San Francisco Bay Aug 2022 Harmful Algal Bloom

1. Bloom evolution and water quality impacts
2. Mechanisms / Hypotheses
3. On-going work

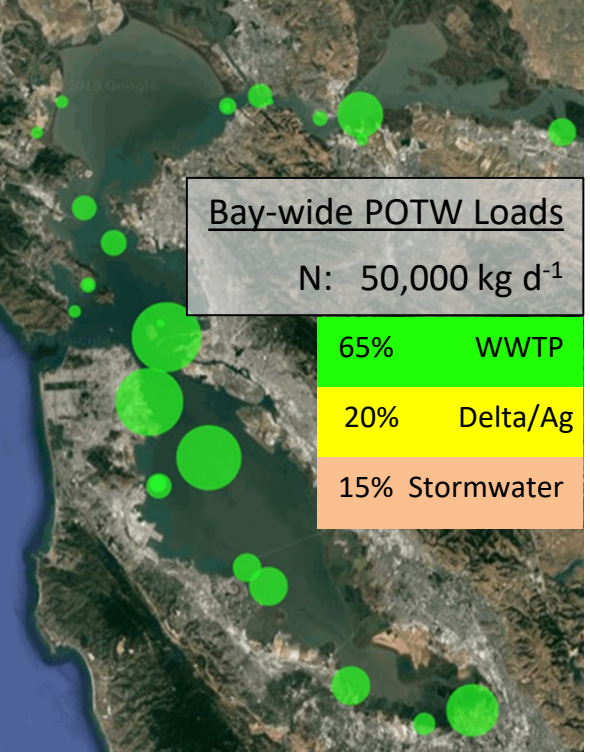
David Senn
San Francisco Estuary Institute
RMP Annual Meeting, October 2023

Collaborators/Co-Authors

SFEI: D Killam, L Mourier, L Sims, A Chelsky, A King, F Karimpour, P Mugunthan, M Volaric

USGS-BGC: K Bouma-Gregson, B Bergamaschi, T Kraus, K O'Donnell, E Richardson, E Nejad

UCSC: R Kudela; **RMA**: R Holleman; **Bend Genetics**: T Otten; **Bay Keeper:** I Wren, J Rosenfeld; **SFSU**: W Cochlan



- Do nutrient loads to SFB result in adverse impacts to ecosystem health, either now or under future scenarios?
- What management actions are needed to prevent or mitigate current or future impairment?

San Francisco Bay

- Highly-enriched in N: primary source POTW effluent

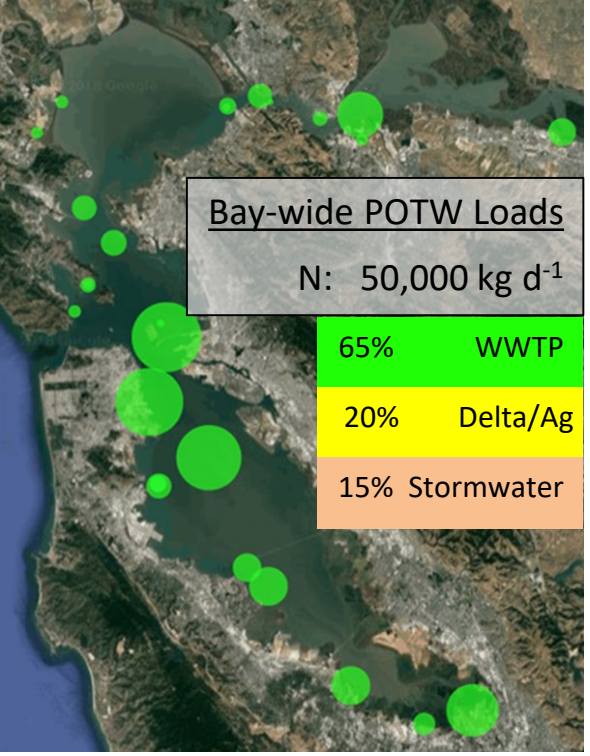
Historically:

- Resistant to classic eutrophication symptoms

'Recently':

- Evidence consistent with changing responsiveness or sensitivity to nutrients.

Cloern et al. 2007, 2020; SFEI 2014a,b; Sutula et al. 2017; Peacock et al., 2018; SFEI 2023



- Do nutrient loads to SFB result in adverse impacts to ecosystem health, either now or under future scenarios?
- What management actions are needed to prevent or mitigate current or future impairment?

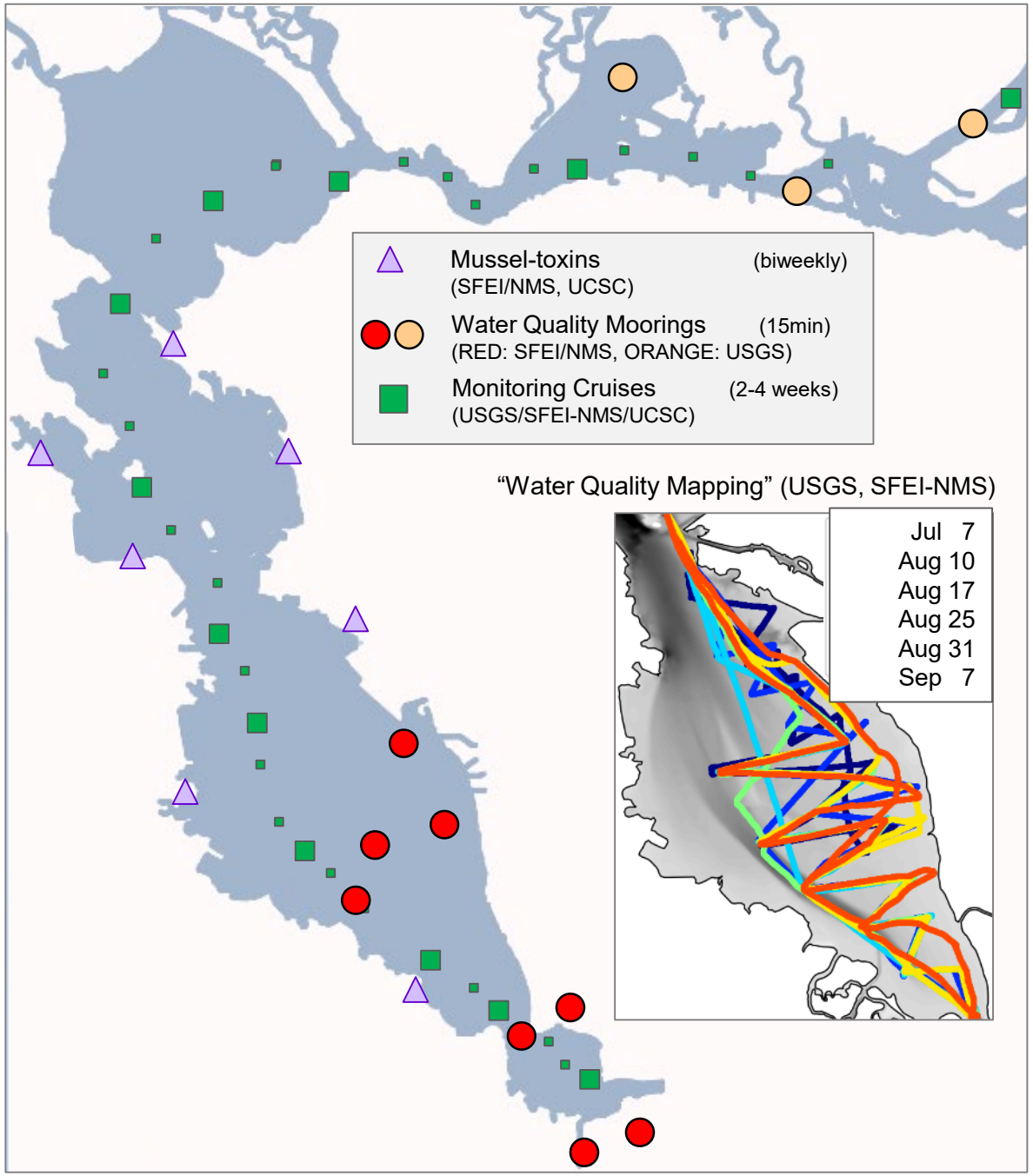
Nutrients: sources, transport, cycling/fate

Ecosystem response to nutrients
- quantify relationship: nutrients → impact
- Identify protective nutrient levels

Evaluate management options → protective loads, effective options

Science Focus Areas

- Nutrient Loads|Transformations
- Phytoplankton Blooms & Low DO
- HABs & Toxins
- Coastal Ocean Impacts
- Future Scenarios



HAB-event Observational & Analysis Resources

- Ship-based monitoring: (USGS, SFEI, UCSC)
  - Long-term record (1970s-present)
  - Building-on, Augmenting: add'l parameters (toxins, DNA-sequencing, IFCB); ↑ analysis frequency

- Continuous Water Quality moorings (w/ USGS-BGC)
  - 5 sites in South Bay , 3 sites in Suisun
  - chl, Dissolved O2, turbidity, T, S, NO3

- High-Res Water quality 'mapping' (w/ USGS-BGC)
  - *flow-thru*: chl, DO, NO3, pH, turbidity, fluoroprobe…
  - *discretes*: chl, DNA sequencing nutrients

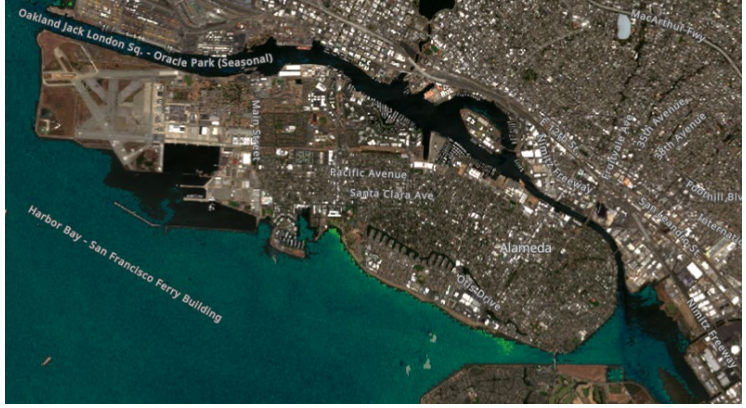
- Remote-sensing: pilot application (SFEI, UCSC, USGS-BGC)
  - Bloom tracking: early warning and planning

- Numerical modeling (SFEI, RMA)
  - *'forensic' or 'diagnostic'* modeling

- *late-Jul 2022*: first observed near-shore Alameda

- *Heterosigma akashiwo*
  - toxic to fish
  - on SFB-NMS harmful algae ‘watch-list’ (SFEI 2014, 2023; Sutula et al 2016, 2017)
    - detected in ~40% of samples (2015-2020) (SFEI 2020, 2021, 2023)

