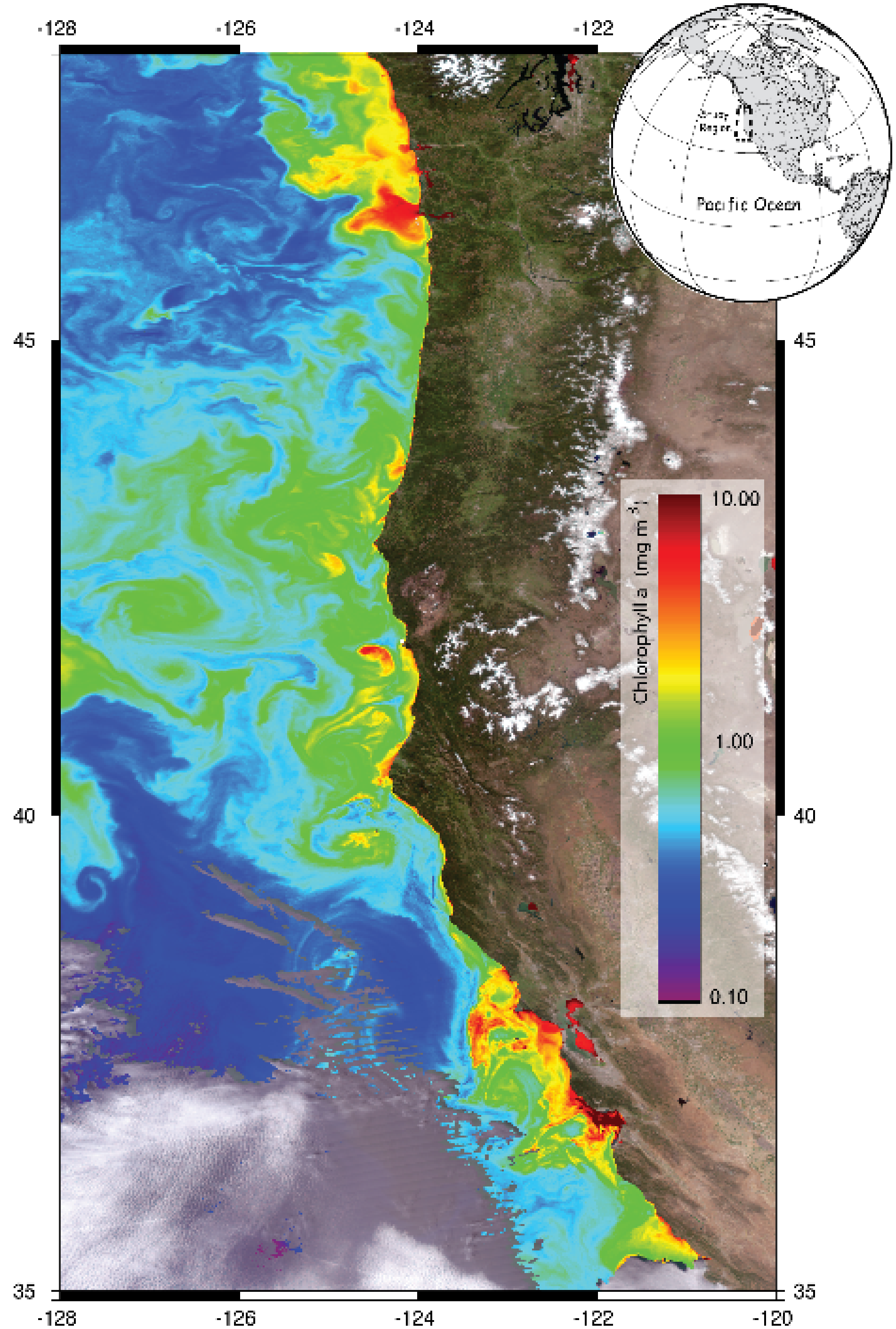
For assistance in accessing this document please send an email to EPACyanoHABs@epa.gov

Droughts, Blooms, Warm Blobs, and Other Anomalies In the Eastern Pacific: Lessons Learned (?)



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Anna McGaraghan
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Cori Gibble
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Nilo Alvarado
Dana Shultz
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Collaborators SF Bay:
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Martha Sutula, SCCWRP
Lisa Campbell, Texas A&M
… and their teams

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ECOHAB/MERHAB:
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Keith Loftin
Drew Lucas
John Ryan
Chris Scholin
G. Jason Smith
Yi Chao

Harmful Algal Blooms

A scientific summary for policy makers

SCOR

UNESCO
United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

GEOHAB
Global Ecology and Oceanography of Harmful Algal Blooms

Summary & Key Points

- HABs result from noxious and/or toxic algae that cause direct and indirect negative impacts to aquatic ecosystems, coastal resources, and human health.
- HABs are present in nearly all aquatic environments as naturally occurring phenomena.
- Many HABs are increasing in severity and frequency, and biogeographical range. Some of this expansion is attributed to climate change and global change.
- Research has improved understanding, leading to better prediction and monitoring, and potentially, mitigation.
- HABs are a worldwide phenomenon requiring international understanding leading ultimately to local and regional solutions.
- HABs must be integrated with policy decisions.

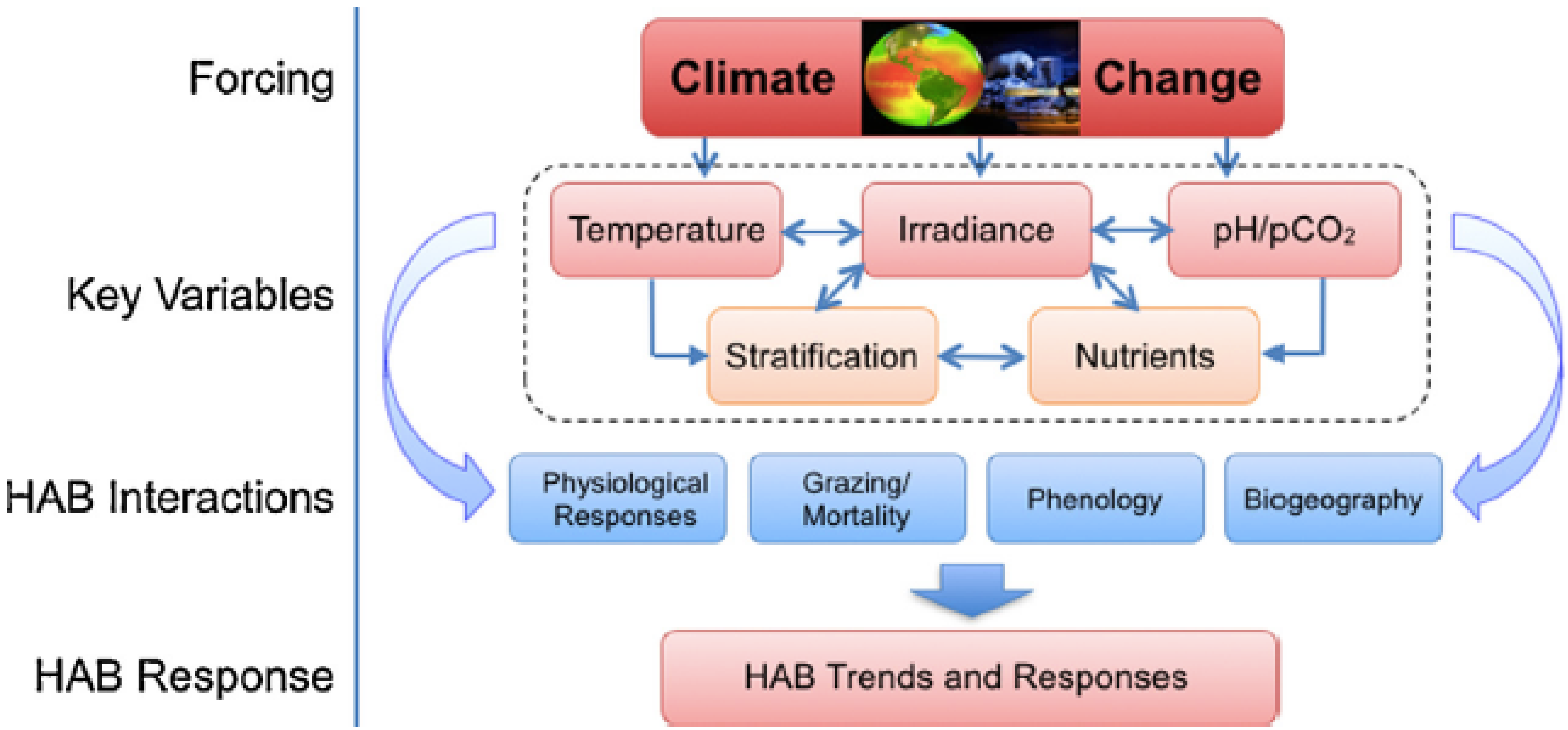
Harmful Algal Blooms
Known Knowns, Unknown Knowns

http://gawker.com/5299327%2Fsad-donald-rumsfeld-is-not-crazy-just-misunderstood

- We know all of the HAB organisms and toxins
- Nutrients and blooms are strongly related
- Blooms like it hot! Blooms like it dry!
- Warm anomalies are indicative of a future warm ocean (the “new normal”)
- Changes in HABs are predictable

Many HABs are increasing in severity and frequency, and biogeographical range. Some of this expansion is attributed to climate change and global change.

