Nutrients in San Francisco Bay

Science to Inform Management Decisions

David Senn
San Francisco Estuary Institute

and MANY collaborators

March 6 2019

sfbaynutrients.sfei.org

San Francisco Estuary Institute

- Established 1993
- 50 scientists and engineers

Applied science → ***effective stewardship of the Bay, Delta, and watersheds***

501(c)3 and JPA

Technical Collaborators

SFEI

Z Zhang, E Nuss, T Winchell, E King,
A Chelsky, A King, D Senn

Menlo Park

J Cloern, L Lucas,
E Nejad, T Schraga

WSC – Sacramento

M Downing-Kunz, B Bergamaschi,
B Downing, L Stumpner, T Kraus

UC Santa Cruz

R Kudela, M Peacock

SCCWRP

M Sutula; M Beck

UC Davis

R Holleman
E Gross

UC Berkeley

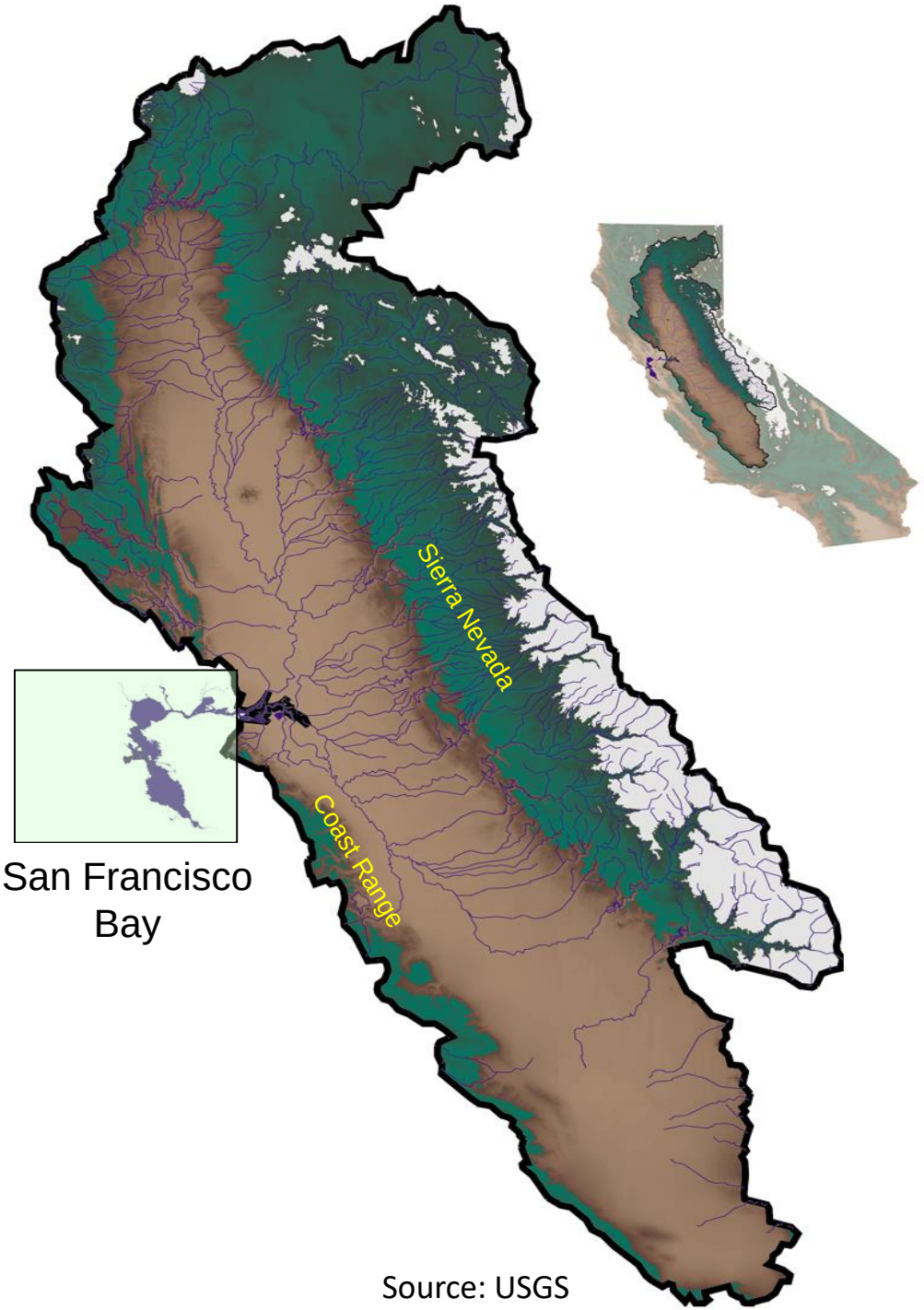
M Stacey

P de Valpine

90% of freshwater

- Largest CA estuary
- Population: 7.5mill people

Drains 40% of California
- Central Valley



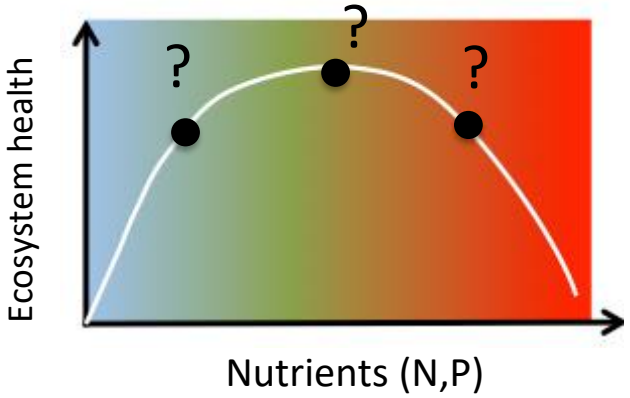
Source: USGS

Does SFB have nutrient problems?

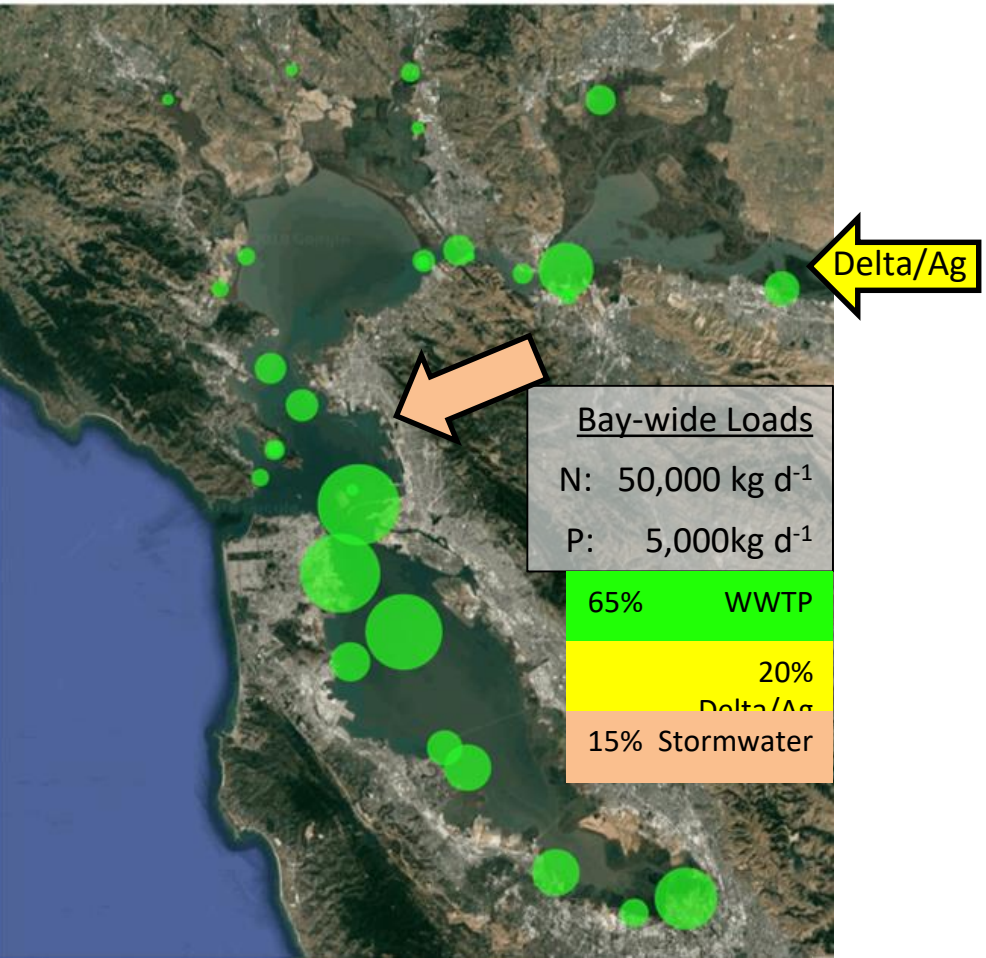
- now?
- future?

How can impacts be mitigated or prevented?

- $5-10bill question



- Large algae blooms
- Low DO
- Harmful algae, toxins



SFB in upper ~90%ile of estuaries worldwide for N and P areal loads (g m^{-2} d^{-1})

Cloern et al., in prep

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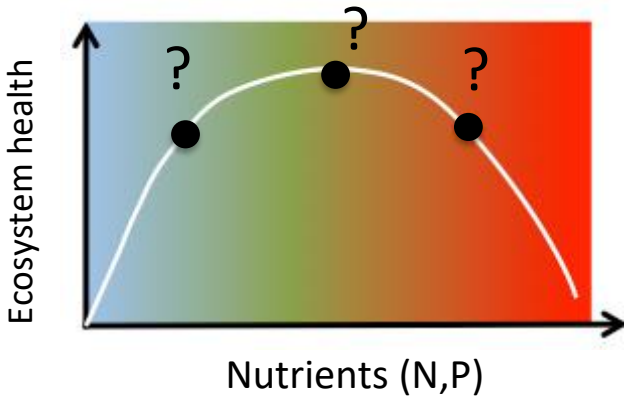
- now?
- future?

How can impacts be mitigated or prevented?

- $5-10bill question



- Large algae blooms
- Low DO
- Harmful algae, toxins

SFB doesn't use most of its nutrients

1. High turbidity
2. Strong tidal mixing
3. Filter-feeding clams

Historically: Resistant to classic eutrophication symptoms

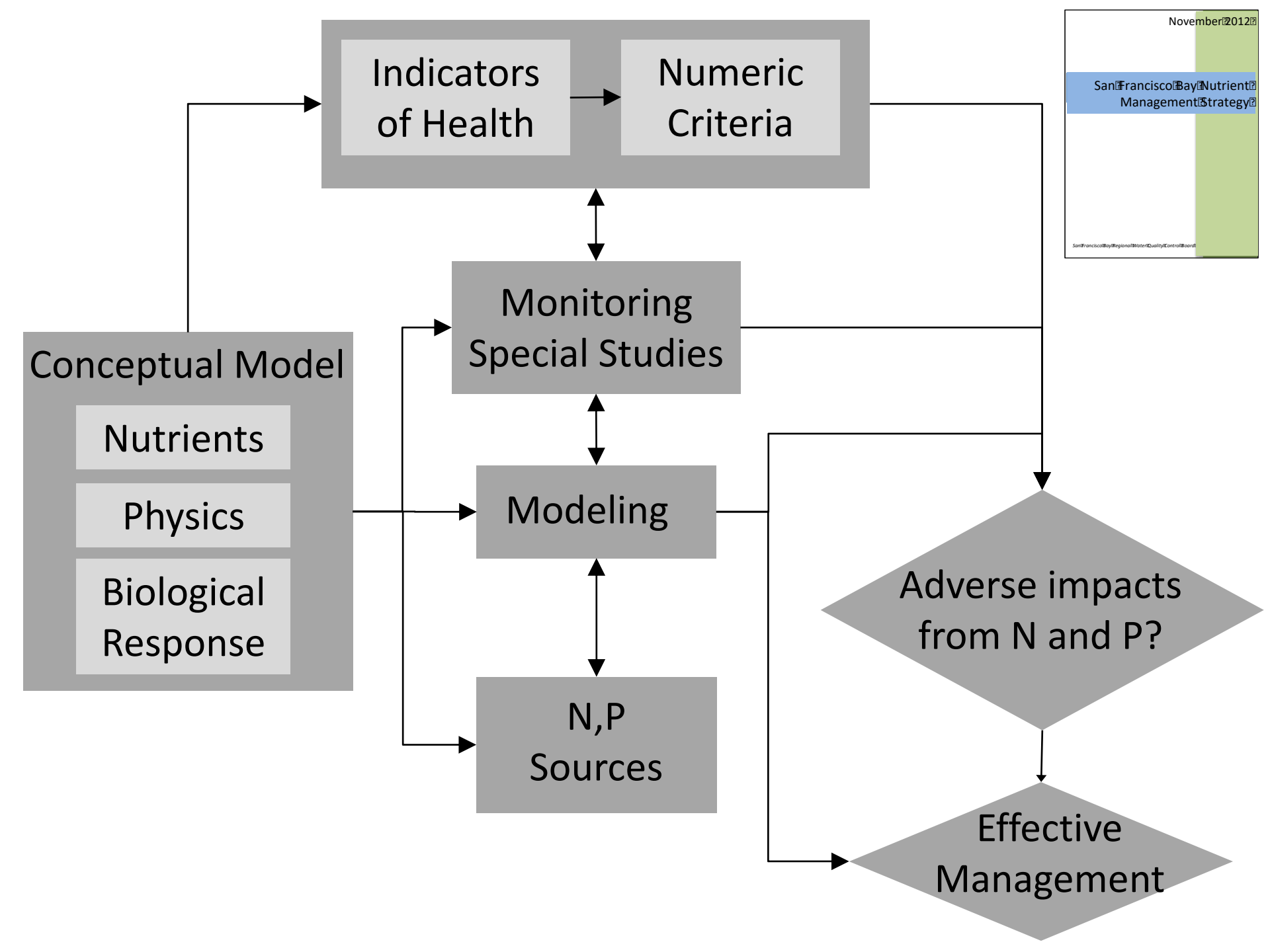
Recently: Evidence of changing response to nutrients

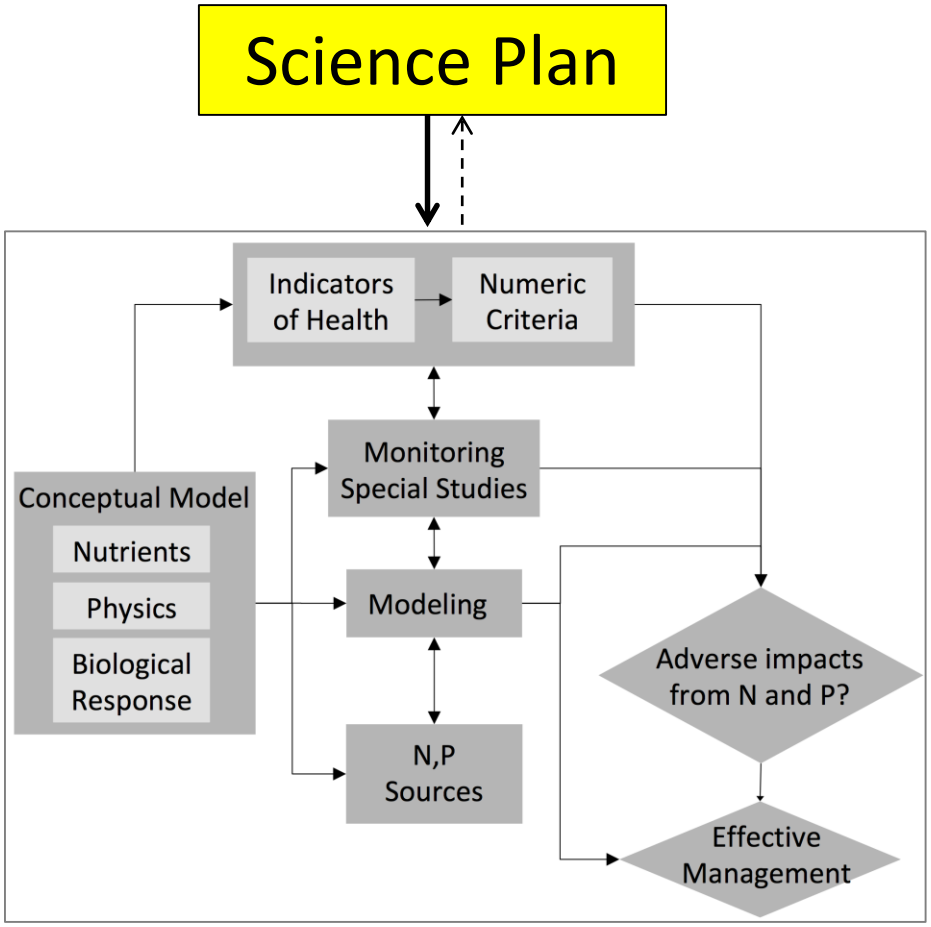
e.g., Cloern et al., 2007, 2010

Nutrient Management Strategy

- What nutrient loads can SFB subembayments assimilate without adverse impacts?

- What management actions would be effective at achieving protective nutrient loads or concentrations?


Indicators of Health
Numeric Criteria
Monitoring Special Studies
Conceptual Model
Nutrients
Physics
Biological Response
Modeling
N,P Sources
Adverse impacts from N and P?
Effective Management
November 2012
San Francisco Bay Nutrient Management Strategy
San Francisco Bay Regional Water Quality Control Board



Science Program Priorities

1. Nutrients loads, transformations
2. Phytoplankton Productivity and Low DO
3. HABs/toxins
4. Impacts on coastal ocean
5. Responses under future scenarios

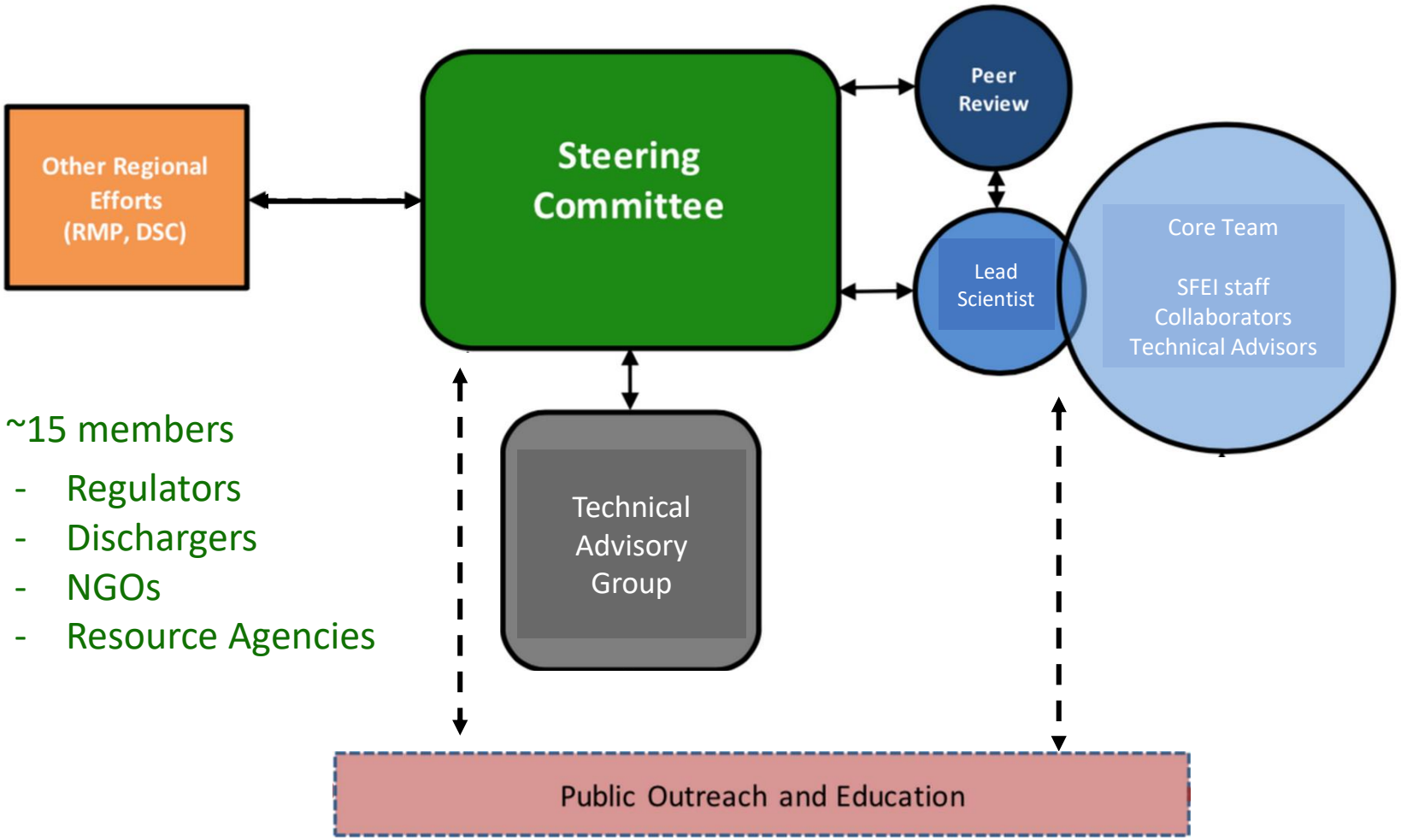
Nutrient Management Strategy Structure

1st 5 yr permit: July 2014

2nd Permit July 2019

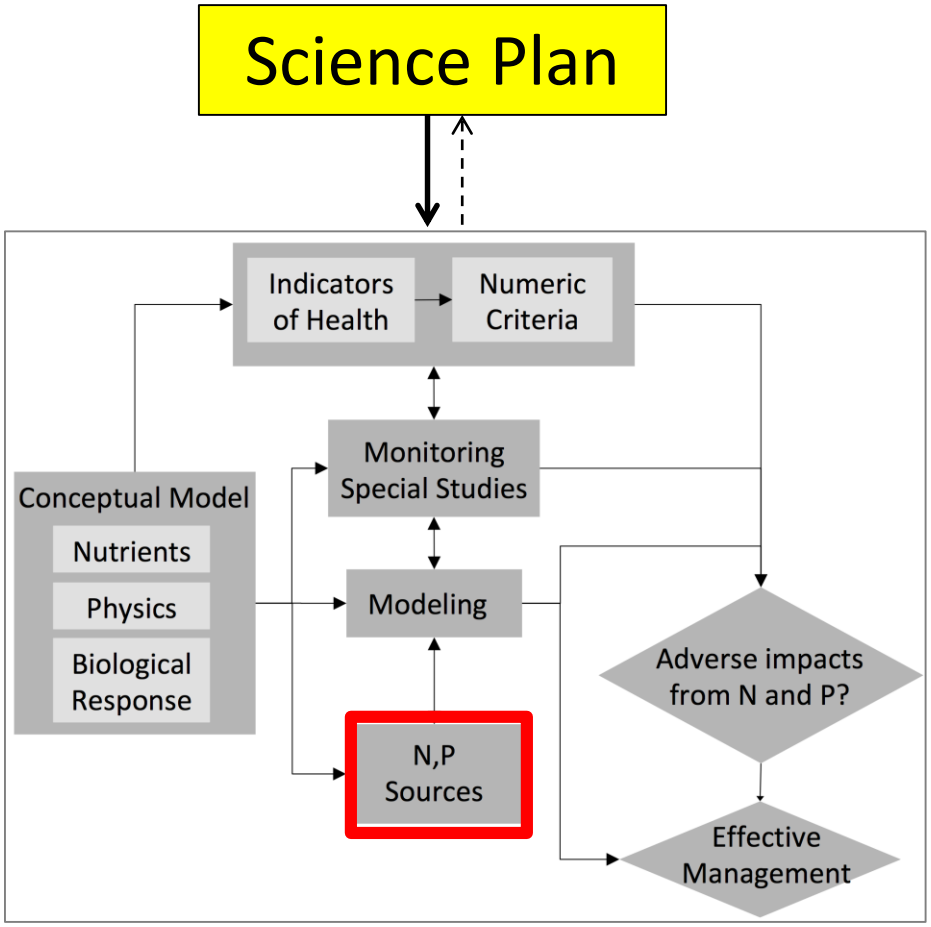
Funding: POTWs → NMS SC

Fundraising



~15 members

- Regulators
- Dischargers
- NGOs
- Resource Agencies



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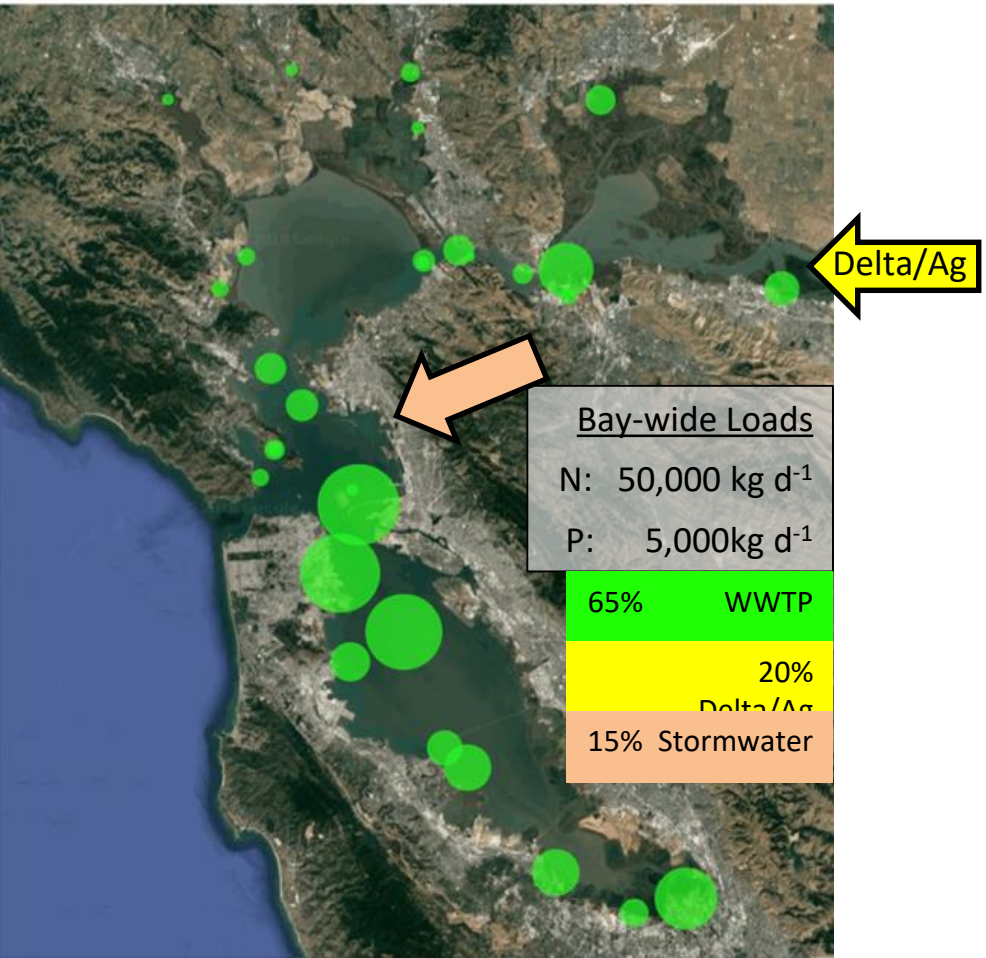