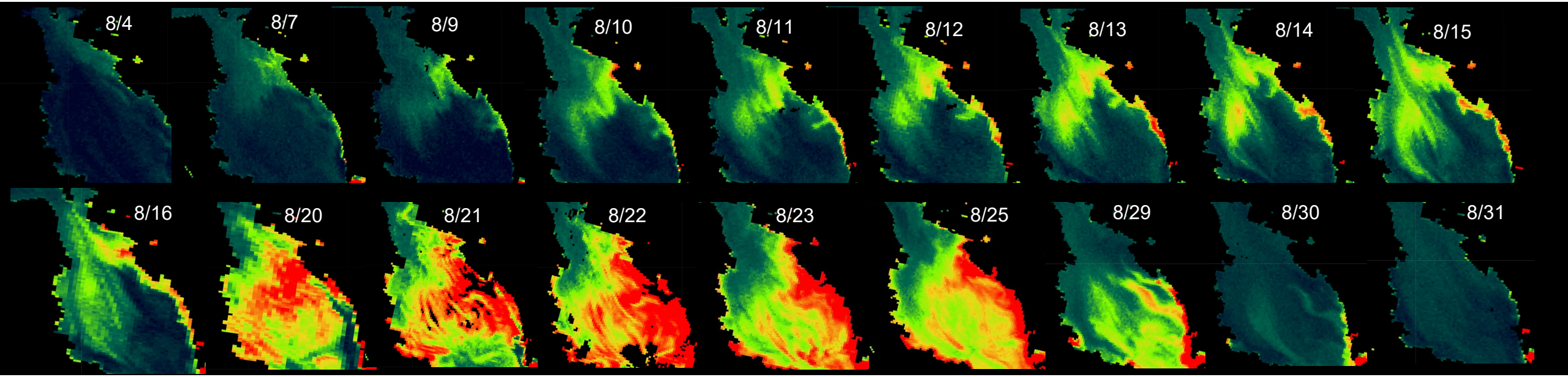
Engesmoa et al 2019



- *early-Aug*: Spread to open waters & throughout South Bay
  - Aug 7-10: spread to South Bay, off Alameda
  - expanded throughout South Bay by ~Aug 20

Impacts:

- chl: >20x typical summer values
- large-scale fish mortality: Lower South, South, Central, San Pablo
- low Dissolved O_2 : South Bay, Lower South Bay

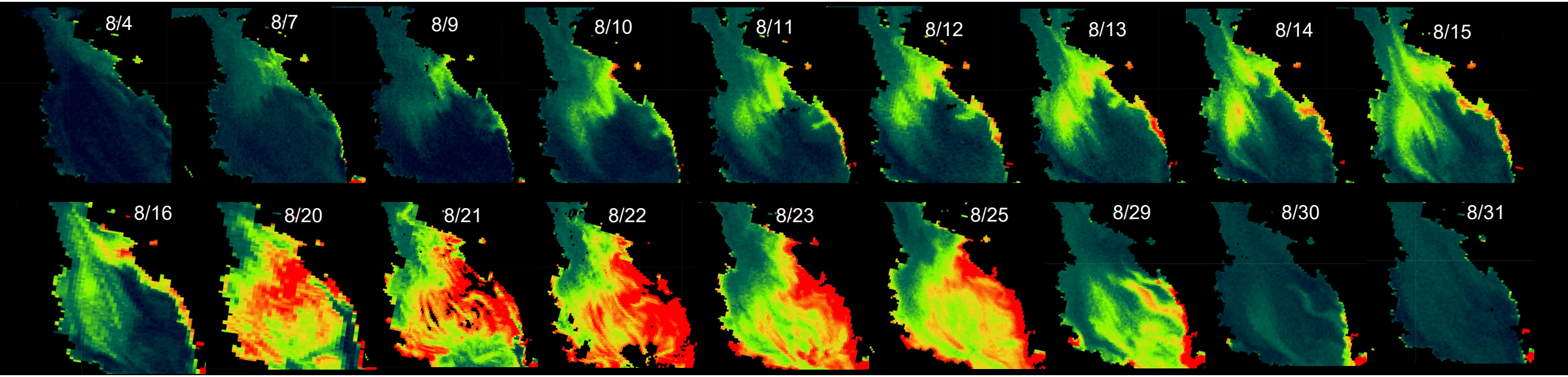


Sentinel-3 chl-a; using UWQV, Zlinszky and Padanyi-Gulyas 2020

What factors ‘caused’ and shaped this event?

What longer-term management options would be effective at preventing or mitigating impacts?

What’s the likelihood of something similar occurring again over different time horizons? (recurrence frequency)



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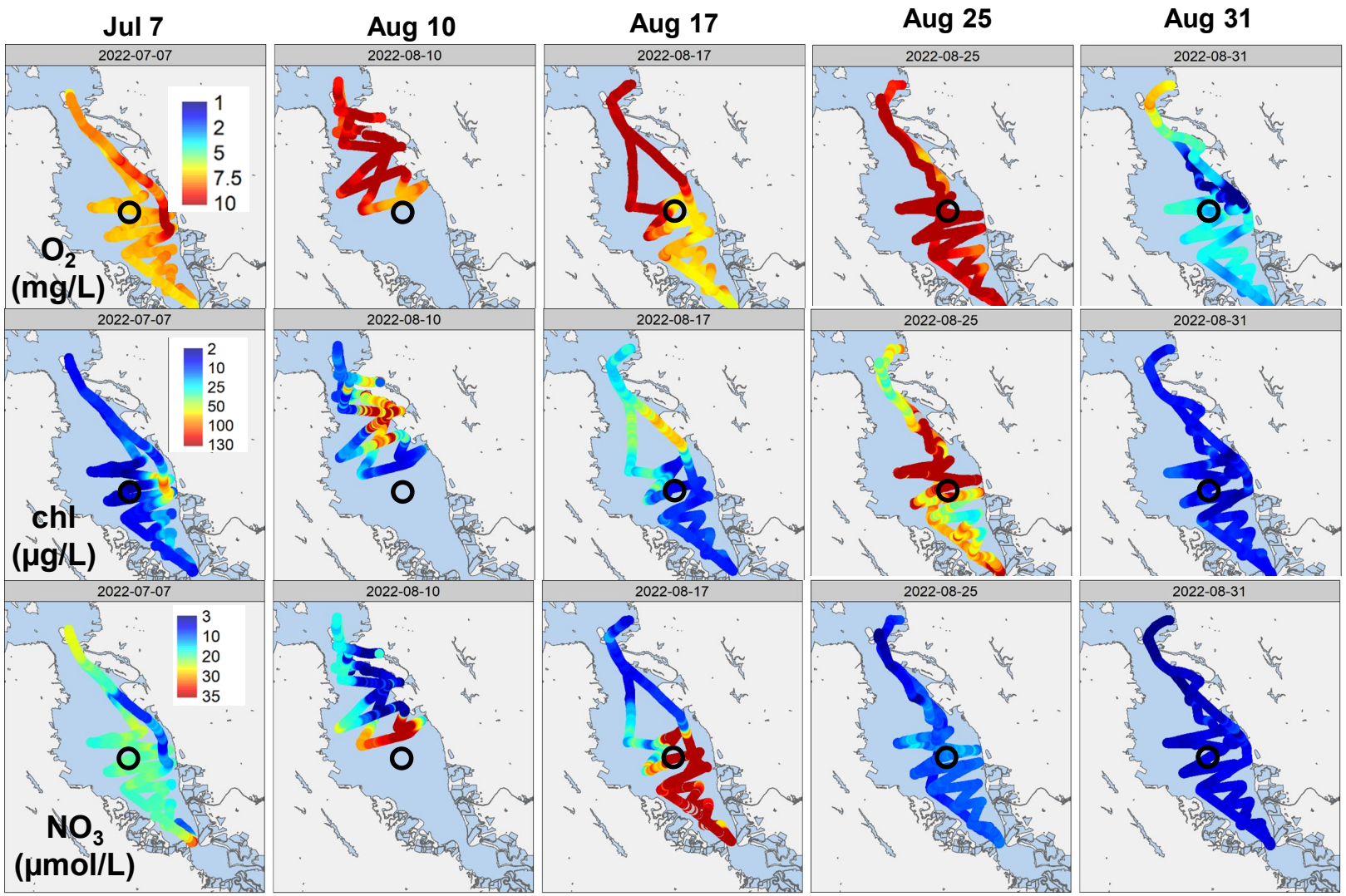
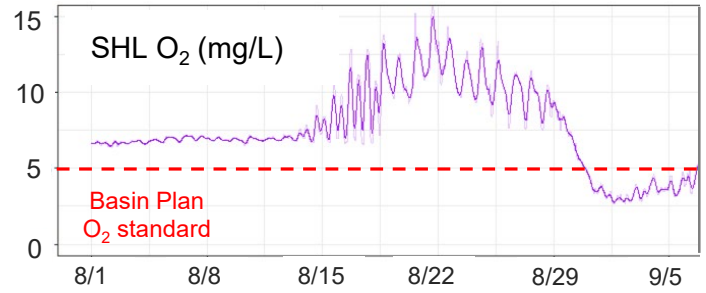
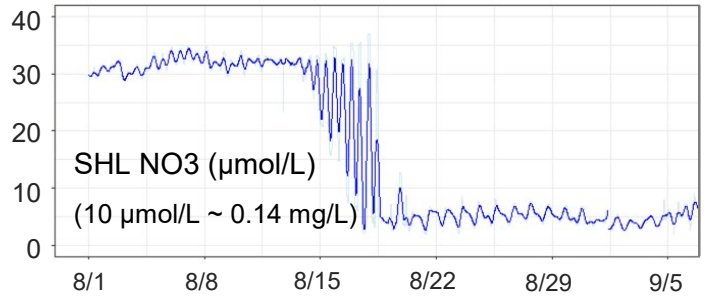


Δ O_2 (BOD)



