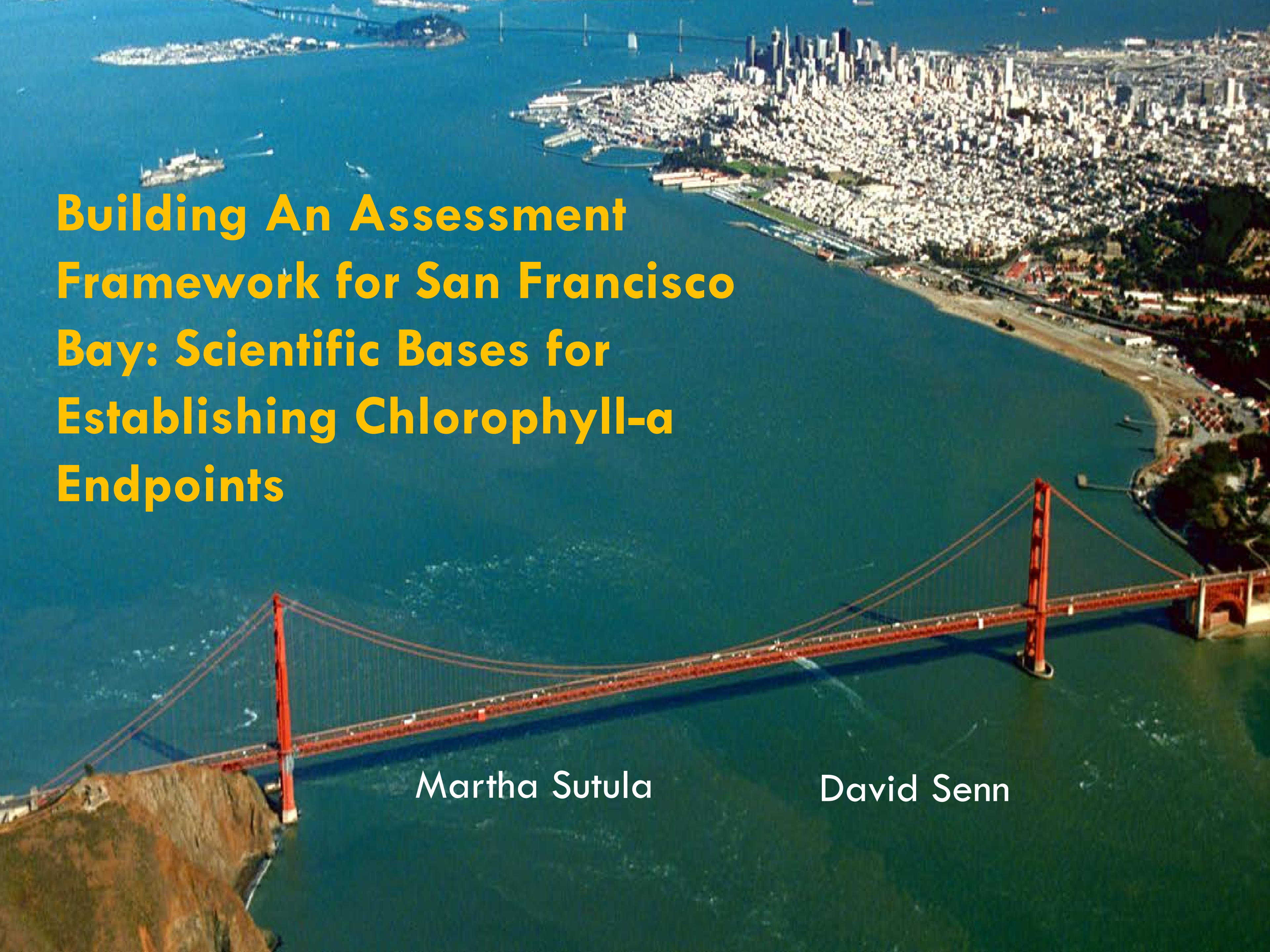
Building An Assessment Framework for San Francisco Bay: Scientific Bases for Establishing Chlorophyll-a Endpoints



Martha Sutula

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Overview of Two-Part Presentation

Part I: Key background on "assessment framework" core principals

Quantitative basis for classification

—Analyses supporting decisions on chlorophyll-a classification

Part II: Rationale behind assessment framework classification tables

Technical Team Members

Experts in assessment frameworks and criteria:

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Local experts:

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Core Principles

- Define geographic scope, habitats included, Bay segmentation
- Identify assessment metrics and specify how to measure them
- Define how metrics link to impairment of beneficial uses
- Define temporal and spatial elements of assessment framework
- Inform a "proto-monitoring program" required to support regular assessments of the Bay

