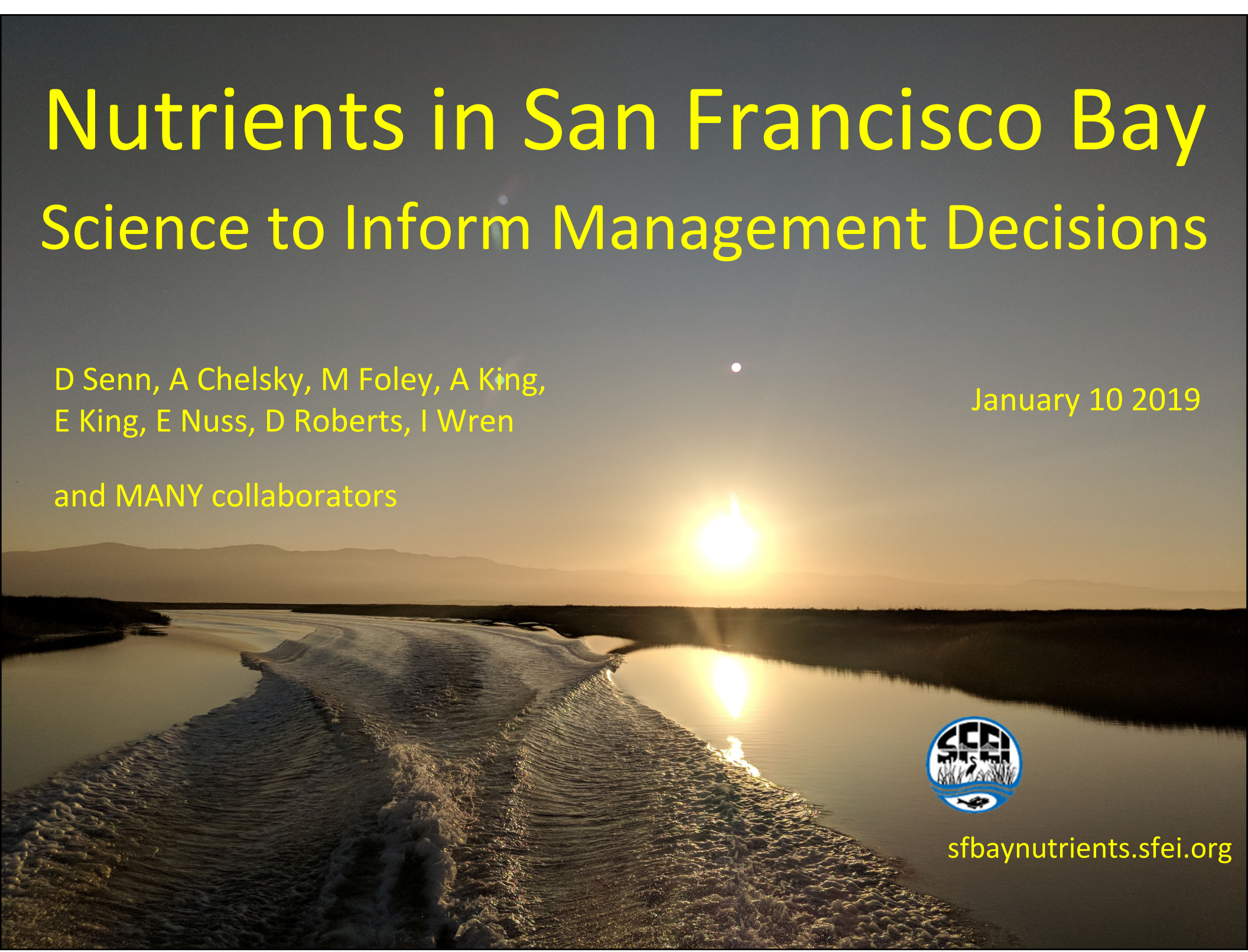
Nutrients in San Francisco Bay

Science to Inform Management Decisions

D Senn, A Chelsky, M Foley, A King,
E King, E Nuss, D Roberts, I Wren

and MANY collaborators

January 10 2019



sfbaynutrients.sfei.org

Collaborators

A Chelsky, E King, E Nuss, D Roberts, M Foley, D Senn, I Shimabuku, I Wren

J Cloern, E Nejad, T Schraga, L Lucas, B Bergamaschi, L Stumpner, T Kraus, B Downing, M Downing-Kunz, D Livsey, J Lacy, R Allen

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W Cochlan, C Ikeda, W Kimmerer

M Van der Wegen, K Nederhoff, T Troust, A Blauw

E Gross, R Rachiele

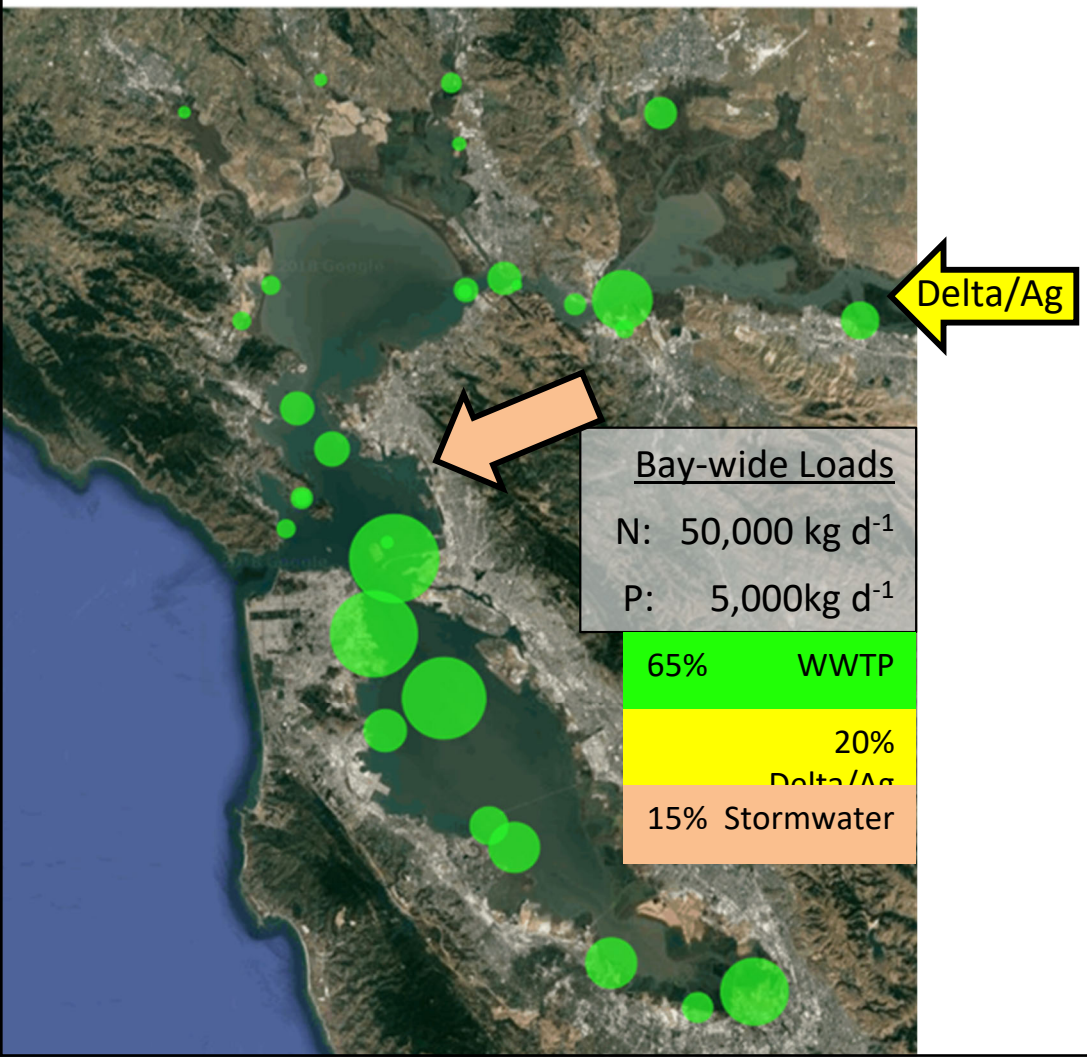
Z Zhang, E Ateljevich

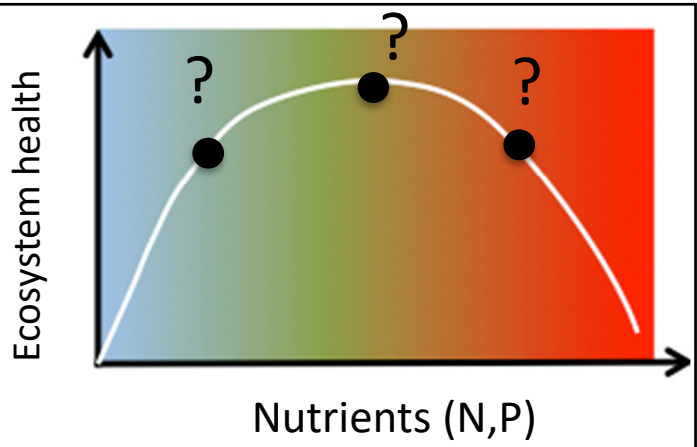
Does SFB have nutrient problems?

- now?
- future?

How can impacts be mitigated or prevented?

- $5-10bill question

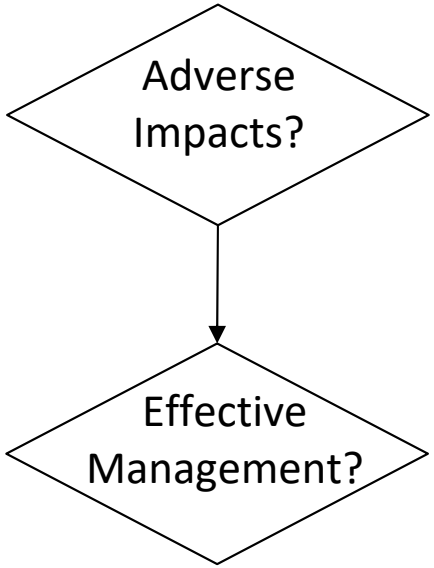


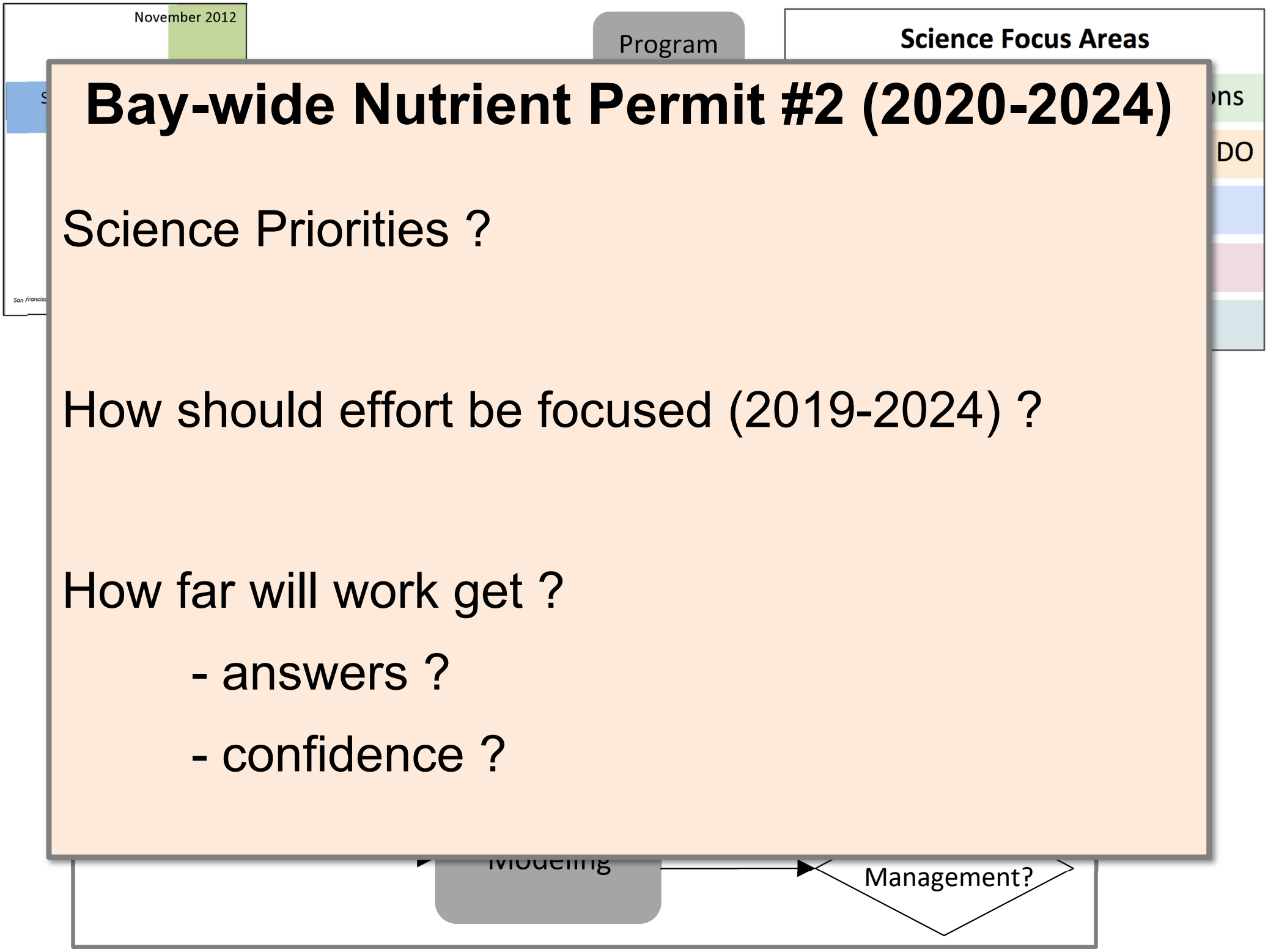


- Large algae blooms
- Low DO
- Harmful algae, toxins

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

- What management actions would deliver protective nutrient loads or concentrations?





Bay-wide Nutrient Permit #2 (2020-2024)

Science Priorities ?

How should effort be focused (2019-2024) ?

How far will work get ?

- answers ?
- confidence ?

Water Board and Discharger Priorities

Monitor: Robust & Sustainable Program

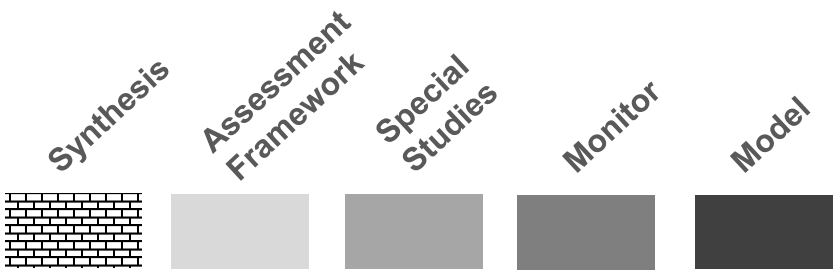
- Condition assessment
- Model calibration
- Trend detection

Model: numerical/dynamic simulations

- Predict nutrient cycling & phytoplankton|DO response
- Test management alternatives
- Evaluate risk of “events”

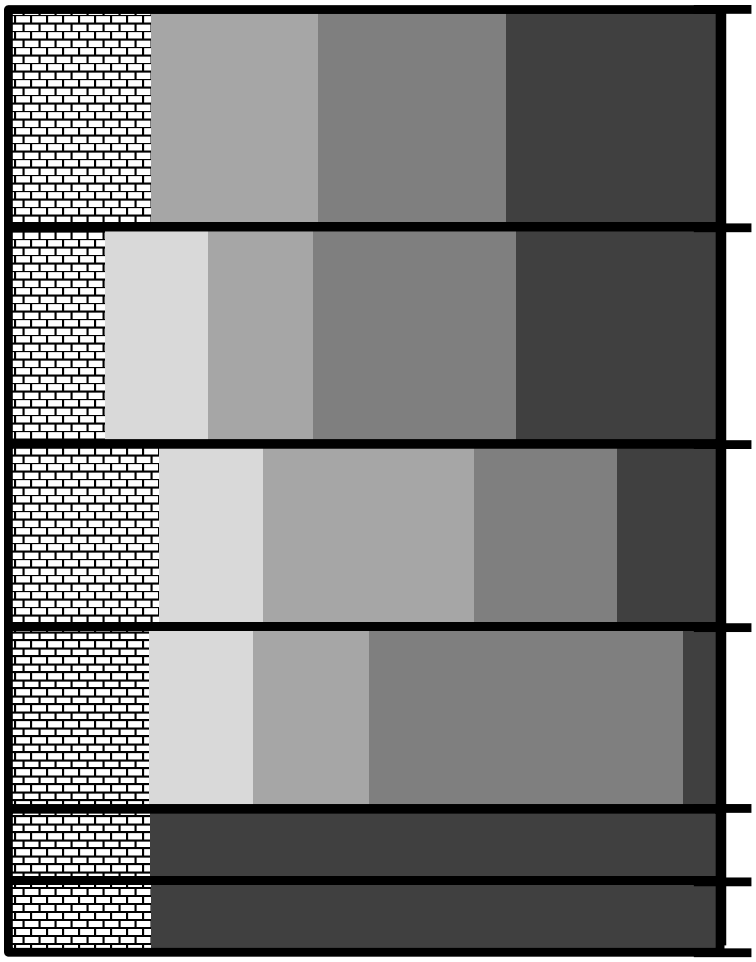
Assessment Framework:

- What represents ‘good’ vs. ‘bad’ condition?



Science Focus Areas

1. Nutrient Loads|Transformations
2. Phytoplankton Blooms & Low DO
3. HABs & Toxins
4. Coastal Ocean Impacts
5. Future Scenarios



Nutrient Dynamics

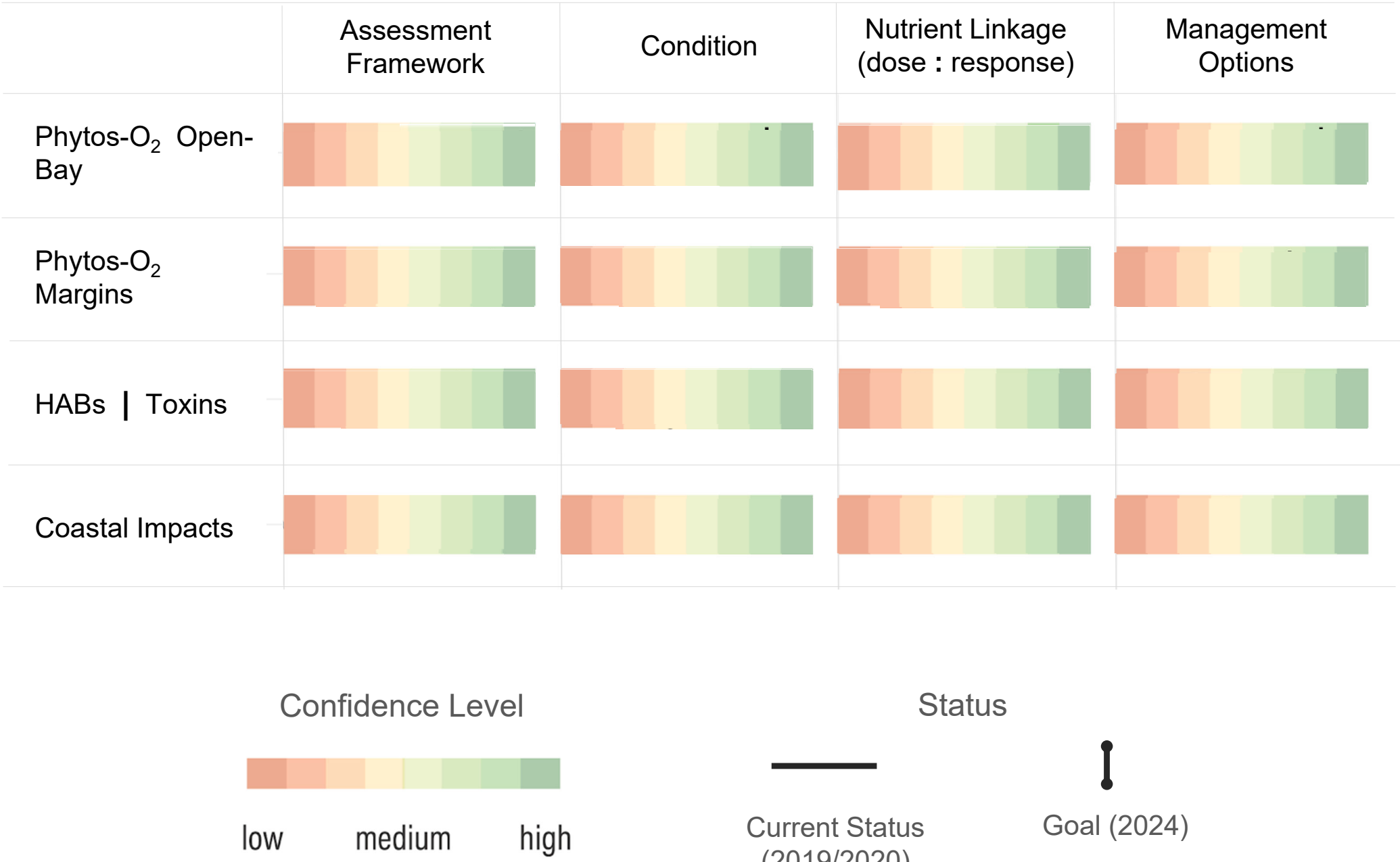
Phytoplankton-DO, Open-Bay

Phytoplankton-DO, LSB 'margins'

HABs

Coastal impacts

Future scenarios


Assessment Framework
Condition
Nutrient Linkage (dose : response)
Management Options
Phytos-O_2 Open-Bay
Phytos-O_2 Margins
HABs | Toxins
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Confidence Level
low
medium
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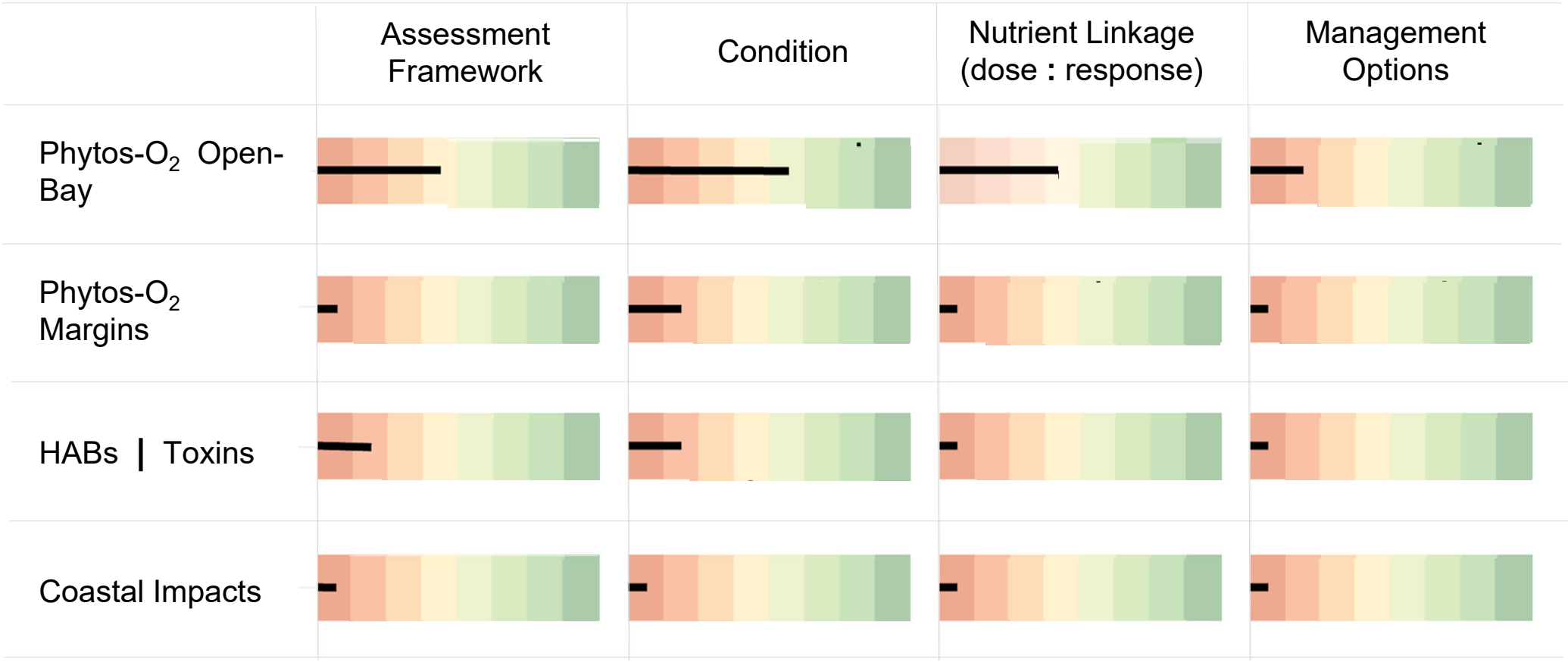
Status
Current Status (2019/2020)
Goal (2024)



Confidence Level

low medium high

Status

Current Status (2019/2020)

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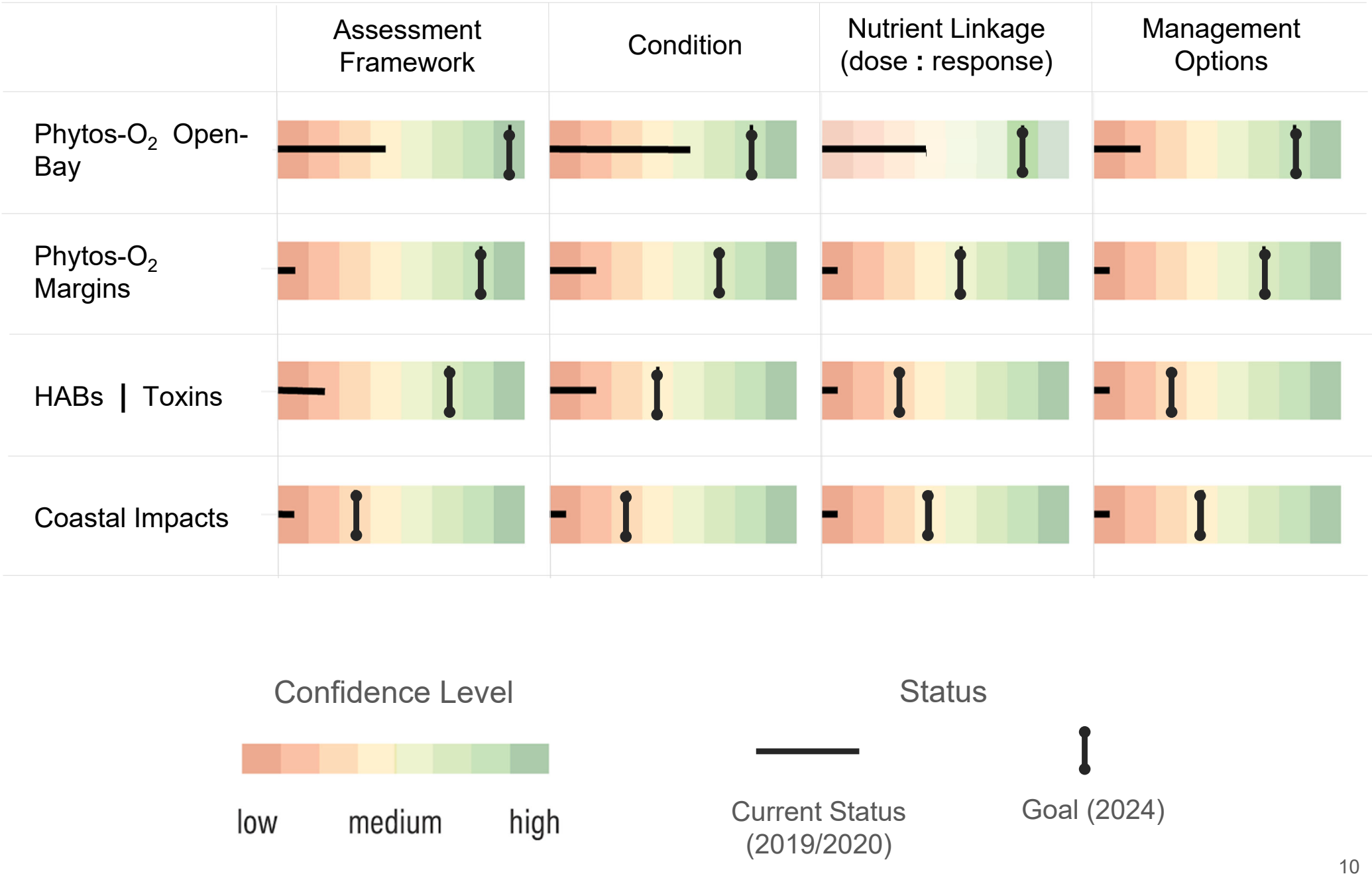
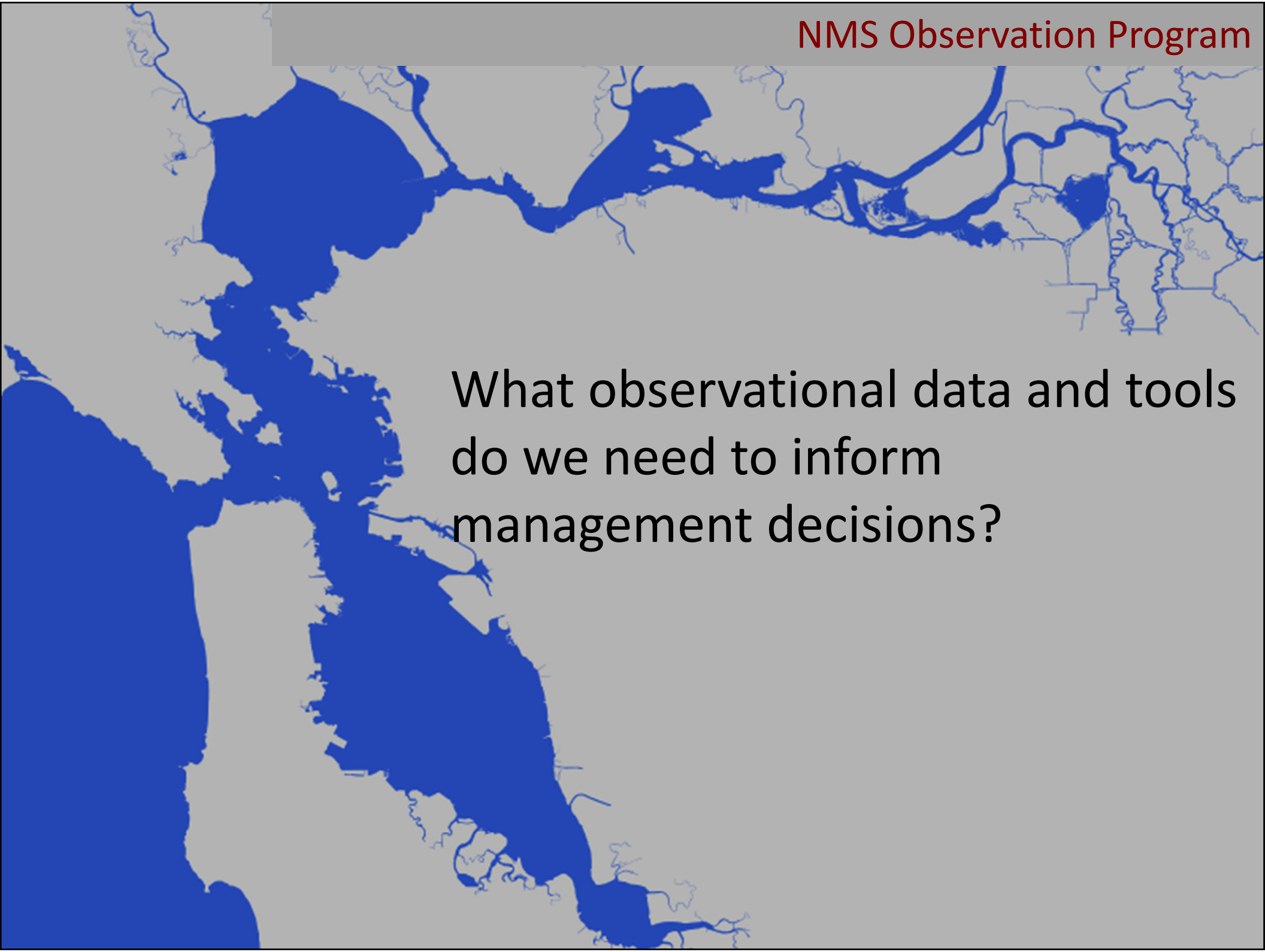
Targeting different confidence levels across range of issues…