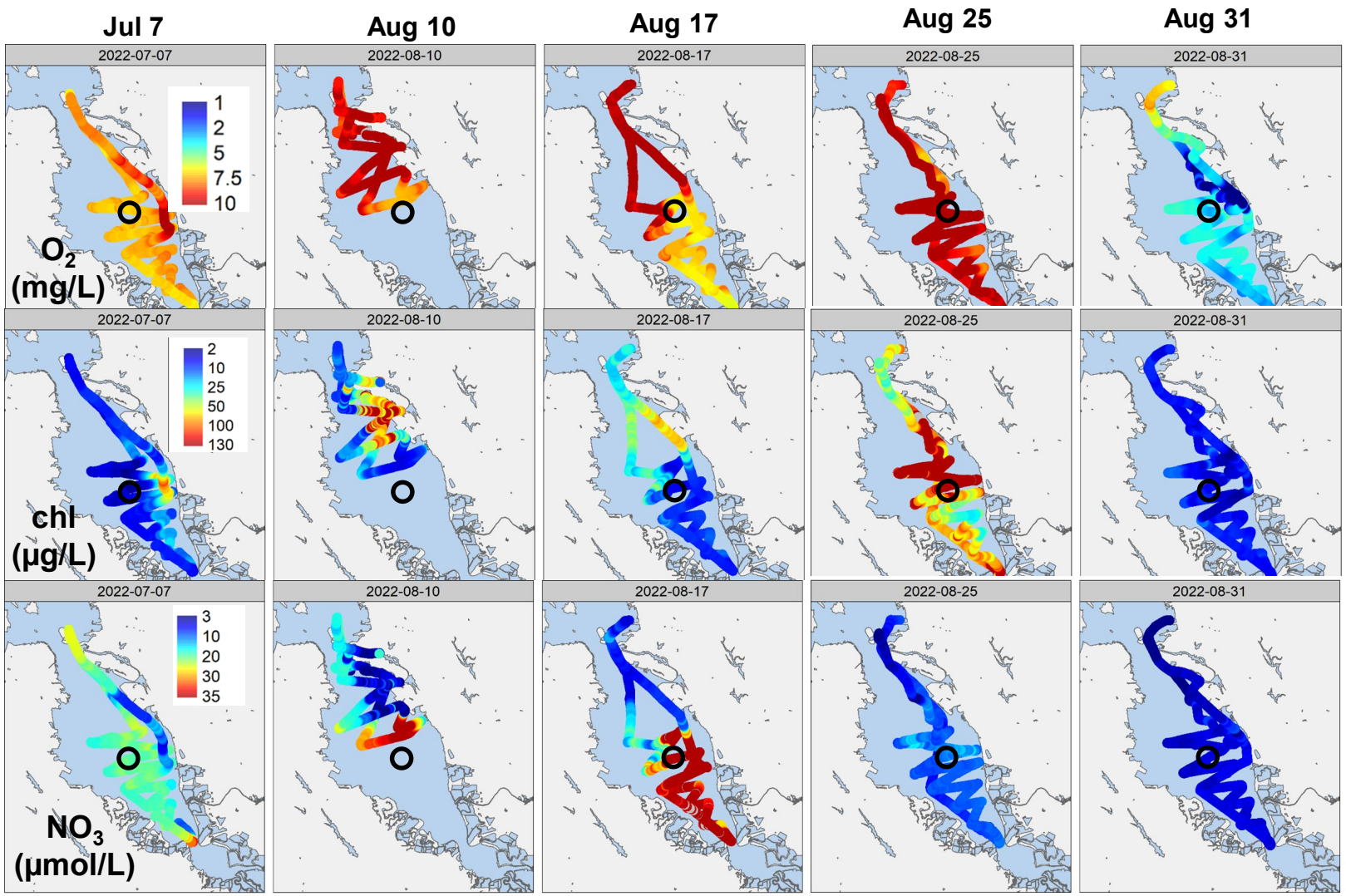
Phyto biomass

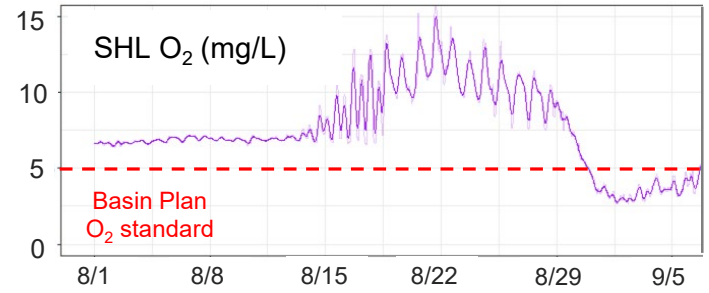
DIN

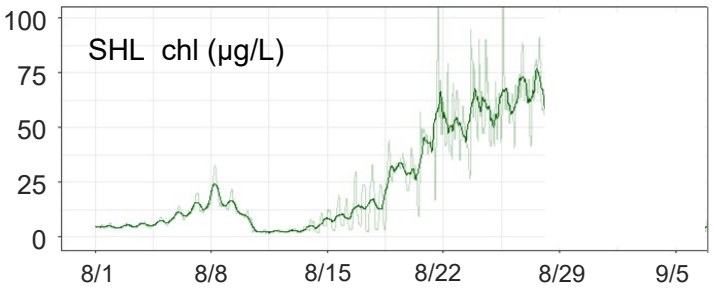


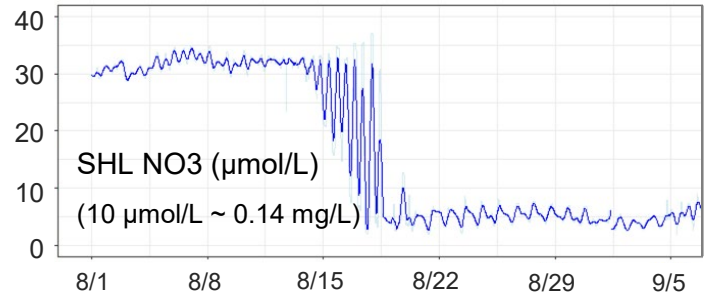
South Bay (DMB↔ Bay Bridge)	
N utilized:	900,000 kg
org-C produced:	5,000,000 kg

Bloom consumed all DIN throughout South Bay









South Bay (DMB↔ Bay Bridge)	
N utilized:	900,000 kg
org-C produced:	5,000,000 kg

What DIN concentration would prevent O_2 from dropping below 5 mg/L ?

~15 µmol/L

(protective for other endpoints? what season or water year?)

- HABs in San Francisco Bay:
  - SFB hosts numerous HAB-forming organisms:
    - moderate frequency, low abundance, occasional ‘break-throughs’
  - prior to August 2022, no/few severe HAB events

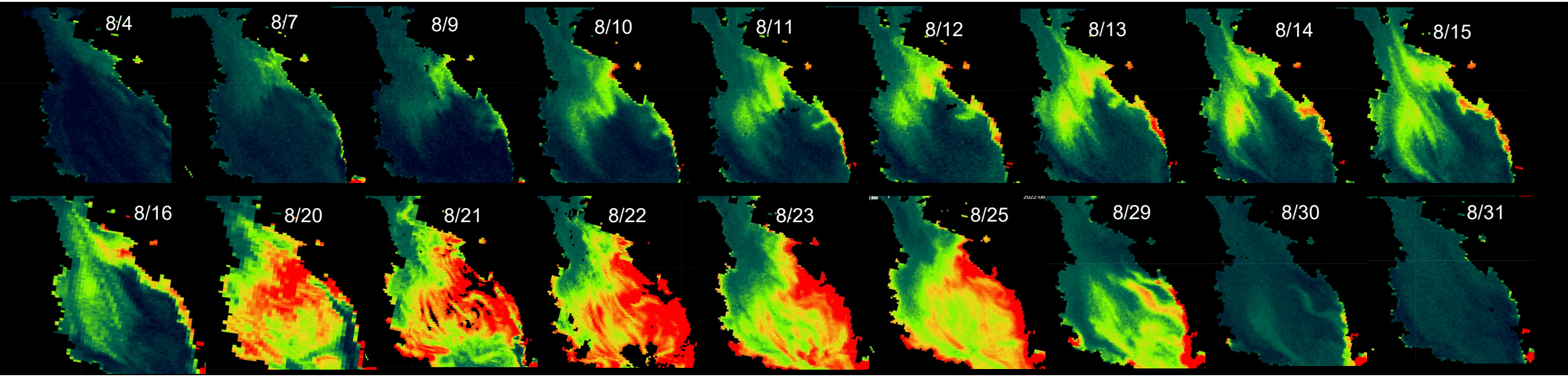
- SFB’s high nutrient loads resulted in severe impacts (biomass, area, duration)
  - high-Nutrients were the fuel
  - *other factors sparked or triggered the event*

- August 2022 HAB event in San Francisco Bay *Heterosigma akashiwo*
  - extremely high abundance (biomass)
  - anomalous timing…not a ‘spring bloom’ (departure from the primary focus of long-term research/monitoring and NMS studies)

What factors ‘caused’ and shaped this event?

What longer-term management options would be effective at preventing or mitigating impacts?

What’s the likelihood of something similar occurring again over different time horizons? (recurrence frequency)