Key Indicators and Link to Beneficial Uses

- Low dissolved oxygen associated with high water column chlorophyll a
- Low fisheries yield associated with too low or excessive primary productivity
- Increased frequency and duration of harmful algal blooms and toxins linked to direct effects on human and aquatic life
  - Increased HAB frequency and duration is associated with elevated chlorophyll a
- Undesirable shifts in phytoplankton community structure results in poor (phytoplankton) food quality for secondary consumers (e.g. zooplankton and fish)

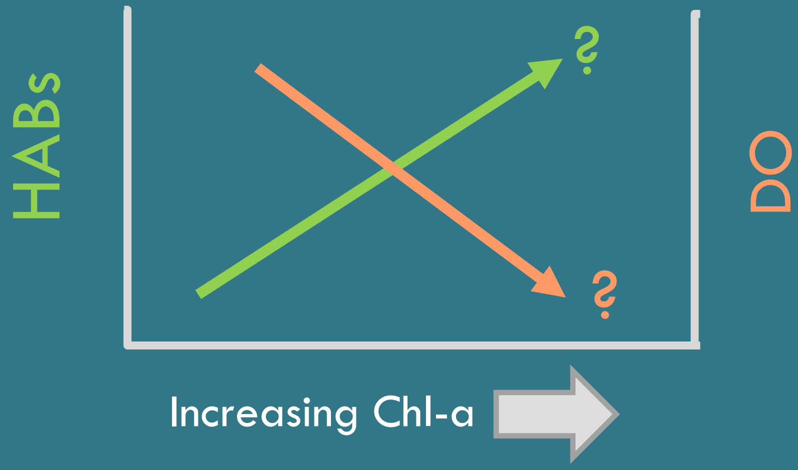
Assessment Framework Quantitative Classification

- Develop assessment framework classification
  - Specify ranges of values that define categories for each metric
  - Purpose of doing this is communicate condition, or level of risk, based on routine monitoring of SF Bay

Classification Based On Ecological Condition	Indicator
Very High	≤ ?
High	? – ?
Moderate	? – ?
Low	? – ?
Very Low	> ?

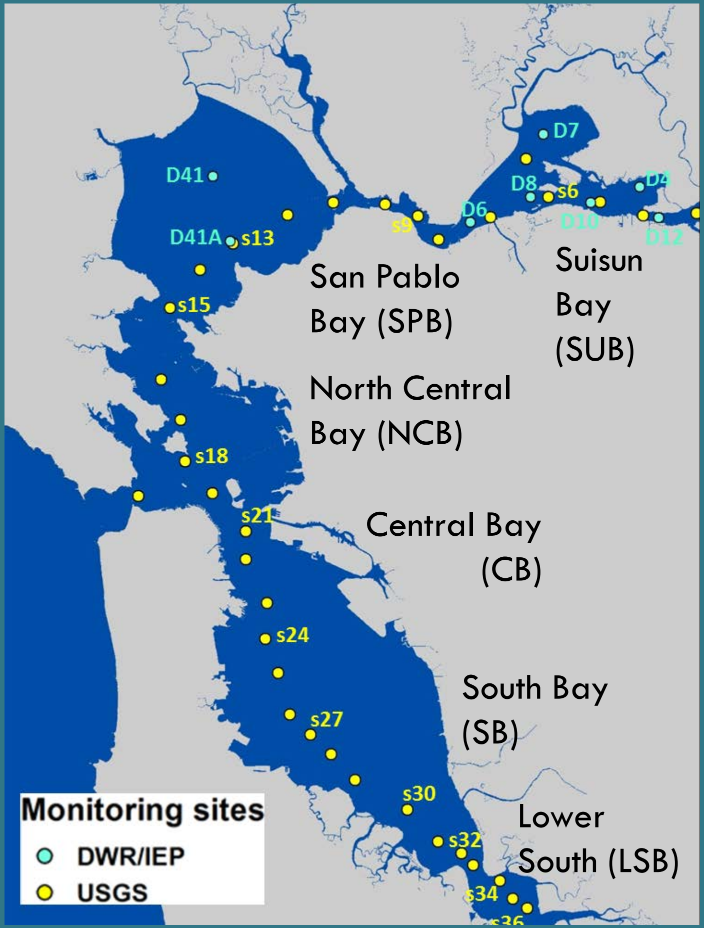
Basis for Quantitative Discussion of Classification Boundaries

- Established guidance or peer-reviewed literature for:
  - Dissolved Oxygen (DO)
  - Gross primary productivity
  - Harmful algal bloom (HAB) cell counts and toxins
- Chlorophyll a
  - Expert team not comfortable with available guidelines
  - Data exist to undertake quantitative analyses to support decision-making



Objectives and Approach of Analysis

- Quantify relationship between *chl-a*, DO, HAB cell density and toxins, by subembayment
  - Where empirical relationship exists, identify thresholds
- Utilize USGS 1993-2014 time series data of *chl-a*, DO and HAB cell density
  - Plus 2012-2014 HAB toxin data (SPATT)
- Where possible (sufficient data density), conduct analysis on subembayments