Delta/Ag
Bay-wide Loads
N: 50,000 kg d-1
P: 5,000kg d-1
65% WWTP
20%
15% Stormwater

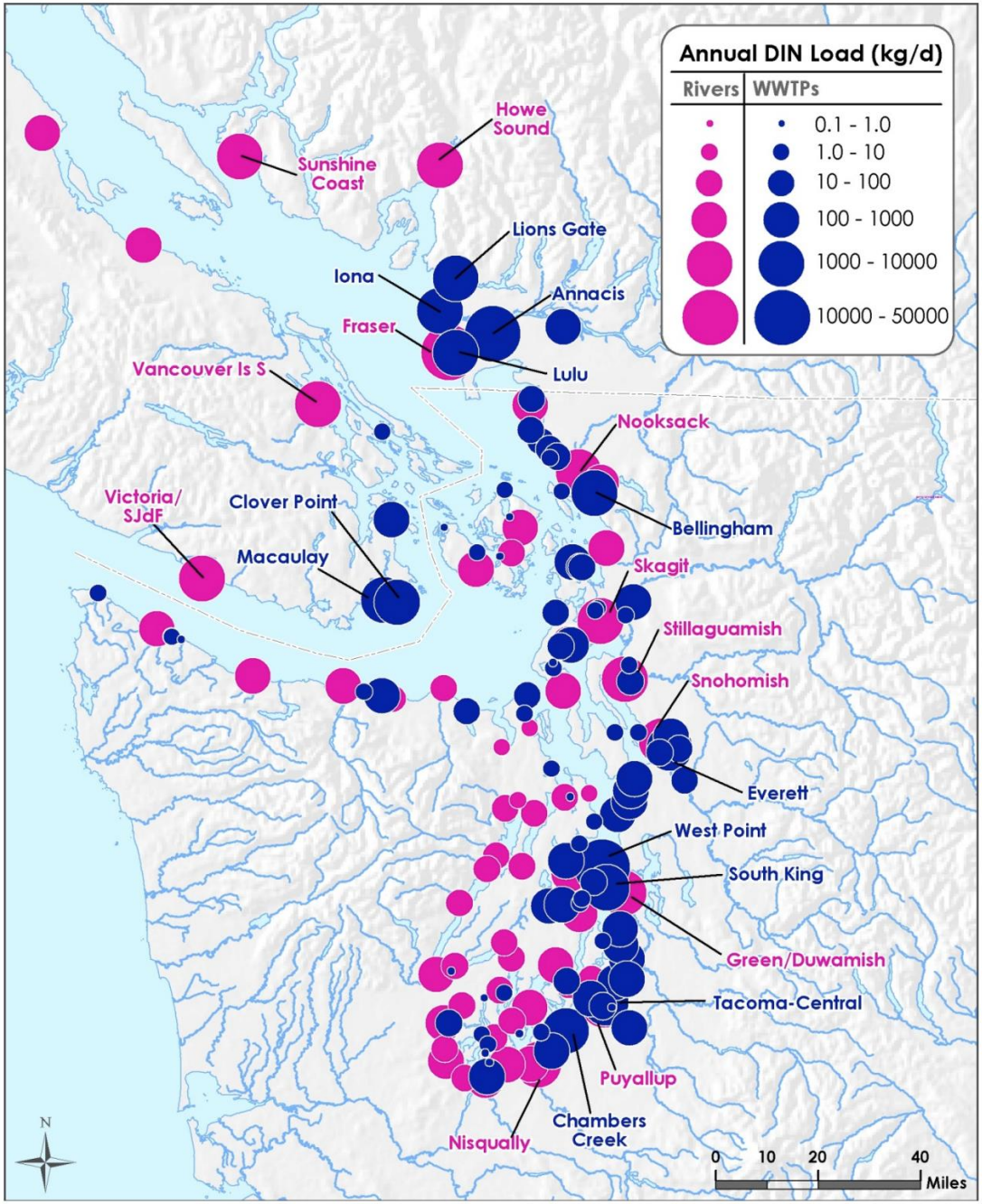
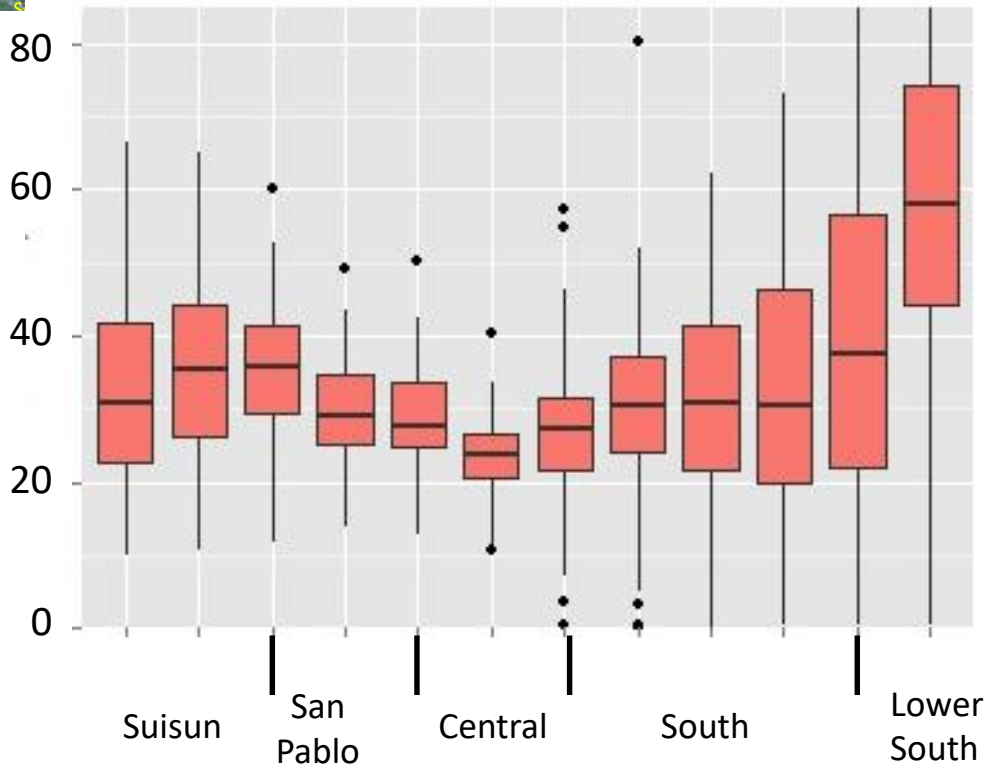


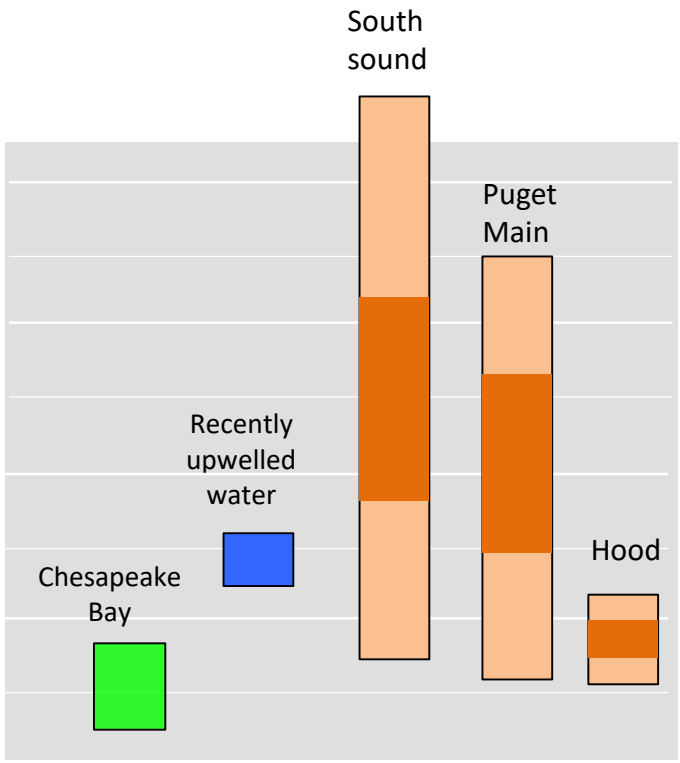
Figure ES-3. Mean annual dissolved inorganic nitrogen (DIN) loads from rivers and WWTPs for 1999 to 2008.

WA Ecology, 2011

Nutrient in San Francisco Bay

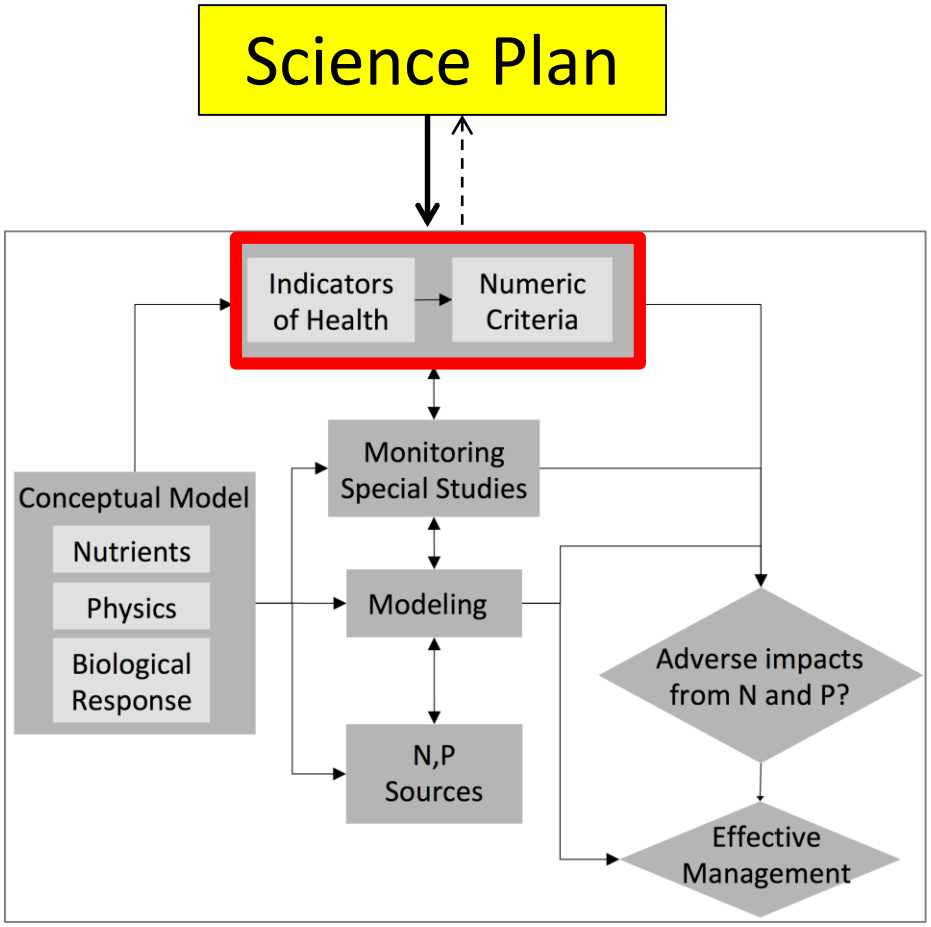
DIN (µM): 2005-2012





DIN = Dissolved Inorganic Nitrogen = NO_3^- + NH_4^+
1 mg/L N ~ 70 µmol/L

Data: USGS
SFEI 2015



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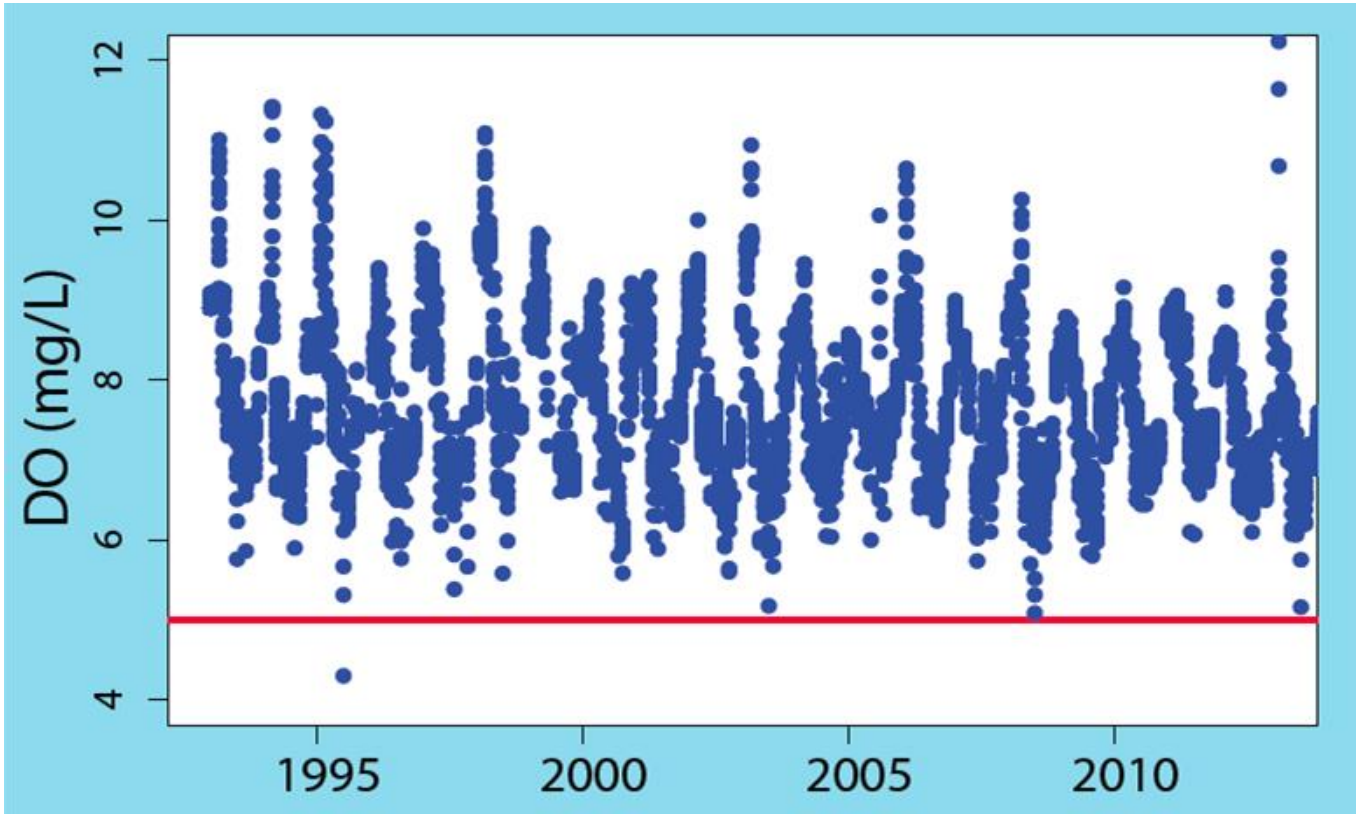
Surface Dissolved oxygen (mg/L): South Bay

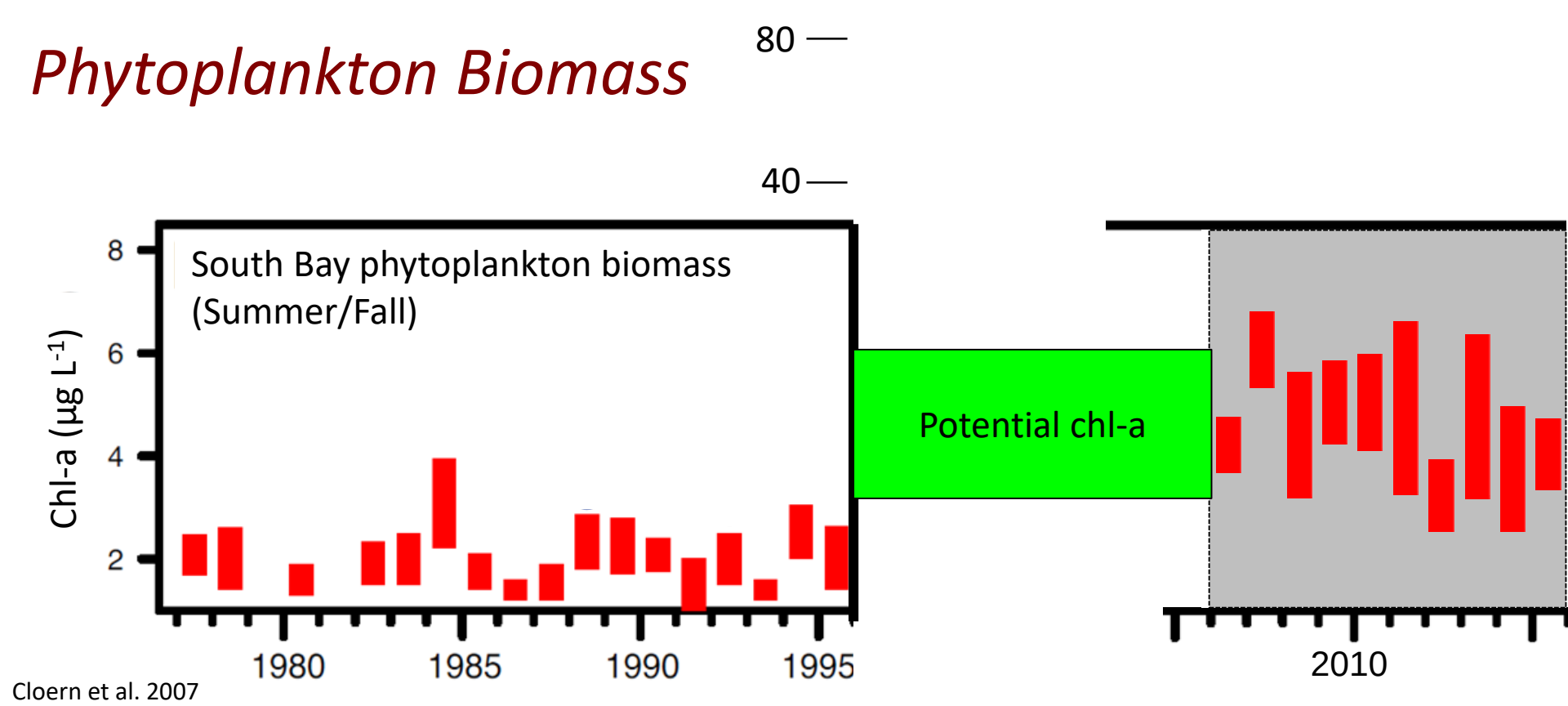


5 mg/L Basin Plan standard

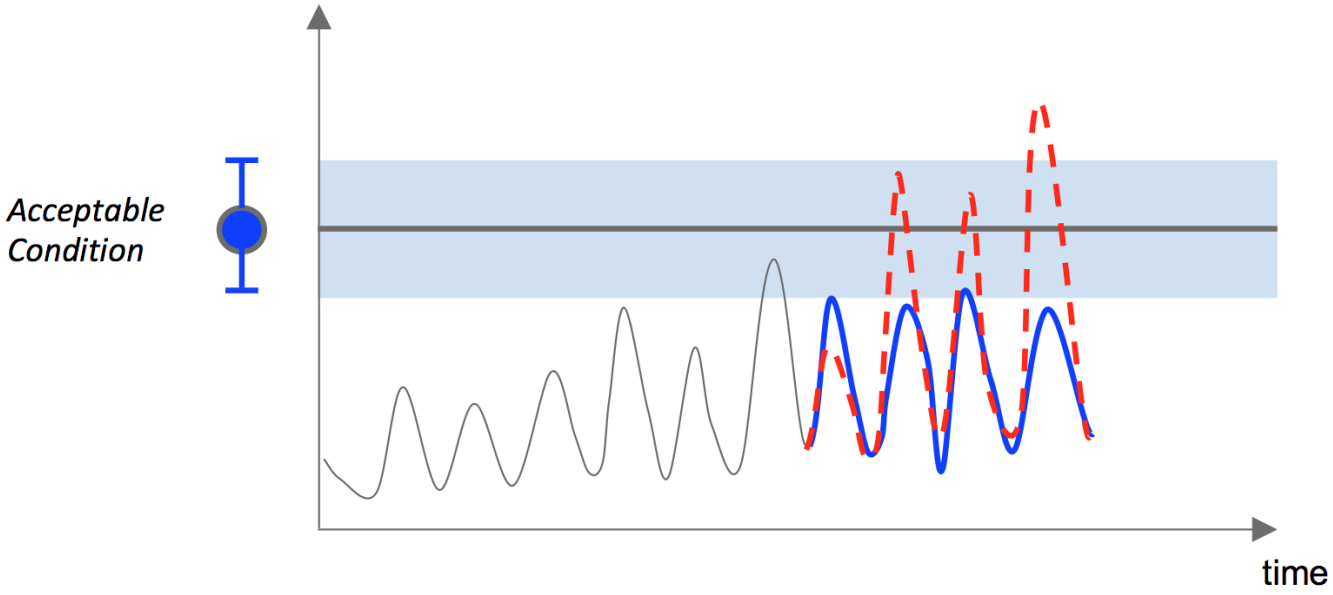
- 99% of measurements > 5mg/L
- But is it changing? How do we account for
  - Seasonality
  - 'Events'

Dumbarton Bridge to Bay Bridge
SFEI 2015
Data: USGS

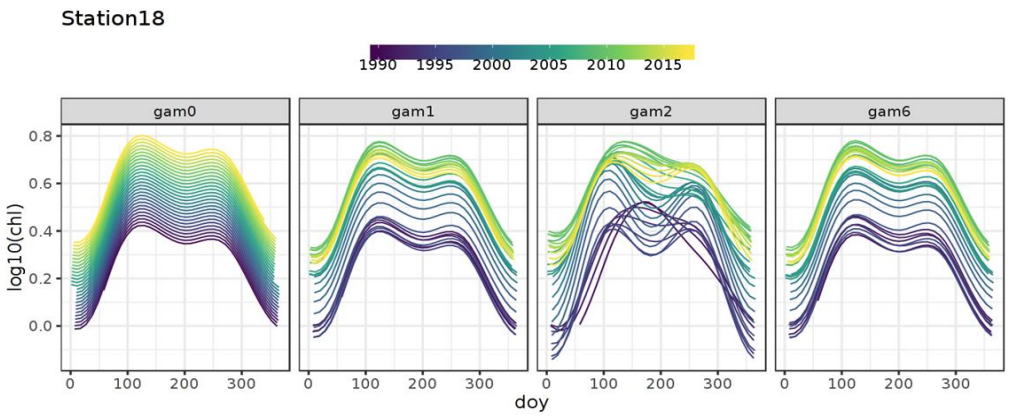
Phytoplankton Biomass



Cloern et al. 2007



1. When did changes cease to be significant? Is the trend now negative?
2. How does chl-a vary in other regions of SFB?
3. How do other relevant nutrient-related indicators changing over time?
4. What trend magnitudes can we realistically detect? Lag?
5. Causal factors?



jupyter R/Stats Nutrient

parameter, plot type (total
l observations at a station
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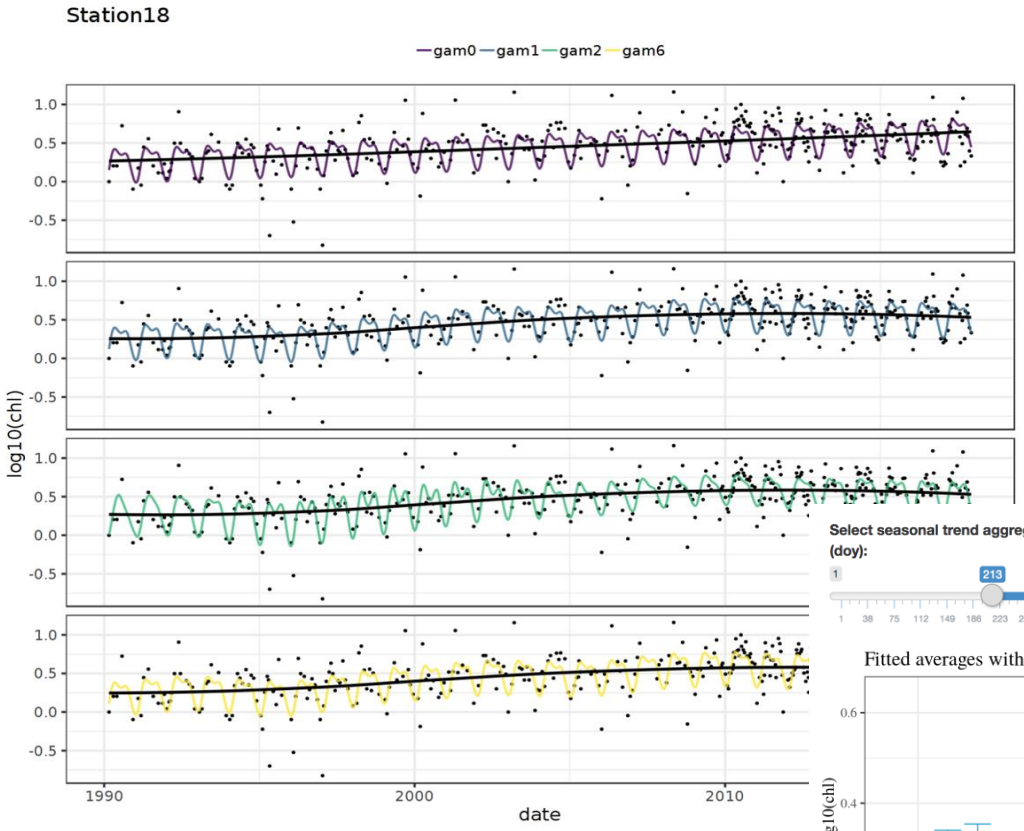
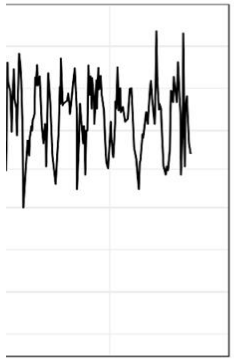
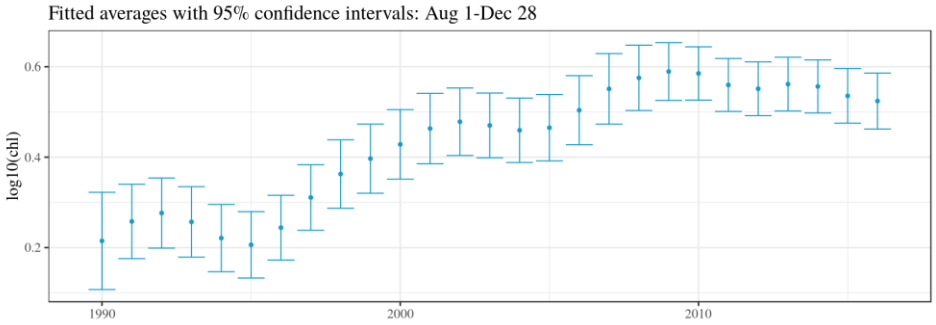
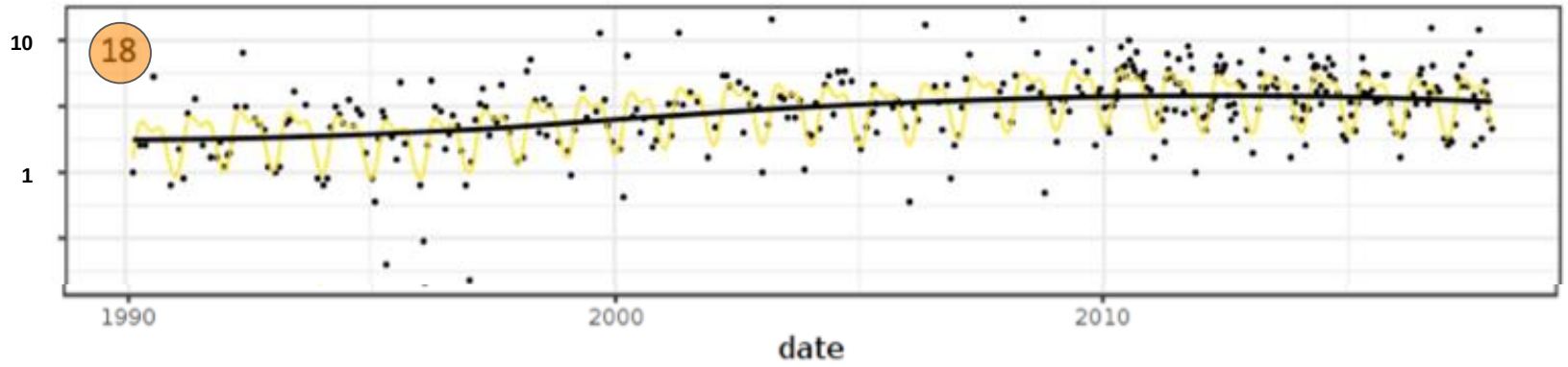