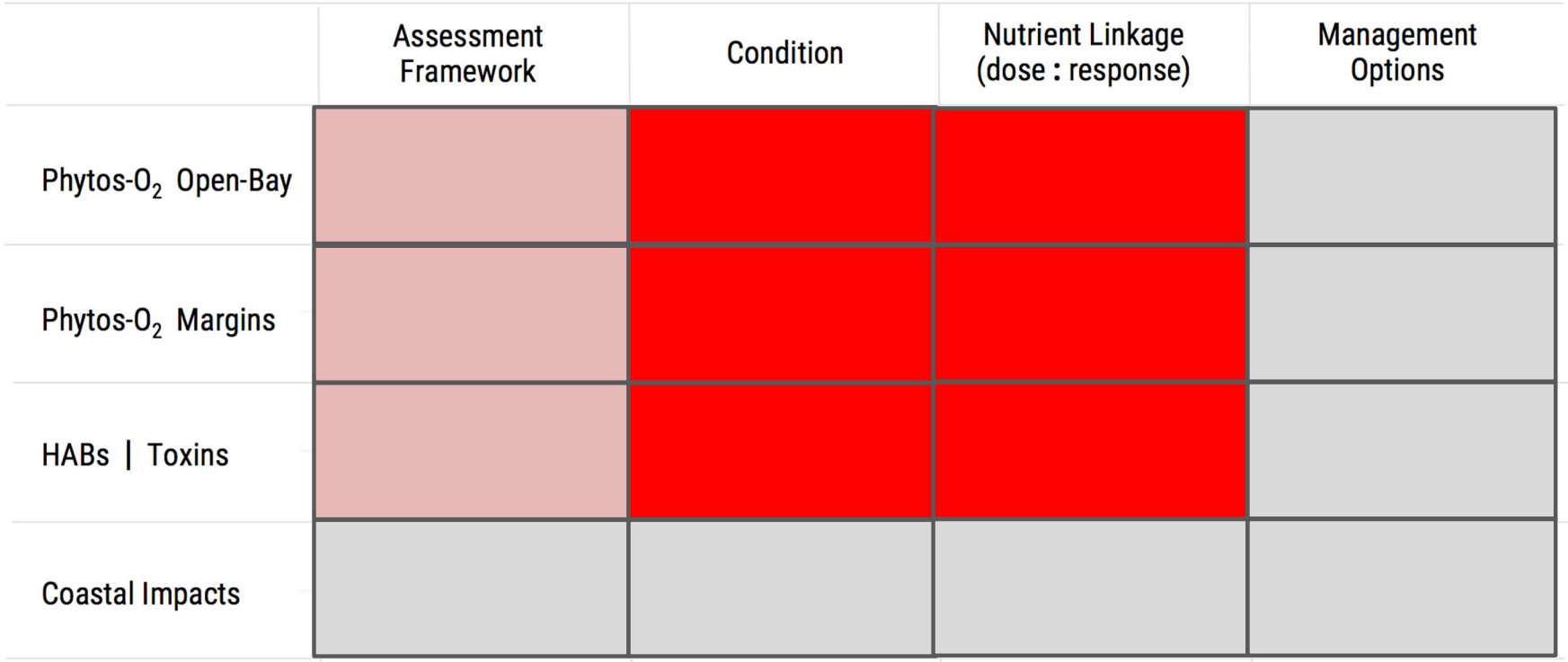
Water Board and Discharger Priorities

Monitor: Robust & Sustainable Program

- Condition assessment
- Model calibration
- Trend detection



What observational data and tools do we need to inform management decisions?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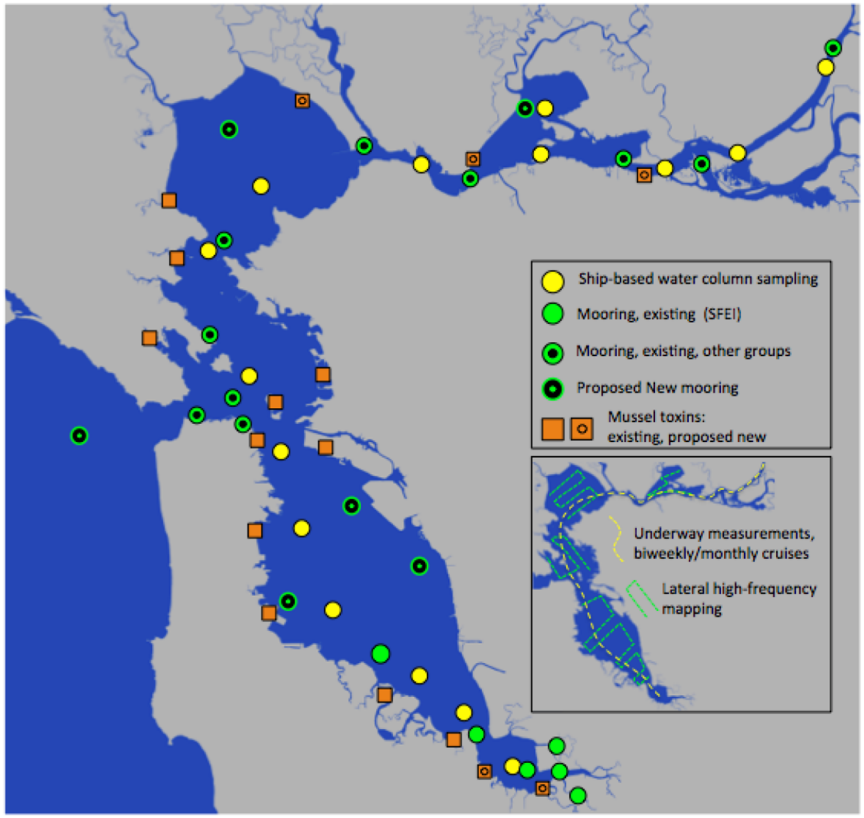
Coastal Impacts

NMS Observation Program

Ship-based monitoring, with USGS

Mussels

San Francisco Bay Nutrient Management Strategy Observation Program



SFEI

December 2016

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ugh
e Creek
iso Slough
Pon 8
(planned
July 2015)
on

	Assessment Framework	Condition	Nutrient Linkage (dose : response)	Management Options
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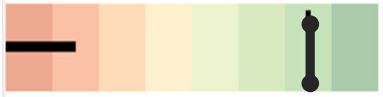
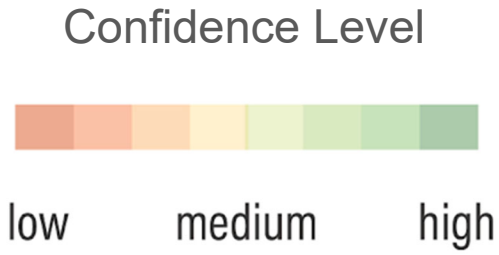
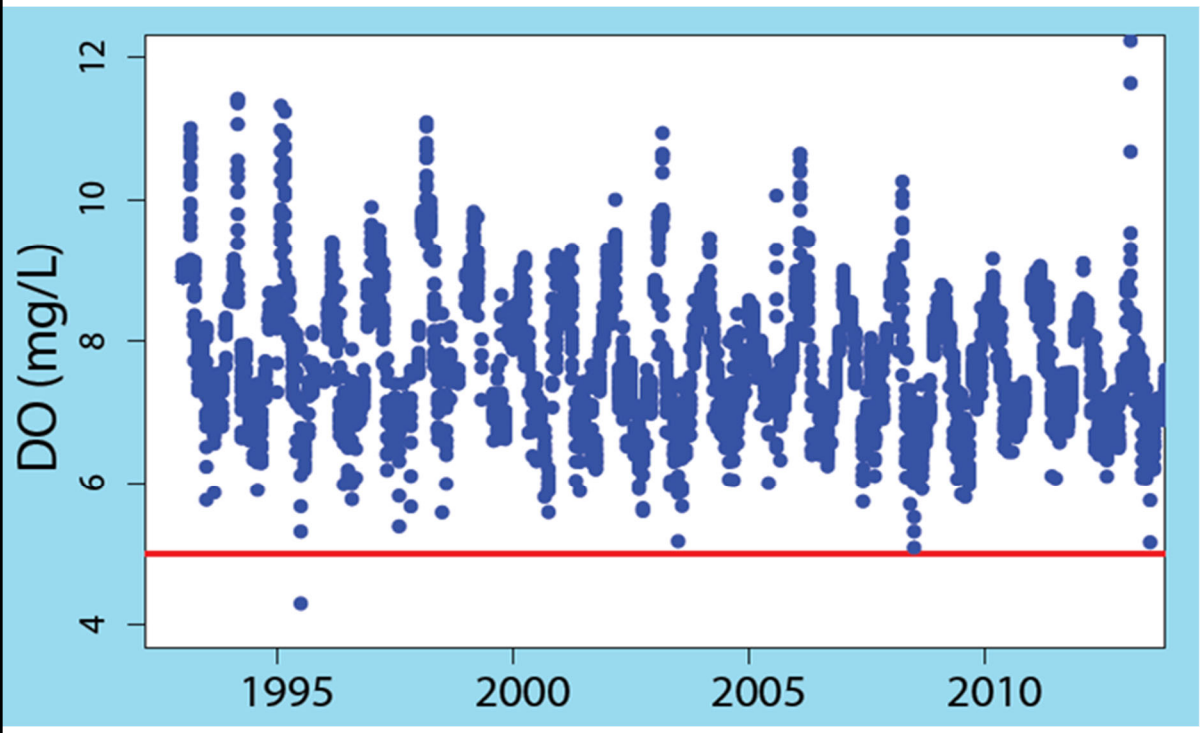
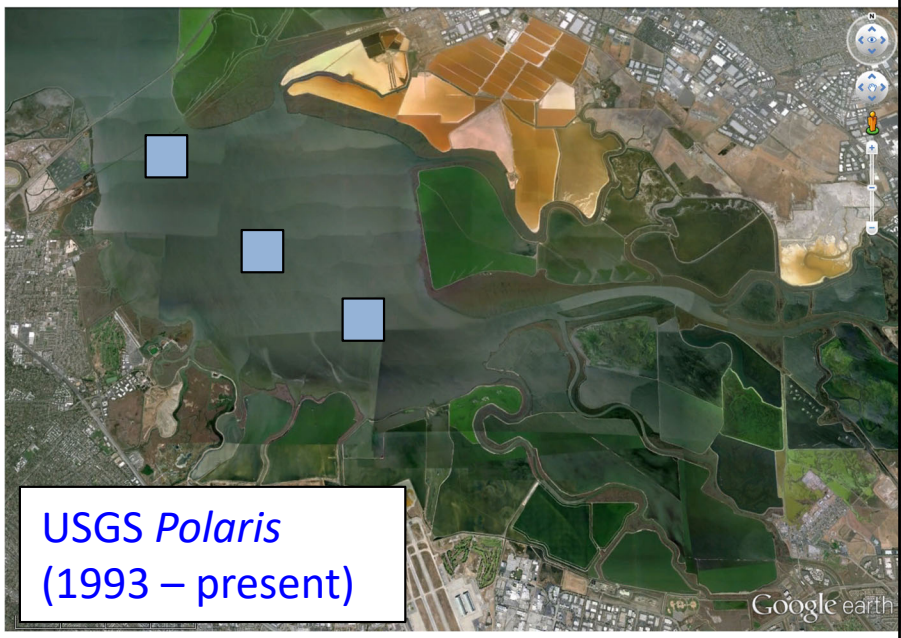
Phytos-O_2 Open-Bay				



Dissolved Oxygen – Deep subtidal

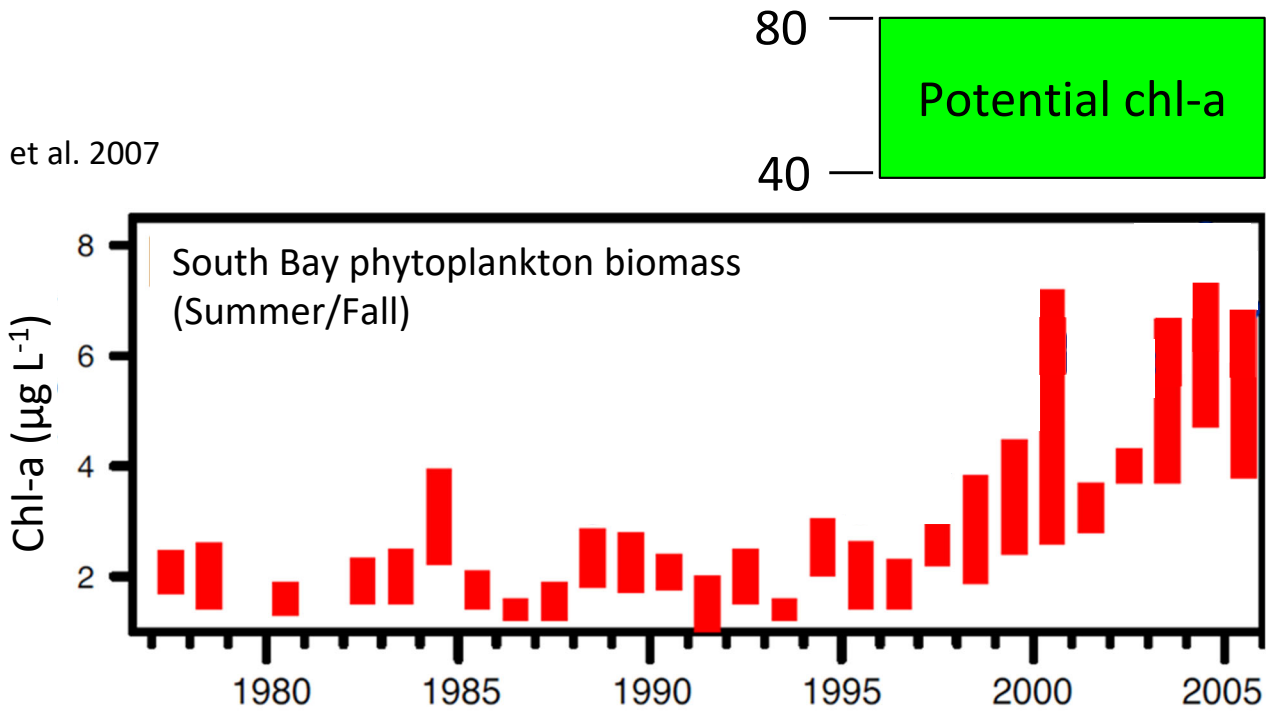




SFEI 2015
Data: USGS

Phytoplankton Biomass

Cloern et al. 2007



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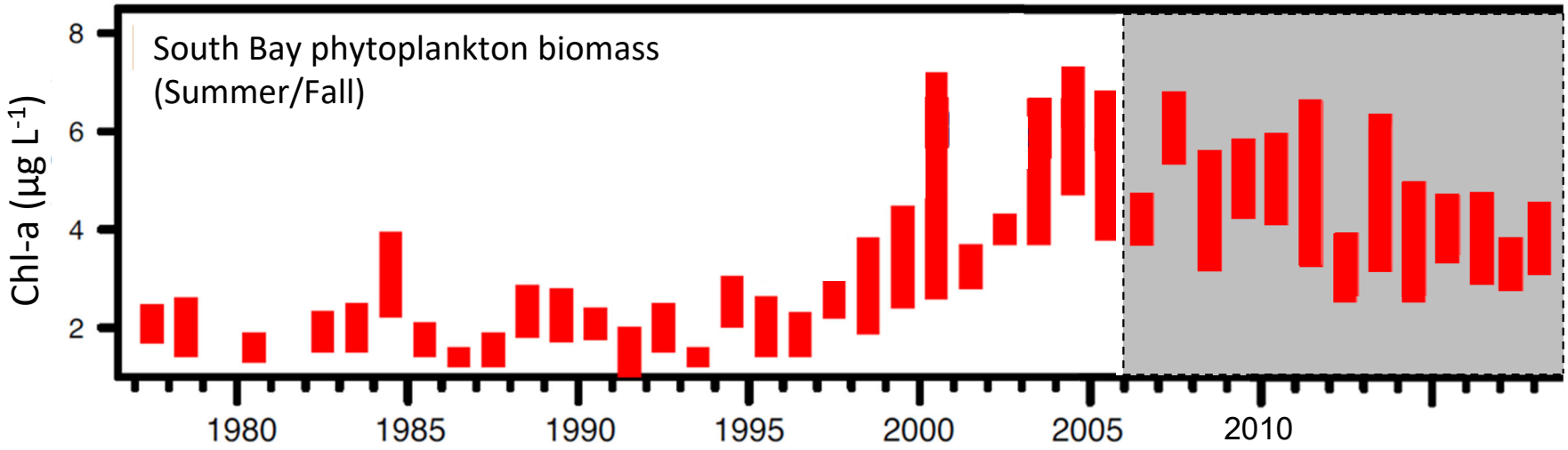


SFEI (2015, 2017)
Data: USGS

1. What trend magnitudes can we detect? Lag before detection?
2. How does chl-a vary in other regions of SFB?
3. How are relevant indicators changing over time?
4. Causal factors?

Tracking Indicators over time: Trend Analysis

GAM evaluation - SF South Bay

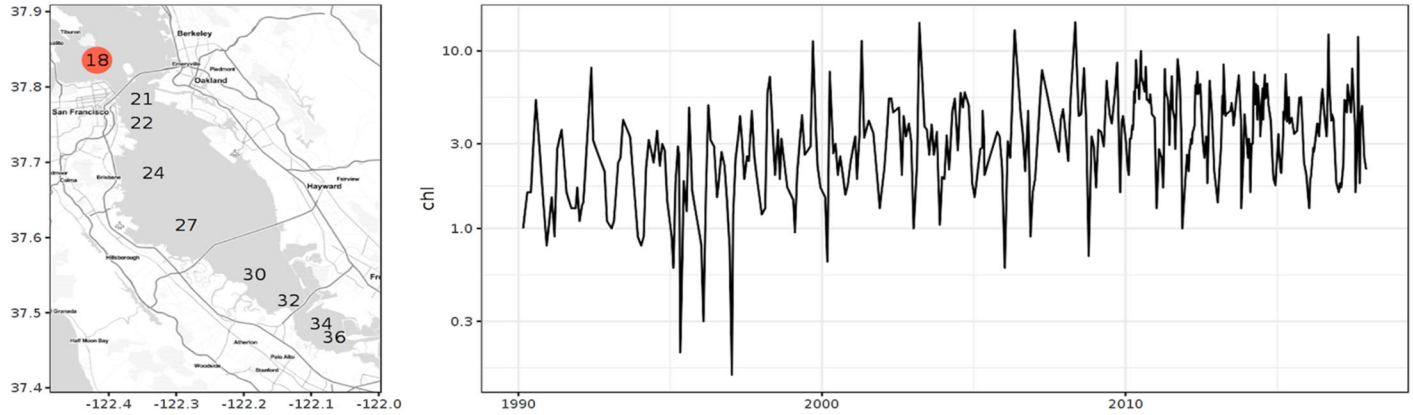
Exploratory plots

The following plots show the raw data for all monitoring stations and parameters in South Bay, 1990 - 2017. Select the parameter, plot type (total time series, by year, or by month), and variable transformation. The year and month plots are aggregated boxplots of all observations at a station for each selected time period. The variable transformation can be used to show the observations in

Choose station: 18

Choose plot type: tot

TRUE



GAMs of log-chlorophyll with annual, seasonal trends

Note: All plots below are shown with model results in log-space, although plot axis-scaling is arithmetic.

Generalized additive models (GAMs) were developed to describe trends in chlorophyll-a at each of the monitoring stations in South Bay. The station and selected model can be chosen from the drop down menus. Four types of GAMs were developed for the time series at each station to model chlorophyll as a function of time, where time is measured as an annual and seasonal effect. The four models descibe the time components differently and represent increasing levels of complexity to describe the chlorophyll trend:

- `gam0` : chl ~ year + s(doy)
- `gam1` : chl ~ year + s(doy) + s(year)
- `gam2` : chl ~ year + s(doy) + s(year) + ti(doy, year)
- `gam6` : chl ~ year + s(doy) + s(year, k = *large*)

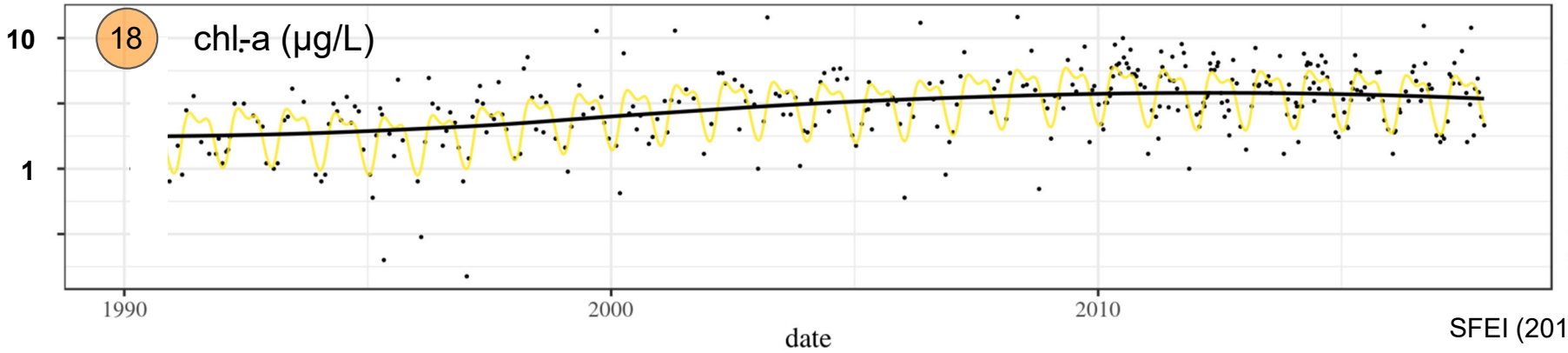
http://sfei.li/nms-trends-chla

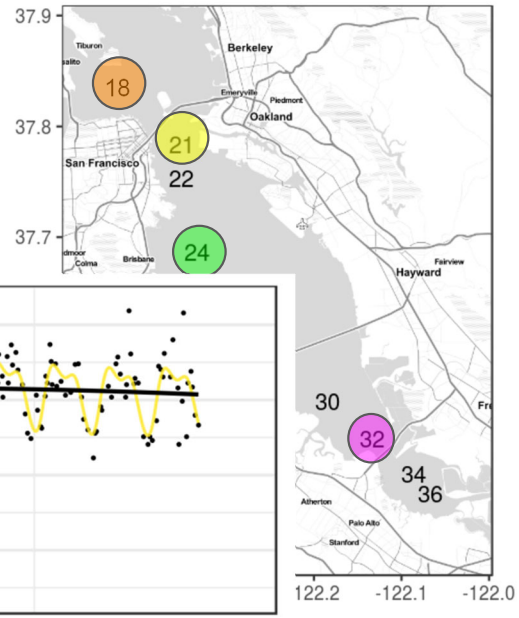
http://sfei.li/nms-trends-docalc

Collaborators: M Beck (TBEP), P de Valpine (UC Berkeley), R Murphy (CBP)

Both represent doubling of Gross Primary Production

- **Far South Bay**…double, then return to near baseline
- **Central Bay**…double, remains elevated. low-mesotrophic to nearly-eutrophic





SFEI (2018); Data:USGS

Other Indicators for Trend Tracking

- chl-a
- Dissolved Oxygen
- GPP
- Suspended particulate matter
- Nutrient Loads
- DIN (?)

http://sfei.li/nms-trends-chla

http://sfei.li/nms-trends-docalc

Targeting different confidence levels across range of issues…

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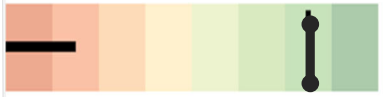
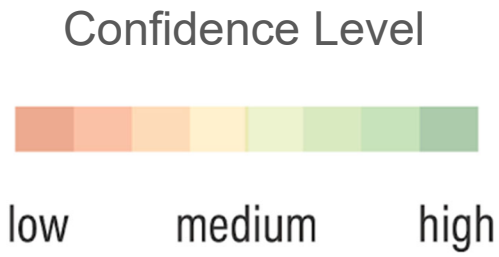
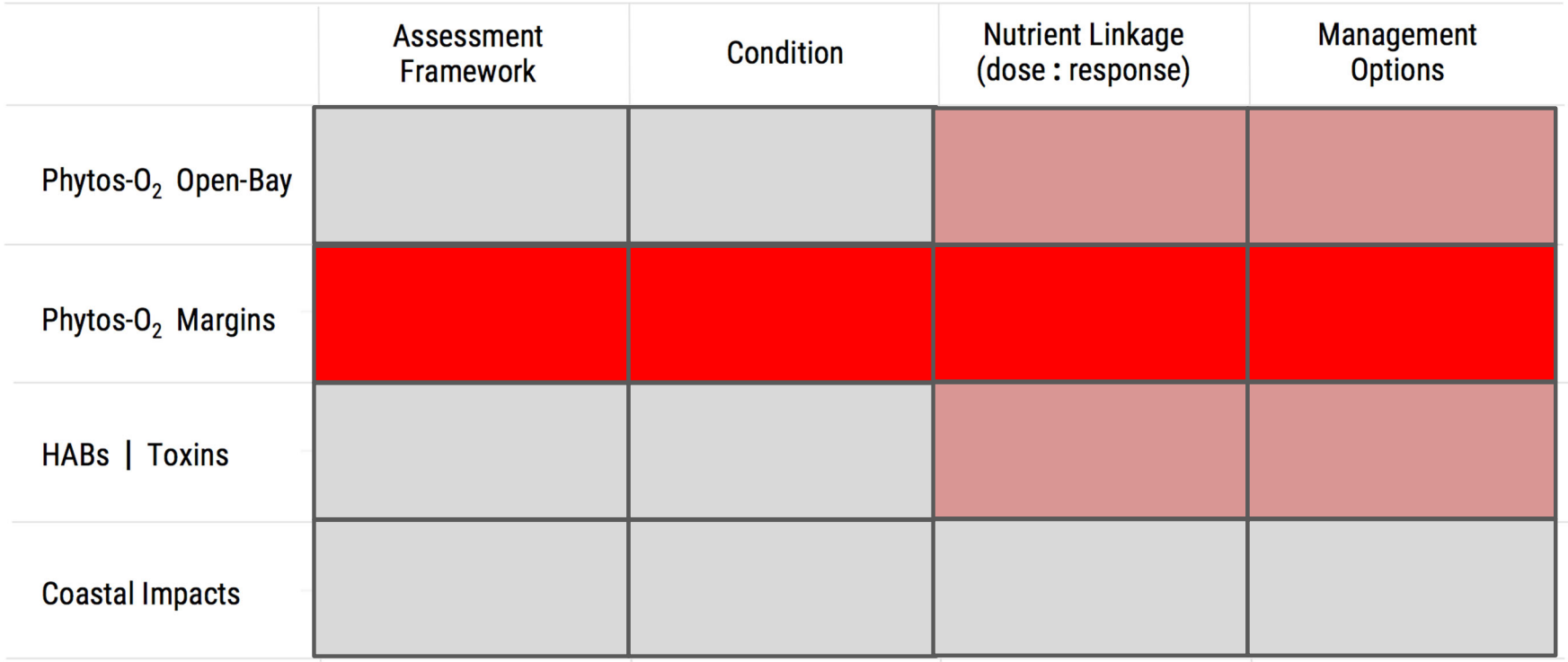
Phytos-O_2 Open-Bay				




