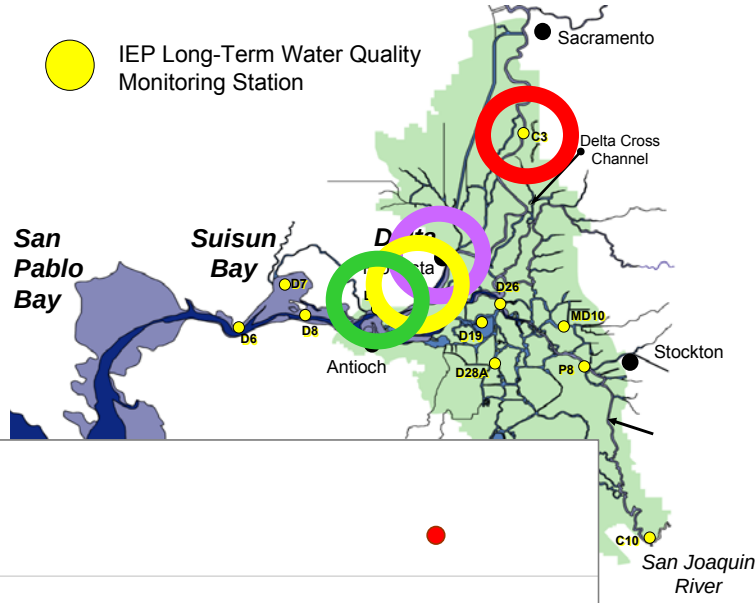


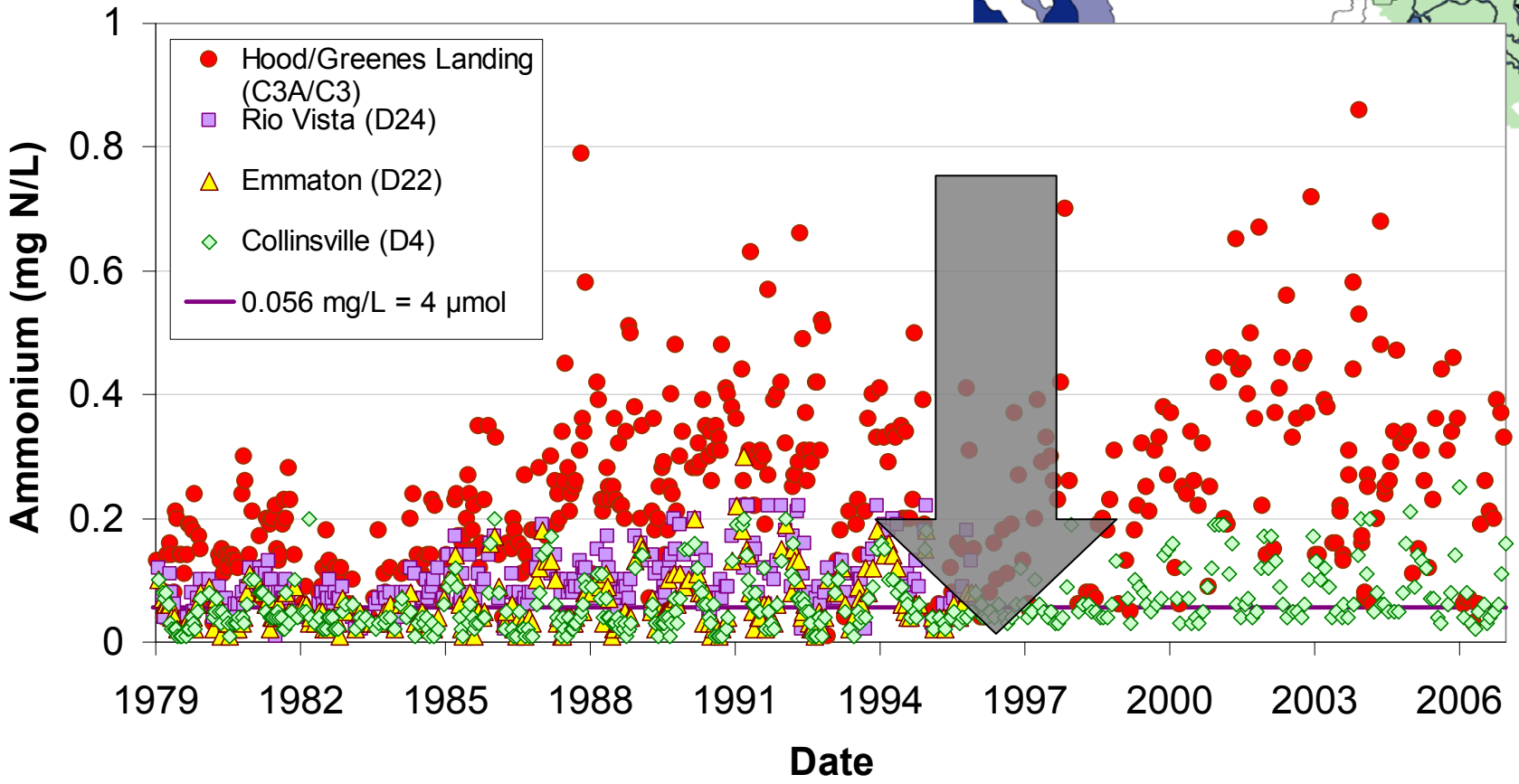
A. Mueller-Solger, unpublished; Volumetric source water "fingerprints" generated with DSM2 by Bob Suits, DWR

A. **Sources, concentrations, fate, transport**

Not conservative!

Physics, Chemistry & Biology





A. **Sources**, **concentrations**, **fate**, **transport**

Some outstanding questions (*see report*):

- Relative NH source contributions?
- Transport under varying hydrological conditions?
- Physical, chemical, and biological processes that affect NH distribution and concentrations?

A. **Sources**, **concentrations**, **fate**, **transport**

Some ongoing POD Work (Universities, NCEAS):

- Data compilation
- Data analysis
- Rate measurements
- Fate & Transport Modeling

New work:

- F&T Modeling with DSM2 – RMA/SWC
- Additional monitoring – Water Boards

Summary of Ammonia/um Investigations

Topic Areas (*following report*):

A. **Sources, concentrations, fate, transport**

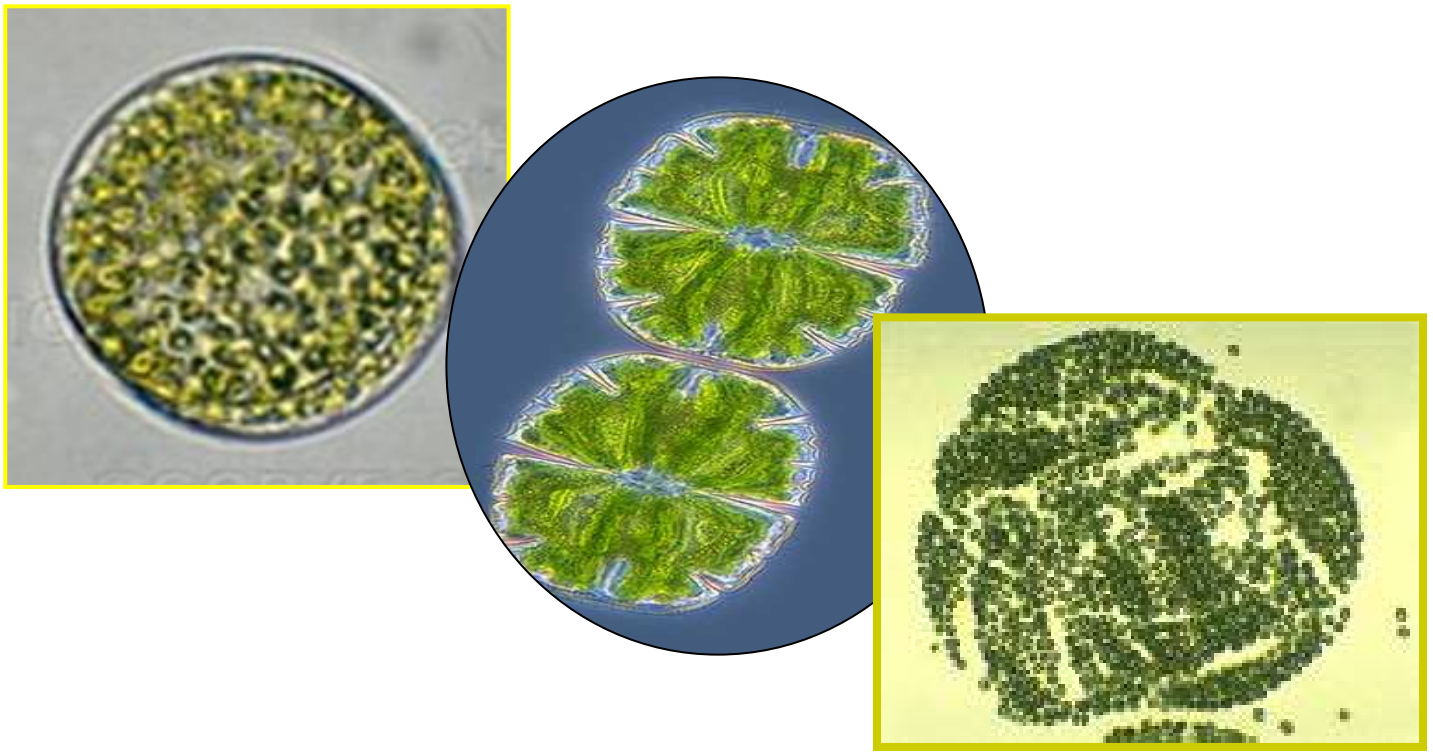
B. Food web effects

C. Toxicity to Delta fish and invertebrates

Food Web Effects - Phytoplankton

Phytoplankton production, biomass and composition in the Delta & Suisun Bay

Light, flow, transport, nutrients



Phytoplankton Primary Production

… is related to Fisheries Yields in many Marine Systems (Nixon 1988)

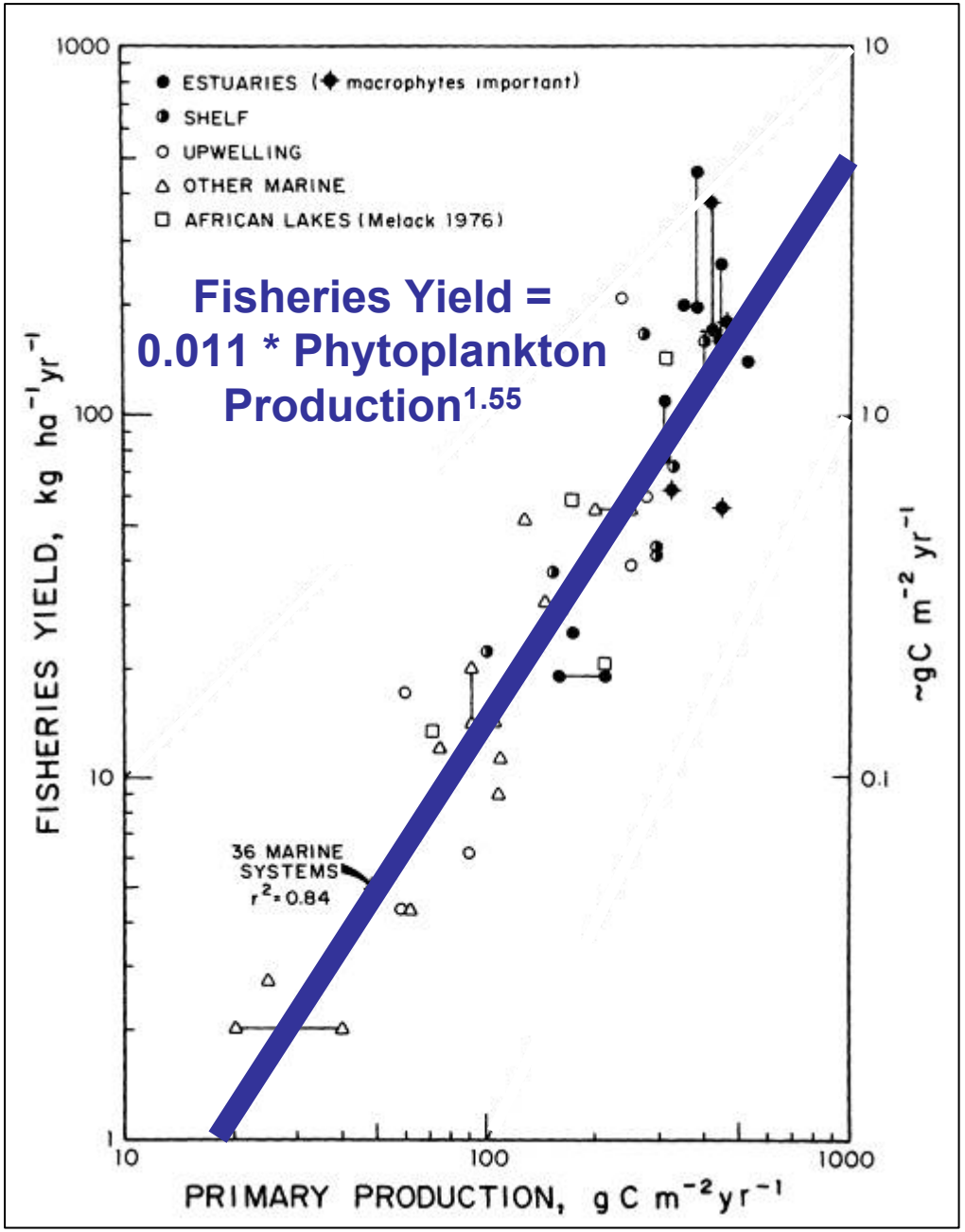
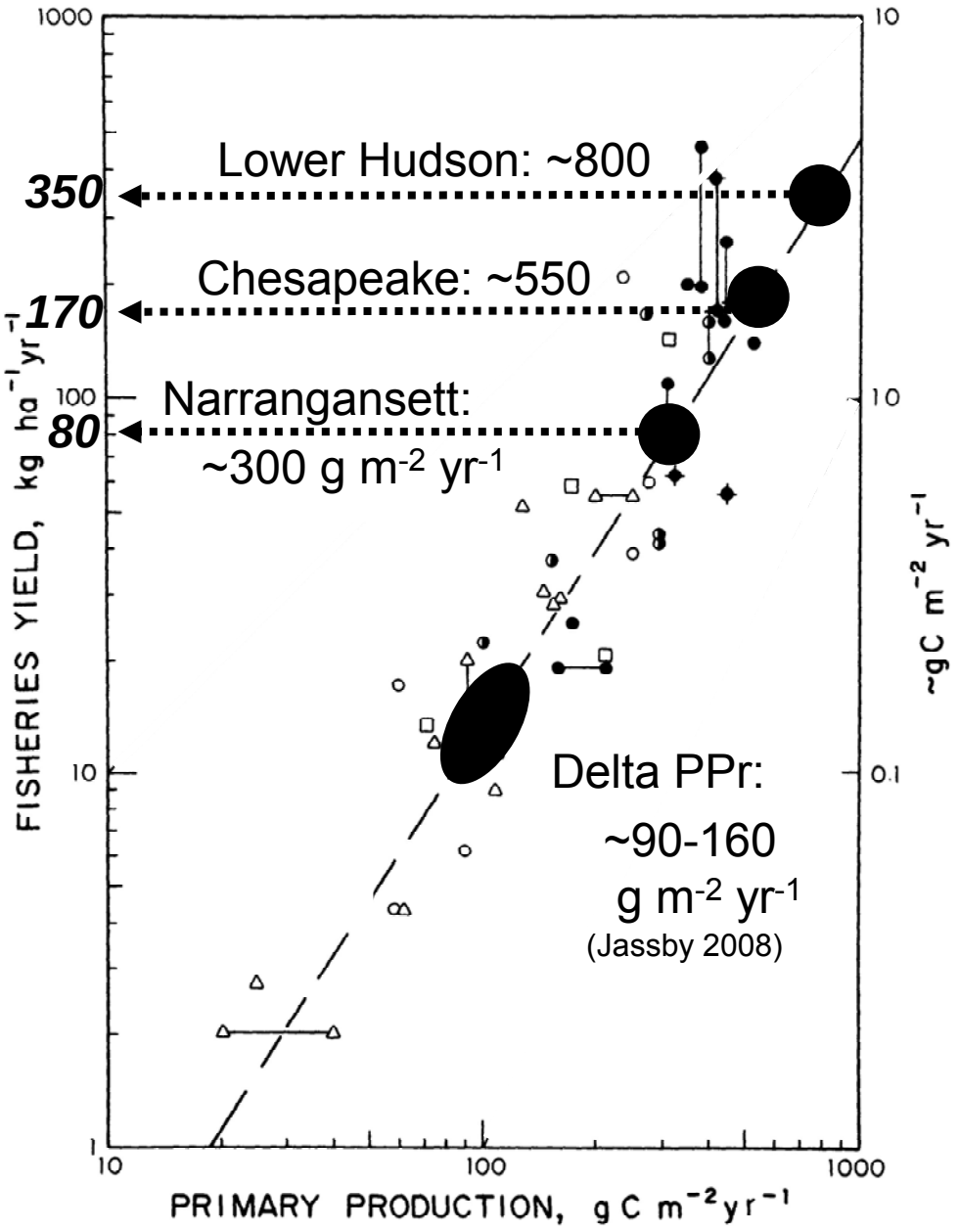