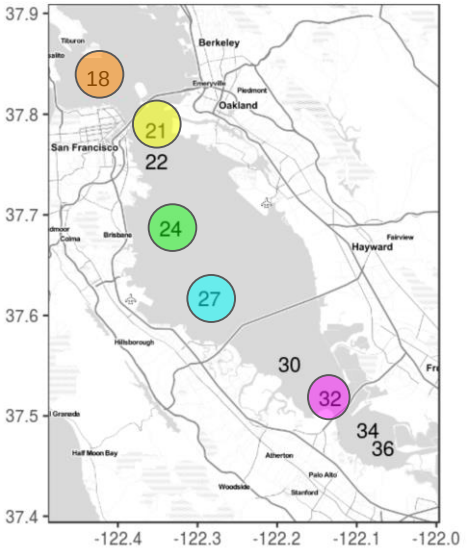


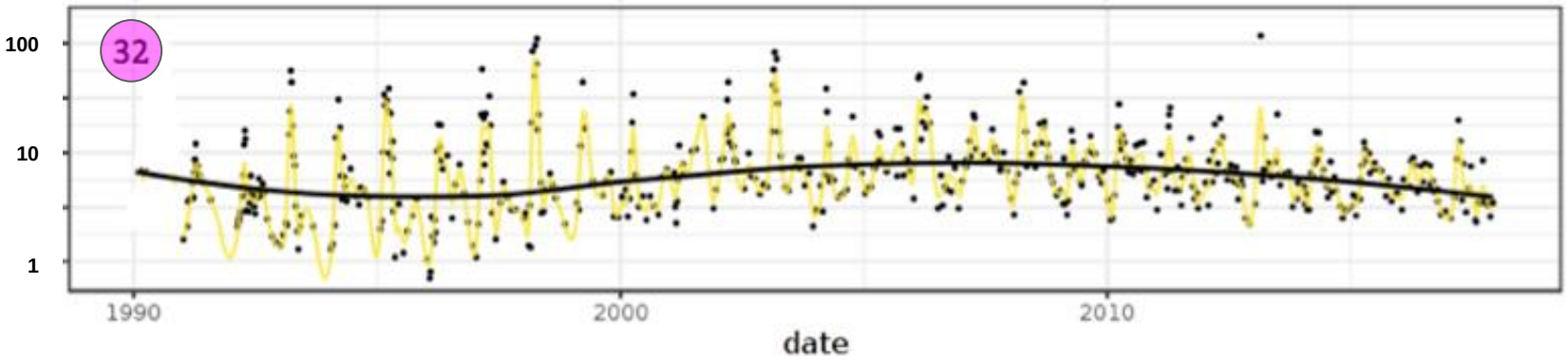
Other parameters…

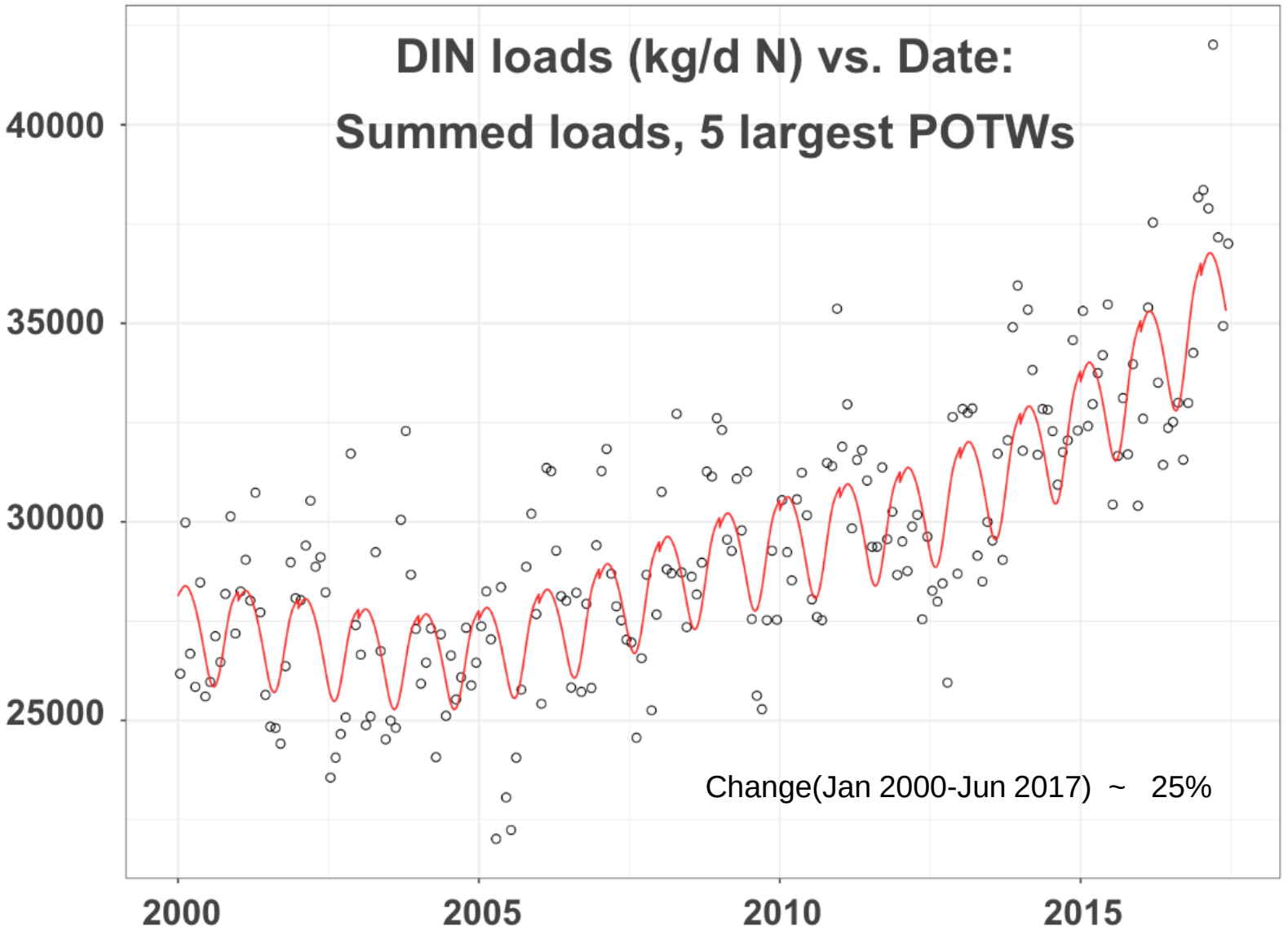
DO_mgL

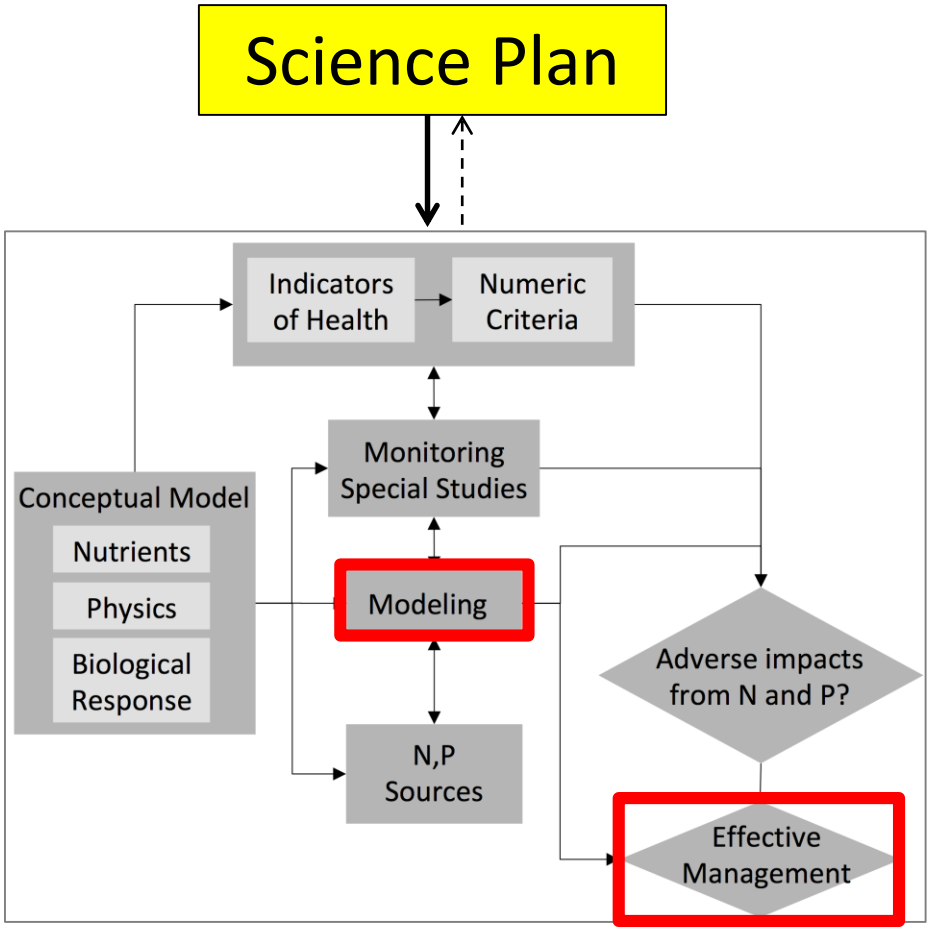
DO%sat

GPP






DIN loads (kg/d N) vs. Date:
Summed loads, 5 largest POTWs
40000
35000
30000
25000
2000
2005
2010
2015
Change(Jan 2000-Jun 2017) ~ 25%



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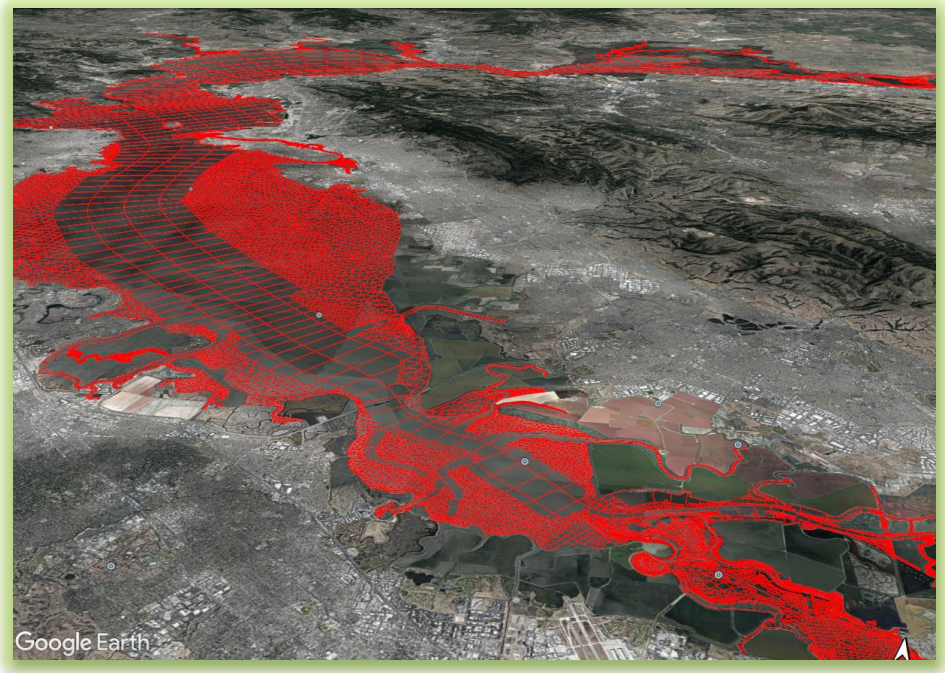
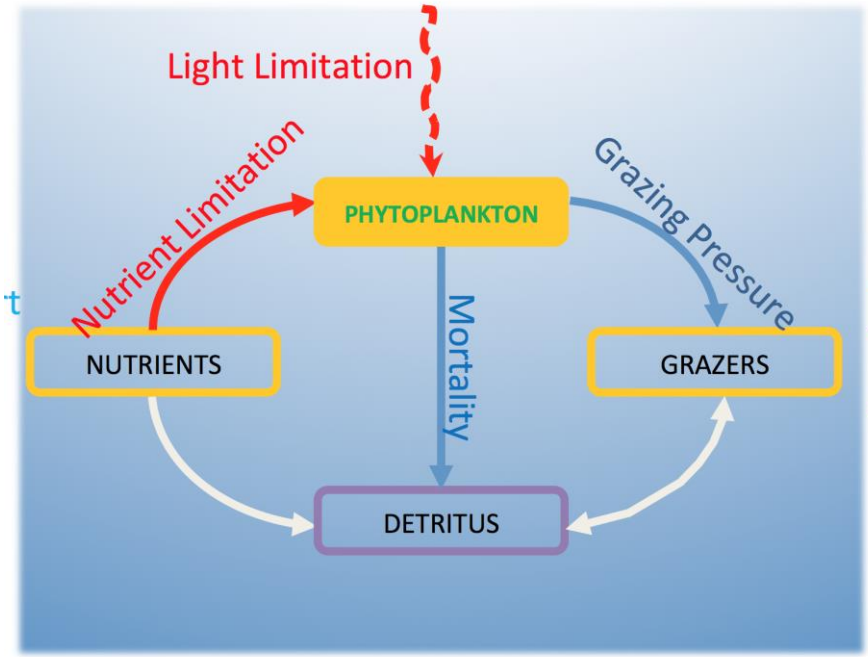
Numerical Models

Hydrodynamic model (Transport)

+

Biogeochemical model (In-situ)





Transport = advection + dispersion + mixing

In-situ = production + grazing + mortality

Modeling related Management Questions

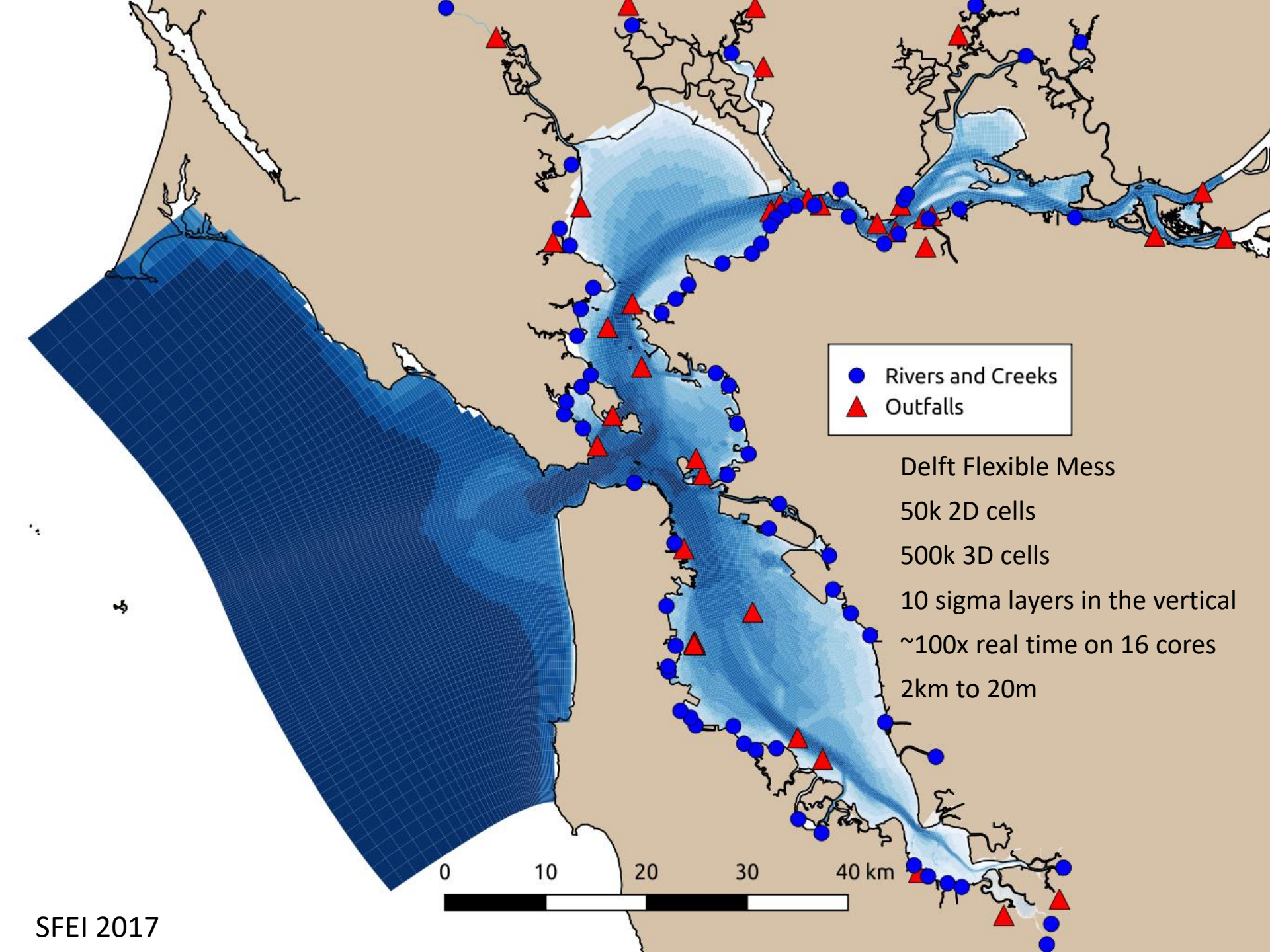
- Source apportionment: What are the nutrient sources to habitats ? *= f(space, season, year)*

- How do individual habitats respond to (and influence) nutrients?
  - Responses: chl, DO, HABs
  - Forcings: loads, tides, wind, suspended sediments, salinity/stratification (Q_{fresh}), upwelling, etc.

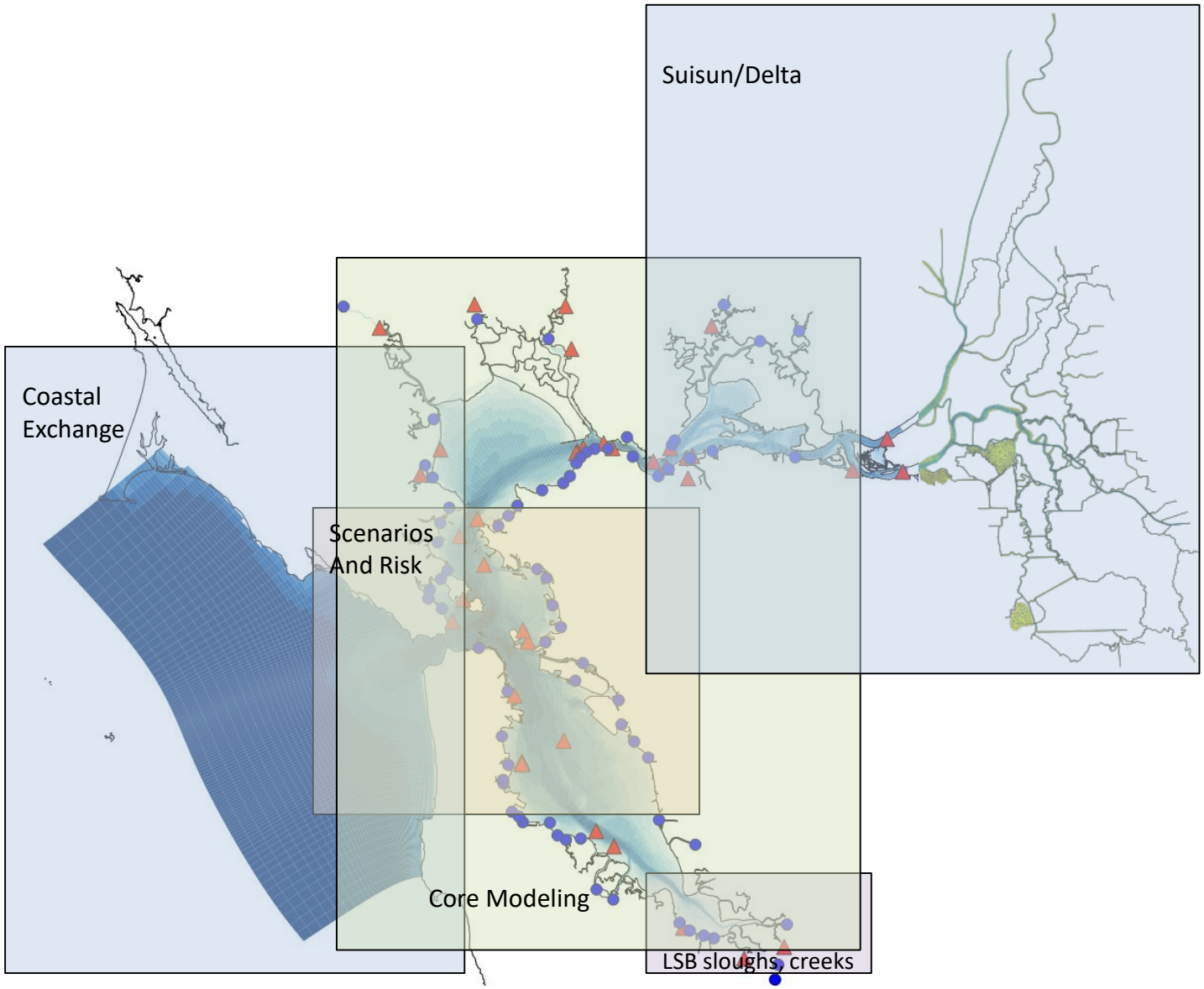
- Dose:Response -- How will the system respond to nutrient ↑ ↓ ?

- How effective will various management approaches be?

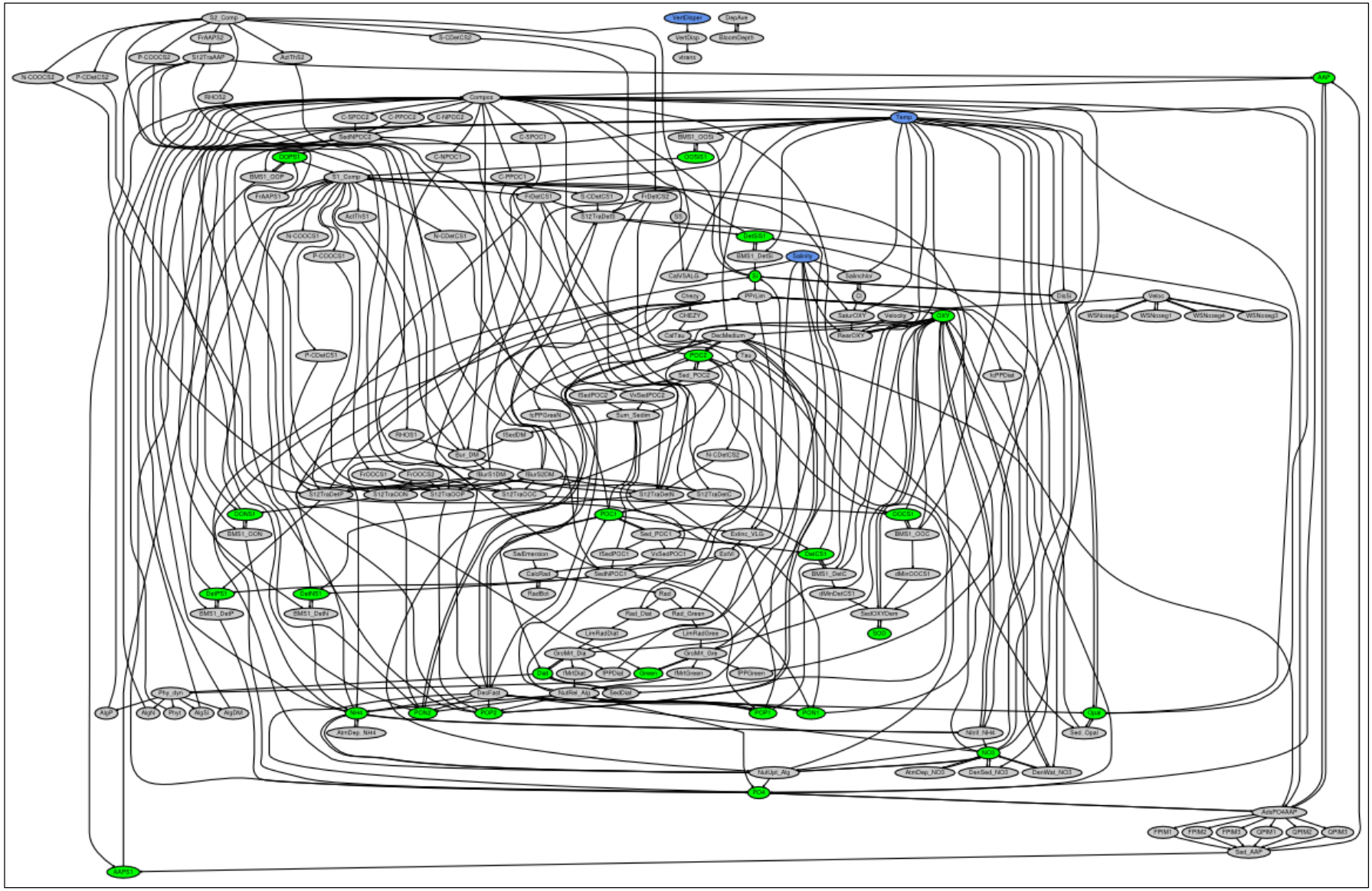
- How much confidence – or uncertainty – do we have in predictions?


