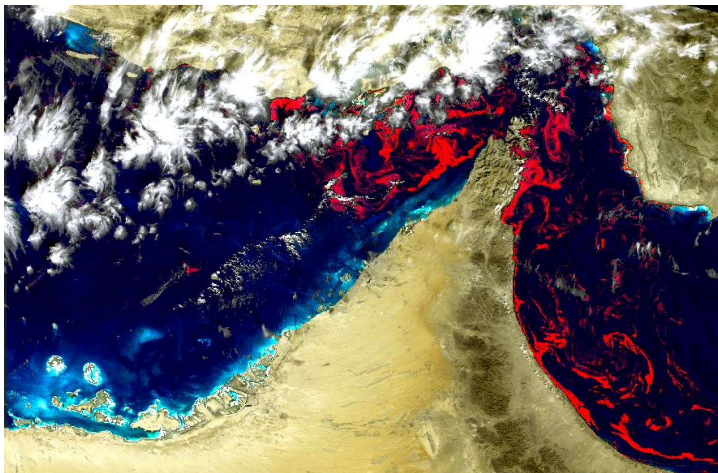
Overview of Harmful Algal Blooms: A Global Perspective



Arabian Peninsula

China

South Africa

Raphael Kudela

University of California Santa Cruz

Harmful Algal Blooms

A scientific summary for policy makers

SCOR

United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

GEOHAB

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.

- *HABs result from noxious and/or toxic algae that cause direct and indirect negative impacts to aquatic ecosystems, coastal resources, and human health*

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

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*	–

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

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 ►

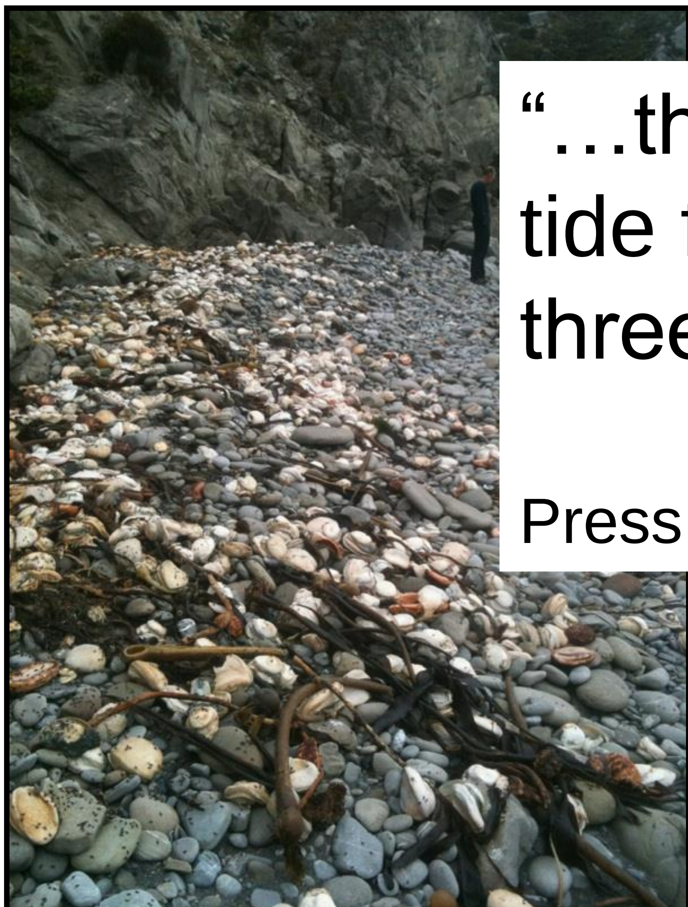
ARTICLE

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

DOI: 10.1038/ncomms4652

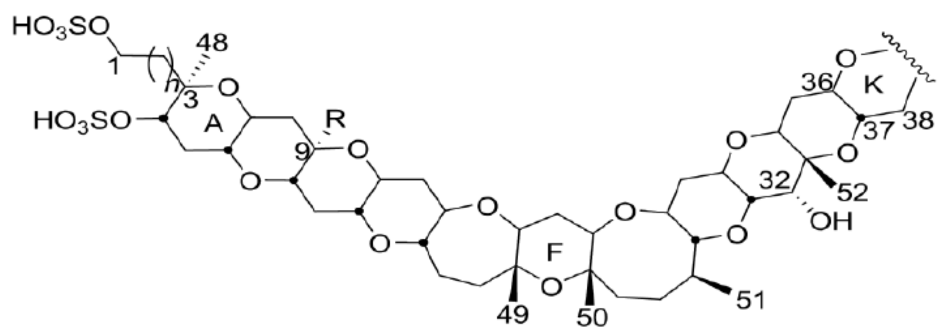
Forensic genomics as a novel tool for identifying the causes of mass mortality events

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



Blooms and Water Quality are Linked

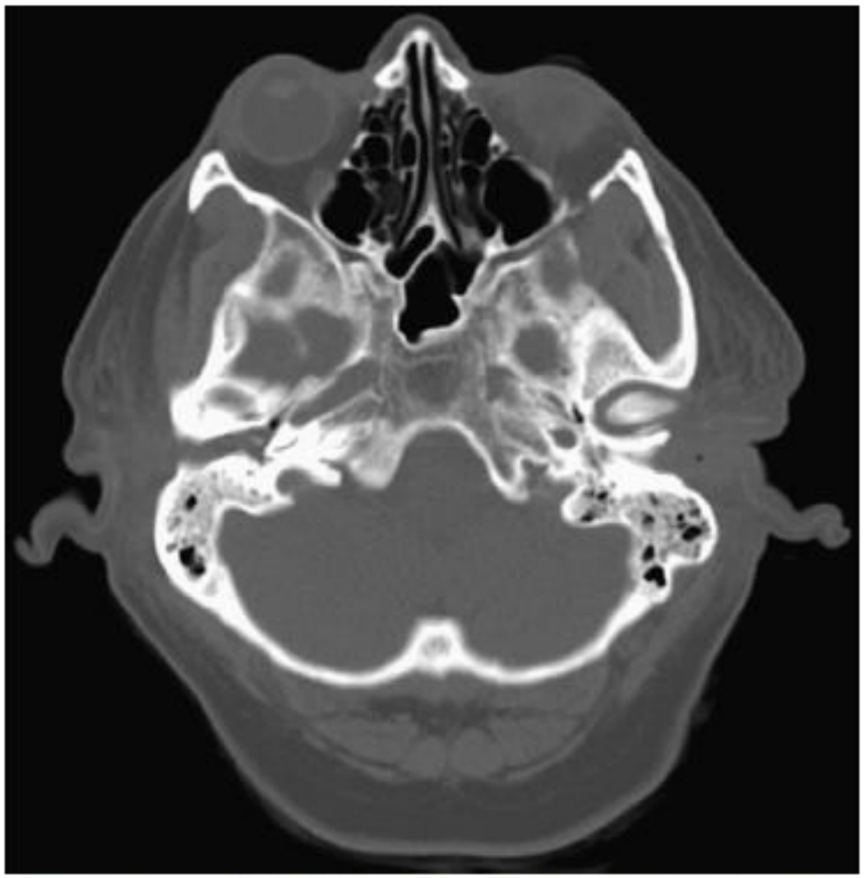
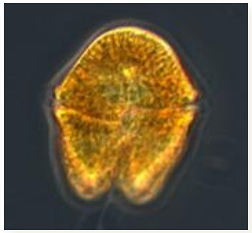


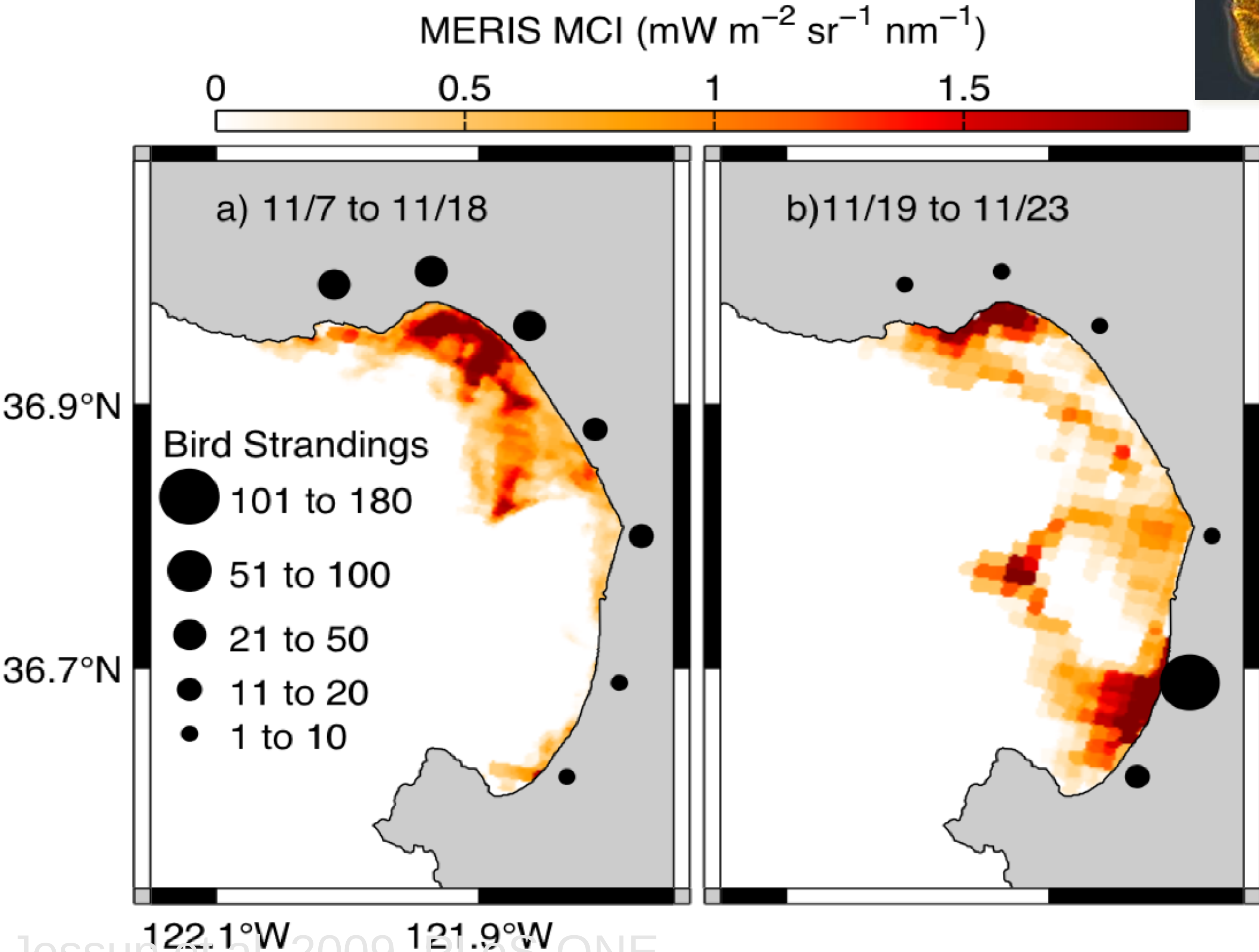
Figure 2. Computed tomography scan showing opacification of the bilateral mastoid air cells.

September 2009—53 year old woman diving in Monterey suffered from bilateral mastoiditis (ear infections penetrating to the brain).

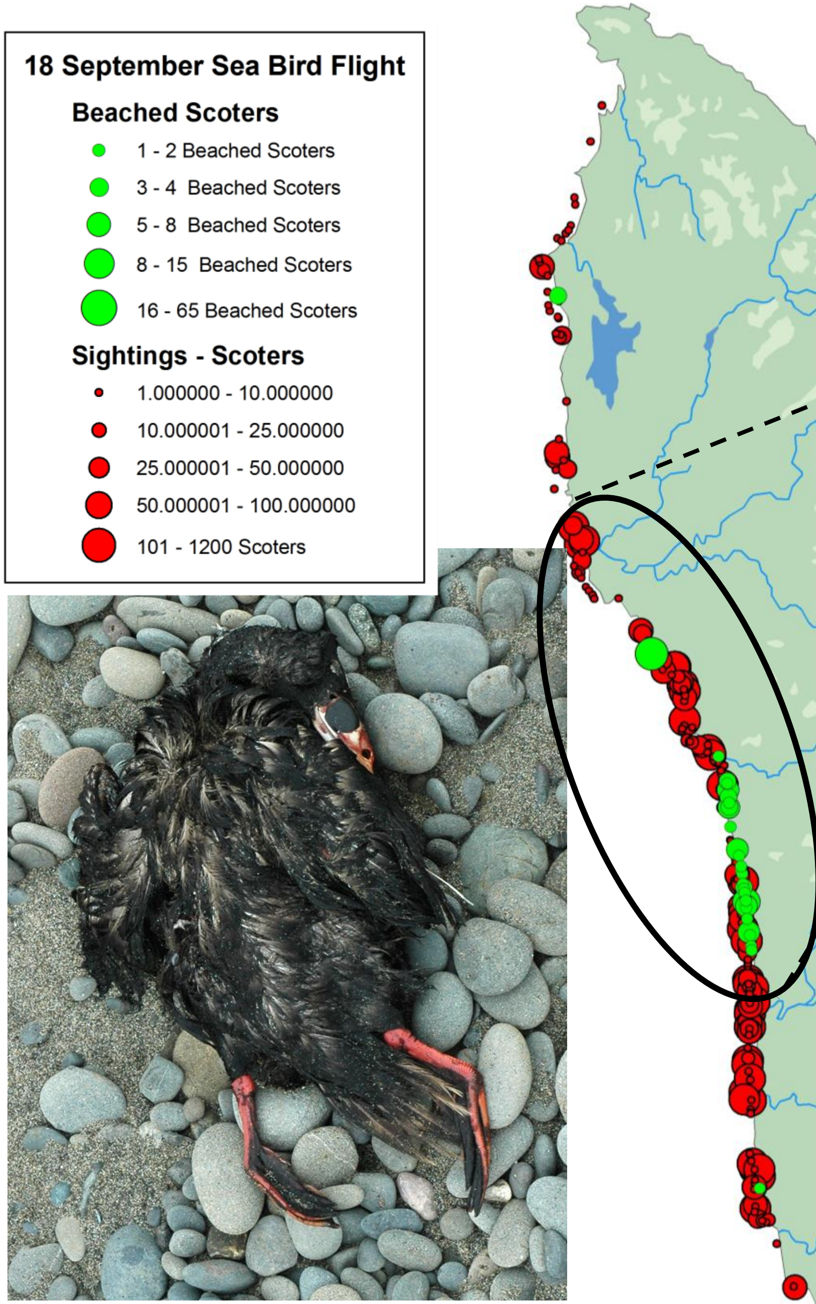
Retrospective analysis linked high pathogen loads to red tides.