Findings

- Relationship of Chl-a with HABs first…
- Then with Dissolved Oxygen

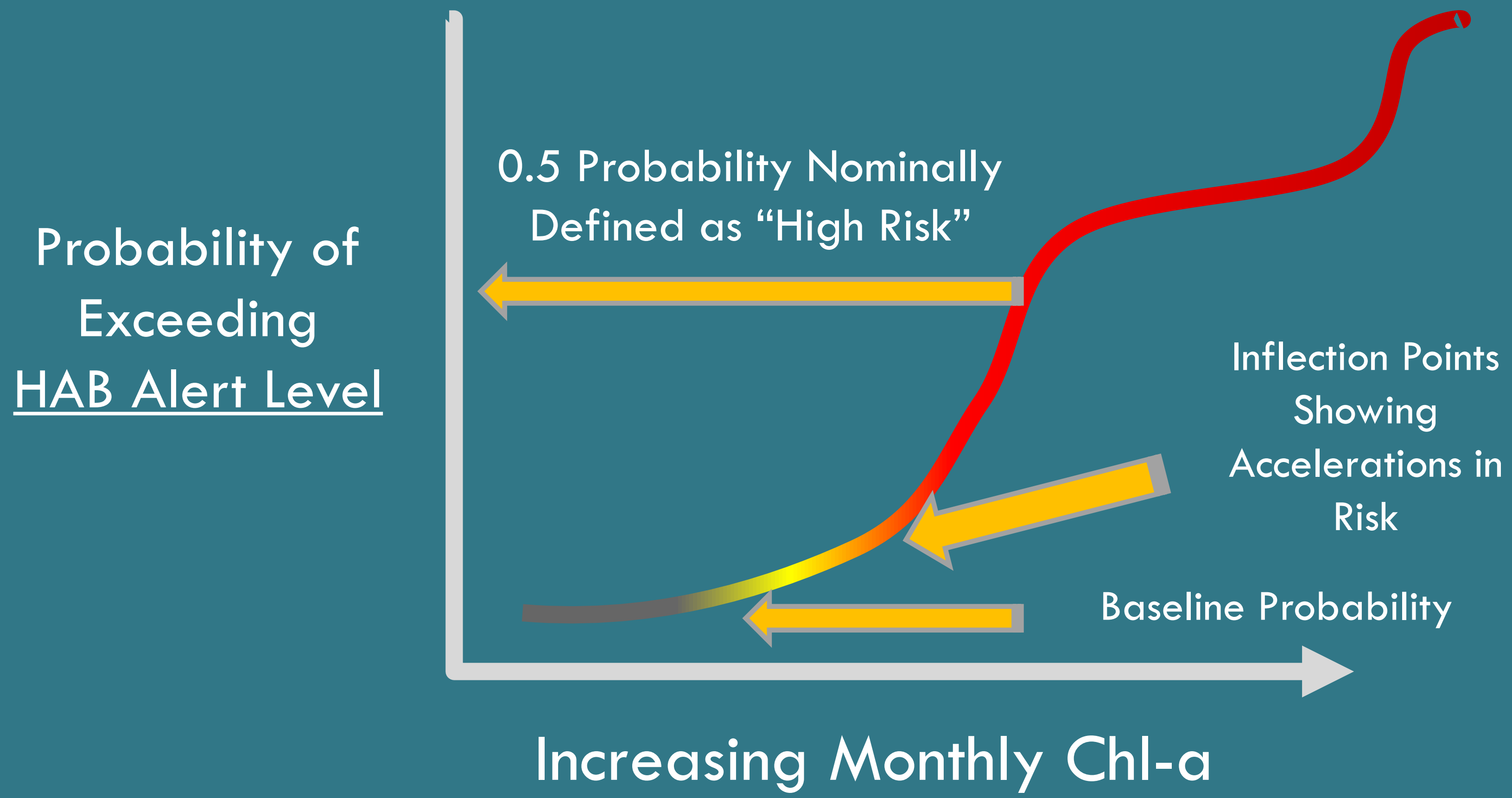
Chlorophyll-A is Significantly Correlated with Abundances of Some HABs

Robust regression of log-transformed surface chlorophyll and HAB abundance; * designates Significant Slope at $P < 0.05$ and ** Designates < 0.01