Rivers and Creeks
Outfalls
Delft Flexible Mess
50k 2D cells
500k 3D cells
10 sigma layers in the vertical
~100x real time on 16 cores
2km to 20m
0
10
20
30
40 km
SFEI 2017

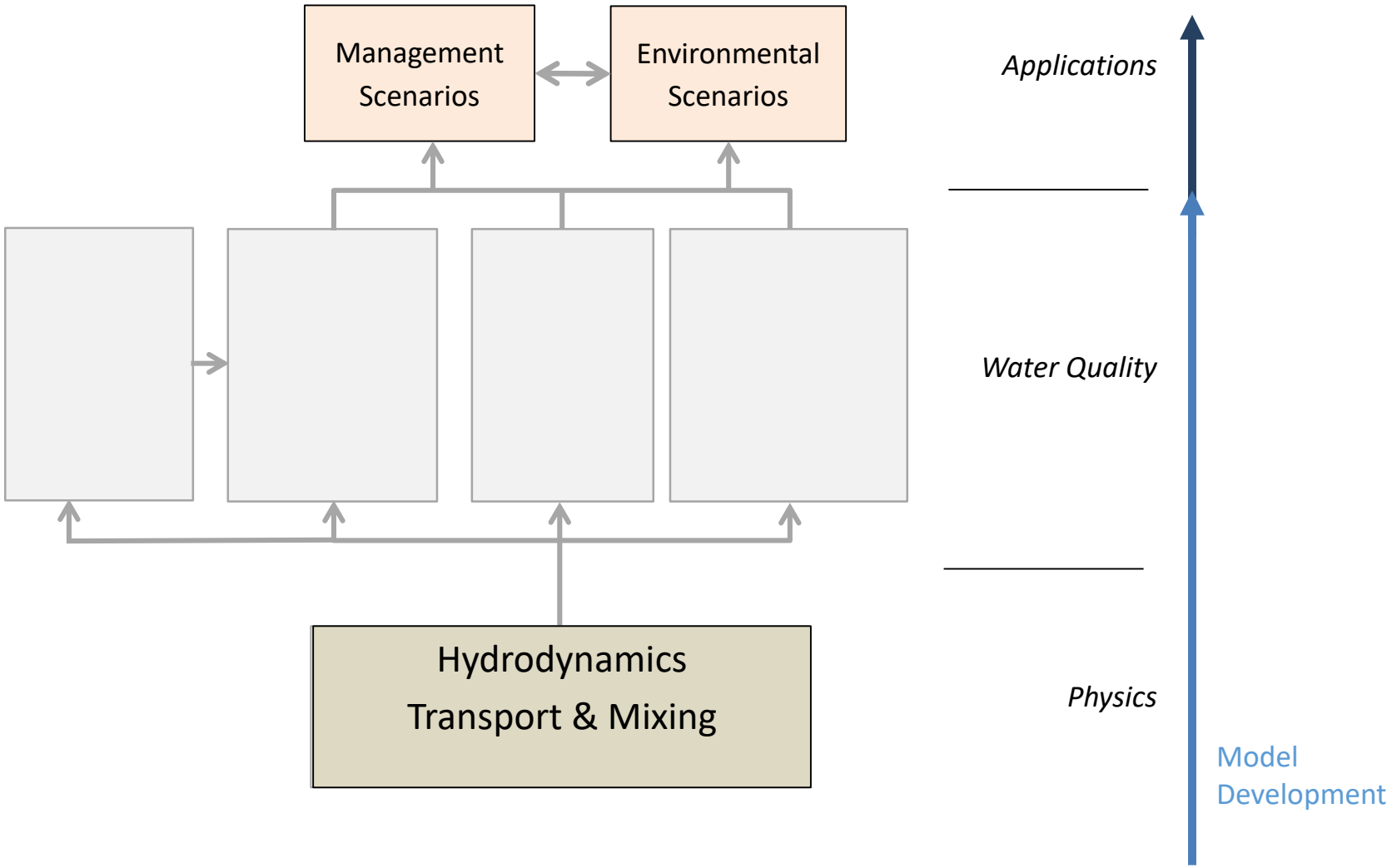
NMS Modeling Focus Areas



Biogeochemical Model – light, nuts, phyto, DO, grazing



Model Development and Application



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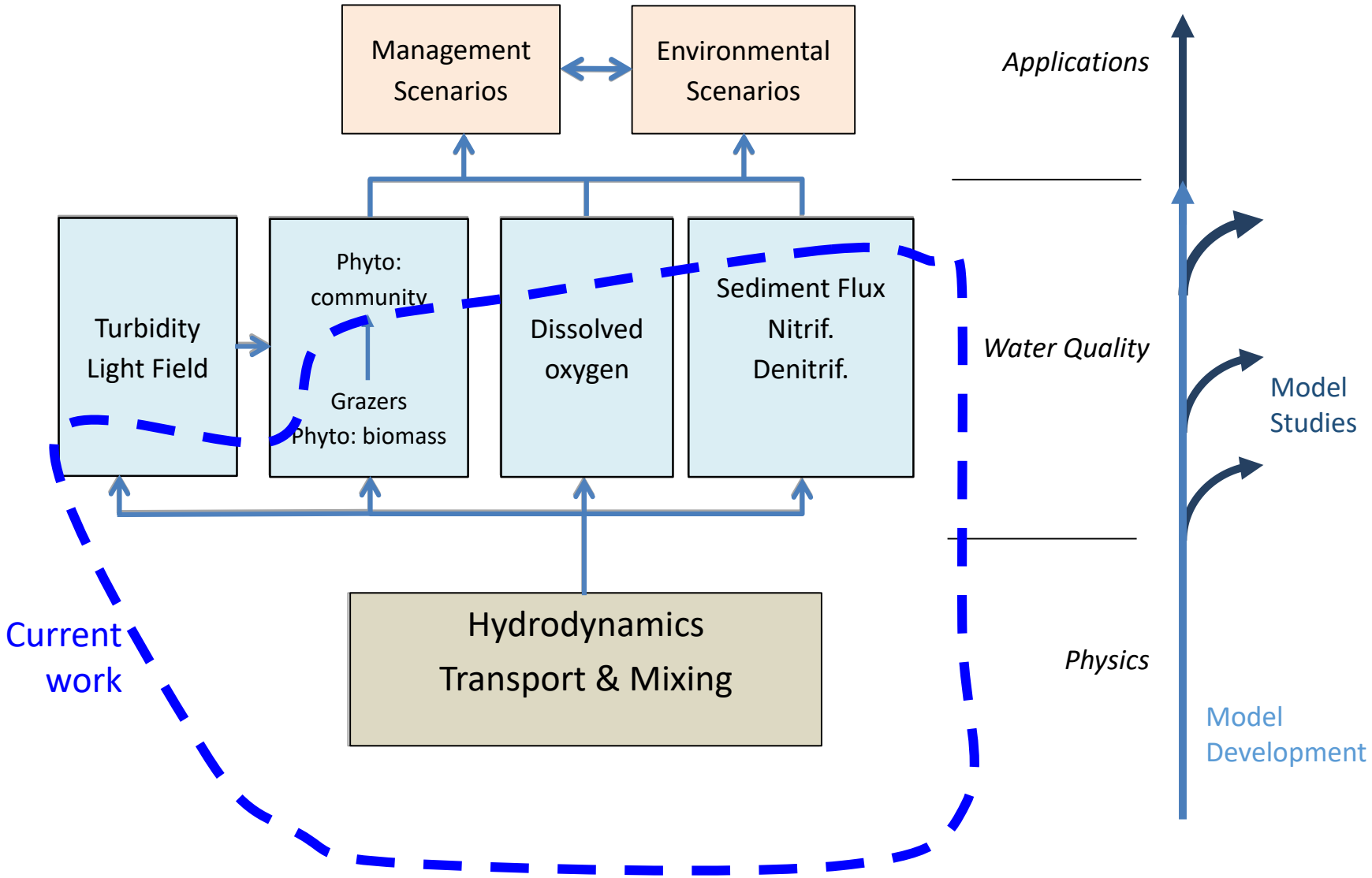
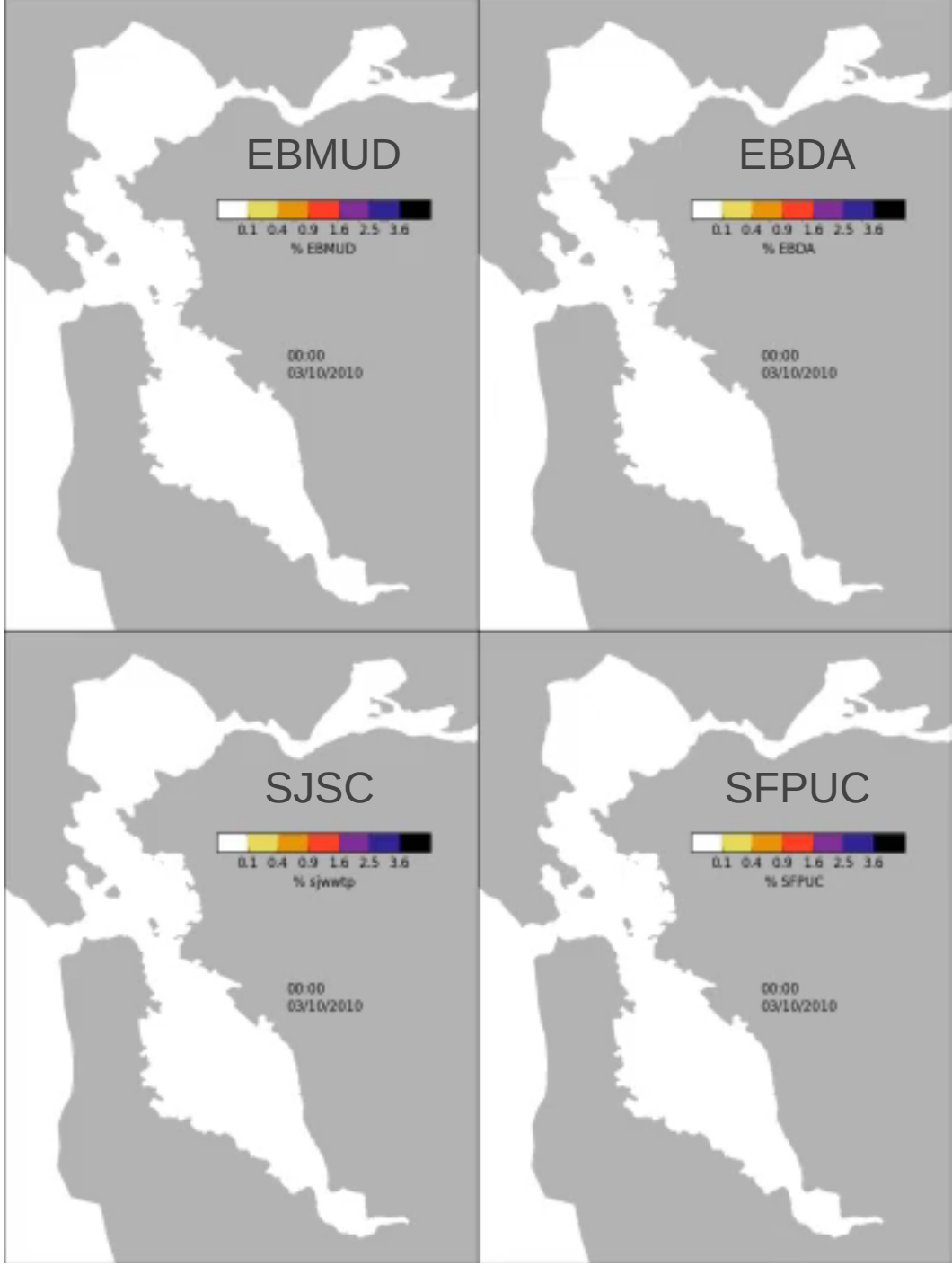


What are the space/time varying contributions of individual POTWs?

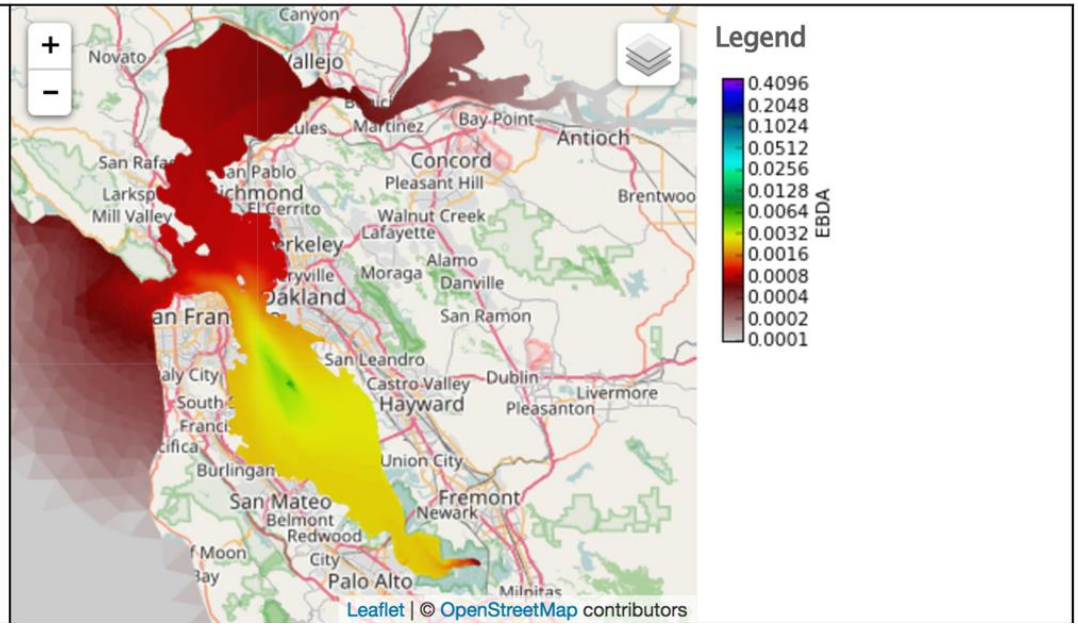
Note: conservative tracer run



Conservative Tracers

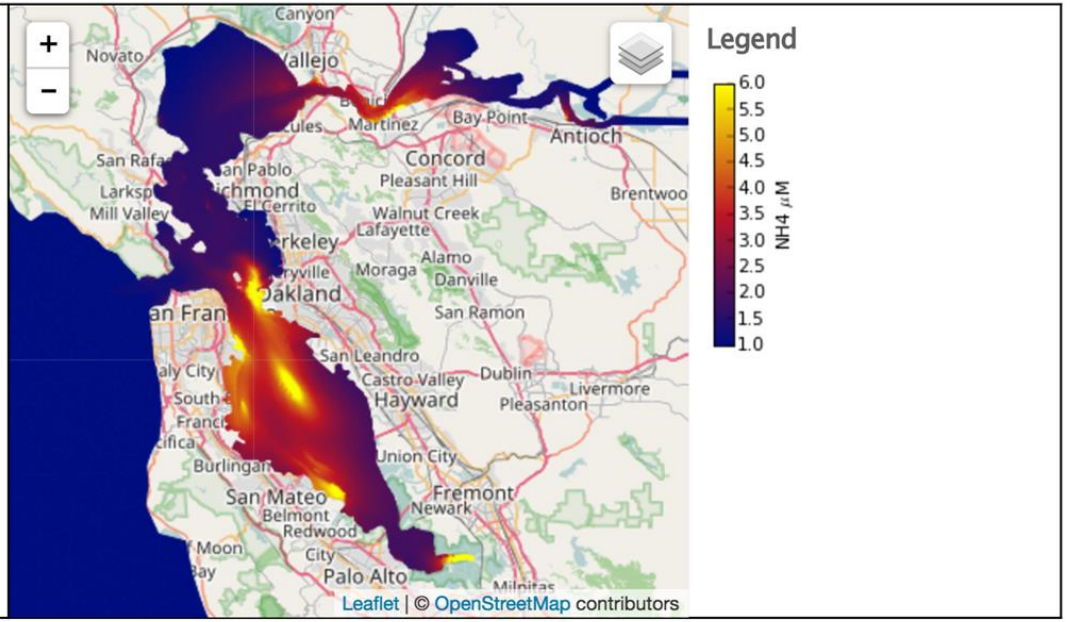
www.sfbaynutrients.sfei.org/modeling/map.html

A snapshot of conservative tracer distributions is displayed in this series of maps. The layer selector in the upper right corner of the map can be used to select a single POTW or refinery source. The colors displayed correspond to the dilution of that source throughout the bay. These simulations show a snapshot in time, corresponding to the start of July, 2013, from a simulation starting in October, 2012. The color scale is logarithmic, with each tick representing a factor of 2 dilution.

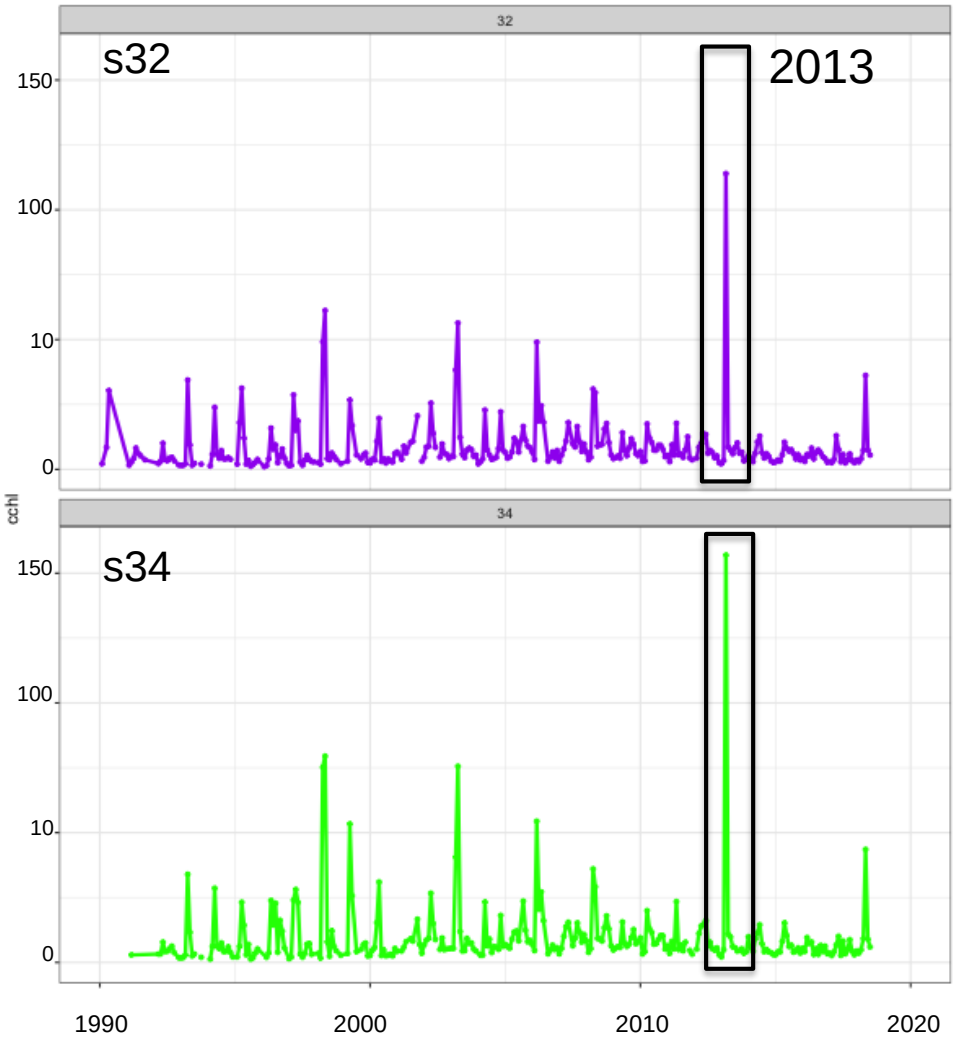


Reactive Nutrients

Here the results of a reactive nutrient water quality simulation is shown. The model run includes estimated NO3 and NH4 loads from the POTWs and refineries. In addition to transport by the underlying hydrodynamic model, the water quality model includes nitrification and denitrification with stock formulations for the rate constants. Hot-spots of NH4 are associated with non-nitrifiying POTW flows, but disperse and nitrify over relatively short periods. The result is a NO3 field which is relatively diffuse with the exception of several significant nitriying POTW flows.



chl-a (µg L^{-1}) at two Lower South Bay Stations



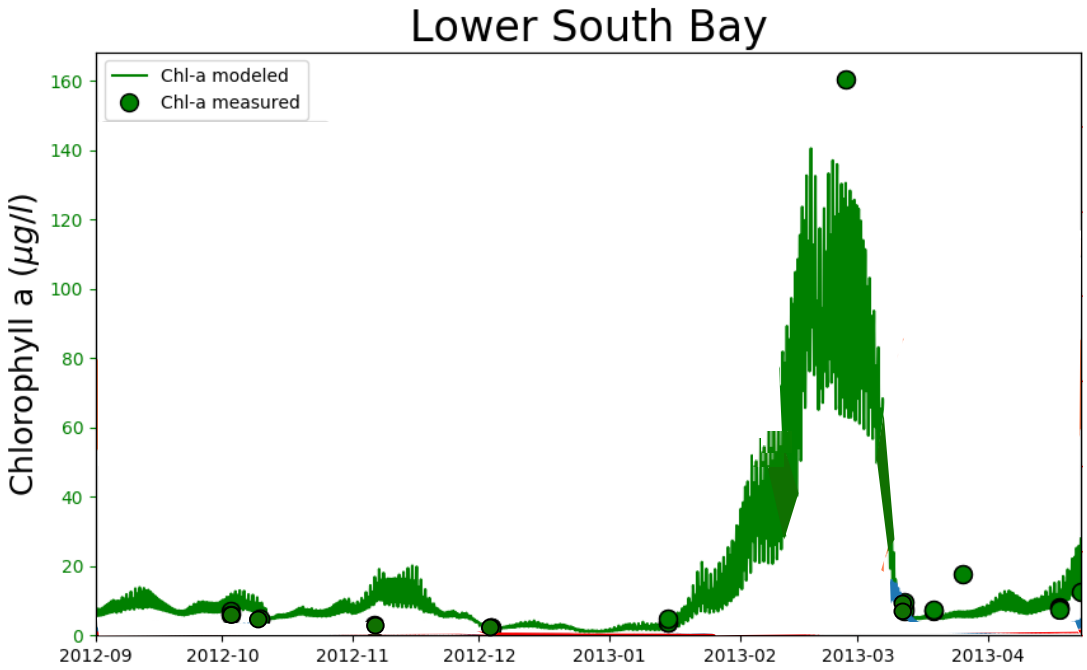
How well does the model capture..