Sentinel-3; using UWQV, Zlinszky and Padanyi-Gulyas 2020

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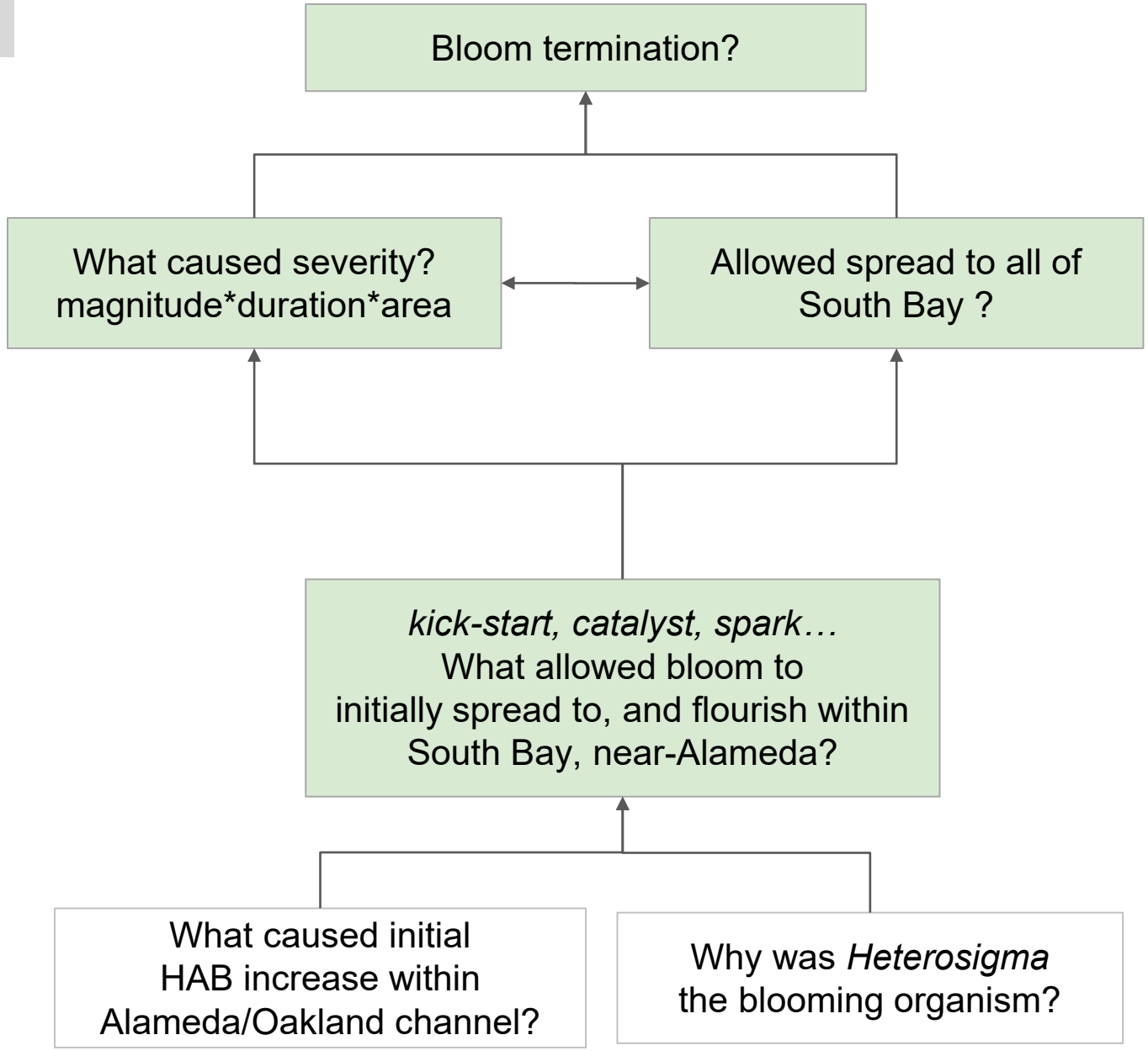
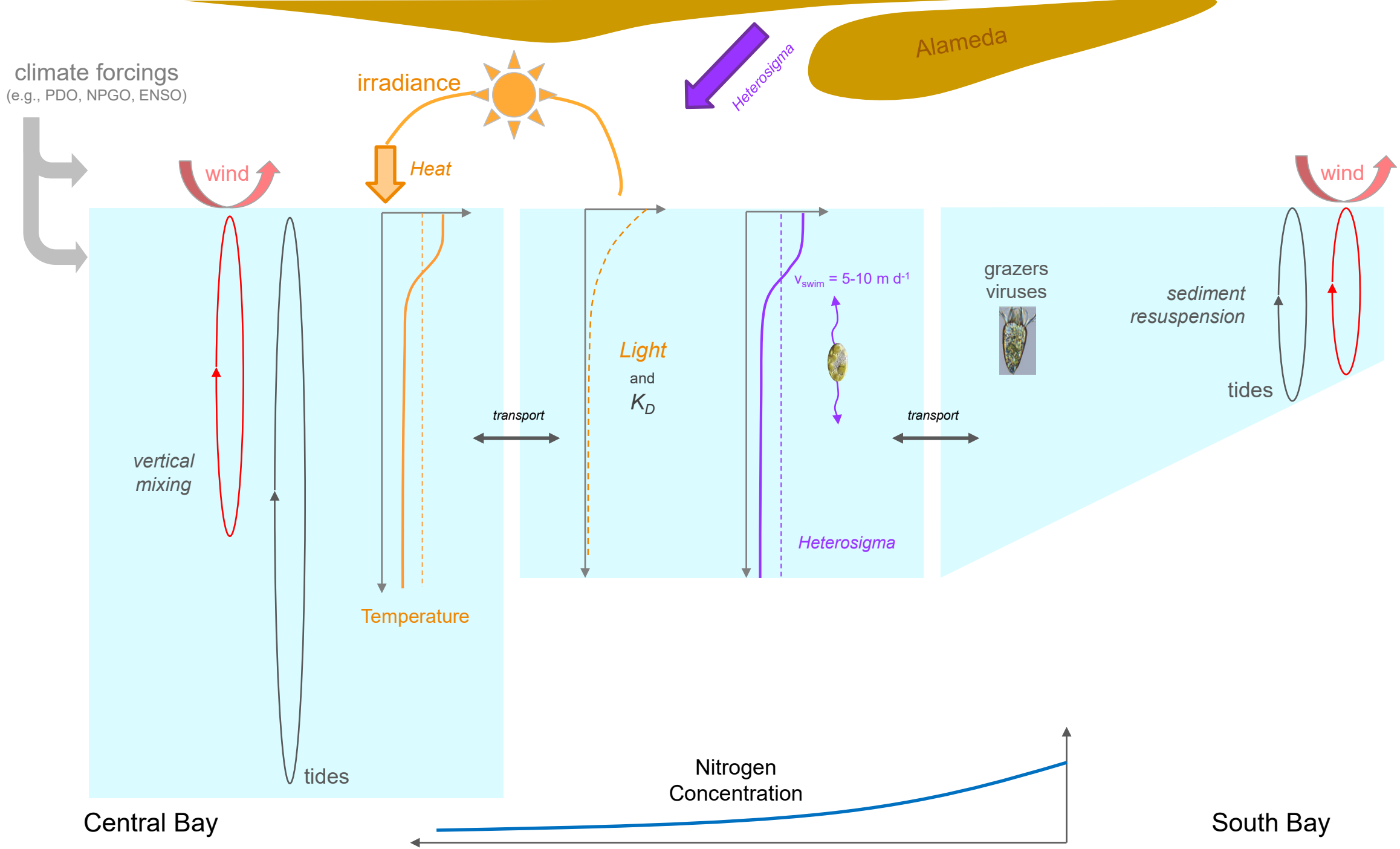
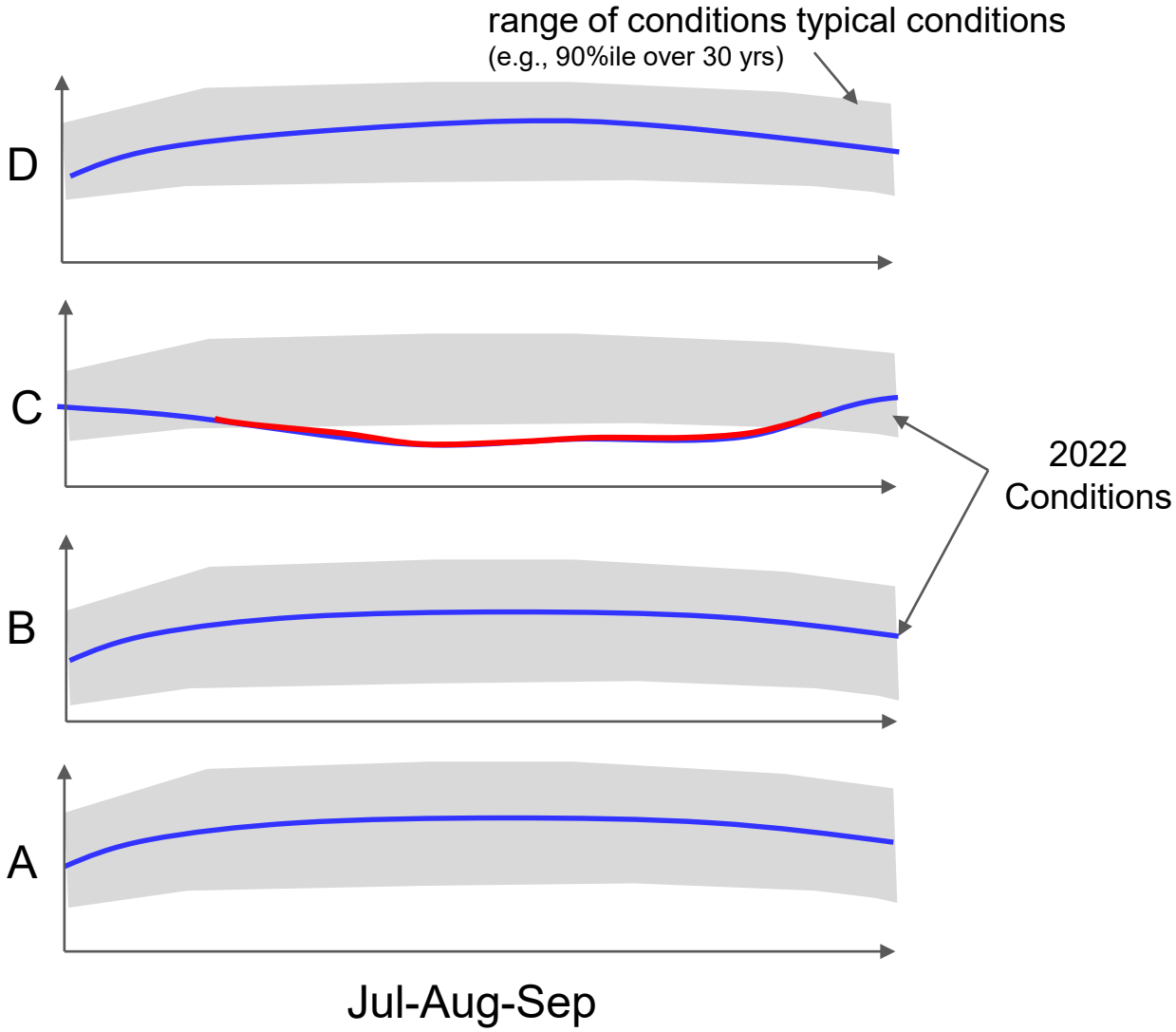