Assessment Framework
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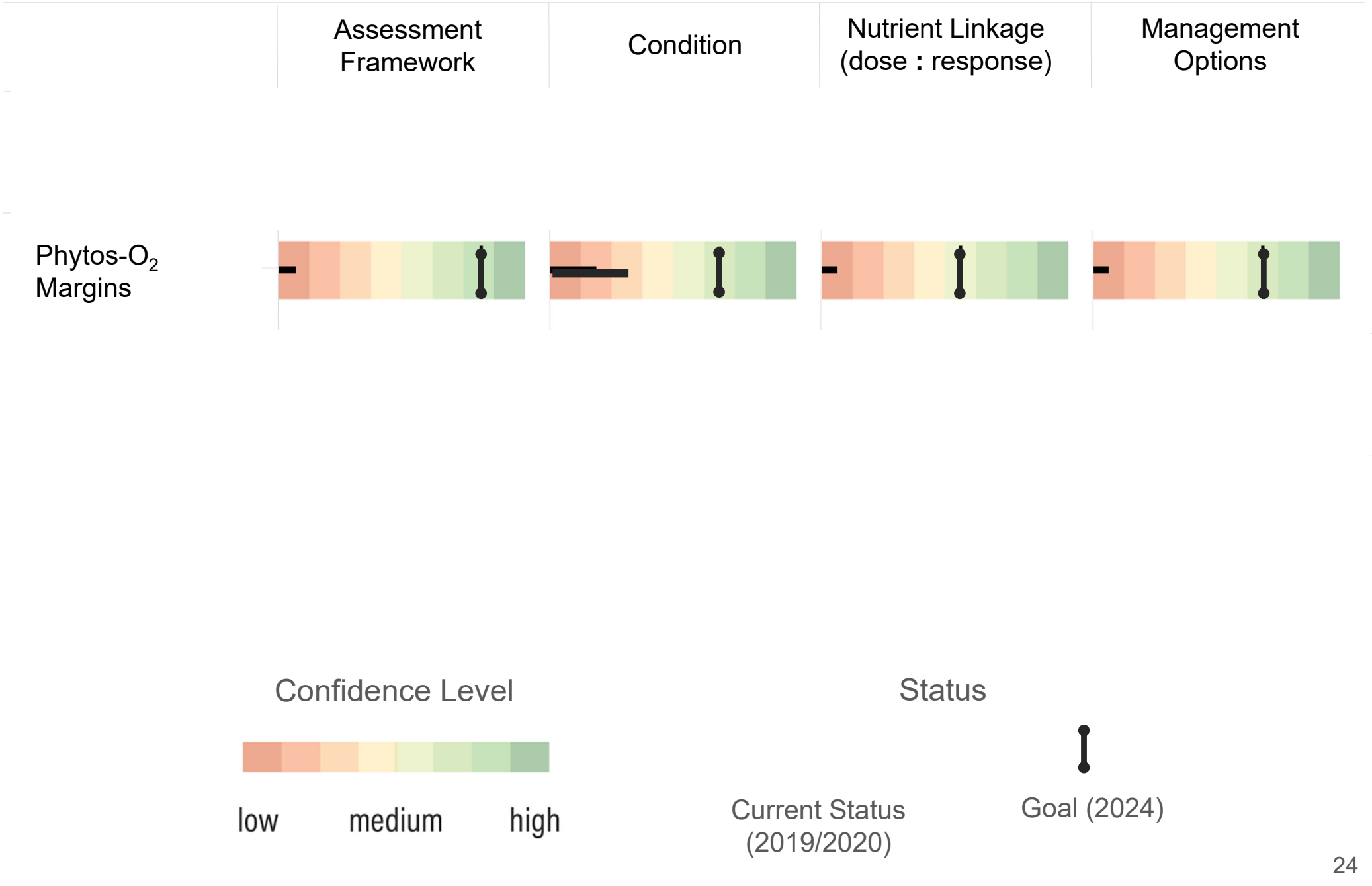
Phytos-O_2 Open-Bay
Phytos-O_2 Margins
HABs | Toxins
Coastal Impacts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medium
high
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Current Status (2019/2020)
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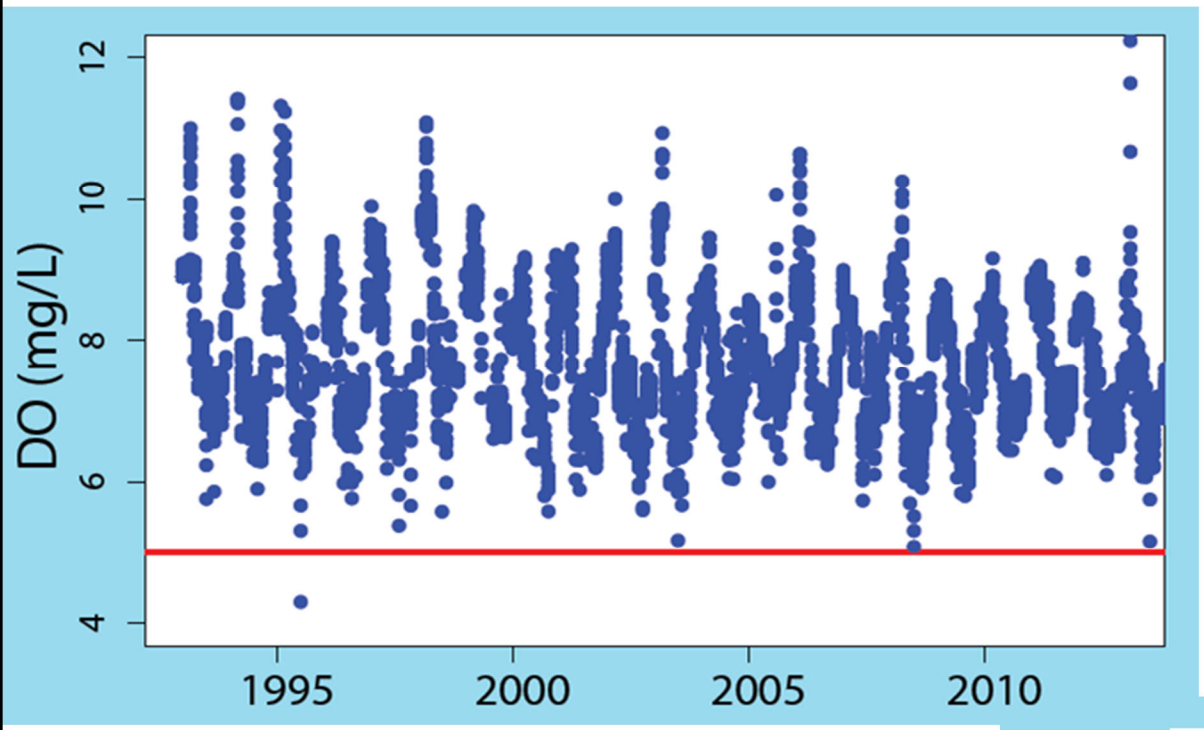
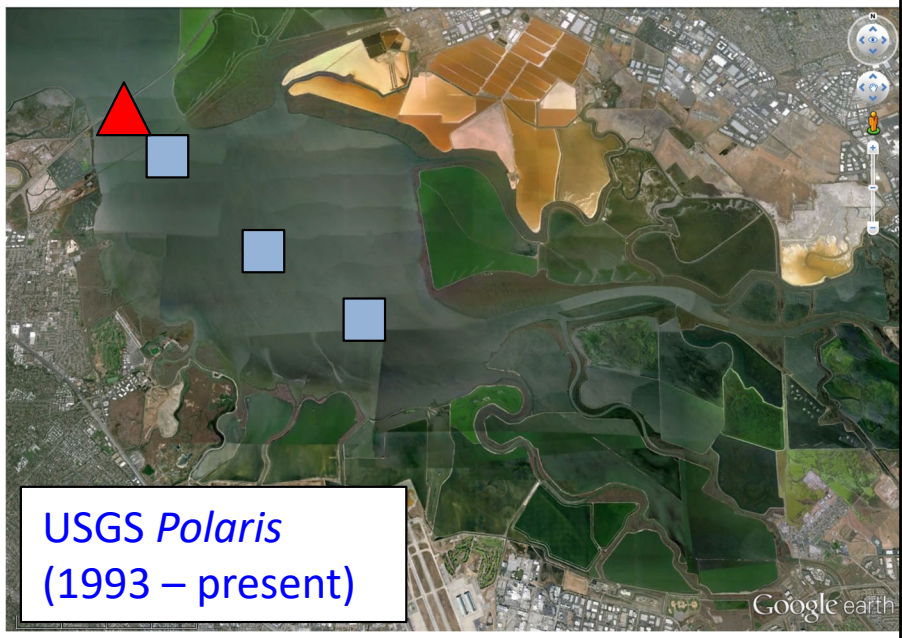
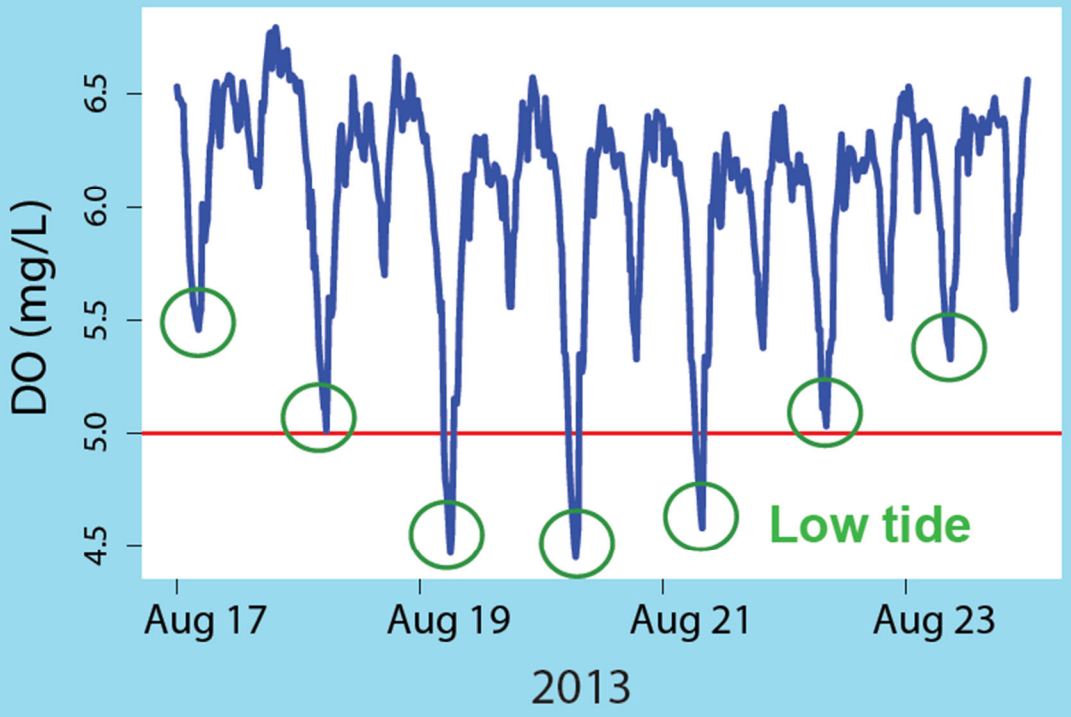




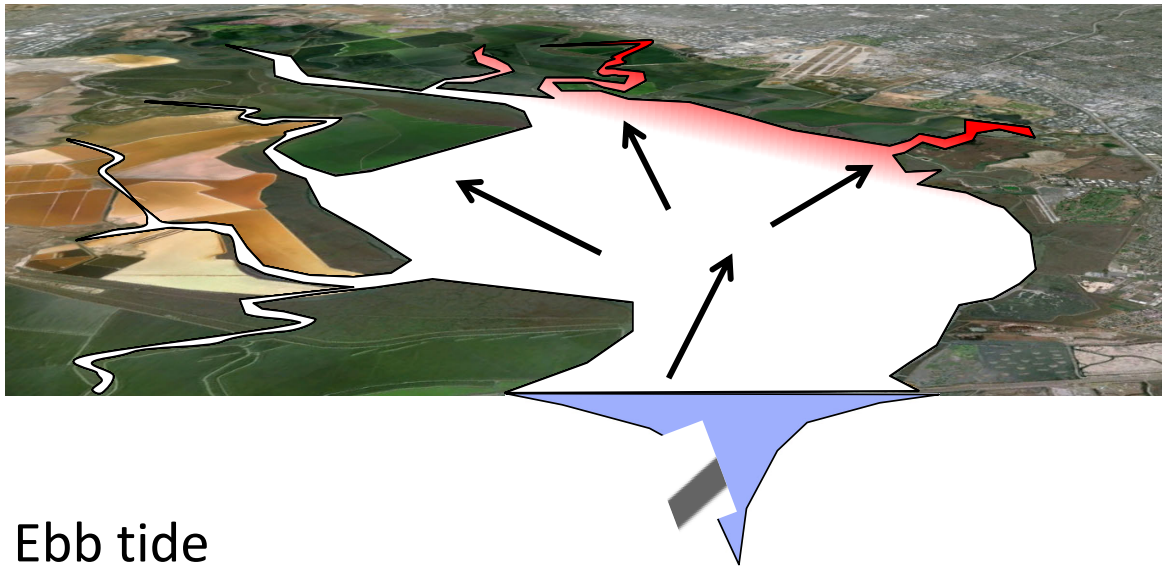
Dumbarton near-surface continuous sensor



SFEI 2015

Conceptualization of water quality/source in LSB as a function of tide

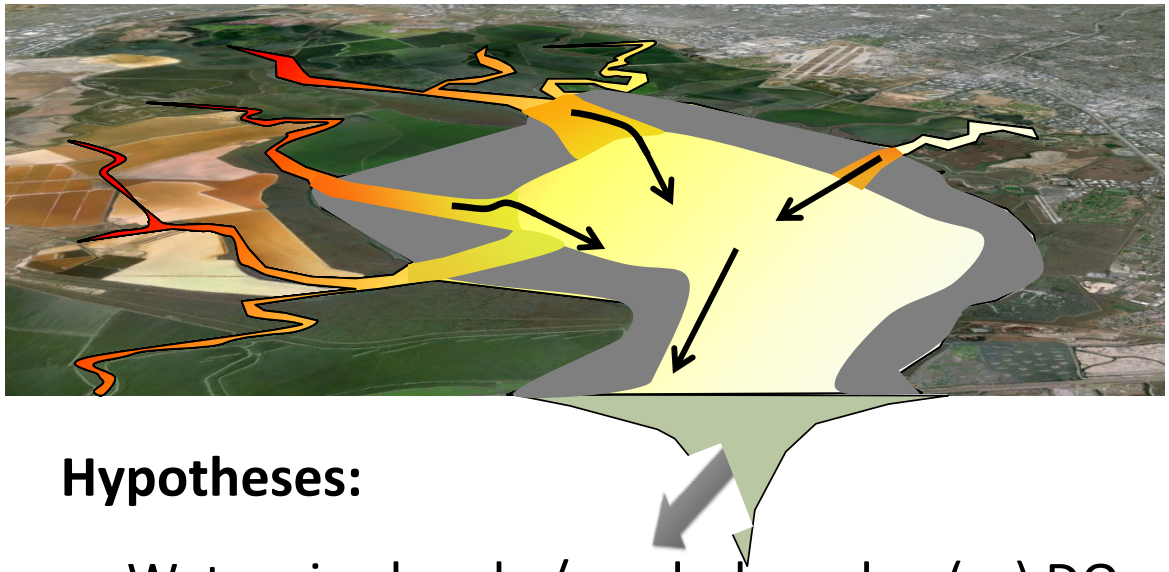
Flood tide



Margin Water:
Sloughs/Creeks/Marshes

Open Bay Water:
Originating north
of Dumbarton

Ebb tide

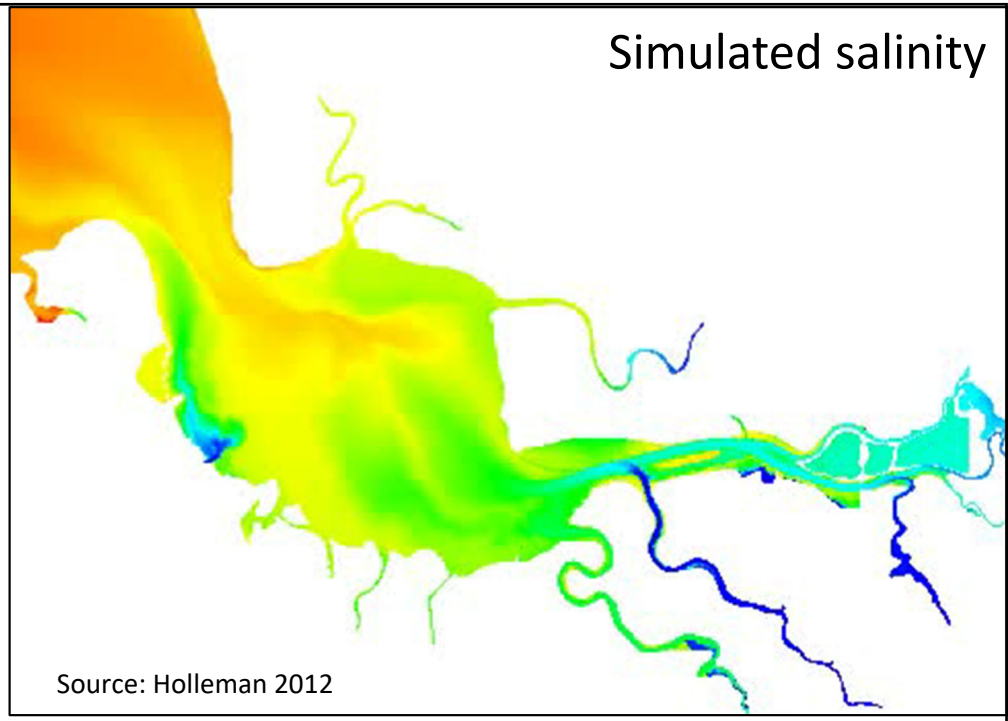


Hypotheses:

- Waters in sloughs/creeks have low(er) DO and higher algal biomass
- Exchange with restored salt ponds is one of several contributing factors

Lower South Bay

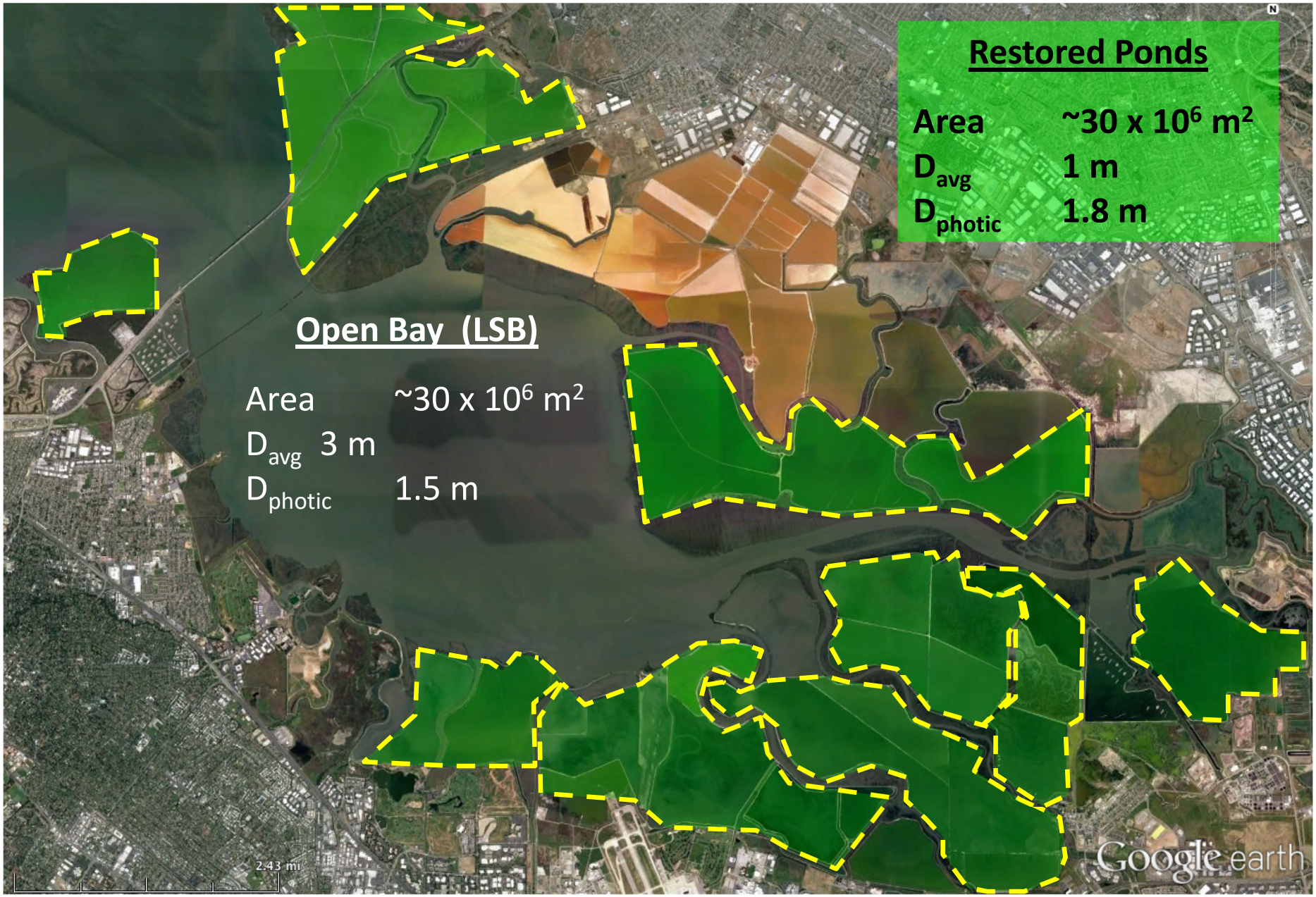
- Complex system, slow flushing
- Highest **N**itrogen and **P**hosphorous concentrations in the Bay
- 3 WWTPs

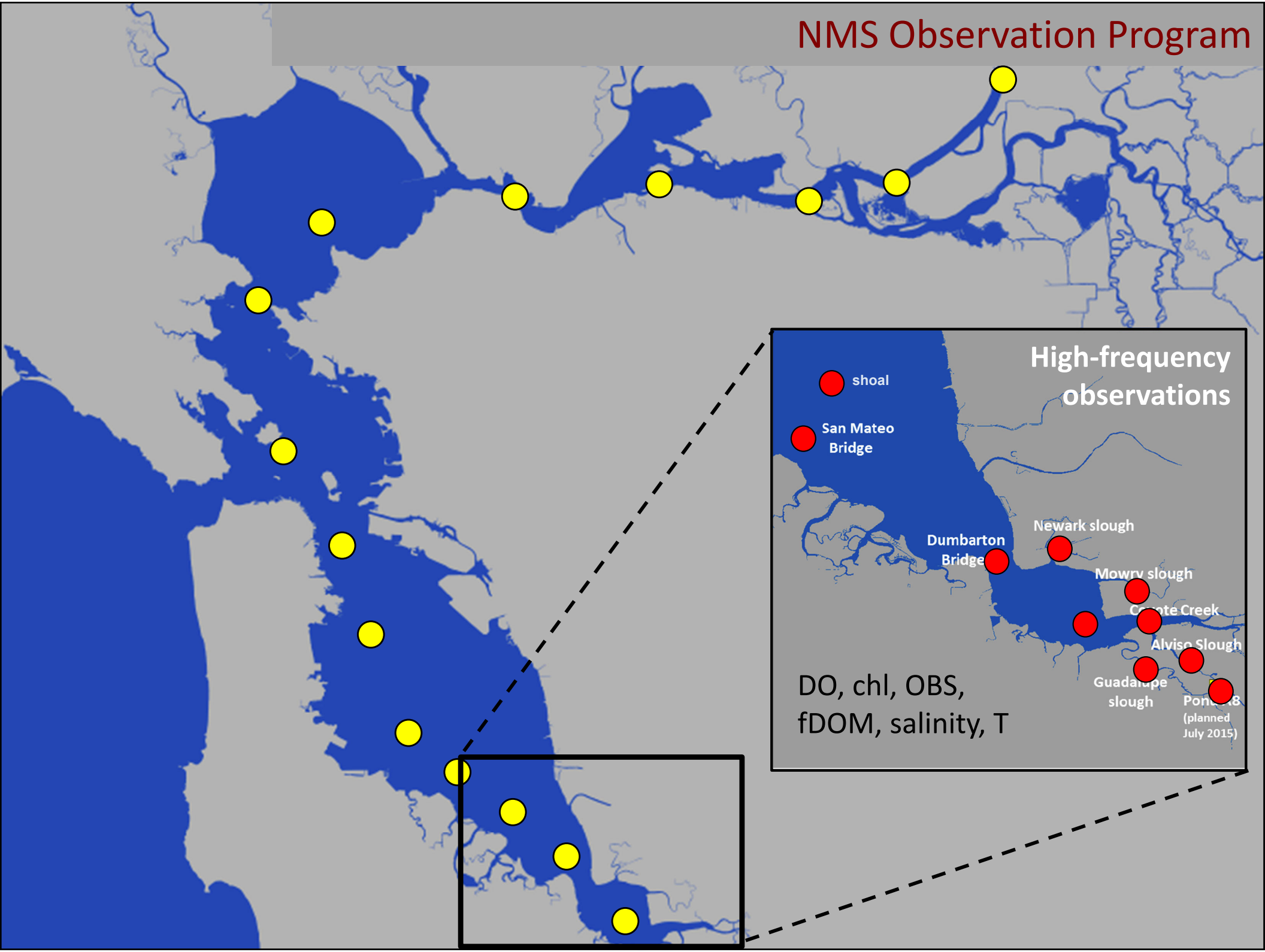


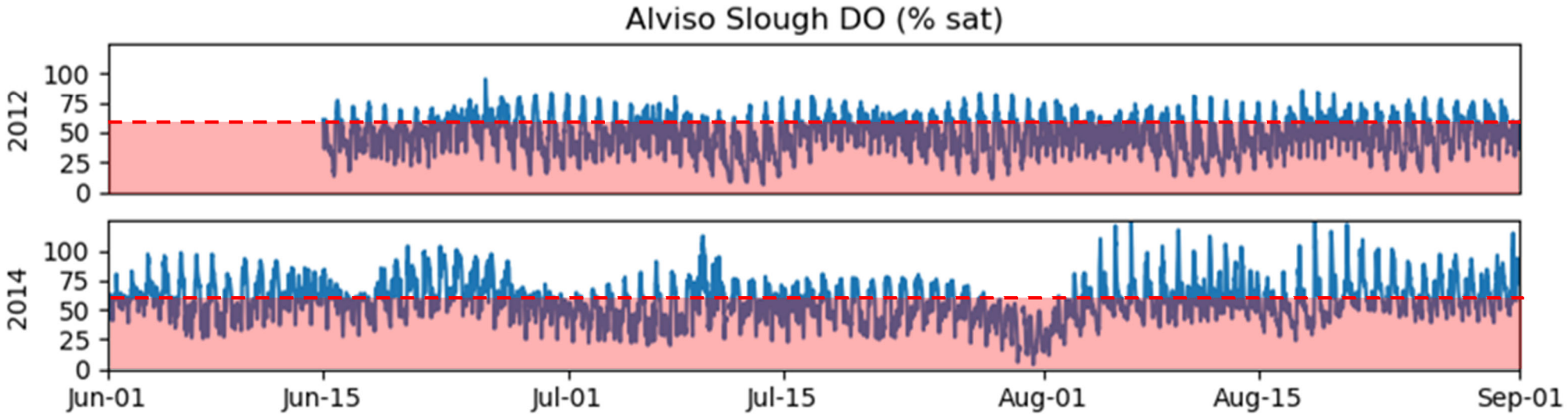
Key Questions

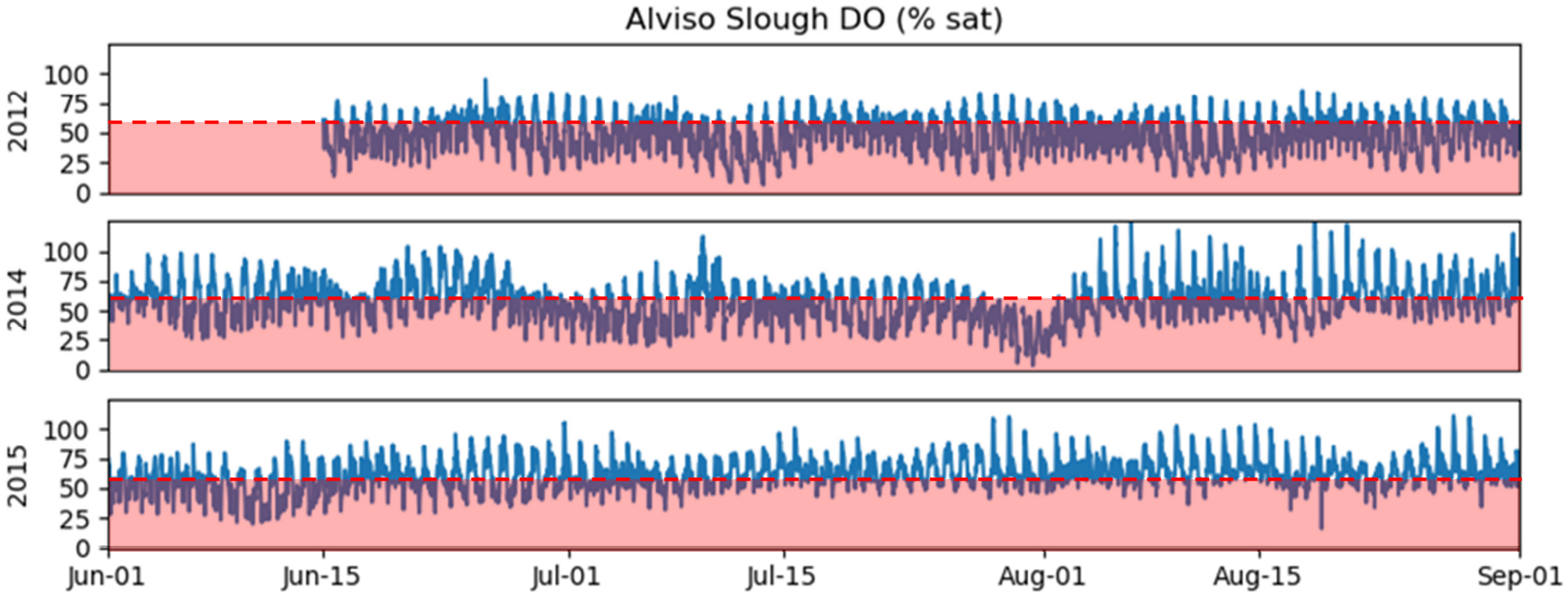
- Condition: Open Bay and sloughs/creeks. Adversely impacting biota?
- Spatial variability: production, biomass, nutrient cycling?
- Restoration efforts affecting DO, phytoplankton?