Honner, Kudela & Handler (2012), J. Emergency Medicine

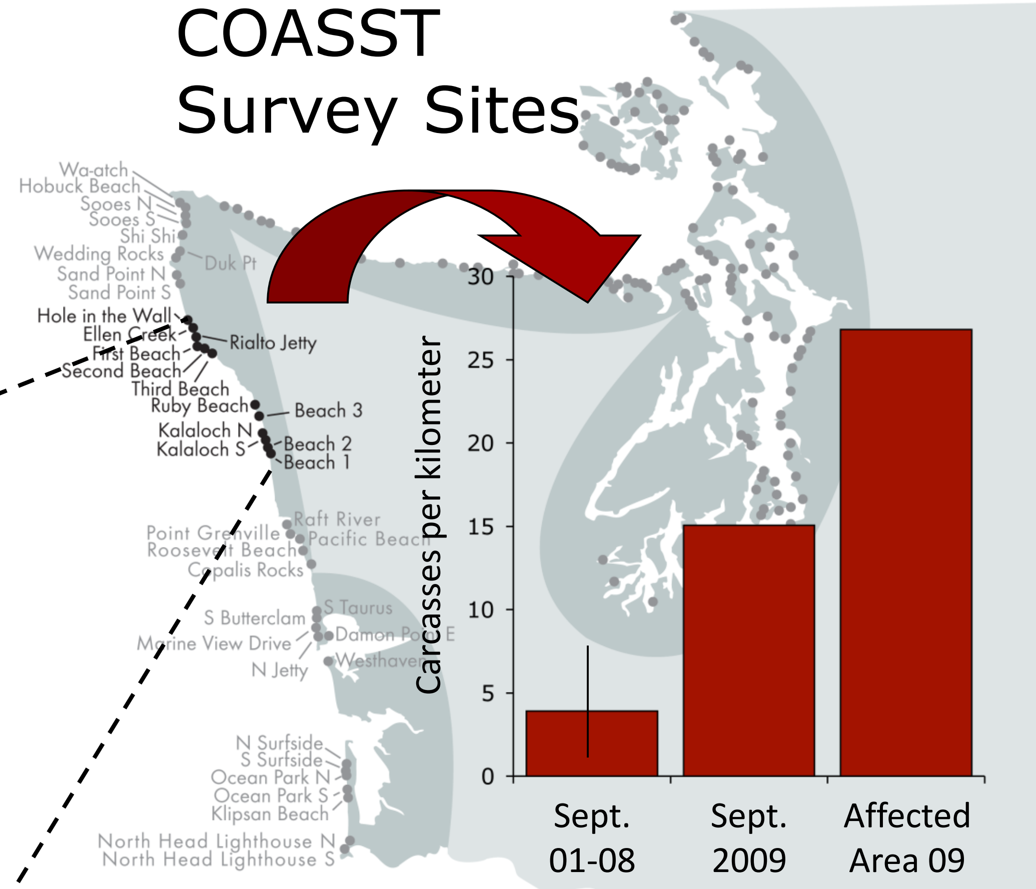




Jessup et al. 2009, PLoS-ONE



COASST Survey Sites



<u>COASST Counts</u>:
800 dead
Hole-in-the-Wall - Beach 1
78% surf scoters
highest beach - 227

<u>Overflight Counts</u>:
13,000 birds on the water
Cape Flattery - Columbia River
93% scoters

overflight data and map - Joe Evenson, WDFW; photo - Chris Cook, Forks Forum; site map and graph - COASST

Harmful Algal Bloom Marine Bird Mortality

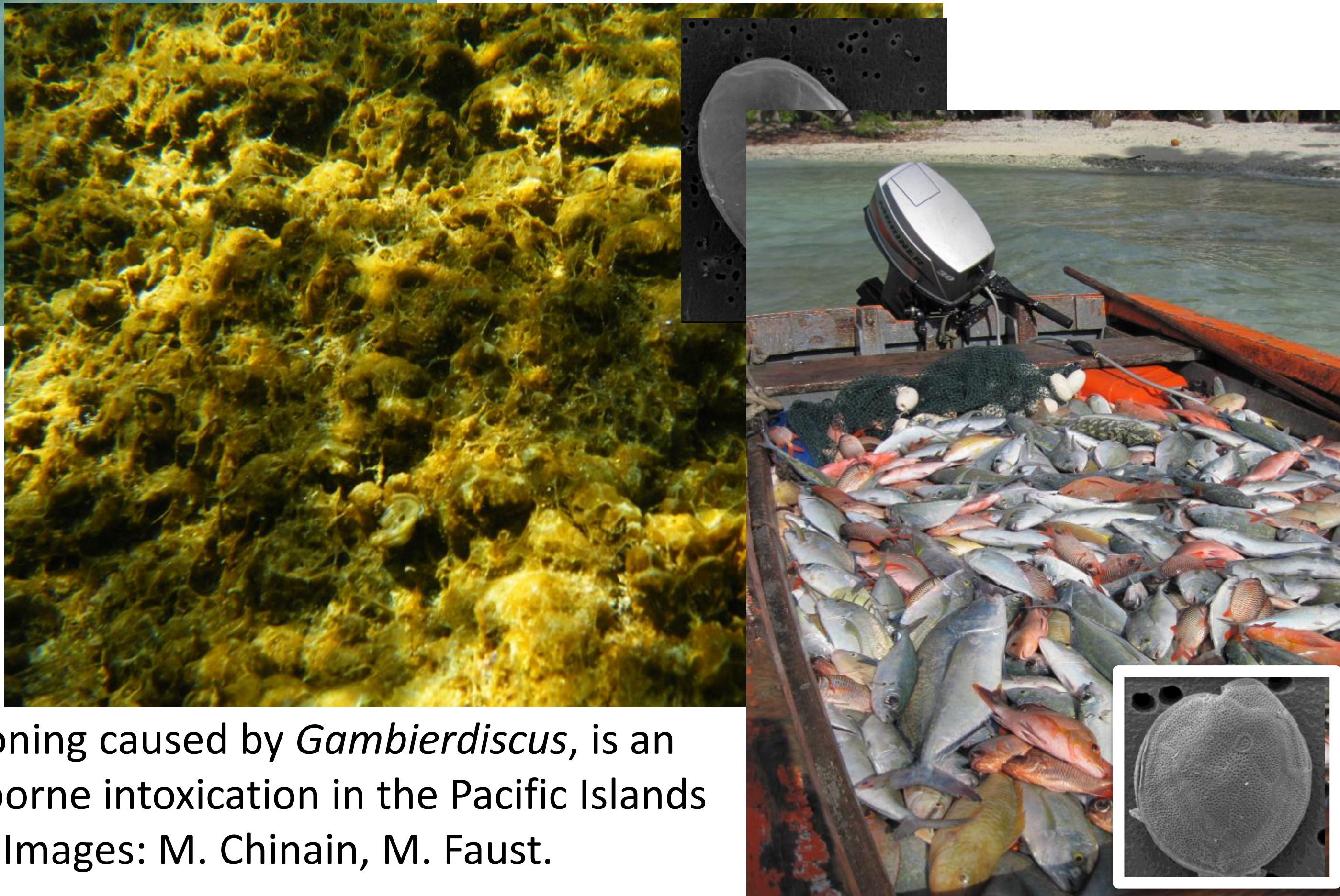
#	Affected Birds	Location, Year	HAB Species
2250	Black Ducks, other waterfowl	New Hampshire, 1972	*Gonyaulax tamarensis*
140	Brown Pelicans, Brandt's Cormorants	Santa Cruz, CA, 1991	*Pseudonitzschia australis*
150	Brown Pelicans	Baja California, 1996	*Pseudonitzschia spp.*
550	Northern Fulmars, Common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

Shumway et al., 2003 Harmful Algae
Jessup et al. 2009 PLOSOne
COASST

HABs are present in nearly all aquatic environments as naturally occurring phenomena

In the Mediterranean, high-biomass blooms of the epiphyte *Ostreopsis* are associated with respiratory irritations in beach users. Images: J.M. Fortuño, M. Vila, ICM-CSIC.

In the Baltic cyanobacteria blooms prevent recreational use of the coast in summer. Photo: B. Karlson, SMHI.



Ciguatera Fish Poisoning caused by *Gambierdiscus*, is an endemic sea-food borne intoxication in the Pacific Islands and the Caribbean. Images: M. Chinain, M. Faust.

Lefebvre et al., 2016, Harmful Algae, DOI: http://dx.doi.org/10.1016/j.hal.2016.01.007

Fish Poisoning More Common Than Believed

Global Health
By DONALD G. McNEIL Jr. JUNE 29, 2015

The New York Times

Ciguatera outbreak confirmed in Germany

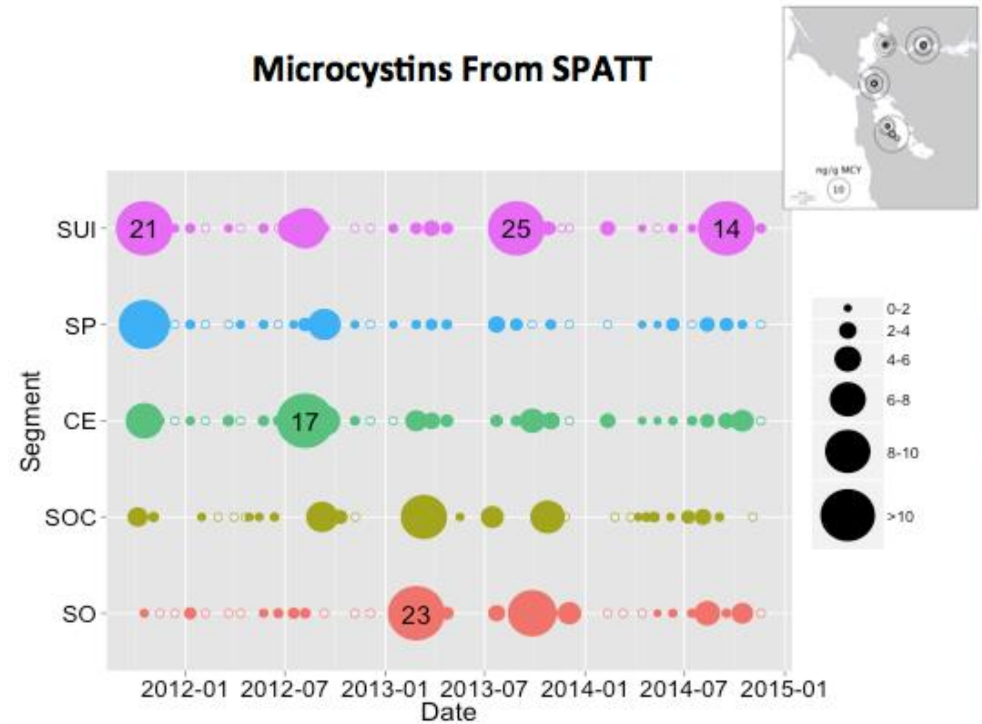
Officials in Germany have confirmed an outbreak of ciguatoxin poisoning associated with fish.

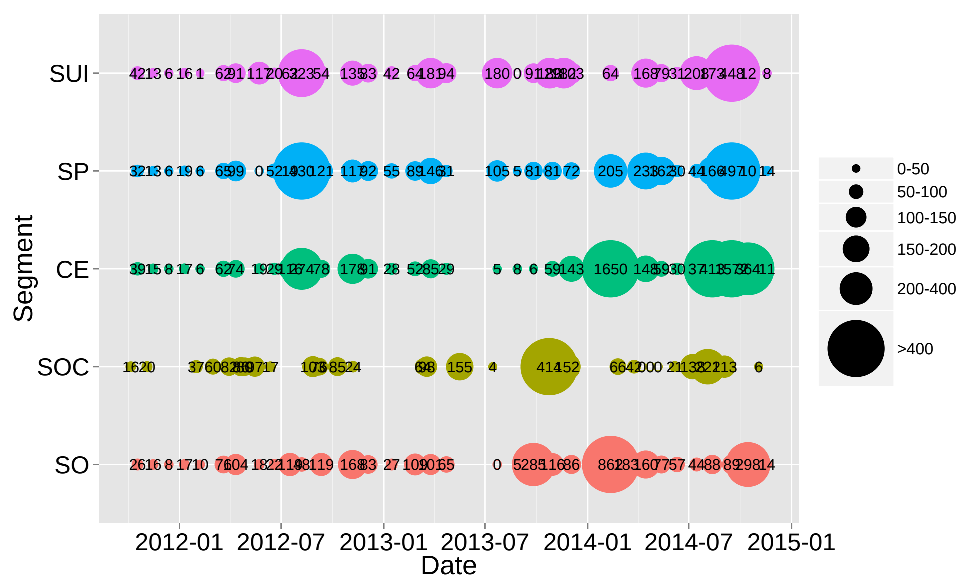
Scientists believe there is a correlation between

Aquarium Corals of Anchorage Poison 10 1/2 Humans, 2 Dogs and 1 Cat

There are few places that seem less likely for a zoanthid coral attack than Anchorage, Alaska. And yet the corals managed to poison around a dozen people in Anchorage over the last few years.