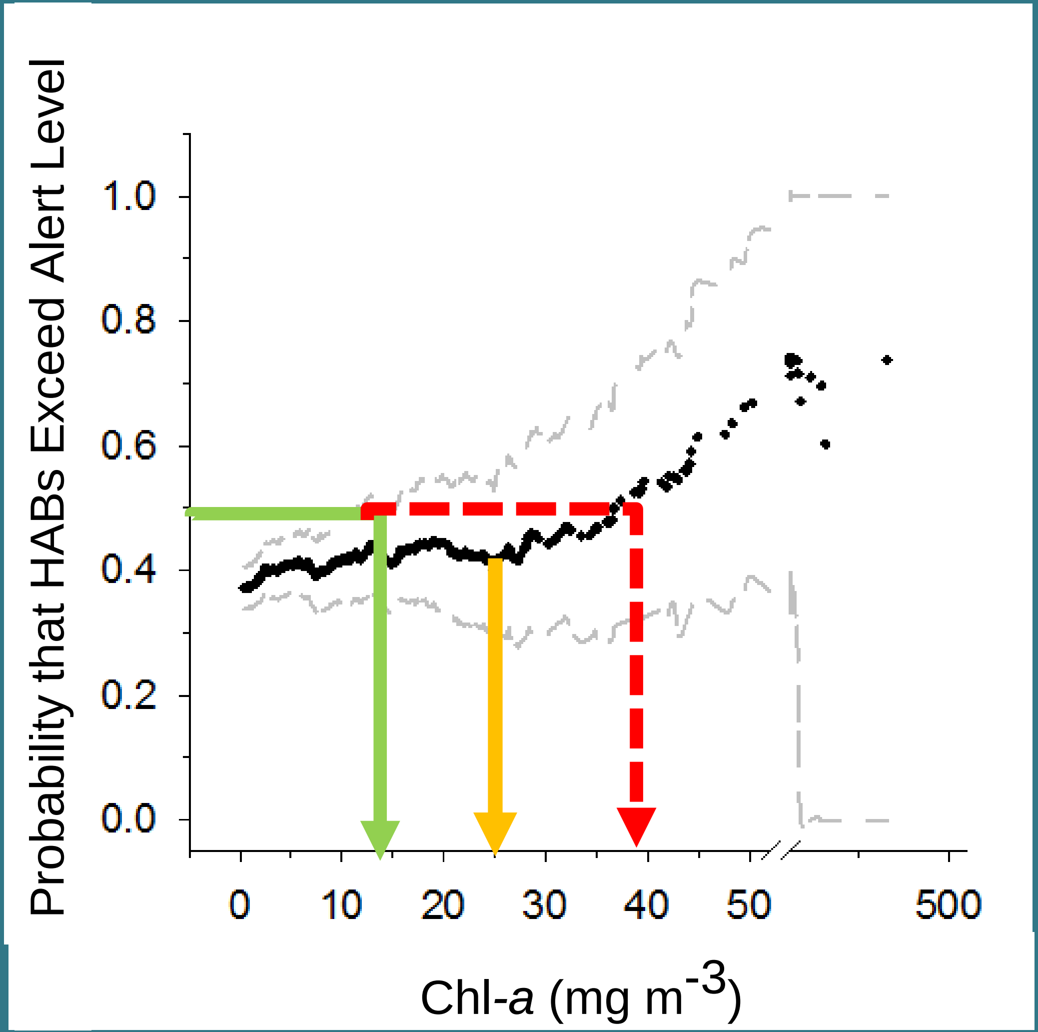
Organism	Slope
Alexandrium	0.488**
BGA	0.177
Dinophysis	0.569*
Heterosigma	0.870
Karlodinium	1.448**
Pseudo-nitzschia	0.431**

Quantify *Thresholds of Increased Risk* of HAB Events with Increasing Chlorophyll-a

Conditional Probability Analysis



Conditional Probability Analysis: Increased Risk of HABs in range of >13-40 mg m^{-3} *chl-a*



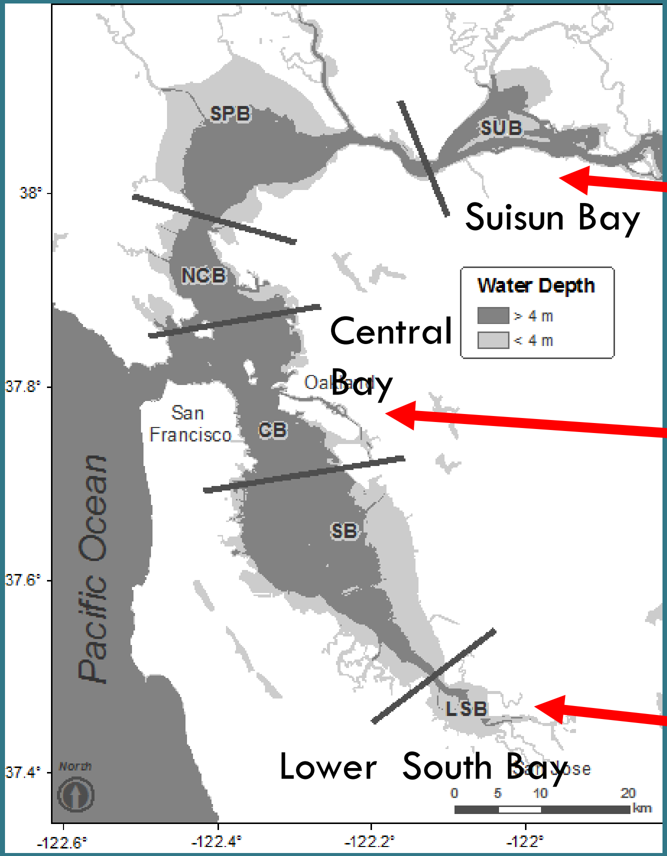
- Elevated baseline, exceeding HAB alert levels 40% of time
- 13-40 mg m^{-3} represents the mean upper 95[th] CI of 50% risk of exceeding alert level
- 25 mg m^{-3} = inflection point of accelerated risk