Figure 6 in Nixon 1988

Phytoplankton Primary Production

… in the Delta & Suisun Bay is lower than in many other estuaries

Fig. 7



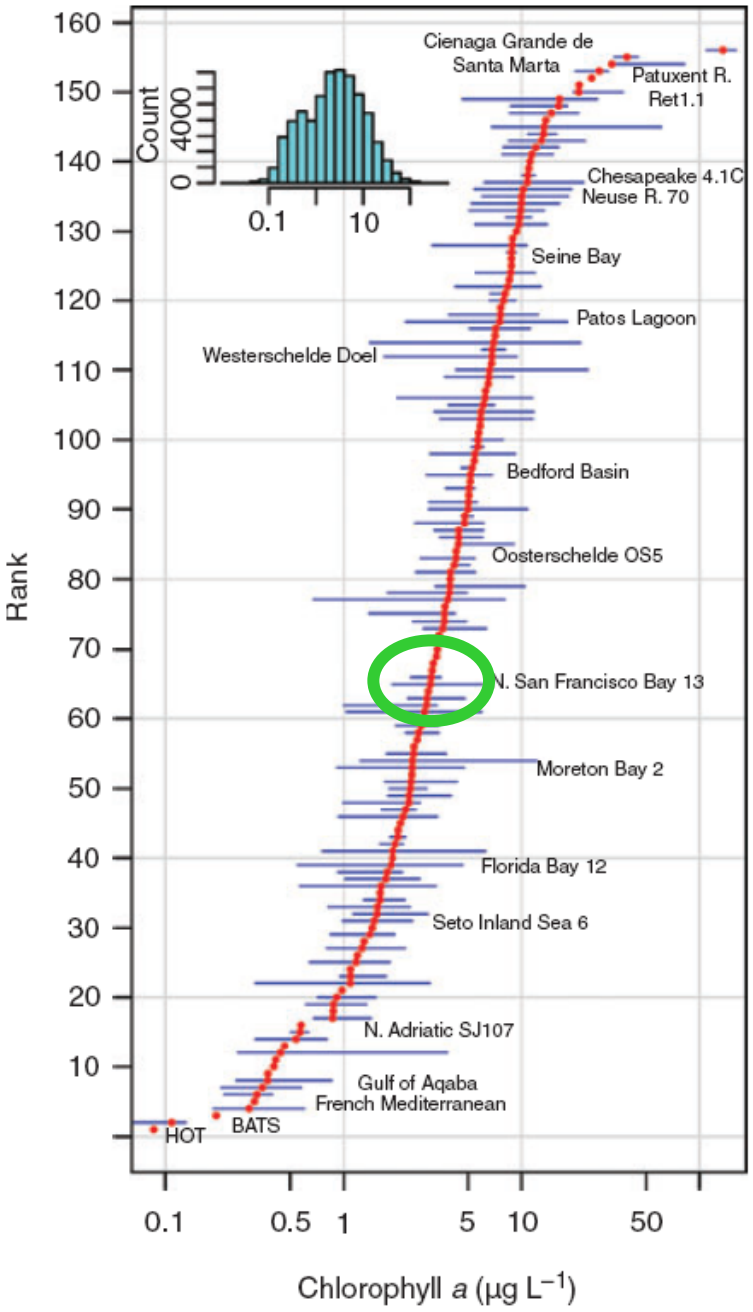


Fig. 1 in Cloern & Jassby 2008, Ecol Letters
(Medians & ranges, 156 sites)

Typical Coastal Phytoplankton Biomass: 1-10 µg Chl a/L

Delta & Suisun Bay:

- Long-term declines
- Recent uptrends in Delta, but not in Suisun Bay
- Typically 2-3 µg Chl a/L (range 0 – 500)
- "High nutrient - Low Chl"

Lehman 2002, 2004
Jassby et al 2002
Cloern et al 2007
Jassby 2008

Mechanisms affecting Delta phytoplankton production & biomass

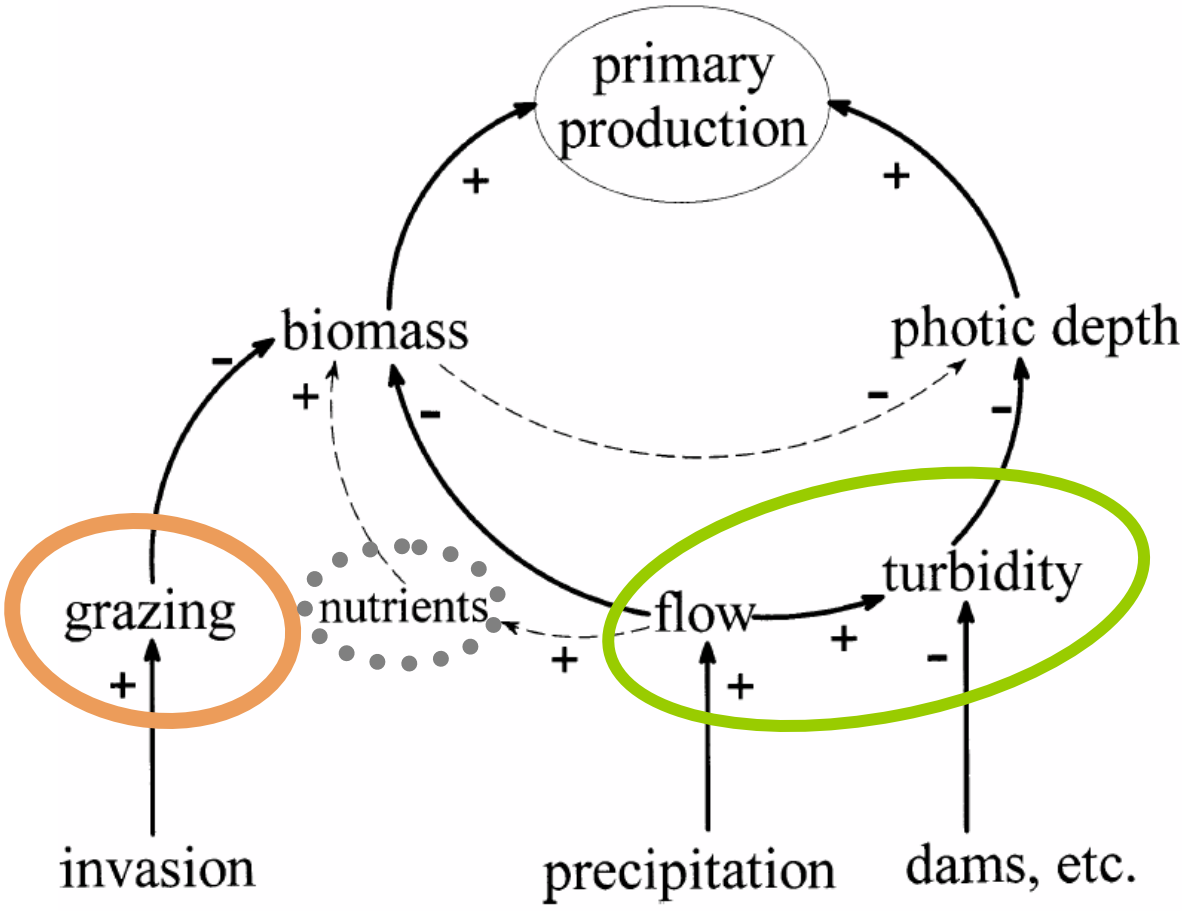
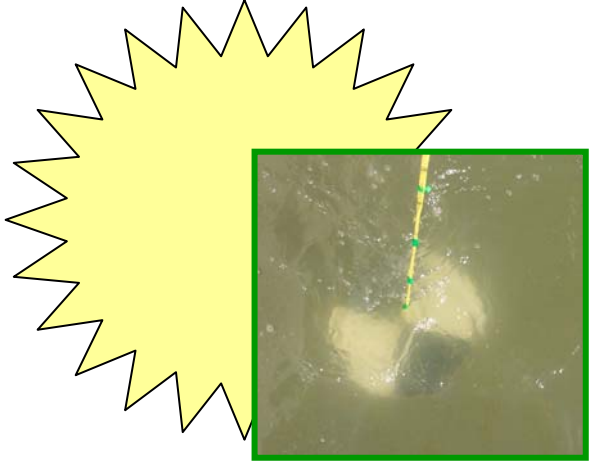


Fig. 12 in Jassby et al 2002

Habitat connectivity is also important (e.g. Cloern 2007)

Light:

Phytoplankton primary production needs “starting biomass” & light



Phytoplankton production in estuaries is highly correlated with phytoplankton biomass, light, and photic zone depth

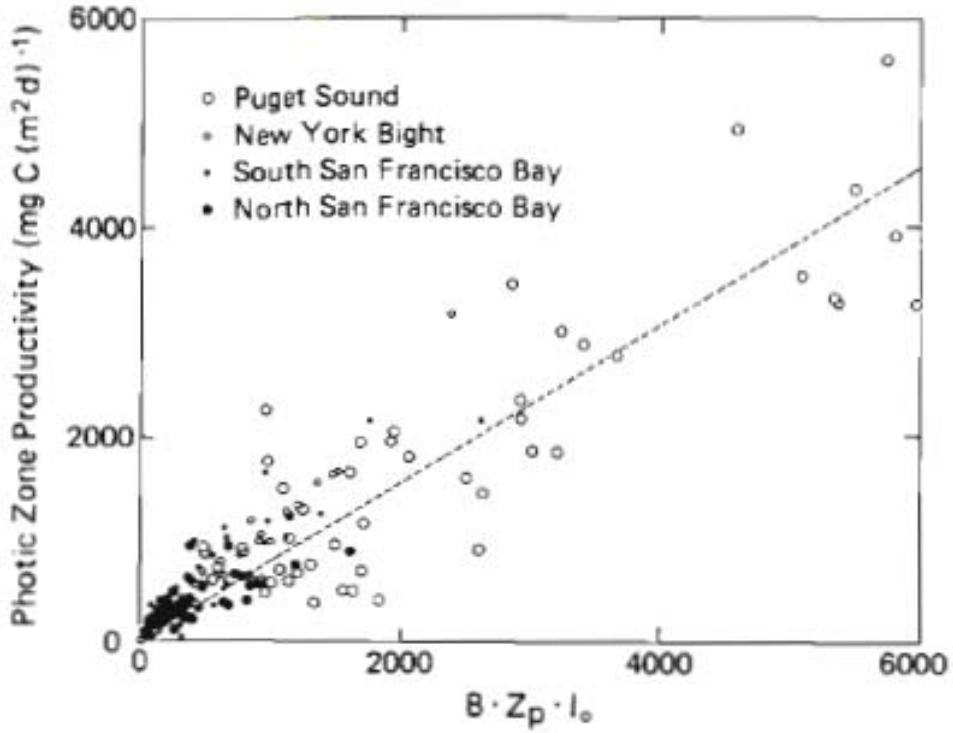


Fig. 2. Regression of photic zone productivity against the composite parameter $B Z_P I_o$ for 211 incubation experiments. $P = 150 + 0.73 (B Z_P I_o)$; $r^2 = 0.82$; S_{yx} (standard error of the estimate) = 410

Fig. 2 in Cole & Cloern 1987

Grazing:

Phytoplankton Biomass & Primary Production

… CRASHED in Suisun Bay right after the 1987 *Corbula* invasion

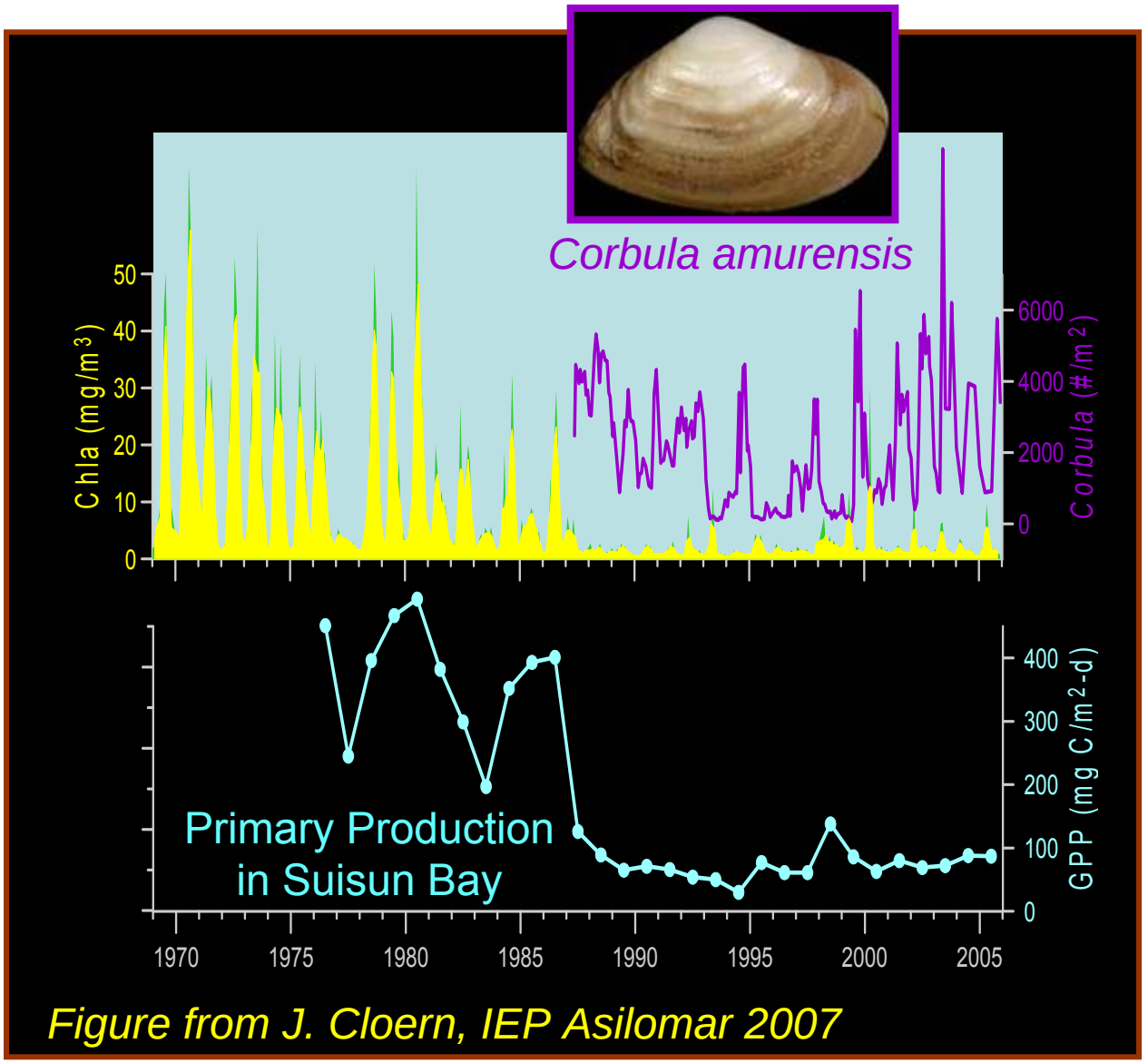


Figure from J. Cloern, IEP Asilomar 2007

Flow:

Less flow, more phytoplankton

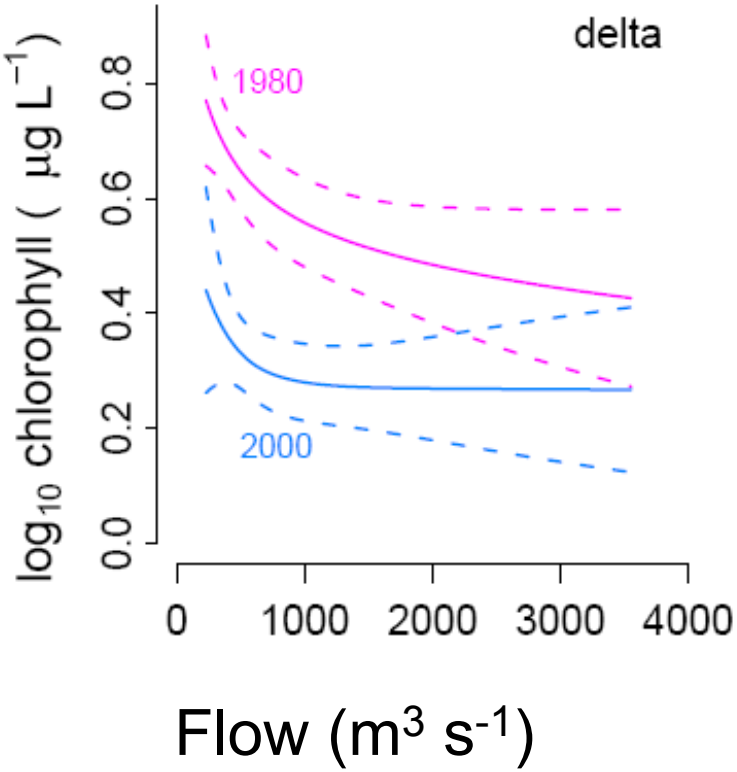


Fig. 10 in Jassby 2008

… & in the San Joaquin River, too

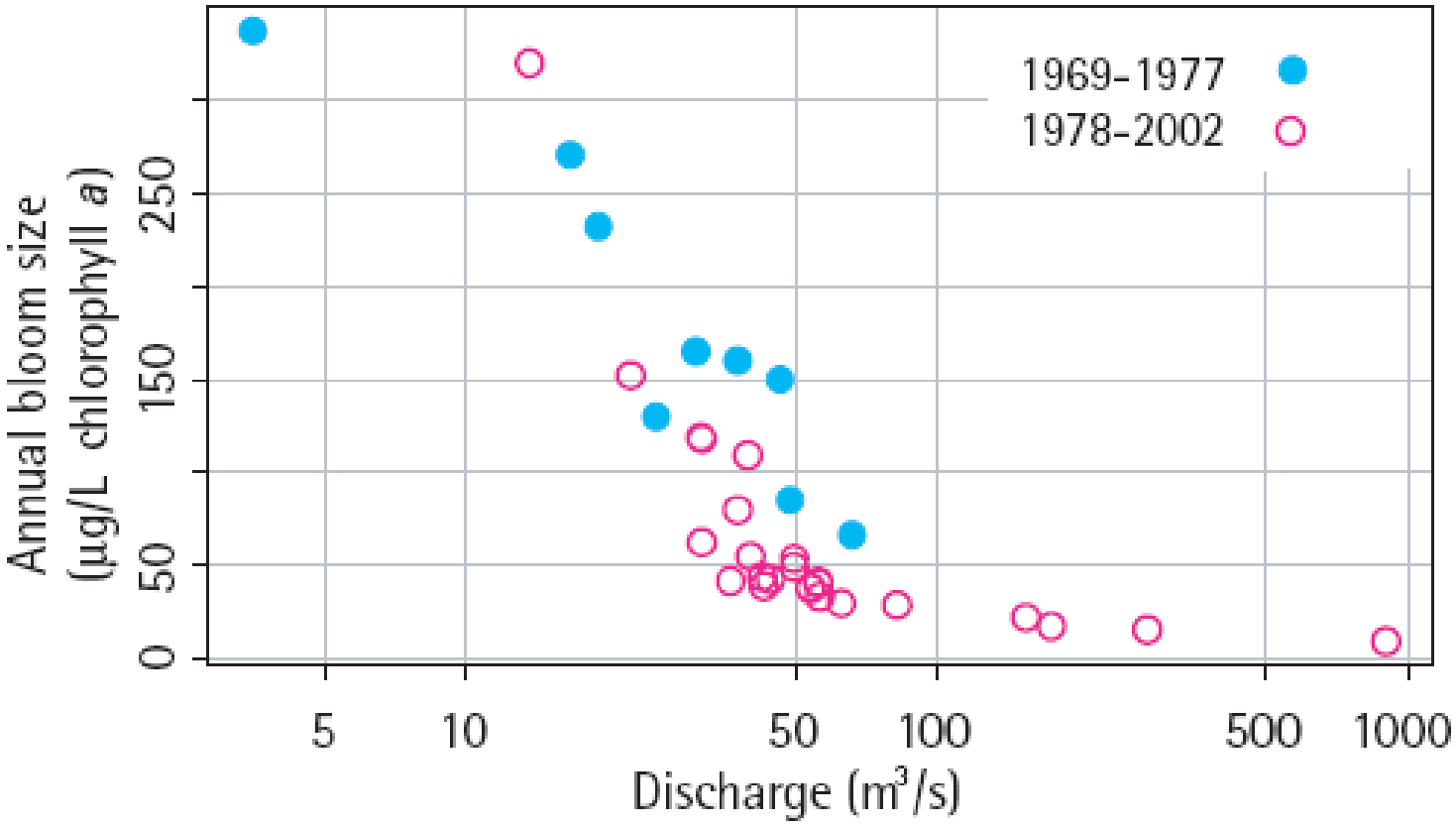


Fig. 8 in Jassby 2005

MUCH more on flow & phytoplankton:
L. Lucas, N. Monsen, W. Kimmerer…

An exception: Suisun Bay in the 2000s
Less flow, LESS phytoplankton

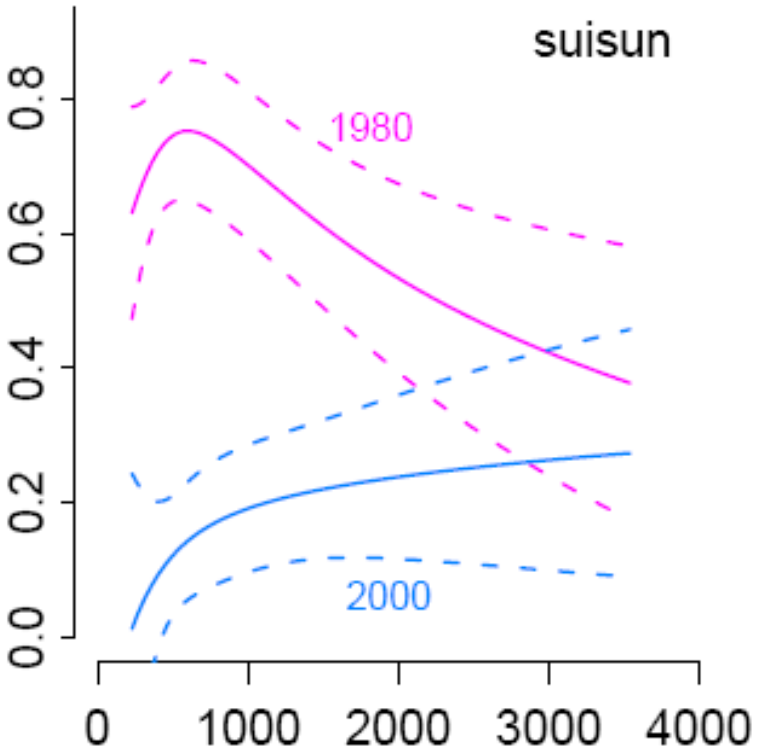
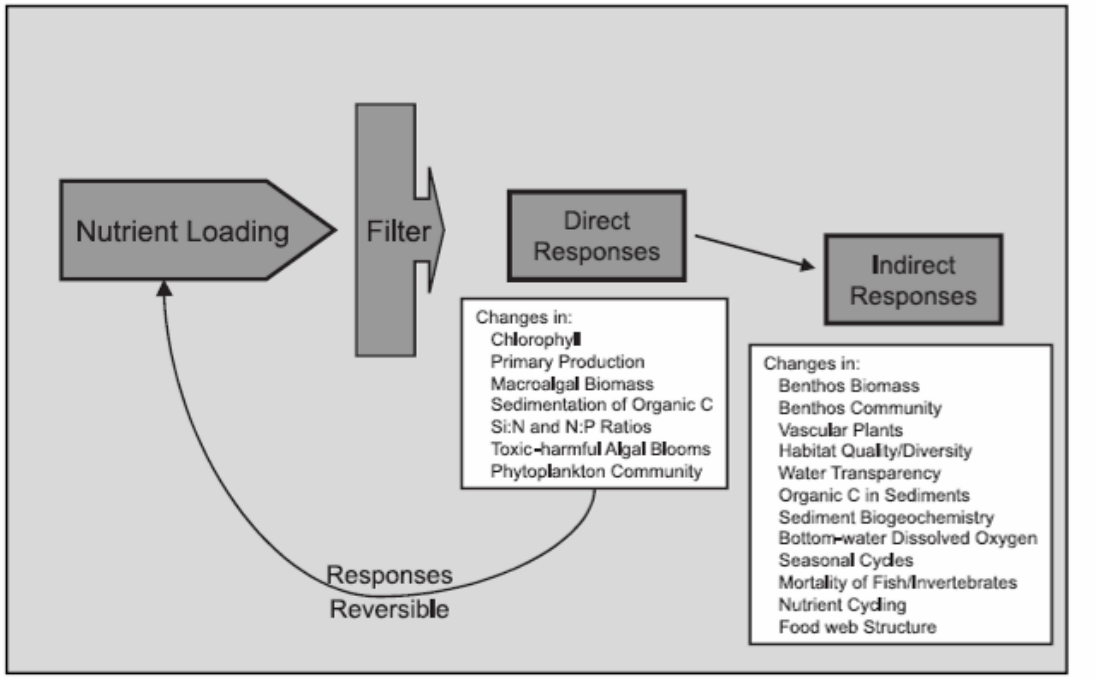


Fig. 10 in Jassby 2008

Turbidity, grazing, flow provide eutrophication "filter"

Eutrophication: "*A myriad biogeochemical and ecological responses, either direct or indirect, to anthropogenic fertilization of ecosystems at the land-sea interface*." (Cloern, MEPS 2001)

Filter causes different sensitivity of coastal systems to eutrophication ***- SFE is not very sensitive***



Filter: e.g. turbidity, benthic grazers, tidal energy, transport & residence times

So never mind nutrients?

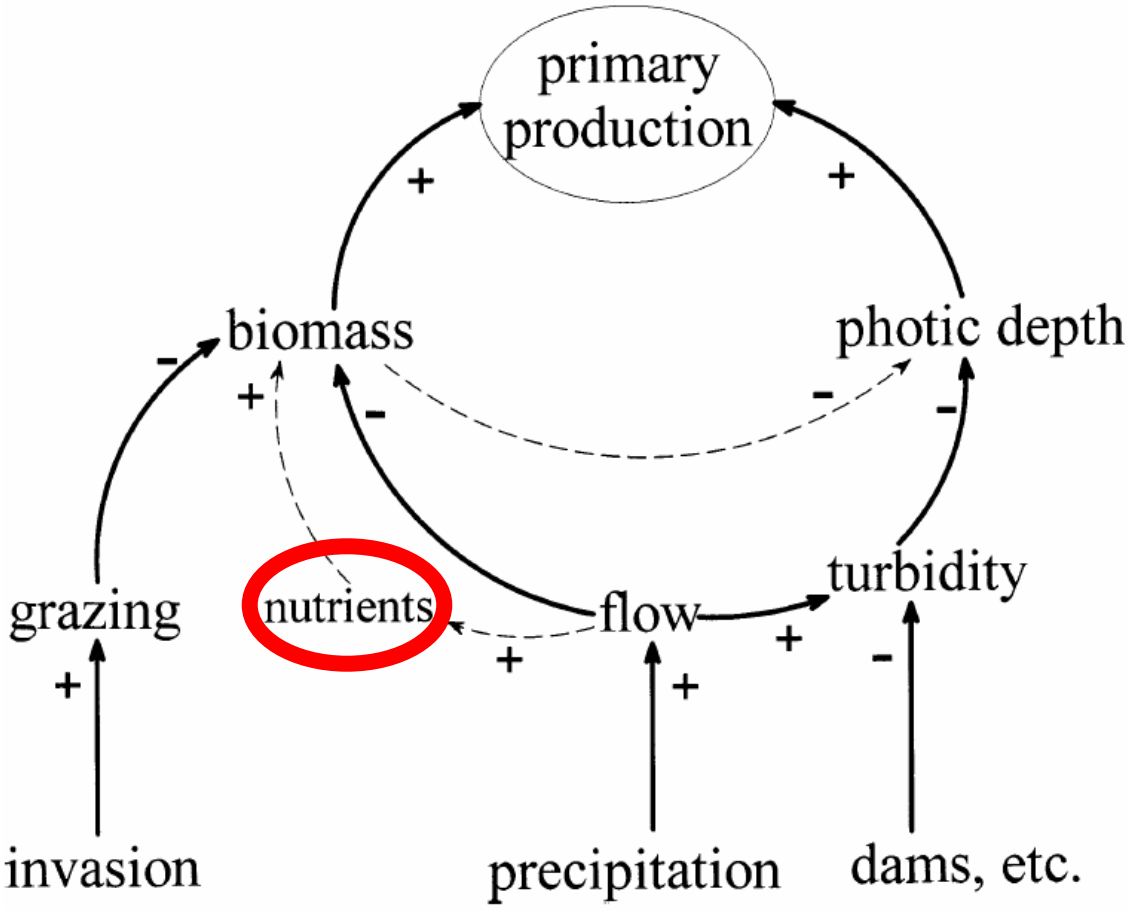
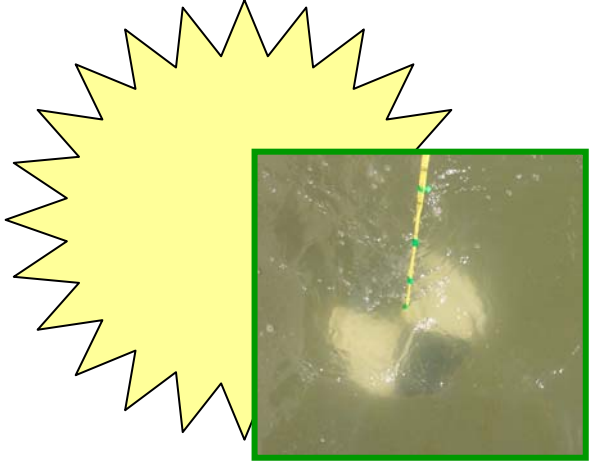


Fig. 12 in Jassby et al 2002

Recent work:

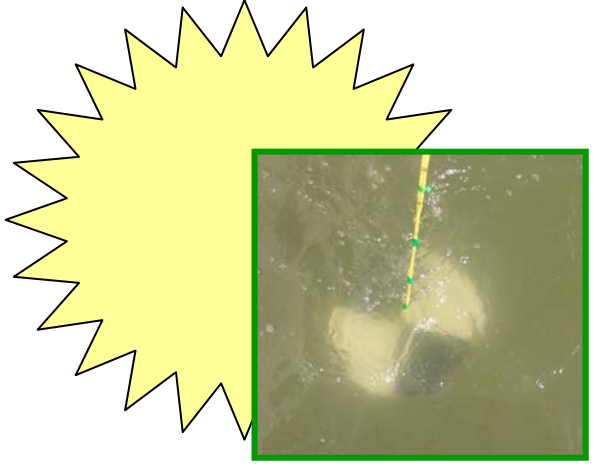


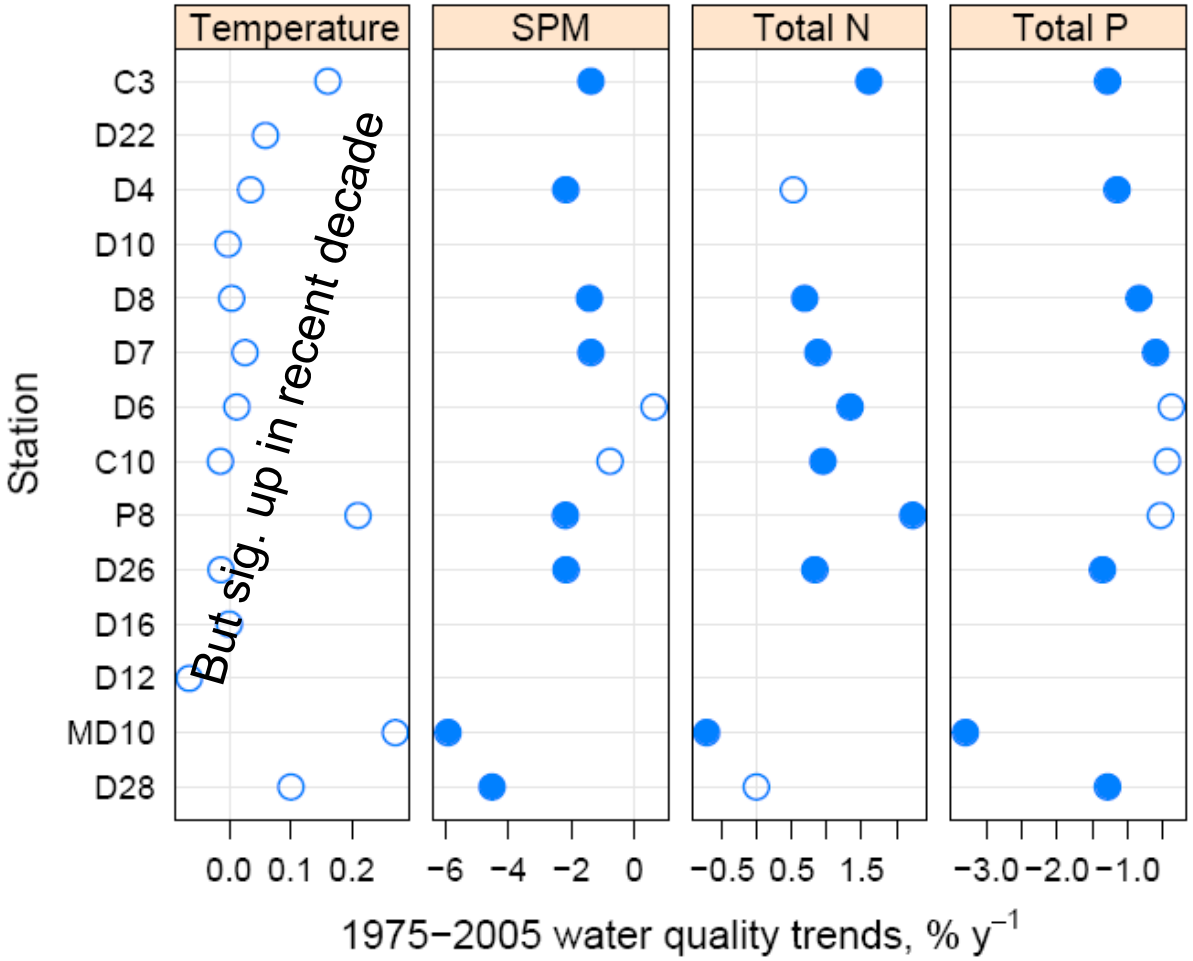
nutrients may matter

– **when light doesn't**

- Dugdale et al 2007, Wilkerson et al 2006: N
- Van Nieuwenhuyse 2007: P
- Cloern 2007: in shallow habitats

Recent work: nutrients may matter – **when light doesn't**



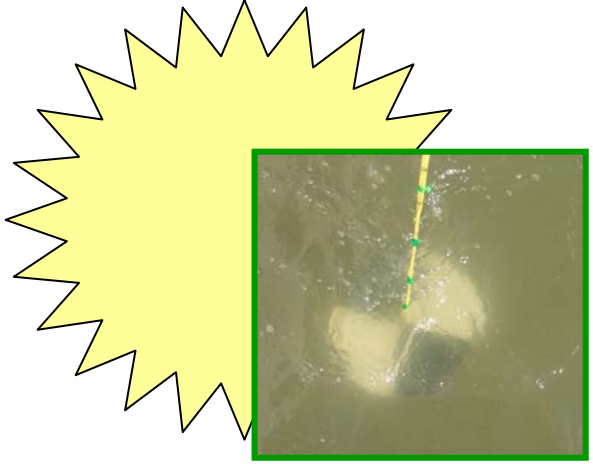


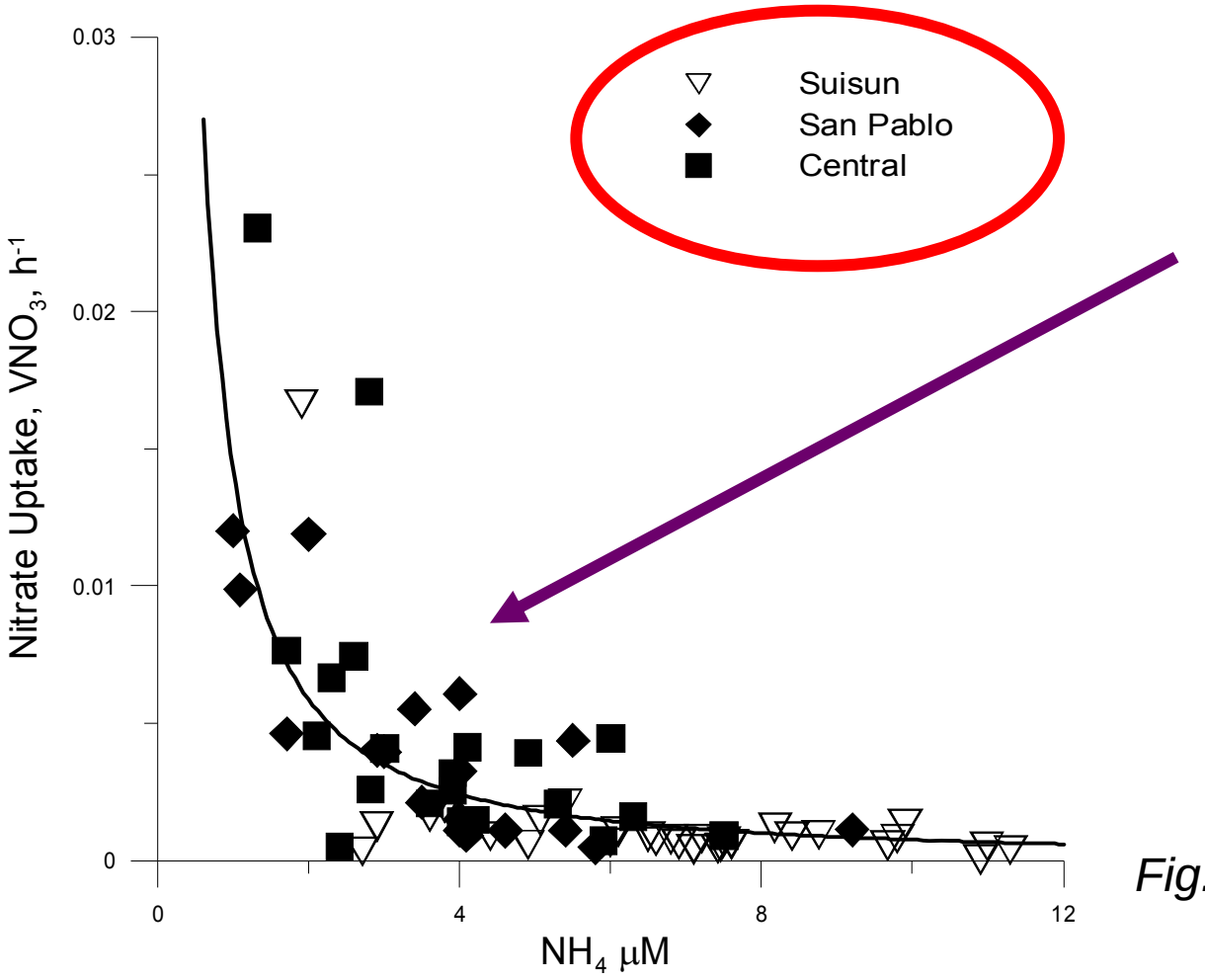
- **Turbidity (SPM) has decreased**
- N has increased
- P has decreased
- Shallow habitat restoration

Fig. 10 in Jassby 2008

Nitrate uptake inhibition hypothesis:

Ammonium inhibits nitrate uptake/growth, especially of **diatoms**





~ 90% inhibition at 4 µmol NH_4-N

(=0.06 mg/L)

Fig. 3 in Dugdale et al 2007

Ammonium levels in the Delta and Suisun Bay are on the rise and mostly > 4 µmol

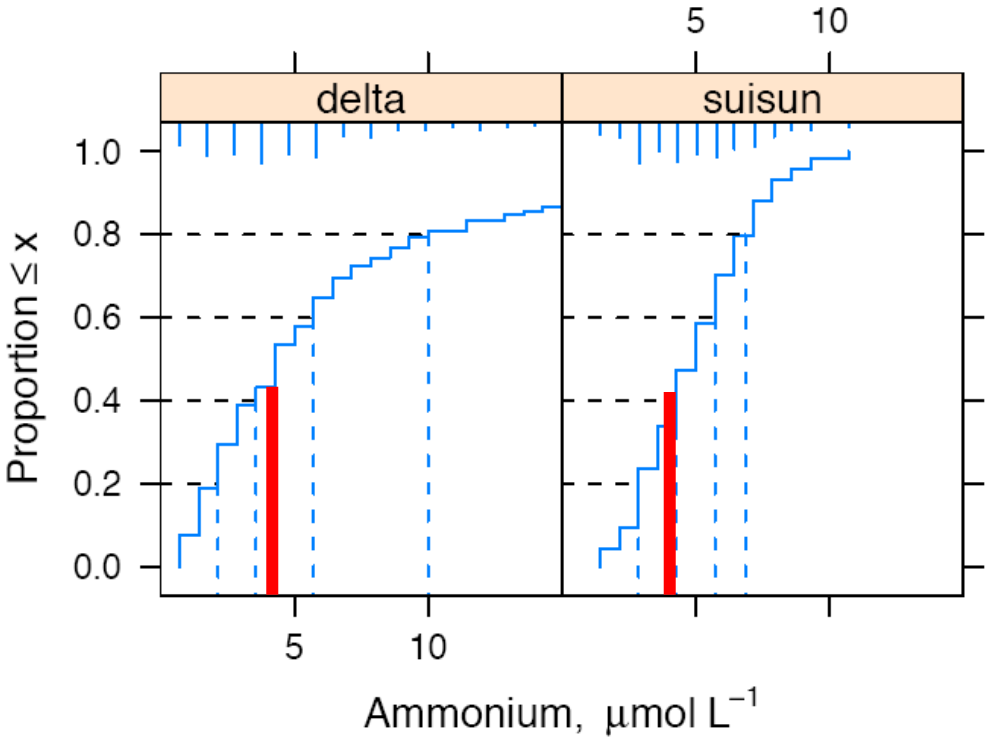


Figure 14. Empirical cumulative distribution of ammonium concentrations during March–June 1996–2005 at delta- and suisun-mode stations. A spike histogram of the data is included above each plot.

Jassby 2008

Long-term declines in diatoms

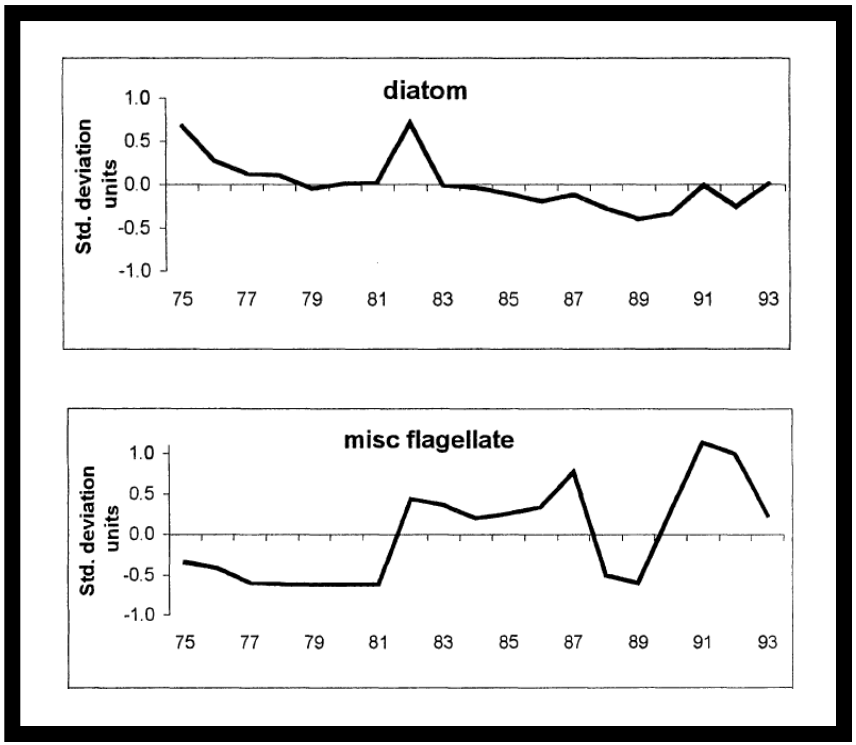


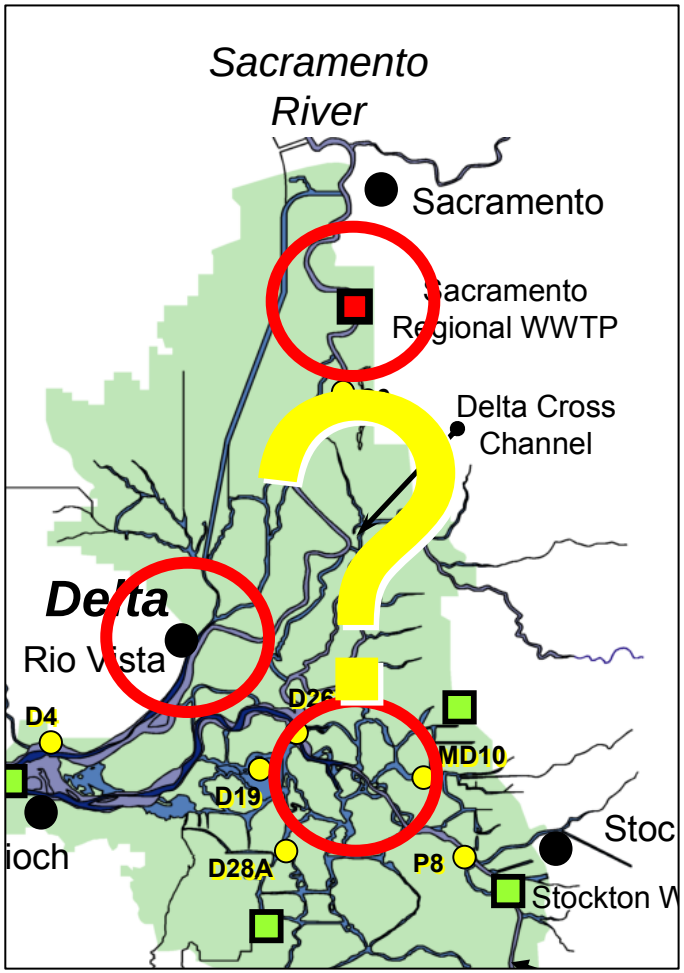
Fig. 3 in Lehman 2000, Limnol. & Oceanogr.

Suisun Bay	1970s	2000s	
Taxon	Ave. Abund	Ave. Abund	Ave. Diss
Thalassiosira	0.90	0.08	15.46
Cyclotella	0.70	0.11	11.50
Skeletonema	0.51	0.08	8.00
Misc Flagellates	0.08	0.42	7.28

T. Brown, IEP-Asilomar 2008

2007-8 PILOT Phytoplankton Tests with river water (Dugdale et al, SFSU)

- Good phytoplankton growth at Freeport *(2 tests)*
- Very little growth in rivers downstream *(7 tests)*
- What's happening between Freeport and Rio Vista/the Delta?



Food Web Effects – Harmful Algal Blooms and Invasive Aquatic Species

???

On the rise:
Microcystis aeruginosa blooms

Toxic!