San Francisco Bay

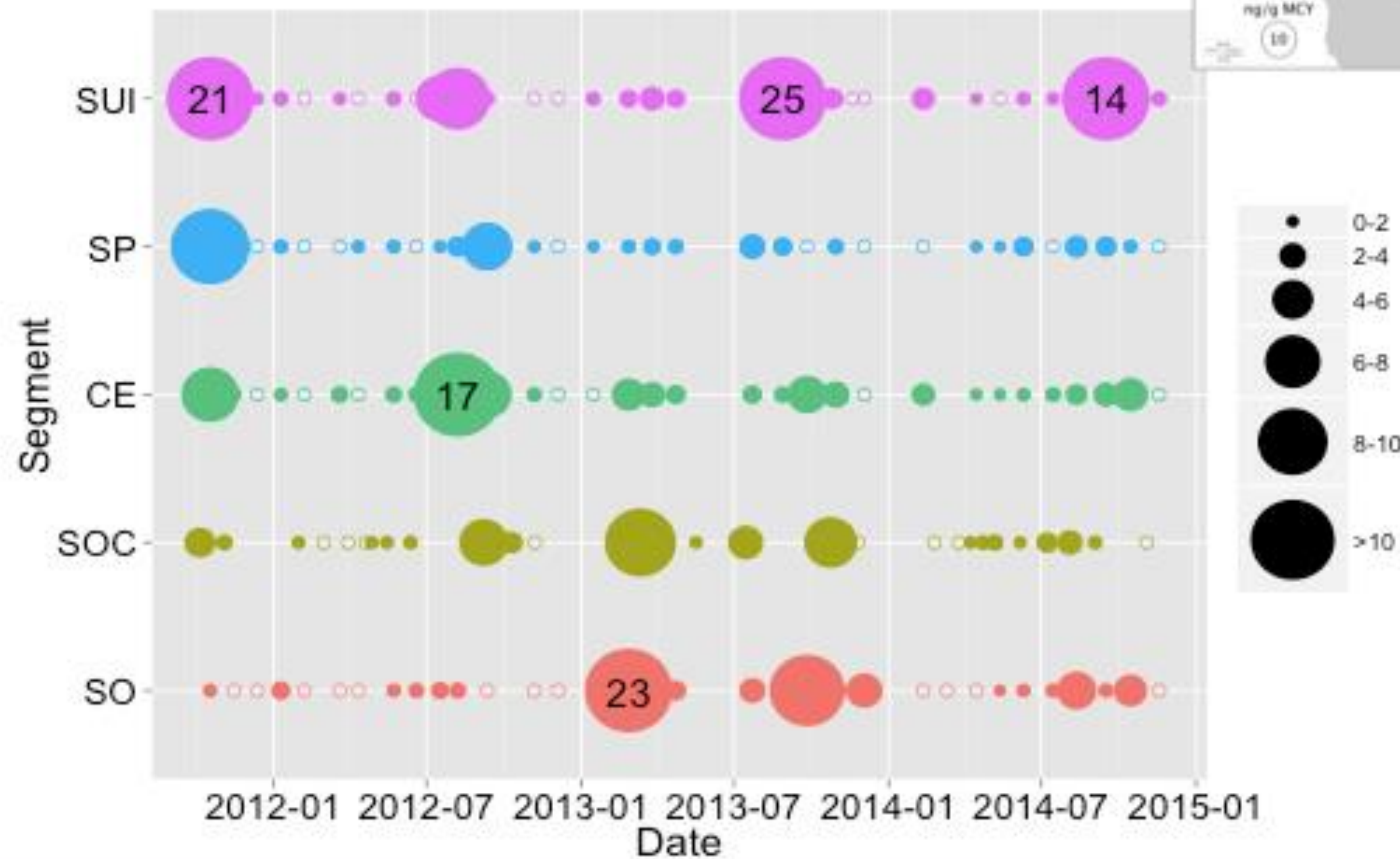




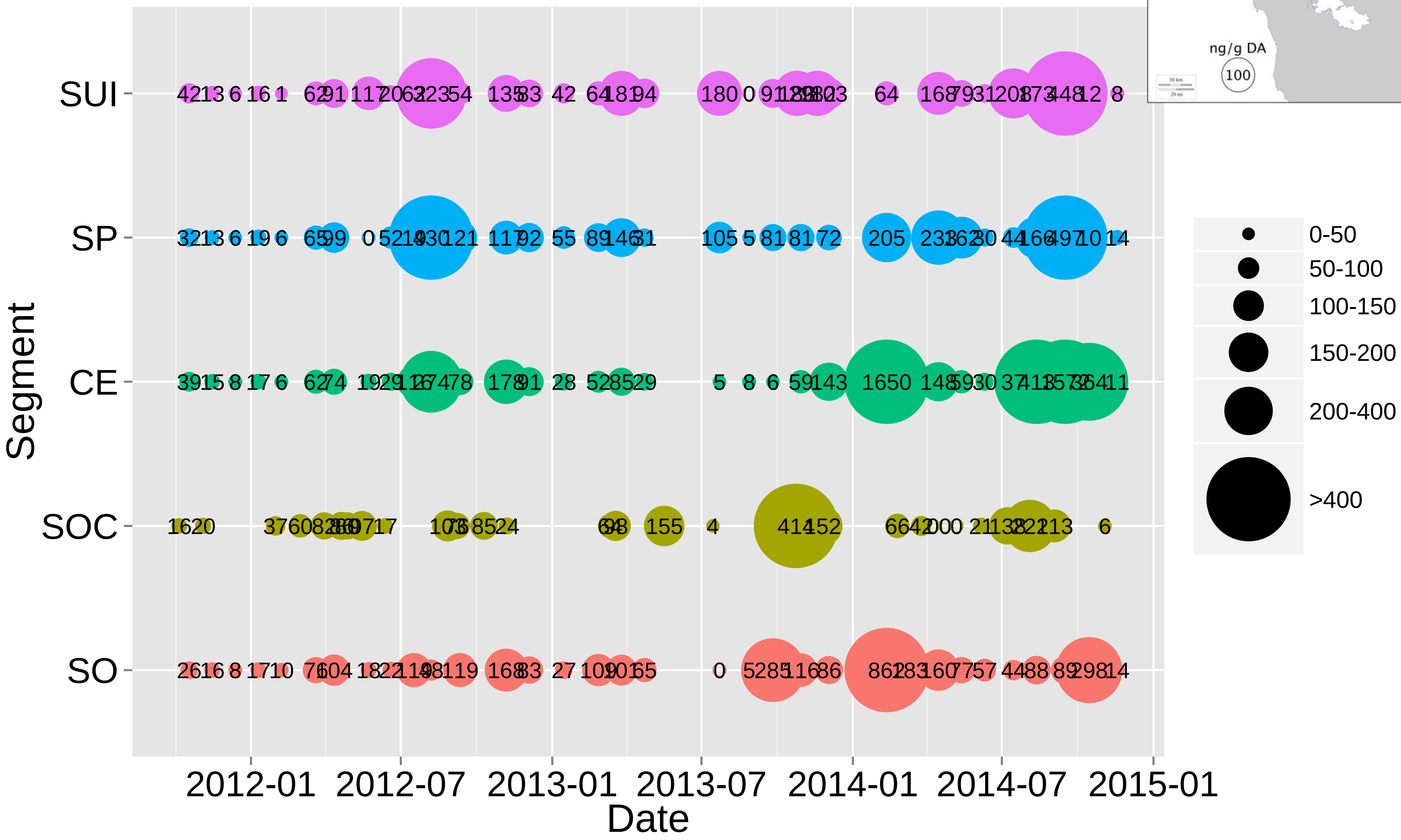
Focusing on SF Bay, we know that several algal toxins are nearly ubiquitous in the Bay.

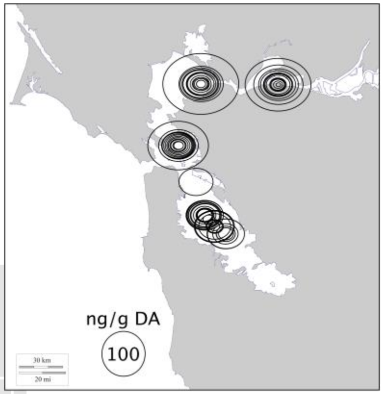
The Bay seems to act as a mixing bowl for both freshwater and marine toxins…

Microcystins From SPATT

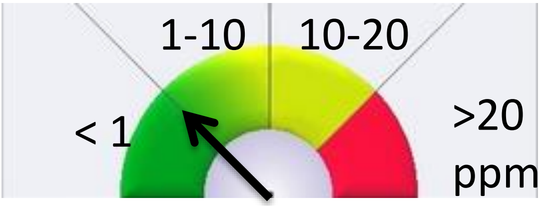


Domoic Acid from SPATT

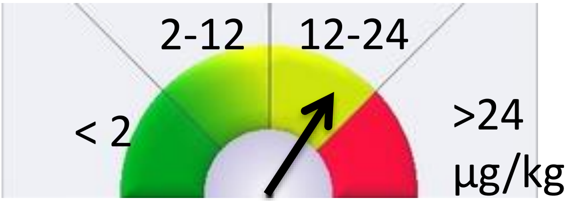




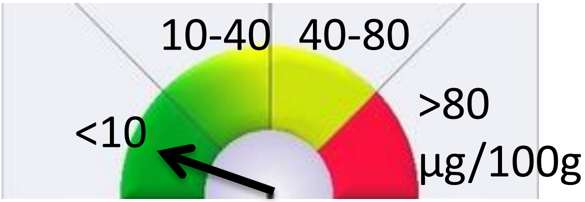
Those toxins accumulate in the food web



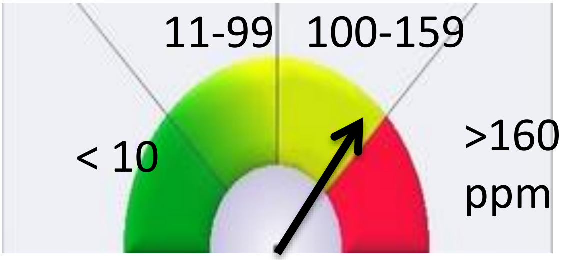
Domoic Acid
(100% of mussels contaminated)



Microcystins
(82% of mussels contaminated)

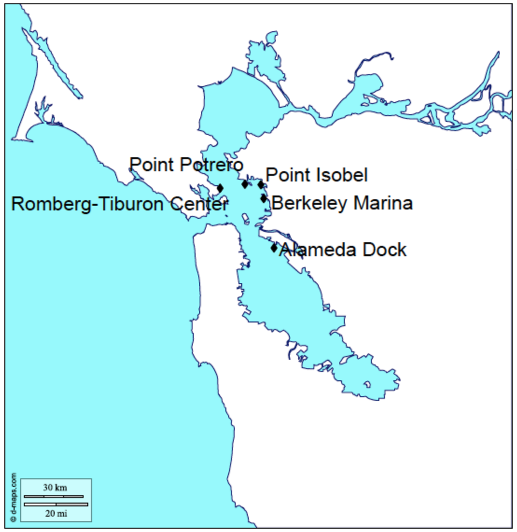


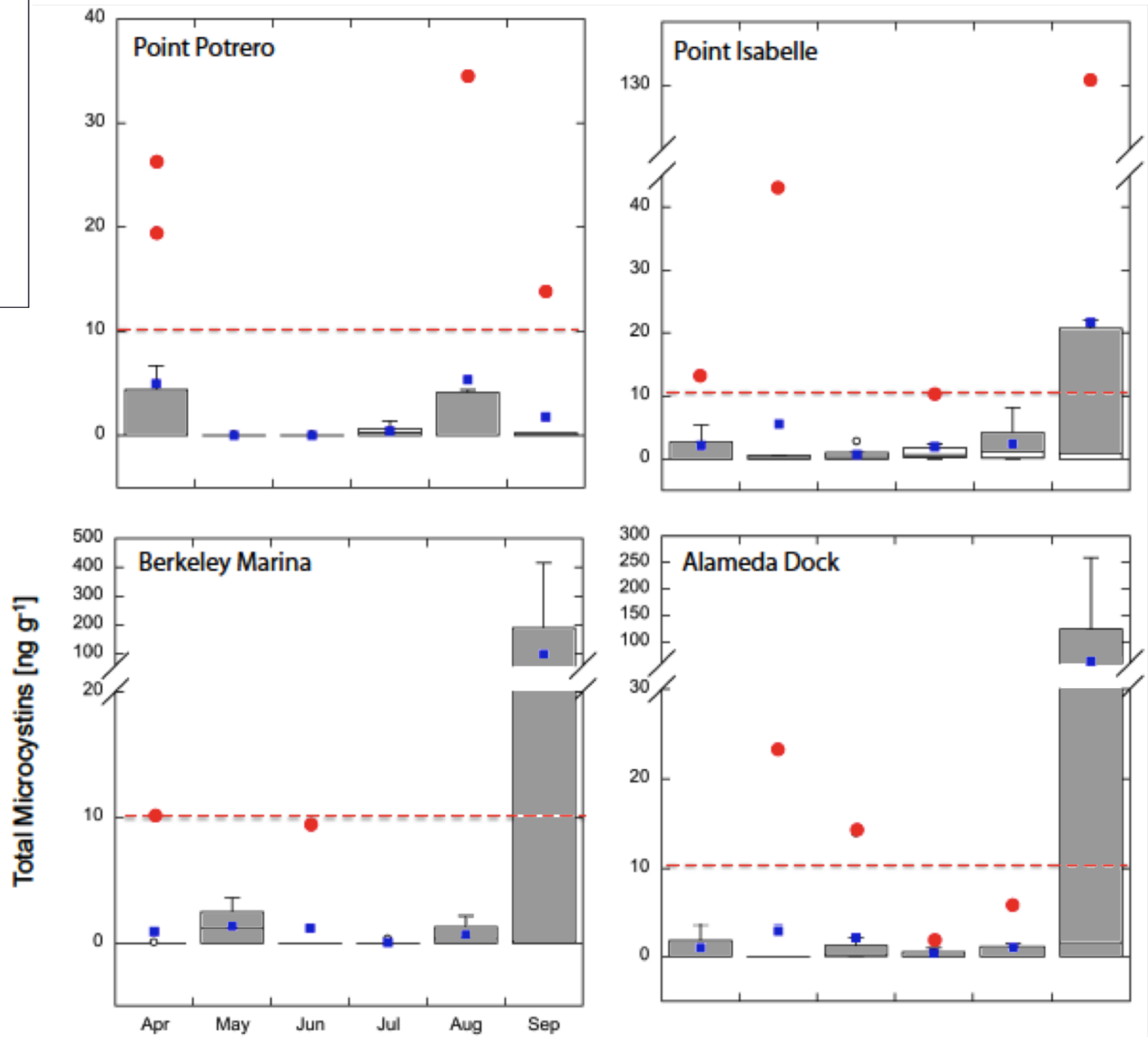
Paralytic Shellfish Toxins
(25% of mussels contaminated)