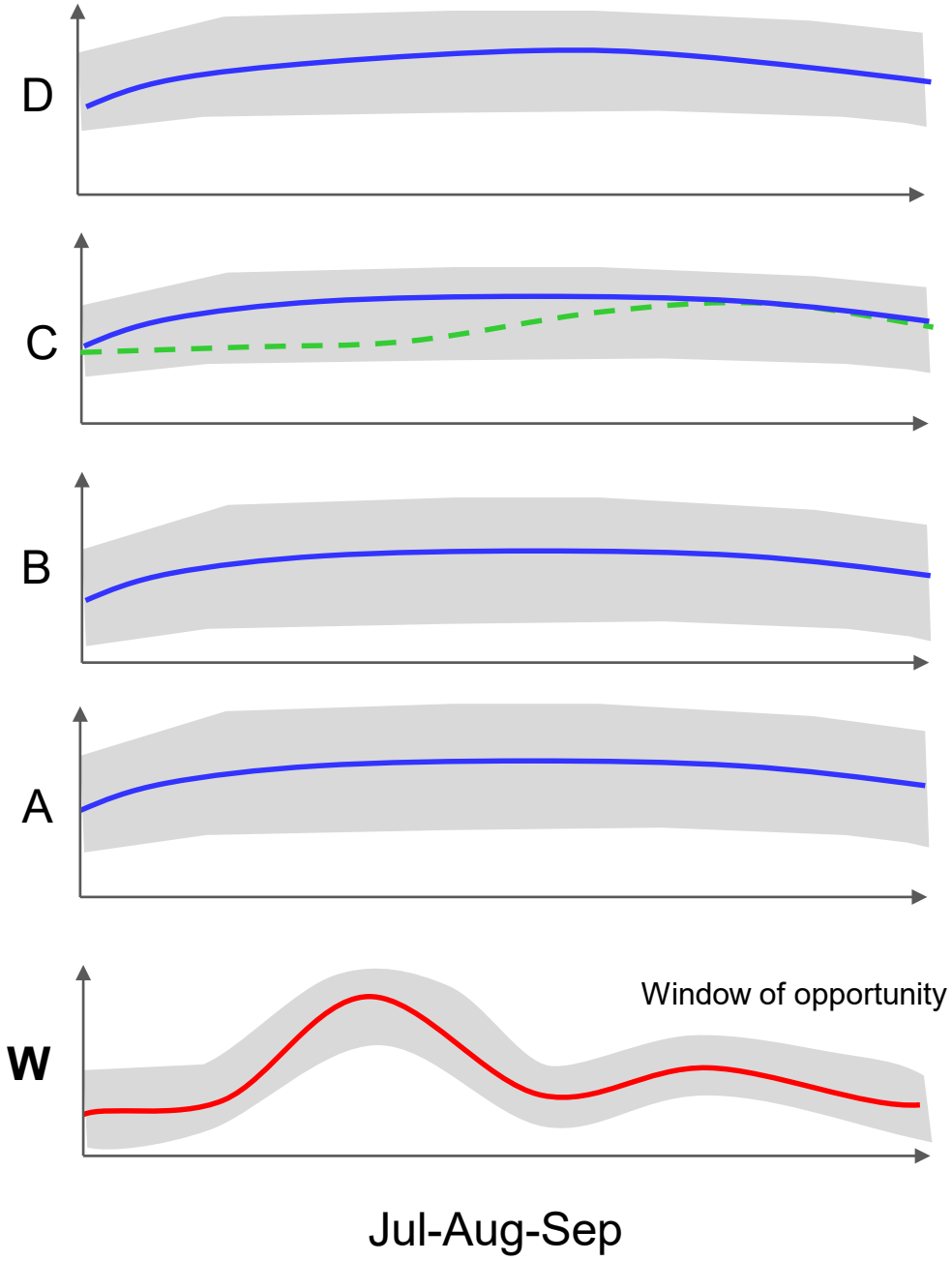
Potentially tractable questions,
Target of Current Work

Insufficient antecedent data,
Not-Target of Current Work


Alameda
Heterosigma
climate forcings
(e.g., PDO, NPGO, ENSO)
irradiance
Heat
wind
wind
vertical
mixing
tides
Temperature
transport
Light
and
K_D
v_{swim} = 5-10 m d^{-1}
Heterosigma
transport
grazers
viruses
sediment
resuspension
tides
Nitrogen
Concentration
Central Bay
South Bay



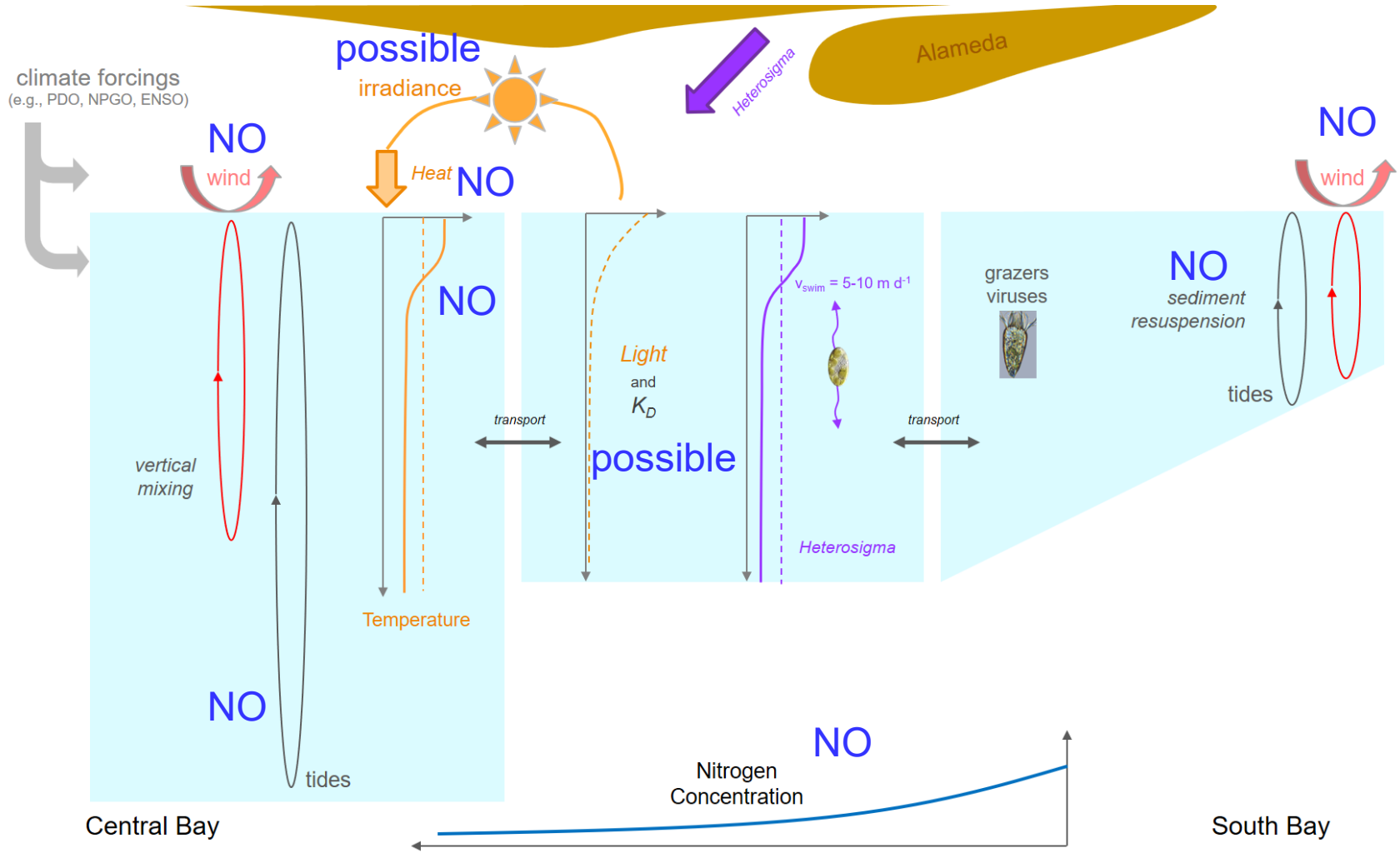
A,B,C,D: Factors that can contribute to a bloom event

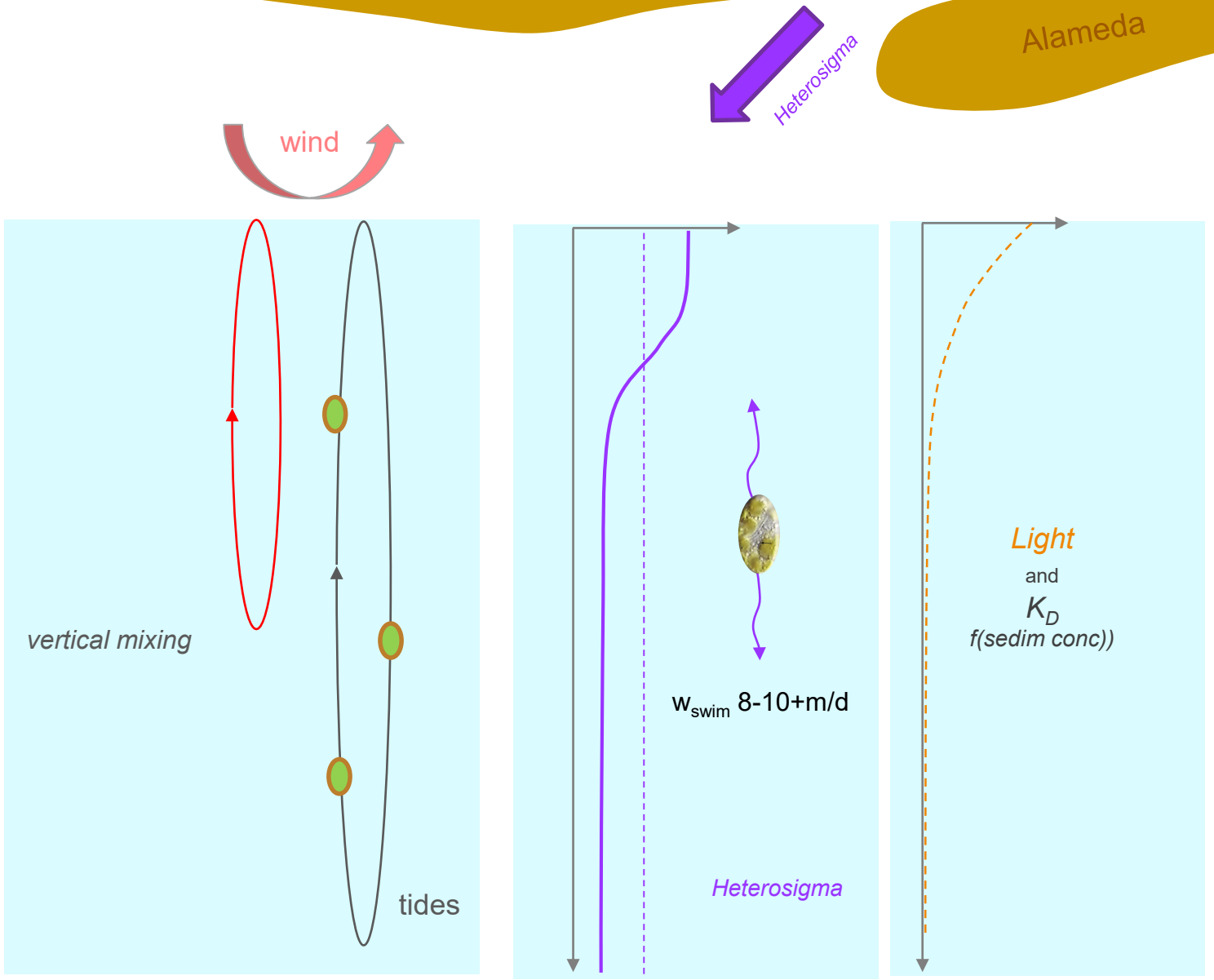


Exploring along two paths…

1) Strongly differing forcings in summer 2022?
   **early indications, work on-going*