M.L. Wells et al. / Harmful Algae 49 (2015) 68–93

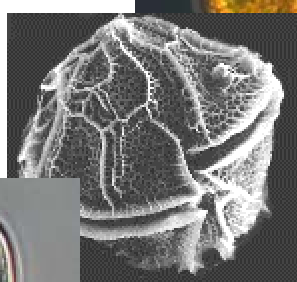


Alexandrium

Pseudo-nitzschia

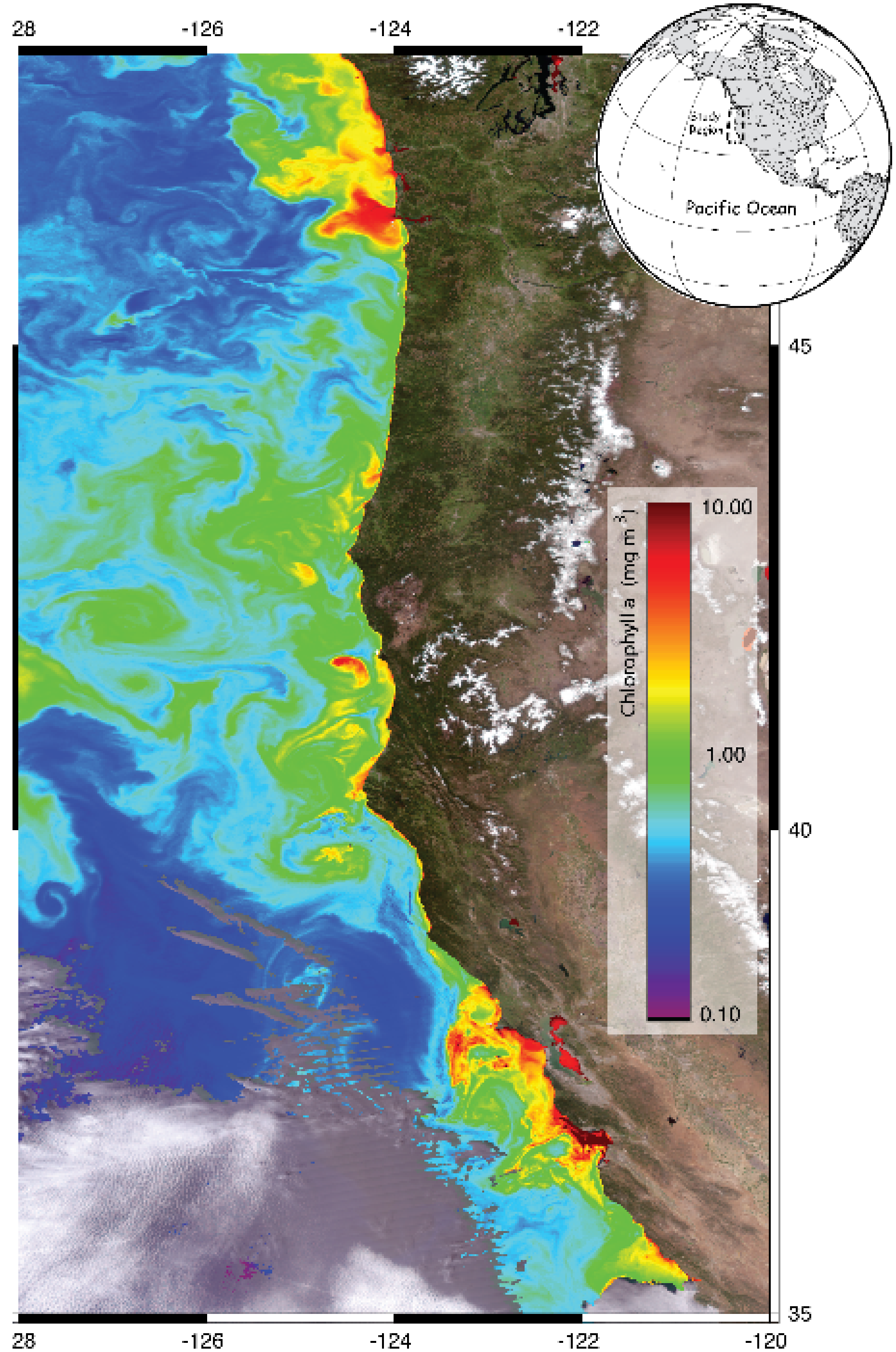
Cyano-HABs

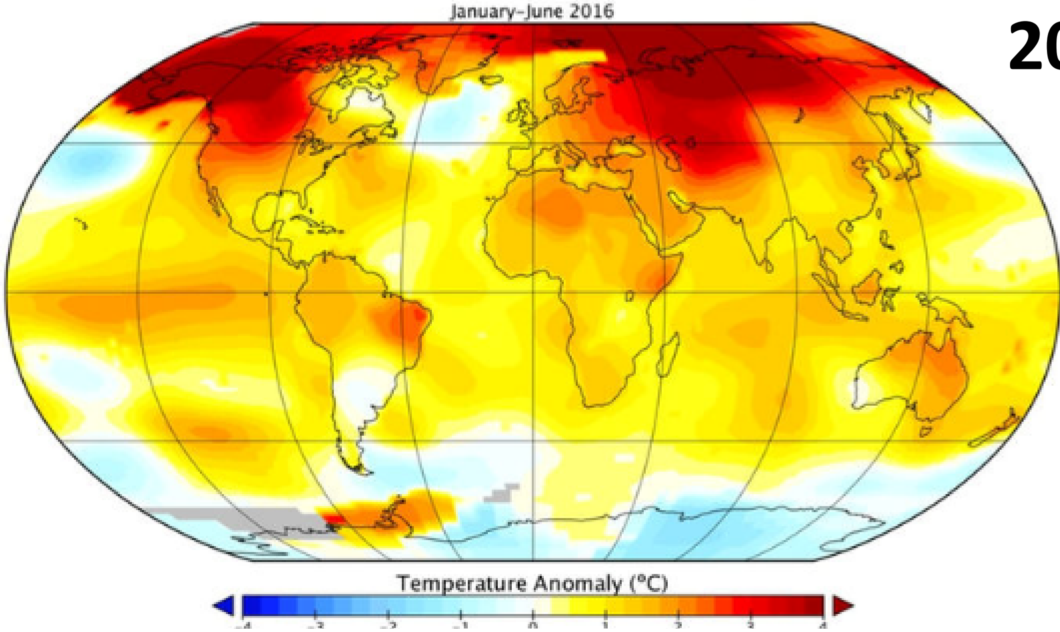
Akashiwo sanguinea



Gonyaulax /Lingulodinium

Dinophysis

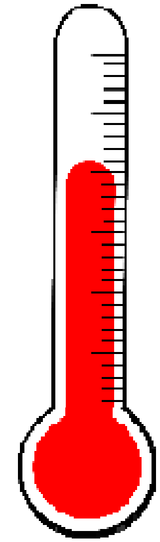


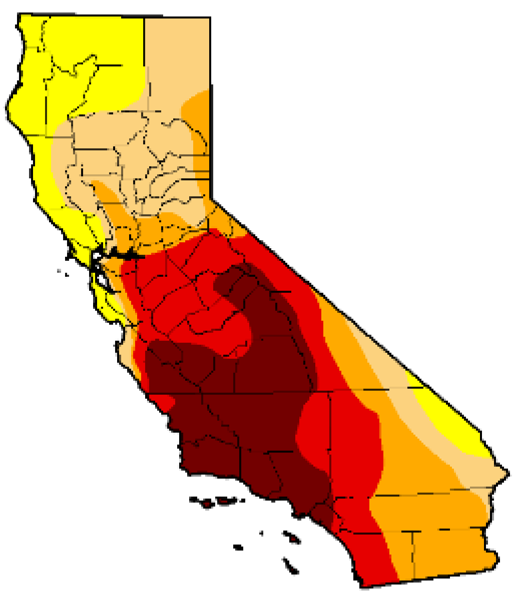


2014

2015

2016





October 4, 2016

(Released Thursday, Oct. 6, 2016)

Valid 8 a.m. EDT

Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.00	100.00	83.59	62.27	42.80	21.04
Last Week	0.00	100.00	83.59	62.27	42.80	21.04
3 Months Ago	0.00	100.00	83.59	58.02	42.80	21.04
Start of Calendar Year	0.00	100.00	97.33	87.55	69.07	44.84
Start of Water Year	0.00	100.00	83.59	62.27	42.80	21.04
One Year Ago	0.14	99.86	97.13	82.33	71.08	46.01

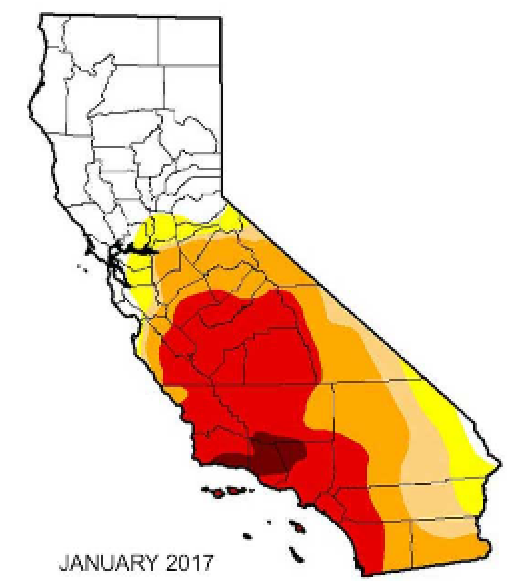
Intensity:

- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:
Brian Fuchs
National Drought Mitigation Center

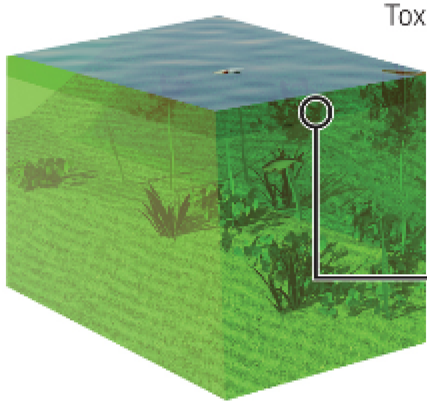
http://droughtmonitor.unl.edu/



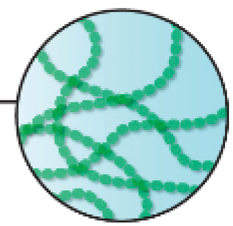
JANUARY 2017

A BLOOMING THREAT

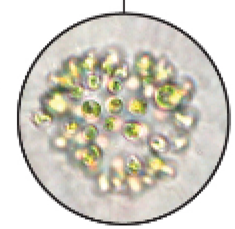
Toxic blue-green algae is an emerging health issue in drought-stricken California.



Cyanobacteria
(blue-green algae)



Microcystis
Type of cyanobacteria that produces a dangerous toxin, which can cause allergic reactions, skin irritation, fever, gastrointestinal illnesses, joint pain, liver damage and even cancer in humans.



Estimated microcystin levels and relative probability of acute health effects, in micrograms per liter (µg/L)

LOW	MODERATE	HIGH	VERY HIGH
<10ug/L	10-20ug/L	20-2,000ug/L	>2,000ug/L

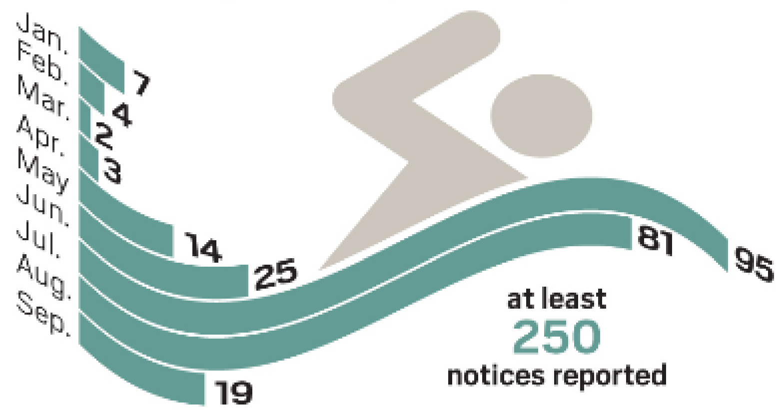
Highest levels of microcystin found in California water bodies, detected between 2011 and 2015

PYRAMID LAKE (L.A. County)	LAKE CHABOT (Alameda County)	PINTO LAKE (Santa Cruz County)	KLAMATH RIVER (Northern California)
81.5ug/L	5,100ug/L	1,013.37ug/L	43,000ug/L
June 23, 2015	December 24, 2014	December 2, 2012	August 6, 2012

Sources: Biological Sciences at Purdue University; Central Coast Regional Water Quality Control Board, California Department of Water Resources and U.S. Environmental Protection Agency

Number of health advisories issued by month, 2015

Including cautions, warnings, public health advisories and public health warnings due to the presence of algae or toxins



STAFF GRAPHIC

http://projects.dailynews.com/blue-green-algae/

Latest algae bloom, in Discovery Bay, threatens way of life

By Kurtis Alexander Updated 11:40 am, Wednesday, July 27, 2016

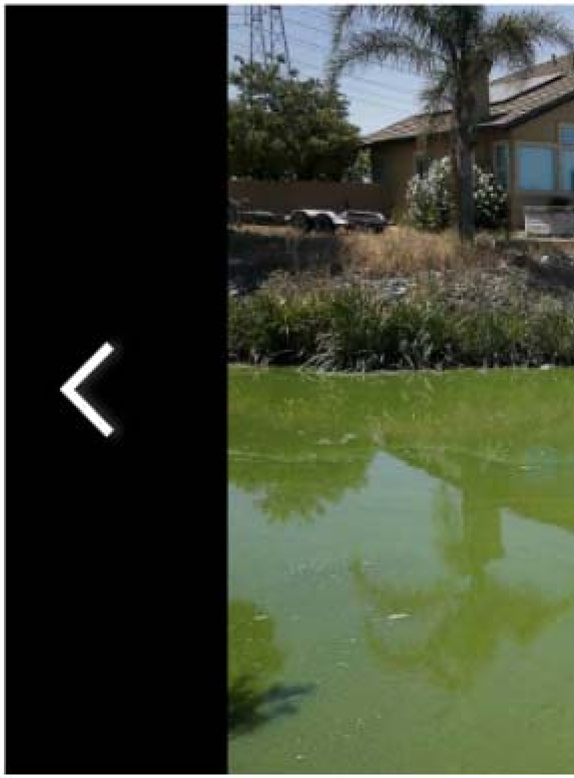


Photo: Paul Chinn, The Chronicle

Berkeleyside

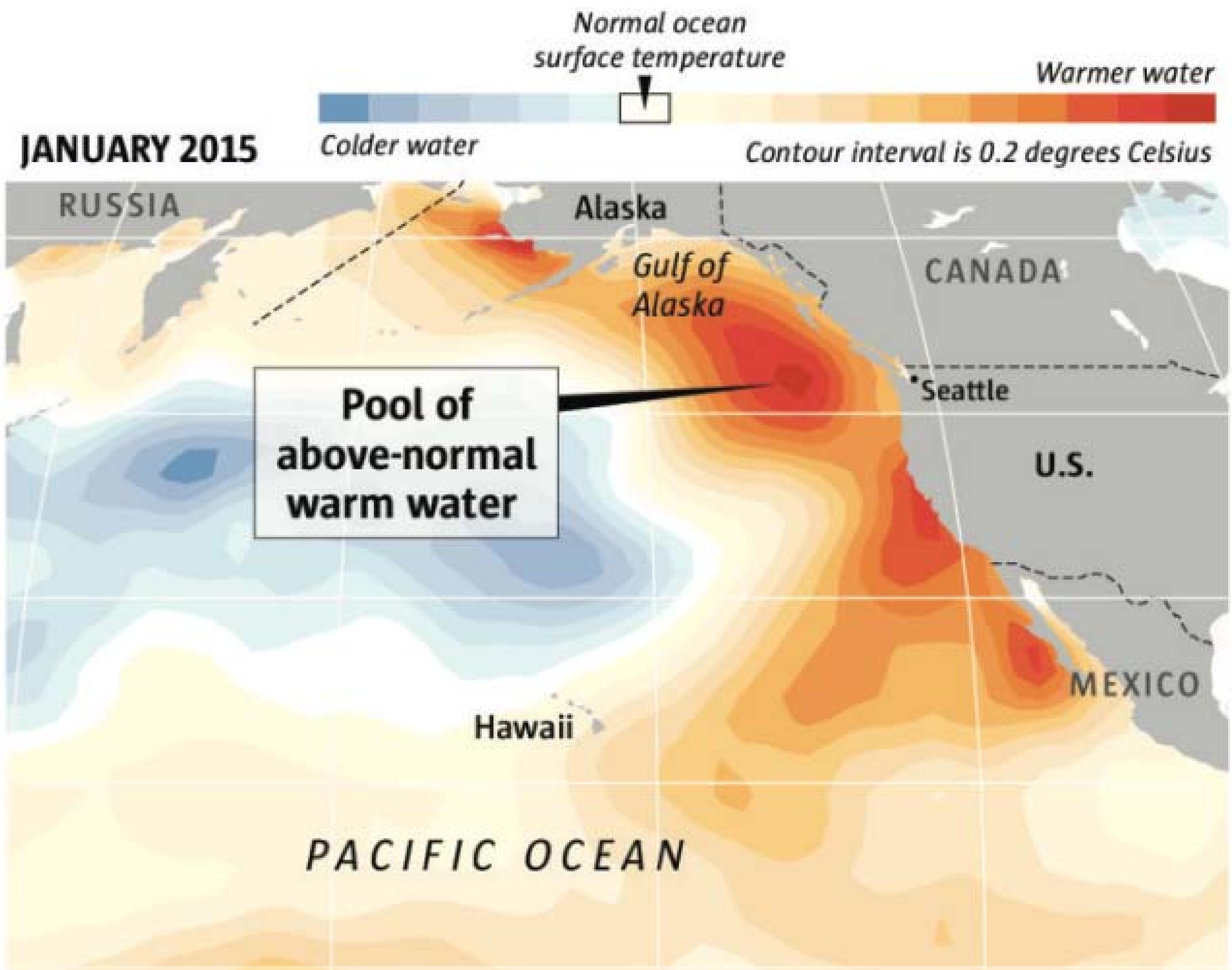
After rains, some East Bay lakes now free of toxic algae

By Emilie Raguso,
Feb. 1, 2016, 2 p.m.

Lake Anza is expected to re-open for swimming in April, now that the algae is gone. Photo: Josh S. Jackson

The blob off our coast

Scientists say a vast pool of warm water off our coast is affecting marine life and local weather, and is part of a bigger pattern that includes California's drought and East Coast blizzards.