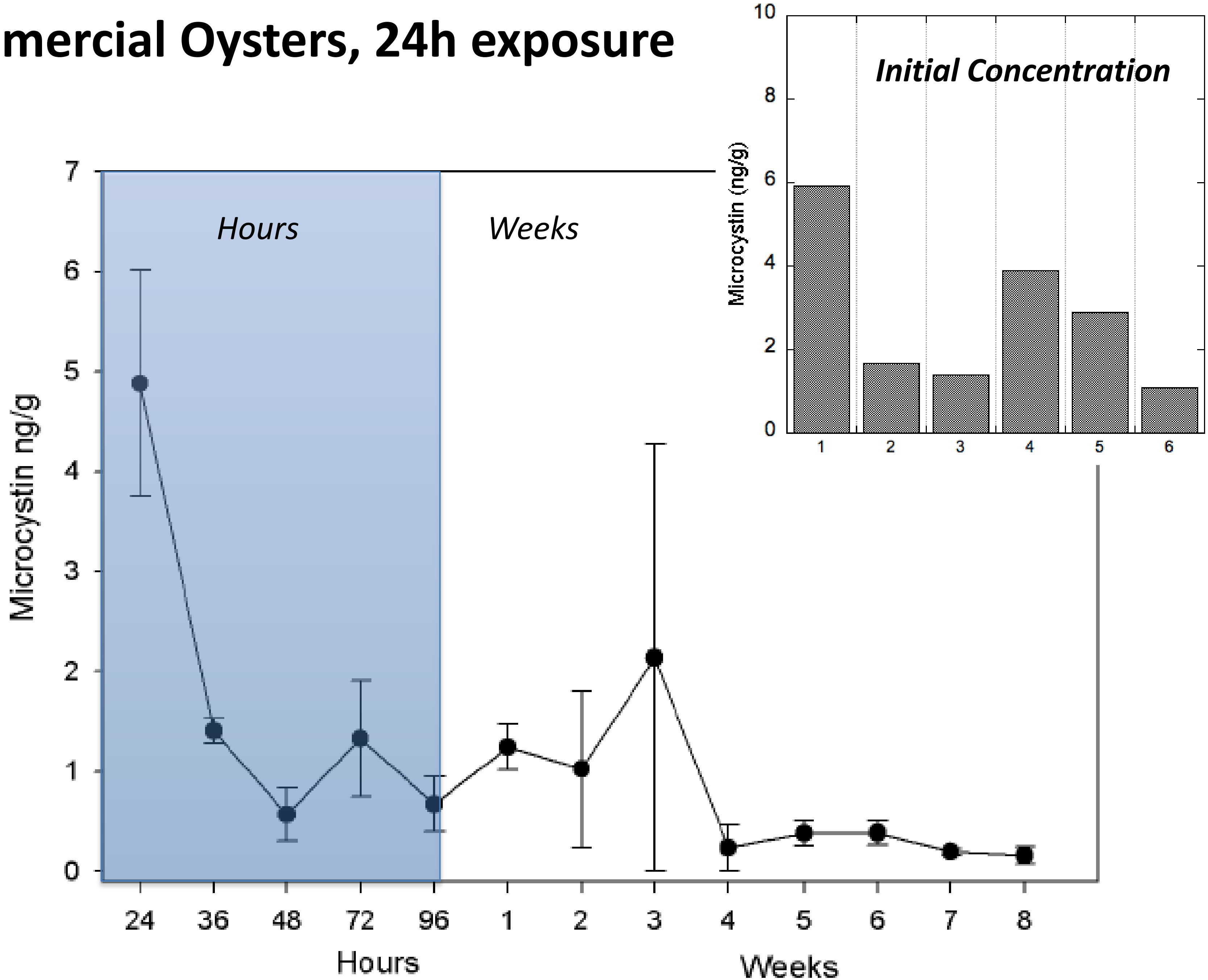
Okadaic Acid and DTX-1
(100% of mussels contaminated)

Microcystins in Natural Mussel Beds



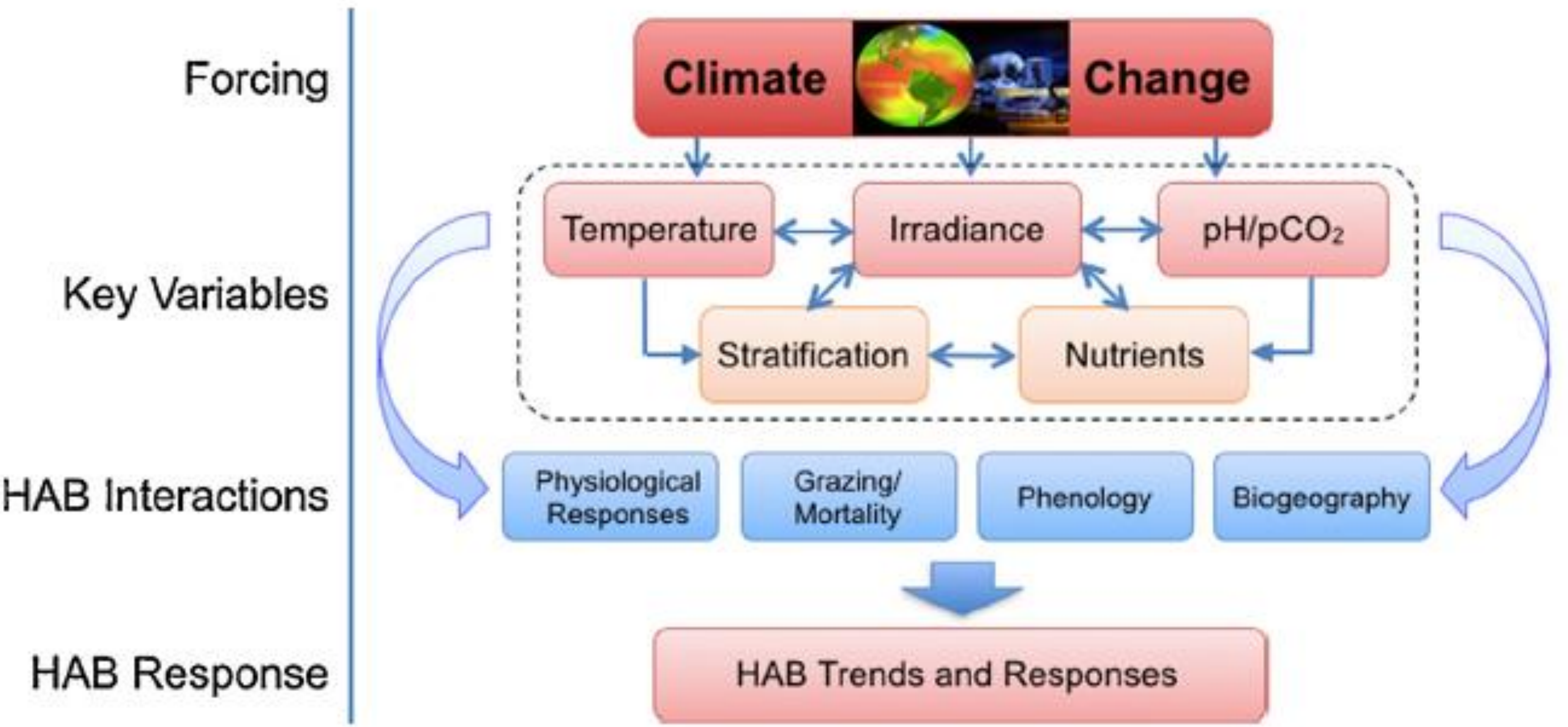


Commercial Oysters, 24h exposure



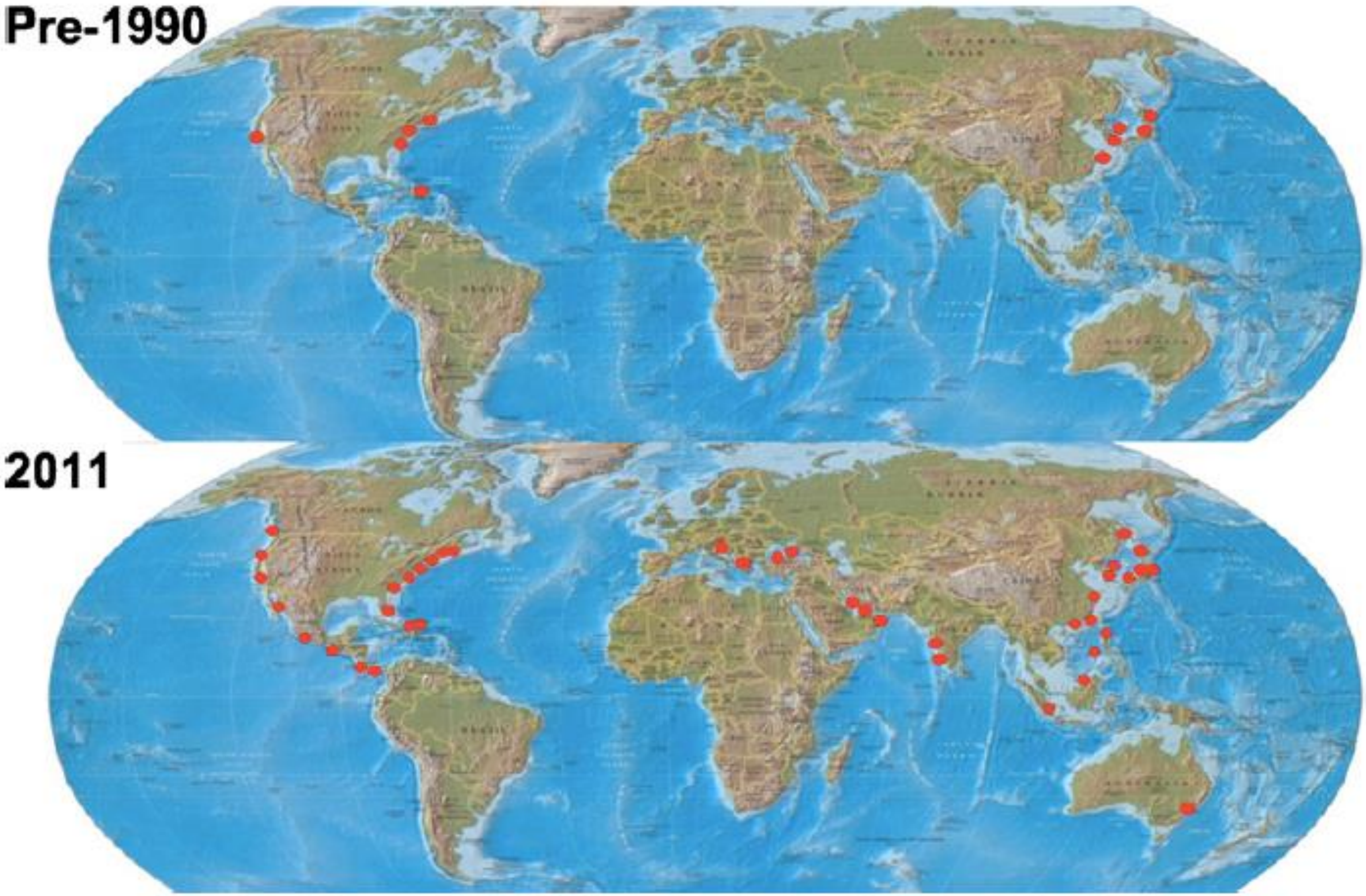
Many HABs are increasing in severity and frequency, and biogeographical range. Some of this expansion is attributed to climate change and global change.

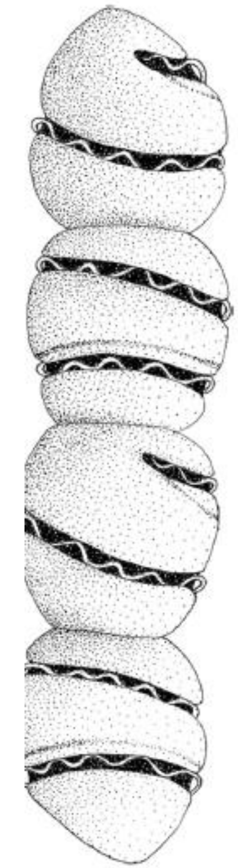
M.L. Wells et al. / Harmful Algae 49 (2015) 68–93