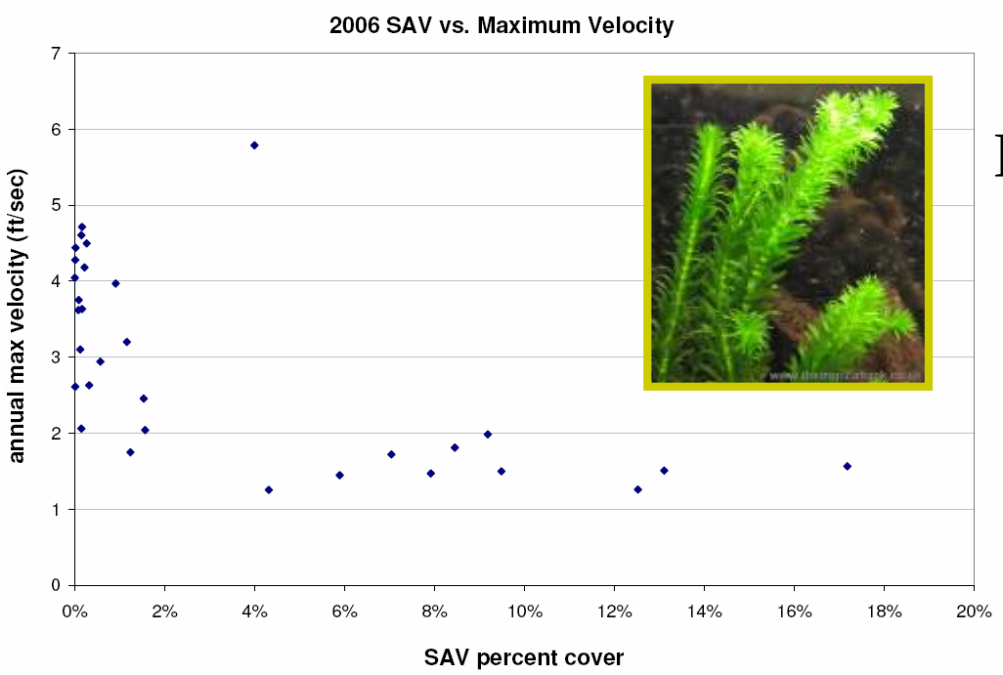
Bad food!

- Seasonal blooms since 1999, June-November
- Blooms peak in the central Delta in August and September (>20°C)
- Low **streamflow** strongly associated with high cell density in 2004; not nutrients
- 2007 & 2008 worst bloom years on record

P. Lehman, Hydrobiologia, 2005 and 2008, & pers. com.

Also on the rise: Invasive Aquatic Plants - *"Ecosystem engineers"*

Water hyacinth
(Eichhornia crassipes)



Brazilian waterweed
(Egeria densa)

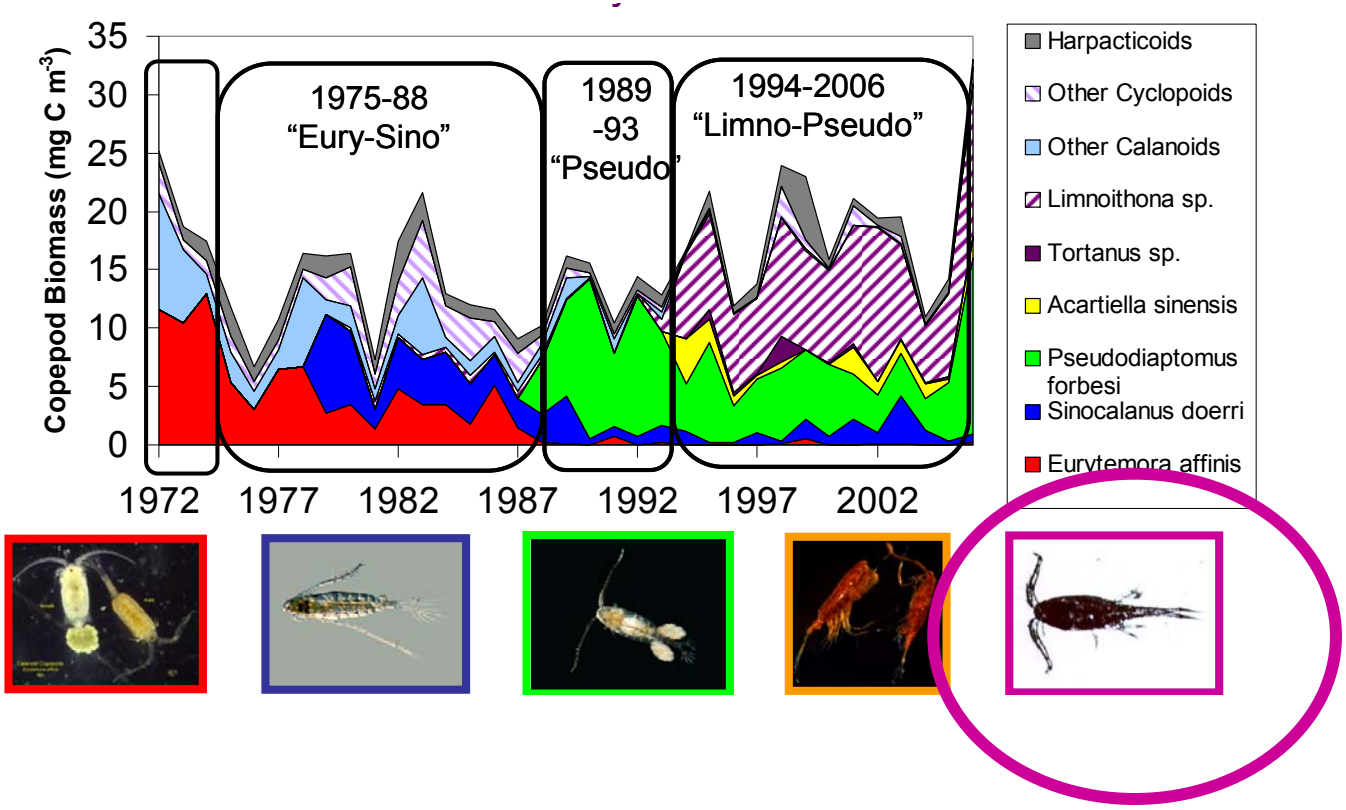
Schoellhamer & Hestir, IEP Asilomar 2008

- *Egeria* cover increased by 12-13% each year from 2004-2006
- Inversely correlated to **flow**

Effects up the food web? – Invasive Consumers

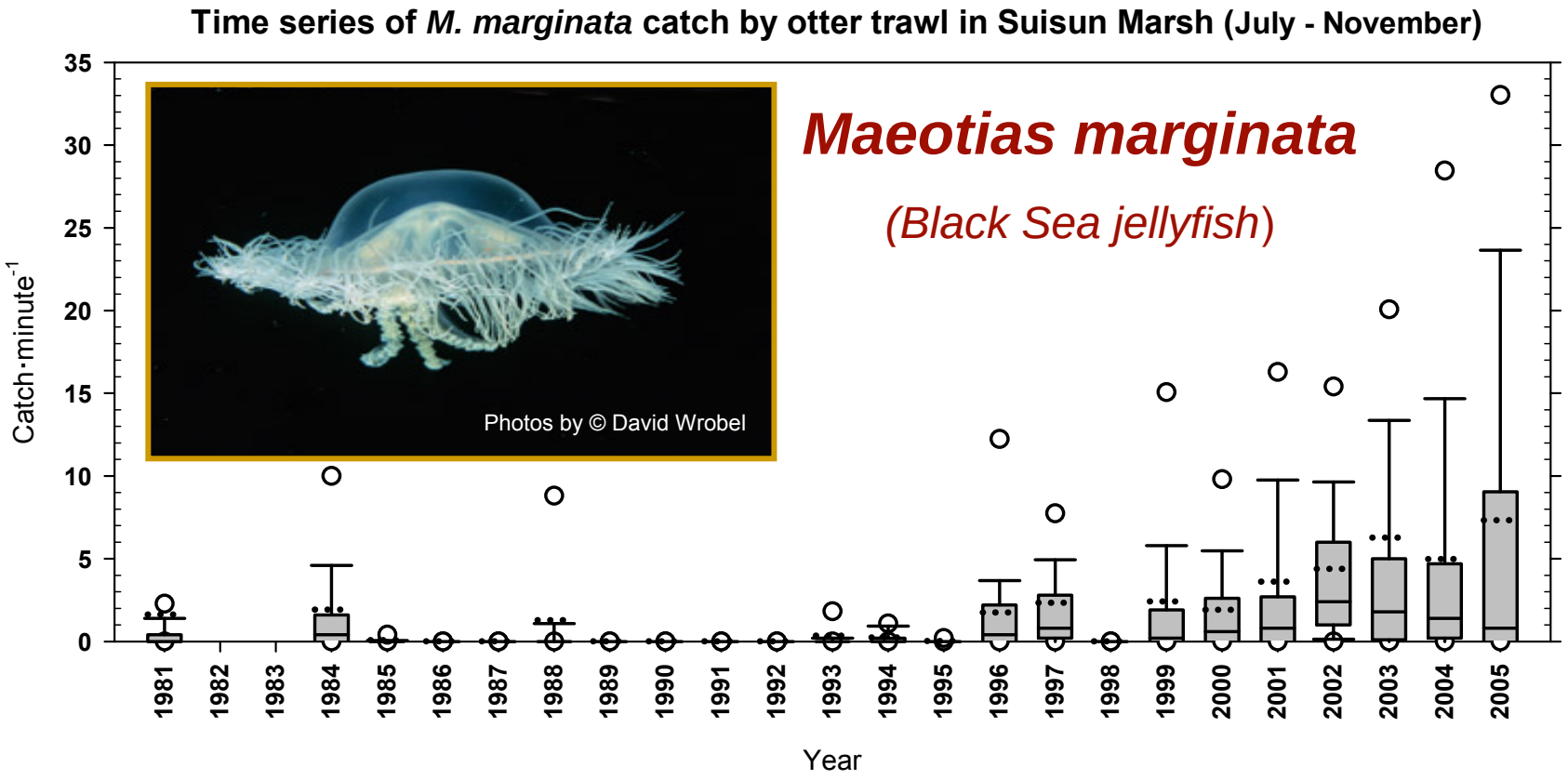
Zooplankton

More small cyclopoids



Effects up the food web? – Invasive Consumers

More Jellies

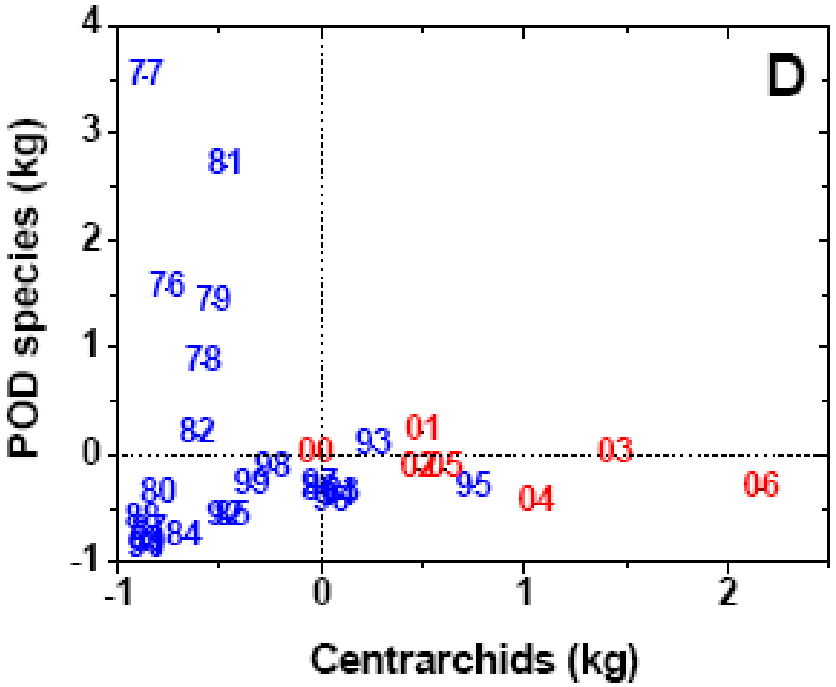


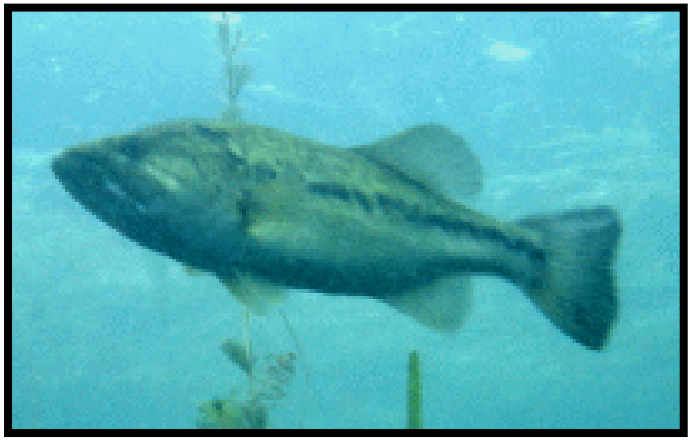
Source: PhD Dissertation Rob Schroeter, UCD

Effects up the food web? – Invasive Consumers

Fish

More centrarchids





Moyle & Bennett, PPIC 2008, Fig. D.2

Food web effects

Some ongoing POD Work (Universities, IEP agencies, SRWTP):

- Phytoplankton growth in “2 rivers” & the Delta
- Effluent exposures
- HAB studies
- Historical data analyses
- SAV remote sensing

New work:

- Phytoplankton growth in the lower Sacramento River/North Delta (SFSU/SWC)

Food web effects

Some outstanding questions (*see report*):

- Extent of NH inhibition of phytoplankton growth in the San Francisco estuary?
- Interactions with other factors?
- Phytoplankton growth responses to other nutrients, ratios
- NH effects on HABs in the Delta?
- NH effects on aquatic weeds in the Delta?
- NH effects up the food web?

Summary of Ammonia/um Investigations

Topic Areas (*following report*):

A. **Sources, concentrations, fate, transport**

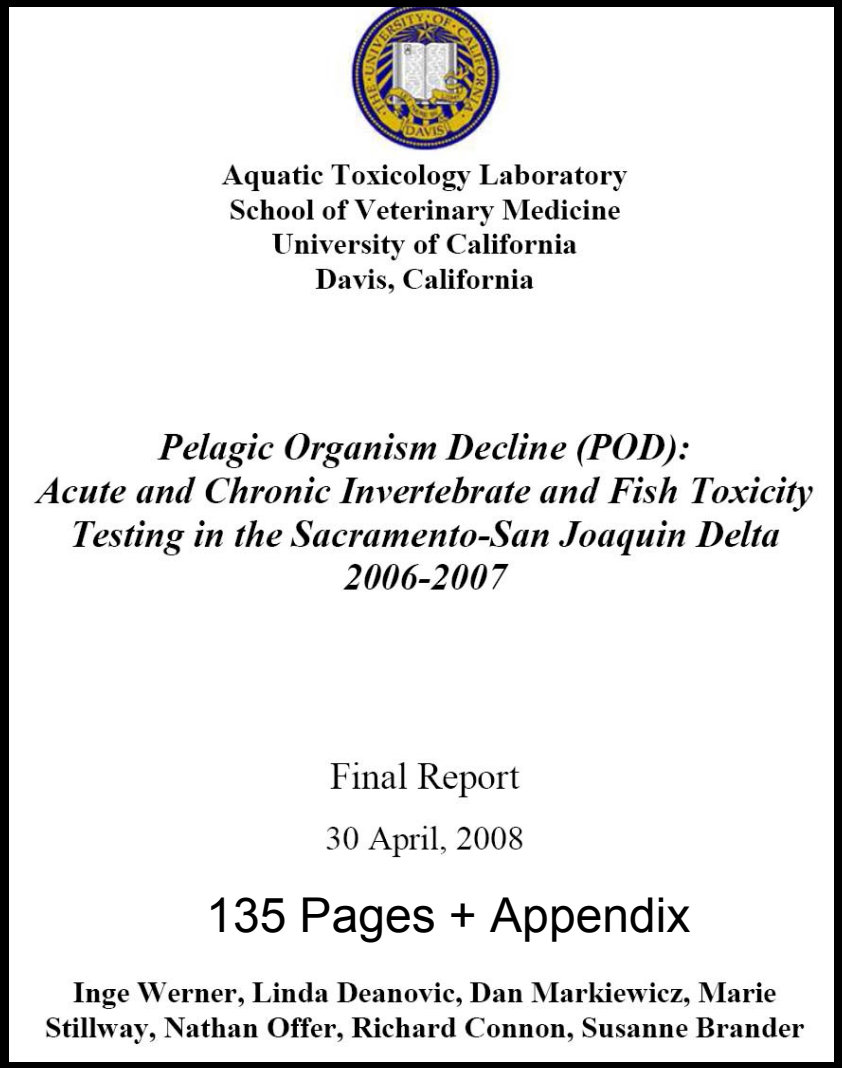
B. **Food web effects**

C. **Toxicity to Delta fishes and invertebrates**

Delta water toxicity to POD fishes and invertebrates

POD Toxicity Monitoring:

- *Hyalella azteca*
- Delta smelt
- Striped bass



Aquatic Toxicology Laboratory
School of Veterinary Medicine
University of California
Davis, California