Could biogeochemical processes in restored salt ponds influence open Bay water quality?




NMS Observation Program
High-frequency observations
shoal
San Mateo Bridge
Dumbarton Bridge
Newark slough
Mowry slough
Alviso Slough
Guadalupe slough
(planned July 2015)
DO, chl, OBS,
fDOM, salinity, T


Alviso Slough DO (% sat)
2012
2014
100
75
50
25
0
Jun-01
Jun-15
Jul-01
Jul-15
Aug-01
Aug-15
Sep-01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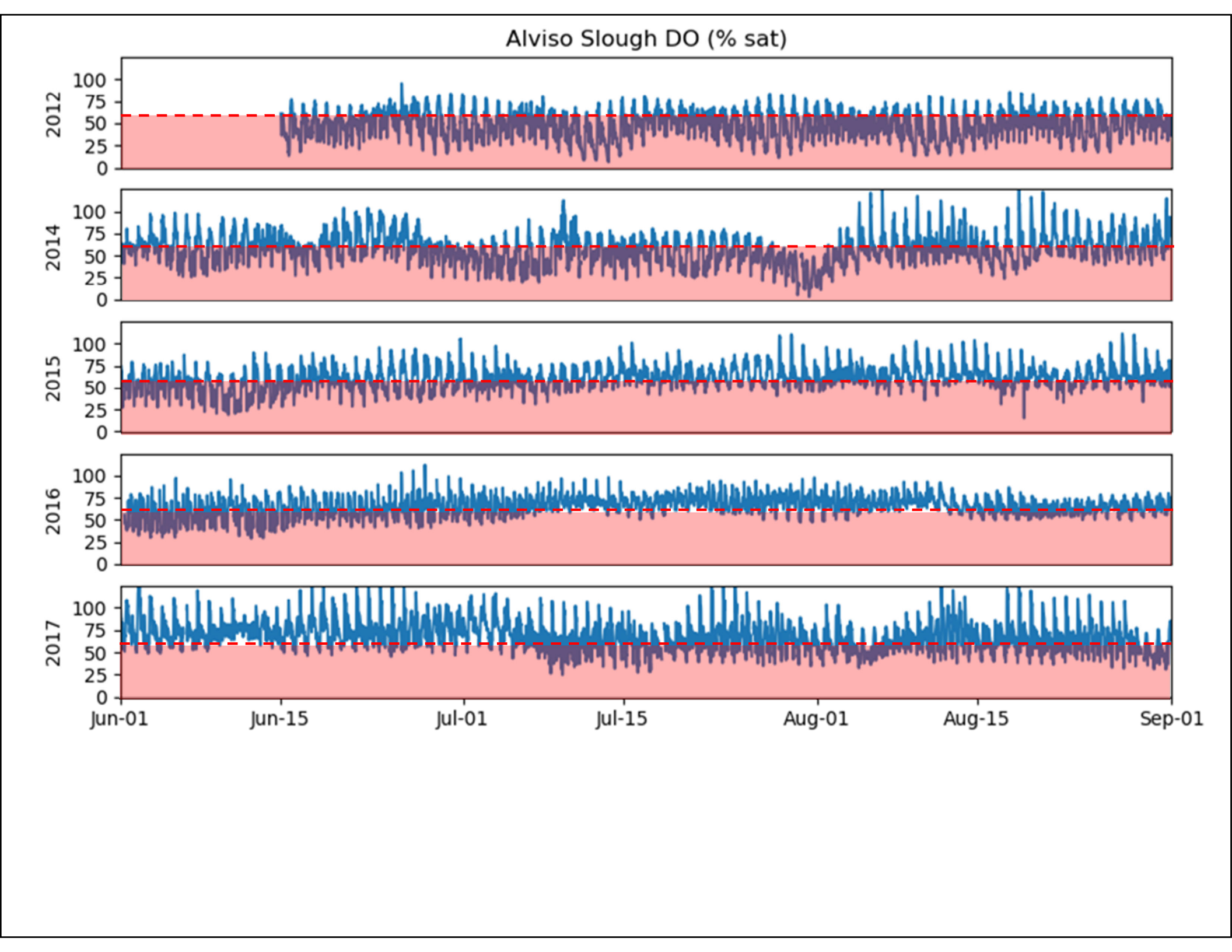
Alviso Slough DO (% sat)
2012
2014
2015
2016
2017
100
75
50
25
0
Jun-01
Jun-15
Jul-01
Jul-15
Aug-01
Aug-15
Sep-01


Assessment Framework
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Management Options
Phytos-O_2 Margins
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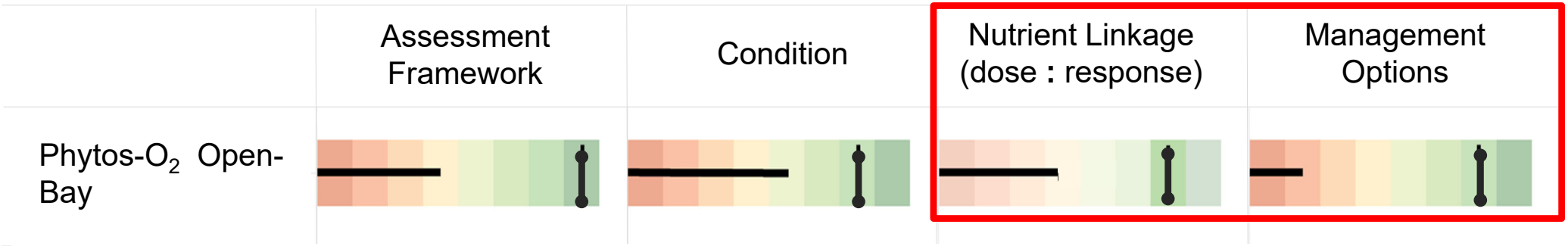

Confidence Level

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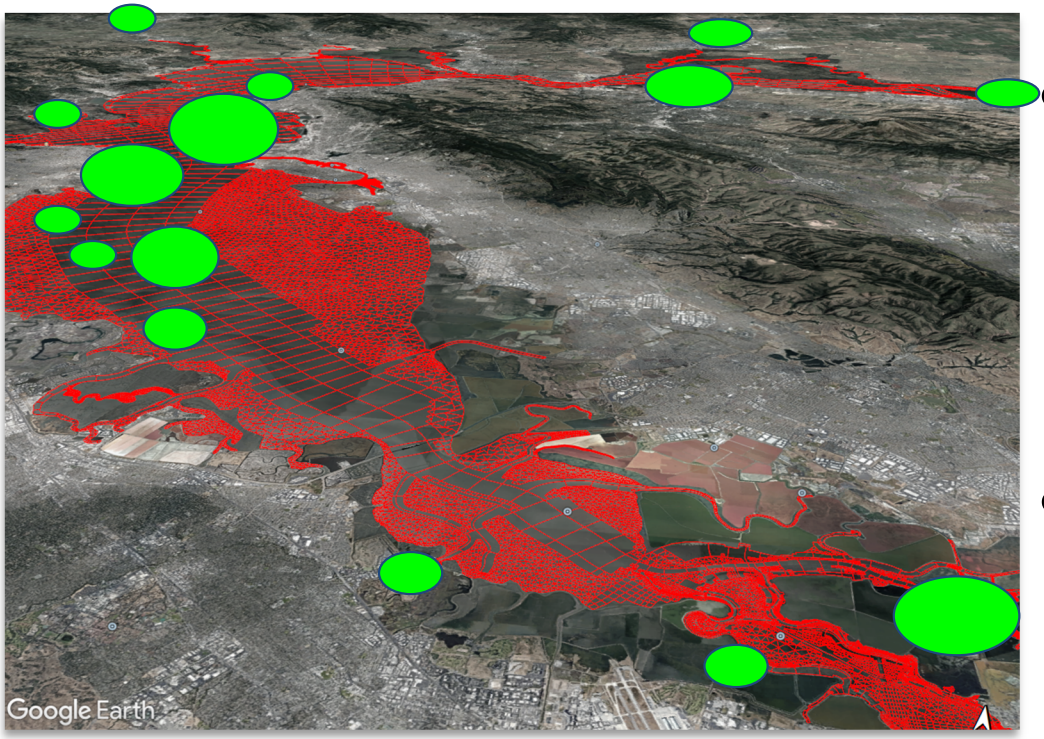
Numerical Models

Hydrodynamic model (Transport)



Transport = advection + dispersion + mixing

Delft Flexible Mess

500k 3D cells (10 vertical sigma layers)

~10 days to run 1 year

Grid resolution: 2km to 20m

- What are the nutrient sources to specific regions of SFB ?

  = f(space, season, year)

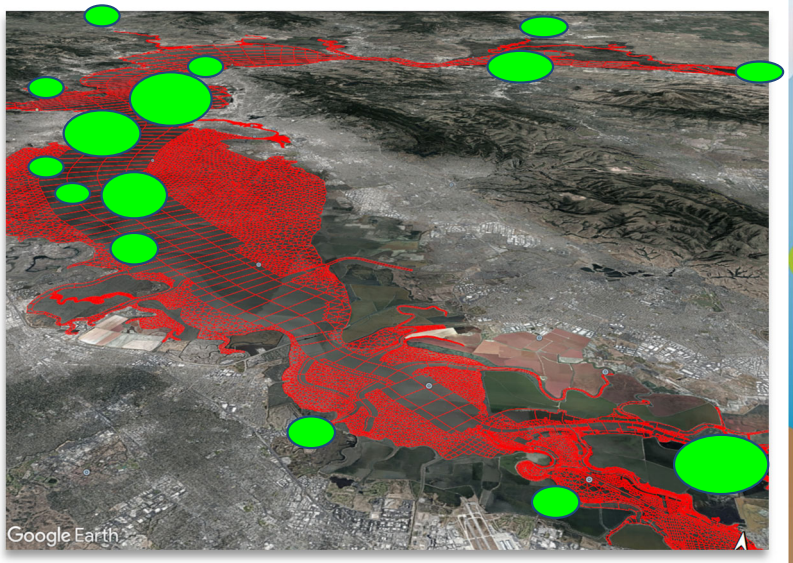
- How do habitats respond to, and influence, nutrients?
  - chl, DO, HABs
  - Nutrient transformations, losses

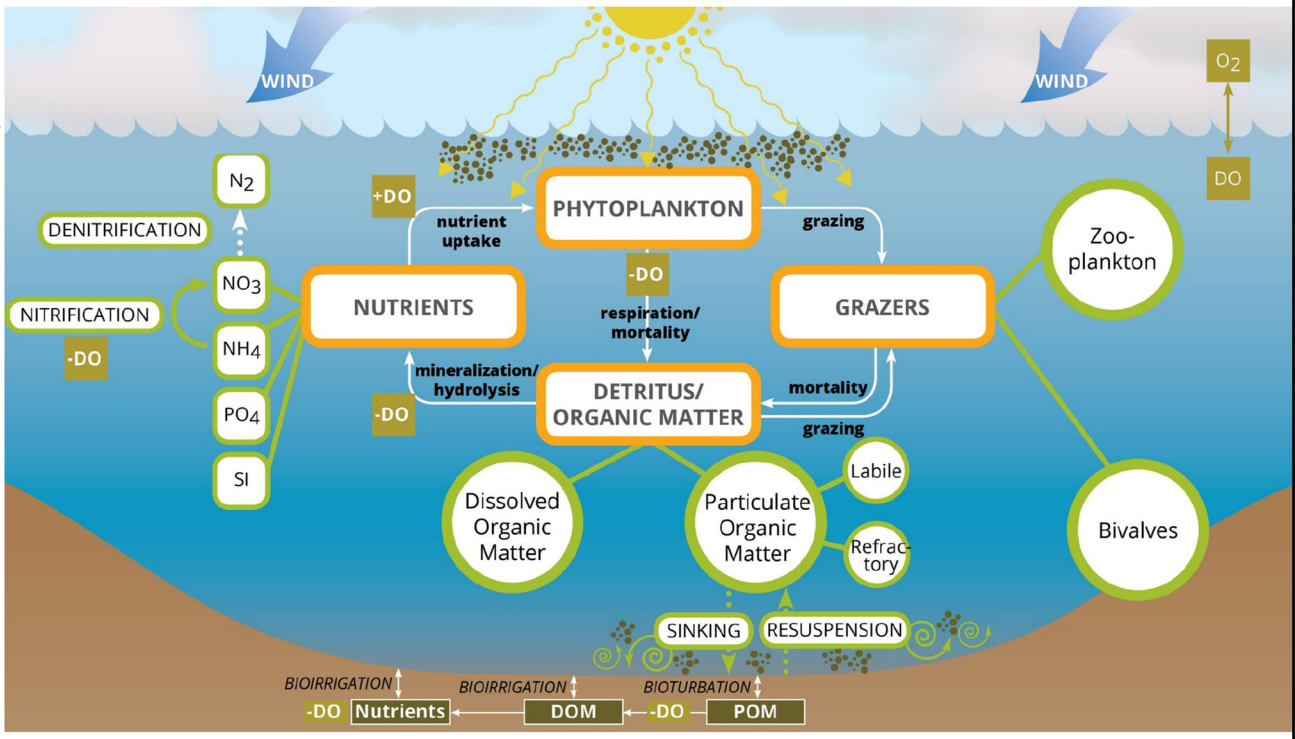
- Dose→Response:
  - How will SFB respond to ↑↓ nutrients?

- What will be the effects be of
  - specific management options?
  - changing forcings: tides, wind, SPM, salinity stratification

Numerical Models

Hydrodynamic model (Transport) + Biogeochemical model (Transformations)





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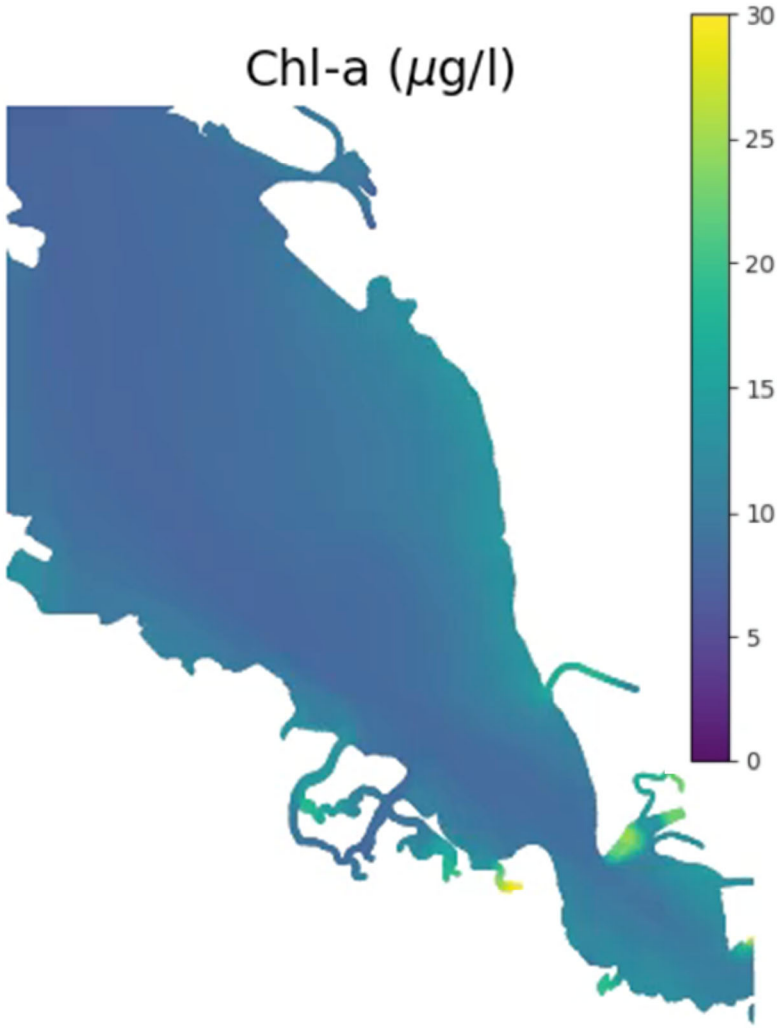
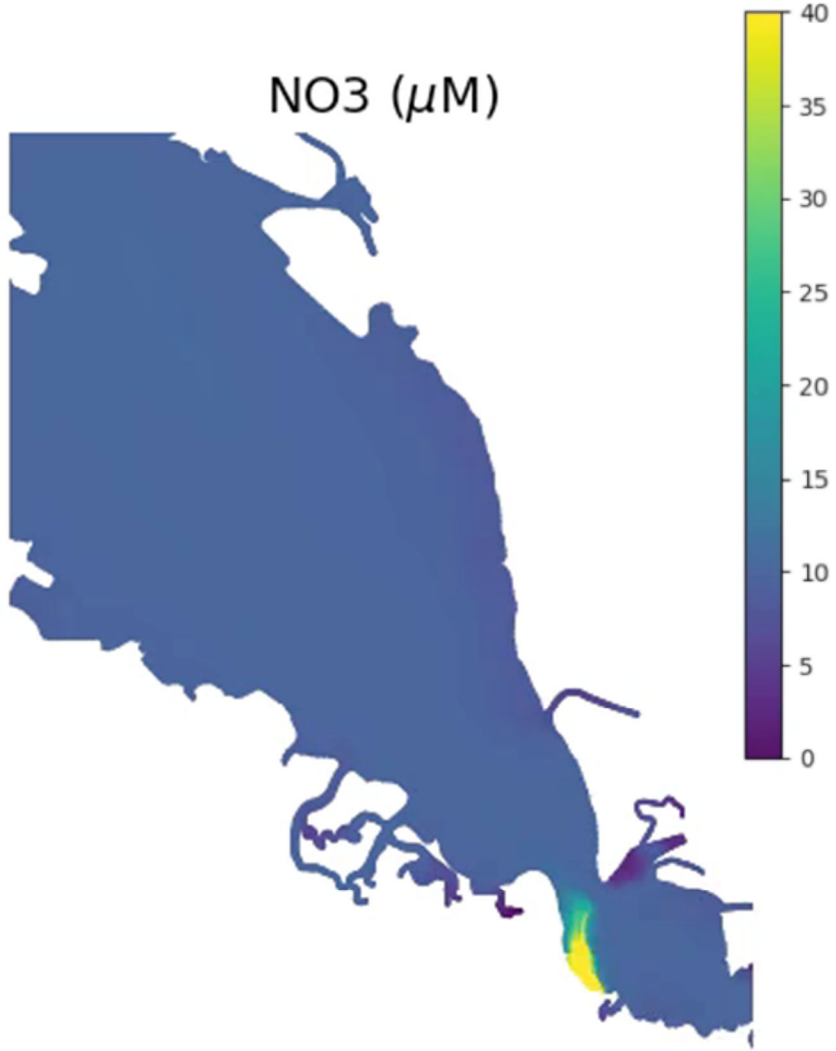
~10 days to run 1 year

Grid resolution: 2km to 20m

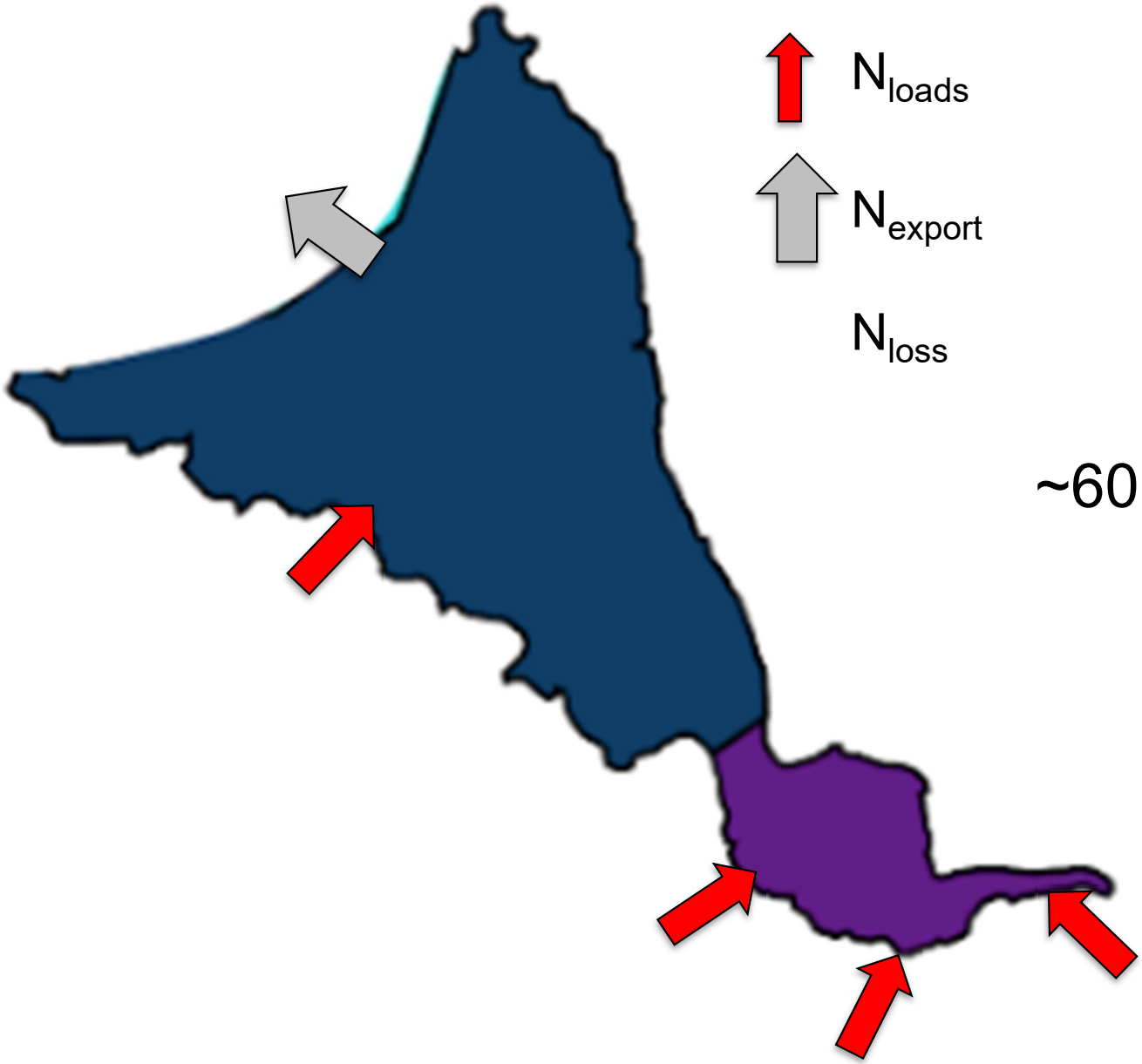
Collaborators: R Holleman (UC-Davis), Deltares, L Lucas (USGS), P Mugunthun (4Peaks)