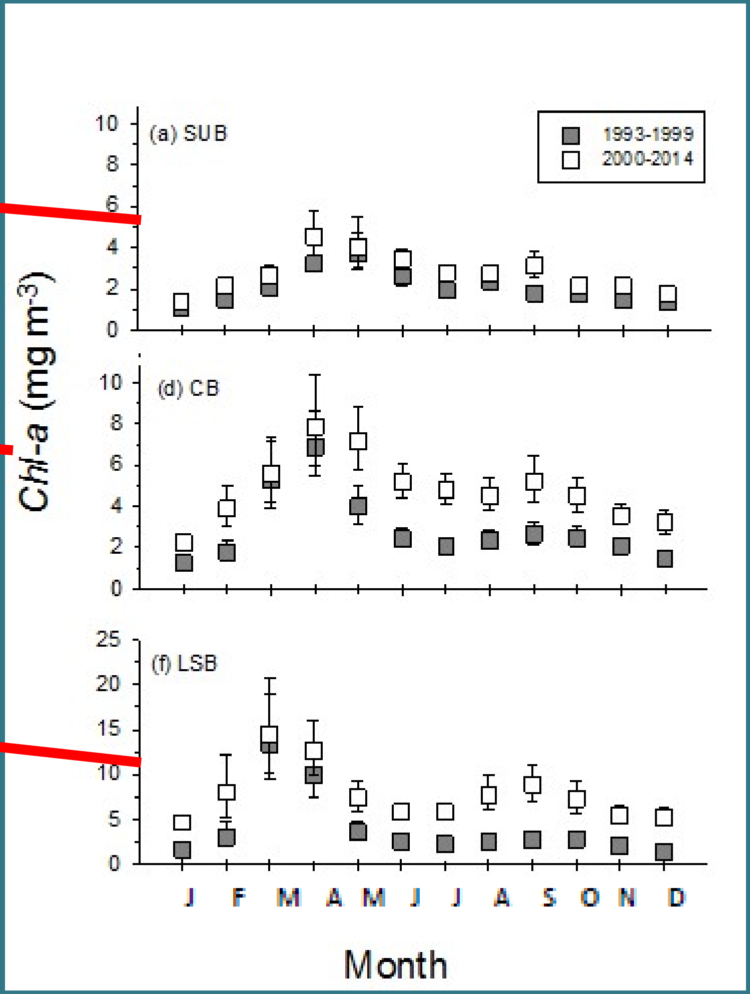
Findings

- Relationship of Chl-a to HABs first…

- Now Dissolved Oxygen

To Examine Relationship of Chl-a with DO, Used Measure that Integrated over Period of Peak Phytoplankton Biomass: Mean February – September





Increasing *Chl-a* & declining DO, significant across subembayments

Chl-a is Significantly Correlated with DO, But Only For South and Lower Bay

Quantile regression of log-transformed chl-a and summertime DO % Saturation; * designates Significant Slope at P< 0.05 and ** Designates < 0.01

Sub-embayment	Slope of Quantile Regressions and Significance Level		
	Feb-May	June-Sept	Feb-Sept
Lower South	0.06	-0.62*	-0.61*
South	-0.38**	-0.58**	-0.73**
Central	-0.43	0.74*	0.15
North Central	-0.20	0.87	0.85
San Pablo	-0.36	-0.58**	-0.37
Suisun	-0.85	-0.45	-0.16

DO Benchmarks Used to Derive *Chl-a* Thresholds for South & Lower South Bays

SFB DO Criteria (SF Bay Water Board)

- 3-month Median DO Saturation> 80%
  - ~7 mg L^{-1} at summertime temp and salinity
- 5.0 mg L^{-1} minimum criterion, downstream of Suisun Bay

Other

- 5.7 mg L^{-1} (High ecological condition, EU estuaries, Best et al. 2007)

All statistical analyses conducted in % saturation, to avoid confounding from temperature and salinity effects on concentration