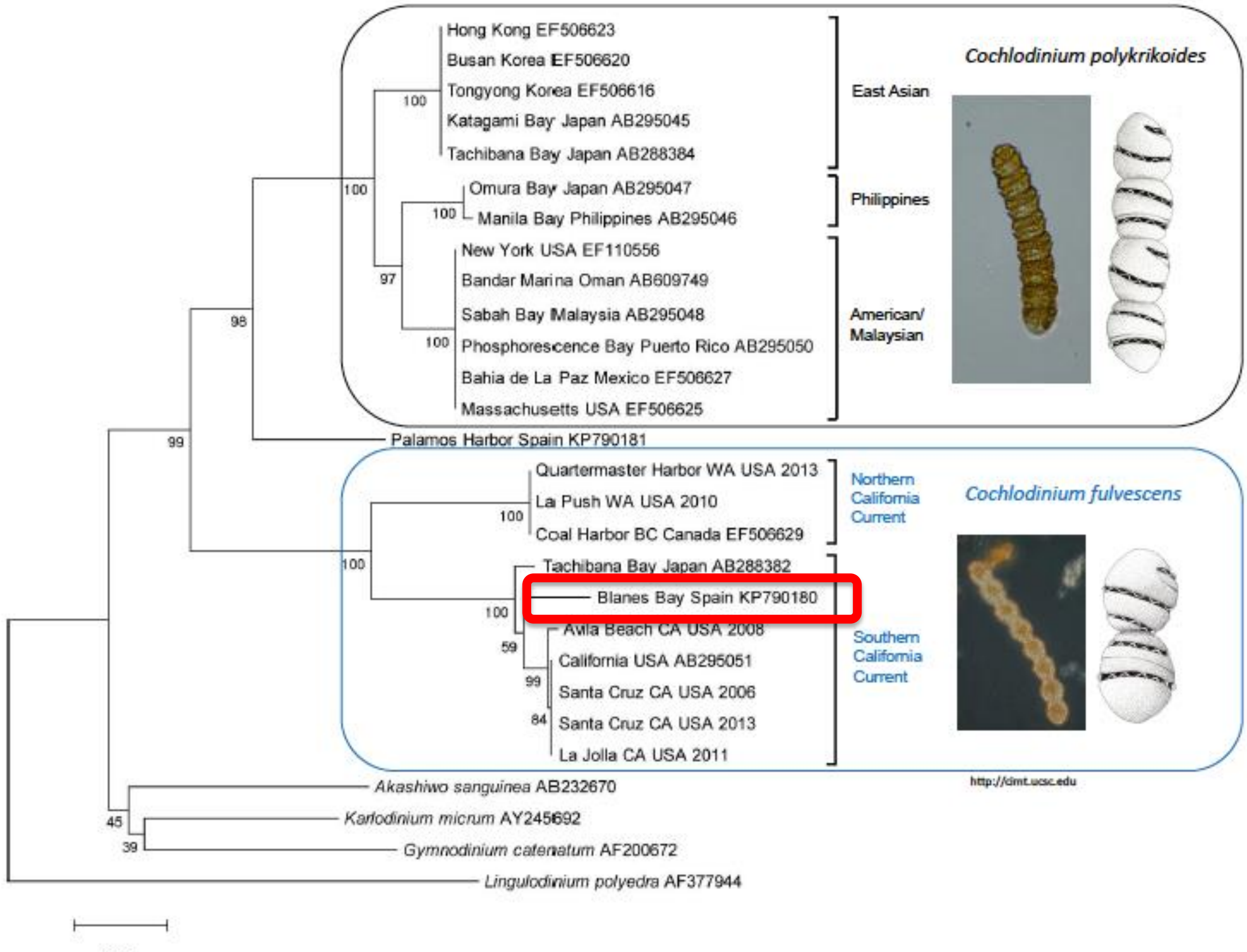


Global Expansion of Multiple HABs

R.M. Kudela, C.J. Gobler/Harmful Algae 14 (2012) 71–86






Hong Kong EF506623
Busan Korea EF506620
Tongyong Korea EF506616
Katagami Bay Japan AB295045
Tachibana Bay Japan AB288384
Omura Bay Japan AB295047
Manila Bay Philippines AB295046
New York USA EF110556
Bandar Marina Oman AB609749
Sabah Bay Malaysia AB295048
Phosphorescence Bay Puerto Rico AB295050
Bahia de La Paz Mexico EF506627
Massachusetts USA EF506625
East Asian
Philippines
American/ Malaysian
Cochlodinium polykrikoides
Palamos Harbor Spain KP790181
Quartermaster Harbor WA USA 2013
La Push WA USA 2010
Coal Harbor BC Canada EF506629
Tachibana Bay Japan AB288382
Blanes Bay Spain KP790180
Avila Beach CA USA 2008
California USA AB295051
Santa Cruz CA USA 2006
Santa Cruz CA USA 2013
La Jolla CA USA 2011
Northern California Current
Southern California Current
Cochlodinium fulvescens
http://dmt.ucsc.edu
Akashiwo sanguinea AB232670
Karlodinium micrum AY245692
Gymnodinium catenatum AF200672
Lingulodinium polyedra AF377944
100
100
100
97
100
98
99
100
100
100
59
99
84
45
39

Vol. 545: 63–76, 2016
doi: 10.3354/meps11590

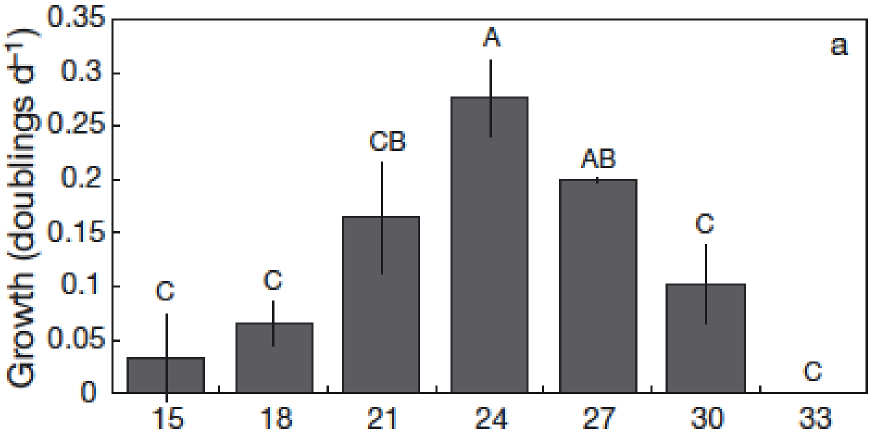
MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

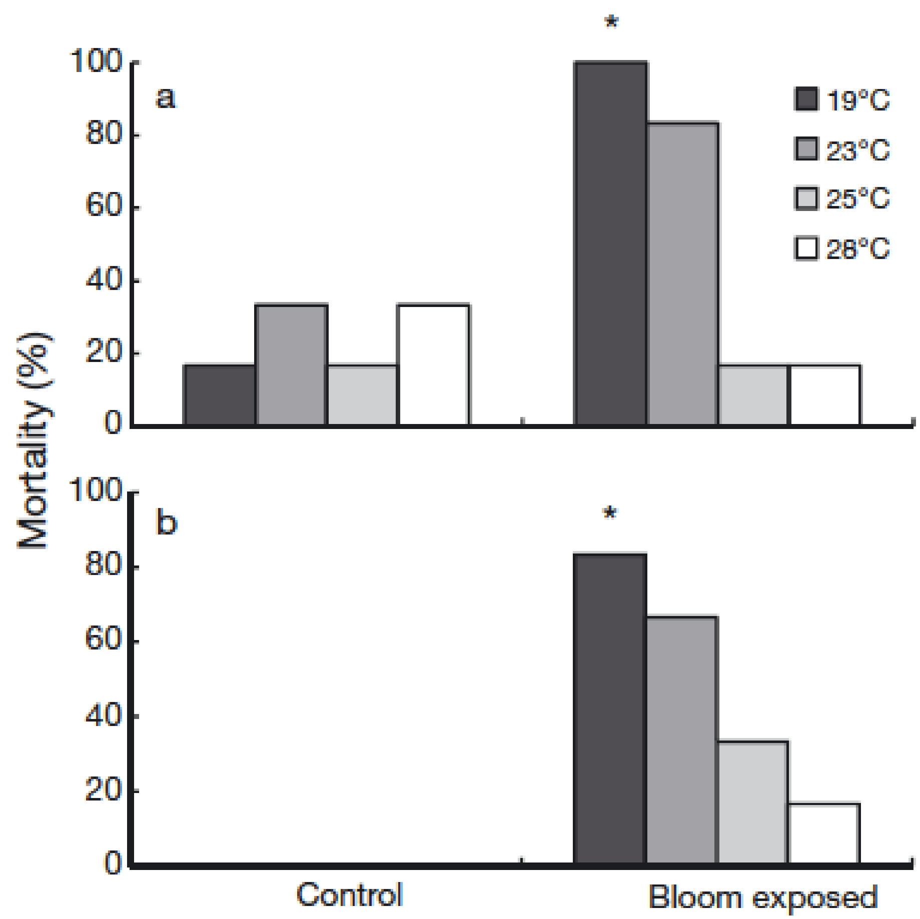
Published March 8

Temperature controls the toxicity of the ichthyotoxic dinoflagellate *Cochlodinium polykrikoides*

Andrew W. Griffith, Christopher J. Gobler*

Cochlodinium has a broad temperature tolerance (bottom), but is most toxic at low growth temperatures (right)



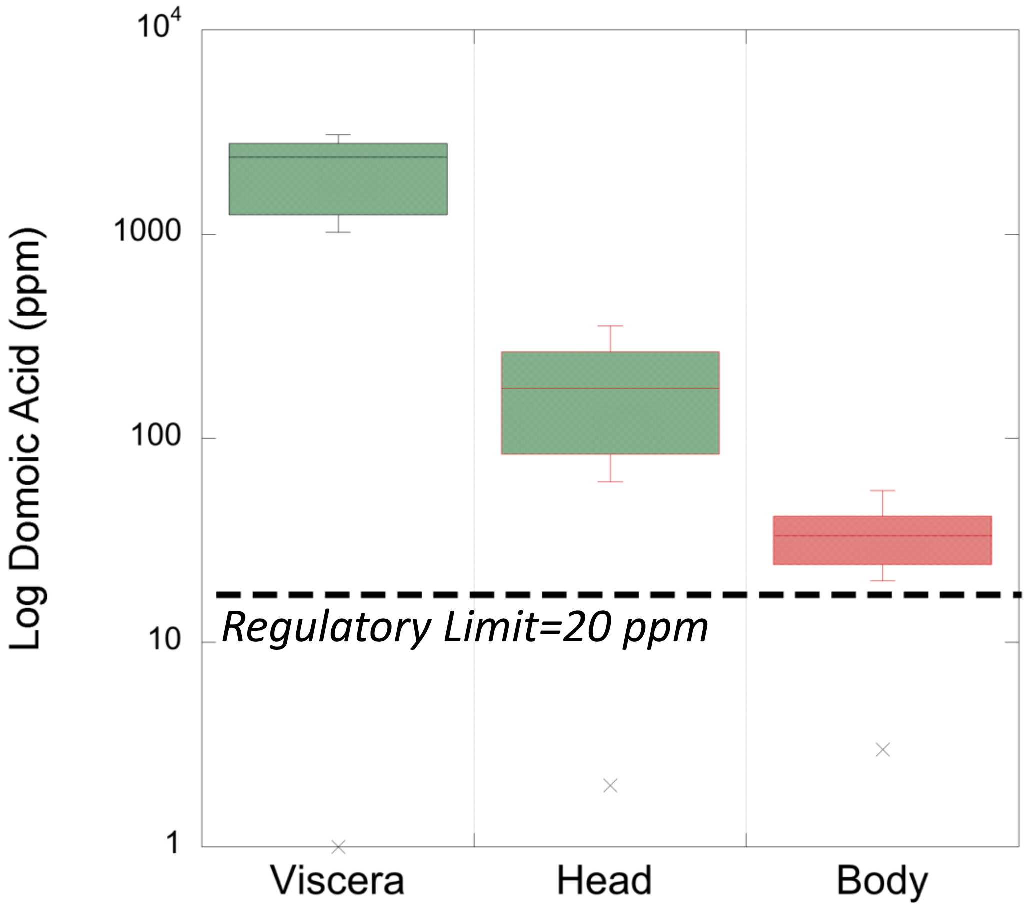


2015: An Unprecedented Year

- ***Trophic Transfer:***
  - Mussels up to 200 ppm
  - Anchovy 100-600 ppm, viscera >3,000 ppm
  - Razor Clam 340 ppm
  - Rock Crab = 1,000 ppm
  - Dungeness = 270 ppm
  - West Coast survey: 100% of fish contaminated

- Feb 16, 2016: California Requests Federal Disaster Relief

Anchovy Contamination



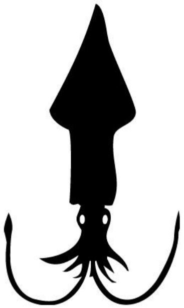
Average Domoic Acid:

Viscera = 2076 ppm

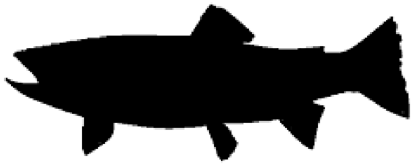
Head = 184 ppm

Body = 35 ppm

N=10 individuals

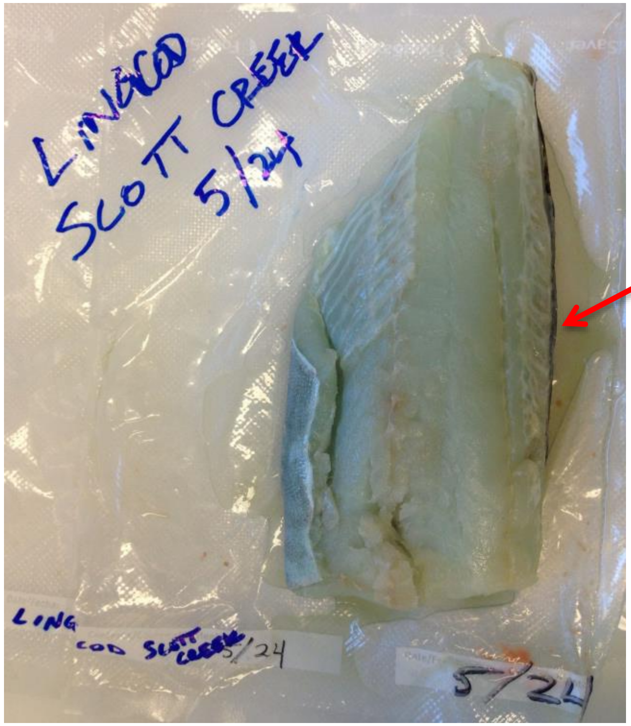


Prolonged Exposure?



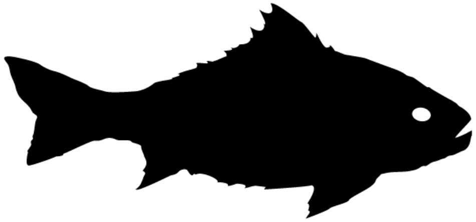
Rockfish	King Salmon
Market Squid	Coho Salmon
Ling Cod	Mackerel
Halibut	Sardinops

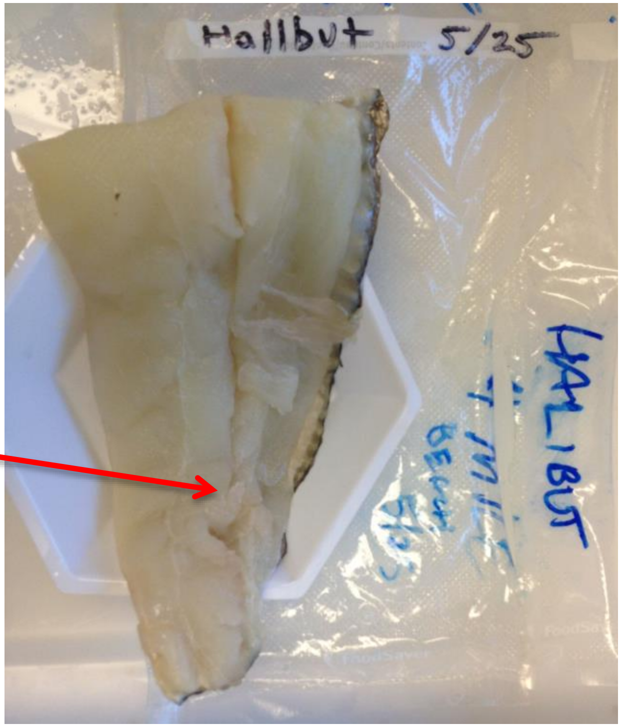
0.03 - 15 ppm



Ling Cod Red Muscle:
0.5 ppm (10x increase)

Halibut Red Muscle:
2.5 ppm (~100x increase)