Source: Department of Atmospheric Sciences, University of Washington

MARK NOWLIN / THE SEATTLE TIMES

$48M Loss 2015-2016

Harmful Algal Blooms
Known Knowns, Unknown Knowns

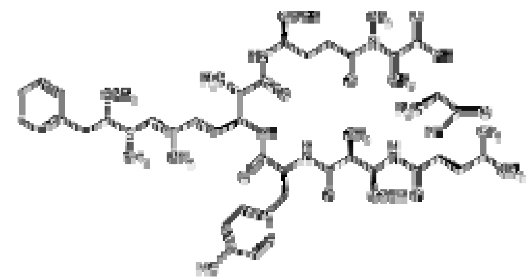
- We know all of the HAB organisms and toxins
- Nutrients and blooms are strongly related
- Blooms like it hot! Blooms like it dry!
- Warm anomalies are indicative of a future warm ocean (the “new normal”)
- Changes in HABs are predictable

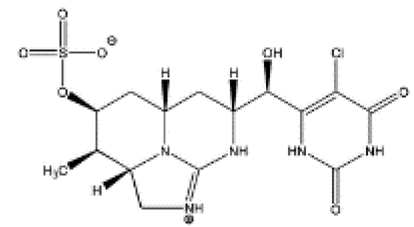
Anderson et al., Coastal & Marine Hazards, Risks, & Disasters, Elsevier 2015 http://dx.doi.org/10.1016/B978-0-12-396483-0.00017-0

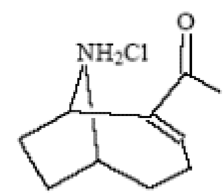
Syndrome	Toxin(s)	Causative Organism	Symptoms
Ciguatera Fish Poisoning (CFP)	Ciguatoxins	*Gambierdiscus* spp.[b]	Nausea, vomiting, diarrhea, numbness of the mouth and extremities, rash, and reversal of temperature sensation. Neurological symptoms may persist for several months.
Paralytic Shellfish Poisoning (PSP)	Saxitoxin and its derivatives	*Alexandrium* spp. *Pyrodinium* spp. *Gymnodinium* spp.	Numbness and tingling of the lips, mouth, face, and neck, nausea, and vomiting. Severe cases result in paralysis of the muscles of the chest and abdomen possibly leading to death
Amnesic Shellfish Poisoning (ASP)	Domoic acid	*Pseudo-nitzschia* spp. *Nitzschia navis-varingica*	Nausea, vomiting, diarrhea, headache, dizziness, confusion, disorientation, short-term memory deficits, and motor weakness. Severe cases result in seizures, cardiac arrhythmia, respiratory distress, coma, and possibly death
Azaspiracid Shellfish Poisoning (AZP)	Azaspiracid and its derivatives	*Azadinium* spp.[a]	Nausea vomiting, severe diarrhea, and abdominal cramps
Neurotoxic Shellfish Poisoning (NSP)	Brevetoxin	*Karenia* spp.	Nausea, temperature sensation reversals, muscle weakness, and vertigo
Diarrhetic Shellfish Poisoning (DSP)	Okadaic acid and its derivatives	*Dinophysis* spp. *Prorocentrum* spp.	Nausea vomiting, severe diarrhea, and abdominal cramps
Diarrhetic Shellfish Poisoning (DSP)[e]	Yessotoxin	*Gonyaulax spinifera* *Protoceratium reticulatum* *Lingulodinium polyedrum*	Nausea, vomiting, abdominal cramps, reduced appetite, cardiotoxic effects, respiratory distress
Diarrhetic Shellfish Poisoning (DSP)[e]	Cooliatoxin[c]	*Coolia* spp.[b]	Nausea, vomiting, abdominal cramps, reduced appetite, cardiotoxic effects, respiratory distress
Palytoxicosis	Palytoxin and its derivatives[d,f]	*Ostreopsis* spp.[b]	Nausea, vomiting, diarrhea, abdominal cramps, lethargy, tingling of the lips, mouth, face, and neck, lowered heart rate, skeletal muscle breakdown, muscle spasms and pain, lack of sensation, respiratory distress
Lyngbyatoxicosis	Lyngbyatoxin-A and its derivatives	*Lyngbya majuscula*[d,g]	Weakness, headache, lightheadedness, salivation, gastrointestinal inflammation, potent tumor promoter

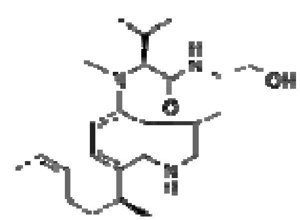
Dittman et al., FEMS Microbiology Reviews 2013,
DOI: 10.1111/j.1574-6976.2012.12000.x.23-43

Cyanobacterial toxin	Producing genera/species	Toxic mechanism	Biosynthetic genes	Genbank accession numbers
Microcystin	*Microcystis* sp. *Planktothrix* sp. *Anabaena* sp. *Nostoc* sp. *Hapalosiphon* sp. *Phormidium* sp.	Hepatotoxic; inhibition of eukaryotic protein phosphatases of type 1 and 2A	*mcyA-J*	AF183408 AJ441056 AJ536156
Nodularin	*N. spumigena*	Hepatotoxic; inhibition of eukaryotic protein phosphatases of type 1 and 2A	*ndaA-I*	AY210783
Cylindrospermopsin	*C. raciborskii* *A. ovalisporum* *U. natans* *R. curvata* *Anabaena* sp. *Oscillatoria* sp.	Hepatotoxic, cytotoxic, neurotoxic; inhibition of glutathione synthesis, protein synthesis and cytochrome P450	*cyrA-O* *aoaA-C*	EU140798 AF395828 FJ418586
Anatoxin-a Homoanatoxin-a	*A. flos-aquae* *Oscillatoria* sp. *Aphanizomenon* sp.	Neurotoxic, mimics the neurotransmitter acetylcholine	*anaA-H*	FJ477836 JF803645
Saxitoxin	*A. circinales* *Aphanizomenon* sp. *A. gracile*	Neurotoxic, blocks voltage-gated Na+ channels	*sxtA-Z*	DQ787200
BMAA	*Many cyanobacteria*	Neurotoxic, motor neuron damage and loss	*Unknown*	–
Lyngbyatoxin	*L. majuscula* *(M. producens)*	Tumor promoting, binds to protein kinase C (PKC)	*ltxA-D*	AY588942
Aplysiatoxin	*L. majuscula* *(M. producens)*	Tumor promoting, binds to protein kinase C (PKC)	*Unknown*	–









Diatoms: A Novel Source for the Neurotoxin BMAA in Aquatic Environments

Liying Jiang, Johan Eriksson, Sandra Lage , Sara Jonasson , Shiva Shams , Martin Mehine , Leopold L. Ilag , Ulla Rasmussen

Published: January

Research Article
Environmental Science and Pollution Research
January 2016, Volume 23, Issue 1, pp 338-350

First online: 26 August 2015

BMAA extraction of cyanobacteria samples: which method to choose?

Sandra Lage, Alfred Burian, Ulla Rasmussen, Pedro Reis Costa, Heléne Annadotter, Anna Godhe, Sara Rydberg

Toxins (Basel). 2014 Feb; 6(2): 488–508.
PMCID: PMC3942747
Published online 2014 Jan 28. doi: 10.3390/toxins6020488

Co-occurrence of the Cyanotoxins BMAA, DABA and Anatoxin-*a* in Nebraska Reservoirs, Fish, and Aquatic Plants

Maitham Ahmed Al-Sammak,[1,3] Kyle D. Hoagland,[2] David Cassada,[3] and Daniel D. Snow[3,*]

Author information ► Article notes ► Copyright and License information ►

ARTICLE

Received 5 Sep 2013 | Accepted 14 Mar 2014 | Published 16 Apr 2014

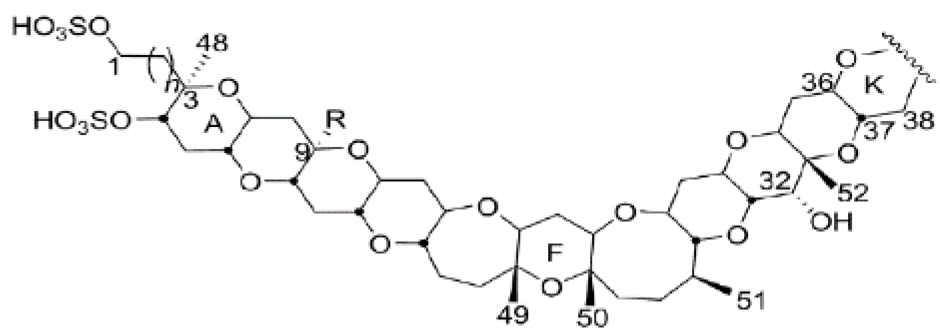
DOI: 10.1038/ncomms4652

Forensic genomics as a novel tool for identifying the causes of mass mortality events

Pierre De Wit[1,2], Laura Rogers-Bennett[3], Raphael M. Kudela[4] & Stephen R. Palumbi[1]

"…this has been the deadliest red tide for state abalone in at least three decades."

Press Democrat, 7-Sep-11



Received 5 Sep 2013 | Accepted 14 Mar 2014 | Published 16 Apr 2014 DOI: 10.1038/ncomms4652

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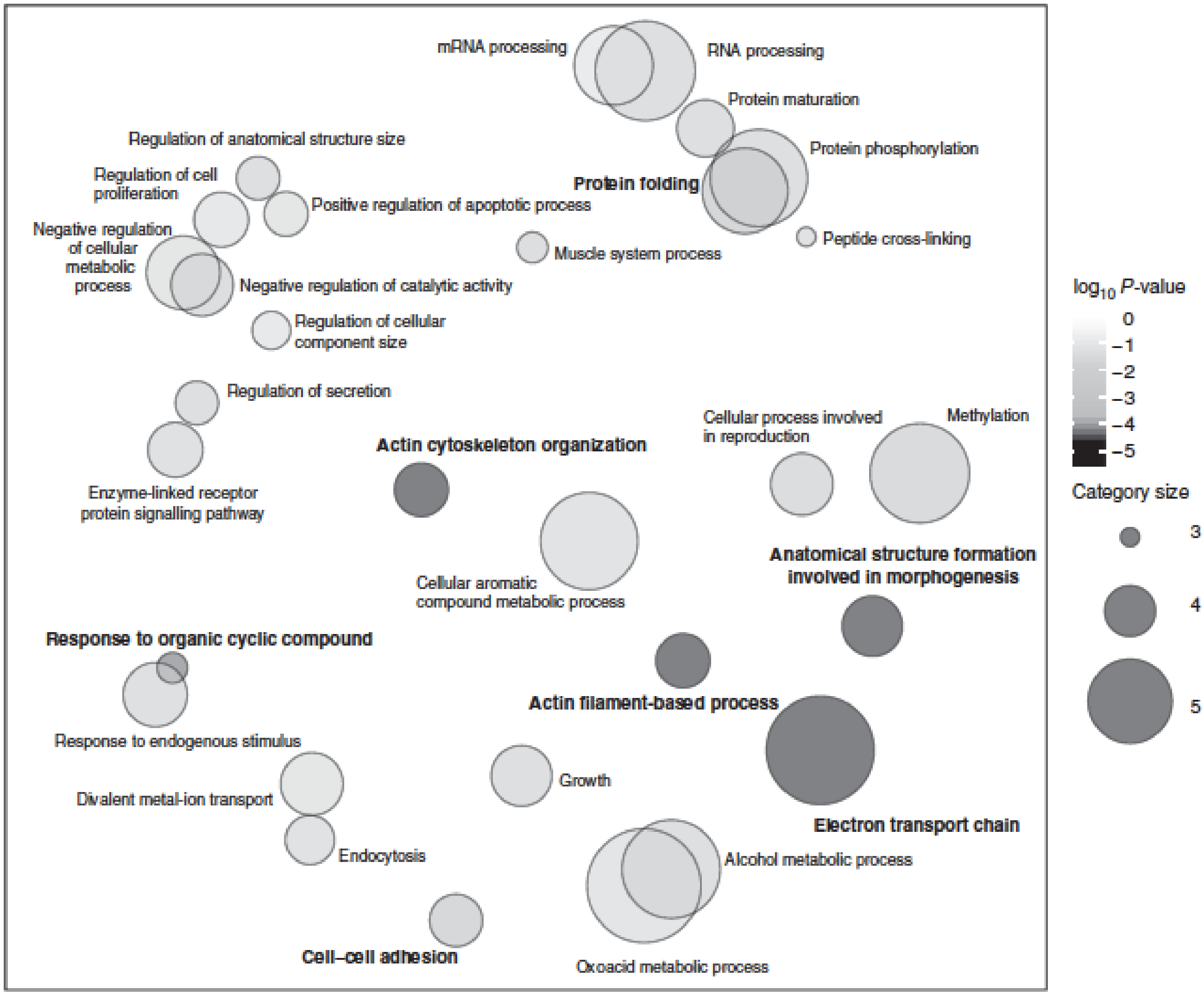
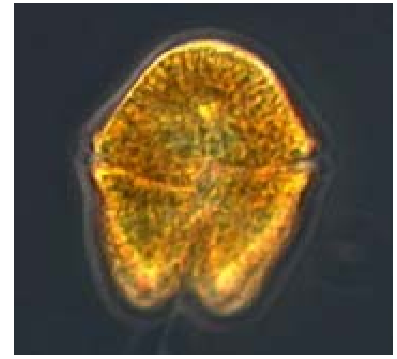
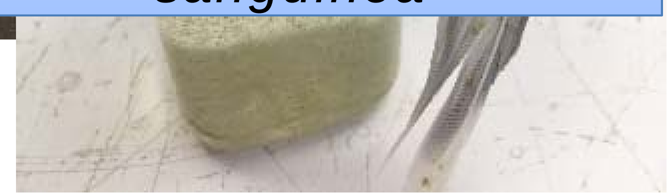