2012-08-02

mid-Summer Total N Budget

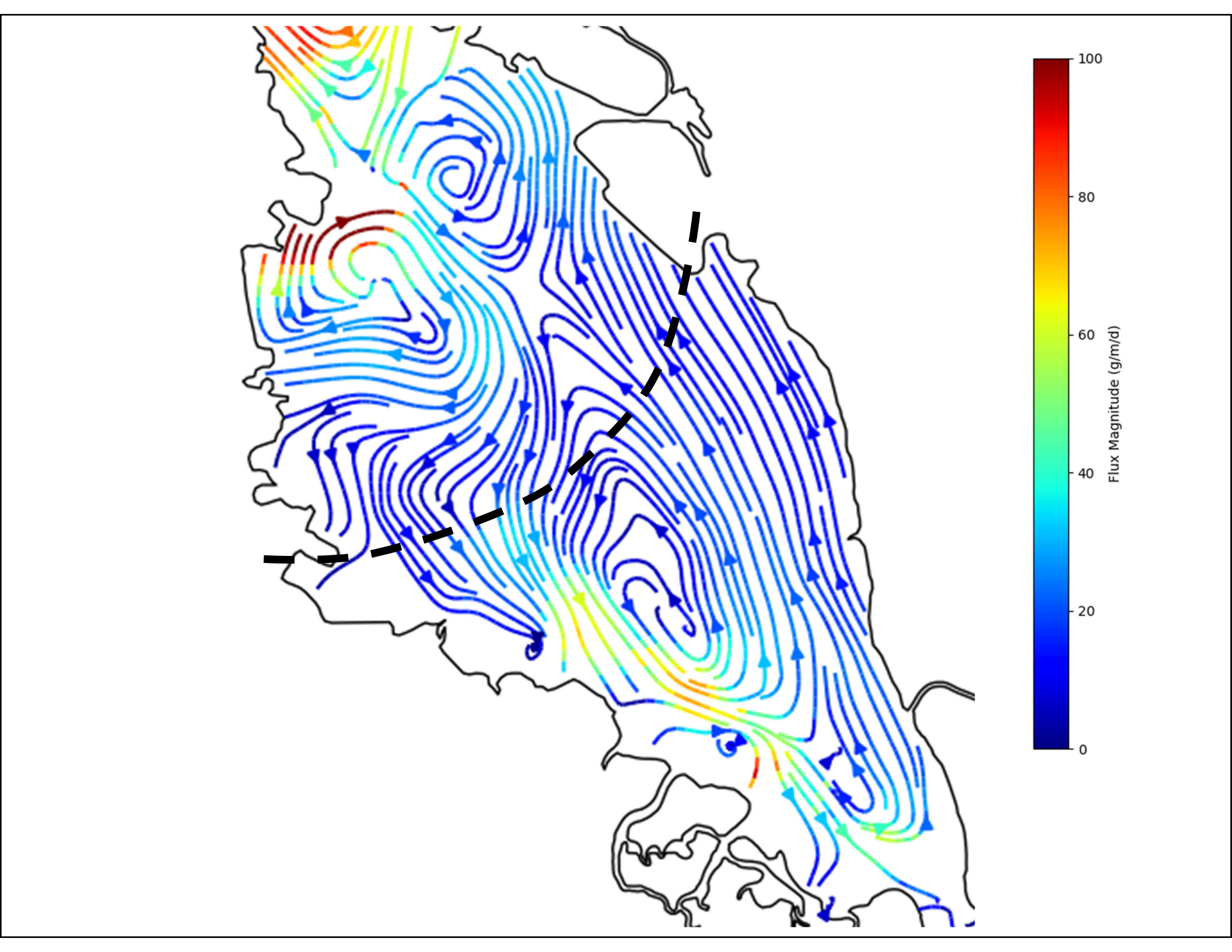


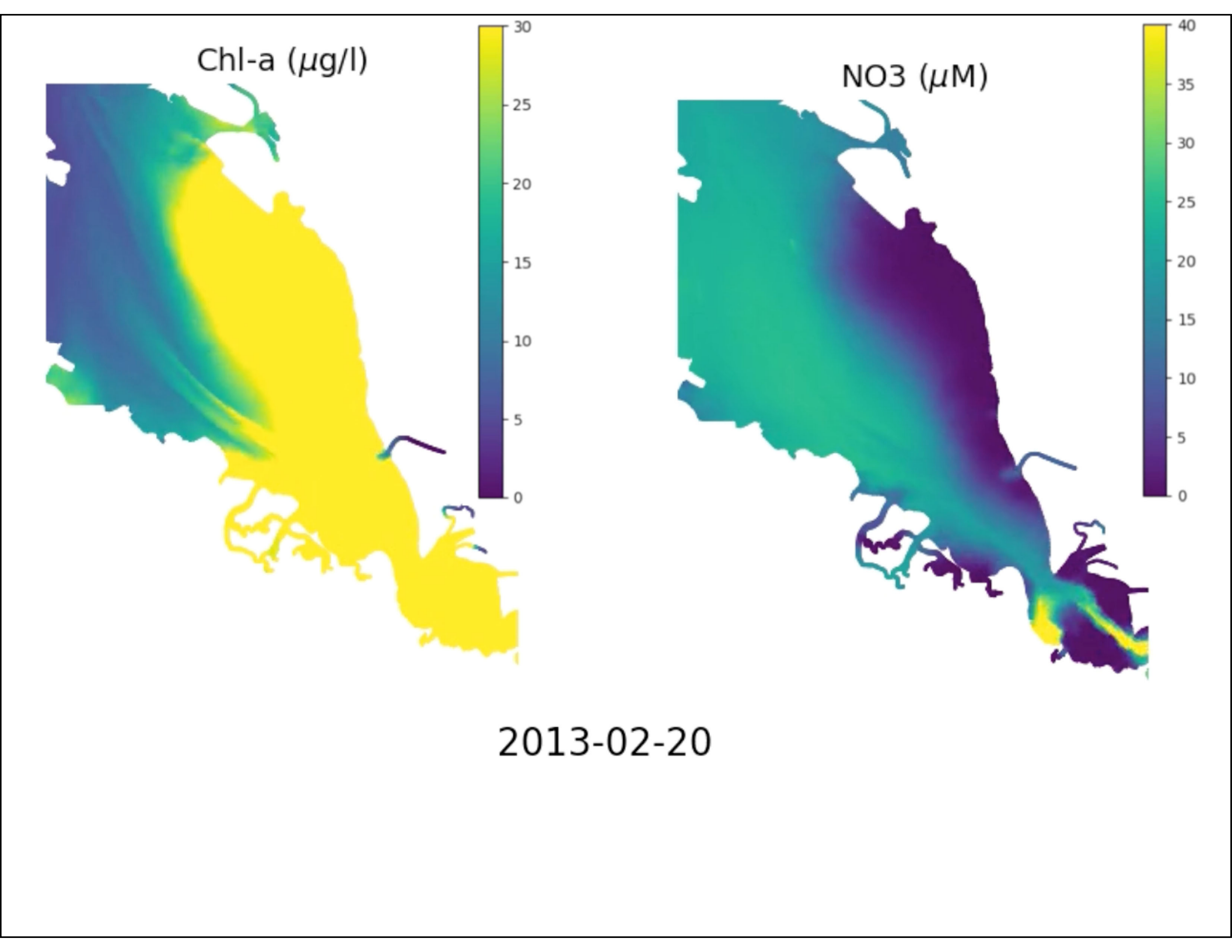
N_{loads} 9,000 kg / d

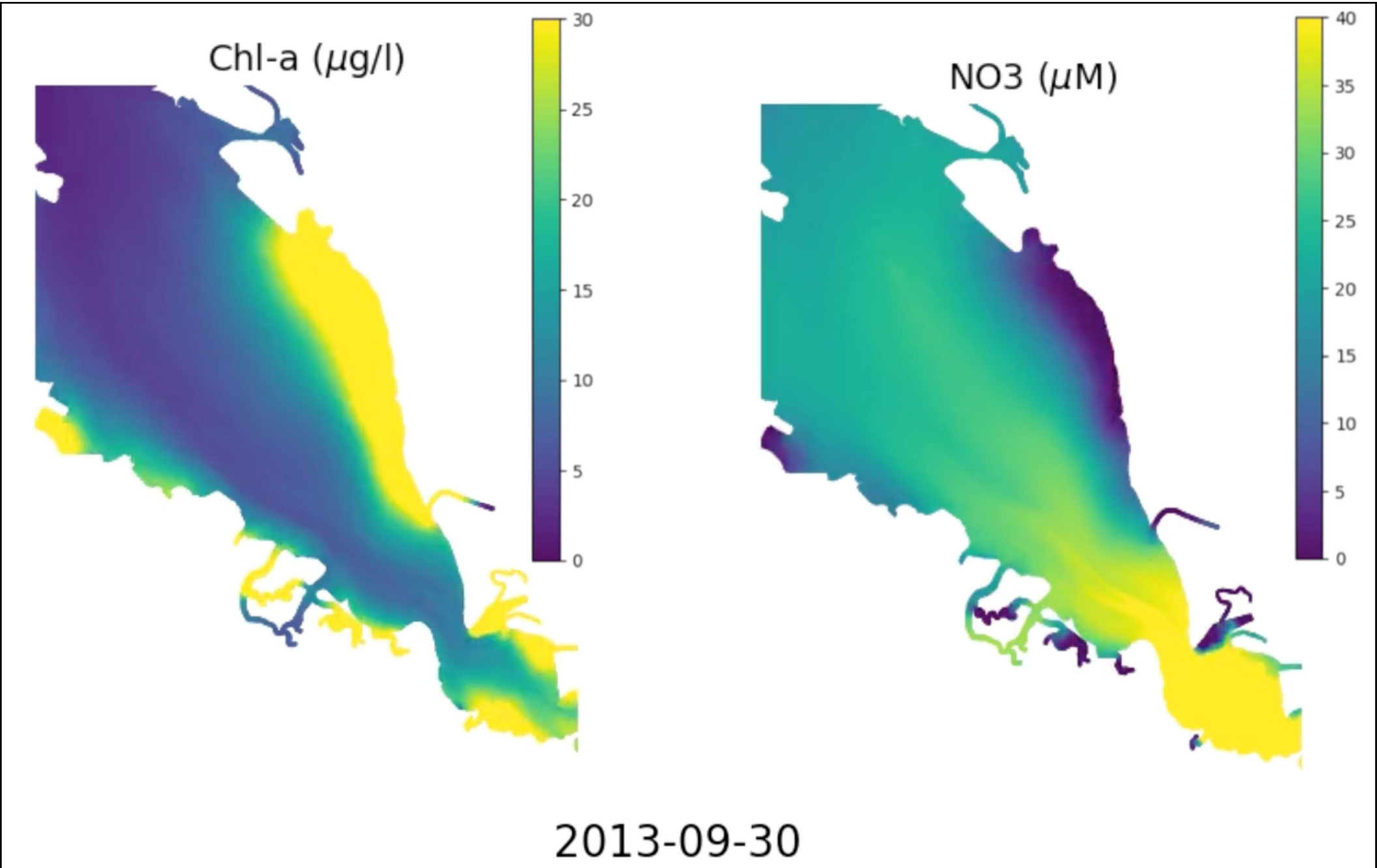
N_{export} 3,300 kg / d

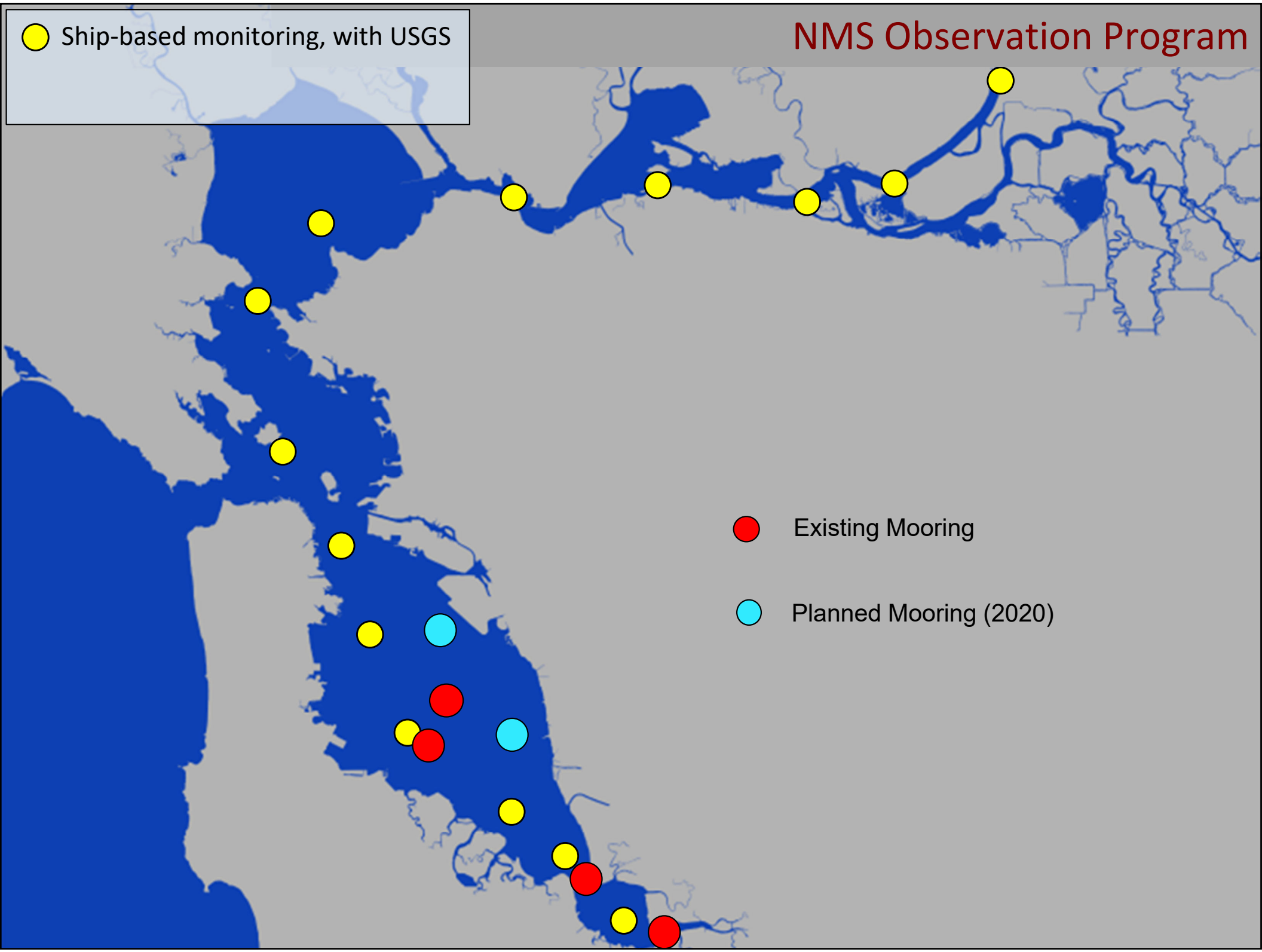
N_{loss} 5,700 kg / d

~60% ‘loss’


100
80
60
40
20
0
Flux Magnitude (g/m/d)

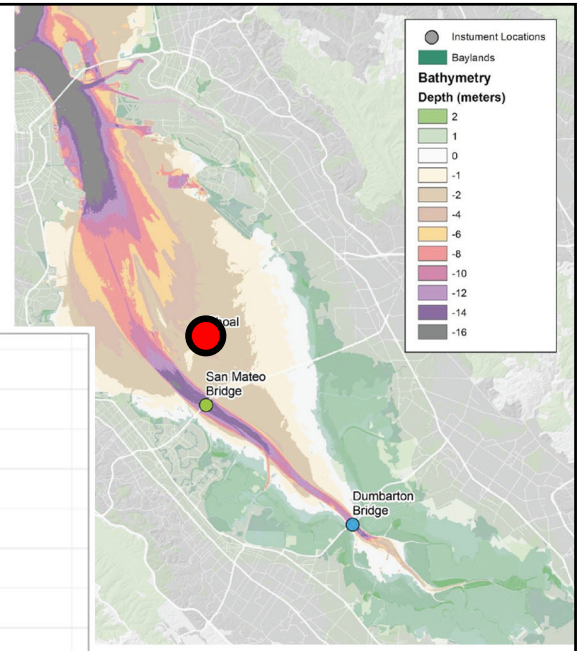

Chl-a (μg/l)
30
25
20
15
10
5
0
NO3 (μM)
40
35
30
25
20
15
10
5
0
2013-02-20

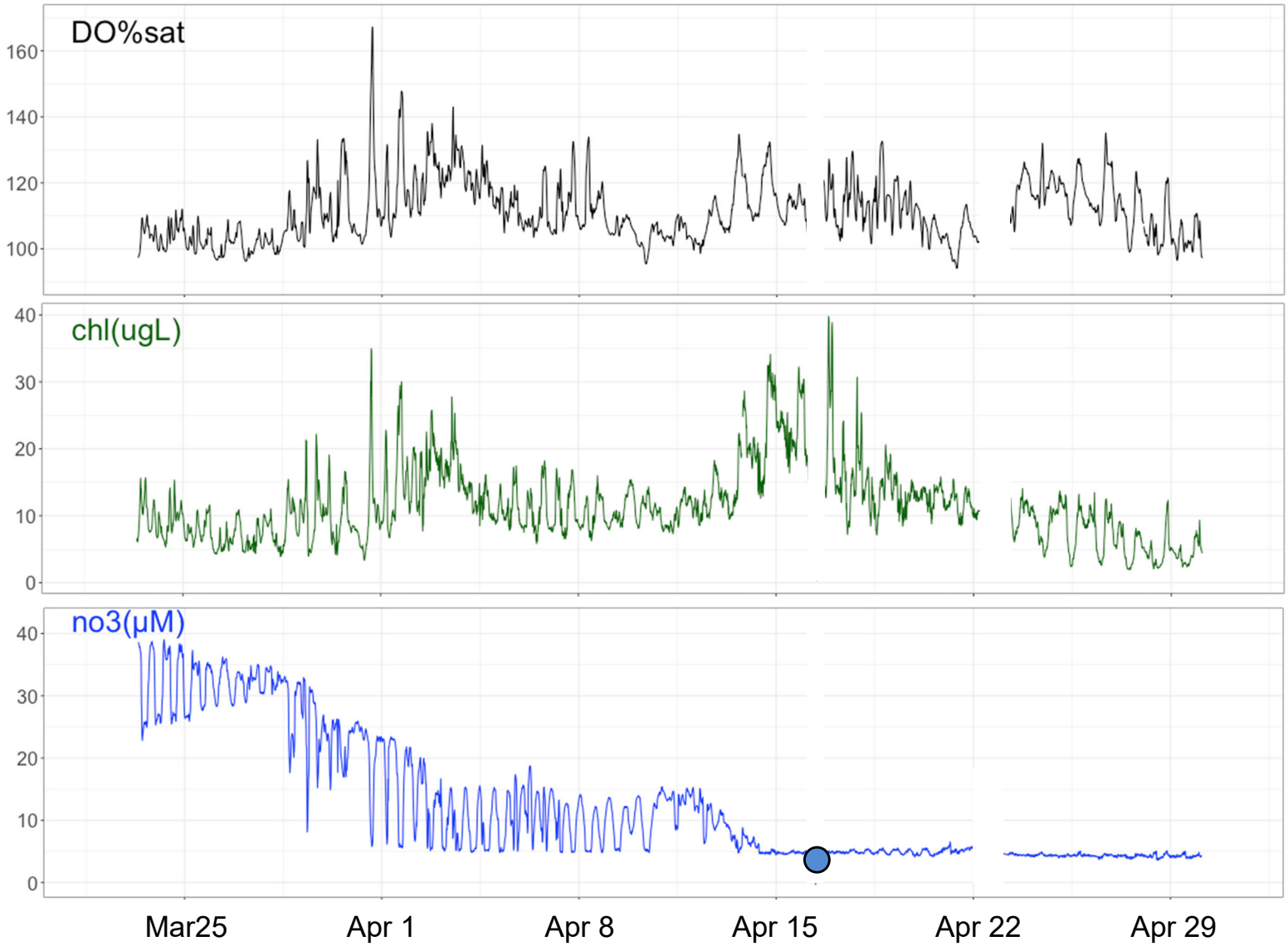

Chl-a (μg/l)
30
25
20
15
10
5
0
NO3 (μM)
40
35
30
25
20
15
10
5
0
2013-09-30


Ship-based monitoring, with USGS
NMS Observation Program
Existing Mooring
Planned Mooring (2020)

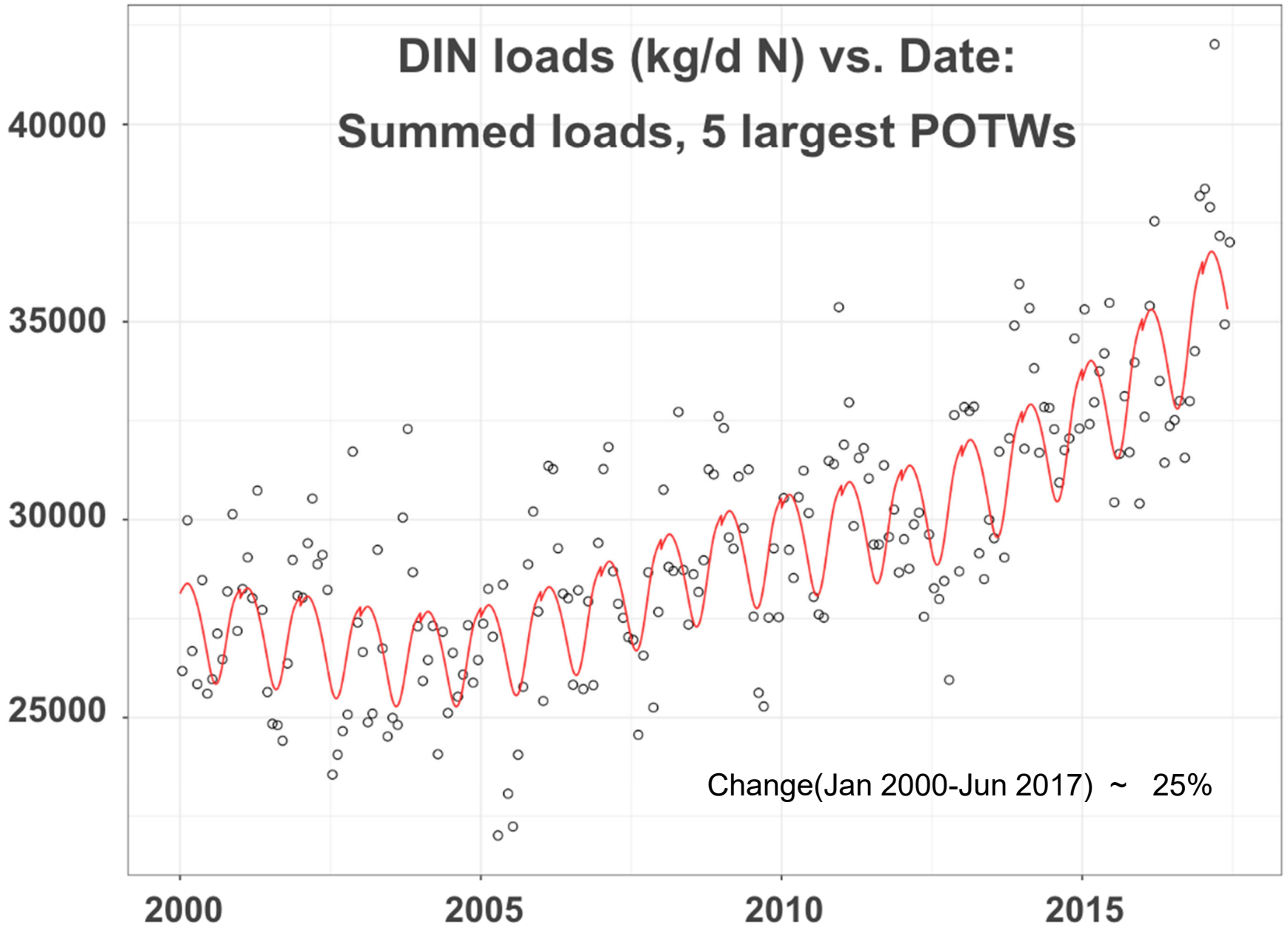
Conditions on South Bay Shoal:

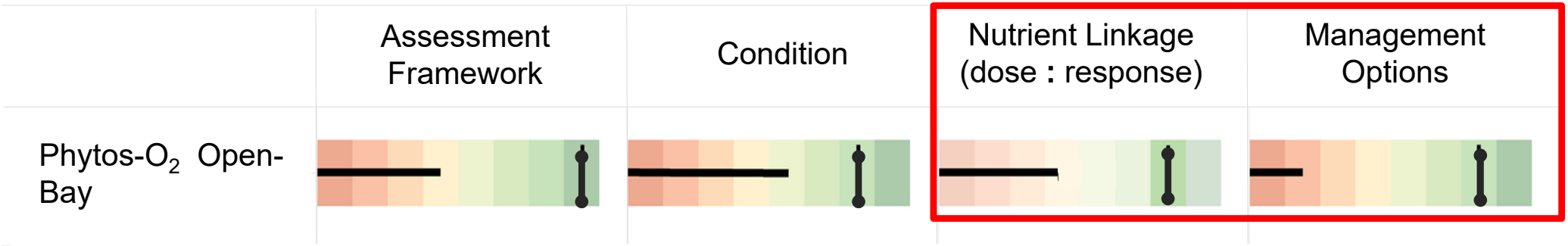
March 18 – April 29, 2019





Collaborators: USGS-BGC


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%



Confidence Level

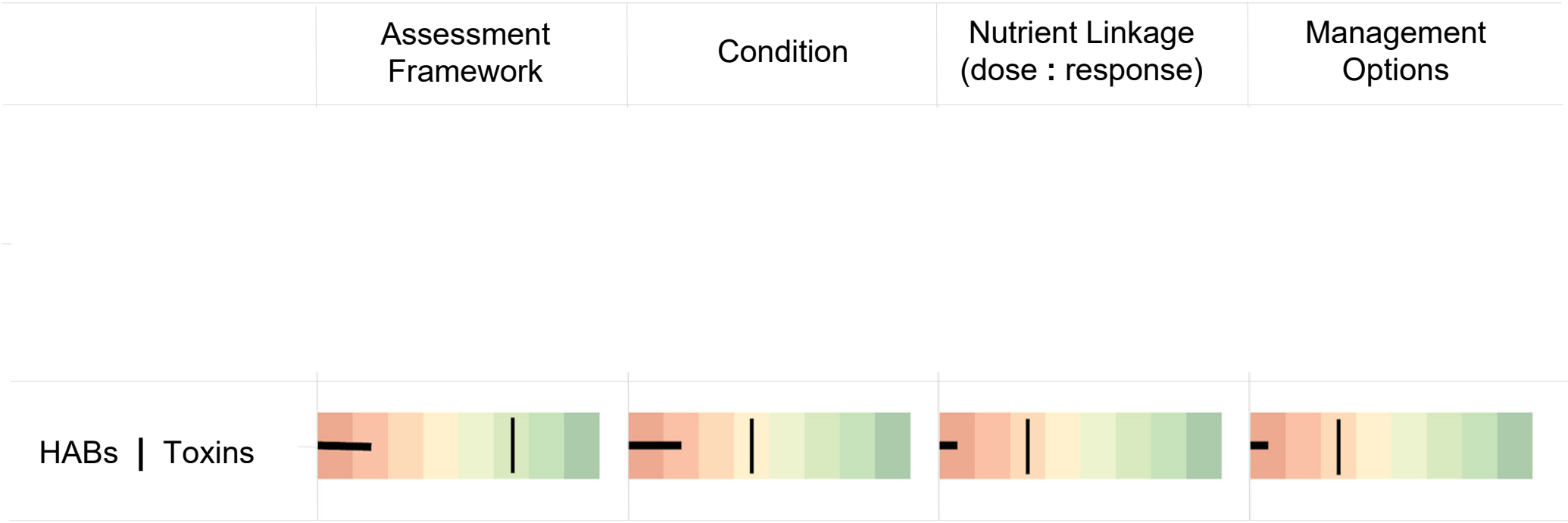
low medium high

Status

Current Status (2019/2020)

Goal (2024)

	Assessment Framework	Condition	Nutrient Linkage (dose : response)	Management Options
Phytos-O_2 Open-Bay				
Phytos-O_2 Margins				
HABs | Toxins				
Coastal Impacts				



Confidence Level

low medium high

Status

Current Status (2019/2020)

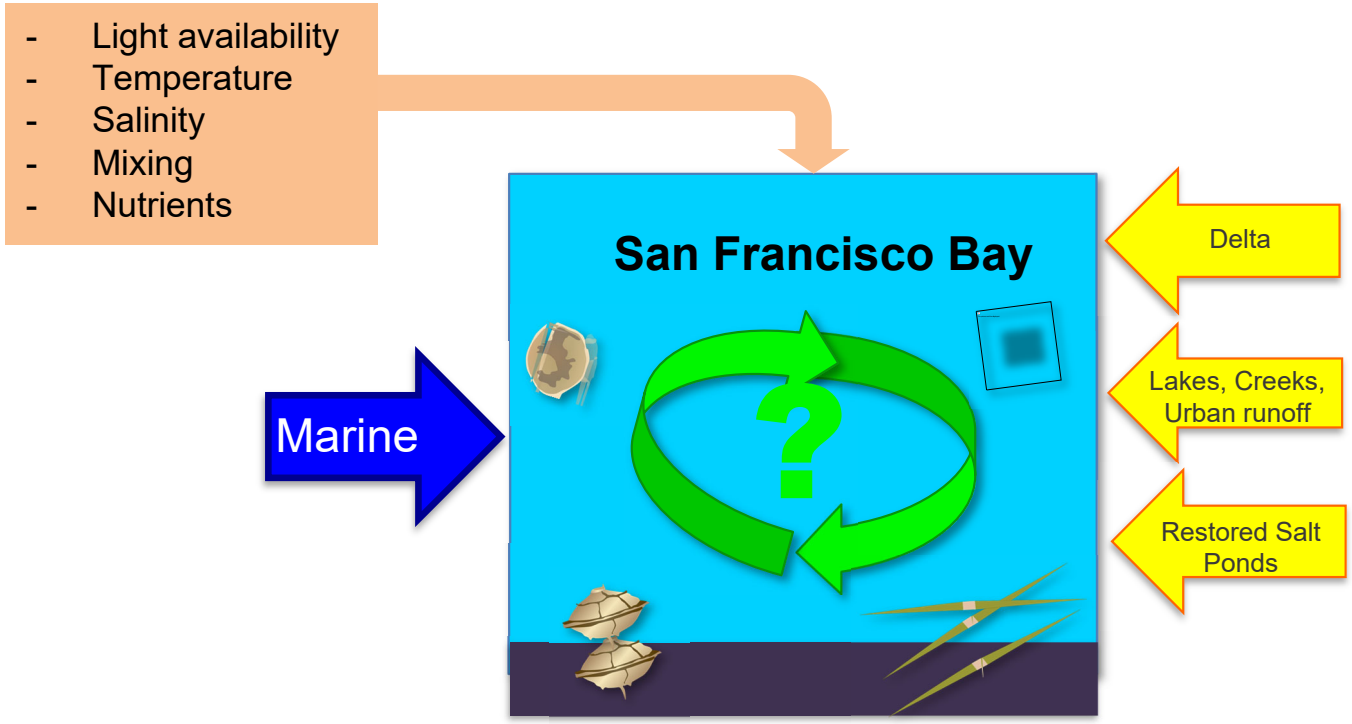
Goal (2024)

HABs and PhycoToxins in SFB: Science/Management Questions

1. Water Quality / Habitat Quality: Are HABs impacting SFB habitat quality?
    a. *Biota? Humans?*
    b. Current vs. *Future* Conditions?

HABs and PhycoToxins in SFB: Science/Management Questions

1. Water Quality / Habitat Quality: Are HABs impacting SFB habitat quality?
   a. *Biota? Humans?*
   b. Current vs. *Future* Conditions?
2. Source(s)? transport into SFB vs. production within SFB
3. Factors influencing HAB abundance and toxins? Role of nutrients?
4. Protective nutrient loads?