Pelagic Organism Decline (POD):
Acute and Chronic Invertebrate and Fish Toxicity Testing in the Sacramento-San Joaquin Delta 2006-2007

Final Report

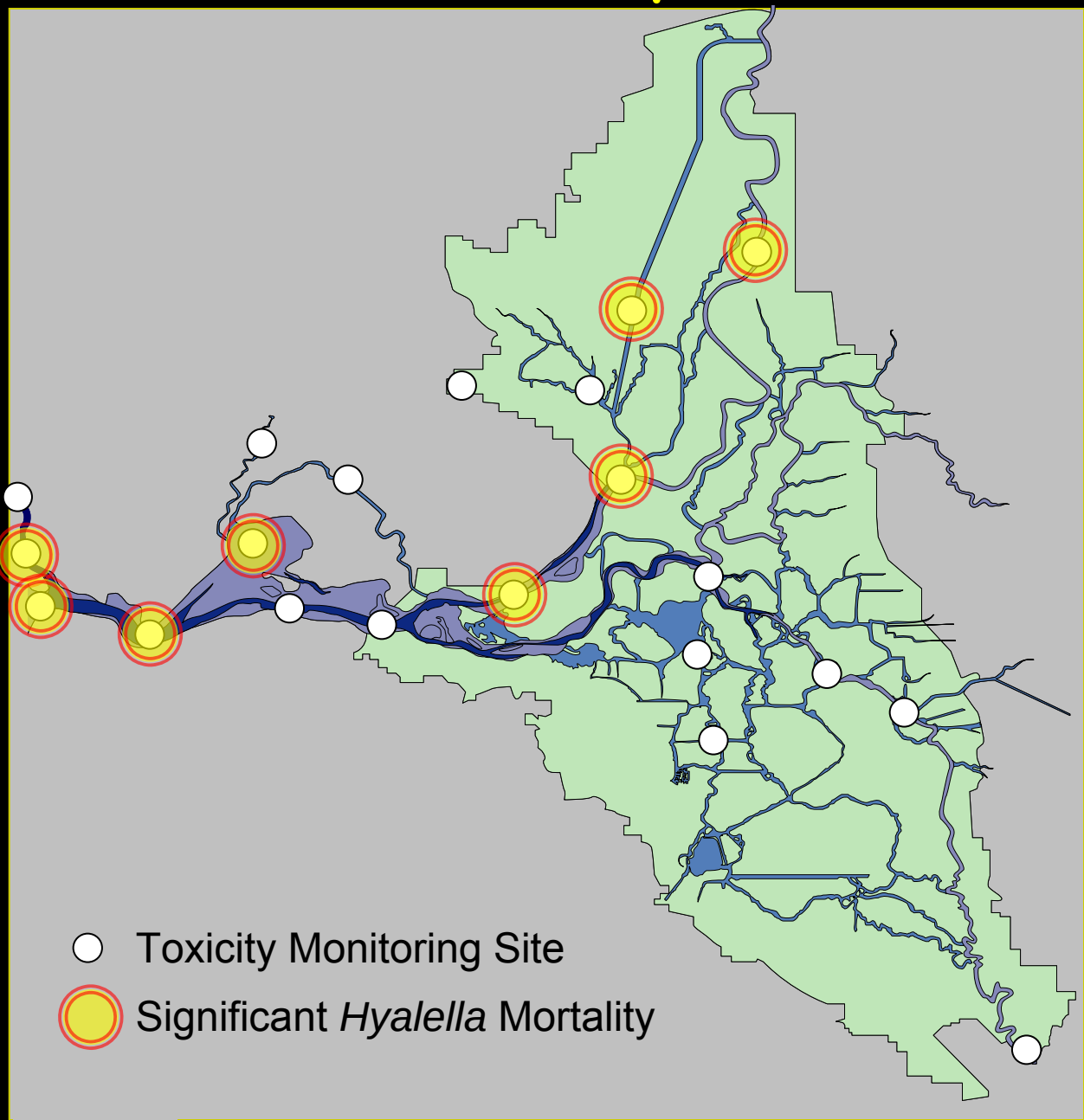
30 April, 2008

135 Pages + Appendix

Inge Werner, Linda Deanovic, Dan Markiewicz, Marie Stillway, Nathan Offer, Richard Connon, Susanne Brander

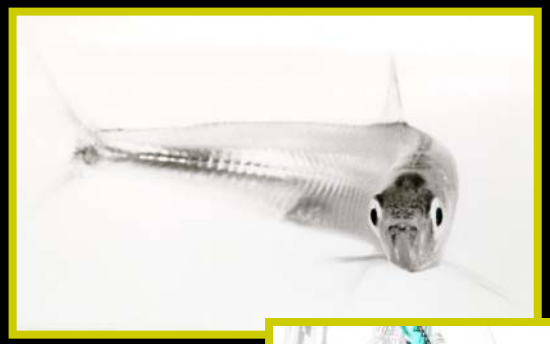
Mortality in 15 of 693 water samples (2.2%)

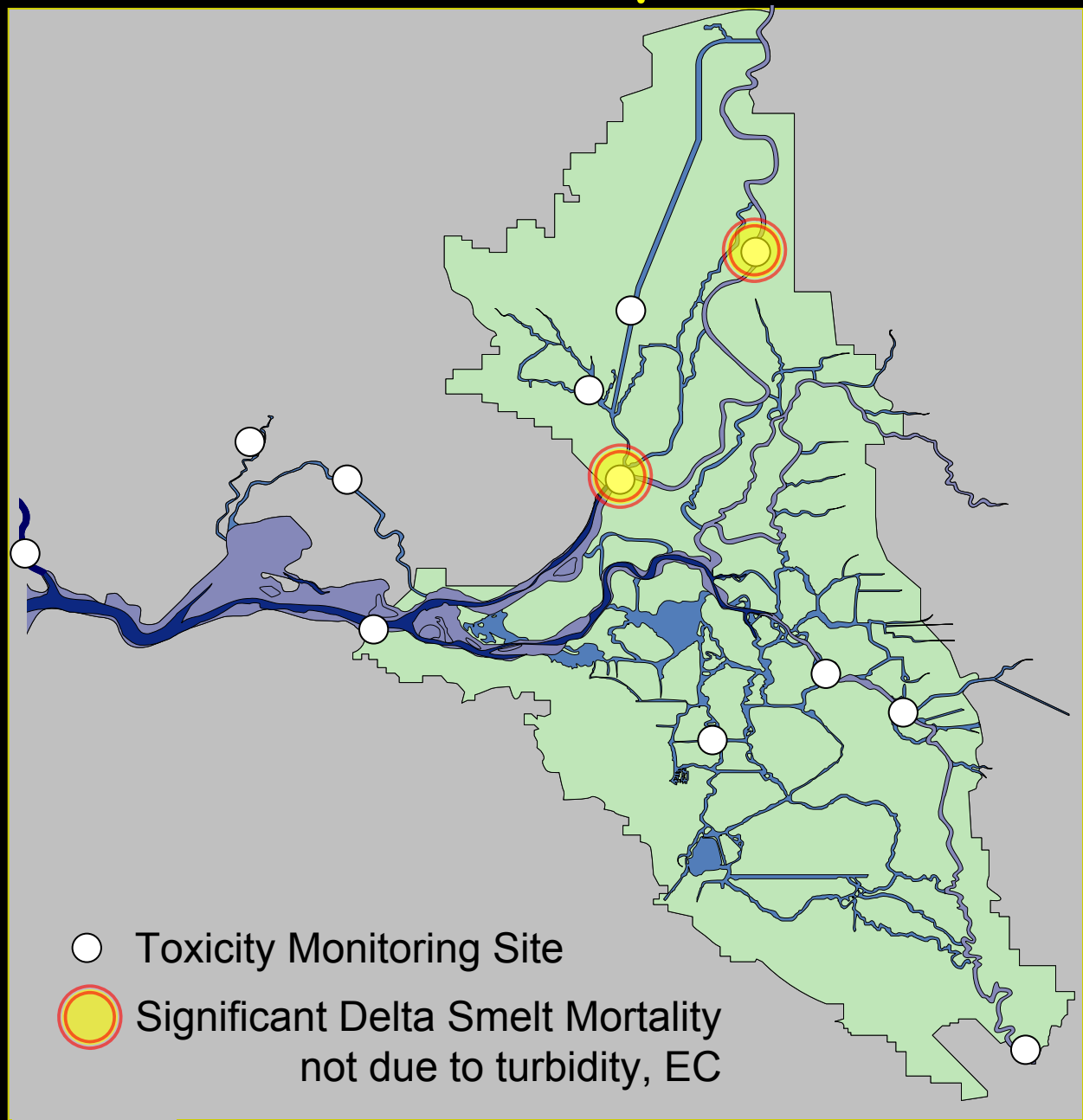
Hyalella azteca



Mortality in 2 of 71 water samples (3%)

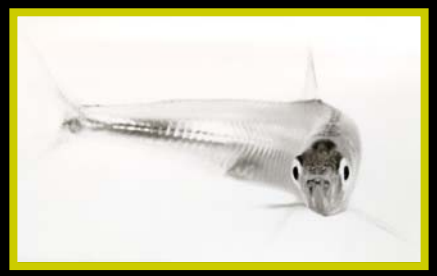
Delta smelt

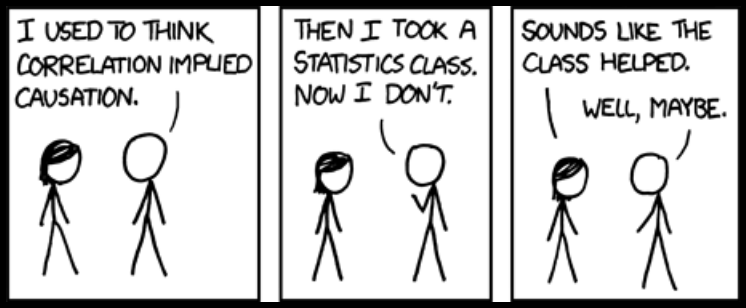




Could ammonia have anything to do with it?

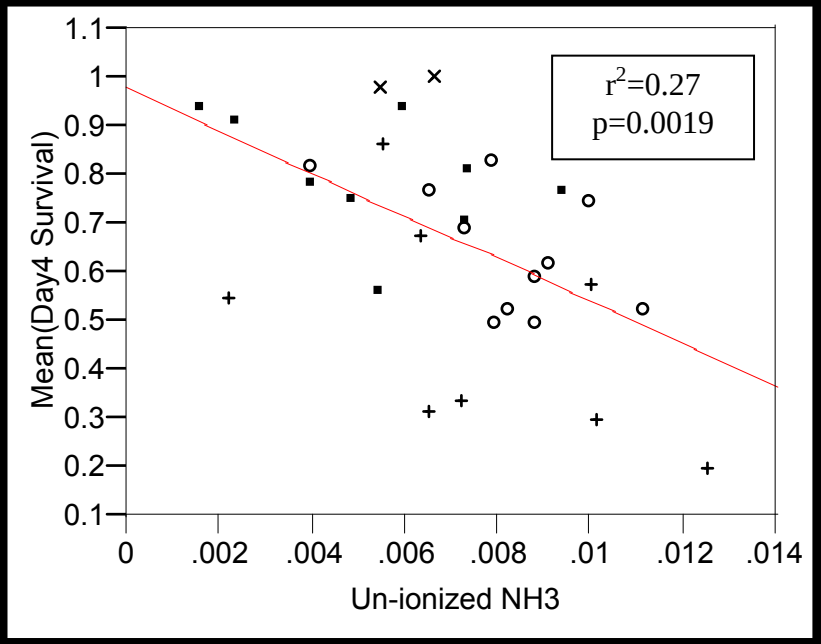
First ***correlative*** *findings:*



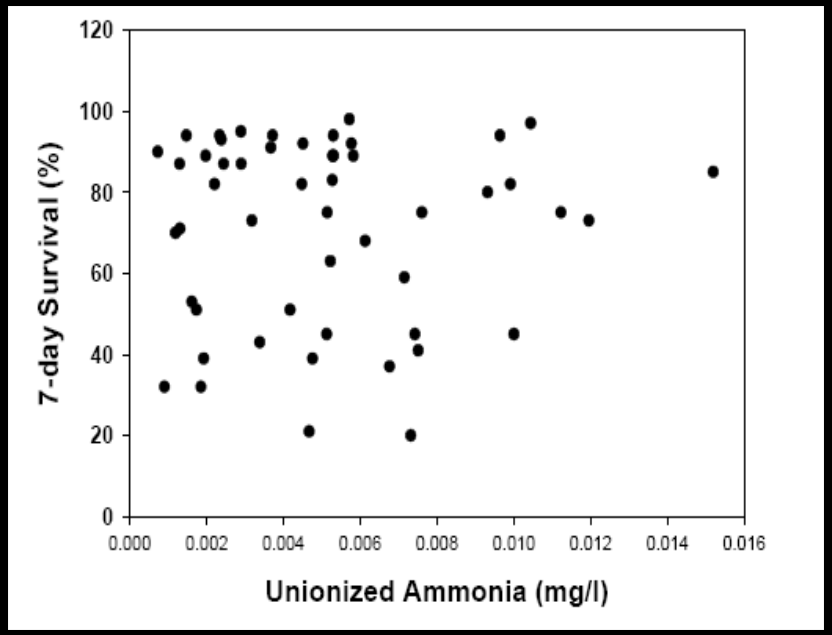


Negative relationship between un-ionized ammonia in ambient water & delta smelt survival in 2006, but not in 2007