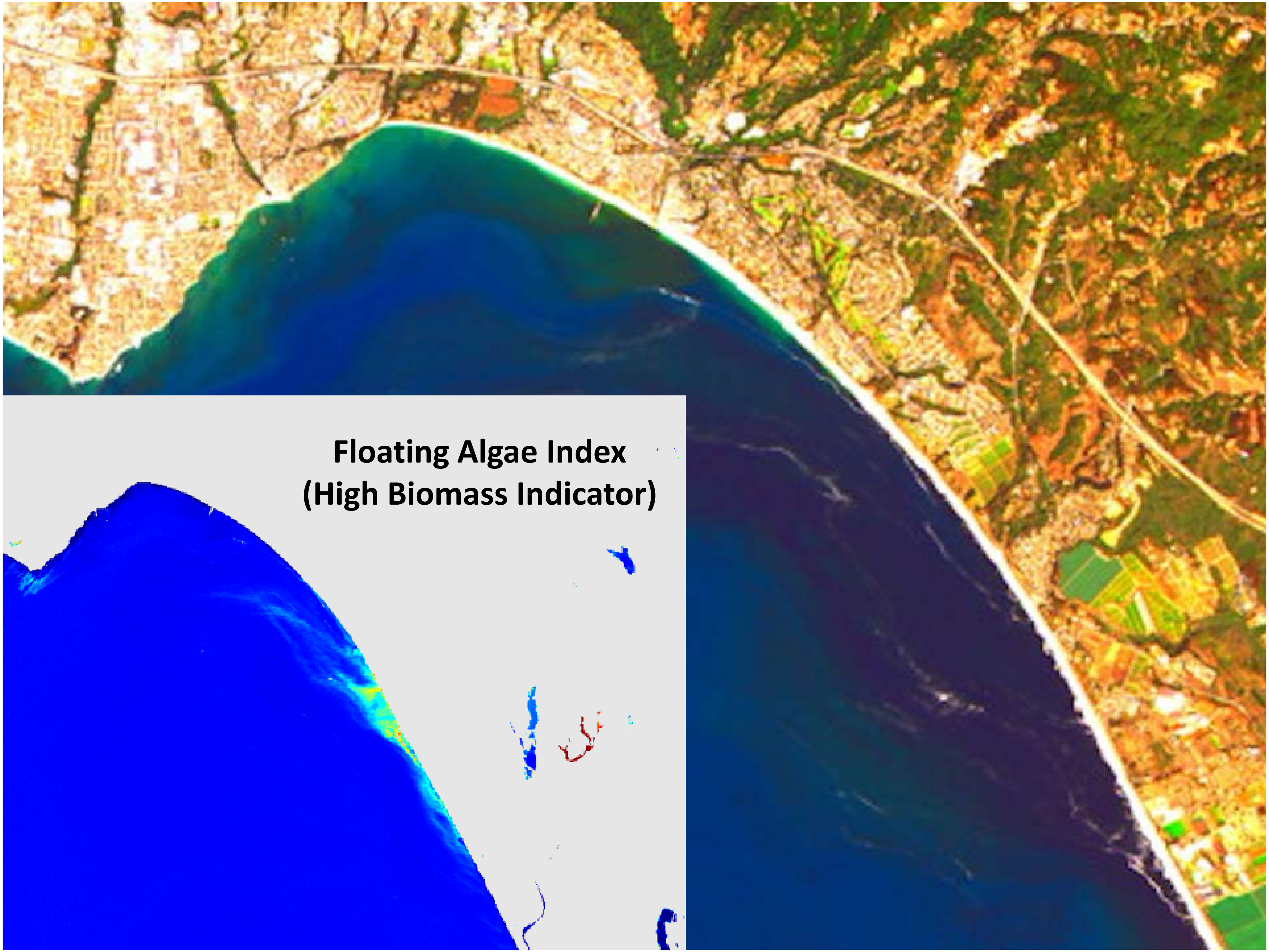
#	Affected Birds	Location, Year	HAB Species
2250	Black Ducks, other waterfowl	New Hampshire, 1972	*Gonyaulax tamarensis*
140	Brown Pelicans, Brandt's Cormorants	Santa Cruz, CA, 1991	*Pseudonitzschia australis*
150	Brown Pelicans	Baja California, 1996	*Pseudonitzschia spp.*
550	Northern Fulmars, Common Murres, large grebes	Monterey Bay, CA, 2007	*Akashiwo sanguinea*
8000	Scoters, other divers	Washington State, 2009	*Akashiwo sanguinea*



September 2016

Browned sea foam and murky water wash across Twin Lakes Beach and onto East Cliff Drive in Santa Cruz during a rainstorm on Sunday. (Kevin Johnson -- Santa Cruz Sentinel)

http://www.santacruzsentinel.com/article/NE/20161016/NEWS/161019597


Floating Algae Index
(High Biomass Indicator)

Harmful Algal Blooms
Known Knowns, Unknown Knowns

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http://gawker.com/5299327%2Fsad-donald-rumsfeld-is-not-crazy-just-misunderstood

Assumption: Blooms are driven by the same environmental factors

CLIMATE

Blooms Like It Hot

A link exists between global warming and the worldwide proliferation of harmful cyanobacterial blooms.

Hans W. Paerl[1] and Jef Huisman[2]

PNAS

Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment

David W. Schindler*[†], R. E. Hecky[‡], D. L. Findlay[§], M. P. Stainton[§], B. R. Parker*, M. J. Paterson[§], K. G. Beaty[§], M. Lyng[§], and S. E. M. Kasian[§]

*Department of Biological Sciences, University of Alberta, Edmonton, AB, Canada T6G 2E9; [‡]Department of Biology, University of Minnesota, Duluth, MN 55812; and [§]Fr

ELSEVIER

Water Research

Volume 45, Issue 5, February 2011, Pages 1973–1983

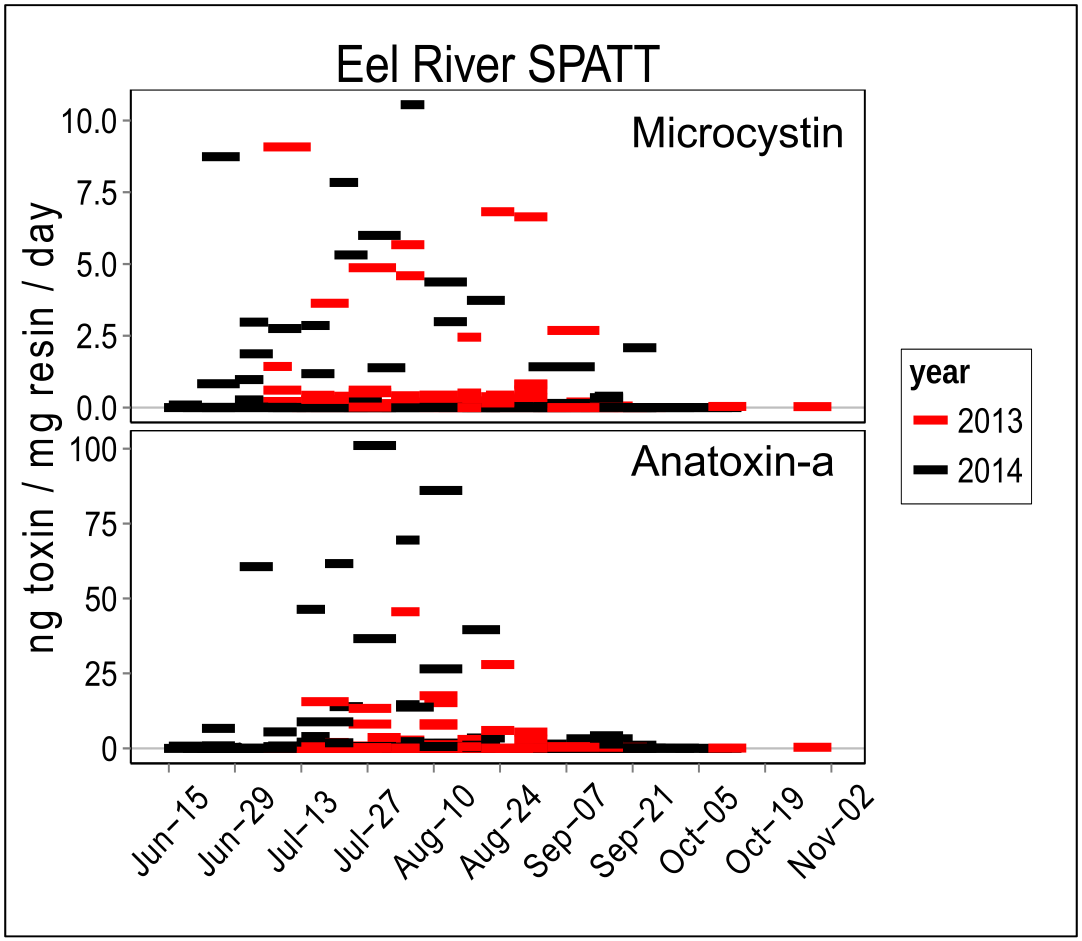
Controlling harmful cyanobacterial blooms in a hyper-eutrophic lake (Lake Taihu, China): The need for a dual nutrient (N & P) management strategy

Hans W. Paerl[a], Hai Xu[b], Mark J. McCarthy[c, d], Guangwei Zhu[b], Boqiang Qin[b], Yiping Li[a], Wayne S. Gardner[d]

High microcystin concentrations occur only at low nitrogen-to-phosphorus ratios in nutrient-rich Canadian lakes

Diane M. Orihel, David F. Bird, Michael Brylinsky, Huirong Chen, Derek B. Donald, Dorothy Y. Huang, Alessandra Giani, David Kinniburgh, Hedy Kling, Brian G. Kotak, Peter R. Leavitt, Charlene C. Nielsen, Sharon Reedyk, Rebecca C. Rooney, Sue B. Watson, Ron W. Zurawell, and Rolf D. Vinebrooke

Effects of the Drought

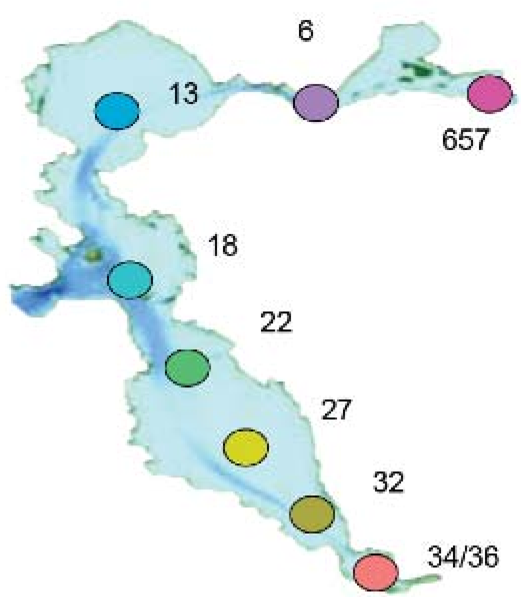


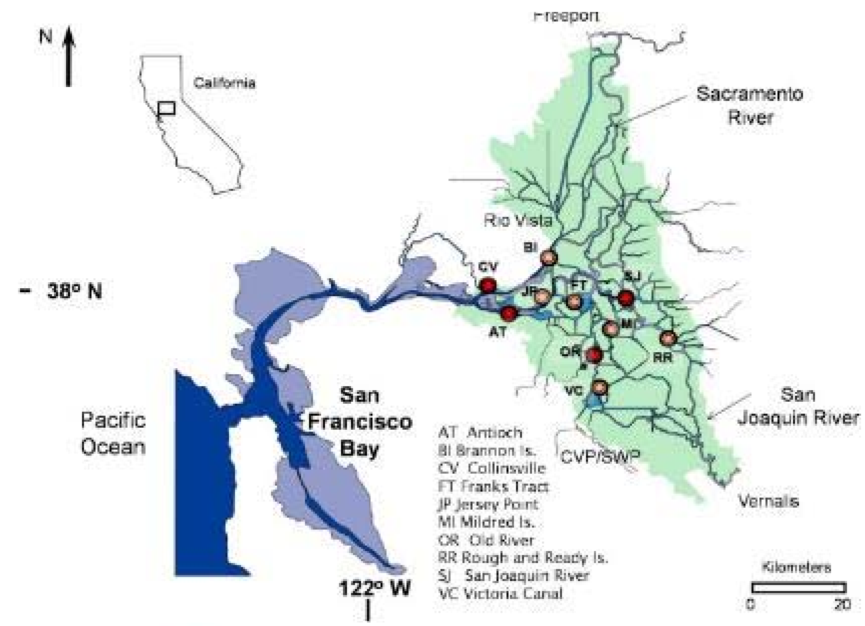
Bouma-Gregson & Higgins, 2014

- Bouma-Gregson et al. 2015: Eel river toxins are associated with warming, low flow
- Lehman et al. (2013): Blooms in the Delta are associated with low river flow
- Fetscher et al. (2015): toxins in wadeable streams are associated with reduced scour
- Lehman et al. (2017): droughts lead to increased frequency and intensity of blooms in the San Francisco Estuary