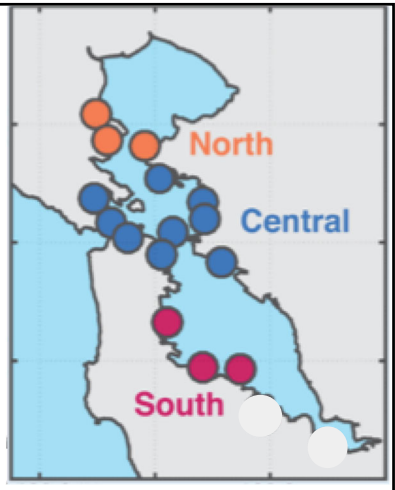


NMS Observation and Forecasting Program

Mussels

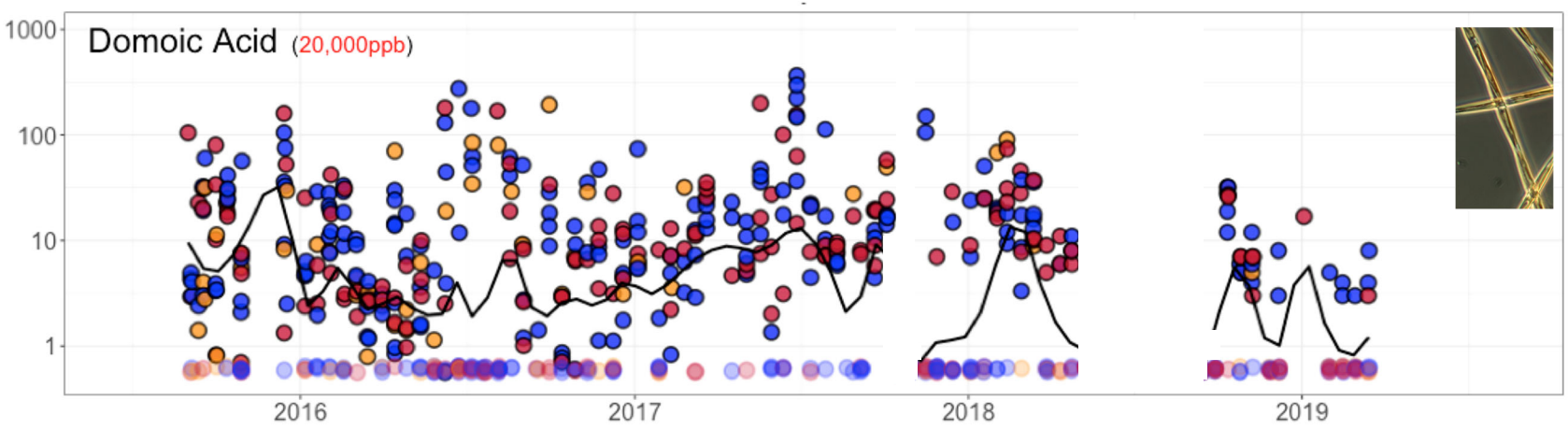
- Naturally occurring mussels
- Floating docks, readily-accessible
- Bi-weekly sampling (Sep 2015-present)
- Domoic Acid, Saxitoxin, Microcystin

Phycotoxins in SFB Mussels: Sep 2015-Jul 2019 ~Biweekly collection

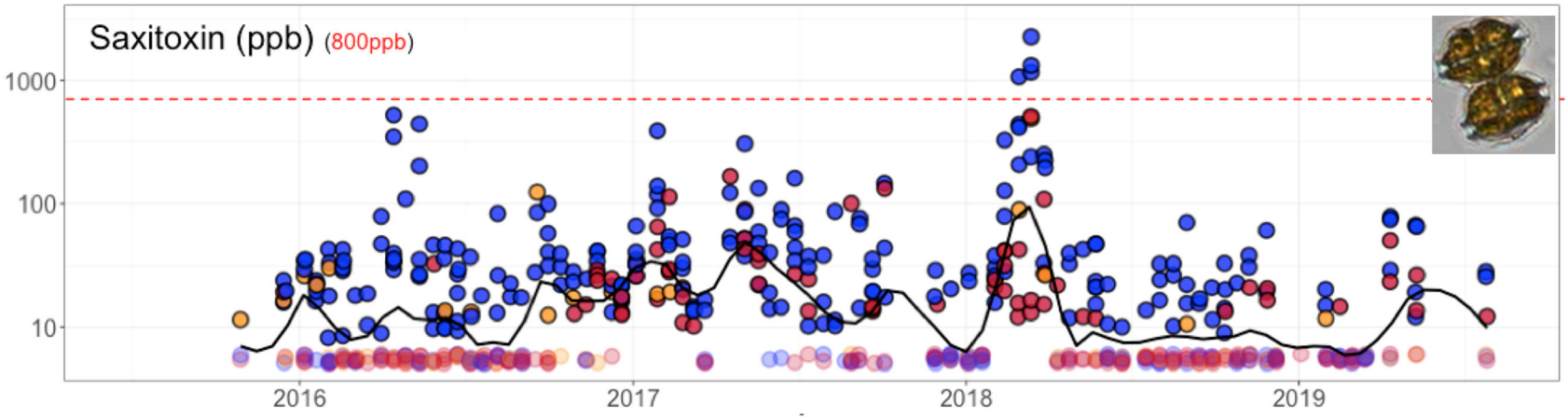


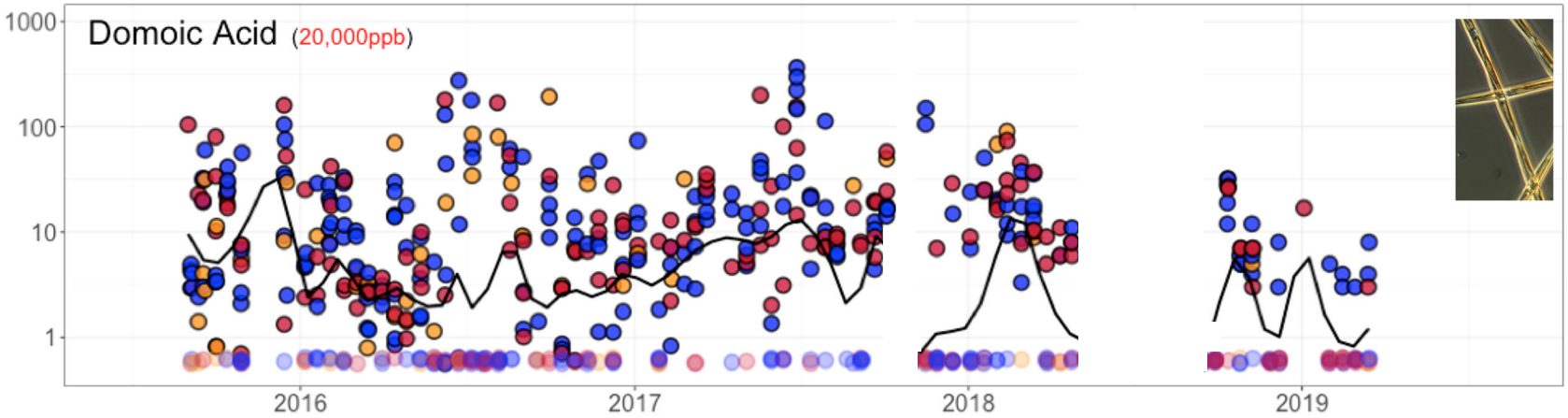
Color = Region
(see map for approx locations)

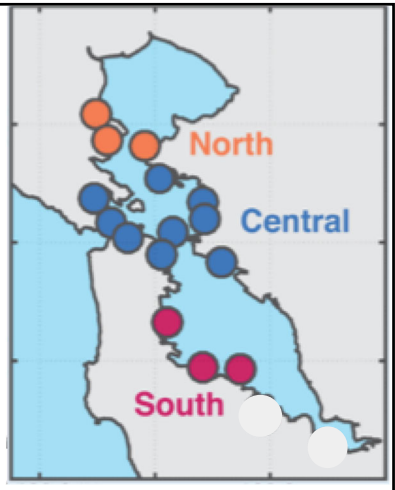
Black curve: smoothed (loess), geometric mean



Phycotoxins in SFB Mussels: Sep 2015-Jul 2019 ~Biweekly collection





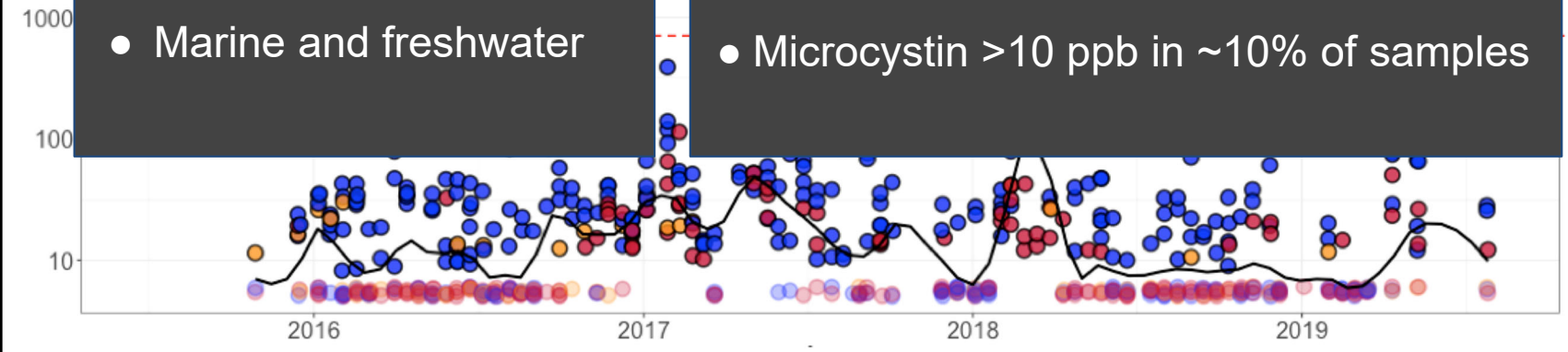


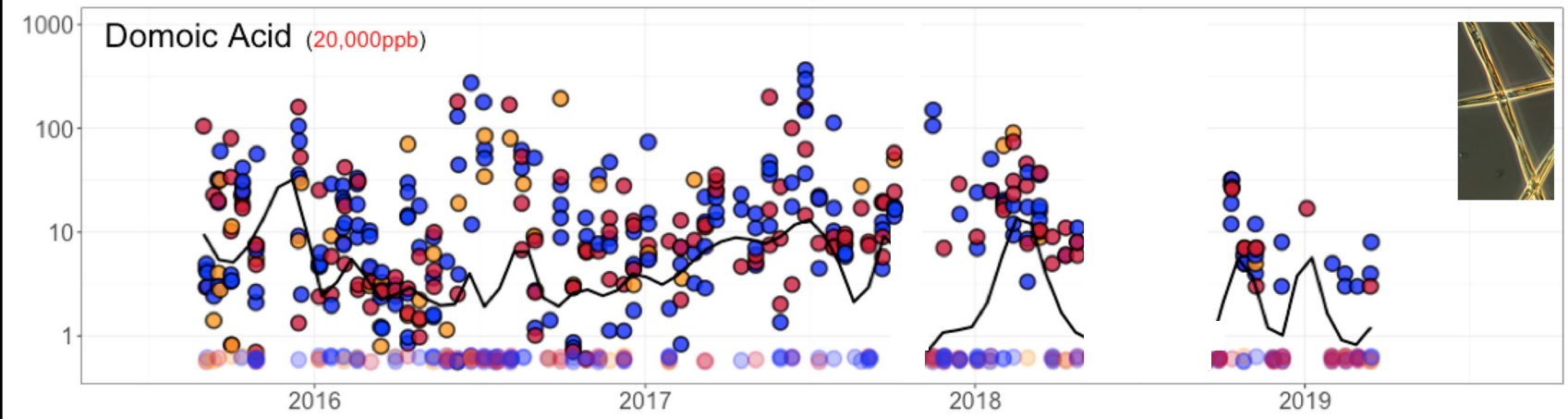
Color = Region
(see map for approx locations)

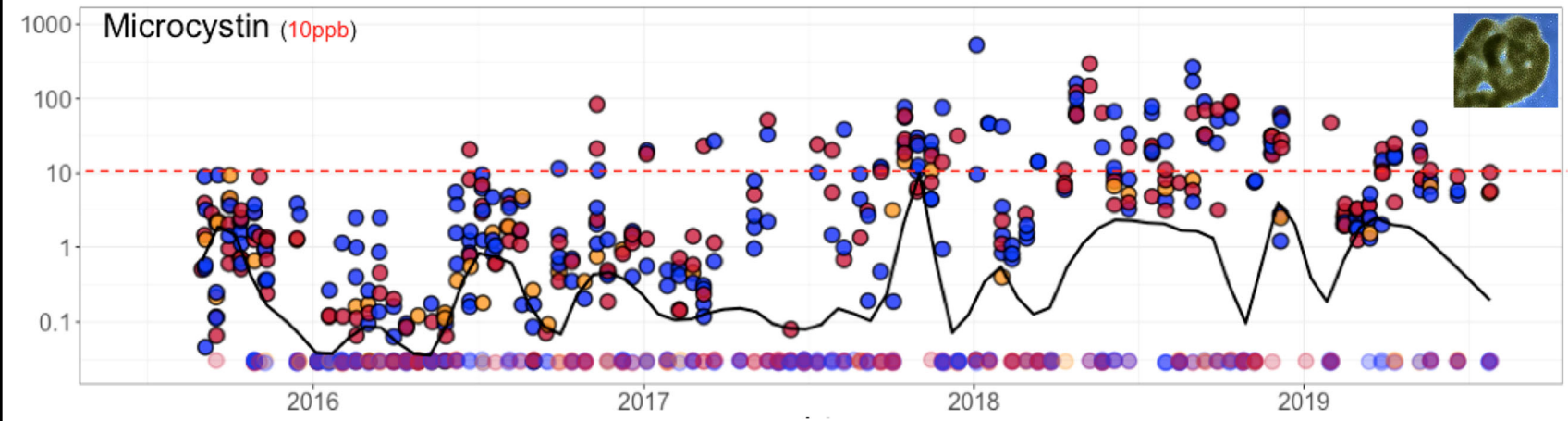
Black curve: smoothed (loess), geometric mean

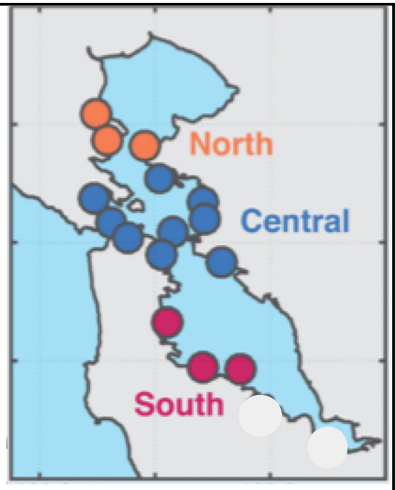
- Multiple toxins frequently detected
- Marine and freshwater

- STX flare-ups, approach or >800 ppb
- DA relatively low
- Microcystin >10 ppb in ~10% of samples







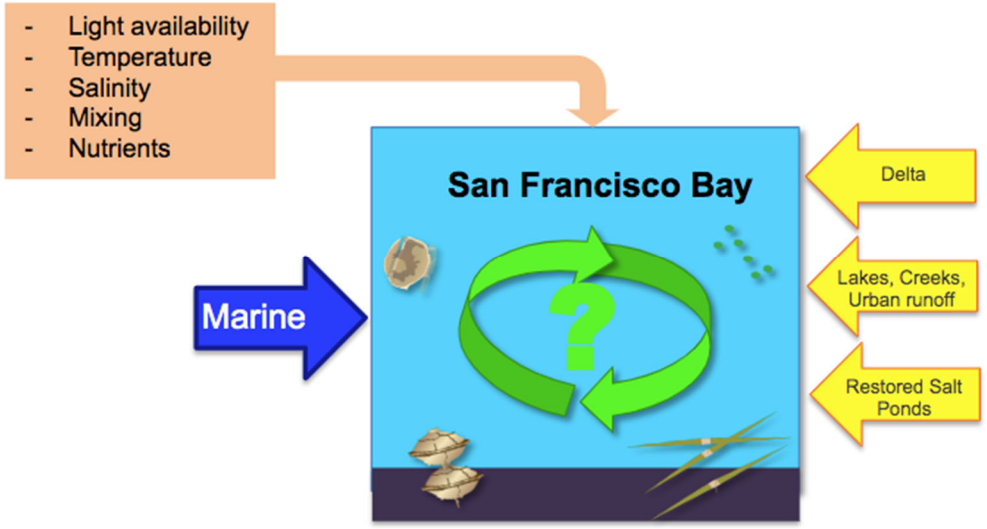


Color = Region
(see map for approx locations)

Black curve: smoothed (loess), geometric mean

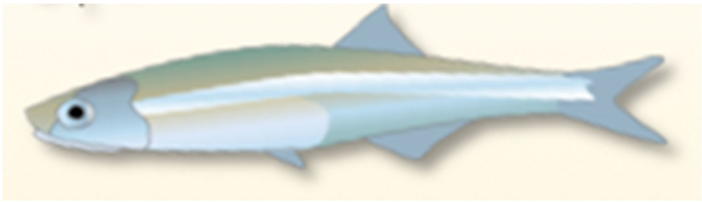
HABs and PhycoToxins in SFB: Science/Management Questions

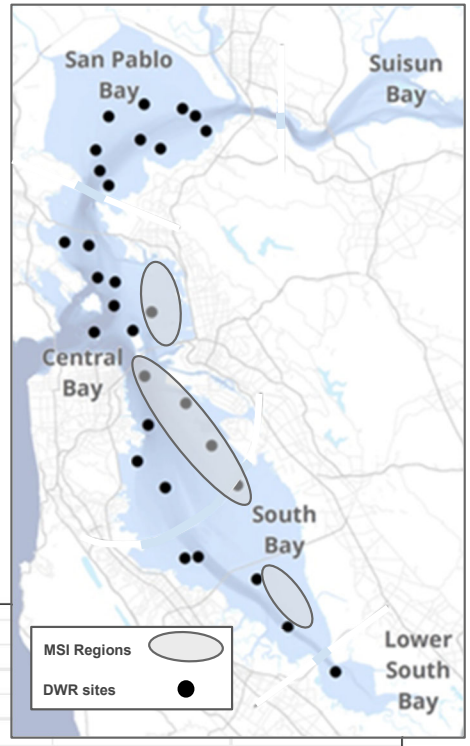
1. Water Quality / Habitat Quality: Are HABs impacting SFB habitat quality?
   a. *Biota? Humans?*
   b. Current vs. *Future* Conditions?
2. What factors regulate HA abundance and toxicity in SFB? transport, *in situ* production
3. Role of SFB nutrients: N,P → frequency or severity of HA events?
4. Protective nutrient loads, with respect to HAs and phycotoxins?

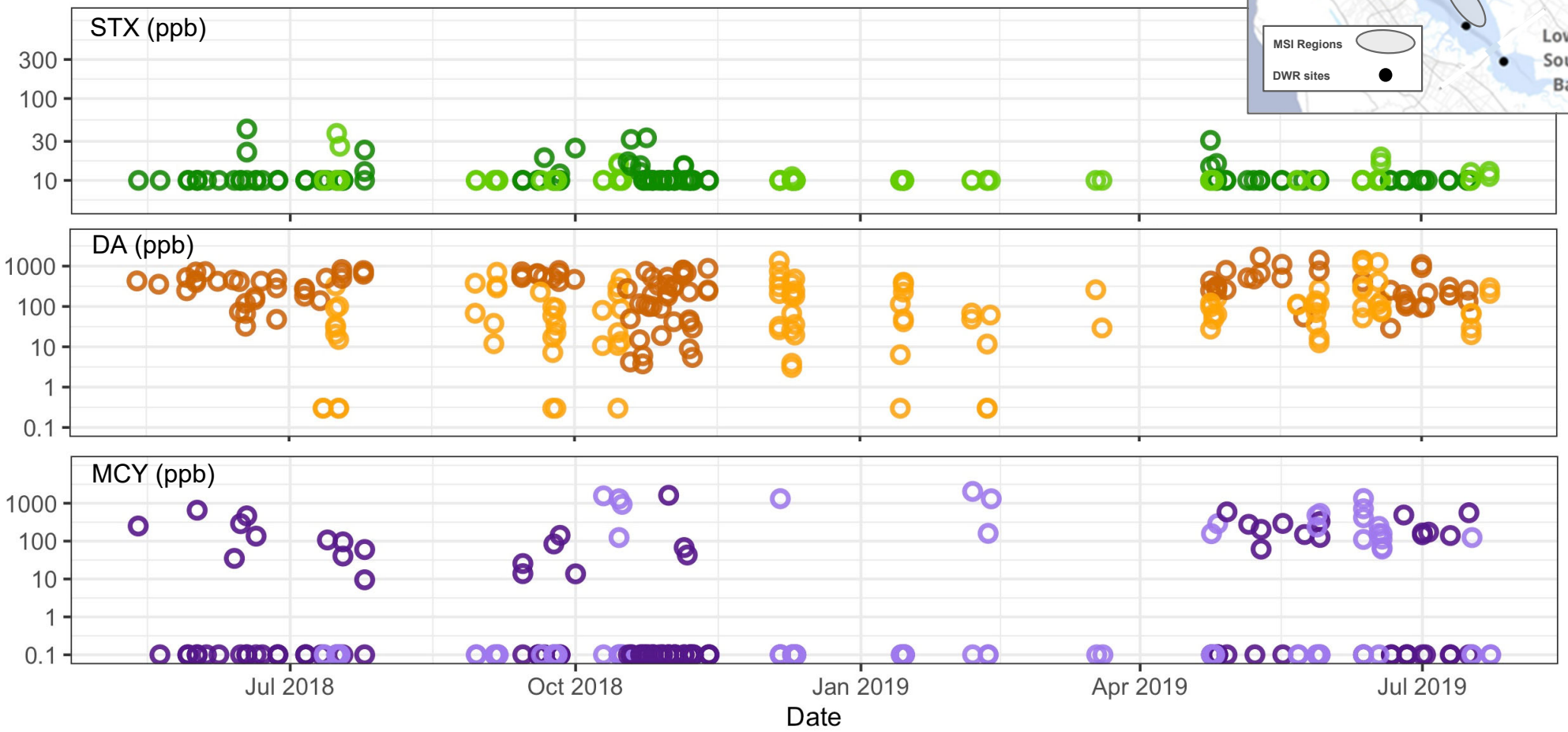


WHAT'S NEXT?

- Continued monitoring and condition assessment (phytos, toxins in water and biota)
- Controlled experiments (P-N, DA)
- Pilot study, other organisms




San Pablo Bay
Suisun Bay
Central Bay
South Bay
Lower South Bay
MSI Regions
DWR sites


STX (ppb)
300
100
30
10
DA (ppb)
1000
100
10
1
0.1
MCY (ppb)
1000
100
10
1
0.1
Jul 2018
Oct 2018
Jan 2019
Apr 2019
Jul 2019
Date

	Assessment Framework	Condition	Nutrient Linkage (dose : response)	Management Options
Phytos-O_2 Open-Bay				
Phytos-O_2 Margins				
HABs | Toxins				
Coastal Impacts				

	Assessment Framework	Condition	Nutrient Linkage (dose : response)	Management Options
Coastal Impacts				

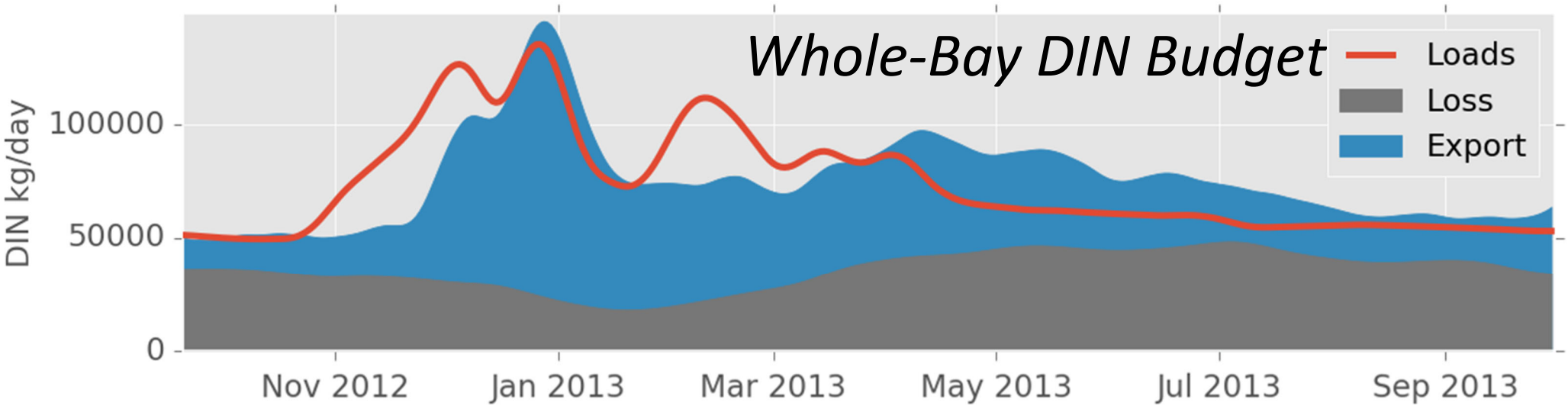
Confidence Level

low medium high

Status

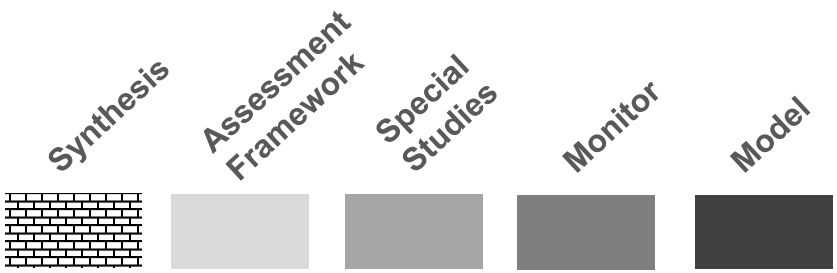
Current Status (2019/2020)

Goal (2024)



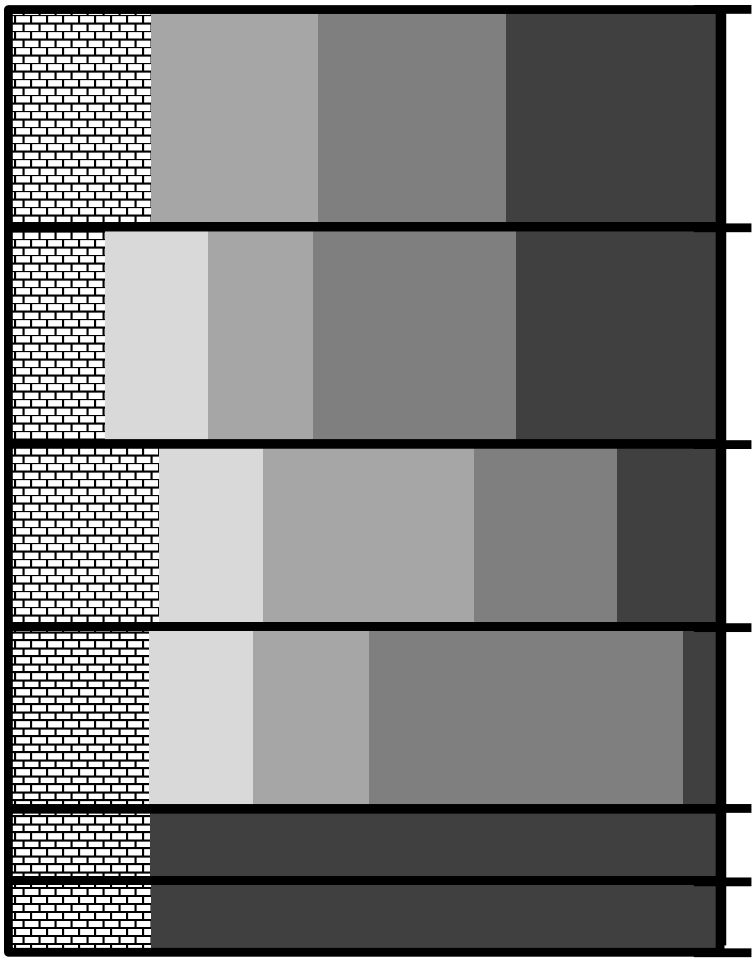
- During spring-summer-fall, >50% of DIN loads are “lost” internally, presumably denitrified within the Bay.