J. Phycol. 49, 54–60 (2013)

DOI: 10.1111/jpy.12008

ENVIRONMENTAL OPTIMA FOR SEVEN STRAINS OF *PSEUDOCHATTONELLA* (DICTYOCHOPHYCEAE, HETEROKONTA)[1]

Birger Skjelbred[2]

Norwegian Institute for Water Research (NIVA), Gaustadalléen 21, Oslo NO-0349, Norway

Bente Edvardsen, and Tom Andersen

Department of Biology, University of Oslo, P.O. Box 1066 Blindern, Oslo NO-0316, Norway

Chile salmon farms lose 23 million fish due to toxic algae bloom

BY KAREN GRAHAM MAR 10, 2016 IN ENVIRONMENT

An ongoing and deadly toxic algae bloom off the coast of Chile, the world's second largest salmon exporter, has sent the country's salmon industry into a tailspin.

http://nordicmicroalgae.org/taxon/Pseudochattonella

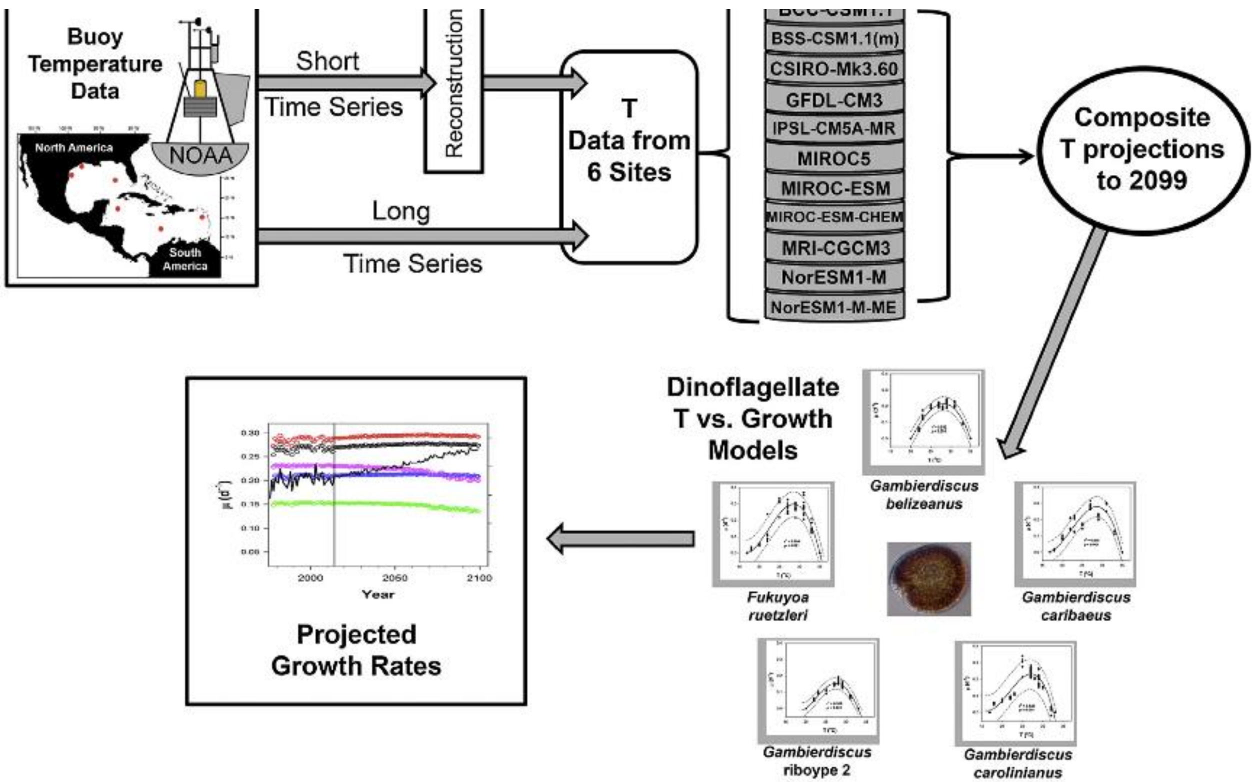
Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Effects of ocean warming on growth and distribution of dinoflagellates associated with ciguatera fish poisoning in the Caribbean

Steven R. Kibler[a,*], Patricia A. Tester[b], Kenneth E. Kunkel[c], Stephanie K. Moore[d], R. Wayne Litaker[a]

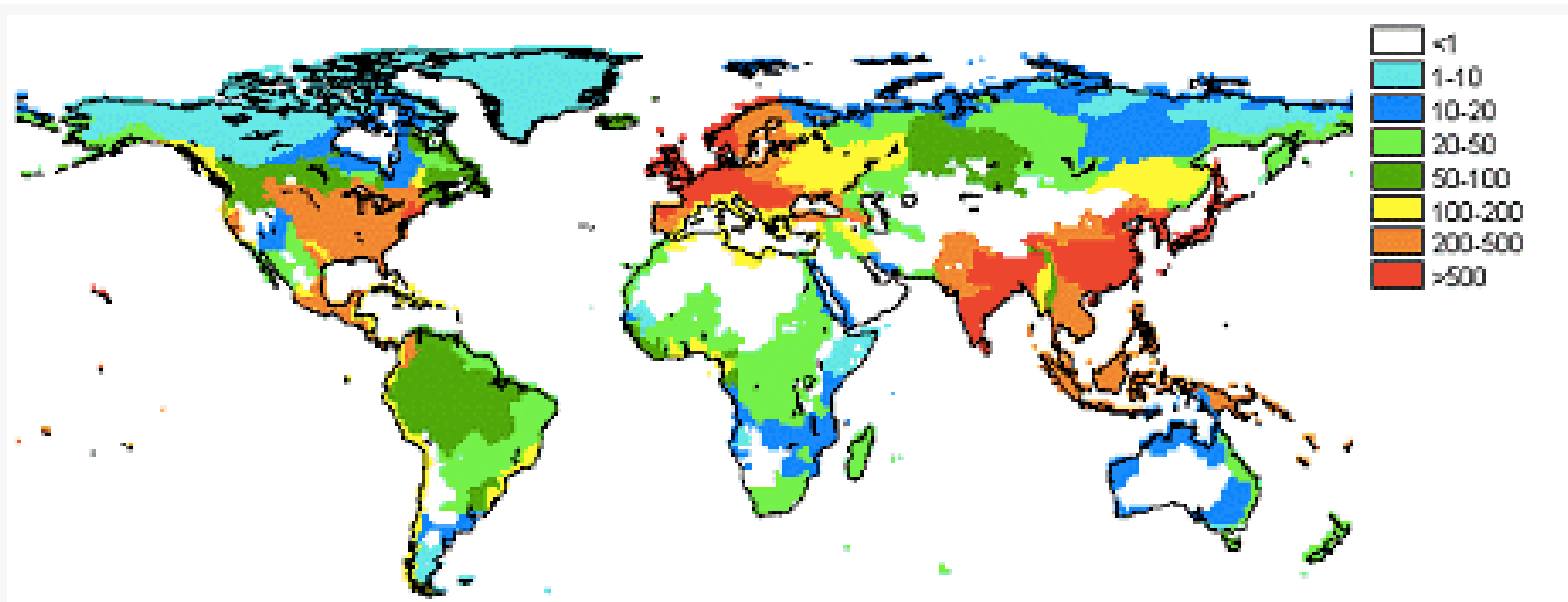


Global Change Biology
celebrating 20 years

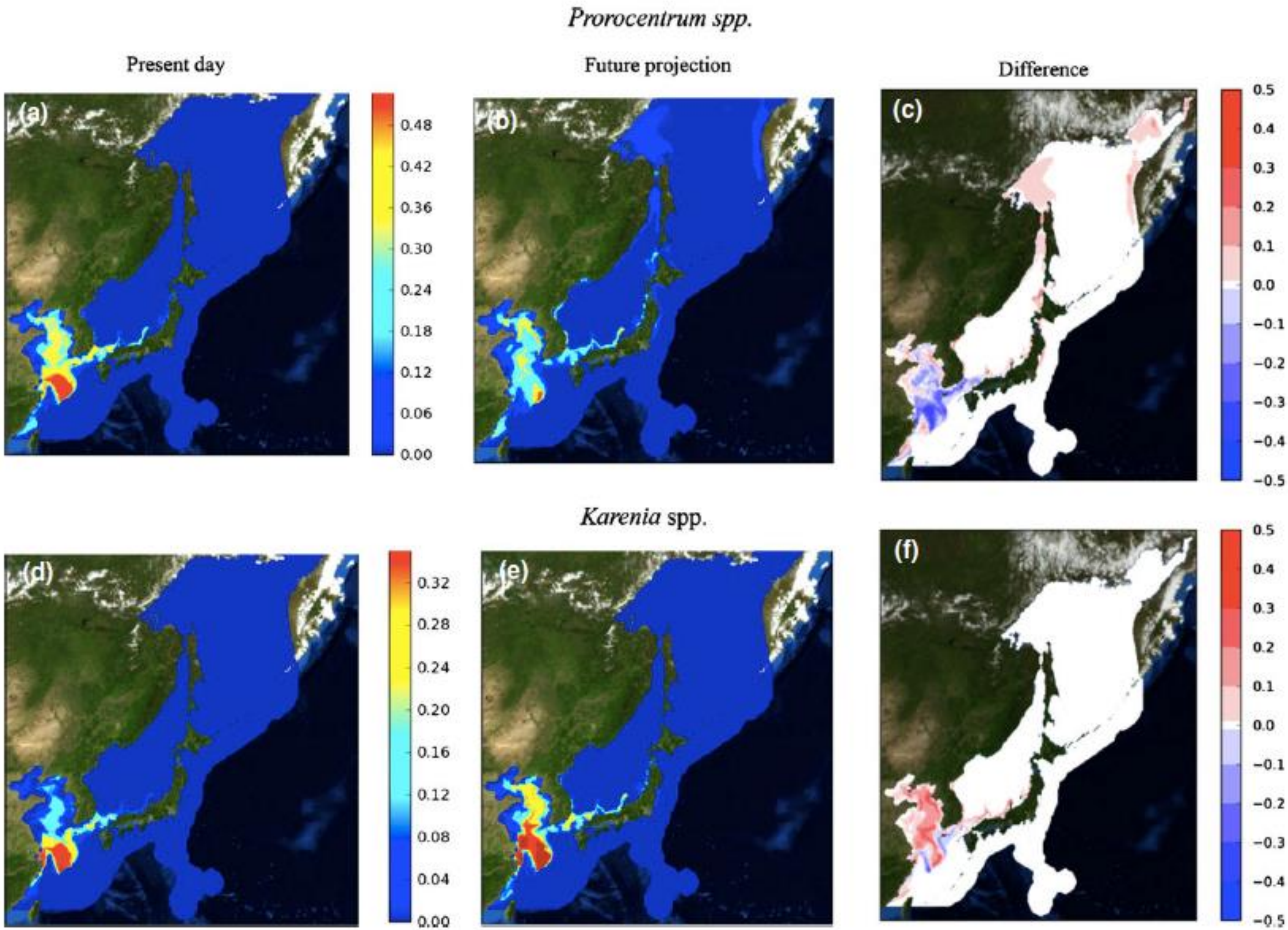
Global Change Biology (2014), doi: 10.1111/gcb.12662

Vulnerability of coastal ecosystems to changes in harmful algal bloom distribution in response to climate change: projections based on model analysis

PATRICIA M. GLIBERT[1], J. ICARUS ALLEN[2], YURI ARTIOLI[2], ARTHUR BEUSEN[3], LEX BOUWMAN[3,4], JAMES HARLE[5], ROBERT HOLMES[2] and JASON HOLT[5]



Nitrogen (inorganic N) export from watersheds to coastal systems. units: kg N km-2 watershed y-1. From S.P. Seitzinger and C. Kroeze 1998. Global distribution of nitrous oxide production and N inputs in freshwater and coastal marine ecosystems. Global Biogeochem. Cycles 12(1): 93-113.



Prorocentrum spp.
Present day
Future projection
Difference
(a)
(b)
(c)
0.48
0.42
0.36
0.30
0.24
0.18
0.12
0.06
0.00
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
Karenia spp.
(d)
(e)
(f)
0.32
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0.00
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.5

Are The Data Correct?

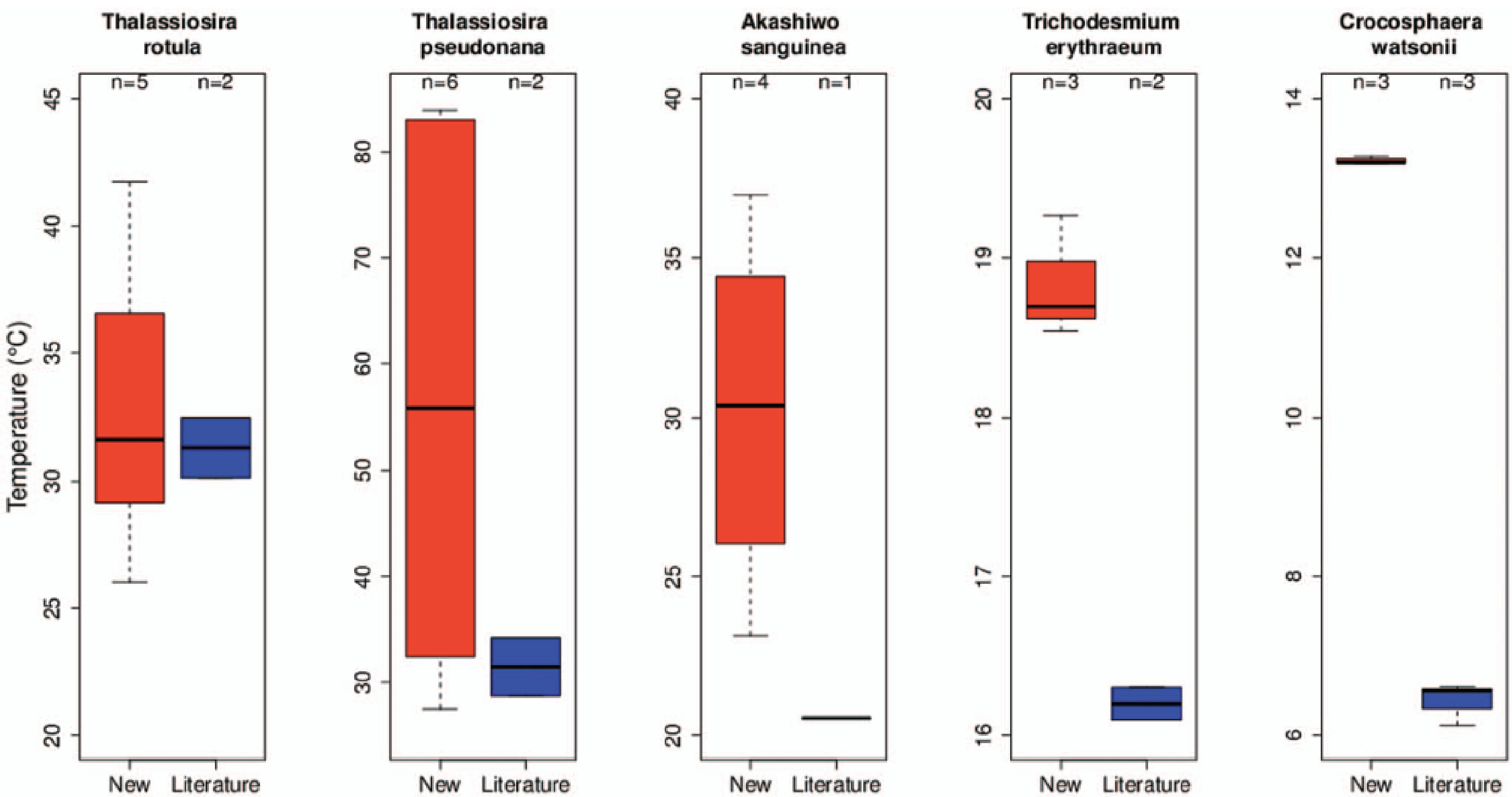


Figure 5. A comparison of the thermal trait, niche width (°C) using box and whisker plots, between previously published studies (using a wide range of experimental protocols, see [43]) and the species/strains used in the present study. The black bands denote the median value, the bottom and top of the red/blue boxes represent the 1st and 3rd quartile of the data respectively. The 'whiskers' extending from the boxes indicate the positions of the lowest & highest values in the data. If the sample size is small enough, the whiskers may not appear (e.g. if there are only 3 equally spaced points, the value represented as the 1st quartile is the lowest value).
doi:10.1371/journal.pone.0063091.g005