2006

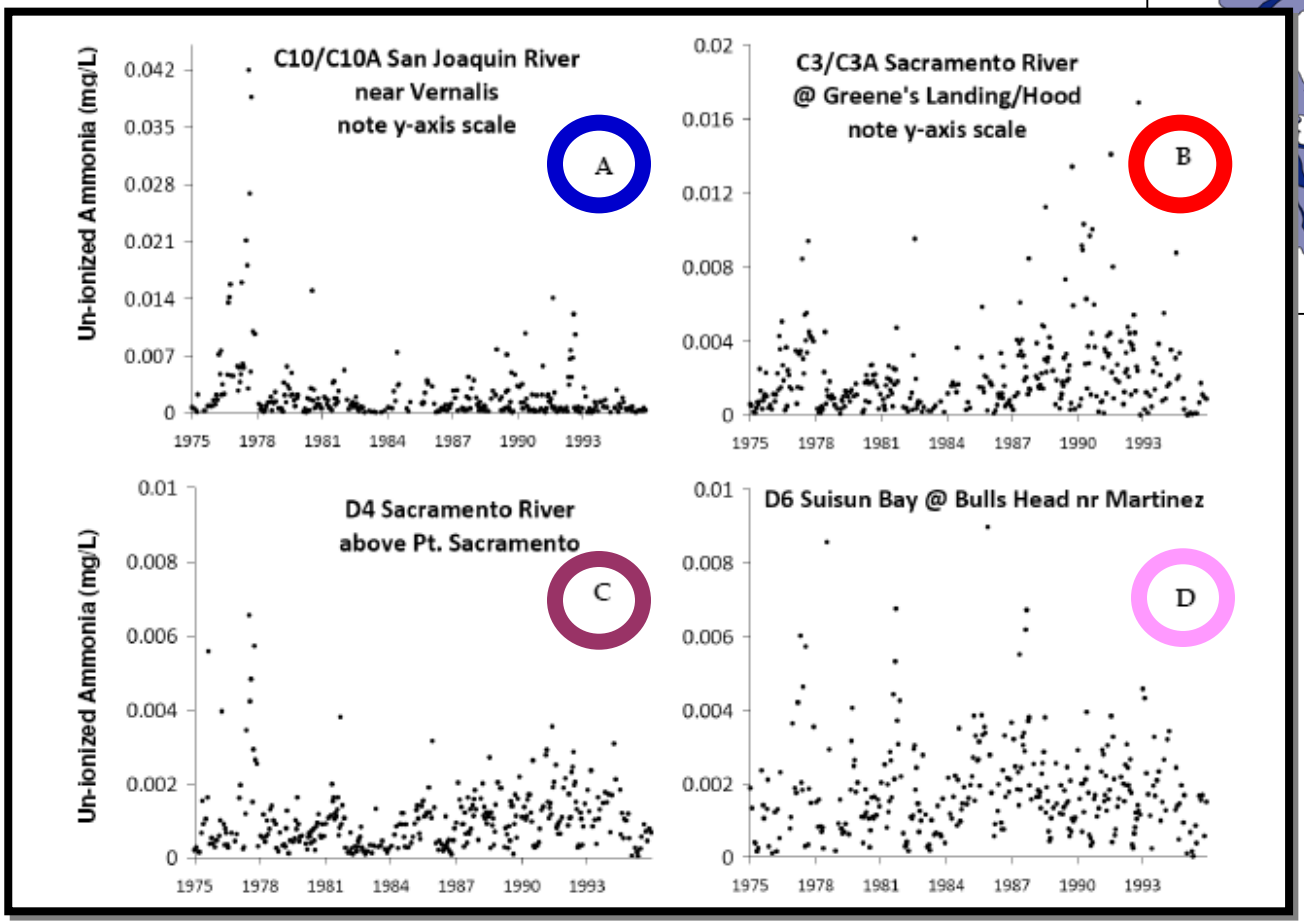


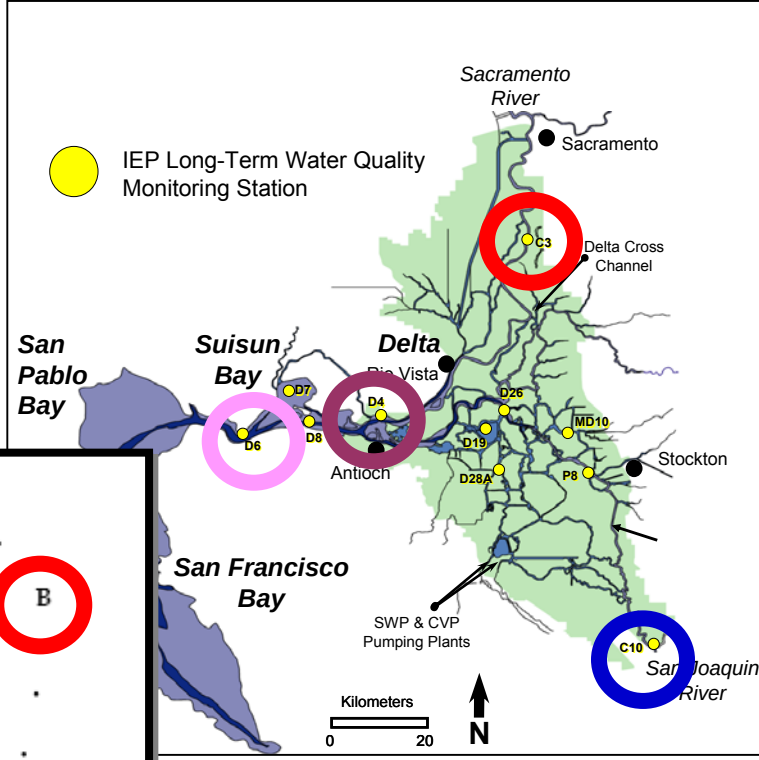
2007



Un-ionized Ammonia-N concentrations 1975-1995

Fig. 4



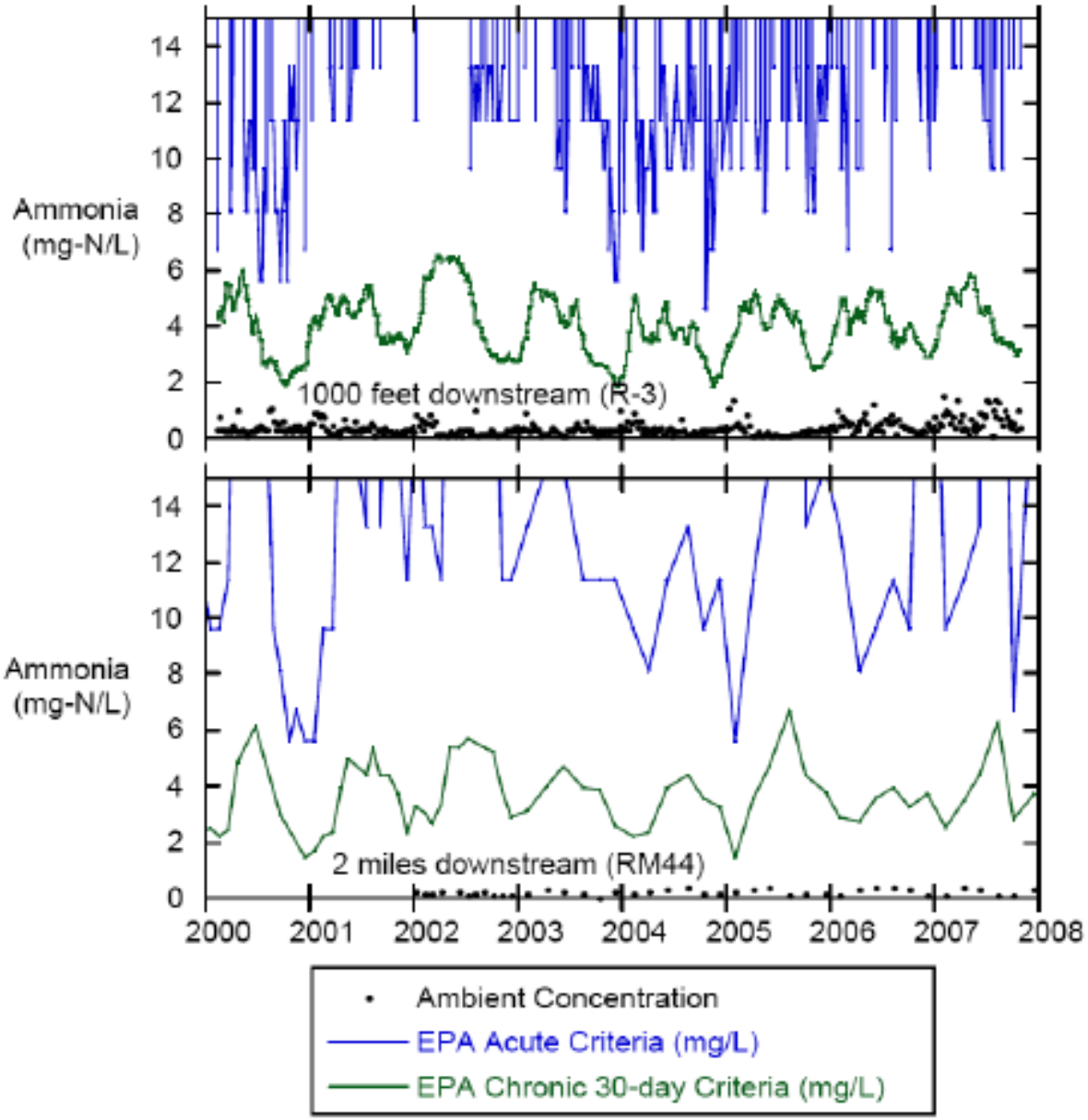


Different y-axis scales!

SRWTP Unpublished;
IEP data available at
bdat.ca.gov

Total ammonia (mg-N/L) levels near the SRWTP outfall are **well below** the EPA acute and chronic toxicity criteria

Fig. 5



Delta smelt sensitivity to ammonia – lab test, UCD ATL

- 96-hour test with 50-day old hatchery delta smelt
- Ammonium additions to filtered delta smelt hatchery water (pH 7.9, Temp. = 16°C)

Table 2

Ammonia Species	*Toxicological Endpoints (mg/L)*			
	NOEC	*LOEC*	*LC10*	*LC50*
Total ammonia-nitrogen	5.0	9.0	4.0	12.0
Un-ionized ammonia	0.066	0.105	0.067	0.147

[1] Sources: Werner et al. 2008a, Werner et al. 2009

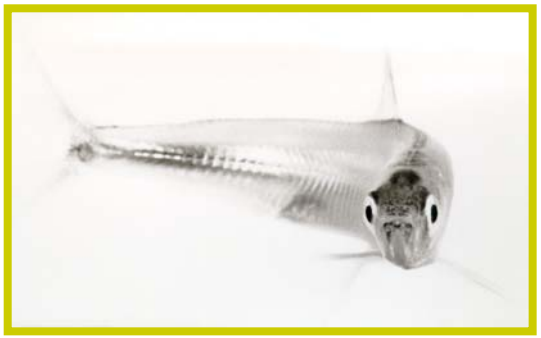
Fathead Minnow

LC10
21
0.36

Delta smelt are about as sensitive as salmonids,
5x more sensitive than fathead minnows

Delta smelt exposure to SRWTP effluent – 2008 **PILOT** study, UCD ATL

- 7-day test with 55-day old hatchery delta smelt
- Parallel incubations with 0 – 8 mg N/L effluent and NH_4Cl added to water from Sac River at Garcia Bend (2 miles upstream of SRWTP); Temp. = 16°C
- 7-day survival in unamended Sac River water: 67%
- No difference in survival in amended water, i.e. **no acute toxicity at ambient Sac River ammonia levels**
- Very limited indication from Cu tests that younger delta smelt might be more sensitive



Werner et al 2009

Ammonia toxicity

Some ongoing POD Work (Universities, IEP agencies, SRWTP):

- Continuation of toxicity work at UCD-ATL
- Compilation and evaluation of existing ambient ammonia/-um data
- Literature review of ammonia effects on sensitive freshwater fish and invertebrates

New work:

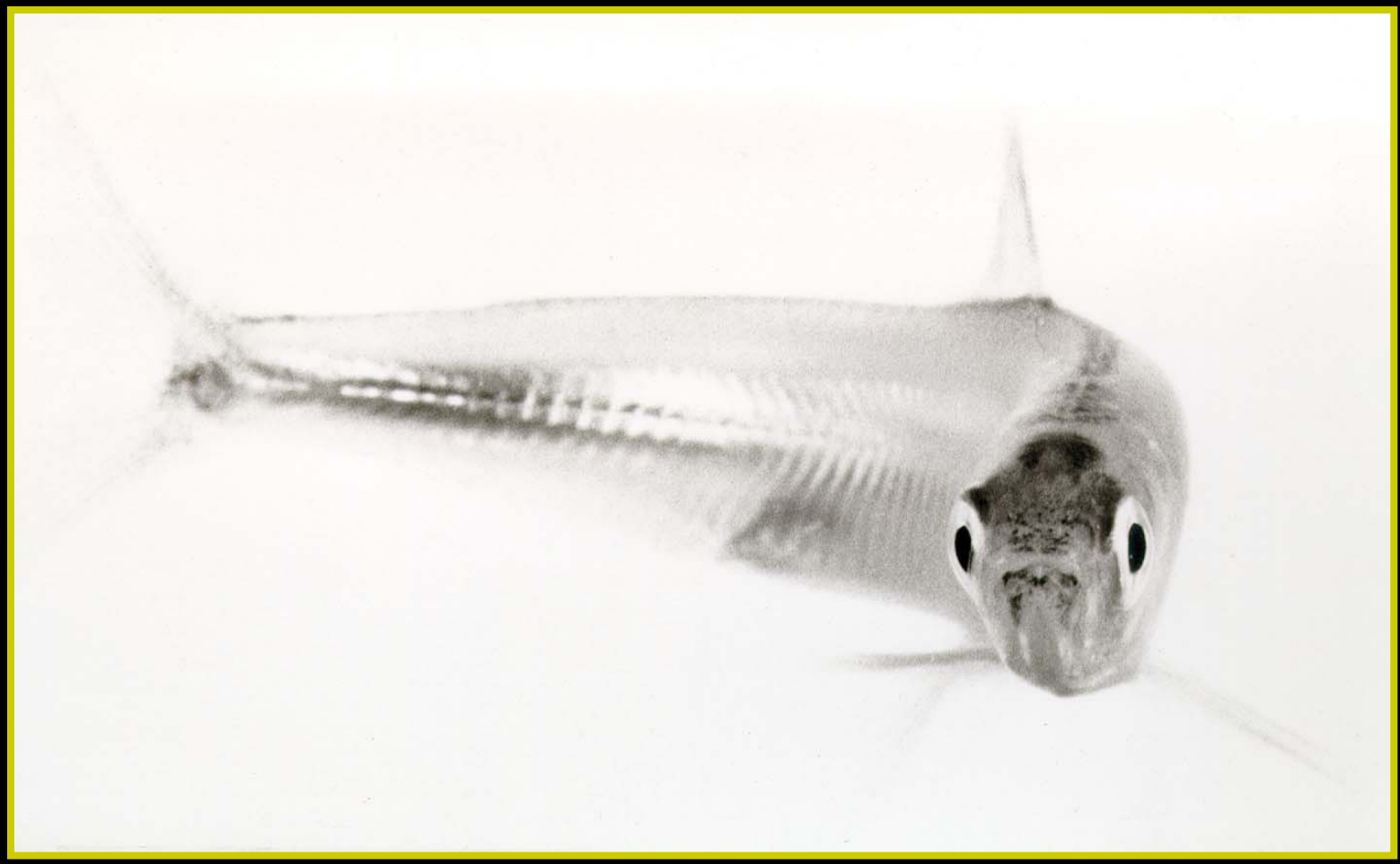
- Additional monitoring – Water Boards

Ammonia toxicity

Some outstanding questions (*see report*):

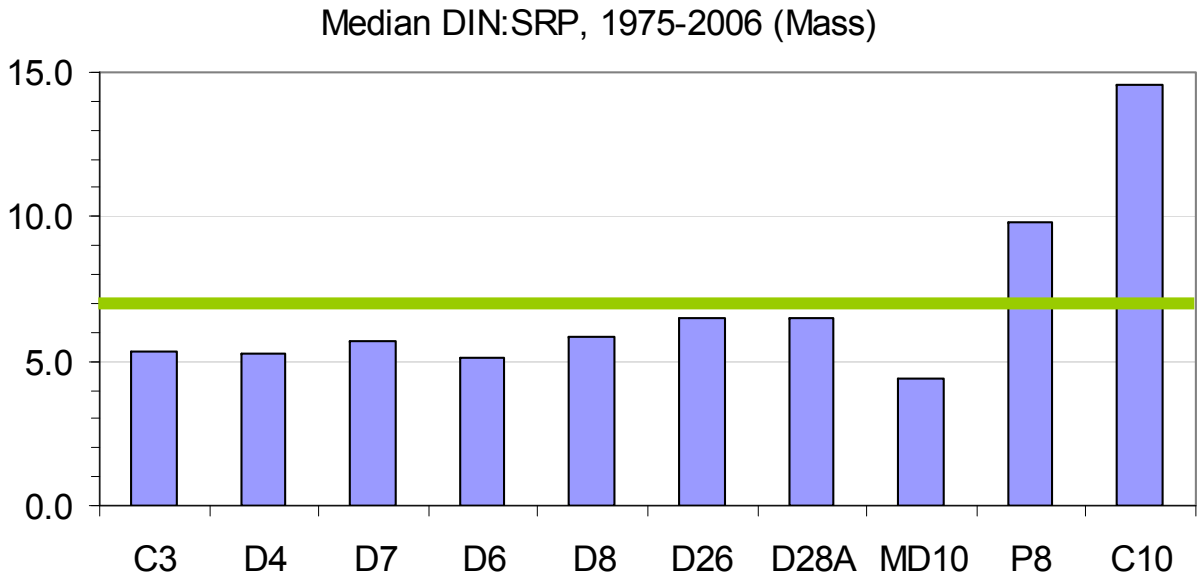
- Extent of acute, chronic, or sub-lethal effects of ammonia on Delta fishes and invertebrates?
- Interactions with other toxicants/factors?
- Exceedances of EPA NH criteria?
- Do EPA ammonia criteria adequately protect Delta species?
- Ammonia monitoring?
- Sublethal effects – biomarkers?

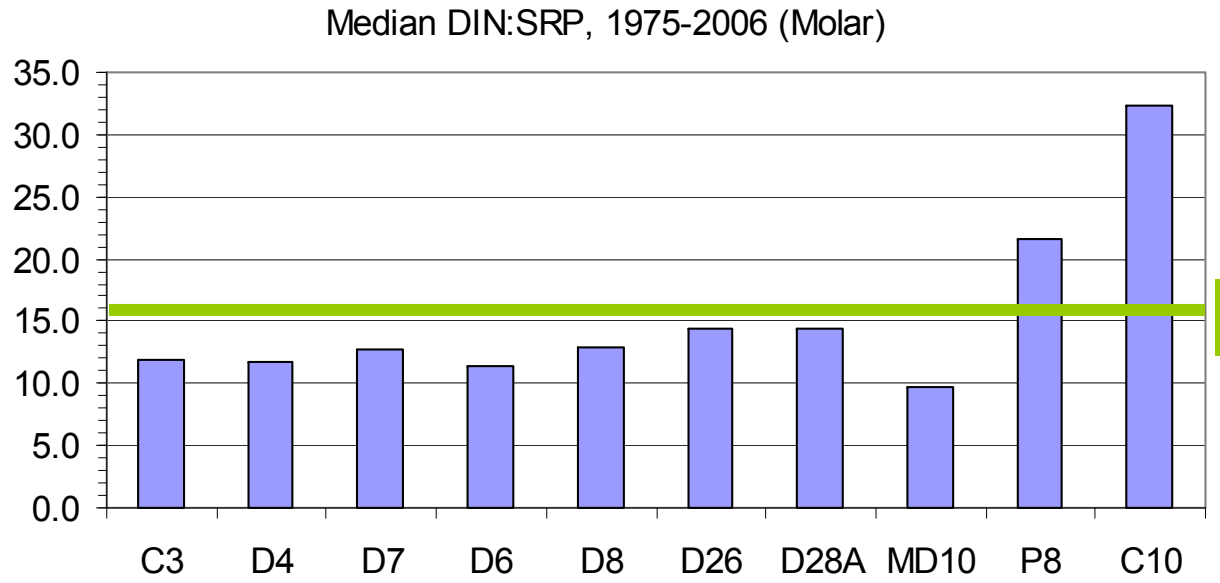
Questions?