San Francisco Bay Time-Series

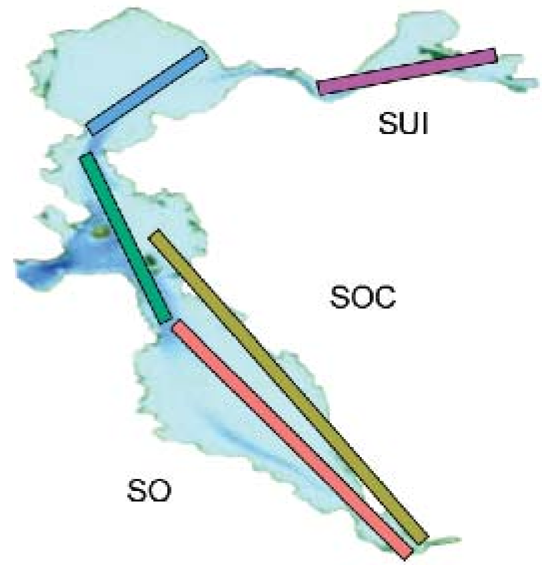
Particulate Microcystins

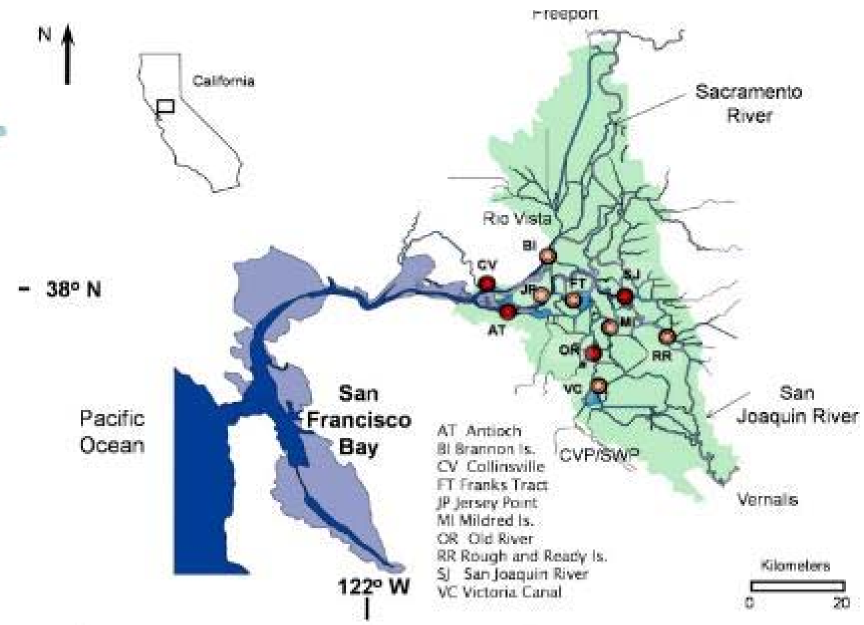


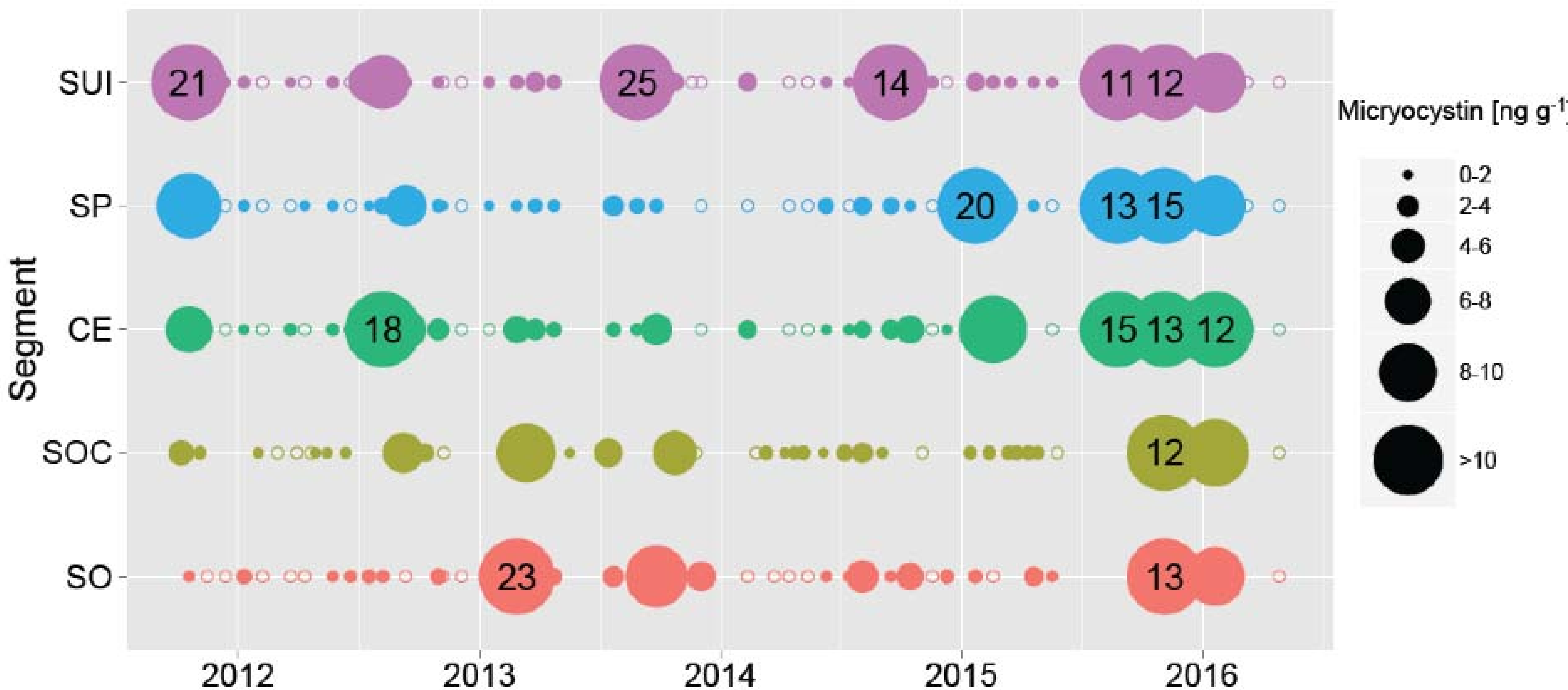


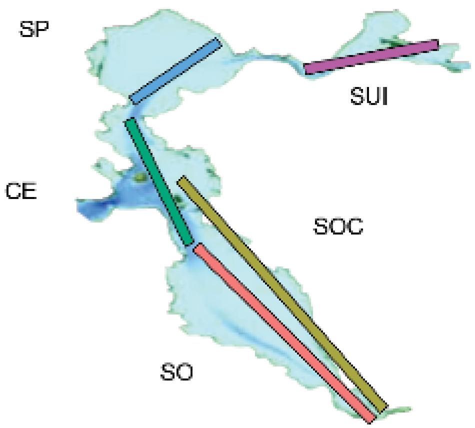
San Francisco Bay Time-Series

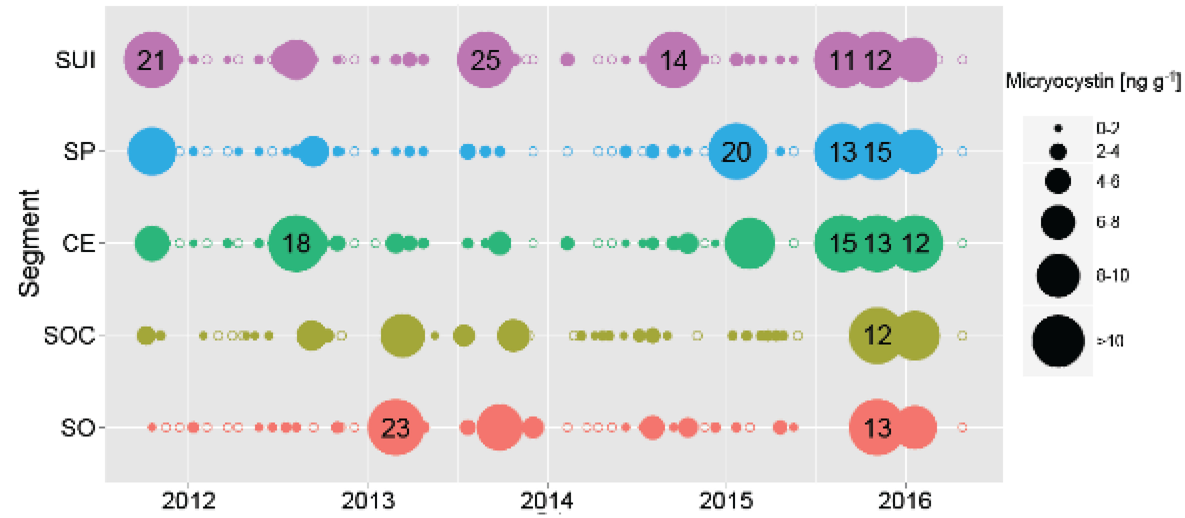
SPATT Microcystins








SP
SUI
CE
SOC
SO


SUI
SP
CE
SOC
SO
Segment
2012
2013
2014
2015
2016
Micryocystin [ng g-1]
0-2
2-4
4-6
6-8
8-10
>10
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18
15 13 12
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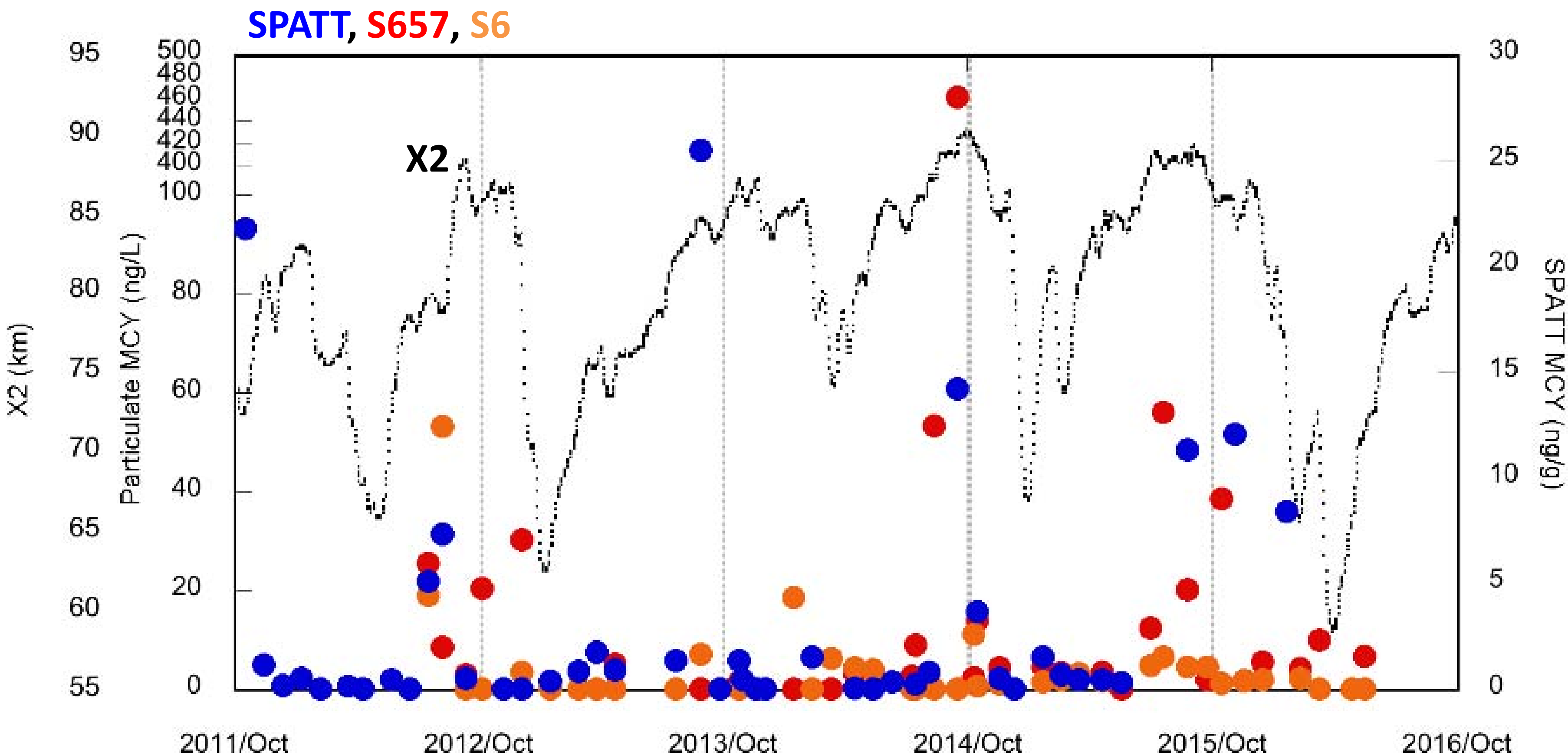
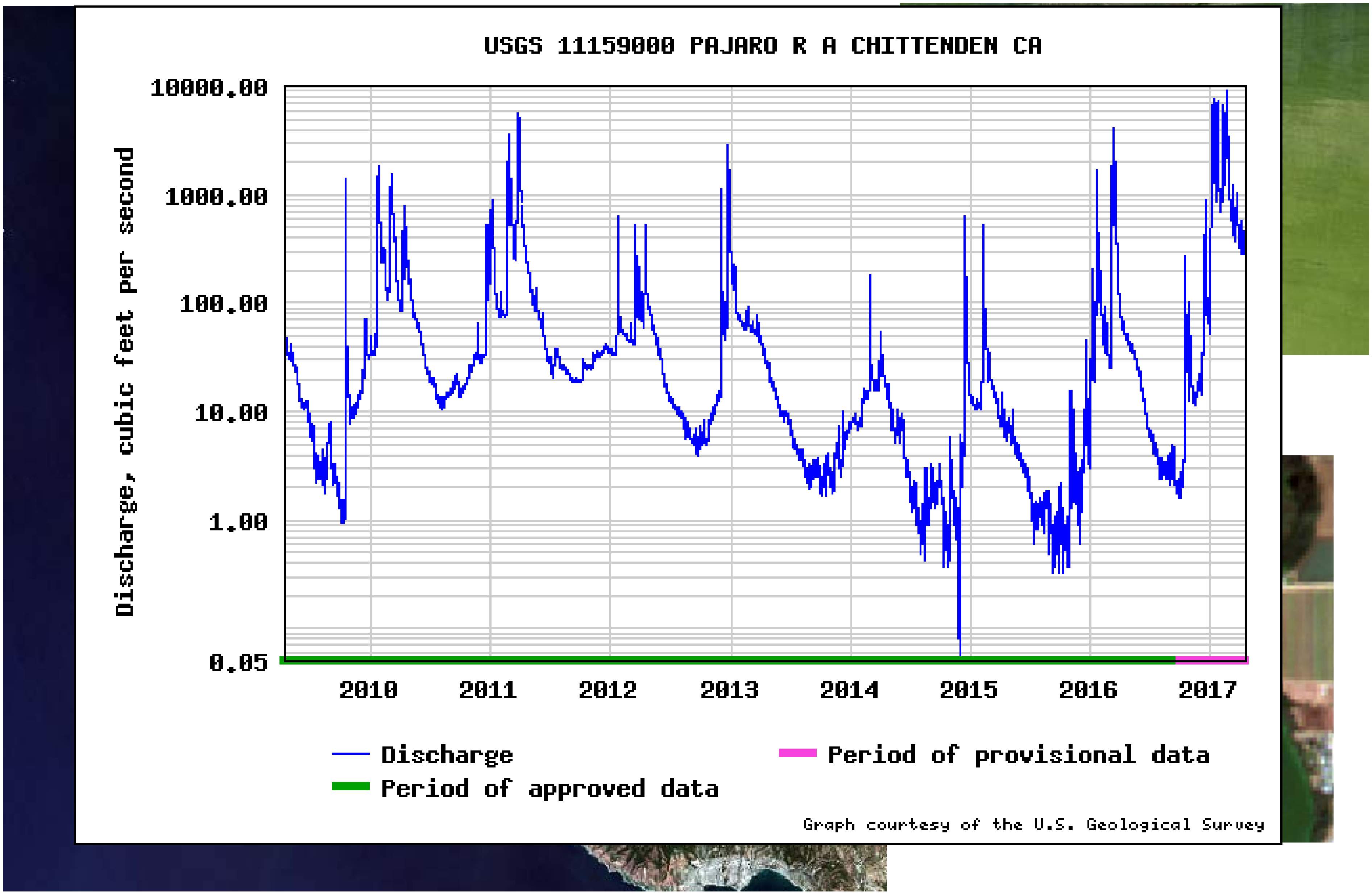
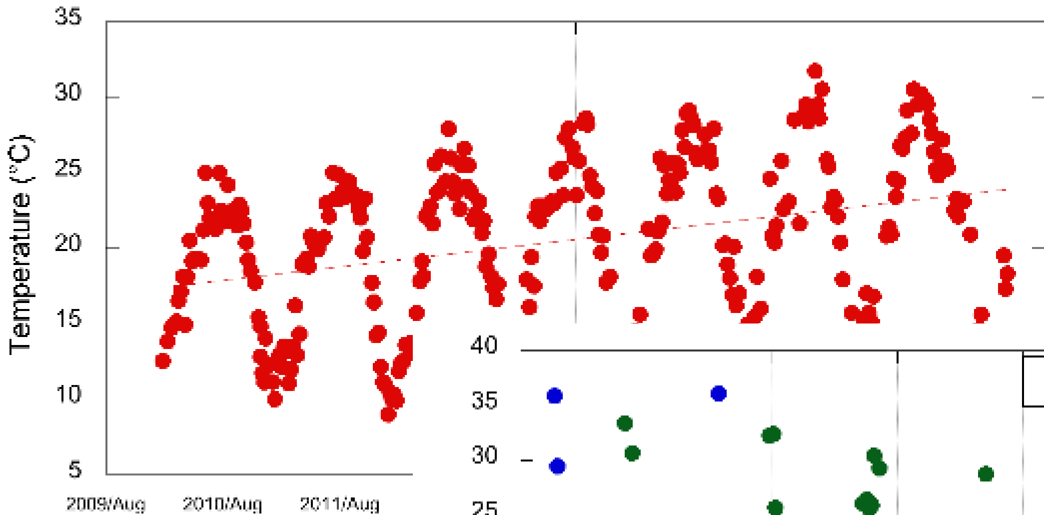