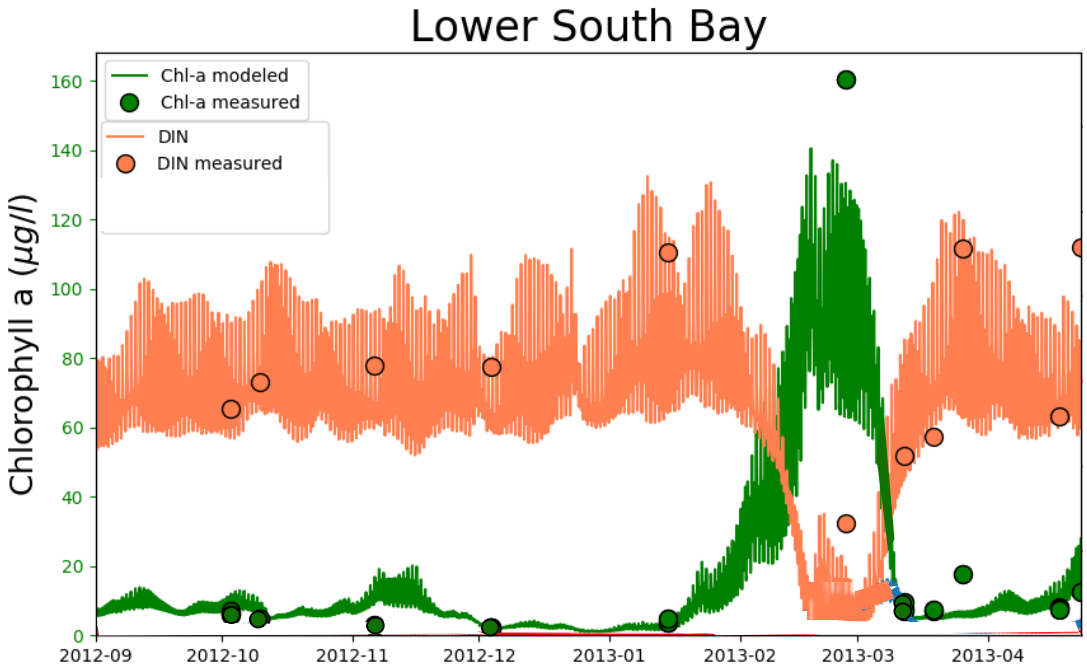
Phytoplankton biomass/blooms

- *Timing…Magnitude…Locations*
- *Factors controlling loss and gain*

Nutrient levels and fate

Dissolved Oxygen


Lower South Bay
Chl-a modeled
Chl-a measured
Chlorophyll a (µg/l)
0
20
40
60
80
100
120
140
160
2012-09
2012-10
2012-11
2012-12
2013-01
2013-02
2013-03
2013-04


Lower South Bay
Chl-a modeled
Chl-a measured
DIN
DIN measured
Chlorophyll a (µg/l)
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40
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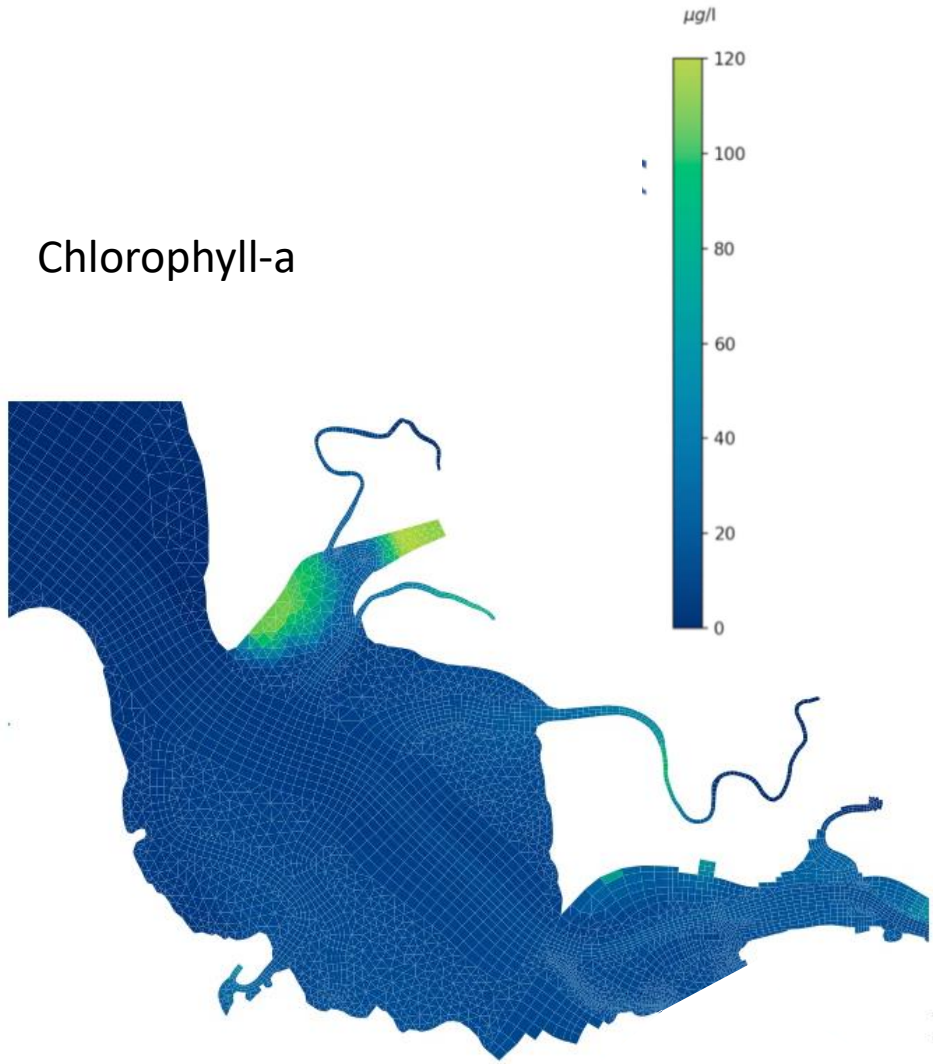
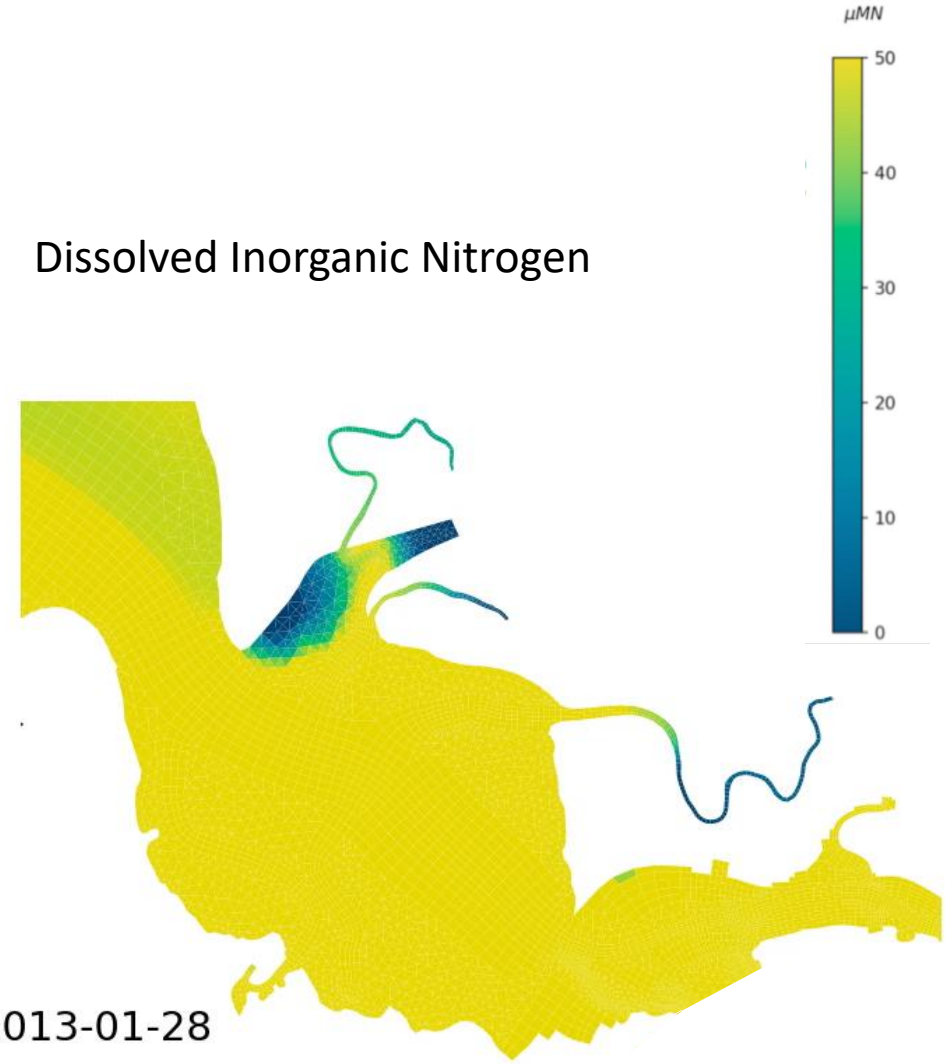
160
2012-09
2012-10
2012-11
2012-12
2013-01
2013-02
2013-03
2013-04

Chlorophyll-a

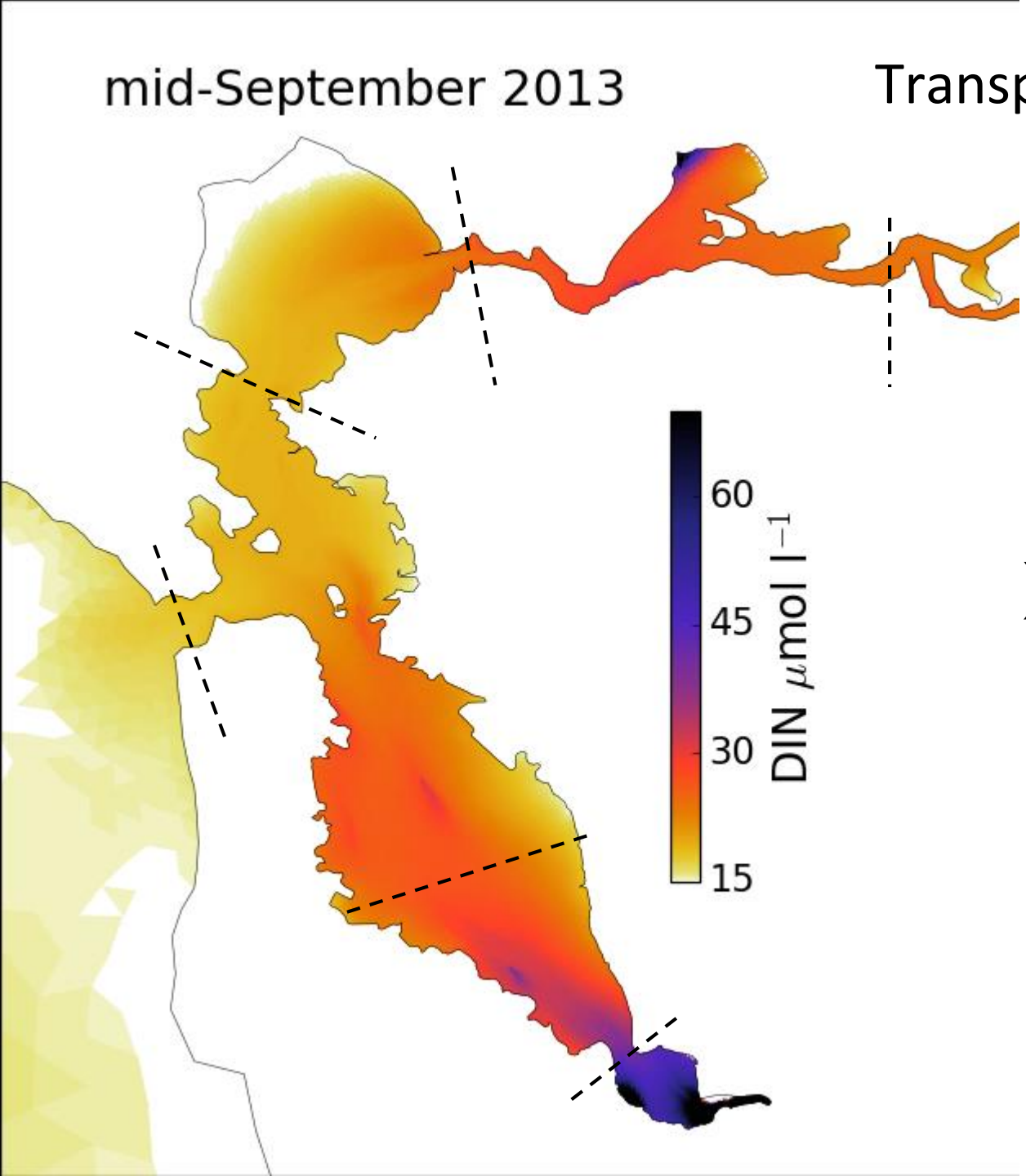


Dissolved Inorganic Nitrogen



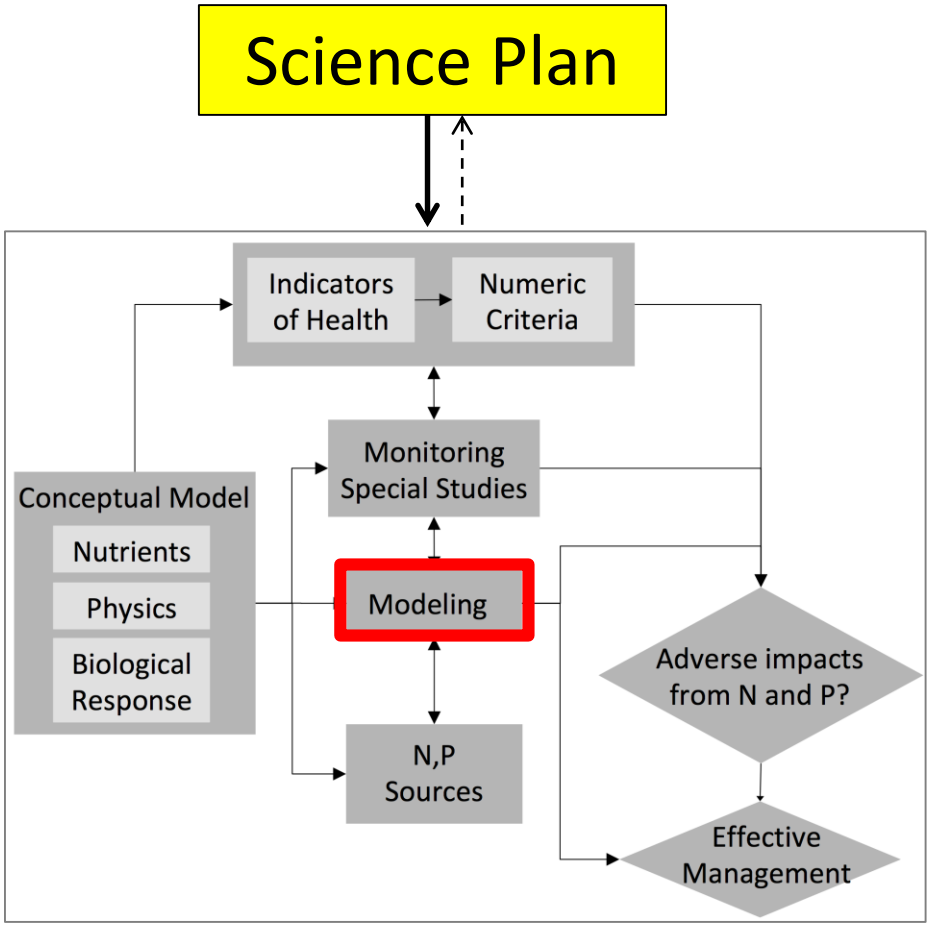
2013-01-28

Transport and Fate of DIN



Nitrogen Budgets

$$\sum \text{Loads} + \text{Import} = \sum \text{Export} + \text{Loss} + \Delta\text{STORAGE}$$



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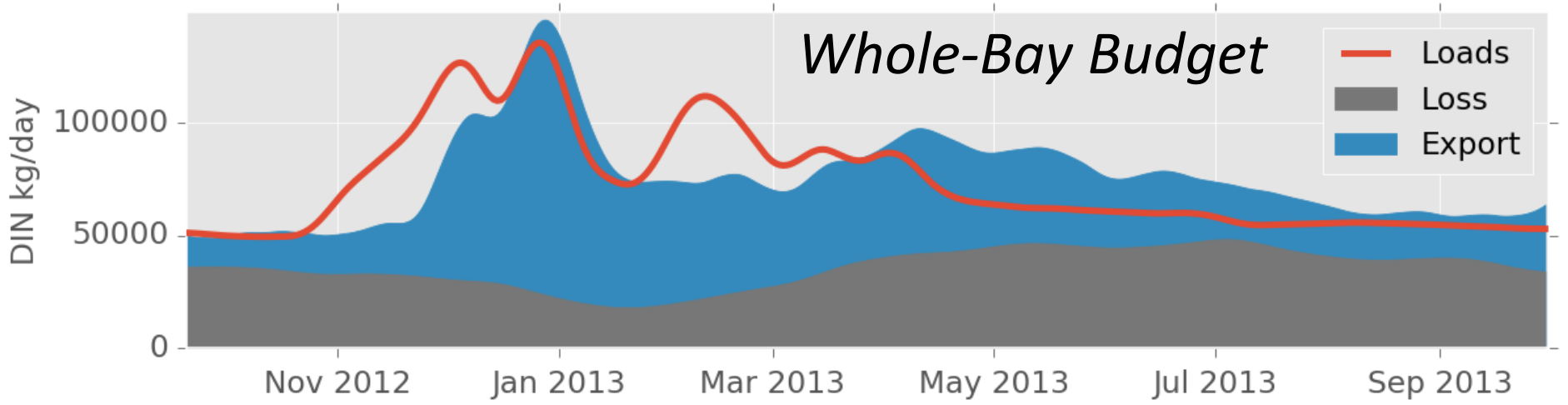
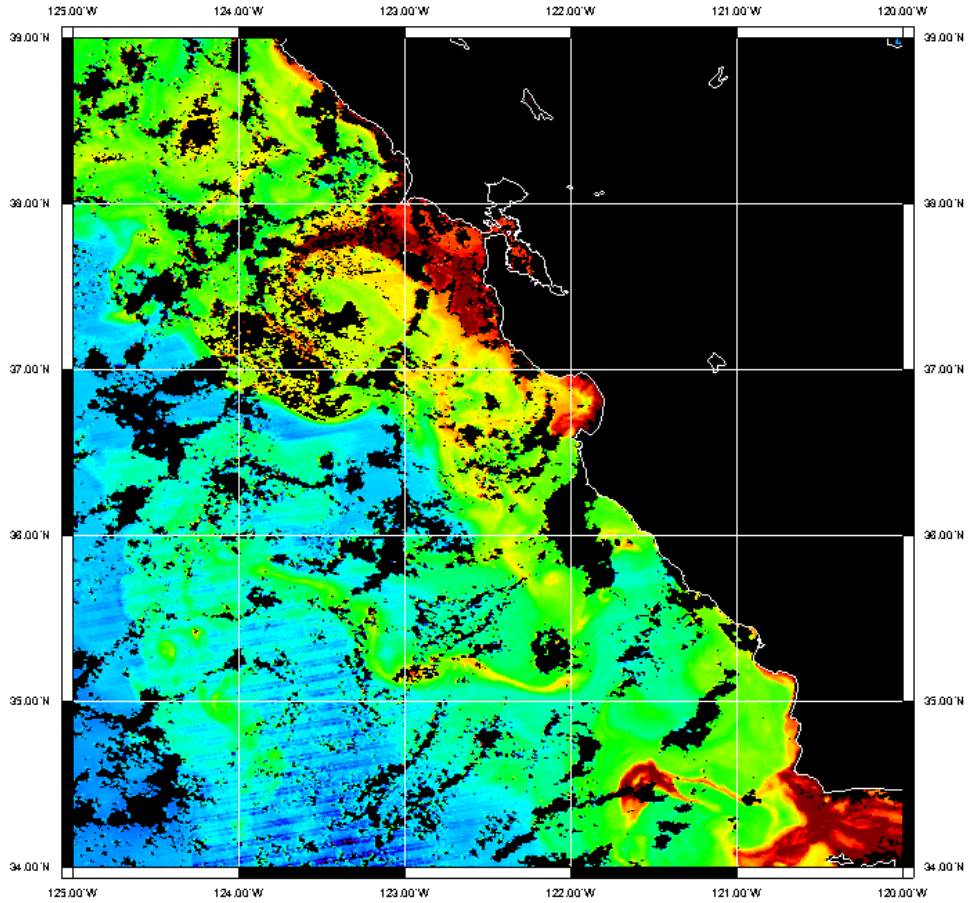
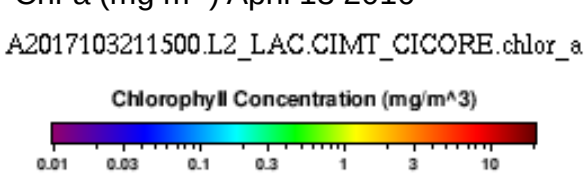
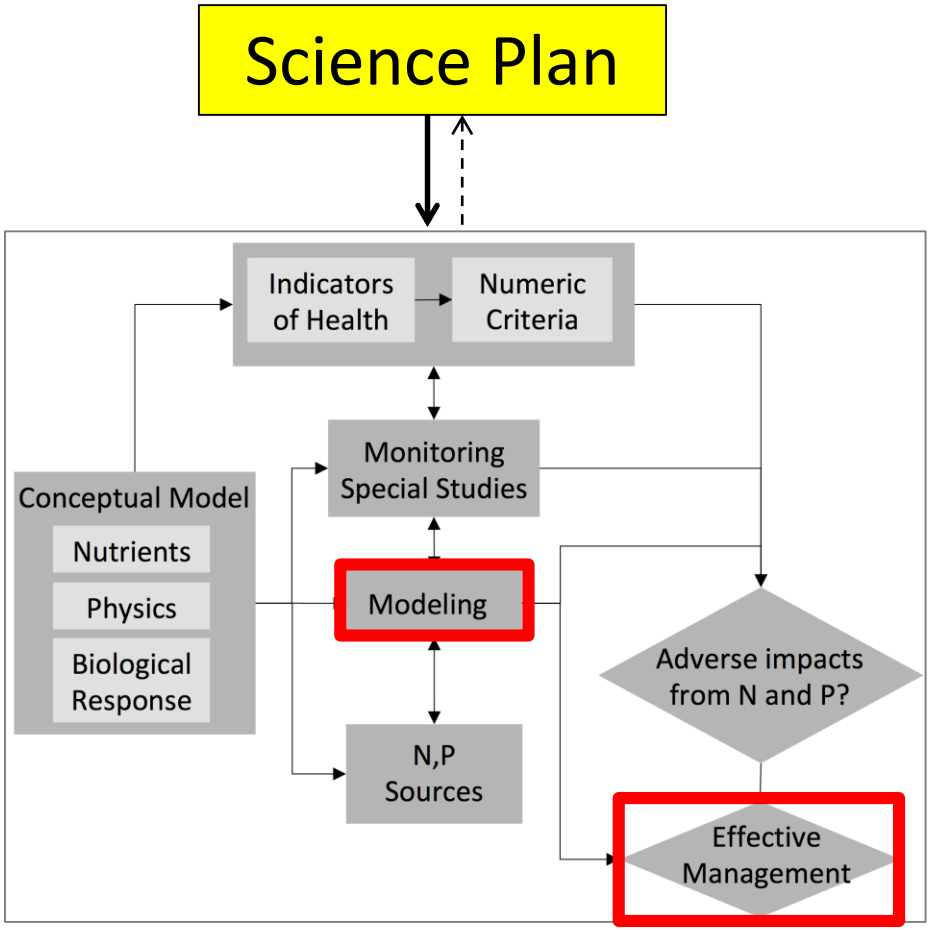




- During spring-summer-fall, >50% of DIN loads are "lost" internally…presumably denitrified within the Bay.
- Cool months…San Francisco Bay acts as >50,000 kg d^{-1} point source to the coastal ocean
  - *Impacts??*

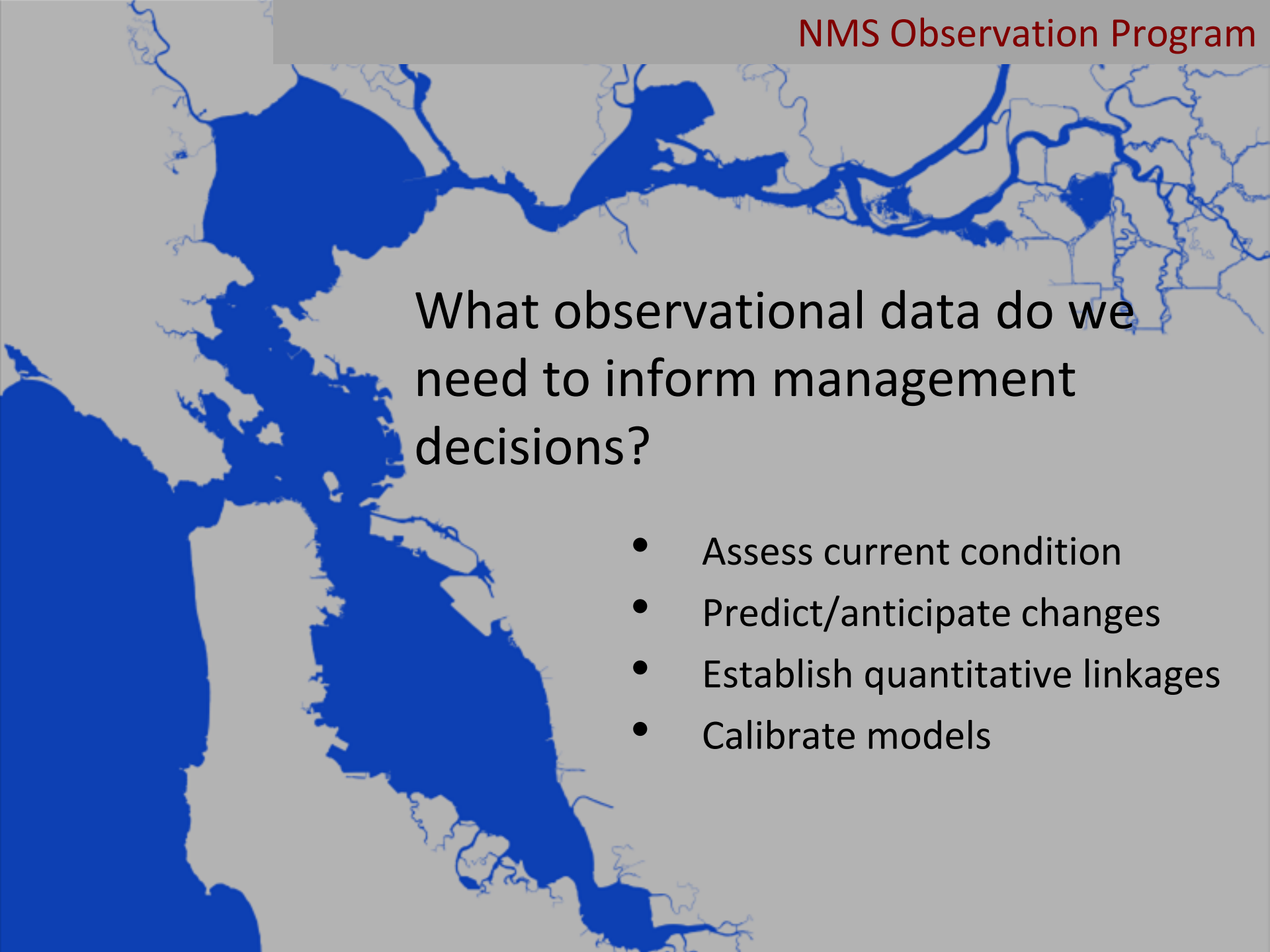
Chl-a (mg m^{-3}) April 13 2016





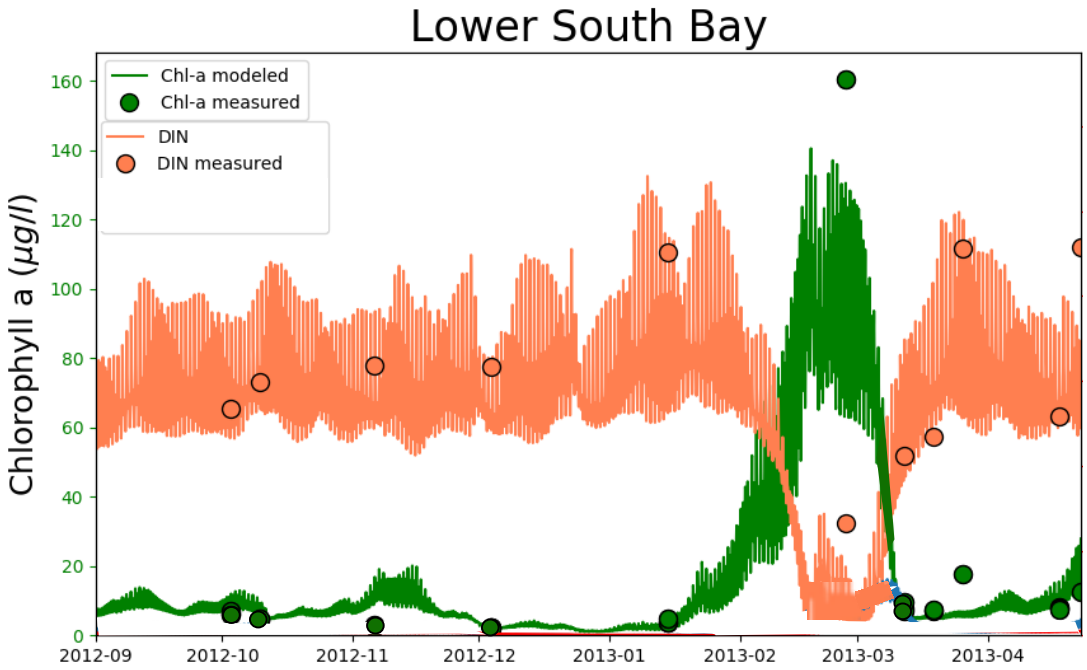
Science Program Priorities

1. Nutrients loads, transformations
2. Phytoplankton Productivity and Low DO
3. HABs/toxins
4. Impacts on coastal ocean
5. Responses under future scenarios
6. Effective management options

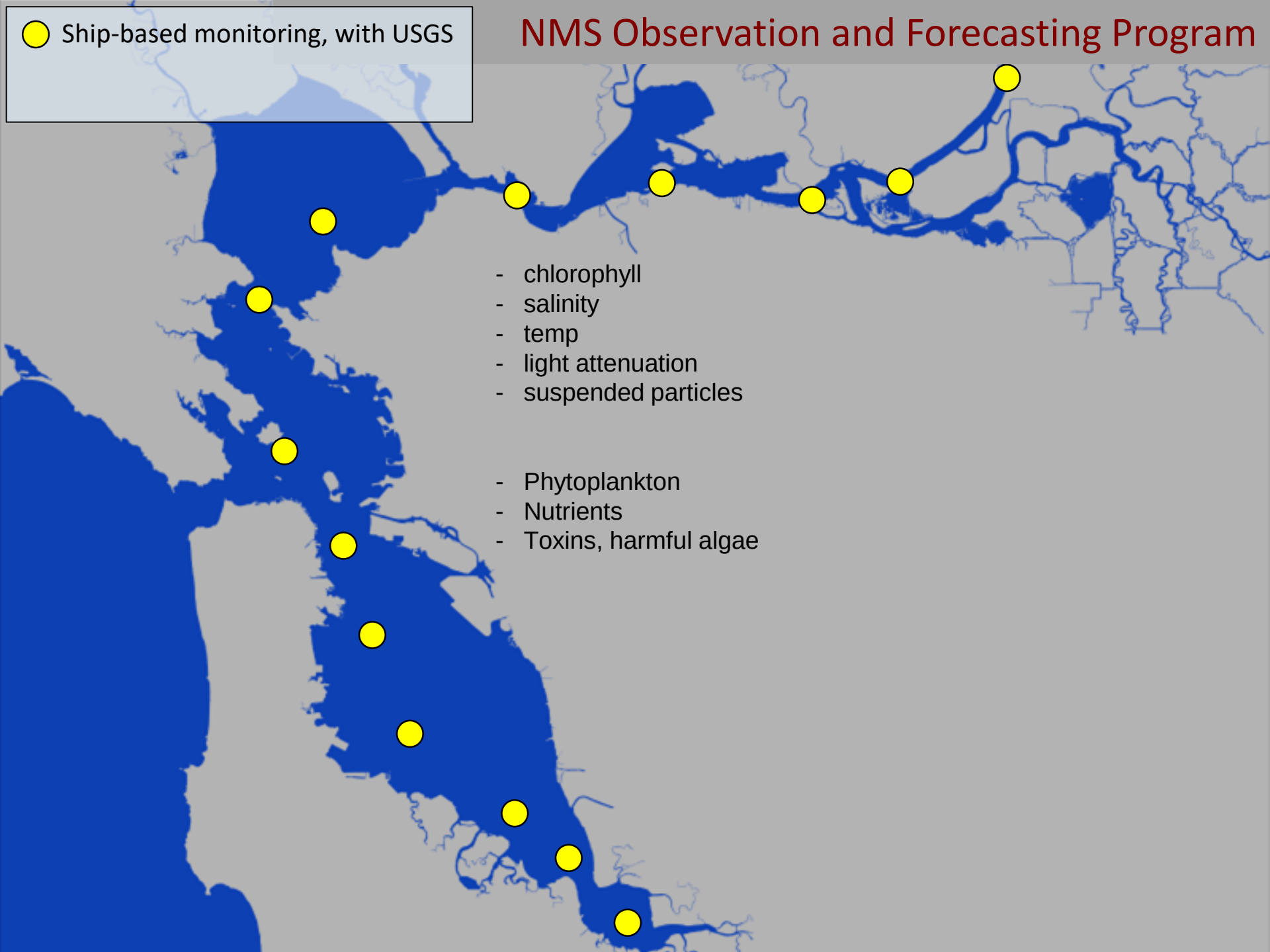


What observational data do we need to inform management decisions?