South & Lower South Bays: *Chl-a* of ~14-40 mg m^{-3} Brackets Low versus High Risk of Low DO

- Range comparable to that found for HABs
- Within similar range of other studies or assessment frameworks, eg.
  - 15 mg m^{-3} reduced risk *Microcystis* blooms in Chesapeake Bay (Harding et al. 2013)
  - Similar range proposed as low and high risk of eutrophication in UK estuaries (10-50 mg m^{-3}) Devlin et al. 2011)

DO % (= ~ DO mg L^{-1})	Predicted Mean Chl-a (95% CI) for $\tau = 0.1$	
	LSB (N=48)	SB (N=161)
80% (~ 7.0 mg L^{-1})	4 (-4 – 12)	14 (13 – 15)
66% (~5.7 mg L^{-1})	25 (15– 39)	32 (30 – 32)
57% (~ 5.0 mg L^{-1})	36 (30 – 54)	44 (40 – 46)

Range of Feb-Sept mean *Chl-a* bracket low versus high risk:

- ~25-36 mg m^{-3} for Lower South Bay
- ~32-44 mg m^{-3} for South Bay

Summary

- Identified range of *chl-a* (~13-40 mg m^{-3}) associated with low to high risk of triggering HAB alert levels and DO benchmarks
  - Numbers represent continuum of risk
  - Are not immutable because fundamental processes underlying relationships can change
  - Empirical relationships imperfectly capture underlying mechanisms

- Use these chl-a endpoints as testable hypothesis, to be refined through improved science, monitoring and modeling studies

- Need for refined science and potential for change = strong rationale to support long-term monitoring program

Questions?

Overview of Two-Part Presentation

Part I: Key background on "assessment framework" core principals

Quantitative basis for classification

—Analyses supporting decisions on chlorophyll-a classification

Part II: Rationale behind assessment framework classification tables

Key Points Before We Begin

- The conceptual models and assessment framework core principles provide a sound scientific foundation for informing modeling and monitoring.
- We acknowledge the uncertainty in the assessment framework classification scheme and suggest refinement, through multiple iterations of basic research, monitoring, and modeling.
- Recommend that near-term use be focused on a scientific "hypothesis testing"
  - —focused on understanding how to collectively use and improve efficiencies for assessment, monitoring and modeling
  - —consider whether or how to combine indicator results into multiple lines of evidence, particularly for communication to the public.
  - —test drive should be conducted in tandem with research, monitoring and modeling to refine the assessment framework.

Assessment Framework Indicators

- Chlorophyll-a
- Harmful algal blooms and toxins
- Primary productivity

Developed Quantitative Classification Scheme

- Dissolved oxygen

Use Existing WQ Objectives

- Phytoplankton Composition
  - Genus and species counts
  - % Biovolume < 0.5 microns
  - Phytoplankton Food Quality Index (Galloway and Winder 2015)

No Classification Scheme Proposed

Rationale for Chl-a Classification Scheme: Linkage to HABs Cell Densities and Toxins

- Based on monthly chl-a (Acute Risk), but condition category downgraded if frequency high (Chronic Risk)
- Applied at subembayment scale, to all subembayments
- Classification bin thresholds derived from key points of interpretation of condition probability analyses

Table 3.4. Chlorophyll-a Classification Table Linked to HAB Abundance, Based on Annual Frequency of Occurrence in Monthly Samples. Classification should be applied to each subembayment.

Subembayment Monthly Mean Chlorophyll-a Linked to HAB Abundance (µg L^{-1})	Ecological Condition Based on Annual Frequency of Occurrence in Monthly Samples			
	1 of 12	2-3	4-6	6+
≤ 13	Very high	Very high	Very high	Very high
>13 – 25	Good	Moderate	Moderate	Low
>25 – 40	Moderate	Moderate	Low	Very Low
>40 – 60	Moderate	Low	Very Low	Very Low
>60	Low	Very low	Very low	Very low

Rationale for Chl-a Classification Scheme: Linkage to Low Dissolved Oxygen

- Based on Mean February-September chl-a (Integrated measure that influences summertime DO, critical condition)
- Applied at subembayment scale, only to South Bay & Lower South Bay
- Classification bin thresholds derived from <u>mean</u> predicted values from quantile regression (Sutula et al., in prep)

Table 3.5. Chlorophyll-a Classification Table Based on Risk of Falling Below DO Water Quality Objectives, Based on Annual February-September Mean Chlorophyll-a, for South Bay and Lower South Bay only.