SPATT, S657, S6
X2
X2 (km)
Particulate MCY (ng/L)
SPATT MCY (ng/g)
95
90
85
80
75
70
65
60
55
500
480
460
440
420
400
100
80
60
40
20
0
30
25
20
15
10
5
0
2011/Oct
2012/Oct
2013/Oct
2014/Oct
2015/Oct
2016/Oct

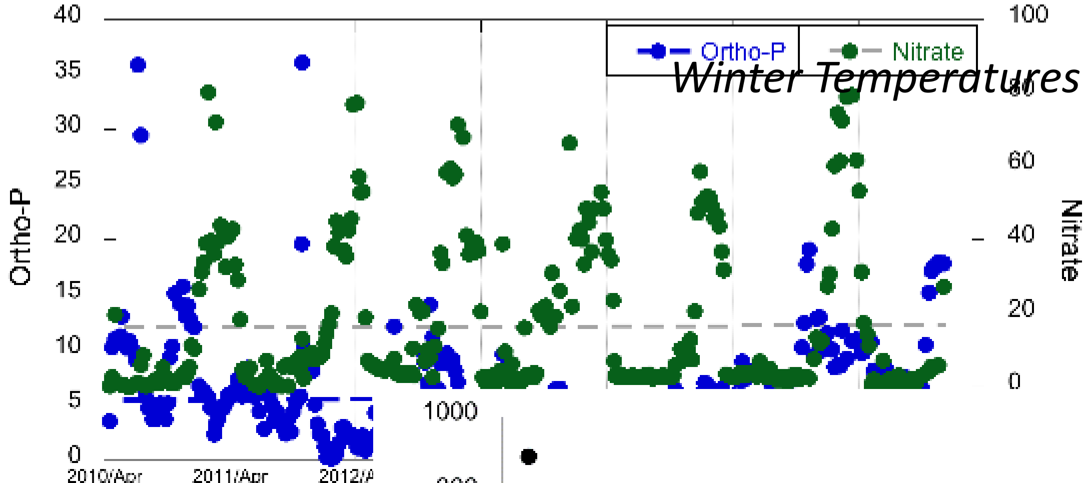
Pinto Lake, California



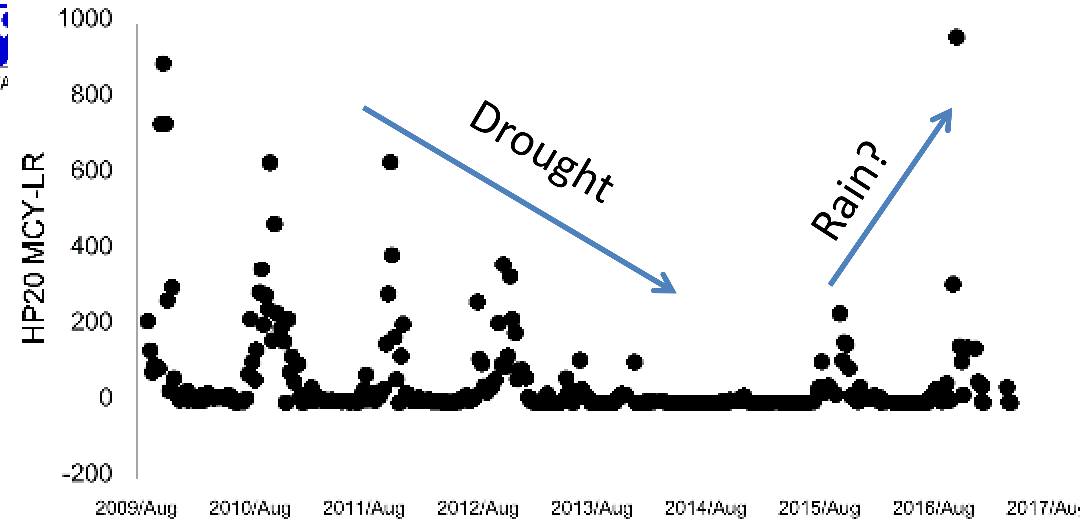
Pinto Lake, California



Summer Temperatures increasing

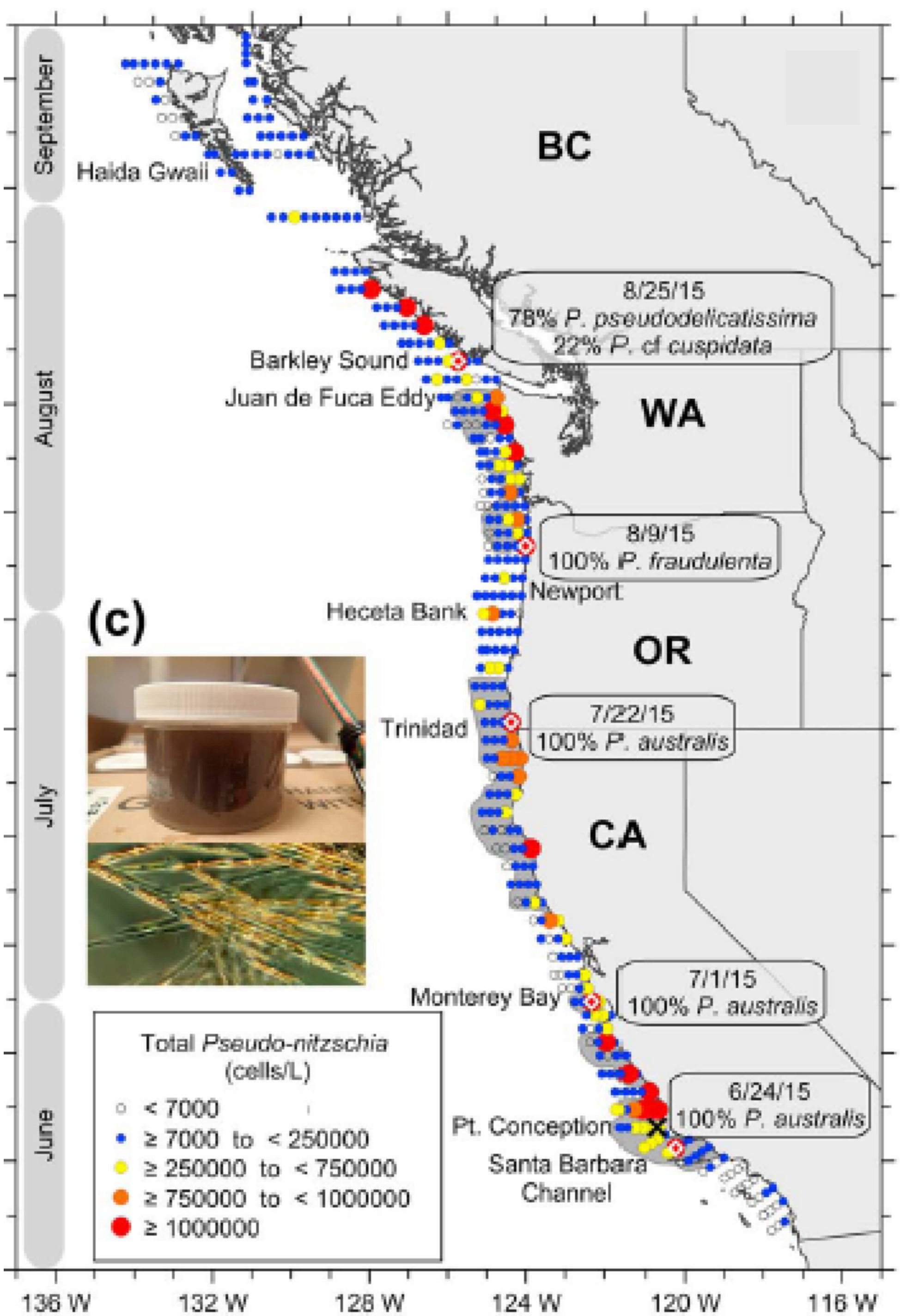


Winter Temperatures about the same



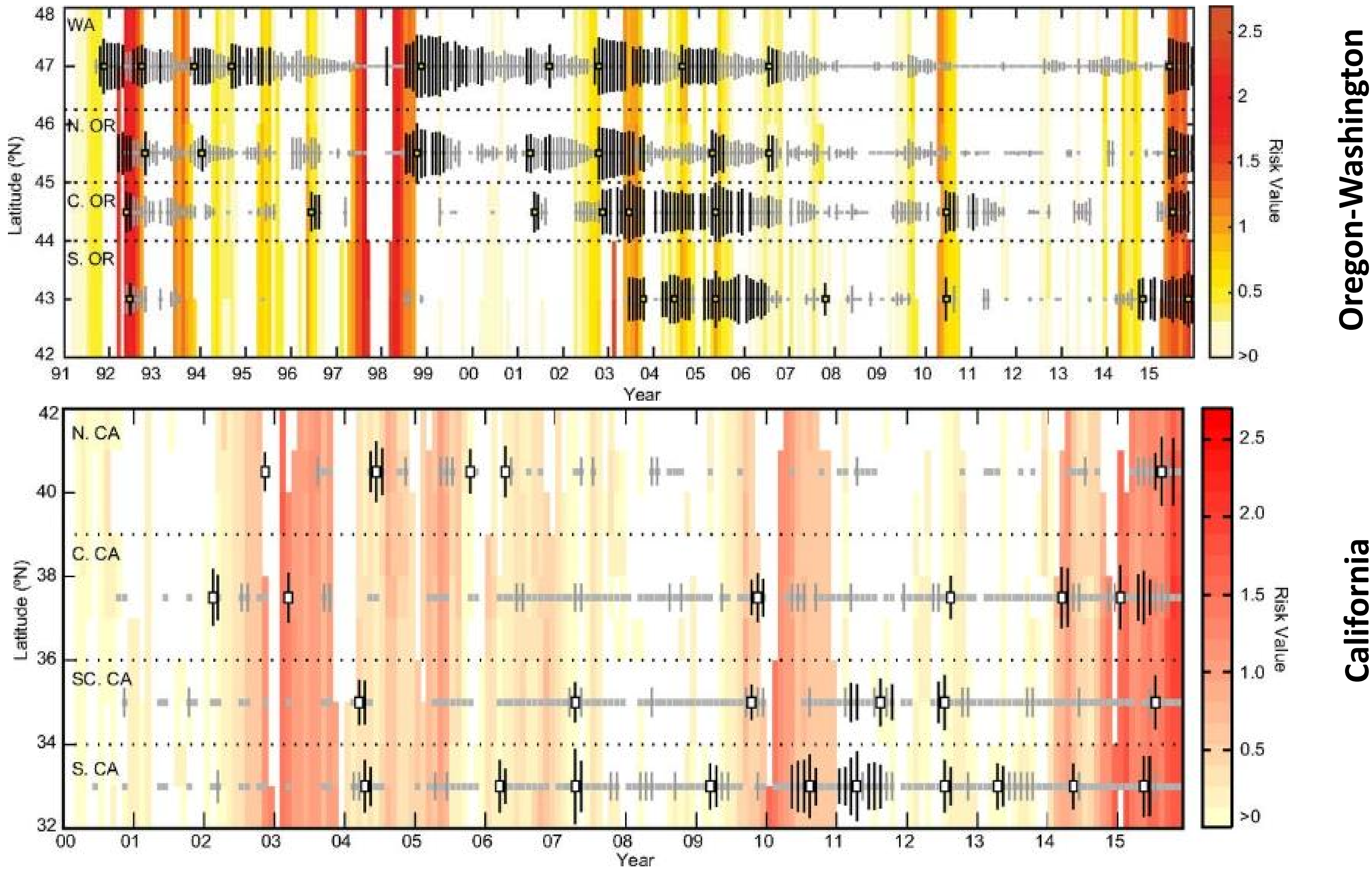
Harmful Algal Blooms
Known Knowns, Unknown Knowns