Boyd et al. 2013, PLoS ONE 8(5) e63091

Harmful algal blooms and climate change: Learning from the past and present to forecast the future

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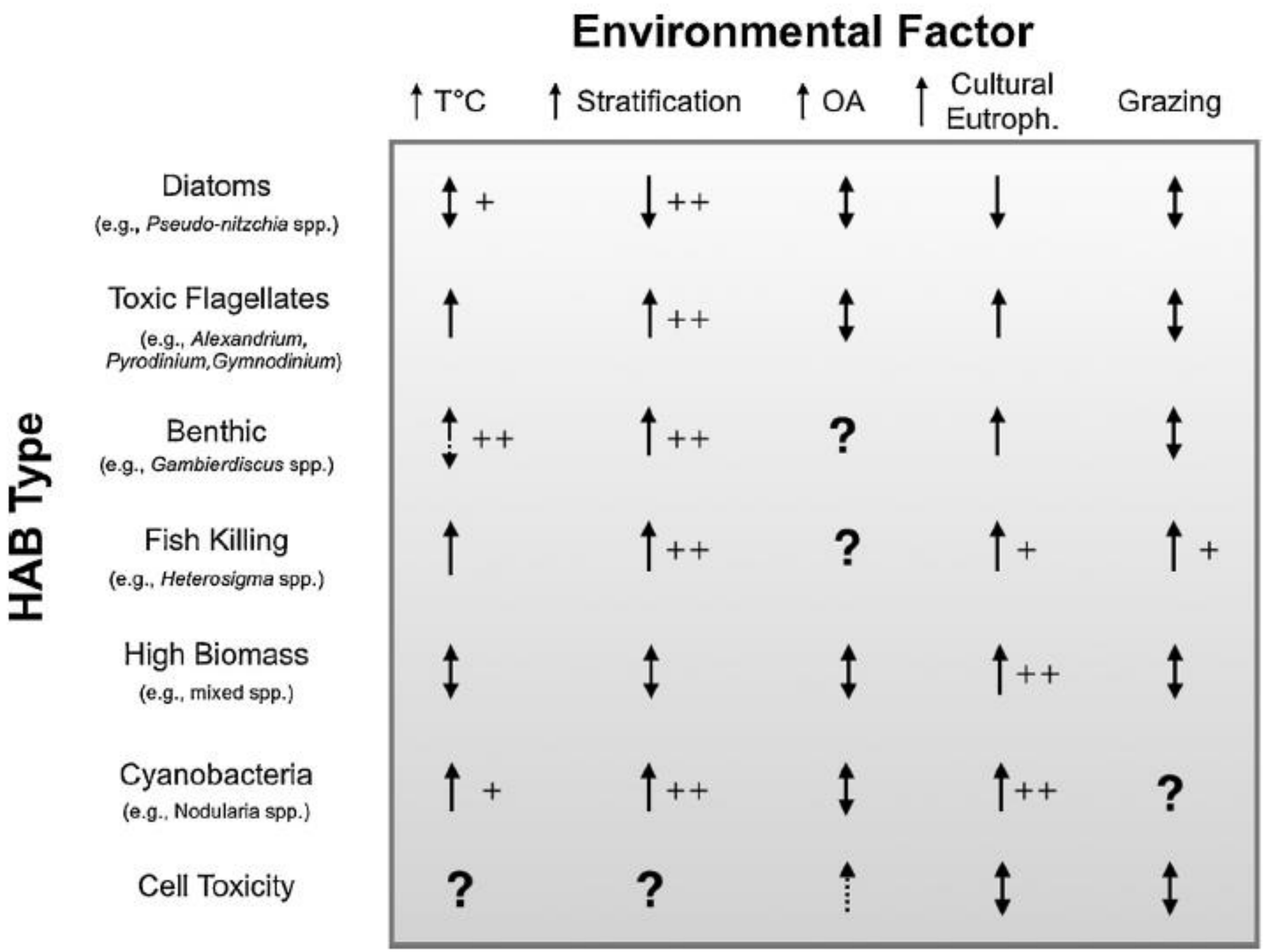
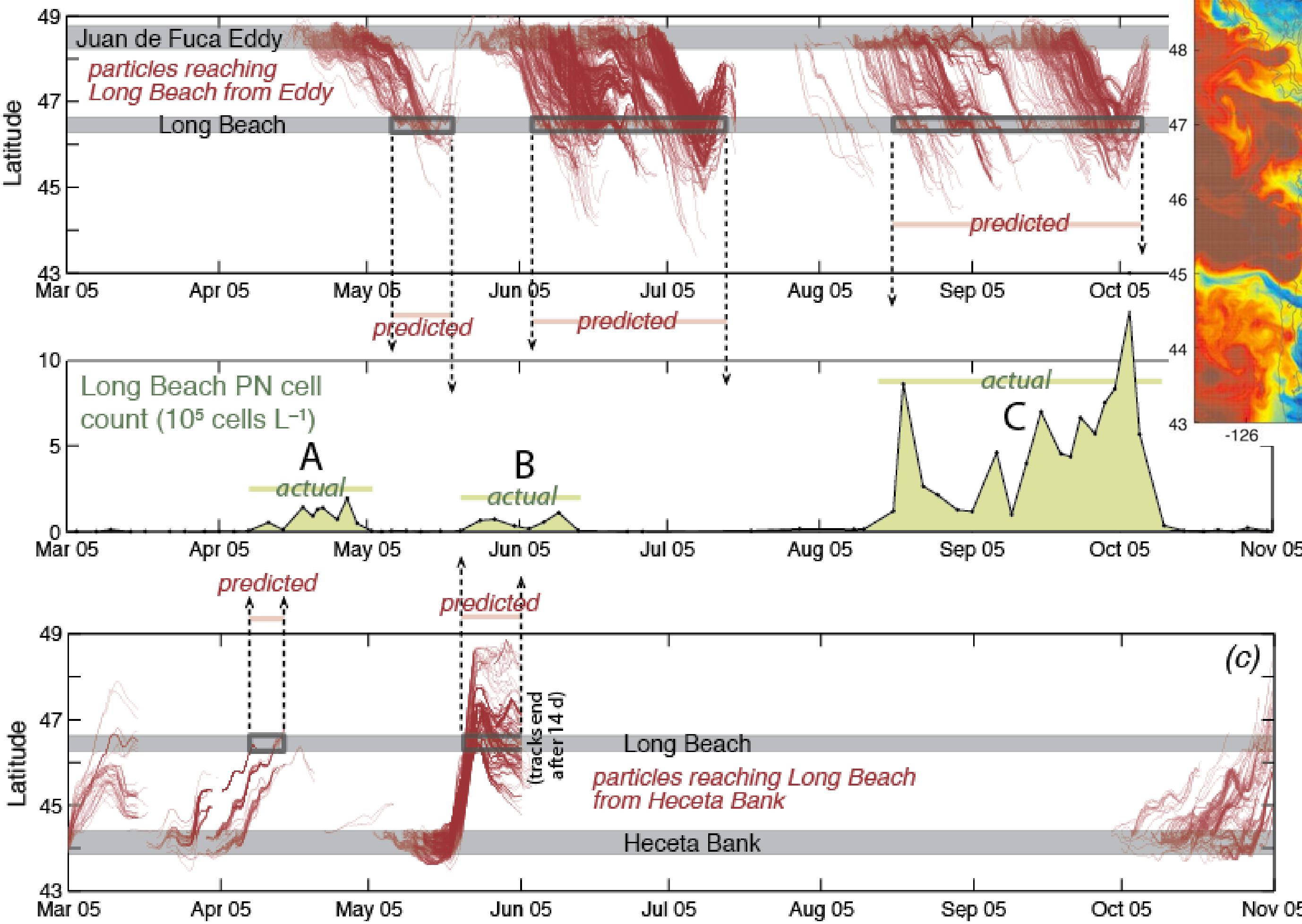


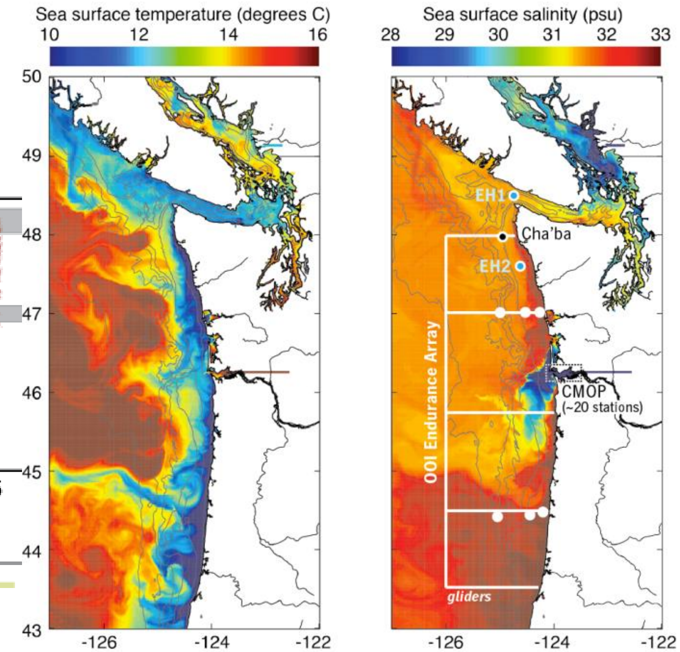
Harmful Algae 2015, 49: 68-93

Recommendations (13 Total):

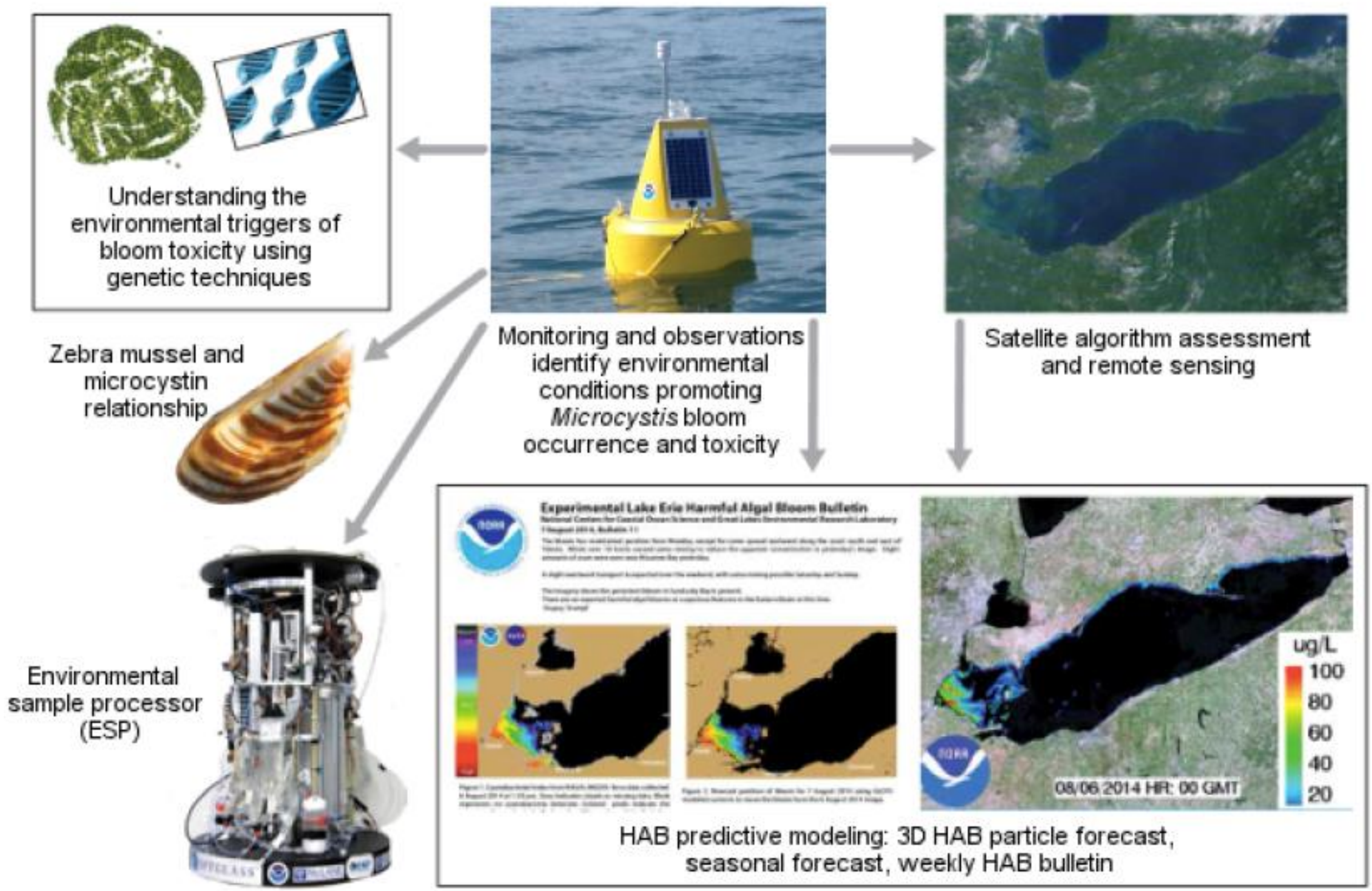
- A best practices manual for HAB and climate change research
- A greater emphasis on multifactorial laboratory experiments
- Better global assessment of HAB species responses through ‘‘Common Garden’’ experiments
- Explicit coupling of HAB modeling and forecasting platforms to complex ecosystem models
- Expand studies on the social science of harmful algal blooms

Research has improved understanding, leading to better prediction and monitoring, and potentially, mitigation.