- Cool months…San Francisco Bay acts as >50,000 kg d^{-1} point source to the coastal ocean
  - *Impacts??*



Science Focus Areas

1. Nutrient Loads|Transformations
2. Phytoplankton Blooms & Low DO
3. HABs & Toxins
4. Coastal Ocean Impacts
5. Future Scenarios



Nutrient Dynamics

Phytoplankton-DO, Open-Bay

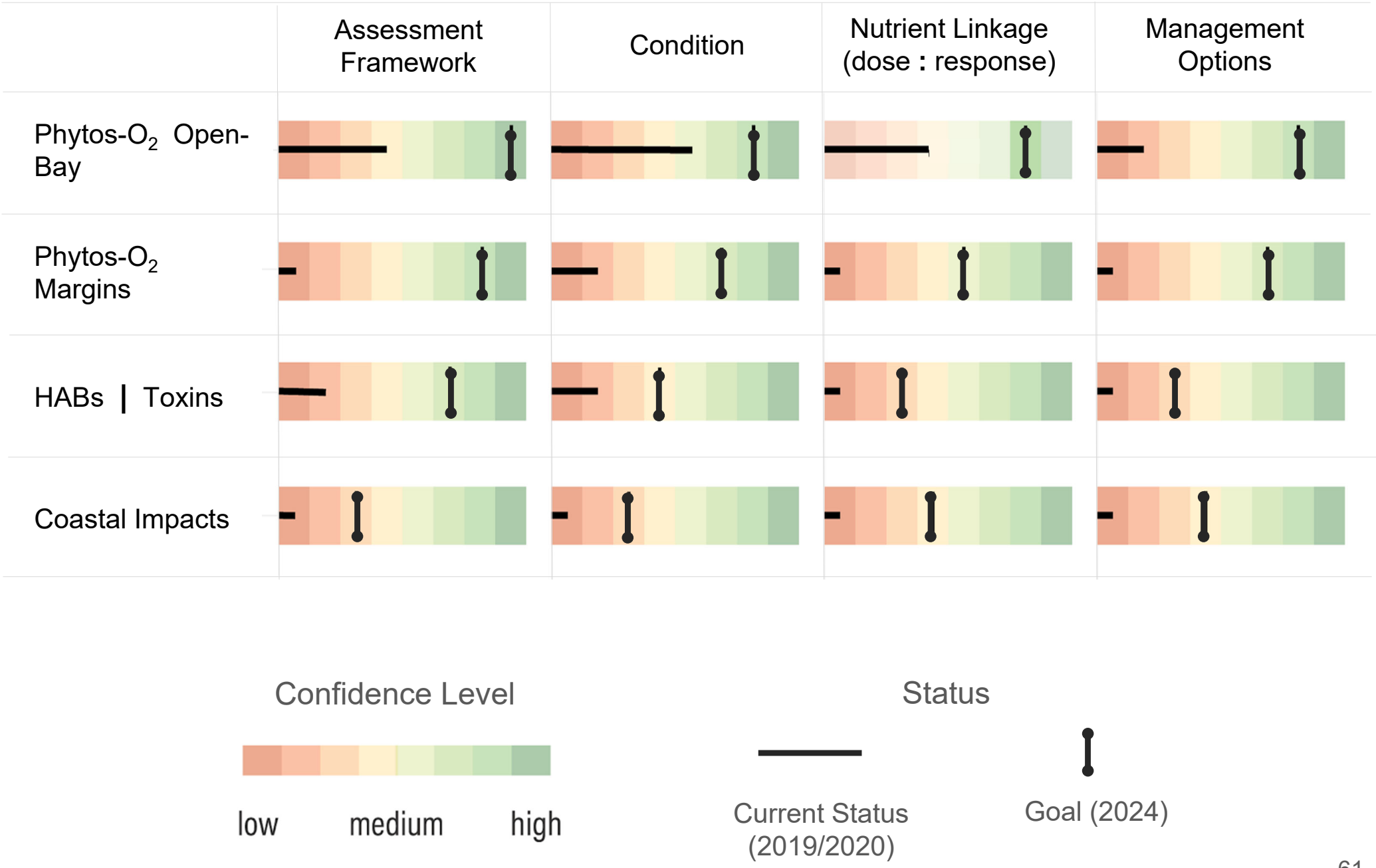
Phytoplankton-DO, LSB 'margins'

HABs

Coastal impacts

Future scenarios

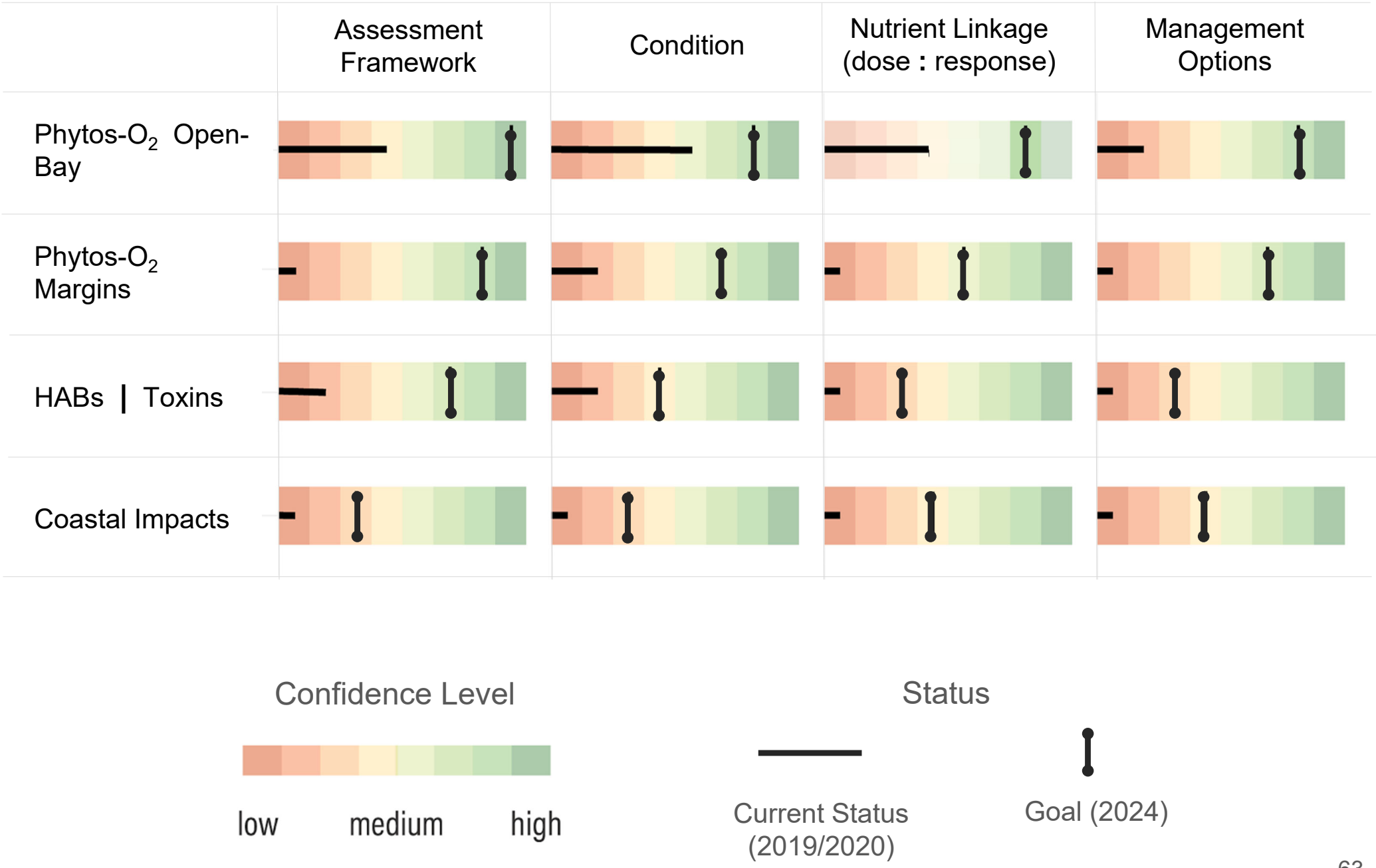
Targeting different confidence levels across range of issues…



Overview…Major progress over NMS' first 5 years

- Enhanced observational network
  - New analytes (e.g., toxins)
  - New approaches: high-frequency data, moorings; mussels
- Major steps forward on modeling capacity
  - Bay physics
  - Nutrient Loads, transport, transformations
  - Early work on phytoplankton blooms
- Shift in perspective / understanding of condition and drivers in LSB, esp. DO
- Understanding of HAB-ambient conditions
- Holistic multi-year Science Plan
- Network of highly-engaged, outstanding technical collaborators

Are these the right priorities?



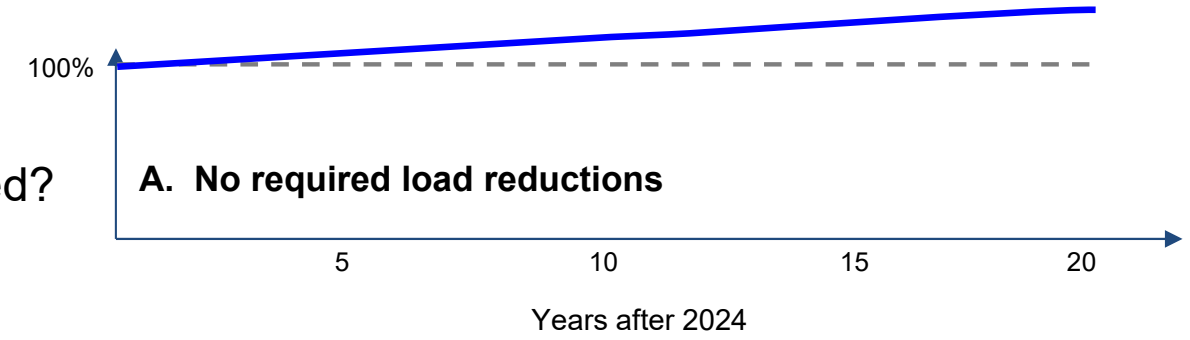
What decision(s) are being considered?

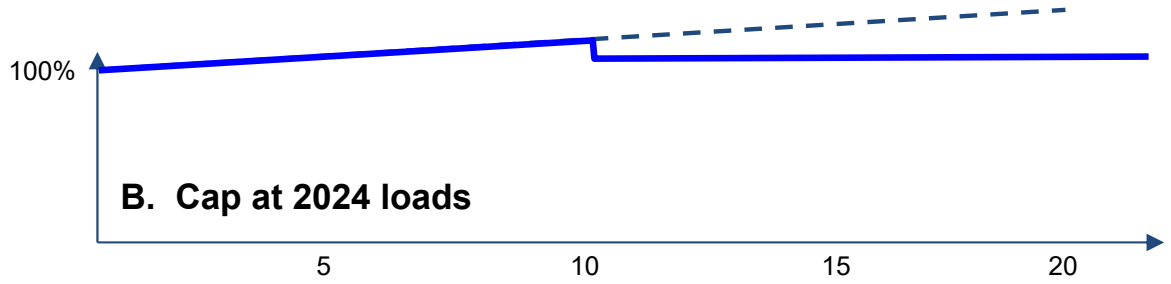
A vs. **B** **?**

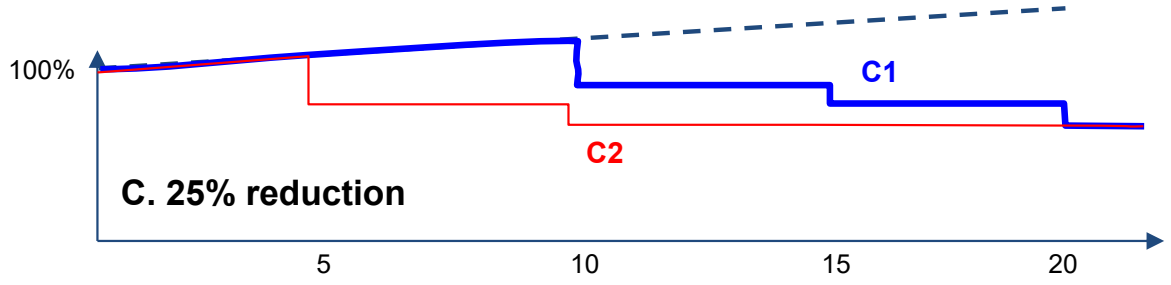
B vs. **C** or **D** **?**

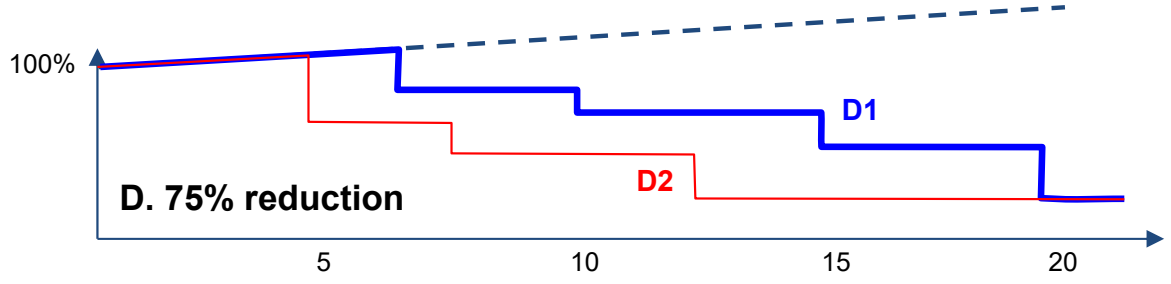
C1 vs. **C2** **?**

D1 vs. **D2** **?**









Collaborators

A Chelsky, E King, E Nuss, D Roberts, M Foley, D Senn, I Shimabuku, I Wren

J Cloern, E Nejad, T Schraga, L Lucas, B Bergamaschi, L Stumpner, T Kraus, B Downing, M Downing-Kunz, D Livsey, J Lacy, R Allen

R Kudela, K Hayashi, M Peacock

M Sutula; M Beck

R Holleman, E Gross

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M Van der Wegen, K Nederhoff, T Troust, A Blauw

E Gross, R Rachiele

Z Zhang, E Ateljevich

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NMS Steering Committee, NMS Planning Subcommittee, and Stakeholders

SFEI staff, Collaborators, and Technical Advisors

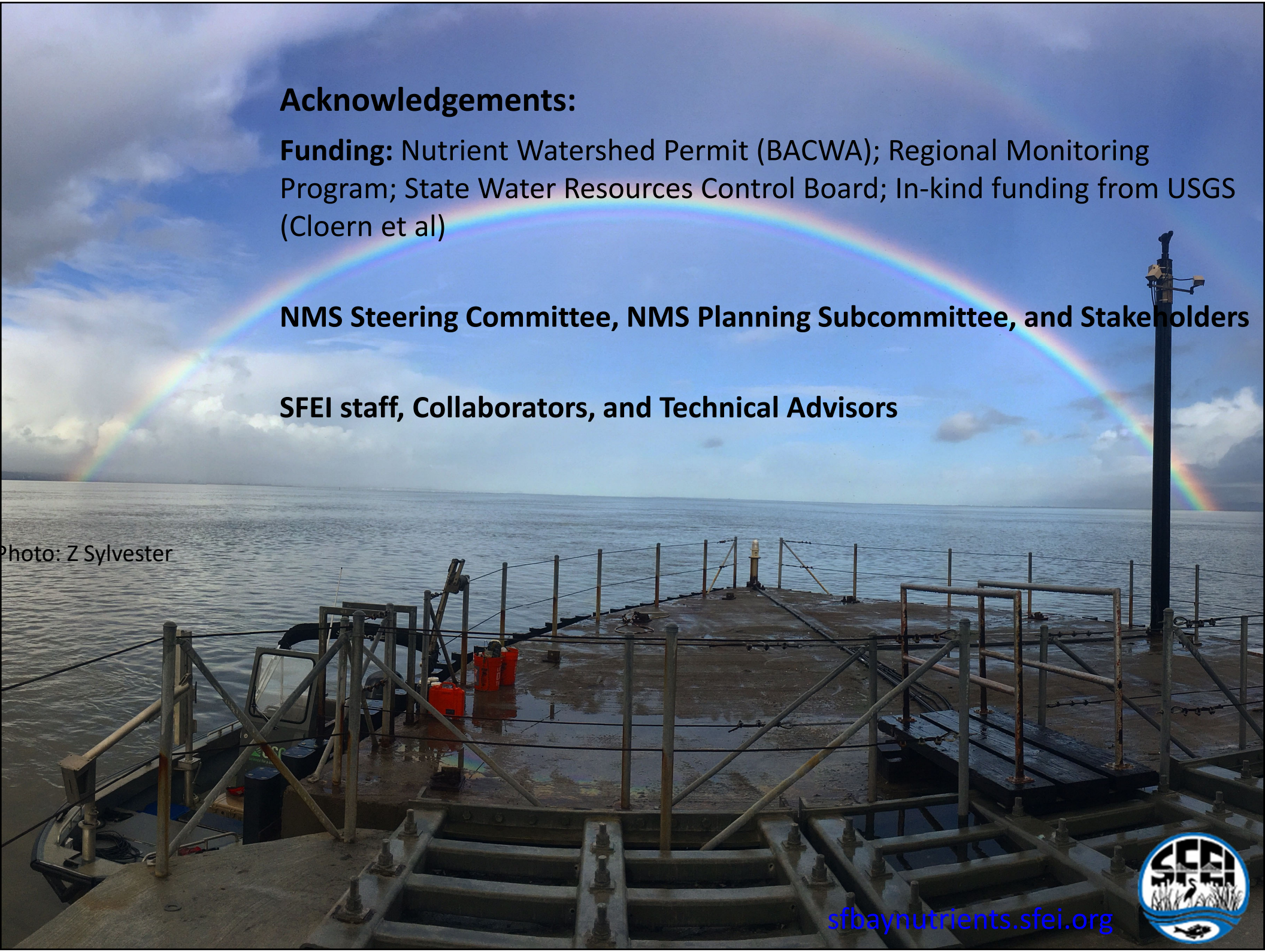


Photo: Z Sylvester

sfbaynutrients.sfei.org

sfbaynutrients.sfei.org

Status/Progress Tracking: San Francisco Bay Nutrient Management Strategy

Background | Management Decisions & Questions | Goals & Work Elements | Work Progress | Project Tracking | Reports & Work Products | NMS Meeting Materials | NMS Implementation | Bibliography

Reports and Work Products

Nutrient Strategy work products are available below, organized by Work Element. This list is regularly updated as new reports become available in draft and final versions.

Annual Reports

- *2015 NMS FY2015 Annual Report*
- *2016 NMS FY2016 AnnualReport*
- *2017_NMS_FY2017_AnnualReport*

Work Element 1: Nutrient Program Administration

- *2012 Nutrient Strategy Nov 2012*
- *2016 NMS Science Plan Report Sep2016*

Work Element 2: Define the problem

- *2011 SFBay NutrientNumericEndpoint Development Lit Review*
- *2014 Nutrient Conceptual Model Draft Final*
- *2014 Suisun Synthesis I*
- *2014 External Nutrient Loads to SF Bay*
- *2015 Lower South Bay Synthesis Report June 2015*
- *2016 Nutrient sources, sinks and transformations in the Delta (MainReport Jan 2016)*
  - Link to technical appendices (Nutrient sources, sinks and transformations in the Delta)
- *2016 Summary and Evaluation of Delta Subregions for Monitoring and Assessment*
  - Link to technical appendices (Summary and Evaluation of Delta Subregions for Monitoring and Assessment)
- *2016 Suisun Synthesis II: Influence of Nutrient Forms and Ratios on Phytoplankton Production (*
- *2017 Nutrient Forms Ratios Workshop Report*
  - Other workshop materials (panel charge, presentations, reading list, etc.)

Work Element 4: Establish Guidelines

- *2011 SF Bay NNE Development Lit Review*
- *SF Bay AF Meeting Summary Feb 2014*
- *Proposed Workplan for Assessment Framework Development*
- *Assessment_Framework_January2016_report*
- *2018 Lower South Bay Dissolved Oxygen and Fish Surveys*

Work Element 5: Monitoring Program Development and Implementation

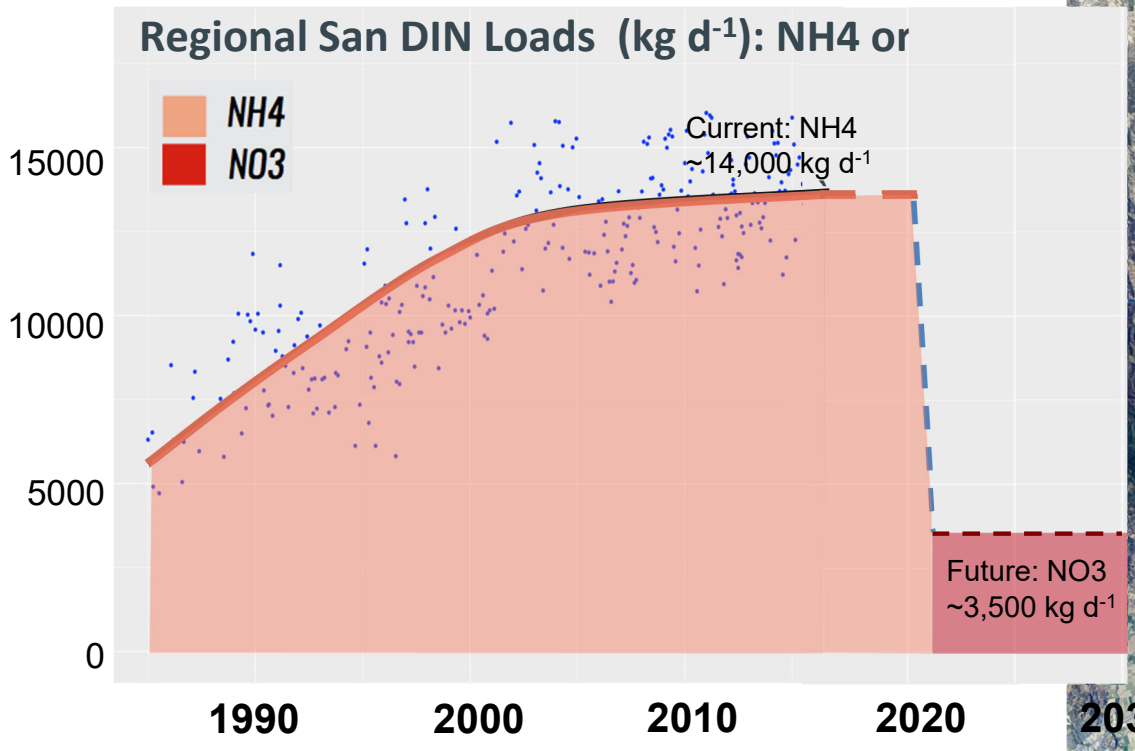
- *2014 Monitoring Program Development Plan Aug 2014*
- *2014 Algal Pigment Final Report*
- *2014 Moored Sensor Yr1 Progress Report*
- *2015 SPATT (Algal Toxins) Final Report May 2015*
- *2017 NMS Observation Program Design*

Work Element 6: Modeling Strategy

- *2014_Model Development Plan to Support SFB Nutrient Management Decisions.pdf*
- *2014_Detailed Modeling Workplan.pdf*
- *FY2016 Modeling Plan*
- *2017 Load Update and Load Reduction Scenario Runs (See Section 6)*
- *2017_SFBay_Interim_Model_Validation_Report*
- *2018_June_Delta_Suisun_Biogeochemical_Model_ProgressReport*

Work Element 7: Control Strategies

- *2017 Conceptual Nutrient Trading Program for San Francisco Bay (See Section 7, Freshwater Trust)*
- *2017 Reducing Nutrients in San Francisco Bay through WWTP Sidestream Treatment (Y Shang [EBMUD]*
- *2017 Treatment Wetlands Opportunities Screening Report*



Points represent Calculated Load = Measured Concentration x Flow
Data: pre-2005, Jassby 2008; 2008-2016, Regional San

- **WWTP Upgrade (by 2021):**

- NH4 → NO3

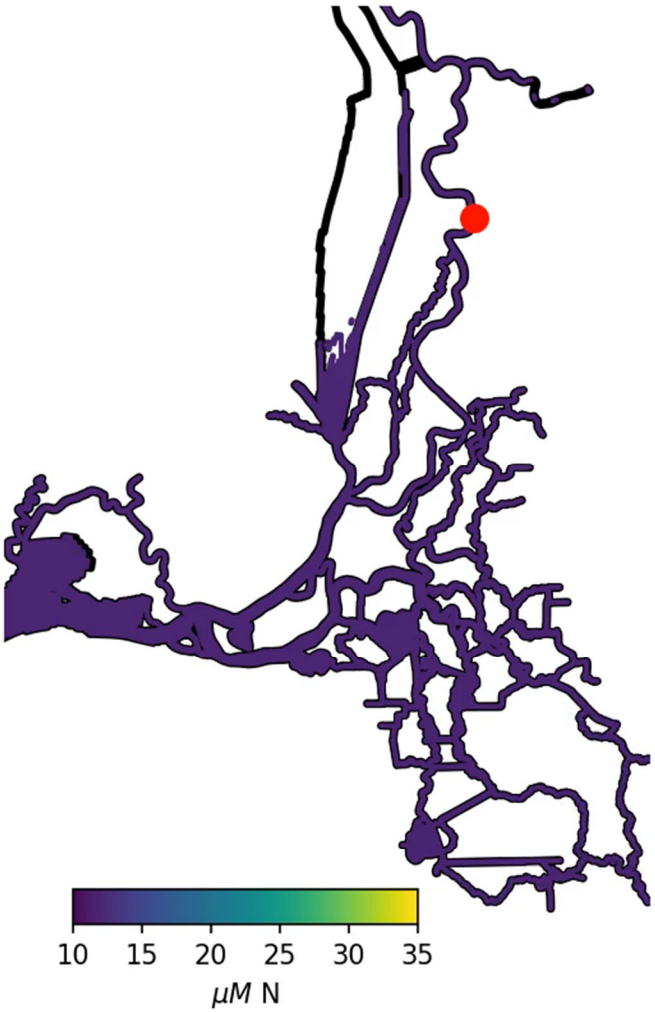
- DIN load: ↓ 70%

- **Load change will be substantial relative to overall loads to the Delta**

How will Regional San's upgrade influence downstream N concentrations?

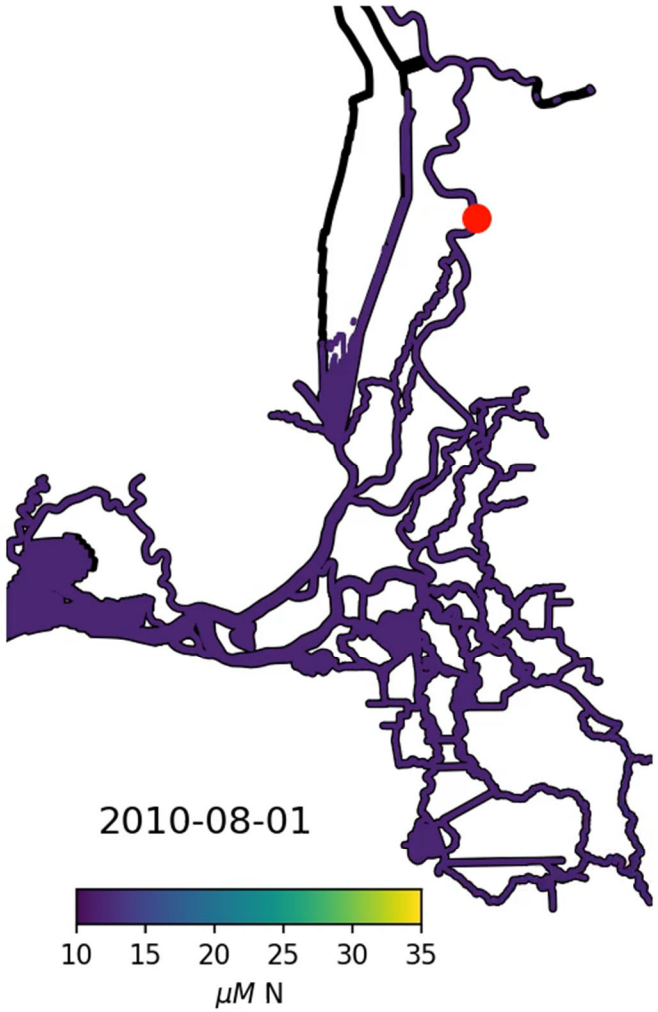
How will Delta and nSFE habitats respond to this large change?

Present-Day Loads



$DIN_{present}$

Post-Upgrade Loads



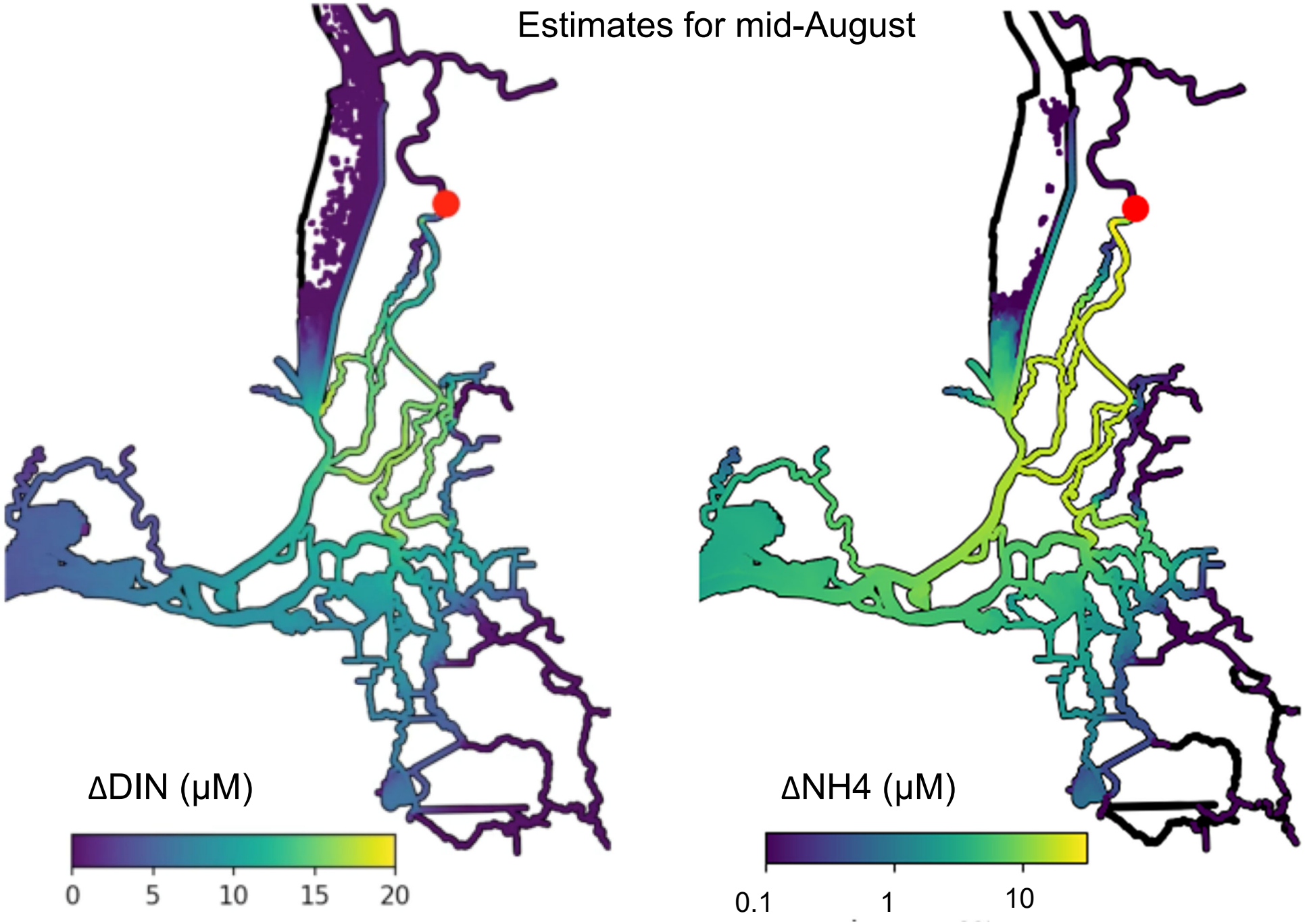
$DIN_{Post\text{-}Upgrade}$

Δ DIN (present-post)