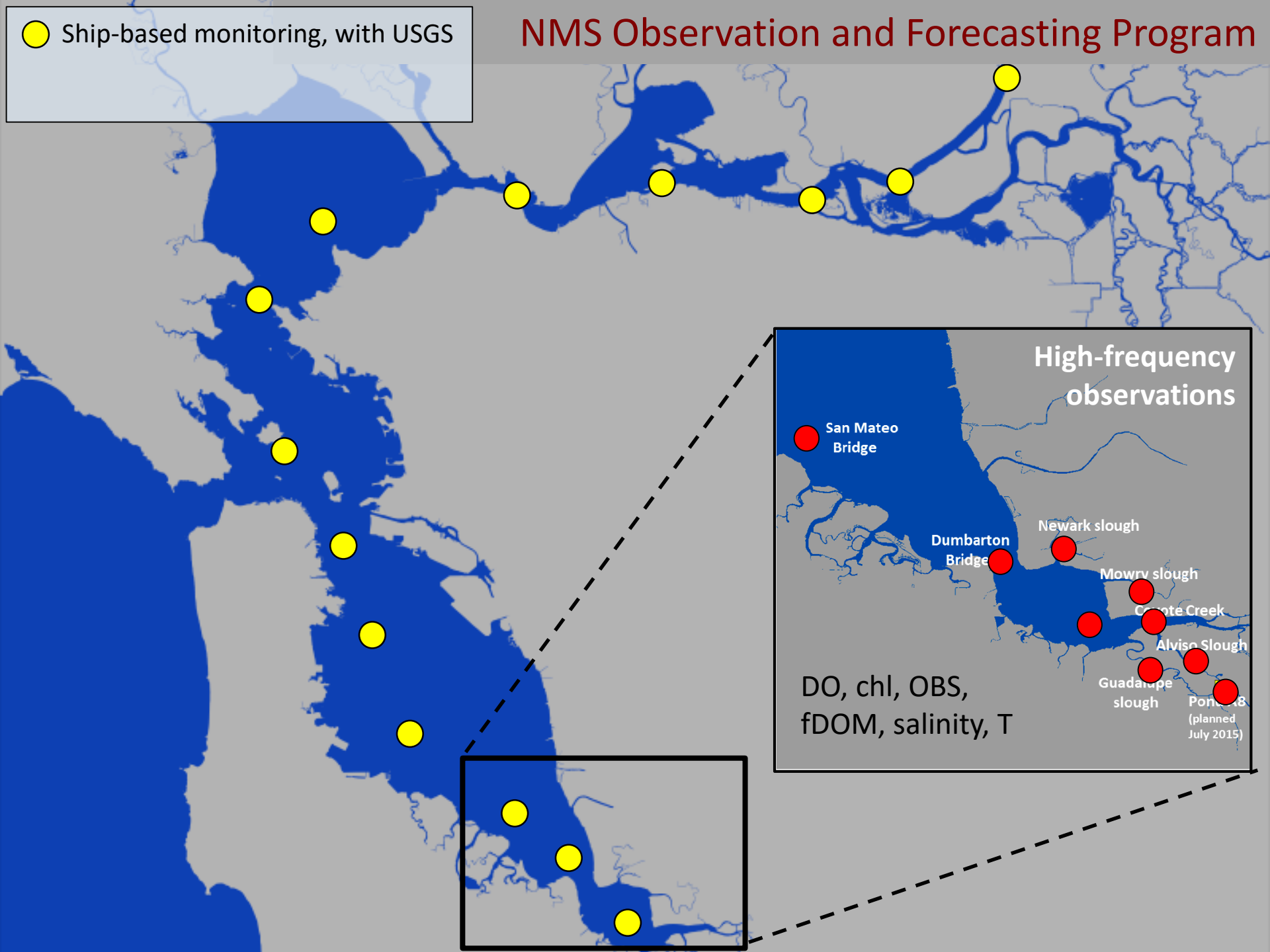
- Assess current condition
- Predict/anticipate changes
- Establish quantitative linkages
- Calibrate models


Lower South Bay
Chl-a modeled
Chl-a measured
DIN
DIN measured
Chlorophyll a (µg/l)
0
20
40
60
80
100
120
140
160
2012-09
2012-10
2012-11
2012-12
2013-01
2013-02
2013-03
2013-04

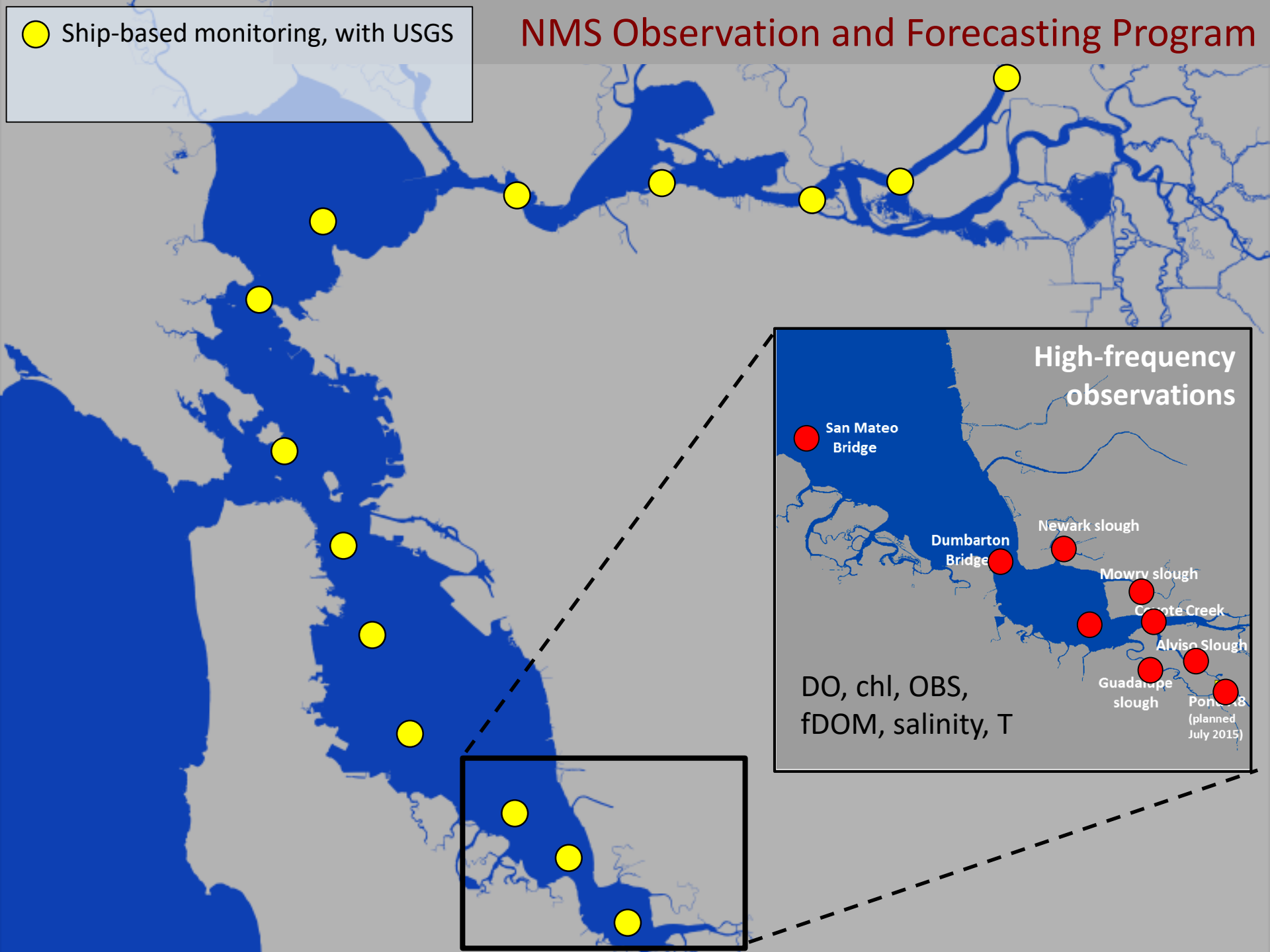
NMS Observation and Forecasting Program



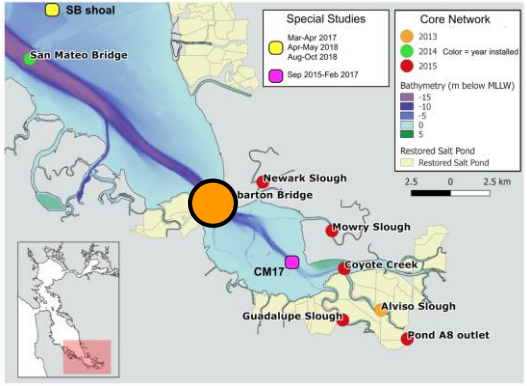
NMS Observation and Forecasting Program



NMS Observation and Forecasting Program

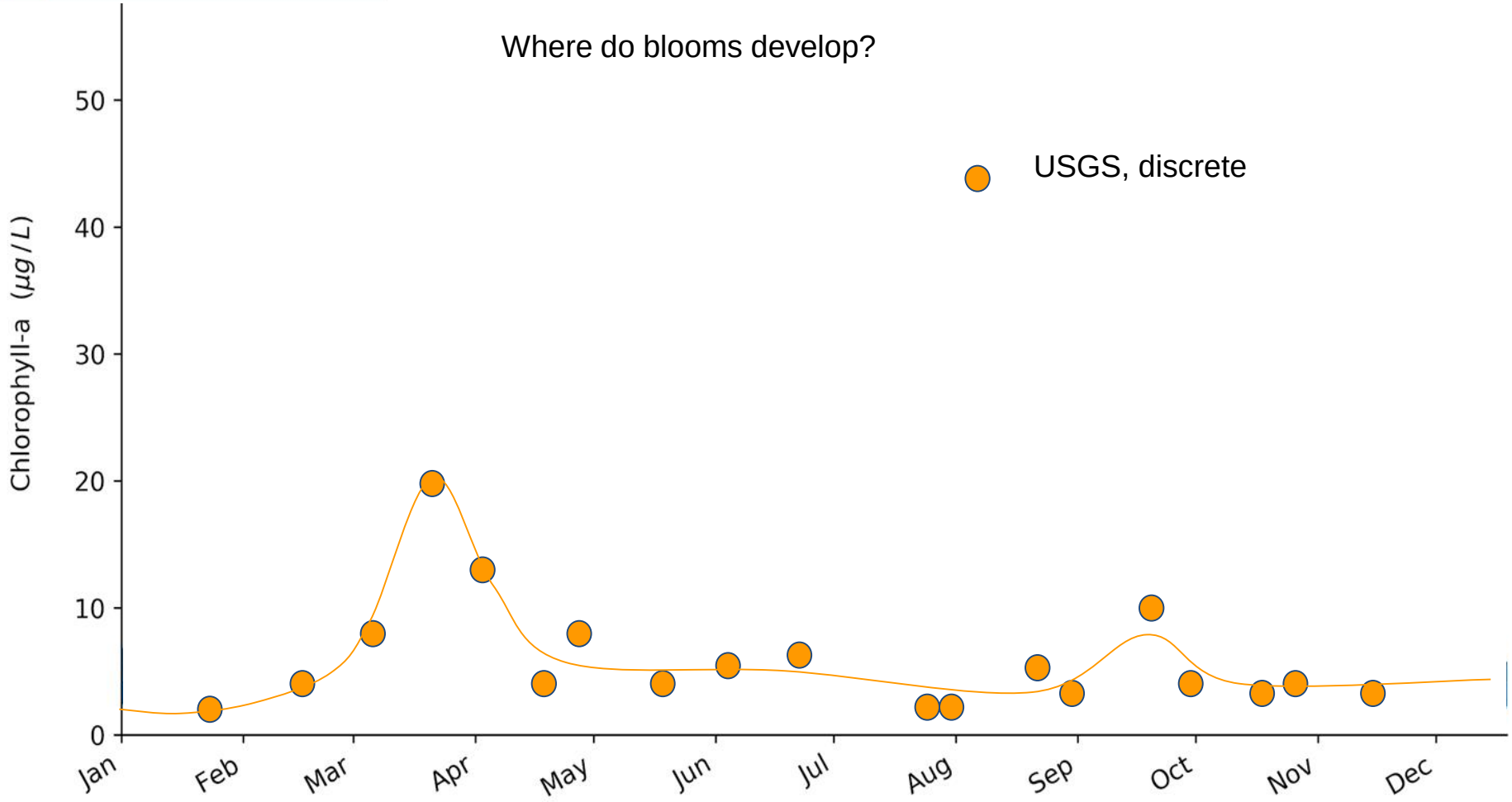


Jan-Dec 2017: Dumbarton Bridge

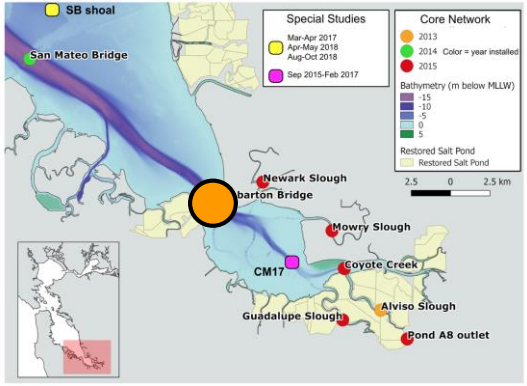


What factors regulate blooms magnitude, timine, duration?

Where do blooms develop?



Jan-Dec 2017: Dumbarton Bridge



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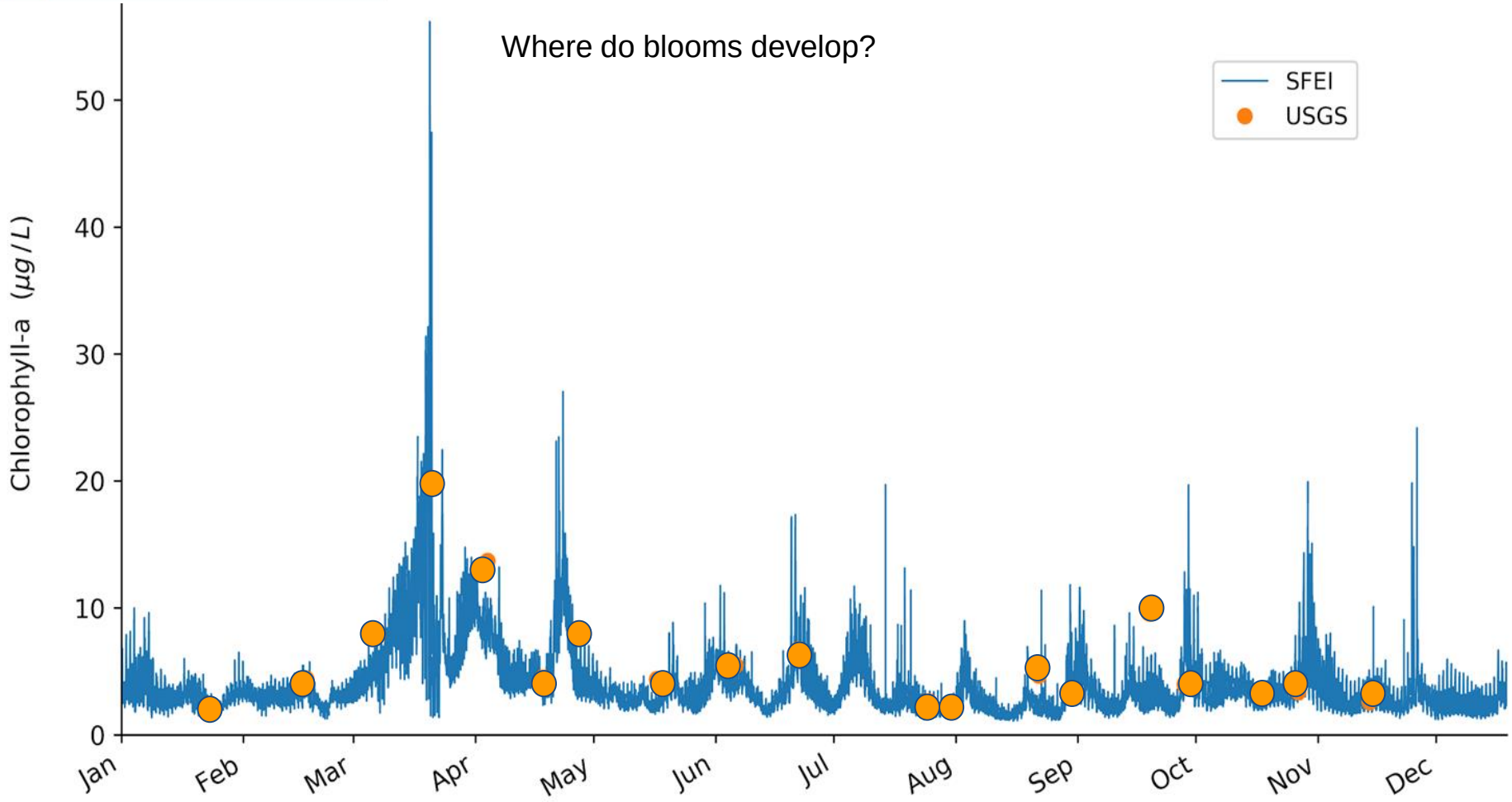
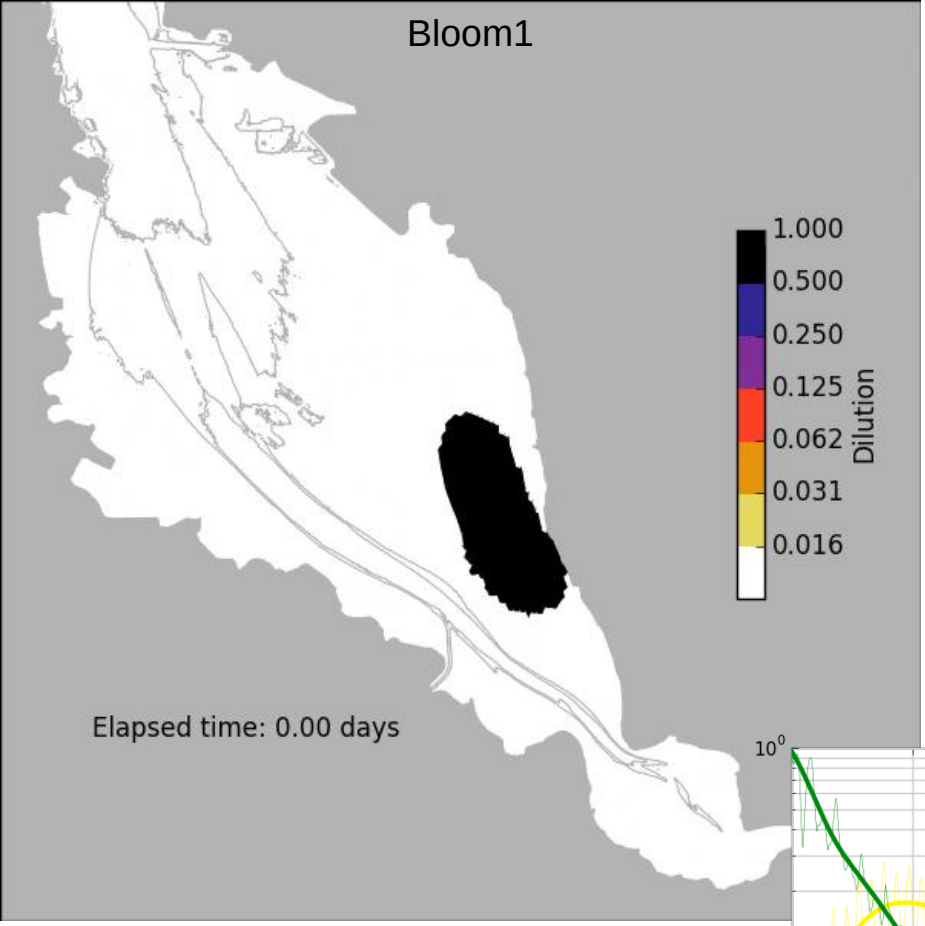
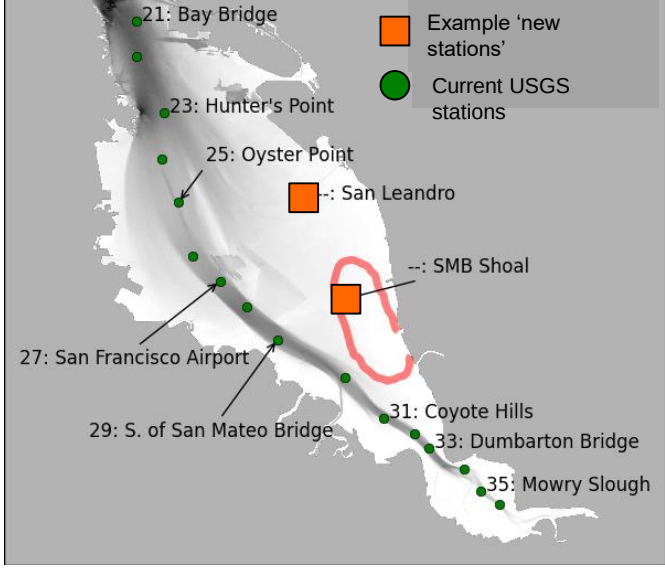
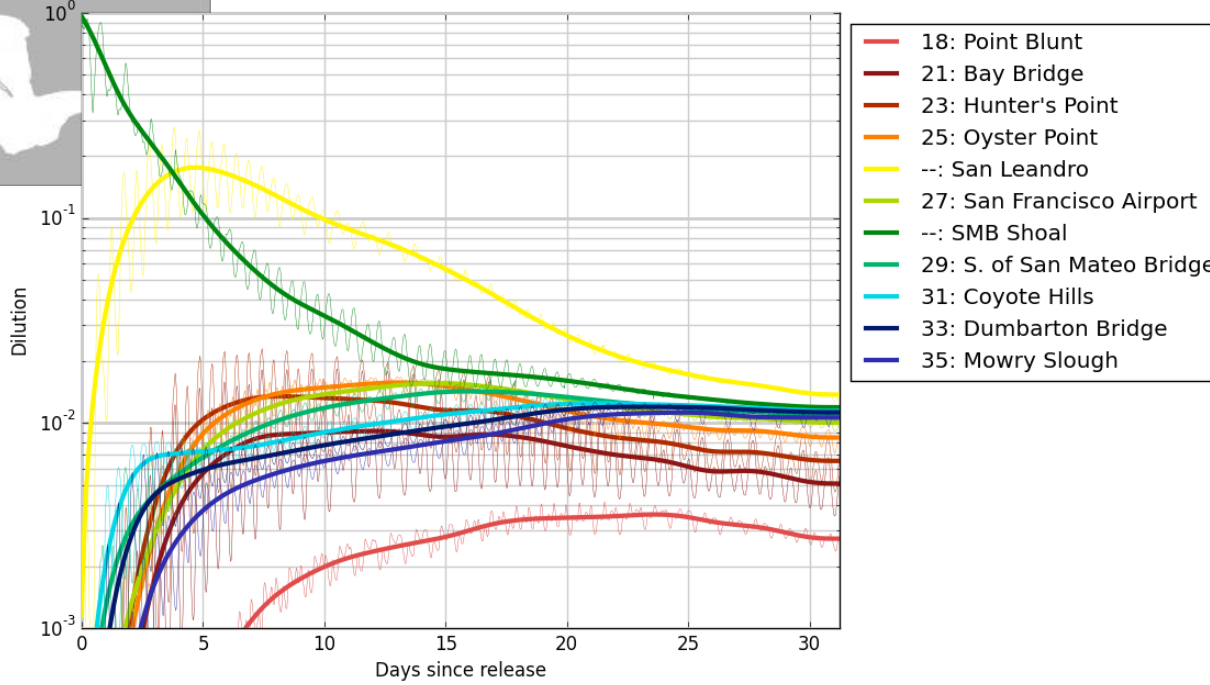
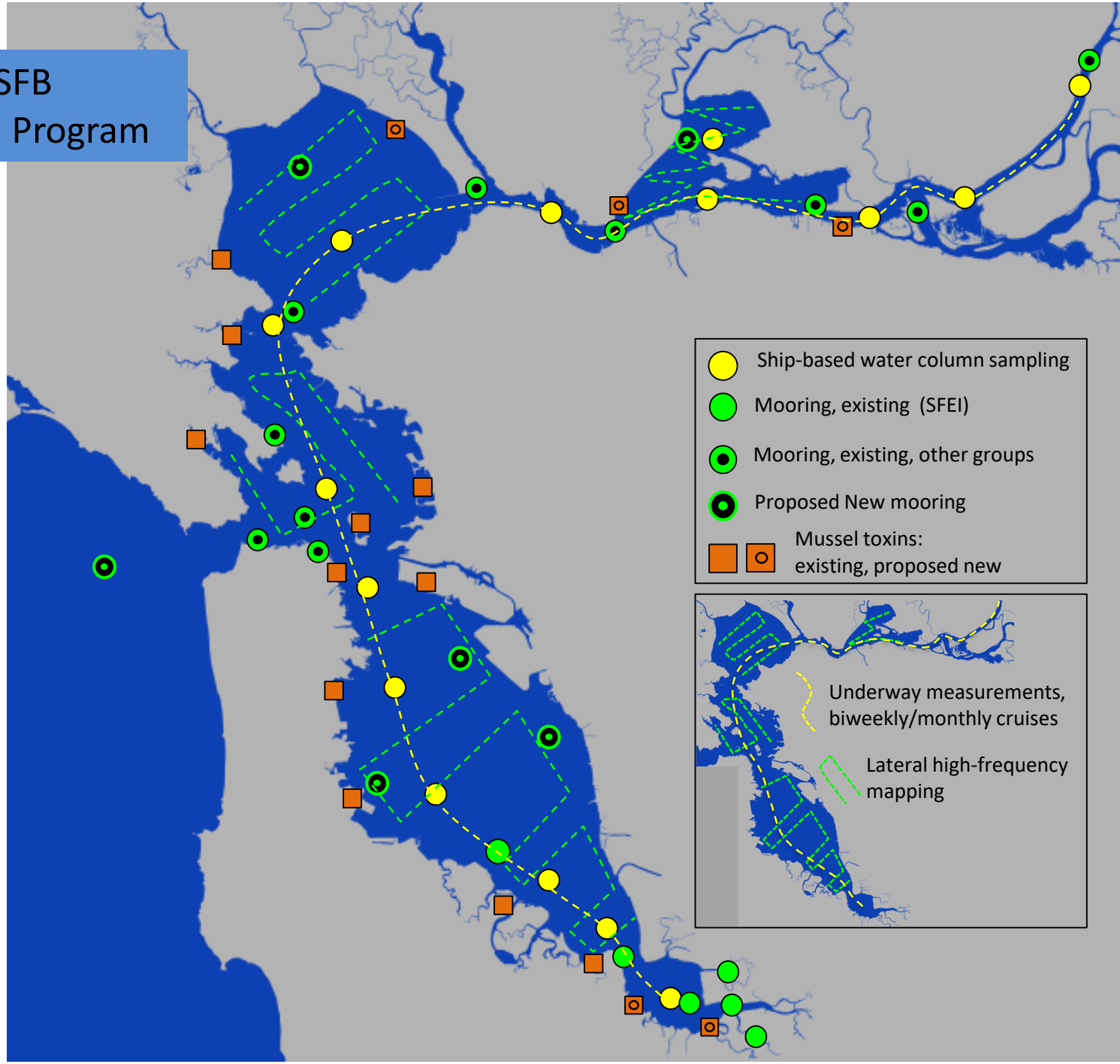