- We know all of the HAB organisms and toxins
- Nutrients and blooms are strongly related
- Blooms like it hot! Blooms like it dry!
- Warm anomalies are indicative of a future warm ocean (the "new normal")
- Changes in HABs are predictable



McCabe et al., GRL 2016

Temperature-Based Threat Index for Domoic Acid



S. Morgaine McKibben et al. PNAS 2017;114:239-244

Southern California

- *Very little toxin*

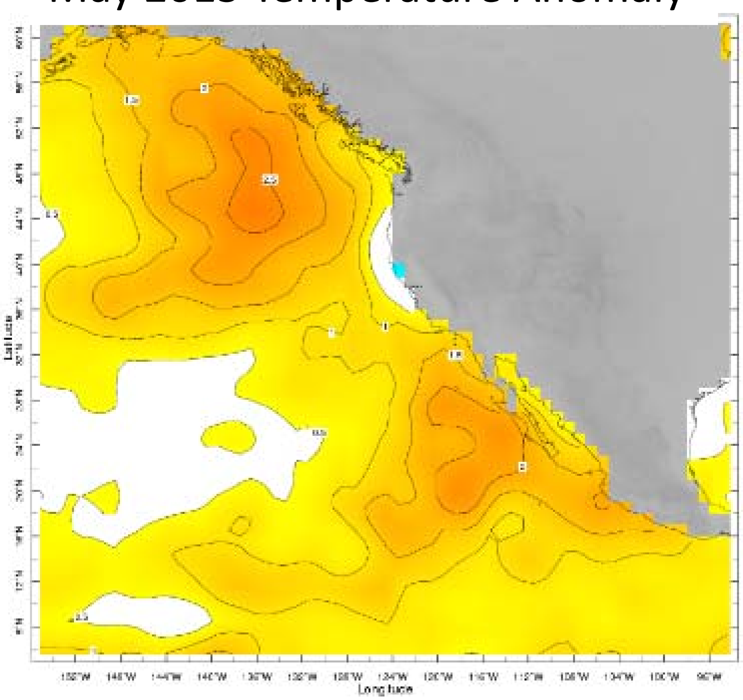
San Francisco Bay

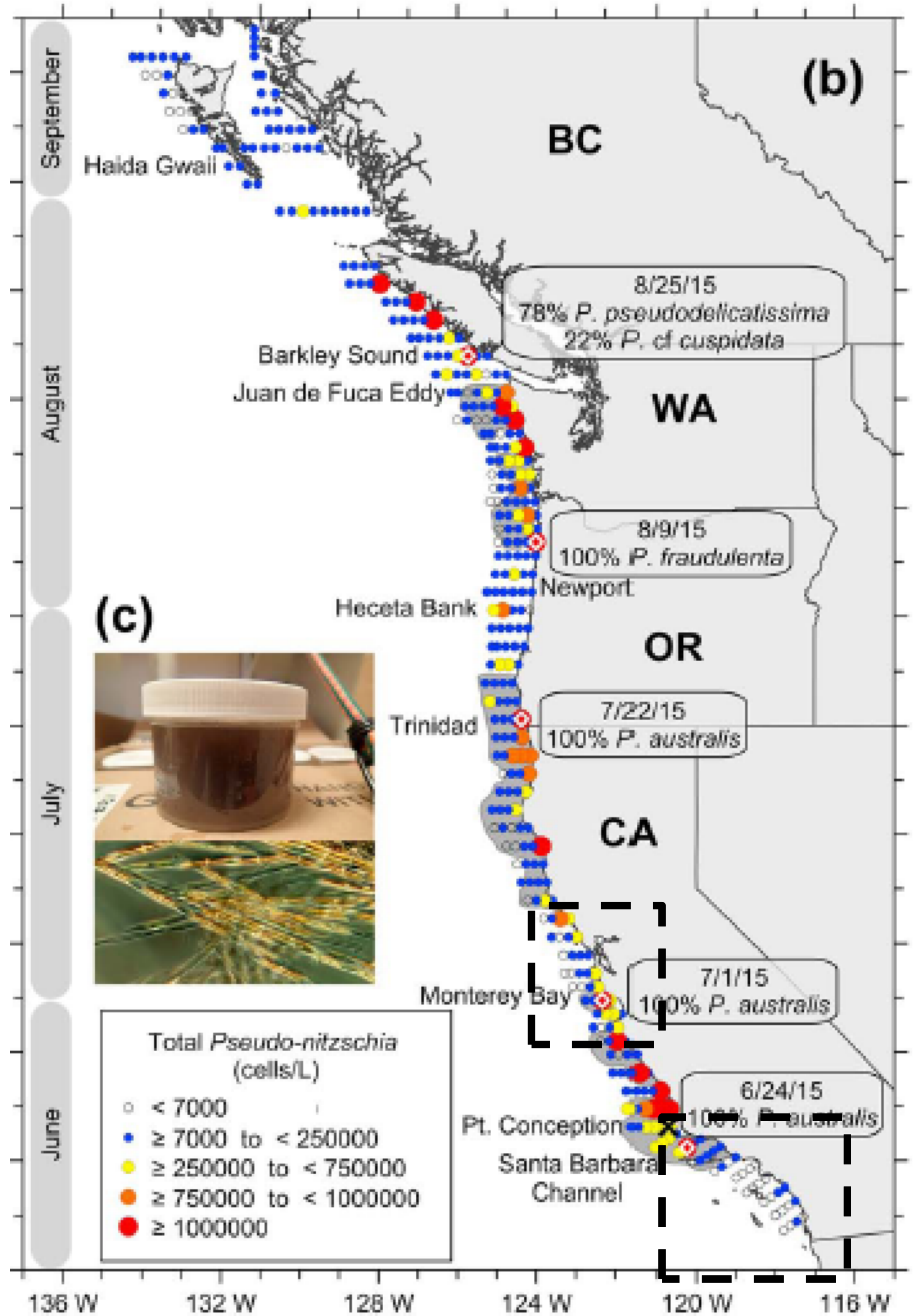
- *Immune?*

Monterey Bay

- *Related to temperature?*

May 2015 Temperature Anomaly



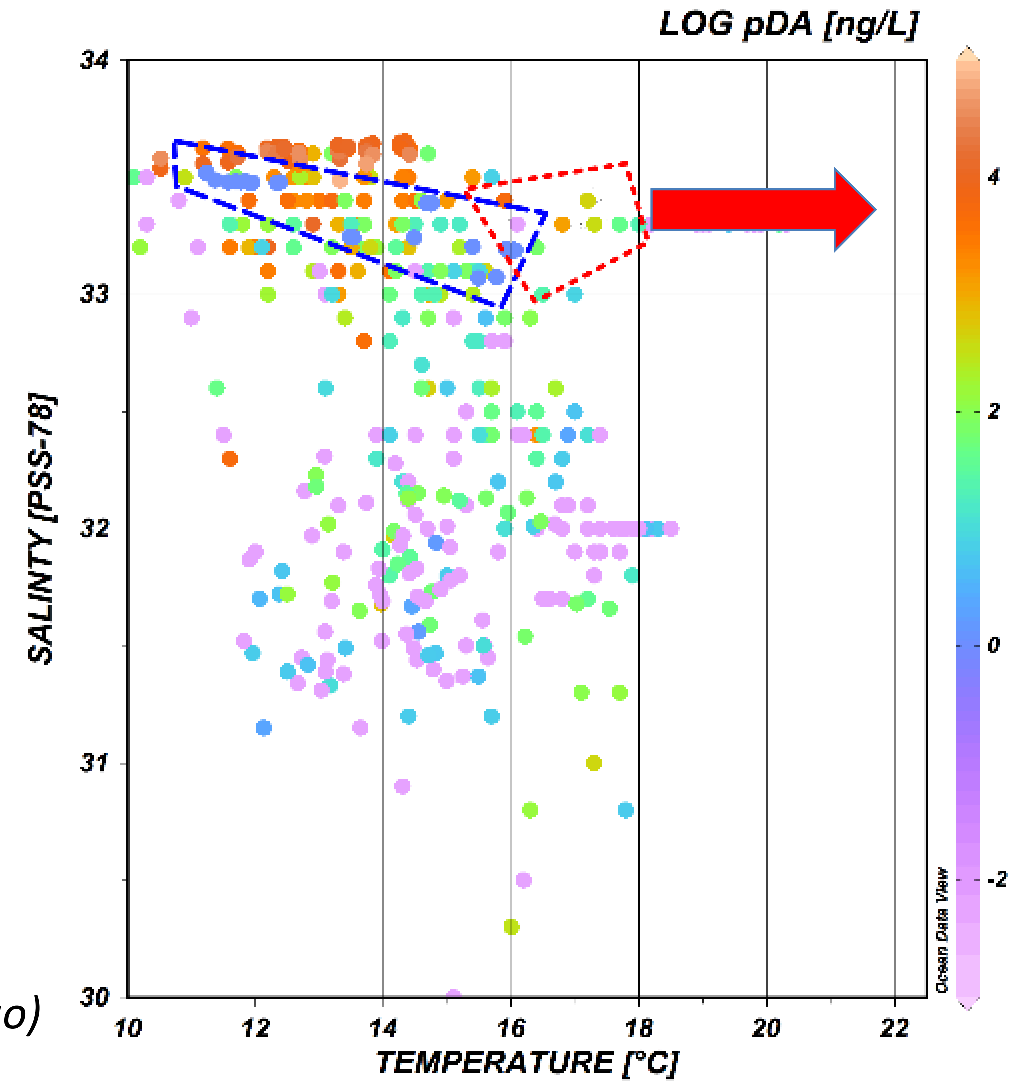


Southern California

Temperatures in Southern California were at the upper limit for cells/toxin in April.

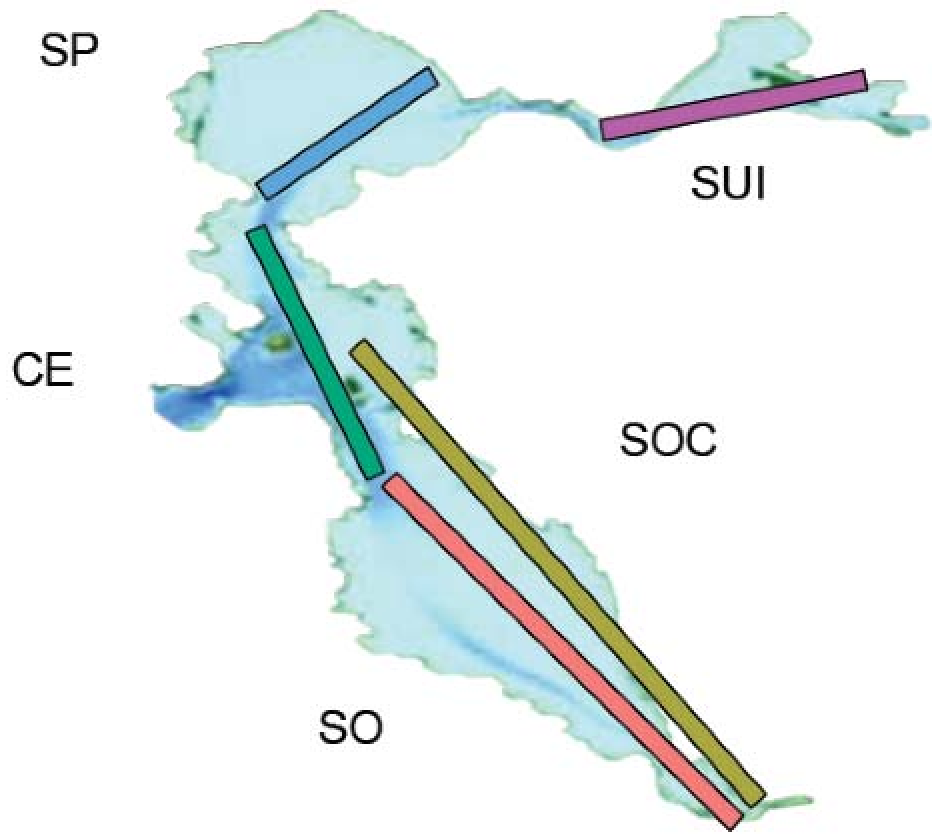
It continued to get warmer through the summer….