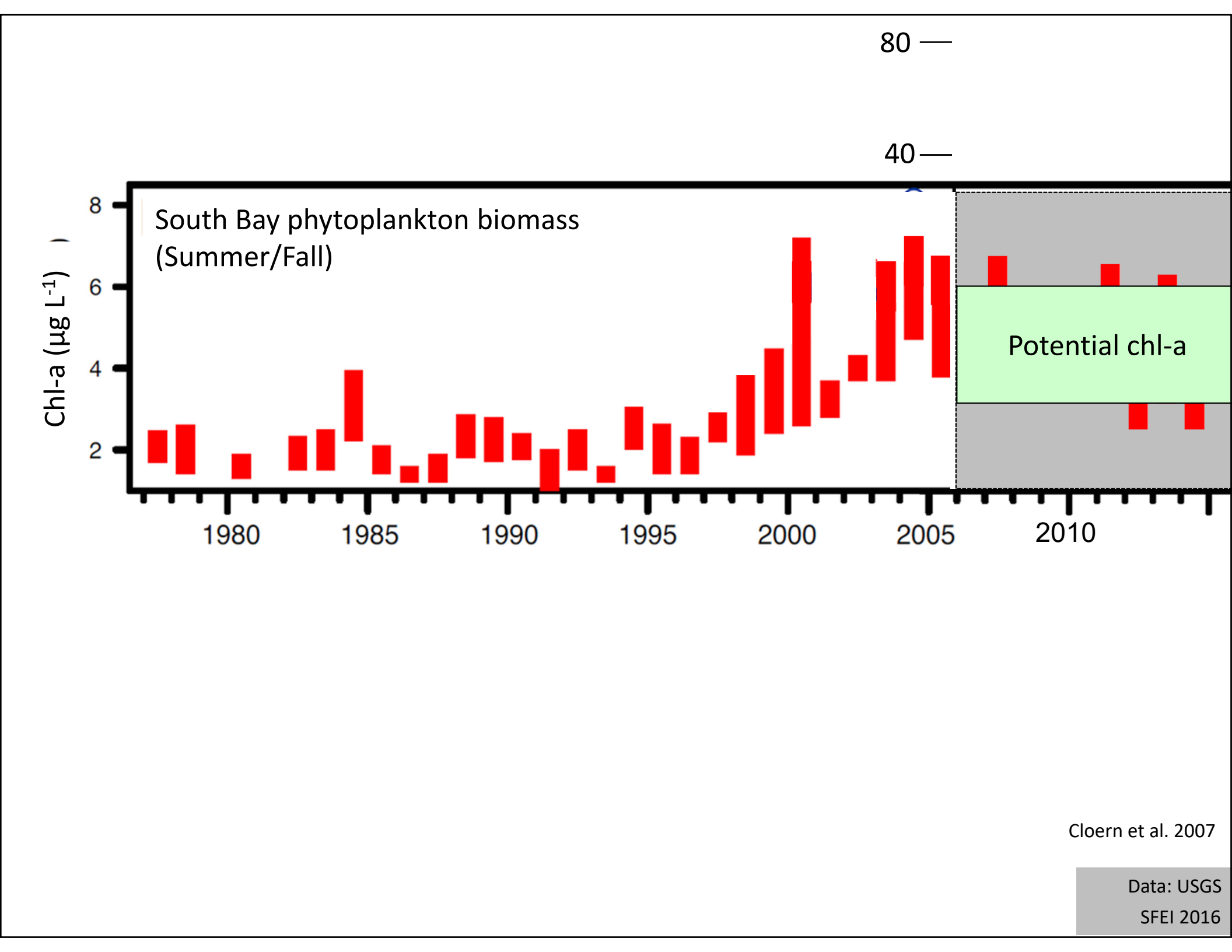
Δ DIN

Predicted Changes in ΔDIN and ΔNH4: pre- and post SacRegional upgrade

Estimates for mid-August



[qualitative, draft]



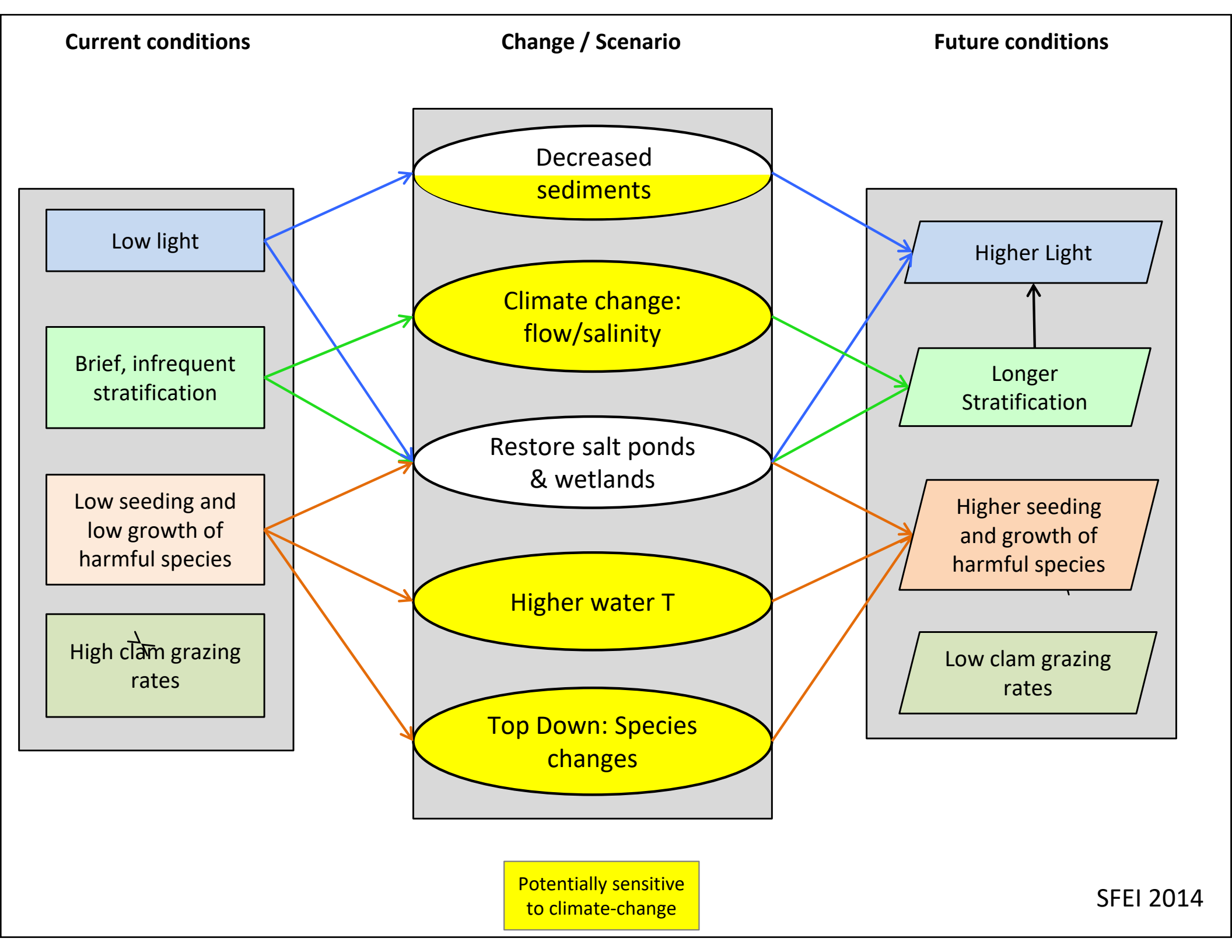
Cloern et al. 2007

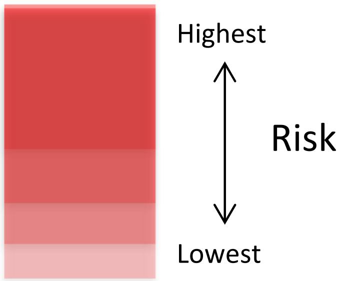
Data: USGS
SFEI 2016

Current conditions

Future conditions

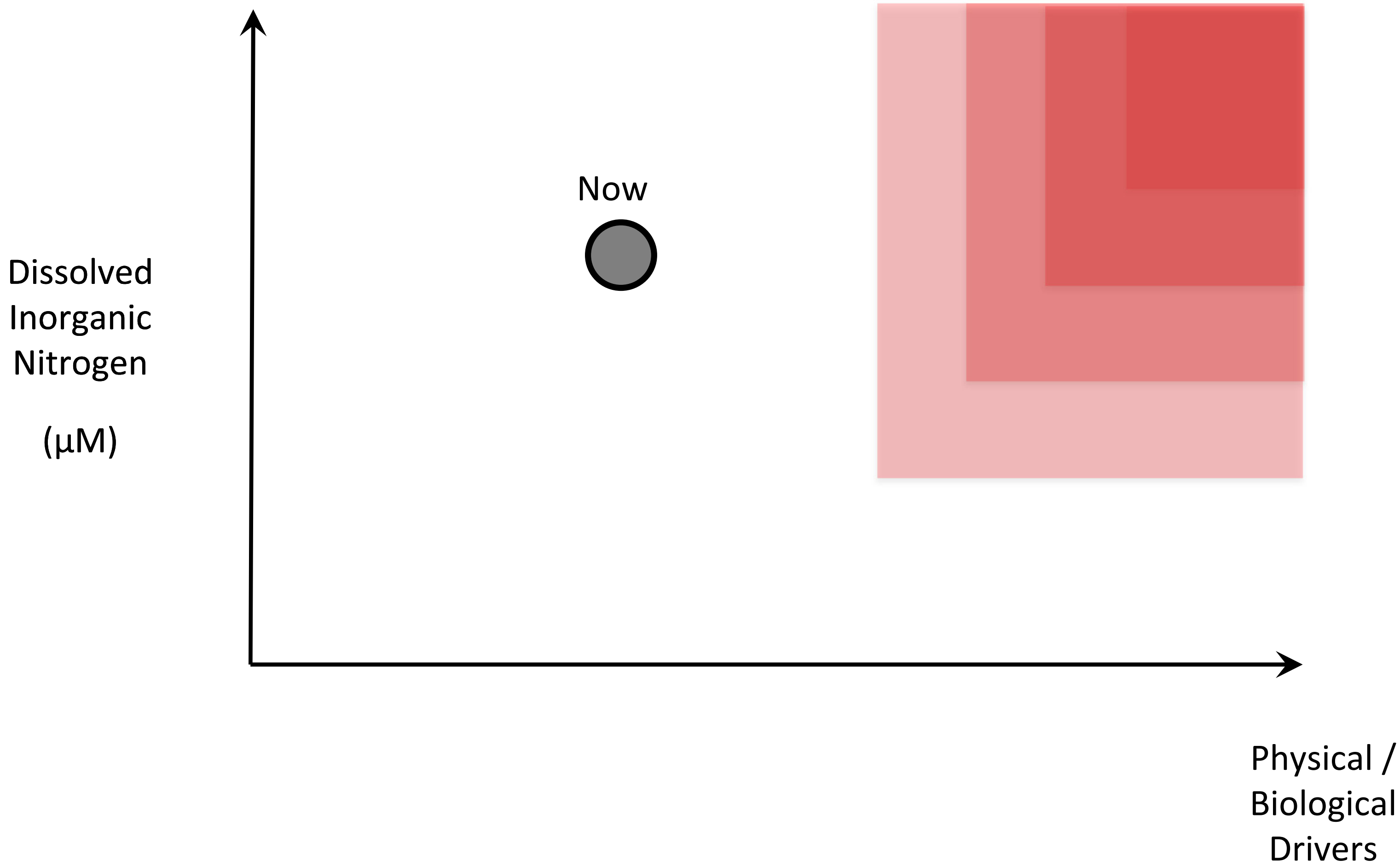
SFEI 2014

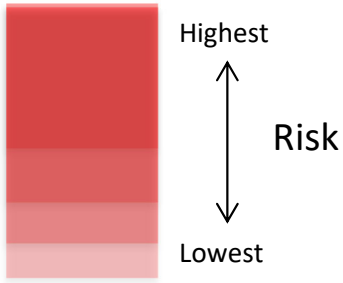

Current conditions
Change / Scenario
Future conditions
Low light
Brief, infrequent stratification
Low seeding and low growth of harmful species
High clam grazing rates
Decreased sediments
Climate change: flow/salinity
Restore salt ponds & wetlands
Higher water T
Top Down: Species changes
Higher Light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



What future conditions are plausible?

What future scenarios should we manage toward preventing?





What future conditions are plausible?

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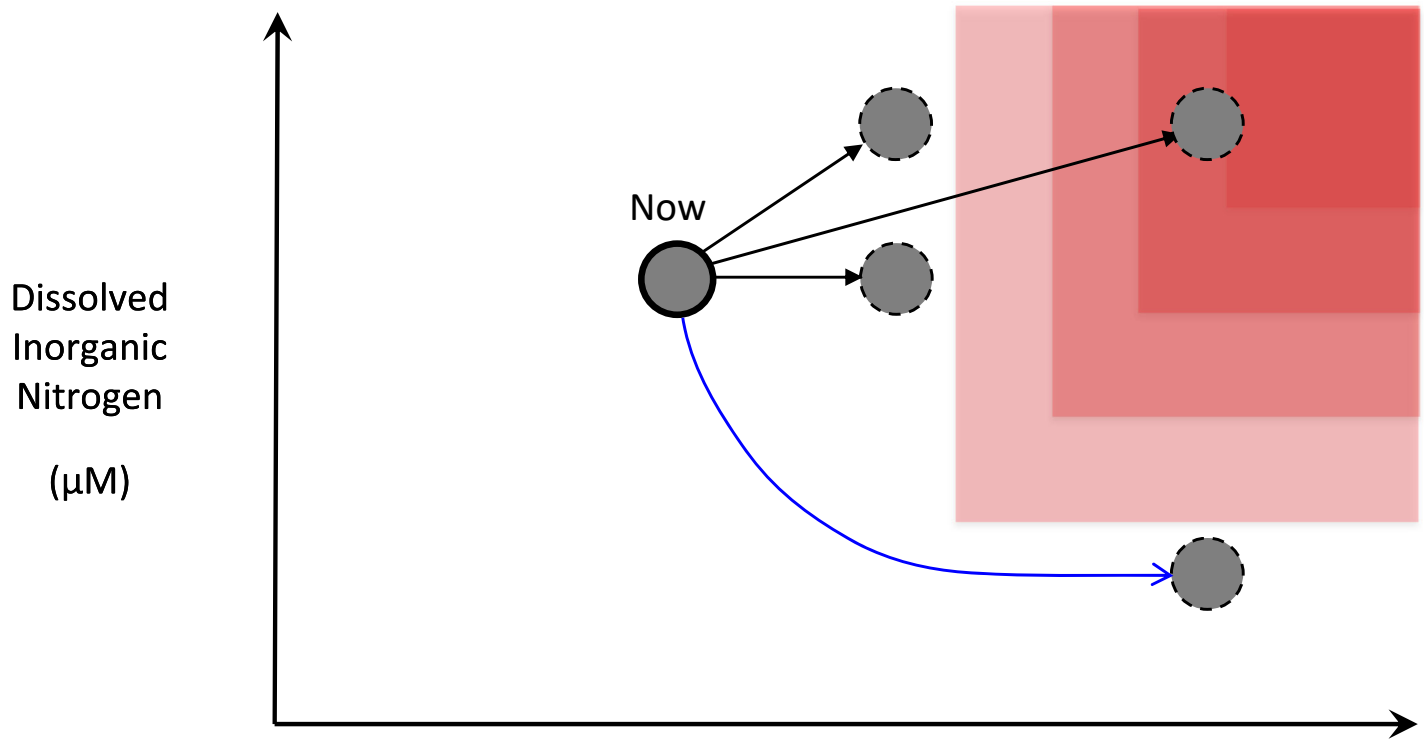


Potential future state

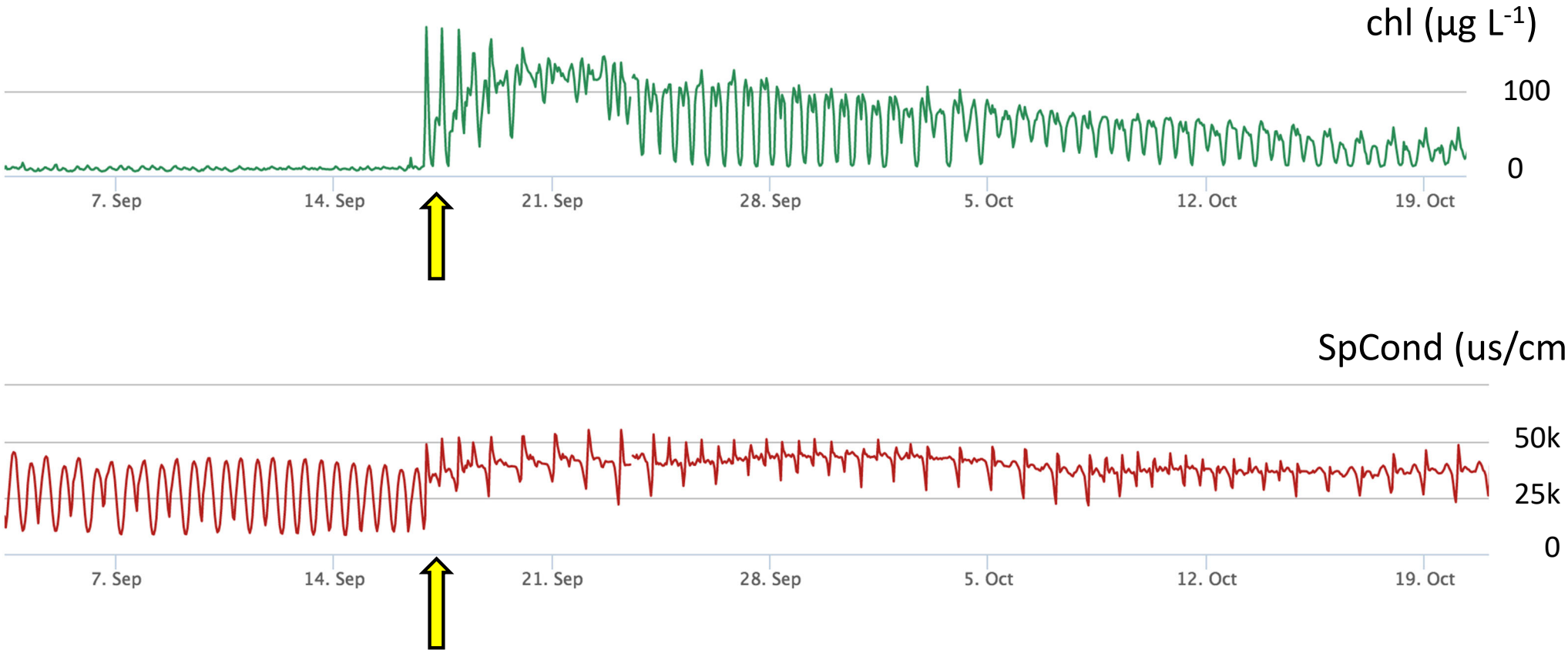
Path with little or no nutrient management actions

Path with some nutrient management actions, to decrease future risk

What are these axes?

What events can move them?

Local Effects? Guadalupe Slough – Sep 2015



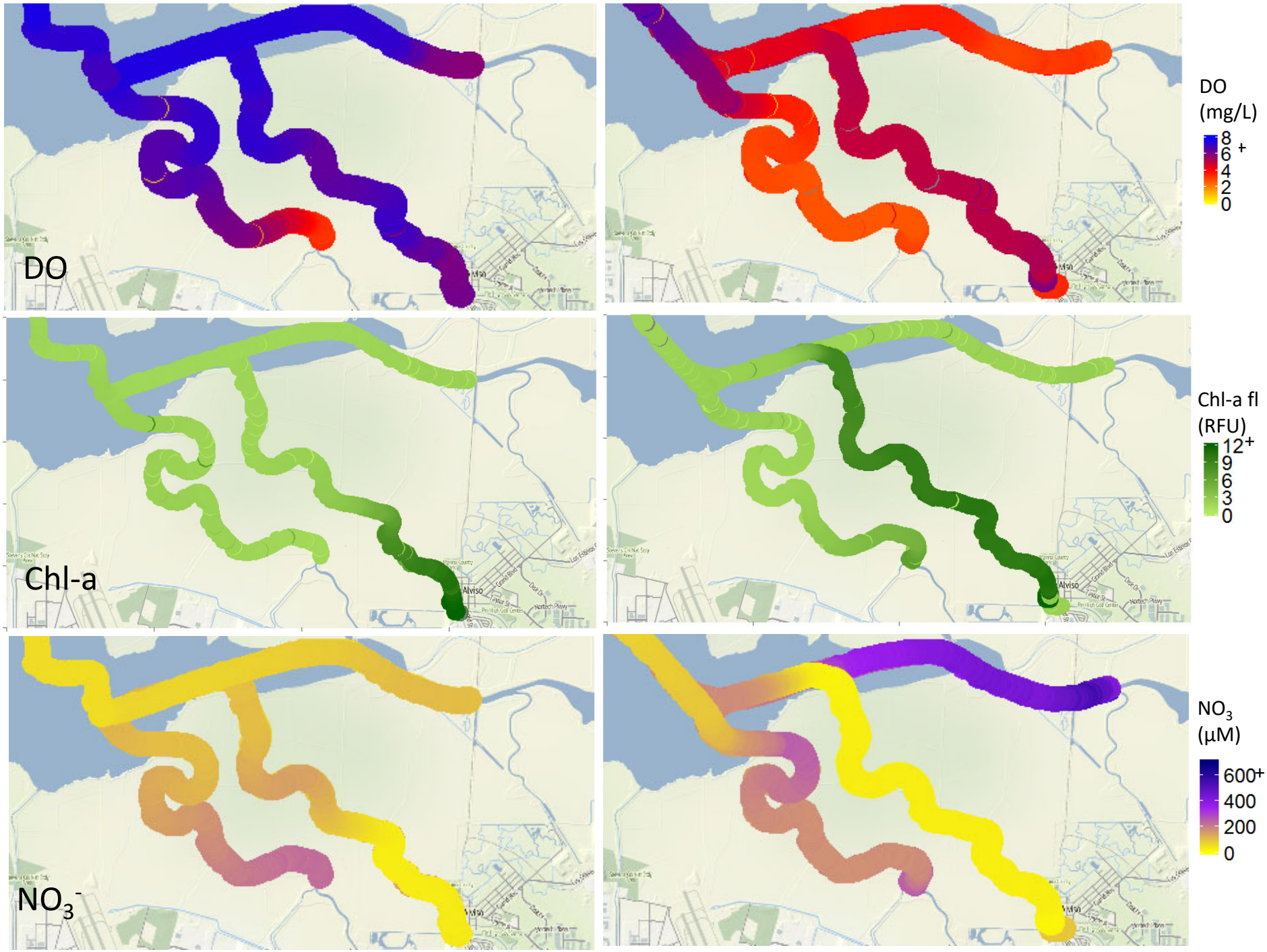
Pond A6
Gate Re-opening

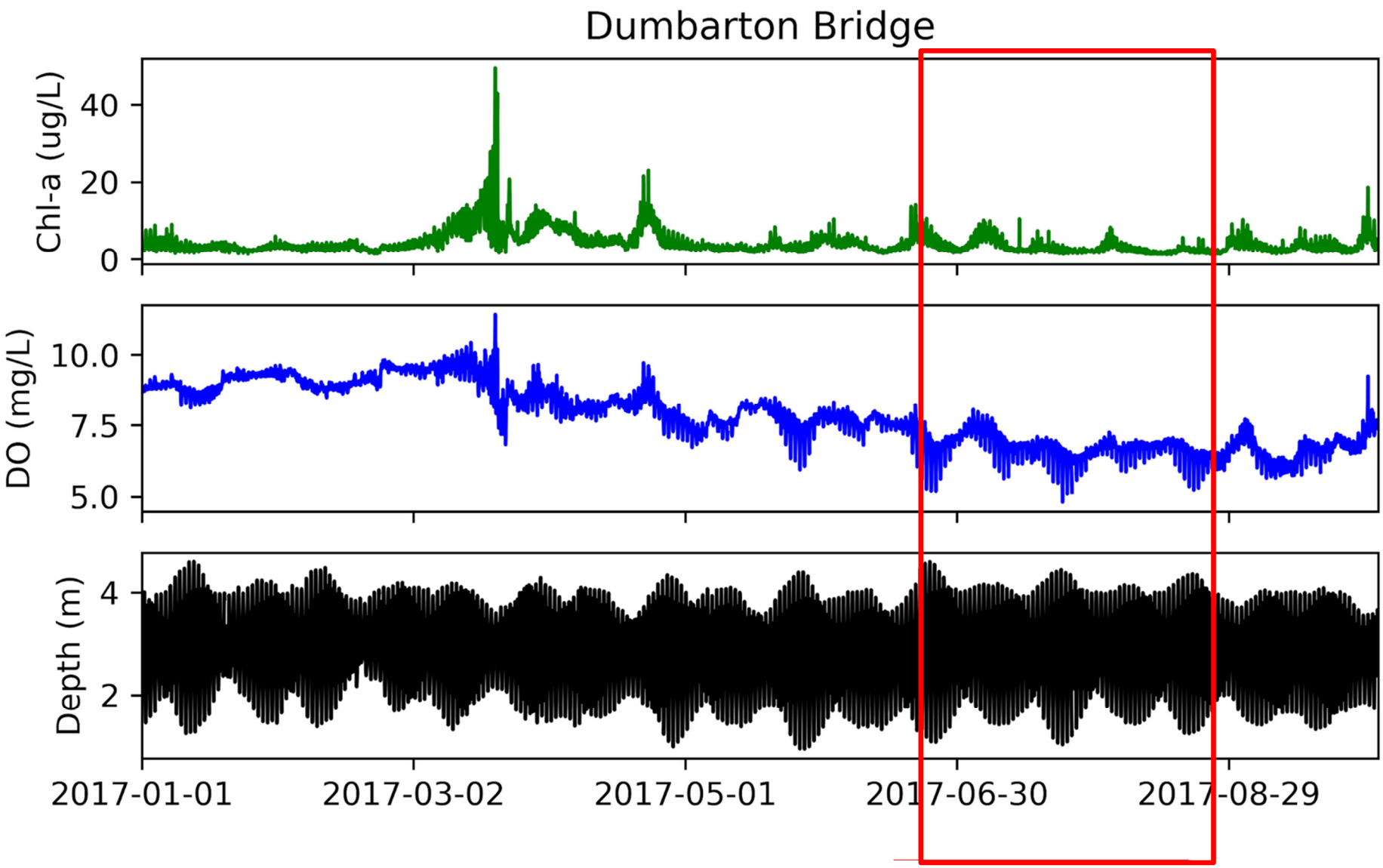
Potential for larger-scale effects (i.e., open Bay) under investigation.

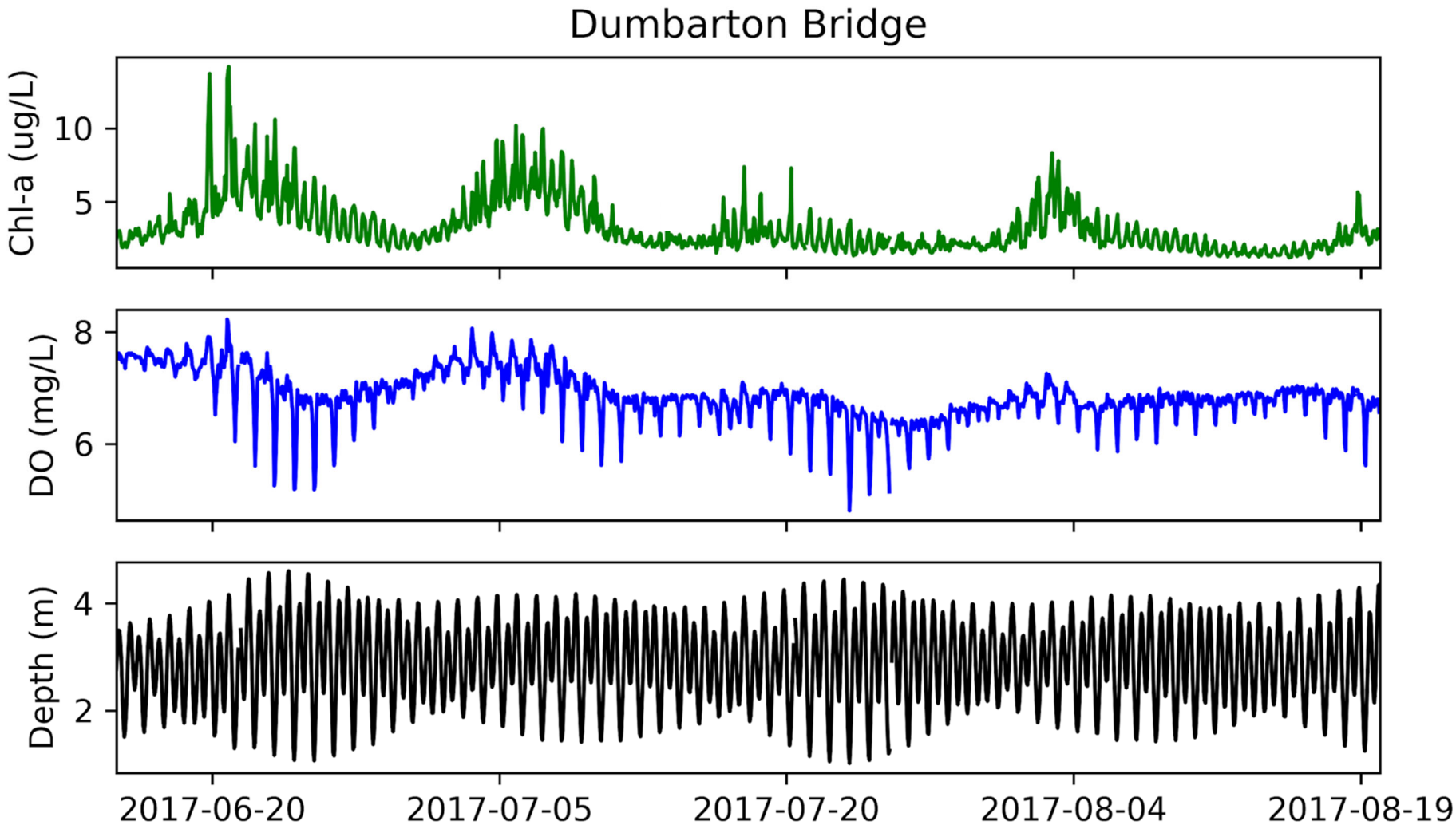
July 15-16 2015

Flood tide

Ebb tide




Dumbarton Bridge
Chl-a (ug/L)
40
20
0
DO (mg/L)
10.0
7.5
5.0
Depth (m)
4
2
2017-01-01
2017-03-02
2017-05-01
2017-06-30
2017-08-29


Dumbarton Bridge
Chl-a (ug/L)
10
5
DO (mg/L)
8
6
Depth (m)
4
2
2017-06-20
2017-07-05
2017-07-20
2017-08-04
2017-08-19

San Mateo Bridge (s27)