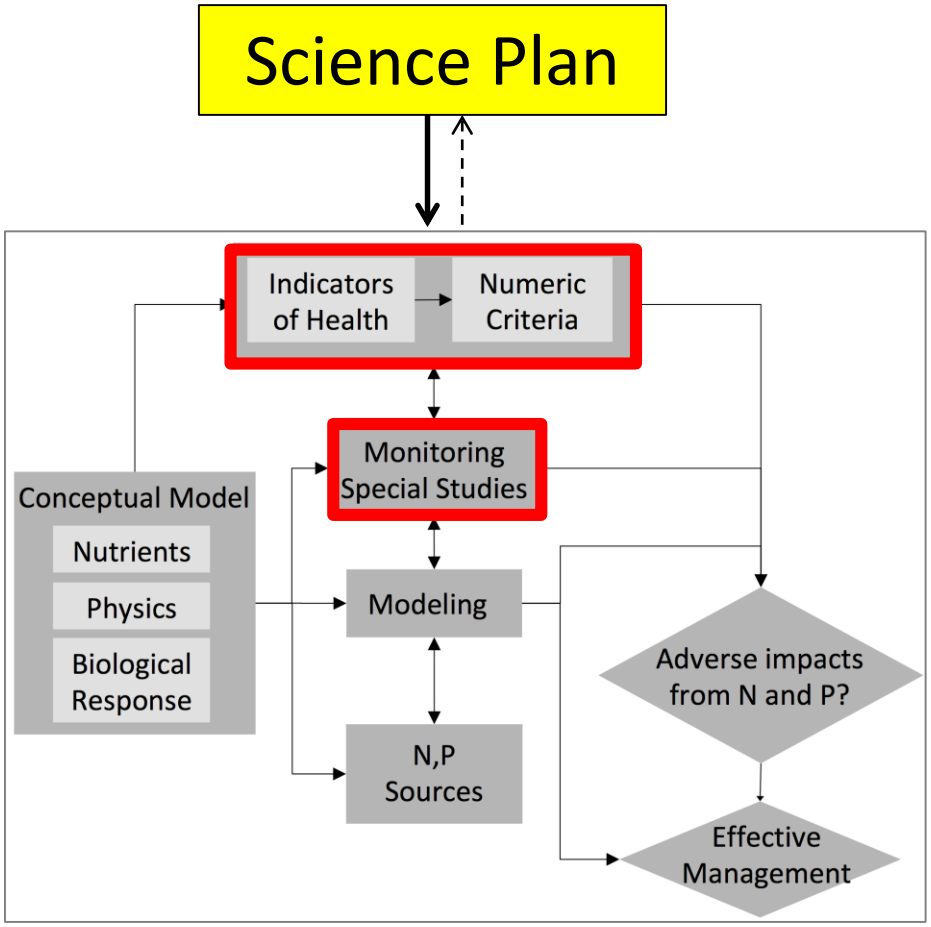

Bloom1
1.000
0.500
0.250
0.125
0.062
0.031
0.016
Dilution
Elapsed time: 0.00 days


21: Bay Bridge
23: Hunter's Point
25: Oyster Point
--: San Leandro
--: SMB Shoal
27: San Francisco Airport
29: S. of San Mateo Bridge
31: Coyote Hills
33: Dumbarton Bridge
35: Mowry Slough
Example 'new stations'
Current USGS stations


Dilution
Days since release
18: Point Blunt
21: Bay Bridge
23: Hunter's Point
25: Oyster Point
--: San Leandro
27: San Francisco Airport
--: SMB Shoal
29: S. of San Mateo Bridge
31: Coyote Hills
33: Dumbarton Bridge
35: Mowry Slough

Next Generation SFB NMS Observation Program





Science Program Priorities

1. Nutrients loads, transformations
2. Phytoplankton Productivity and Low DO
3. HABs/toxins
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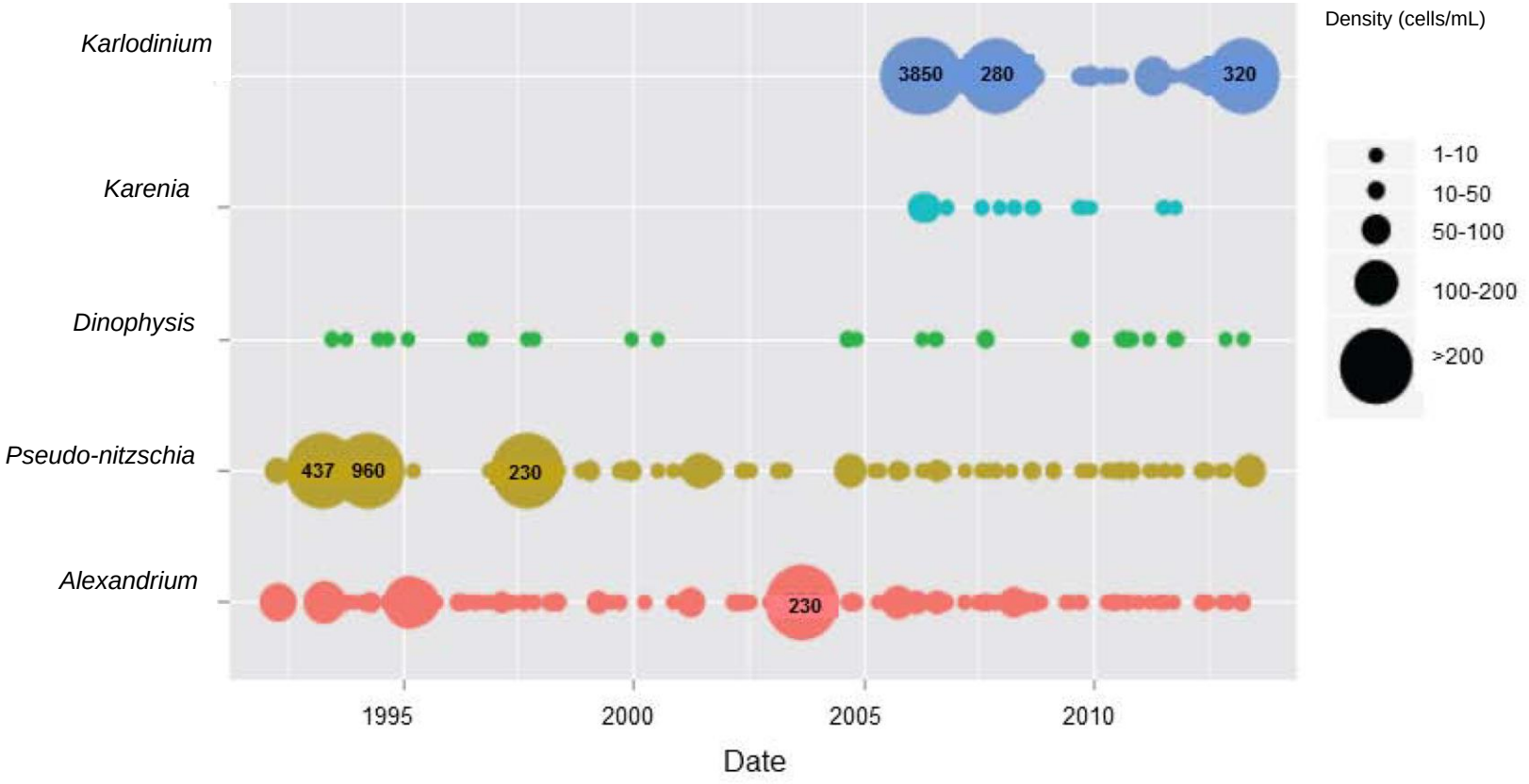
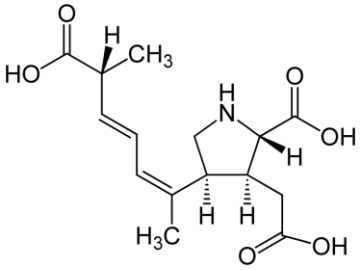
Harmful Algae Detections in San Francisco Bay



Sutula et al 2017

Domoic Acid

(Amnesic Shellfish Poisoning)



Pseudo-nitzchia

Photo: Eric Risberg, Associated Press

HABs and PhycoToxins in SFB: Science/Management Questions

1. Substantial HABs / phycotoxin threat ?
   a. Sensitive population(s)? *Biota? Humans?*
   b. Current vs. *Future* Conditions?
2. What factors regulate HA abundance and toxicity in SFB?
3. Role of SFB nutrients: N,P → frequency or severity of HA events?
4. Protective nutrient loads, with respect to HAs and phycotoxins?

- Light availability
- Temperature
- Salinity
- Mixing
- Nutrients

NMS Observation and Forecasting Program

Ship-based monitoring, with USGS

Mussels

Phytoplankton: Microscopy, Sequencing (qPCR)

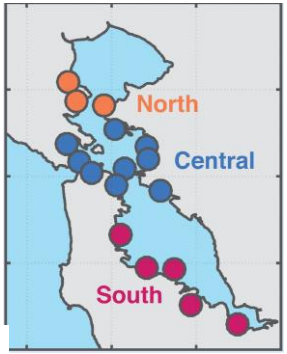
Algal toxin measurements

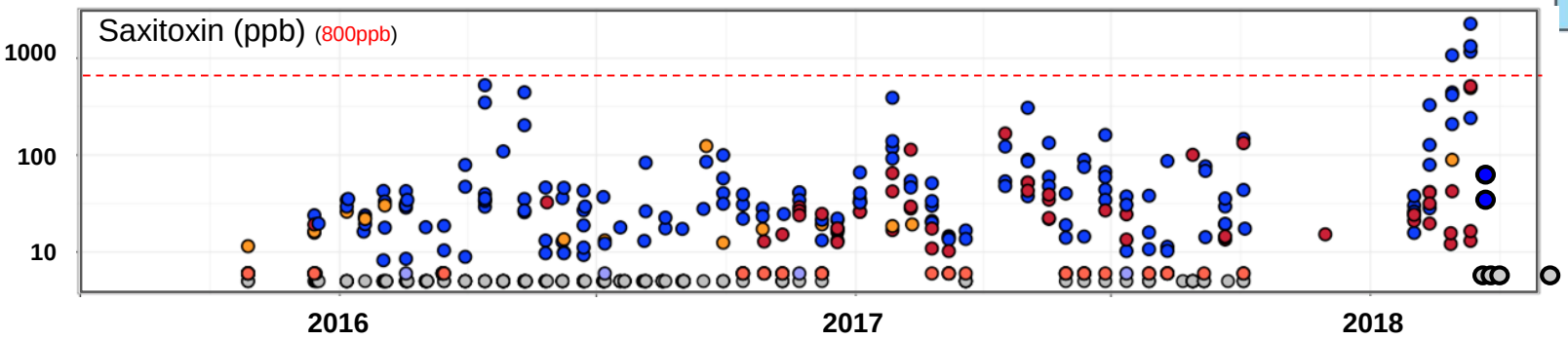
- Naturally occurring mussels
- Floating docks, readily-accessible
- Bi-weekly sampling (Sep 2015-present)
- Domoic Acid, Saxitoxin, Microcystin

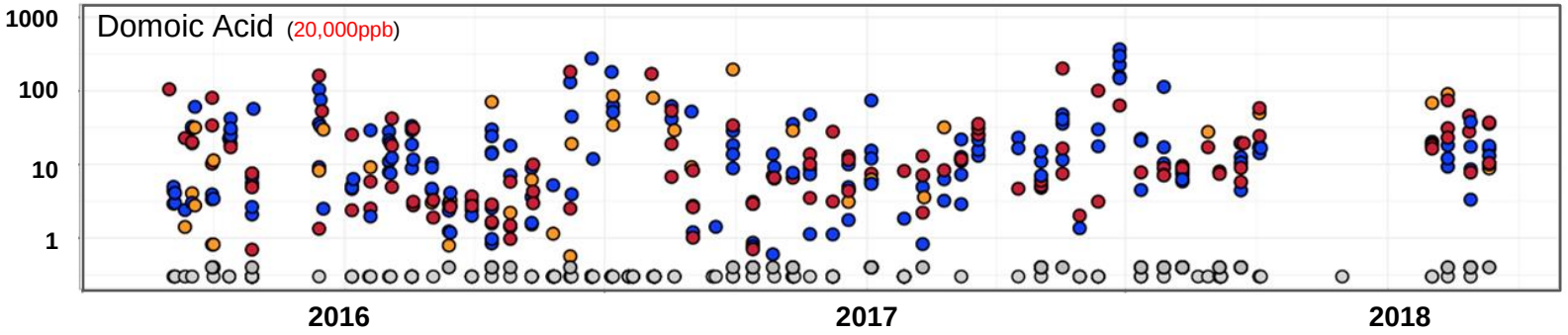
Mussel Toxin concentrations, 9/2015-3/2018

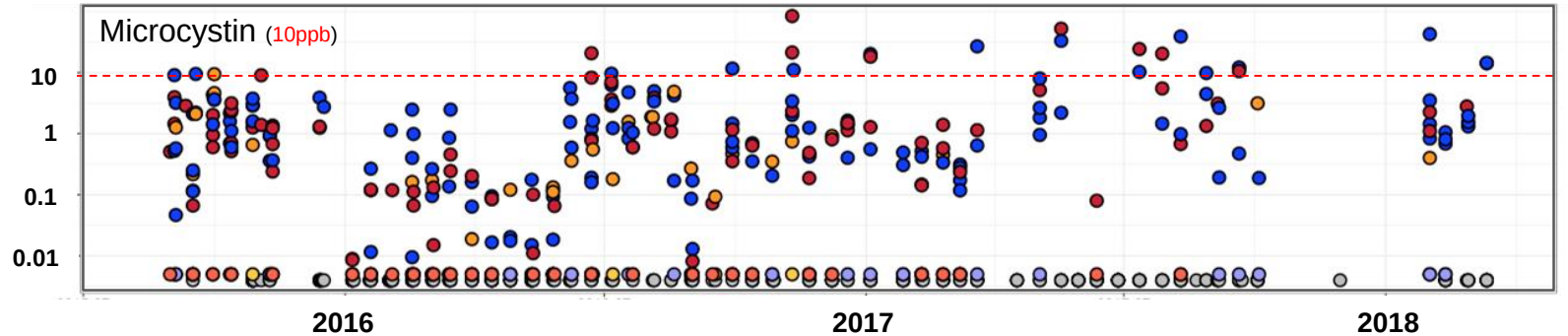
Lighter shade: [tox] < LOQ
Grey: [tox] < LOD

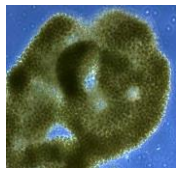
Symbol colors correspond SFB region's in map



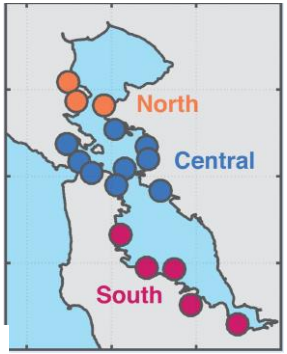




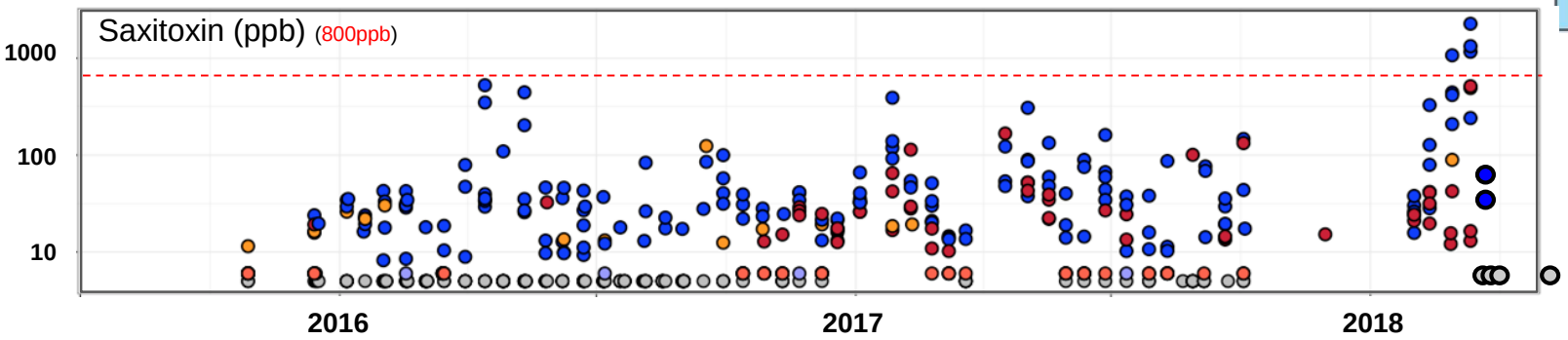


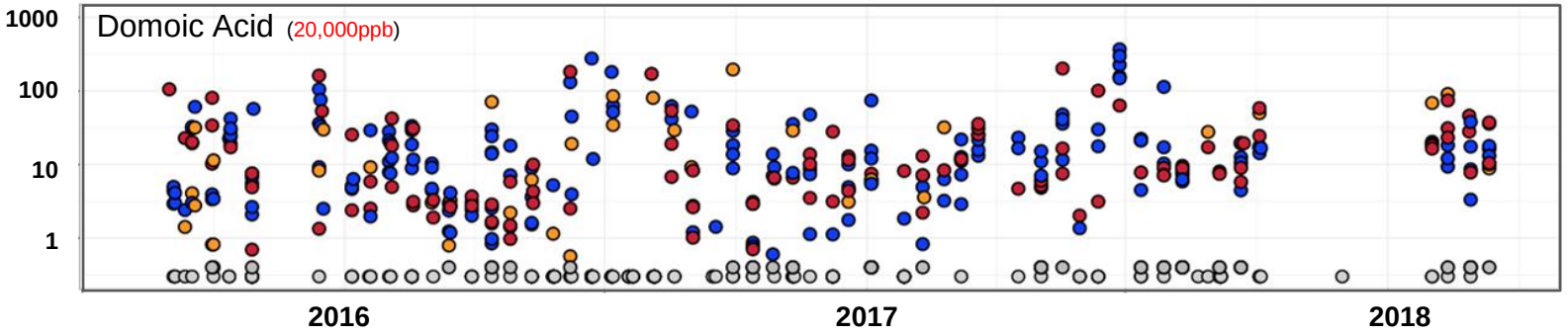


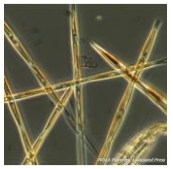
- Multiple phycotoxins regularly detected in biota and water (particulate, dissolved)
- Regularly detect multiple HA taxa

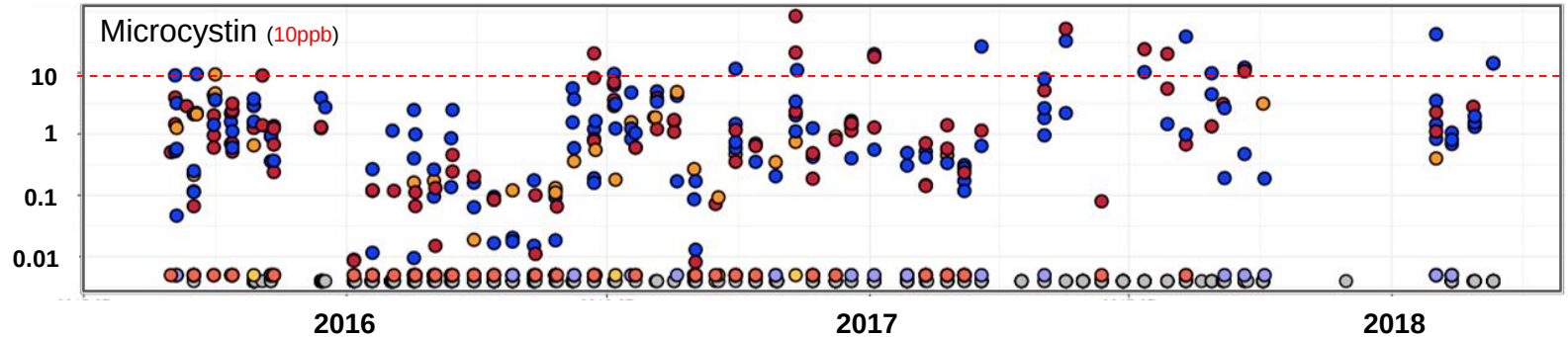


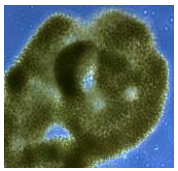
(SFEI, in prep; SFEI 2017; Peacock et al 2018)