2) Analysis/Simulation approaches that integrate/test multiple-forcings

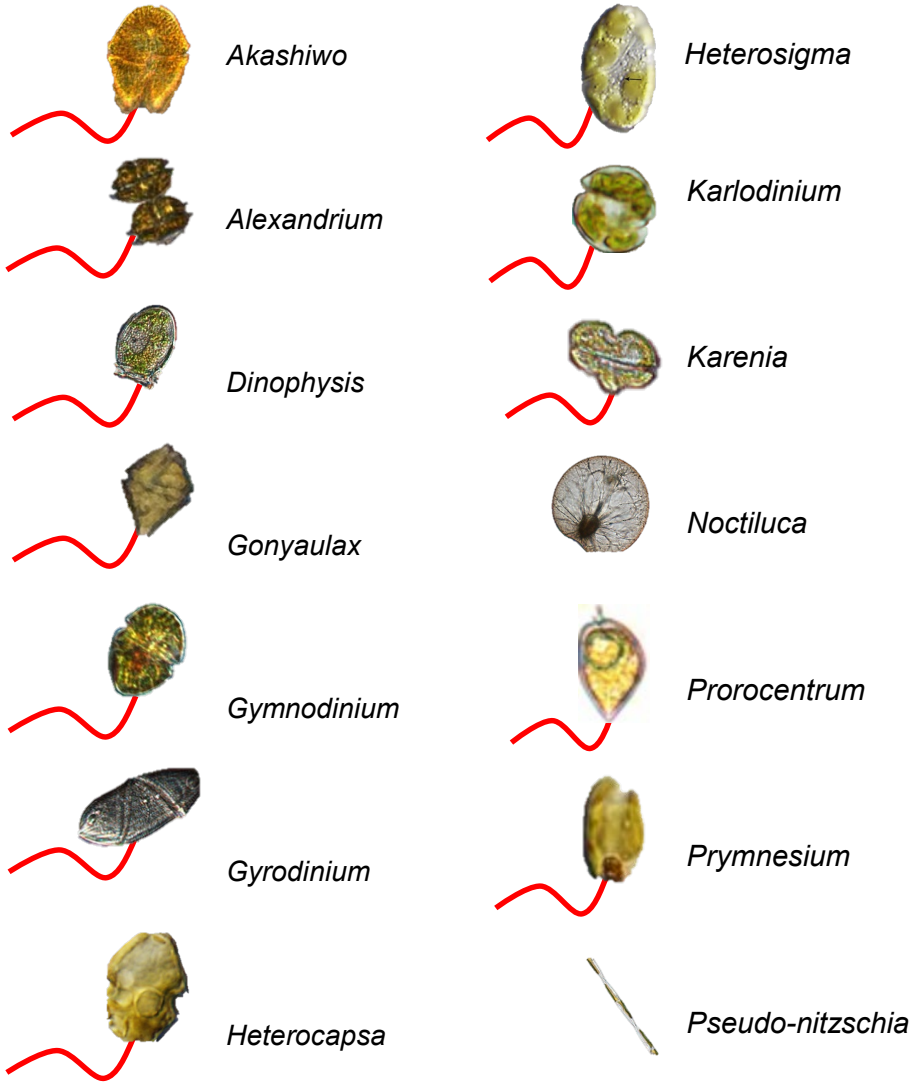




summer

Priority HAB-forming organisms in SFB

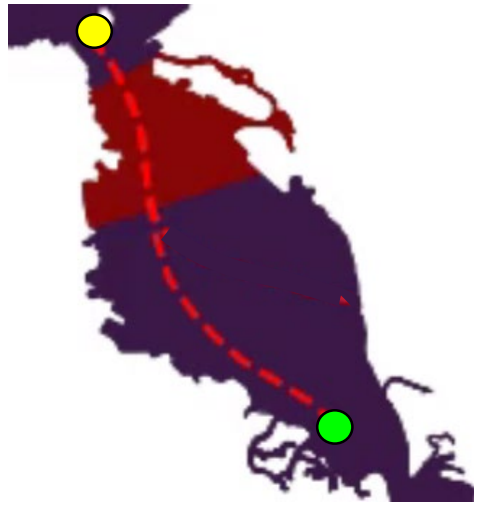
12 of 14 priority HABs are flagellates



SFEI 2020, 2021, 2023

concentration

depth (m)



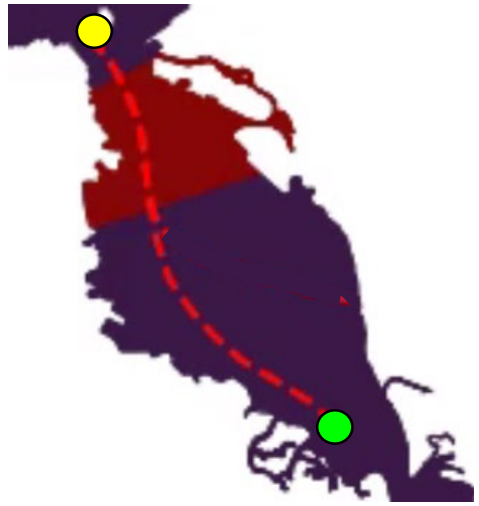
Importance of swimming vs. mixing?

Modeling experiment

- hydrodynamics (transport)
- numeric tracers or ‘dye-studies’
  …that can swim…

nceptration

depth (m)



Importance of swimming vs. mixing?

Modeling experiment

- hydrodynamics (transport)
- numeric tracers or ‘dye-studies’
  …that can swim…

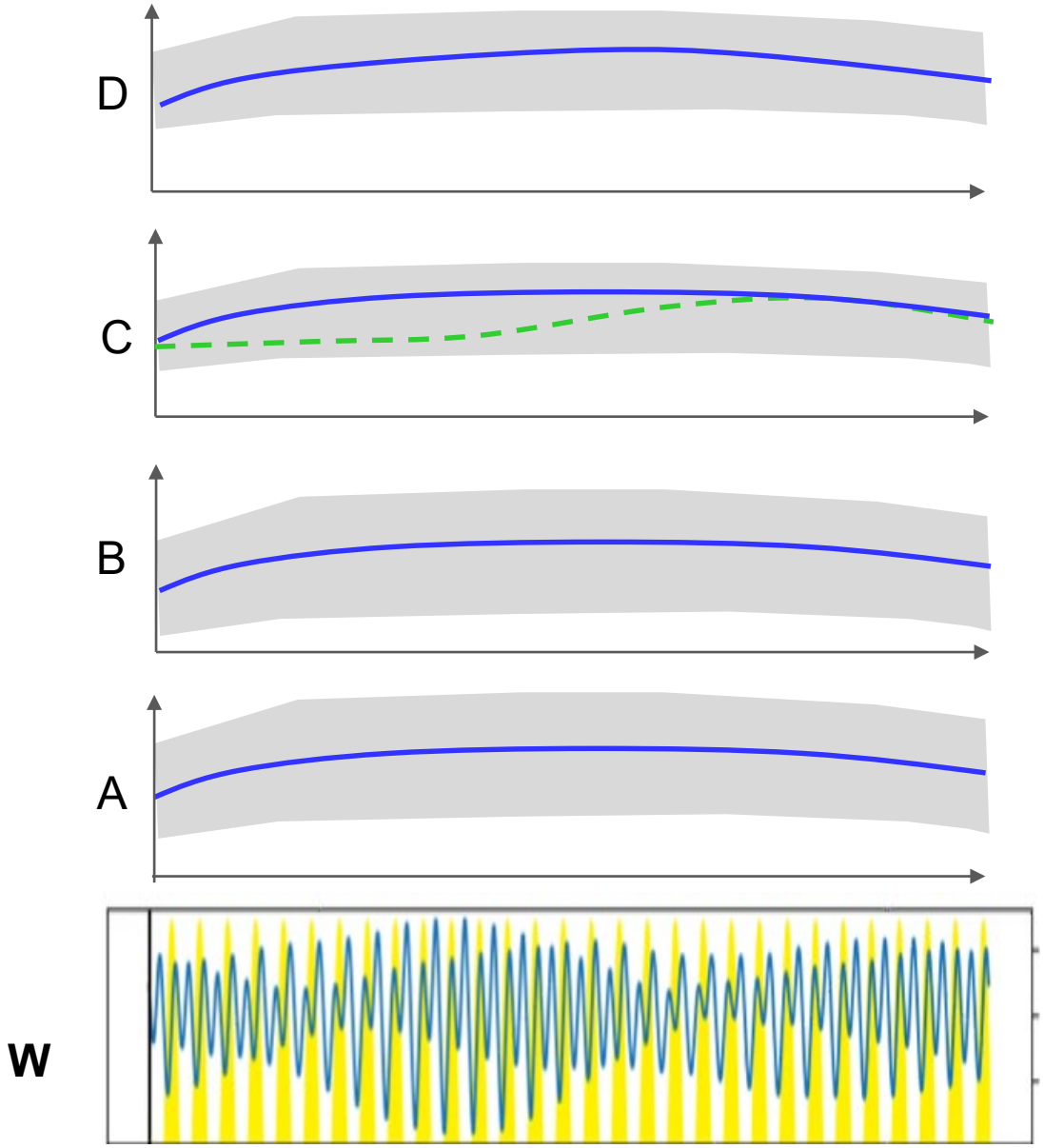
Daily Depth-integrated
growth rate constant