Classification of ecological condition based on mean February - September chlorophyll-a (mg m^{-3}) linked DO benchmarks - South Bay and Lower South Bay Only		
Category	**Lower South Bay**	**South Bay**
Very high)	≤25	≤14
High		>14 - 32
Moderate	>25 - 36	>32 - 44
Low	>36 - 51	>44 - 58
Very Low	>51	>58

Five Major Types of Uncertainty in Chlorophyll-a Classification

- Significance of HAB risk
- Linkage to HAB cell counts rather than toxin
  - SPATT toxin data were used (Calibration of SPATT to particulate or mussel toxin tissues still ongoing)
- Alert levels are based on acute toxin exposure, so uncertainty capturing risks of chronic exposure
- Data limitations re DO in margin subtidal habitats
  - Likelihood that diurnal DO minima are not captured
- Scientific basis for DO objectives in shallow water margins, tidal sloughs and intertidal wetland habitat

Basis for Alert Levels for HAB Cell Densities In SFB

Table 3.7. Potential HABs from San Francisco Bay, and alert levels used in other regions.

Organism	**Alert Level (cells/L)**	**Reference**
Alexandrium spp.	Presence	http://www.scotland.gov.uk/Publications/2011/03/16182005/37
Blue-Green Algae	20-100X10^6	WHO, 2003
Dinophysis spp.	100-1,000	http://www.scotland.gov.uk/Publications/2011/03/16182005/37; Vlamis al. 2014
Heterosigma akashiwo	500,000	Expert opinion
Karenia mikimotoi	5,000	National Shellfish Sanitation Program Guide for Control of Molluscan Shellfish, www.issc.org
Karlodinium veneficum	500,000	Expert opinion
Pseudo-nitzschia	10,000	Cal-HABMAP ; Shumway et al. 1995; Anderson et al. 2009

Table 3.11. HAB Abundance Classification Table. Classification should be applied to each subembayment. If multiple HABs are detected within a subembayment on an annual basis, lowest rating for the year should be applied.

Cell Count By Taxonomic Group	**Ecological Condition Based on Annual Frequency of Occurrence in Monthly Samples**			
	1 of 12	2-3	4-6	6+
Cyanobacteria[1]. Applies at salinities ≤ 2 ppt.				
Absent to < 20,000 cells per ml	Very high	Very high	Very high	Very high
20,000 – 10^5 cells per ml	High	Moderate	Low	Very Low
10^5 – 10^7 cells per ml	Moderate	Low	Very Low	Very Low
> 10^7 cells per ml	Low	Very Low	Very Low	Very Low
Pseudo-nitzchia spp.				
<100 cells per l	Very high	Very high	Very high	Very high
100 to 10,000 cells per l	High	High	Moderate	Low
10,000 -50,000 cells per l	Moderate	Low	Low	Very Low
> 50,000 cells per l	Low	Very Low	Very Low	Very Low
Alexandrium spp.				
Non detect	Very high	Very high	Very high	Very high
Detectable to < 100 cells	High	Moderate	Low	Very low
>100 cells	Low	Very low	Very low	Very Low

[1] Cyanobacteria include: Cylindrospermopsis, Anabaena, Microcystis, Planktothrix, Anabaenopsis, Aphanizomenon, Lyngbya, Raphidiopsis, Oscillatoria, and Umezakia

Basis for Toxin Table Classification

Particulates and Tissues Concentrations

- Regulated by State of California
- Action level = regulatory closure level
- Warning level = 50% of action level

SPATT

- Derived from empirical relationships between particulates and SPATT concentrations