HABMAP data shows that above ~20°C, *Pseudo-nitzschia* is not present



CalCOFI Data for April 2015 Line 80 (Santa Barbara) and Line 90 (San Diego)

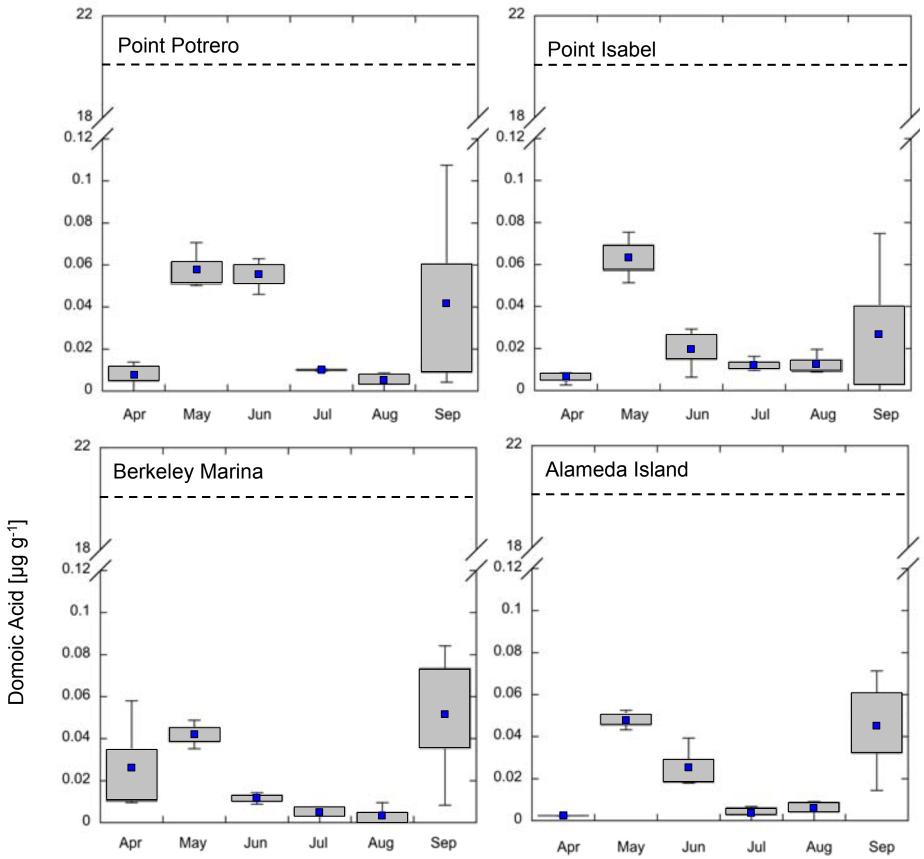
San Francisco Bay

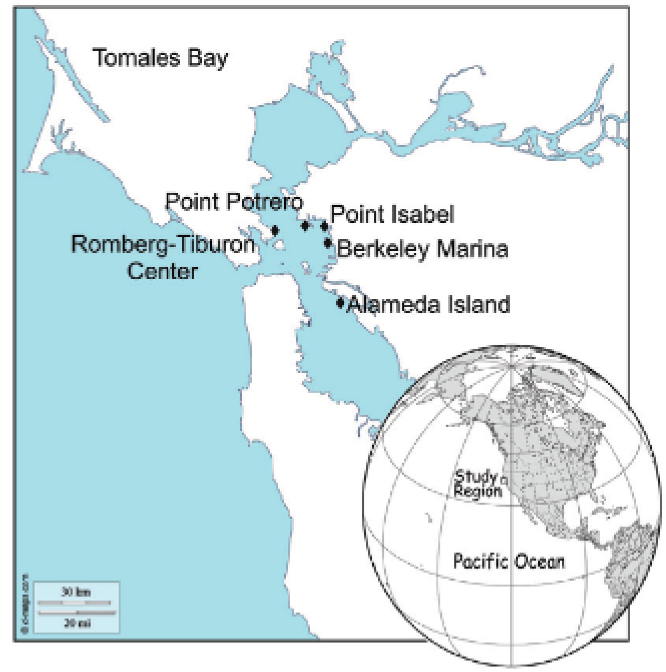


Time-series of SPATT

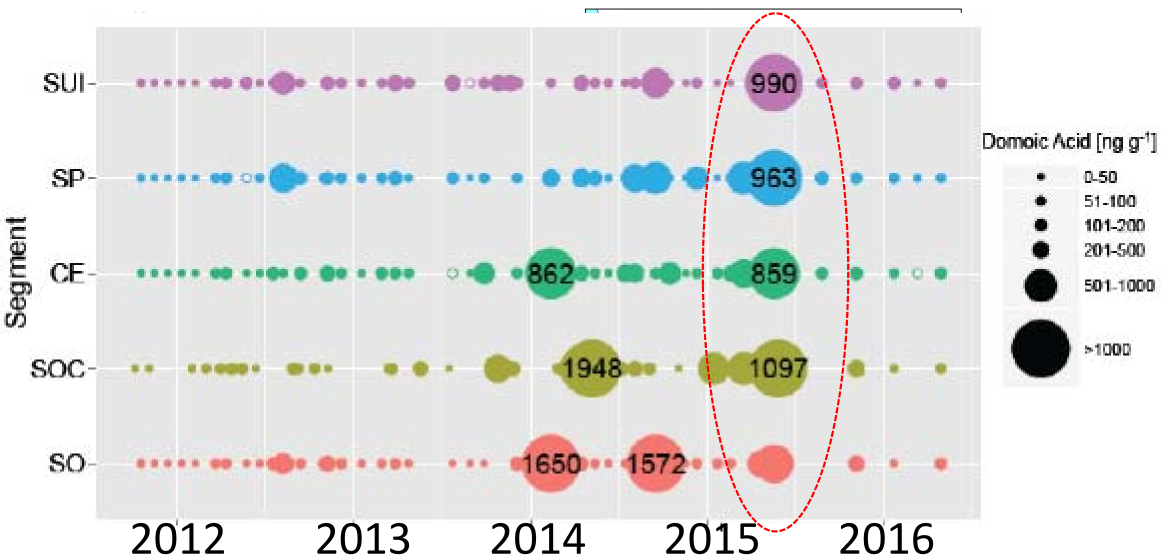
2015—Mussel samples

Domoic Acid in Mussels





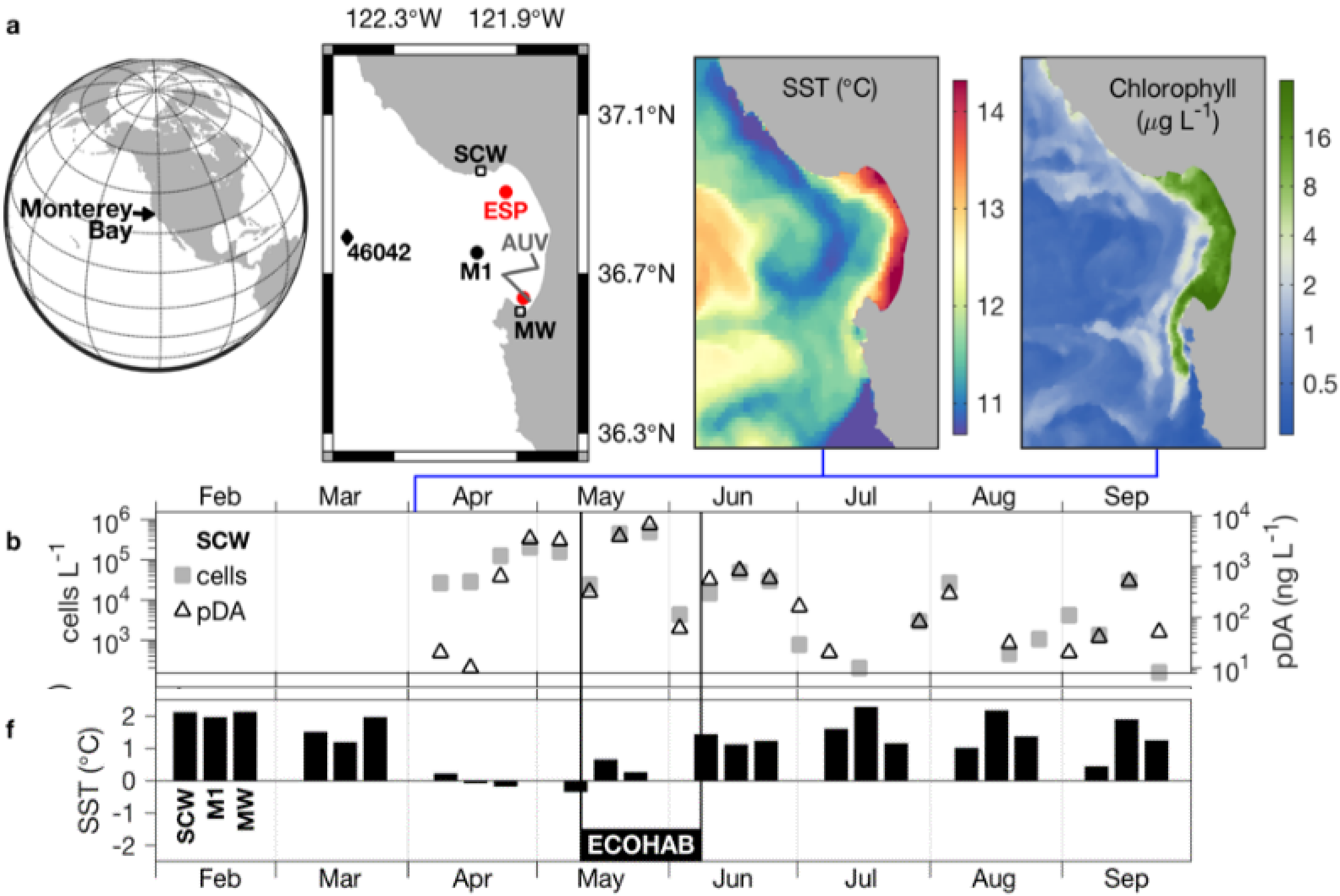
Domoic Acid in SPATT



Record high water temperatures in San Francisco Bay

--Work et al. 2017

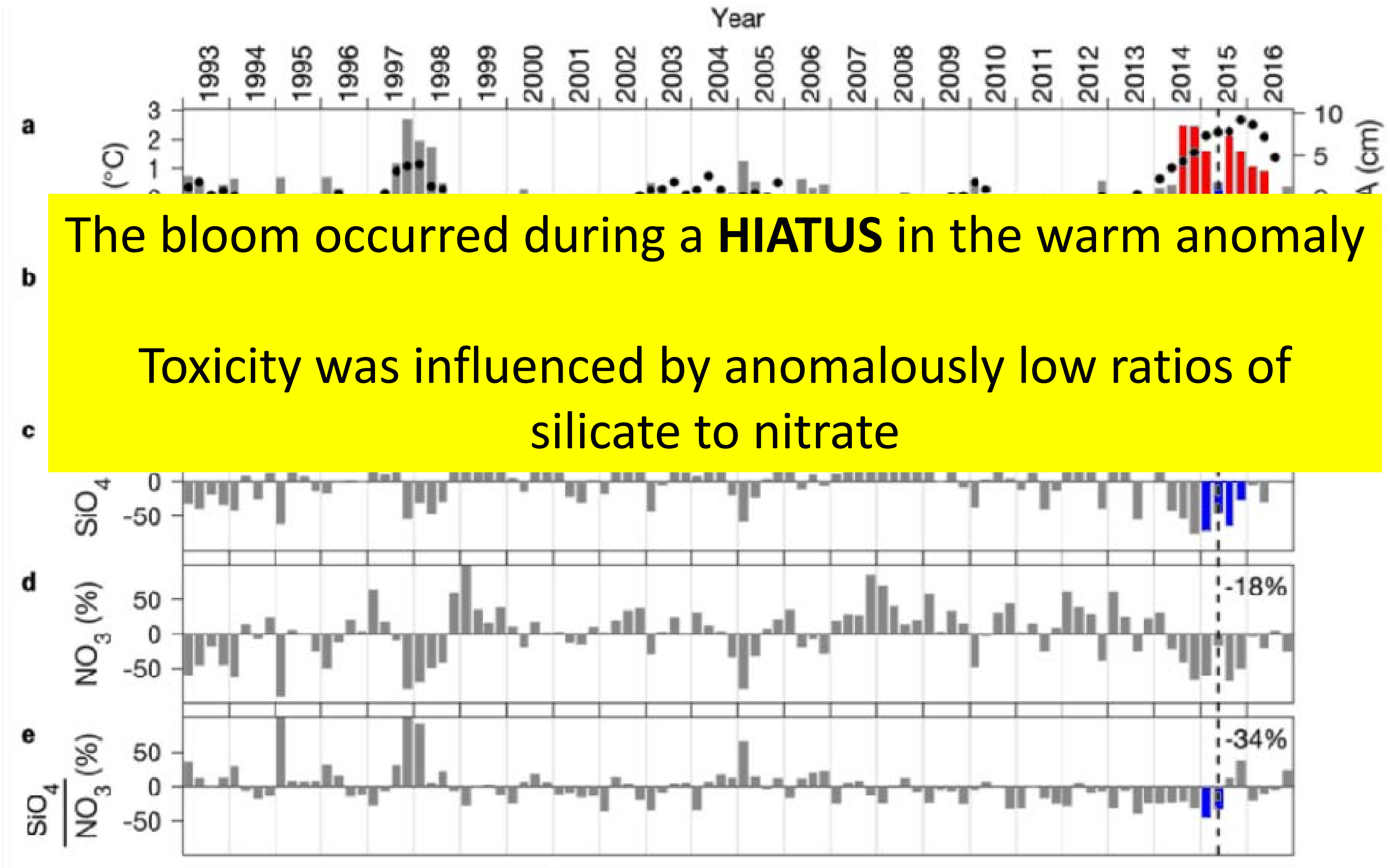
Monterey Bay



Causality of an extreme harmful algal bloom in Monterey Bay, California during the 2014–2016 northeast Pacific warm anomaly

J. P. Ryan[1], R. M. Kudela[2], J. M. Birch[1], M. Blum[1], H. A. Bowers[1,4], F. P. Chavez[1], G. J. Doucette[3], K. Hayashi[2], R. Marin III[1], C. M. Mikulski[3], J. T. Pennington[1], C. A. Scholin[1], G. J. Smith[4], A. Woods[4], Y. Zhang[1]

Monterey Bay Trends



The bloom occurred during a **HIATUS** in the warm anomaly

Toxicity was influenced by anomalously low ratios of silicate to nitrate

A Rumsfeldian View of HABs

Known Knowns:

- There **ARE** large-scale drivers such as temperature and drought that drive HAB events *(blooms do like it hot… and dry…)* and we **DO** know most of the HAB organisms and toxins

Unknown Knowns:

- There is considerable variability within individual events that are not clearly tied to these "big drivers" and are poorly constrained (for example, what are the temperature optima?)
- We are still caught off guard by new and "known" HAB events (e.g. foam-producing algae, new impacts of known toxins)

Unknown Unknowns:

- How well can we predict a "future ocean" by modeling large-scale patterns, but not necessarily getting the details correct?