Windo

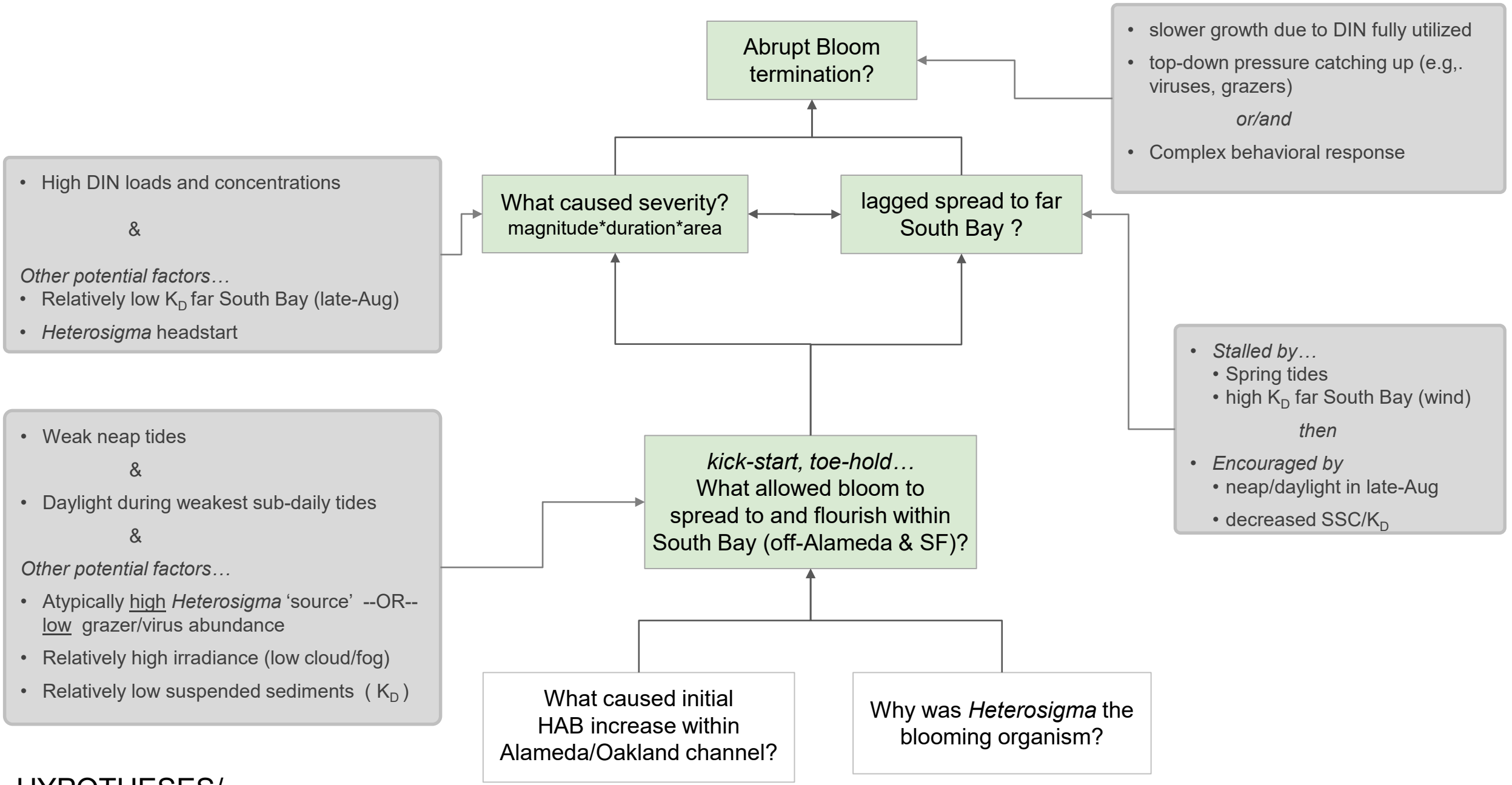
'Growth

- trace
- swim
- irradiance = f(x, y, t)
- K_D = f(x, y, t) (remote-sensed, Sen3; tuned with field observations)
- *Growth Potential*: f(x,y,t)
  daily depth-integrated growth rate

- Exploration-to-date (semi-quantitative) suggests:
  - captures key features of August 2022 bloom
  - aligns with *H akashiwo*'s re-emergence in late-July 2023 (Central Bay), mid-August 2023
  - consistent with timing of 2004 *Akashiwo* bloom



HYPOTHESES/
Early Conceptual Model



HYPOTHESES/ Early Conceptual Model

Summary

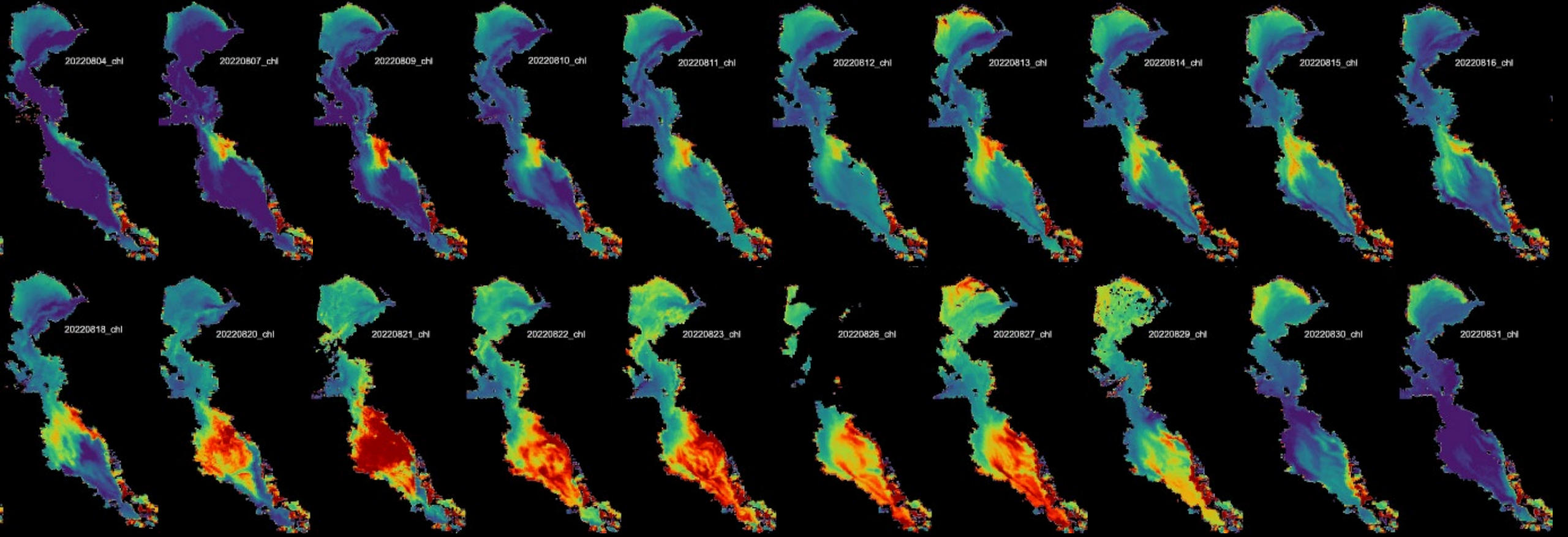
- HABs in San Francisco Bay:
  - SFB hosts numerous HAB-forming organisms:
    - moderate frequency, low abundance, occasional ‘break-throughs’
  - prior to August 2022, no/few severe HAB events

- August 2022 HAB event in San Francisco Bay *Heterosigma akashiwo*
  - extremely high abundance (biomass) , anomalous timing (summer vs. spring)
  - low oxygen levels throughout South Bay
  - fish mortality (impacts from toxicity and low O_2 ?)

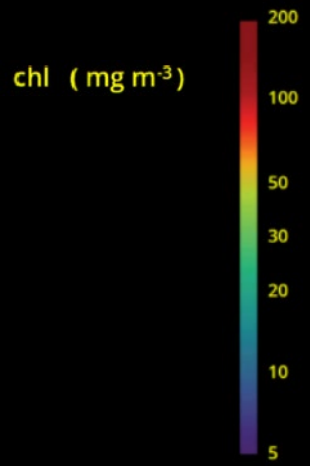
- SFB’s high nutrient loads resulted in severe impacts (biomass, area, duration)
  - high-Nutrients were the fuel…*Bloom consumed all DIN in South Bay*
  - *other factors sparked or triggered the event*

On-going Work

- Expanded/Intensified monitoring, including ‘early-warning system’



August 2022



SFB-tuned chl algorithm (Sentinel-3)

(Kudela et al., in prep; SFEI, in prep

On-going Work

- Expanded/Intensified monitoring, including ‘early-warning system’
  - Recently-awarded $3mill grant from NOAA, HAB-monitoring (program development/operationalize)
    Project Leads: SFEI, USGS, DWR
    Collaborators: UCSC, Baykeeper, RB2, RB5, CDPH, Cal Maritime Academy, Restore the Delta

- Investigate important mechanisms / factors, e.g.,
  - swimming vs. vertical mixing intensity (and other factors)
  - strong organism source, or weak ‘top-down’ control
  - differences between summer 2022 and prior years

- Exploring management scenarios to prevent or mitigate future events

Collaborators

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USGS-BGC Field and Data Teams (CA-WSC)

USGS-Menlo *R/V Peterson* crew

SFEI: T Hale

UCSC: K Negey

BayKeeper: A Mevoli, J Dowell

UC-Davis: L Lewis

CA DFW: J Hobbs

Water Board: R Looker, K Lundy, T Mumley, E White

BACWA: L Fono, E Dunlavey

Bay Area Citizen Science contributors (fish mortality reporting)

Funding:

SFB Nutrient Management Strategy;

USGS PES

NOAA-HABs rapid-response

SFB RMP (mooring network)