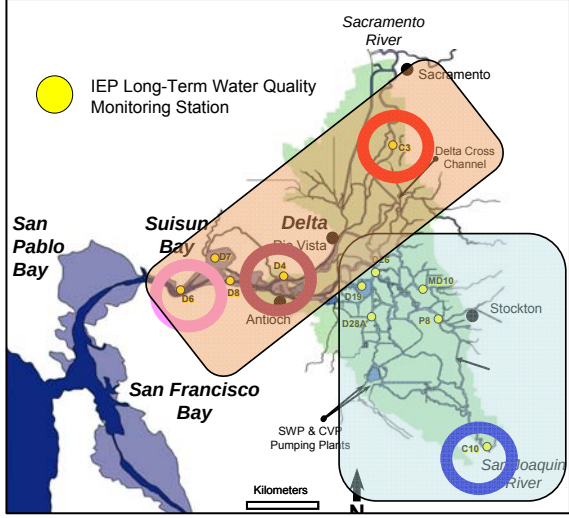


Additional Slides

DIN : SRP Ratio







Redfield Ratio

A. Mueller-Solger unpublished;
IEP data available at bdat.ca.gov

Britto & Kronzucker, J. Plant. Physiol. 2002:

"Ammonium is a paradoxical nutrient ion"

- Major N source
- Easy uptake by plants (no reduction necessary)
- Intermediate in many metabolic reactions

BUT:

- Can inhibit algae production
- Can be toxic to plants
- Can be toxic to animals (NH_3)
- Can be toxic to humans – neurological, insulin, liver disorders

Ammonium toxicity known since at least 1882: Charles Darwin described NH_4+-induced growth inhibition in *Euphorbia peplus* (aka Petty spurge, Cancerweed)

Ammonium affects different groups of algae differently; Diatoms are especially affected

(Dortch, MEPS 1990)

Table 3. Percent of reports[a] of species preference for ammonium[b] compiled from Table 2 and Antia et al. (1975)

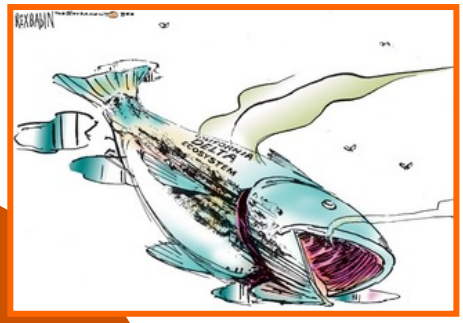
Taxon	% Preference NH_4^+	
	V_{max}	μ_{max}
Diatoms	65 (17)	16 (25)
Dinoflagellates	45 (11)	20 (5)
Cyanobacteria	50 (4)	28 (14)
Chlorophytes	50 (4)	57 (7)
Other	100 (6)	26 (19)

[a] Number of reports given in parentheses. Duplicates or conflicting reports for the same species counted seperately since environmental conditions can influence preference

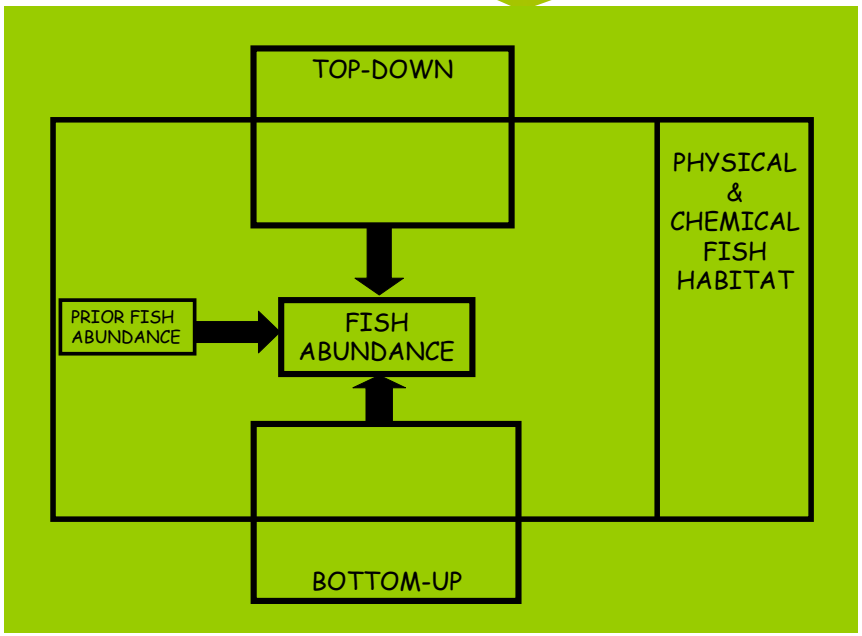
[b] Preference defined as in Table 2

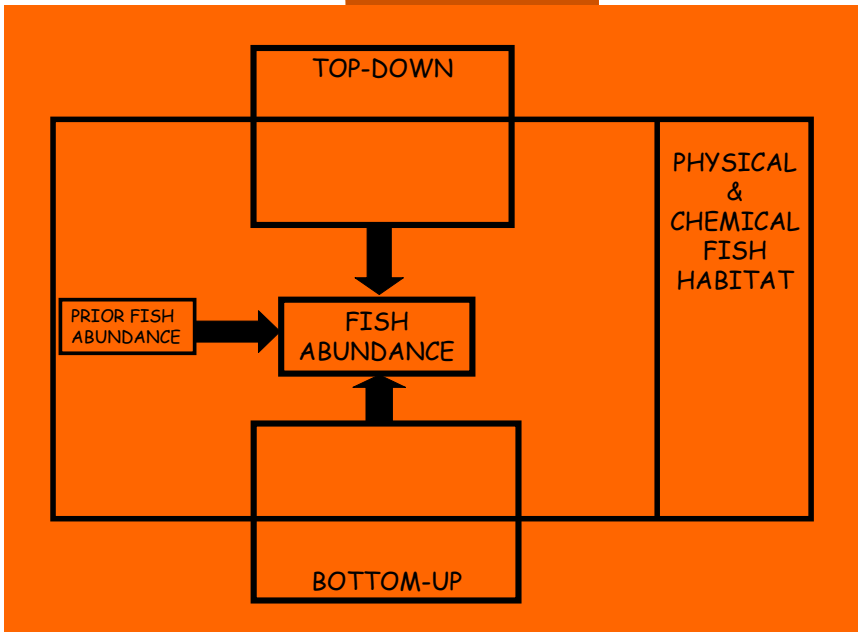
Shift back

???



NOT part of POD Investigations!





- Proposed Longfin Smelt Listing
- Status Change for Delta Smelt?
- Restrictions on Sampling

PRIOR ABUNDANCE → PRESENT ABUNDANCE

- Refuge Populations
- Hatcheries

TOP-DOWN

Water Diversions

FISH ABUNDANCE

Lawsuits

Severe Pumping Restrictions

Renewed Push for Peripheral Canal

New Operational <u>Triggers</u>

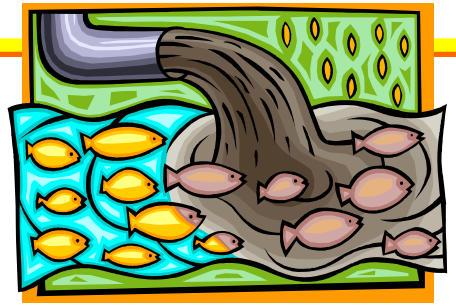
- Old and Middle River Flow
- Turbidity

A Major Emphasis on *Habitat Restoration* to Boost the Delta Food Web

New Regulations:
Fall Salinity Standards

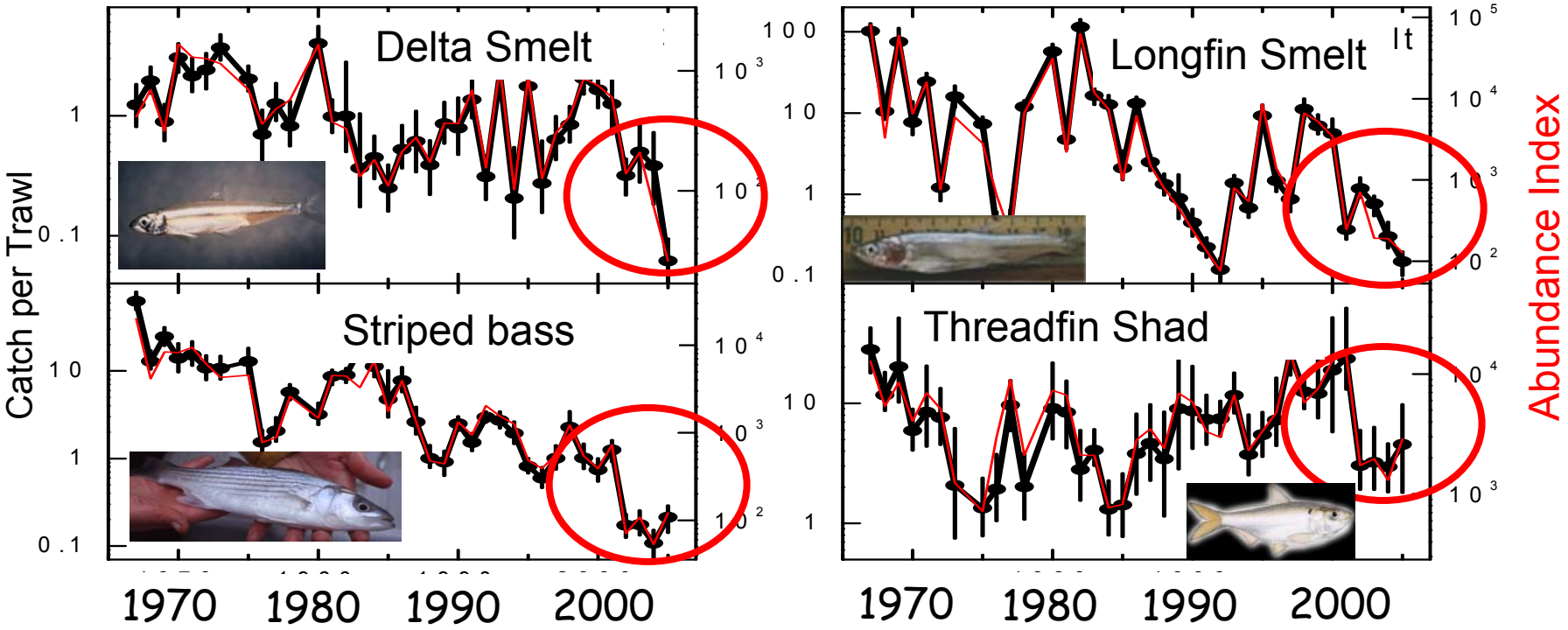
FISH ABUNDANCE

Other water quality standards?
E.g. Ammonia/um?



PHYSICAL
&
CHEMICAL
FISH
HABITAT

2. POD: Pelagic Organism Decline

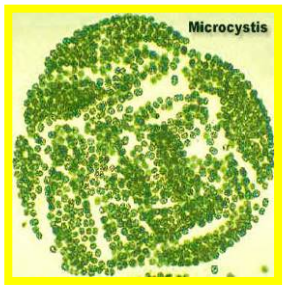


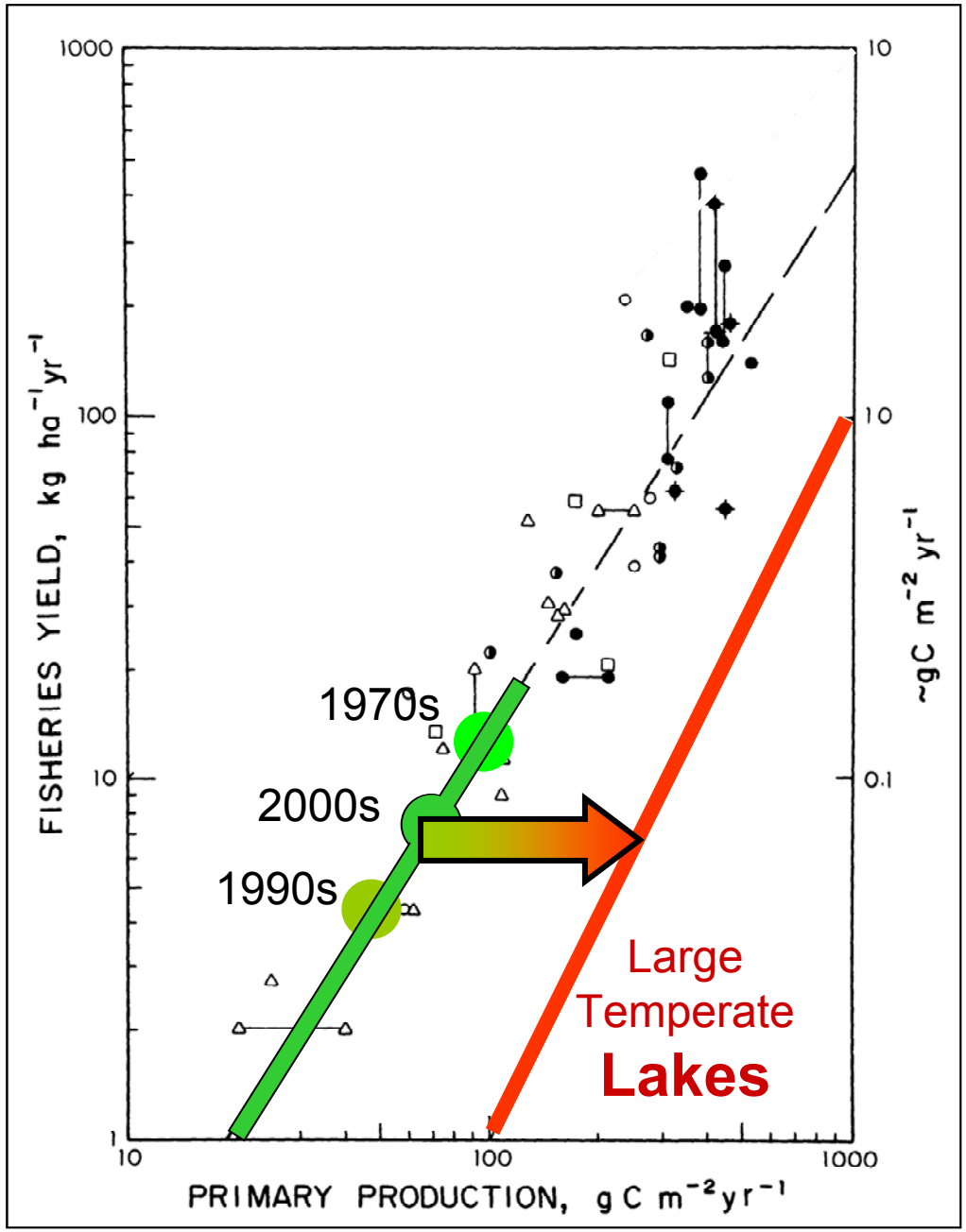
Source: Sommer et al. (2007)

Phytoplankton Primary Production in the upper estuary

… **may** be becoming less nutritious, causing **lower "trophic efficiency"** as found in lakes.

Causes: changes in flows, nutrients, turbidity…





On the rise:
Microcystis aeruginosa blooms

Microcystis & nutrients elsewhere:

- N-specialist: can grow rapidly on NH4+ & NO3-
- P-storage-adapted species: high capacity to absorb & store inorganic phosphorus
- Nutrient uptake not inhibited by high light intensity
- Float/migrate vertically