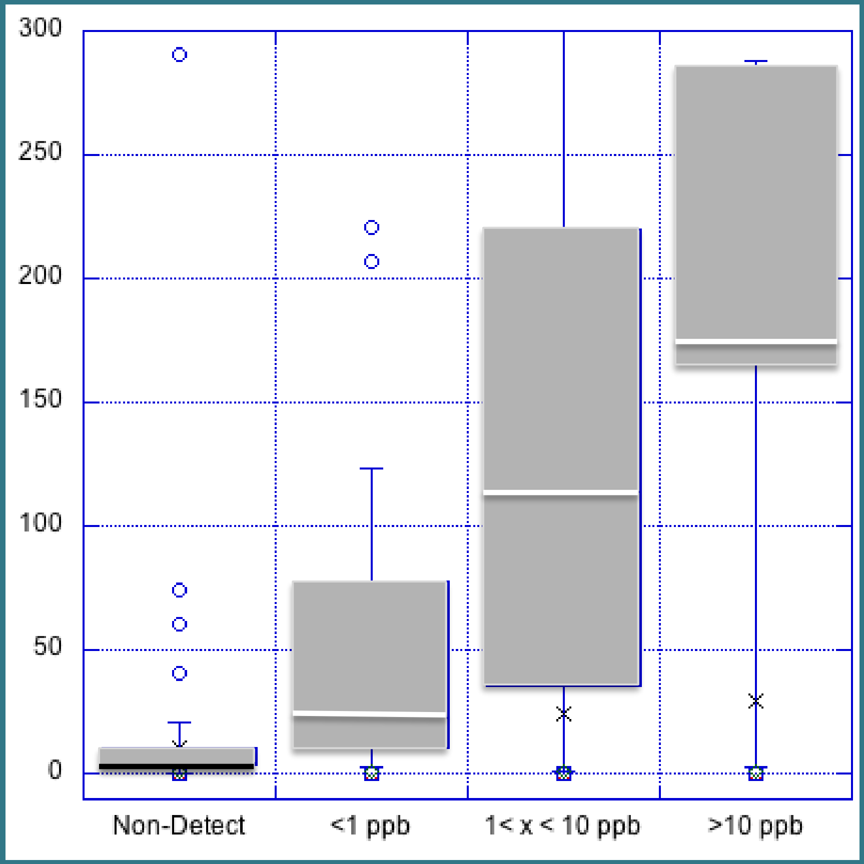
SPATT Validation

Values are reported as mass (ng) toxin per gram resin deployed, for some period of time. Difficult to directly compare to regulatory limits, which are typically based on grab samples or on contamination of food products.

Grab vs. SPATT (7 day deployments*)

Grab Sample (ppb)	SPATT (ng/g)
Non-Detect	5-13
< 1 ppb	20-50
1< x < 10 ppb	100-200
> 10 ppb	175-245

Domoic Acid Mussel (ppm)	SPATT (ng/g)
0-5 ppm	0-30
5-10 ppm	30-50
10-20 ppm	50-75
>20 ppm	>150



Sources of Uncertainty: HAB Cell Density and Toxin Classification

- Use of existing national NSSP and OEHHA guidelines - no SF Bay or statewide numeric objectives/regulatory numbers have been adopted
- Significance of threat uncertain
  - Human health
    - Uncertainty about levels of exposure linked to classification bins
    - Risk based on acute exposures
  - Aquatic Risk
    - Lack of information about acute and chronic exposures
- SPATT as a tool has not undergone rigorous calibration.

Primary Productivity Classification

TABLE 3.6. GROSS PRIMARY PRODUCTIVITY CLASSIFICATION TABLE BASED ON ANNUAL RATE (G M^{-2} YR^{-1}). CLASSIFICATION SHOULD BE APPLIED TO EACH SEGMENT.

Category	Gross Primary Productivity (g m^{-2} yr^{-1})
Very high/High	≤300
Moderate	>300 - 500
Low/ Very Low	≥ 500

N.B. Nixon (1995) oligotrophic and mesotrophic are combined into one category (very high/high ecological condition), expressly to avoid categorizing very low productivity values as indicative of very high ecological condition, since some level of productivity is considered important.

Two Major Sources of Uncertainty in GPP Classification

- Uncertainty of lumping of highly oligotrophic GPP into the highest category
  - —We do not have the scientific basis to determine at what level oligotrophy is harmful.

- Use of an indirect approach to estimate GPP
  - —But… because the intent is to calibrate indirect estimates on a frequent basis with direct GPP measures, this uncertainty will be constrained.

Deferred on Classification for Dissolved Oxygen, but Offered Recommendations

- Refine expectations for deepwater and margin habitats
- Consider in future iterations of the SF Bay assessment framework classification of DO that captures a fuller gradient of condition
- The use of the percentile approach doesn't distinguish between high frequency short duration events and low frequency but long duration events
- Consider how to address “natural” hypoxia or low DO
- Recommend revising DO monitoring program
  - Coupled to assessment framework that characterizes seasonal DO requirements of the most sensitive species and important habitats

Offered Advice on how to Use Indicators as Multiple Lines of Evidence, given Uncertainty

- Three indicators should be given strong weight given their strong linkage to beneficial uses:
  - DO
  - HAB toxins
  - GPP
- Two indicators should be given moderate weight in motivating management action, <u>at this time, pending additional science</u>
  - HAB abundances, pending better characterization of HAB risk
  - Chlorophyll-a endpoints, because of uncertainty in thresholds that lead to unacceptable risk of HAB toxins and low DO
  - Use these endpoints as testable hypotheses, to be refined by modeling and monitoring
- Focus on research and data visualization for phytoplankton composition and food quality index investigate trends and explain drivers

Vision for Near Term Use of Assessment Framework

- The conceptual models and assessment framework core principles provide a sound scientific foundation for informing modeling and monitoring.
- Fully acknowledge the uncertainty in the assessment framework classification scheme and need for refinement, through multiple iterations of basic research, monitoring, and modeling.
- Recommend that near-term use be focused on a scientific "test drive"
  - —focused on understanding how to collectively use and improve efficiencies for assessment, monitoring and modeling
  - —consider whether or how to combine indicator results into multiple lines of evidence, particularly for communication to the public.
  - —test drive should be conducted in tandem with research, monitoring and modeling to refine the assessment framework.

Questions? Comments?

Thank you!