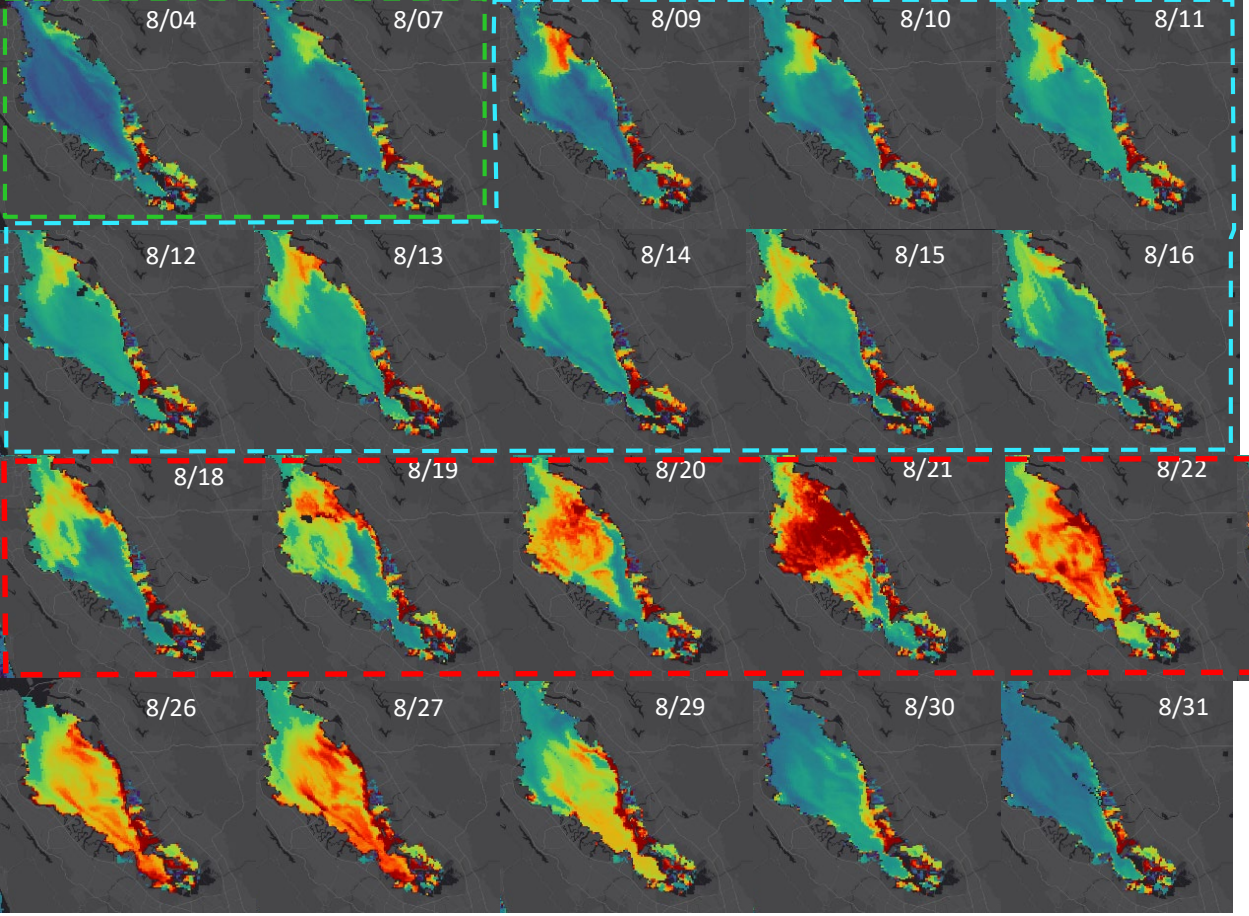
Reports and Work Products

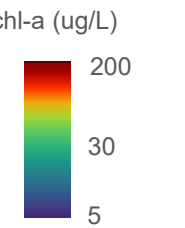
Nutrient Strategy work products are available below, organized by NMS Work Element (WE). This list is regularly updated as new reports become available in draft or final versions.

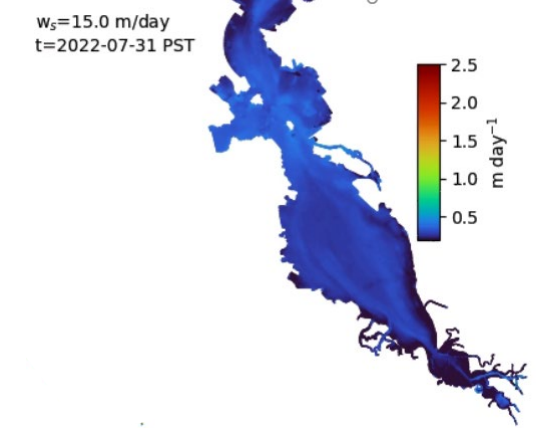
NMS Program Administration (WE #1)	Annual Reports
2012 Nutrient Strategy Nov 2012 *2016 NMS Science Plan Report Sep2016* *SF NMS Charter Revised 10082020.pdf*	*2015 NMS FY2015 Annual Report* *2016 NMS FY2016 AnnualReport* *2017 NMS FY2017 AnnualReport* *2021 NMS FY2021 AnnualReport*
Synthesis/Interpretation (WE #2)	
2011 SFBay NNE Development Lit Review *2013 Year1 POTW Effluent Characterization* *2013 GG NutrientFlux conceptual LargierStacey* *2014 Scientific Foundation SFB NMS* *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* • *Link to technical appendices (Appendix 1-6)* *2016 Summary and Evaluation of Delta Subregions for Monitoring and Assessment* *2016 Suisun Synthesis II: Influence of Nutrient Forms and Ratios on Phytoplankton Production and Community Composition*	*2017 Nutrient Forms Ratios Workshop (Suisun-Delta)* • *Other workshop materials (charge, presentations, reading list)* *2018 Stakeholder Workshop Summary: OperationBaseline Science and Monitoring Needs* *2018 nSFE water quality changes Beck et al 2018* *2018 SFB HABsToxins Peacock et al 2018 HarmfulAlgae* *2020 Delta Nutrient Reduction Responses* *2020 LSB Hypsography Report Aug2020* *2021 LSB Metabolism Draft Sep2021* *2021 SmokeDay LowDO LSB sloughs* *2021d_SFB_Trends_Beck_et_al*

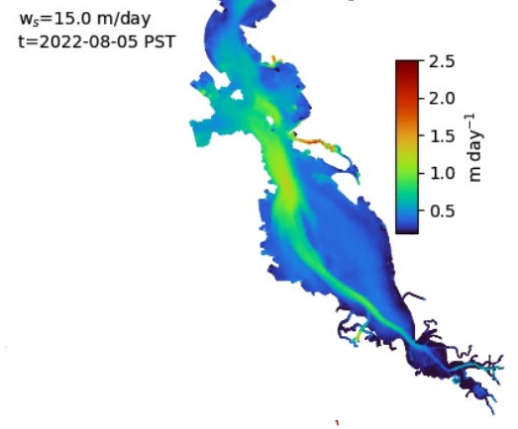
Assessment Framework (WE #3)	Monitoring (WE #4)
2011 SF Bay NNE Development Lit Review *2014 SFBay AF Meeting Summary* *Proposed Workplan for AF Development* *2016 Assessment Framework Report (AF1.0)* • *Link to Technical Appendices (Appendix A-D)* *2017 SFB AF Development Sutula et al 2017 ECSS* *2018 LSB DO and Fish Habitat* *2019 Trend Analysis Pilot Study (chl-a)* *2021 NMS AF1.0 TestDrive Jun2021* *2022 NMS AFWorkplan Feb2022 DRAFT*	*2014 Monitoring Program Development Plan* *2014 Algal Pigment Final Report* *2014 Moored Sensor Yr1 Progress Report* *2015 SPATT (Algal Toxins) Final Report* *2016 NMS Observation_Program* *2019 Moored_Sensor_Program_Update* *2019 Shoal_Mooring_Pilot* *2020 SFEI WQ SFB Perimeters Report* *2020 SFB Anchovy Toxins* *2020 chl intercalibration study_NMS_DRMP* *2020 Phyto HAB MolSeq PilotStudy* *2021c PhytoHAB molecular-microscopy comparison*
Modeling (WE #5)	
2014 SFB NMS Model: Options, Recommended Approach *2014 Detailed Modeling Workplan* *FY2016 Modeling Plan* *2017 Load Update & Reduction Scenario Runs (See Section 6)* *2017 SFBay Interim Model Validation* *2018 Delta-Suisun BGC Model Development Year1 Progress* *2018 SFB Hydrodynamics Biogeochemical Model Calibration* *2019_Delta-Suisun BGC Model Development Year2 Progress*	*2019 DeltaSuisun Hydrodynamics wy2016* *2020 SFEI DeltaSuisunBiogeochem WY2016* *2020 NMS SFB ModelingUpdate Sep2020* *2020 ShoalChannel exchange Zhou et al JGR* *2020 SedimentTransport TUDelft-Deltares (thesis)* *2021 SFB DIN Source Apportionment* *2021 DeltaSuisun N sources/transport WY2016* *2021 SFEI Delta-Suisun BGC Model: WY2016, WY2011*
Management Options / Control Strategies (WE #6)	
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] and others)* *2017 Treatment Wetlands Opportunities Screening Report* *2018 Nutrient Reduction Study: Potential Nutrient Reduction by Treatment Optimization, Sidestream Treatment, Treatment Upgrades, and Other Means (Bay Area Clean Water Agencies)*	

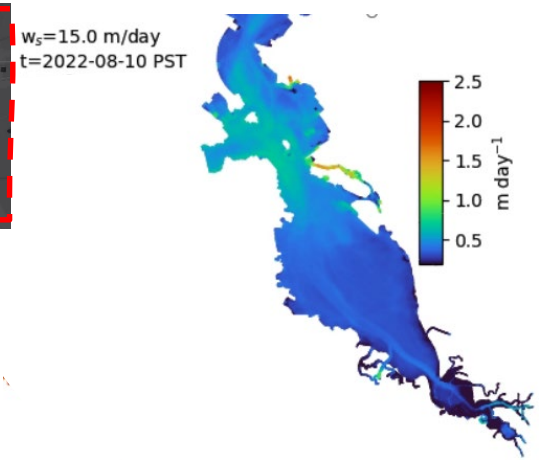
https://sfbaynutrients.sfei.org/books/reports-and-work-products

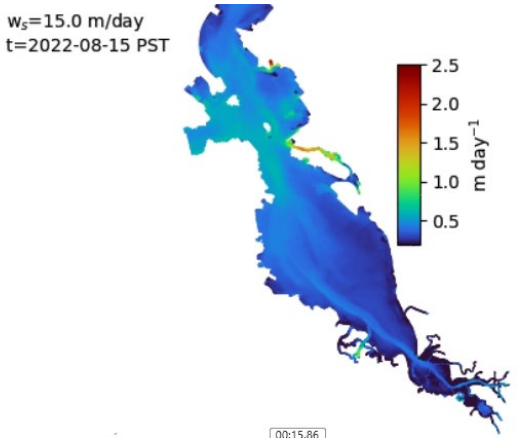


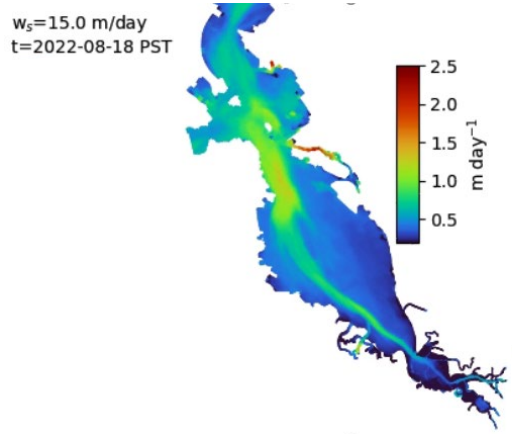


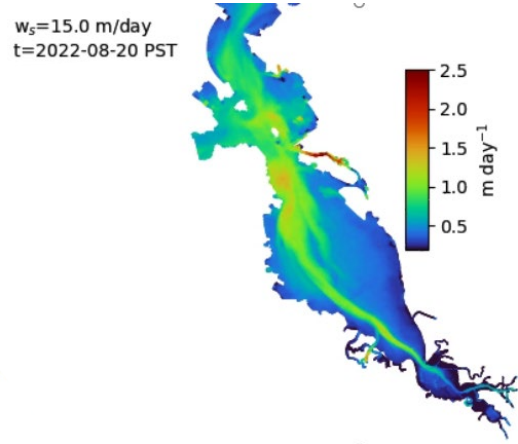












8/4-8/8 Bloom expansion to and development in deep channel

8/9-8/16 Limited spread within northern South Bay

8/17-8/23 Rapid Spread over remainder of South Bay