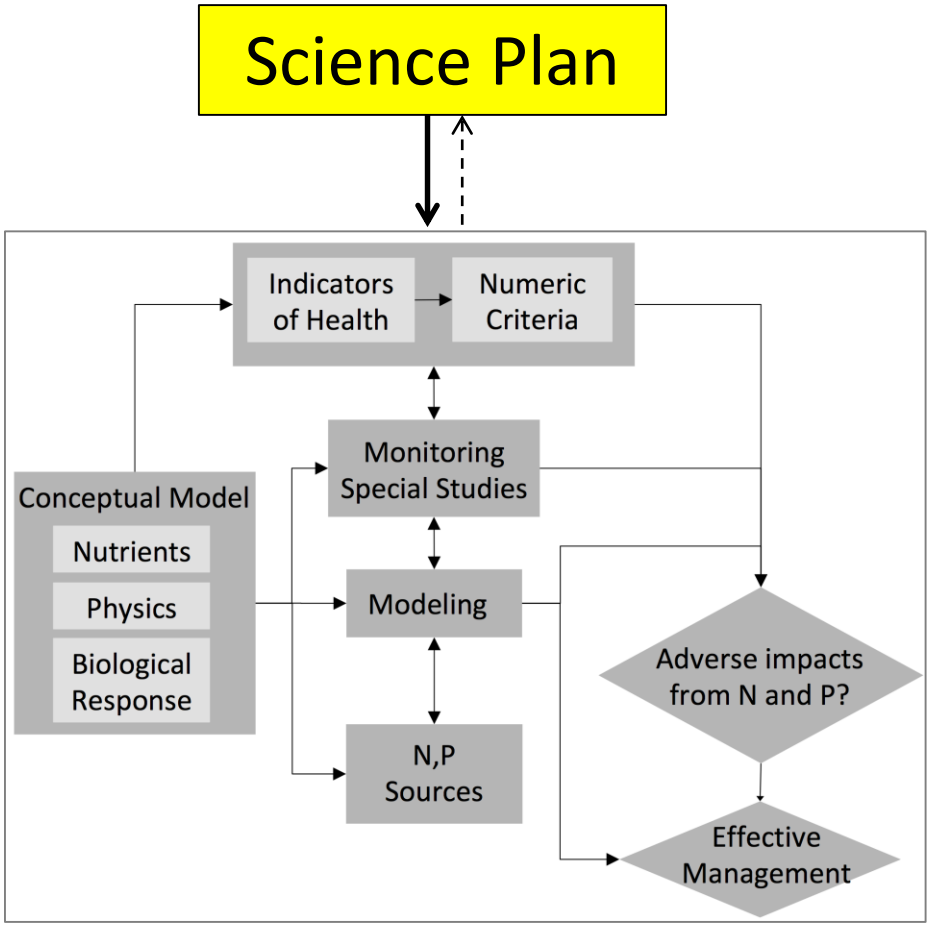












Science Program Priorities

1. Nutrients loads, transformations
2. Phytoplankton Productivity and Low DO
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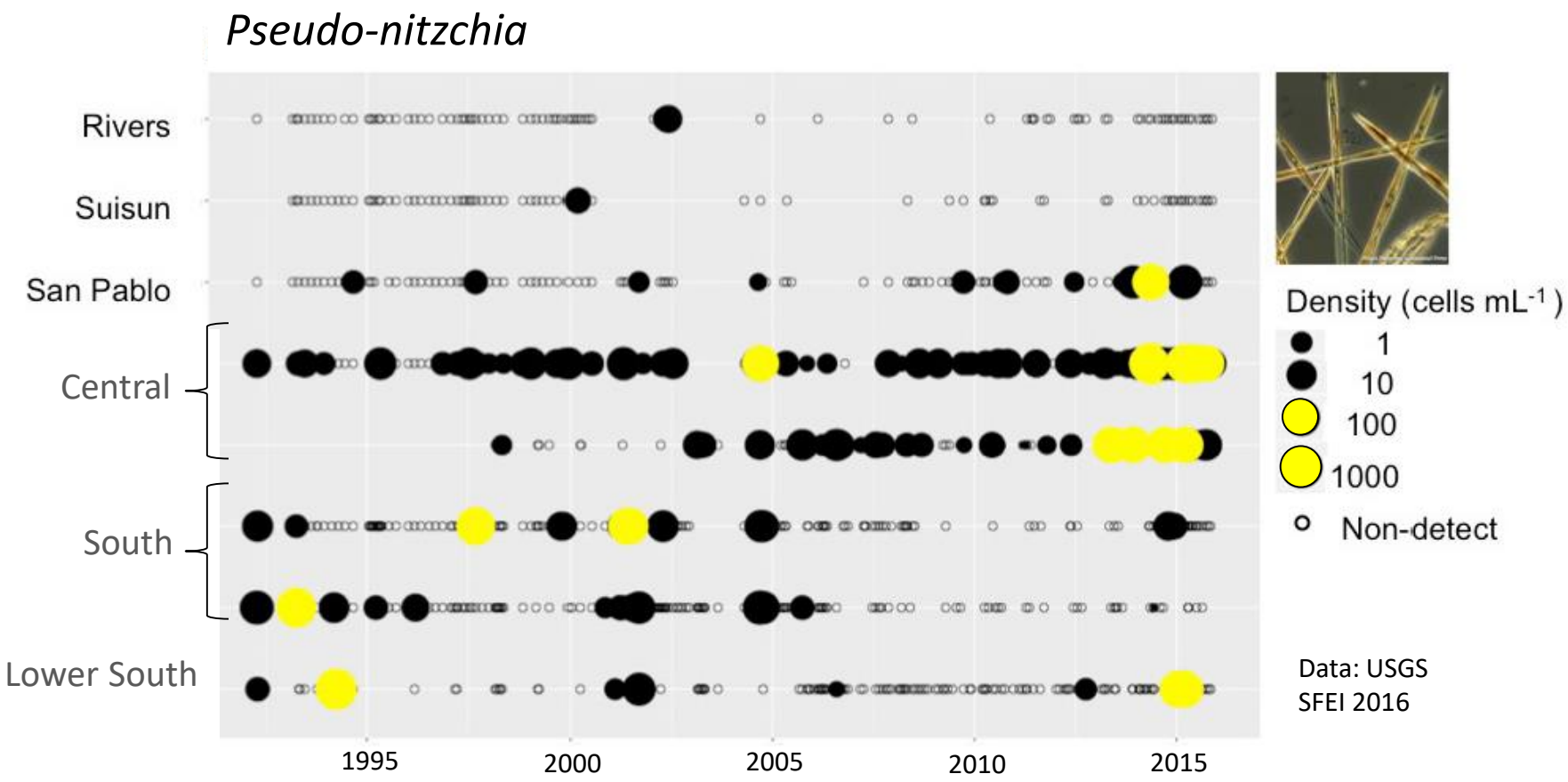
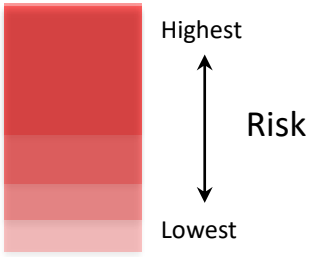
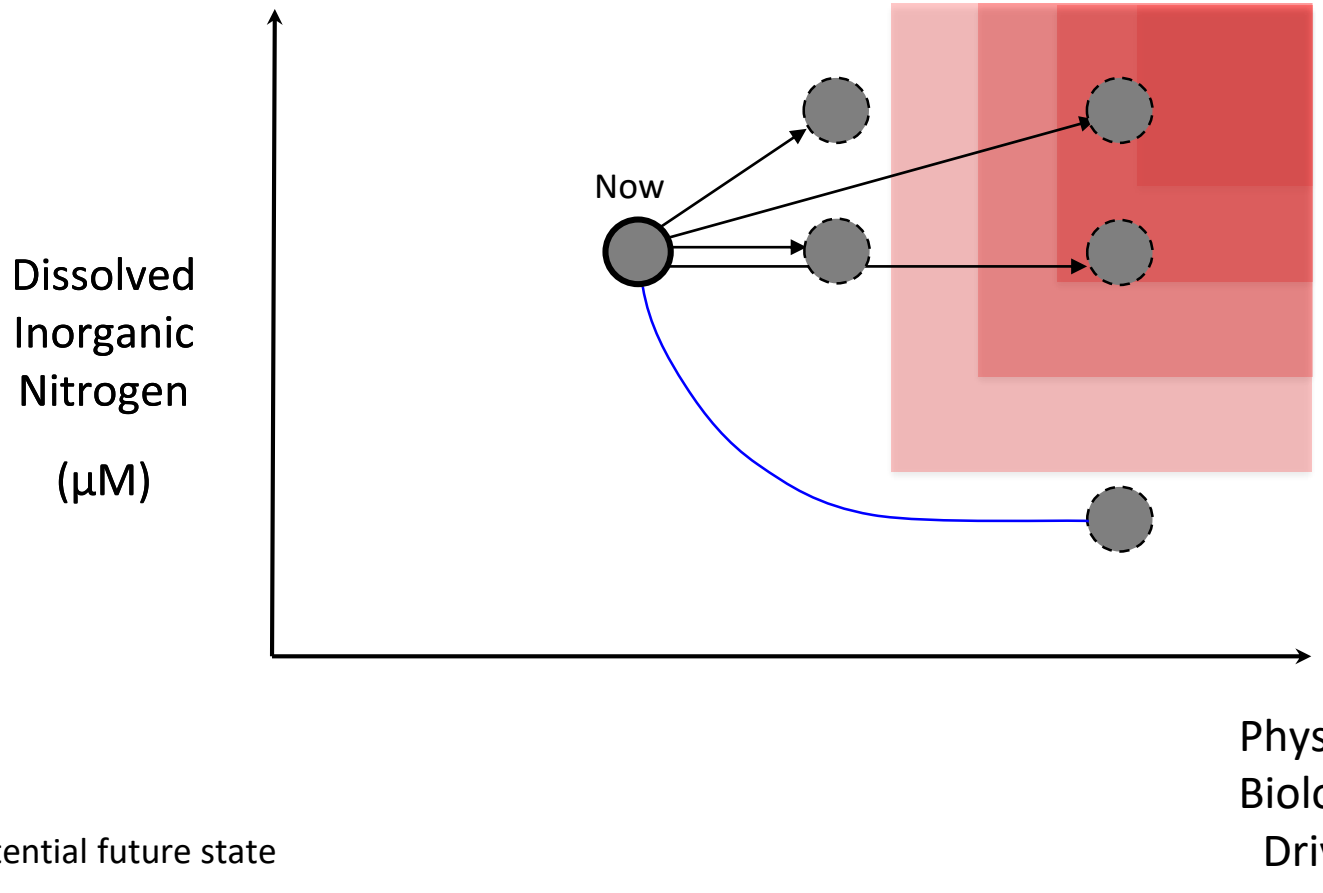
What contributes to P-N occurrence and abundance in SFB?





What future conditions are plausible?

What future scenarios should we manage toward preventing?



Potential future state

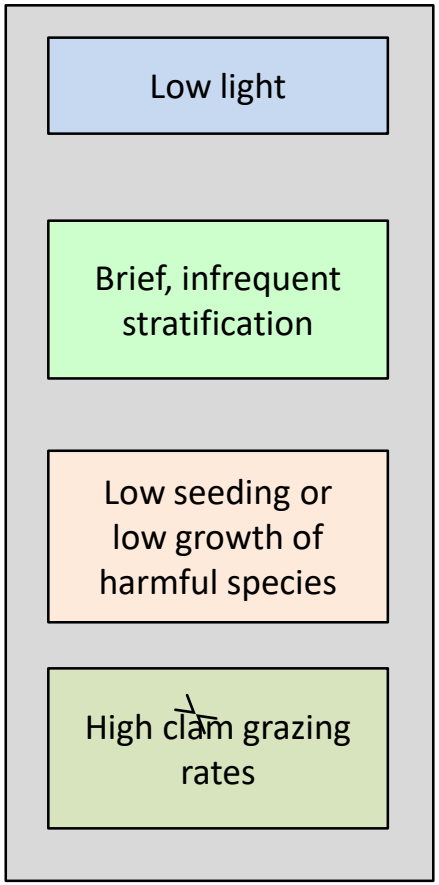
Path with little or no nutrient management actions

Path with some nutrient management actions, to decrease future risk

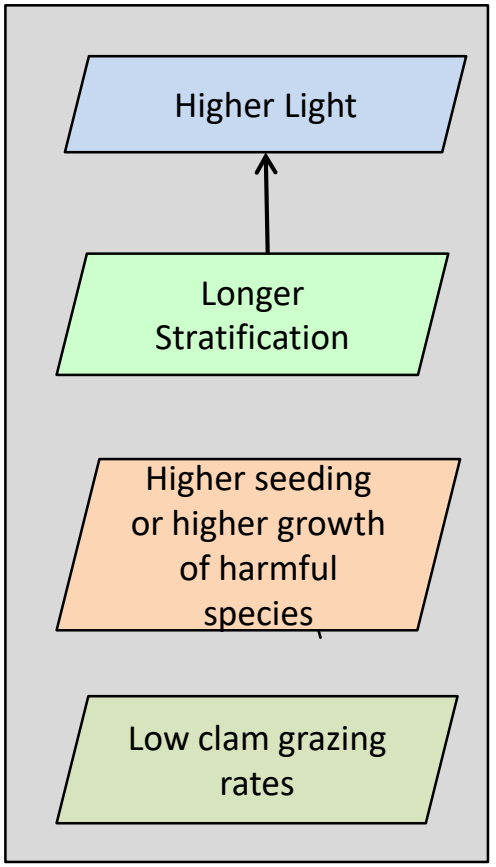
What are these axes?

What events can move them?

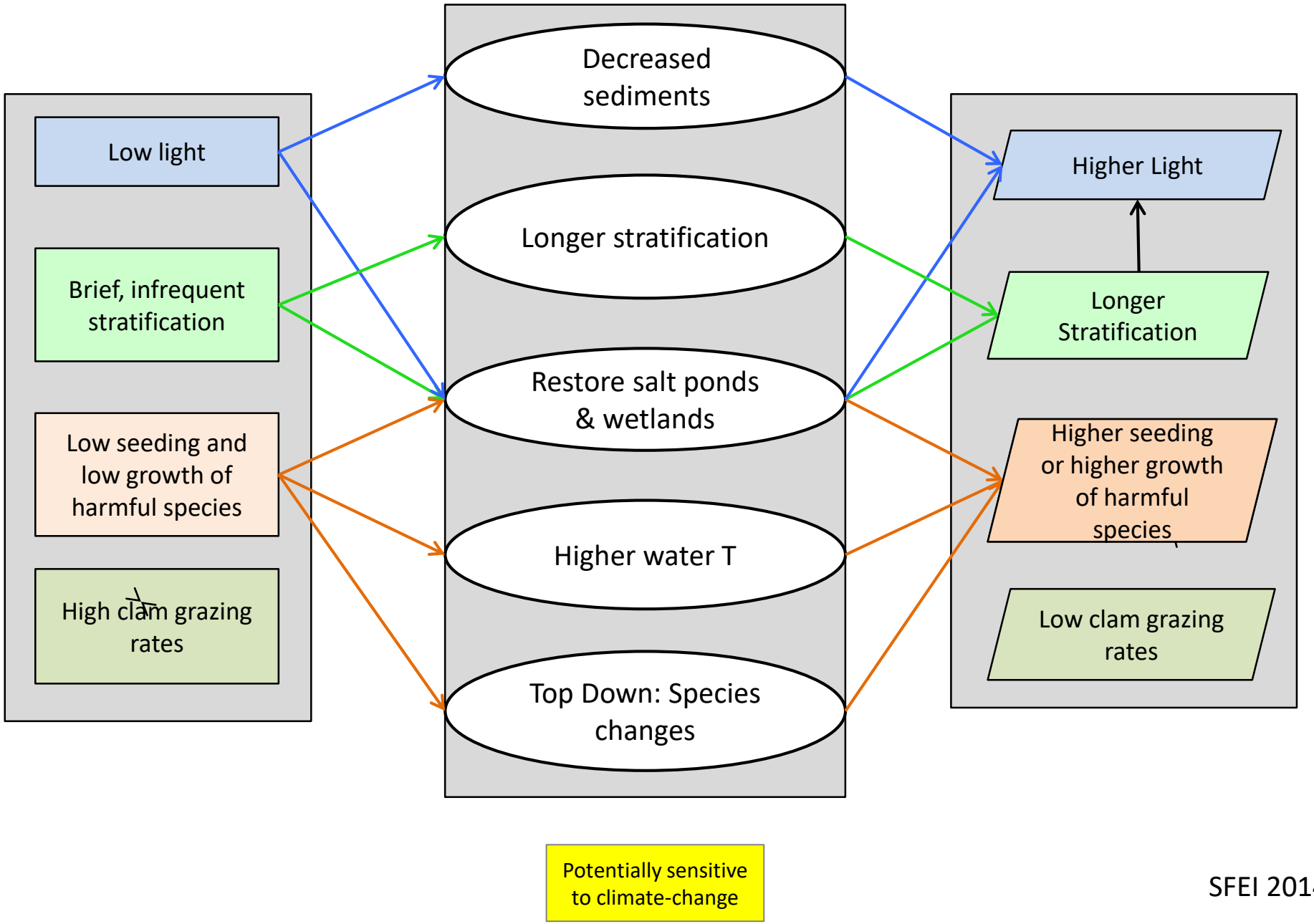
Current conditions



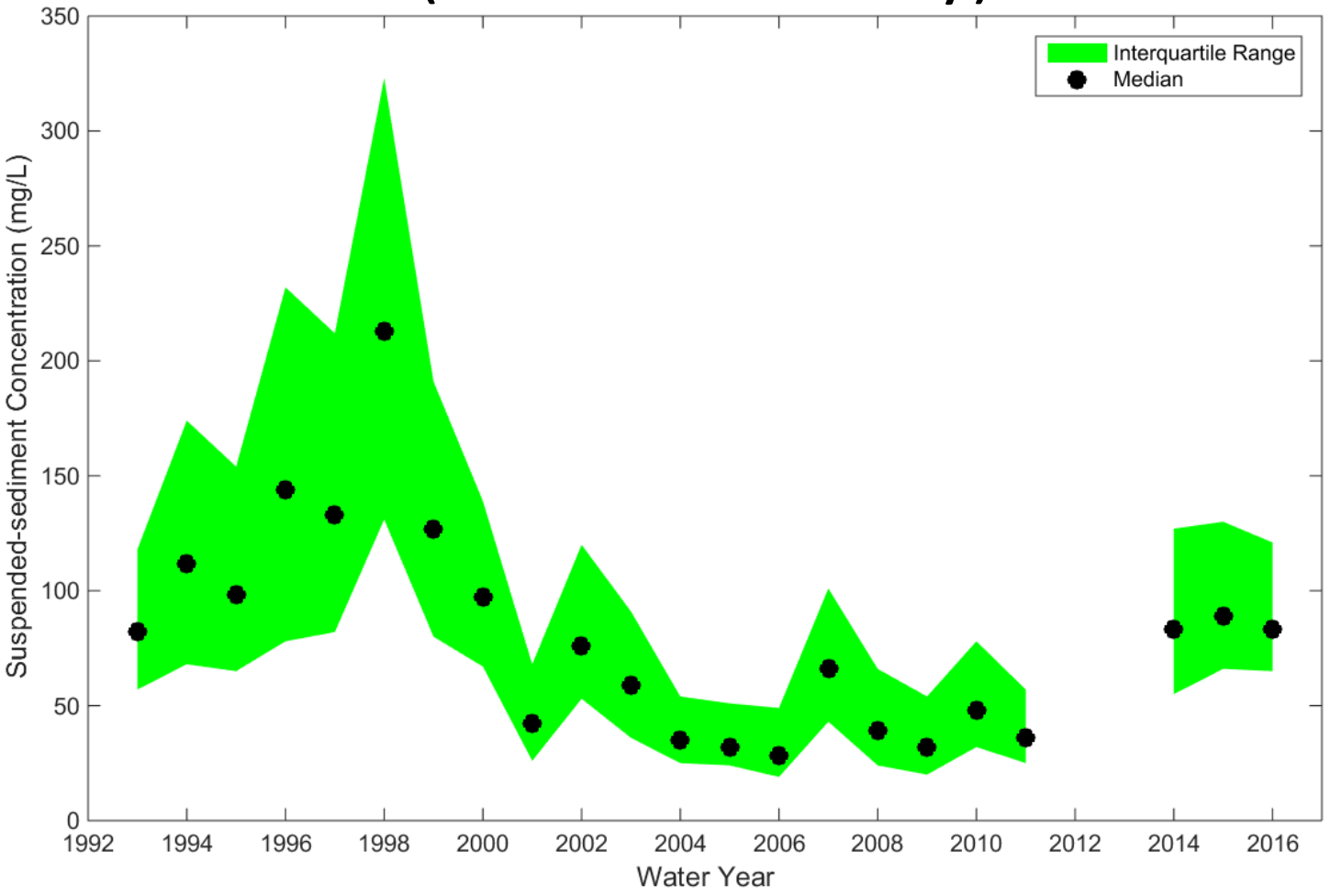
Future conditions



SFEI 2014

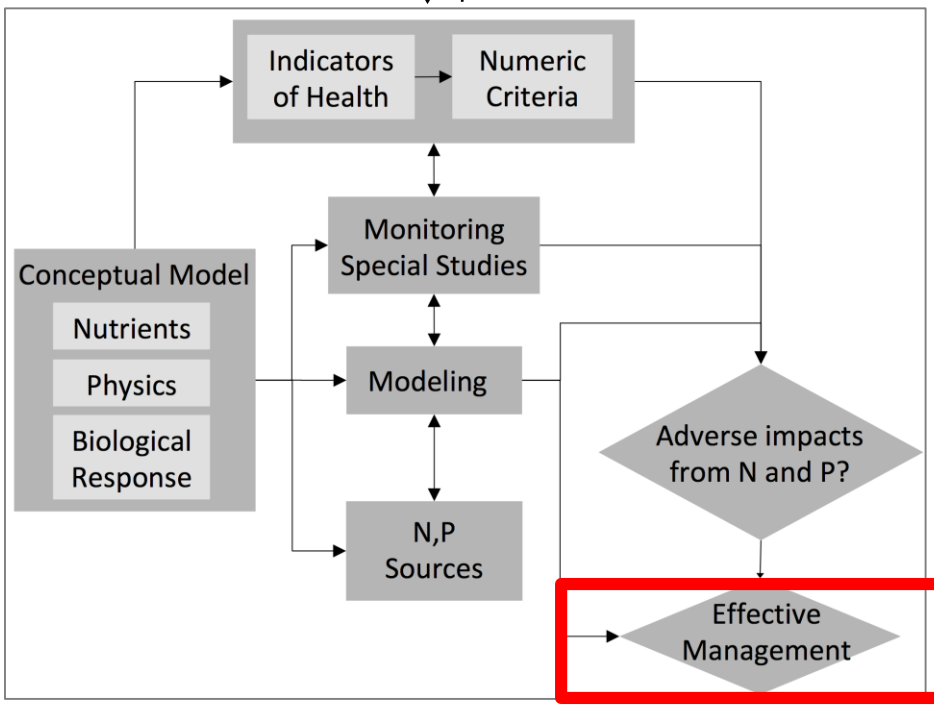

Current conditions
Change / Scenario
Future conditions
Low light
Brief, infrequent stratification
Low seeding and low growth of harmful species
High clam grazing rates
Decreased sediments
Longer stratification
Restore salt ponds & wetlands
Higher water T
Top Down: Species changes
Higher Light
Longer Stratification
Higher seeding or higher growth of harmful species
Low clam grazing rates
Potentially sensitive to climate-change
SFEI 2014

Suspended sediments…Dumbarton Bridge (Lower South Bay)



Schoellhamer et al. 2015
SFEI 2015

Science Plan



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Treatment Levels

Level	Study	Ammonia	TN	TP
Level 1	Optimization / Sidestream	--	--	--
Level 2	Upgrades	2 mg N/L	15 mg N/L	1.0 mg P/L
Level 3	Upgrades	2 mg N/L	6 mg N/L	0.3 mg P/L

Study Findings for Total Nitrogen (TN) Load Reduction Across the Bay

Summary

Strategy	TN Load Reduction to the Bay	Capital Cost ($Millions)
Optimization	7%	$119 M
Sidestream Treatment	19%	$391 M
Upgrade Level 2	57%	$7 B
Upgrade Level 3	82%	$8.5 B

Summary

- San Francisco Bay has highly-elevated levels of N and P
  - Greater than those that cause impairment in other estuaries
- Physical and biological factors have allowed SFB to avoid impairments experienced by other nutrient-enriched estuaries
  - But some of those factors have shown signs of weakening
  - Also…Low DO in places we weren't looking previously
  - Harmful Algae and algal toxins are prevalent
  - Two sides of coin…if not a SFB problem, impacts along coast?
- NMS Program: Targeting highest priority science needs to inform management decisions
  - SFB's assimilative capacity for nutrients
  - Dose **:** Response
  - Protective nutrient levels

Major Focus Areas or Challenges Ahead – Science Program 2019-2024

1. Building and Maintaining essential 'Tools'
   - Monitoring: What/Where/When → wise and timely decisions
   - Modeling: Predicting, Forecasting, Uncertainty

2. Identifying safe or protective loads and concentrations

3. Assessing risk of "events" – present, and future

4. Testing mechanistic linkages to nutrients:
   - HABs and toxins
   - Low DO in sloughs

5. Effects of Bay nutrients on coastal water quality ?

Collaborators

SFEI

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E Gross

UC Berkeley

M Stacey

P de Valpine

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NMS Steering Committee, NMS Planning Subcommittee, and Stakeholders

SFEI staff, Collaborators, and Technical Advisors

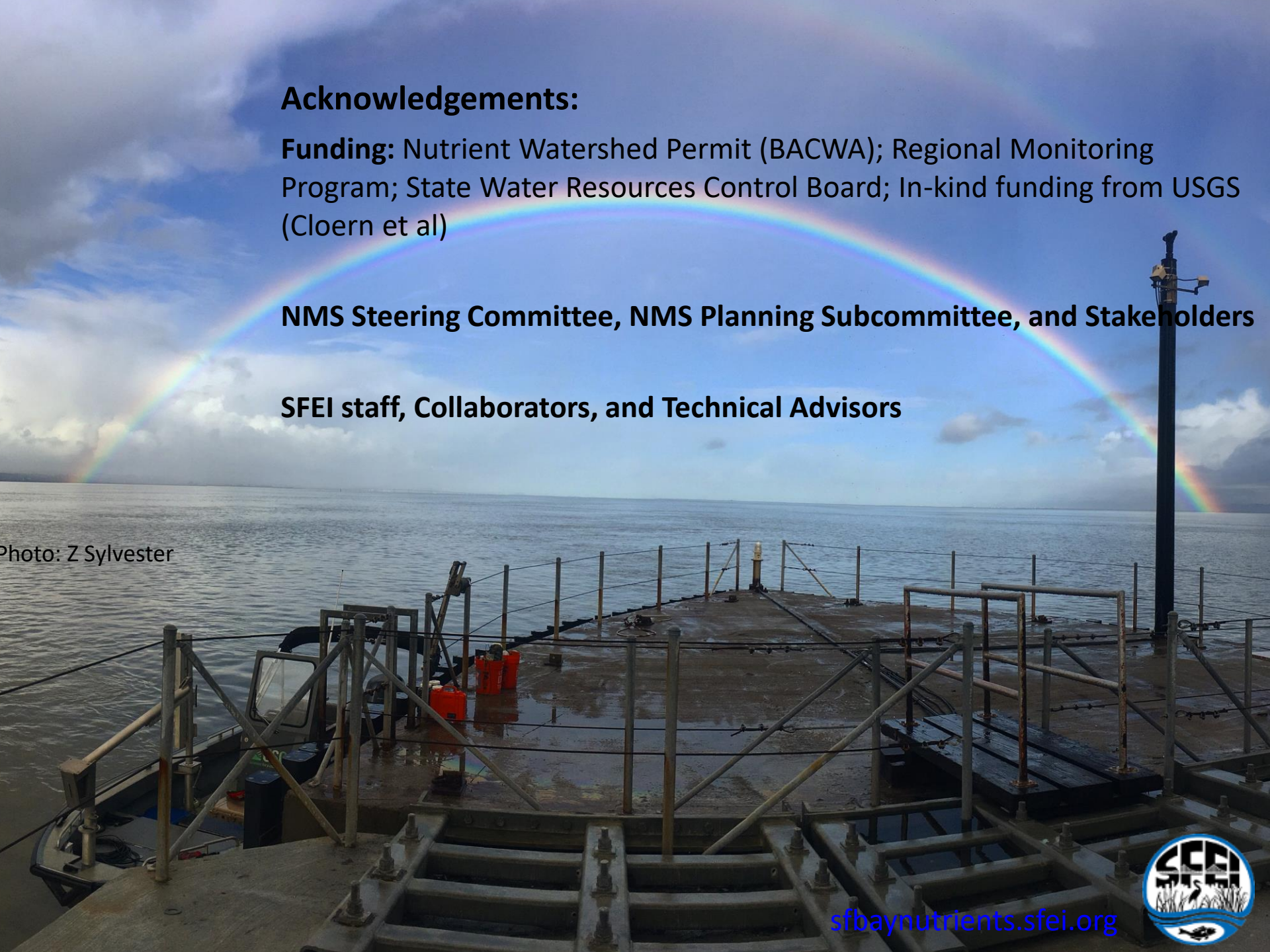

Photo: Z Sylvester

sfbaynutrients.sfei.org