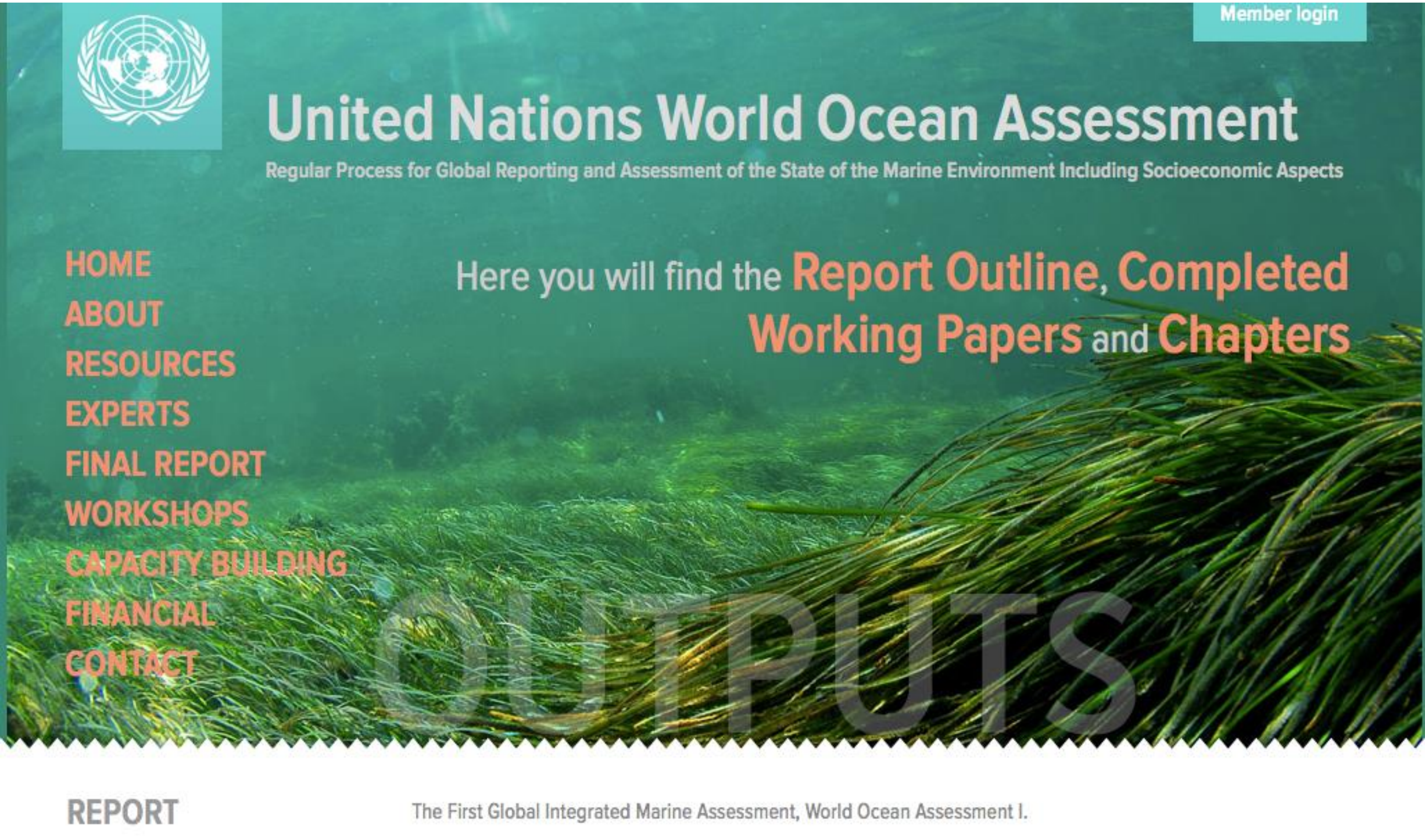


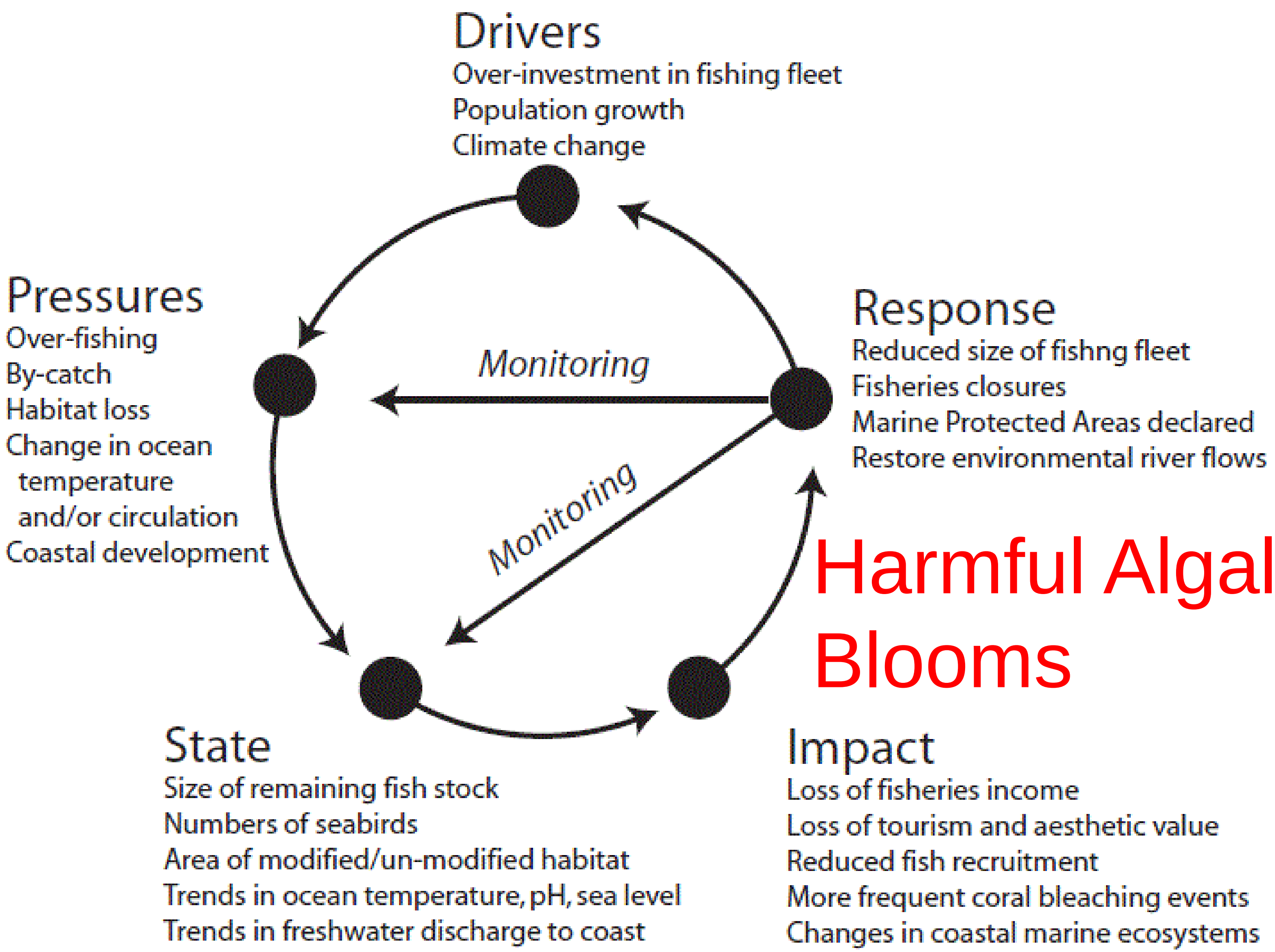
Developing Predictive Models to Improve Coastal and Human Health and Beach Forecasting - HAB Component



https://www.epa.gov/sites/production/files/2014-12/documents/habs-davis-12-10-14.pdf

HABs must be integrated with policy decisions





Harmful Algal Blooms

HABs must be integrated with policy decisions

CONSERVATIVE ANNUAL COST

Marine HABs

USA	± US$ 95 million
Europe	> US$ 850 million
Japan	> US$ 1 billion

Freshwater HABs

USA	± US$ 4,6 billion
China	± US$ 6,5 billion (1998, Lake Tai)
Australia	± US$ 150 million
UK	± US$ 150 million
South Africa	± US$ 250 million

Source: Bernard et al., 2014, Developing global capabilities for the observation and prediction of harmful algal blooms. Oceans and Society: Blue Planet. Cambridge Scholars Publishing.

Using a typical Value of Information estimate of 1% of the "resource" (in this case HAB-related losses), **a comprehensive global HAB observing and forecasting information system would represent a value of ± $100 million annually**, one-tenth of the direct cost.

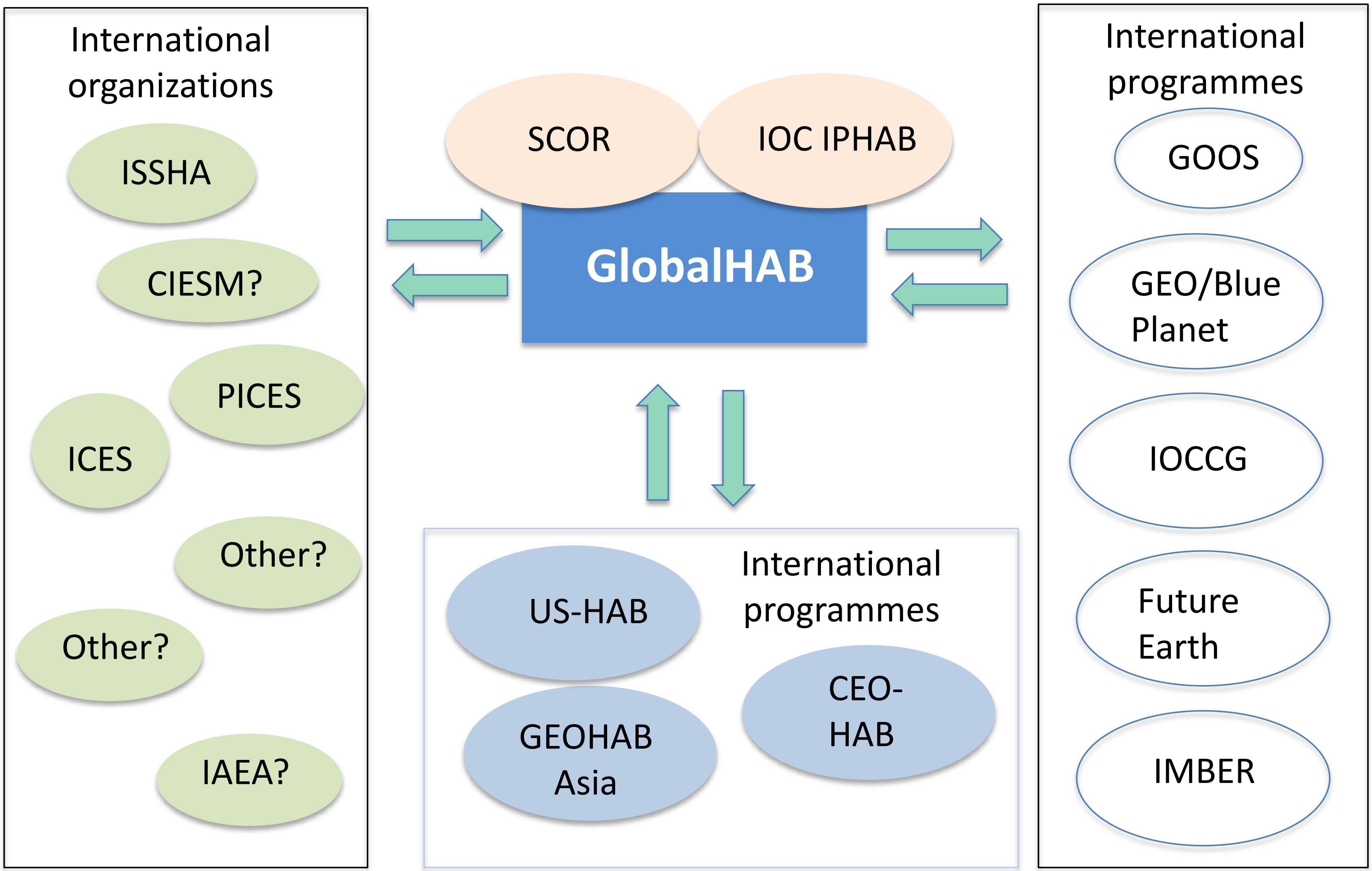
In the near future, HAB-related costs are going to increase because the problem will become more severe with global climate change and increased exploitation of coastal resources. Although predicting the impact of a shifting climate on HABs is complex, range expansion of harmful species, changes in algal community dynamics, and impacts to formerly unaffected ecosystems, as well as by previously unknown HAB organisms, are already occurring.


ISBN 978-1-927797-11-2
ISSN 1198-273X
PICES SCIENTIFIC REPORT
No. 47, 2014
WARNING . . .
TOXIC
SHELLFISH
Proceedings of the Workshop on Economic
Impacts of Harmful Algal Blooms
on Fisheries and Aquaculture
NORTH PACIFIC MARINE SCIENCE ORGANIZATION

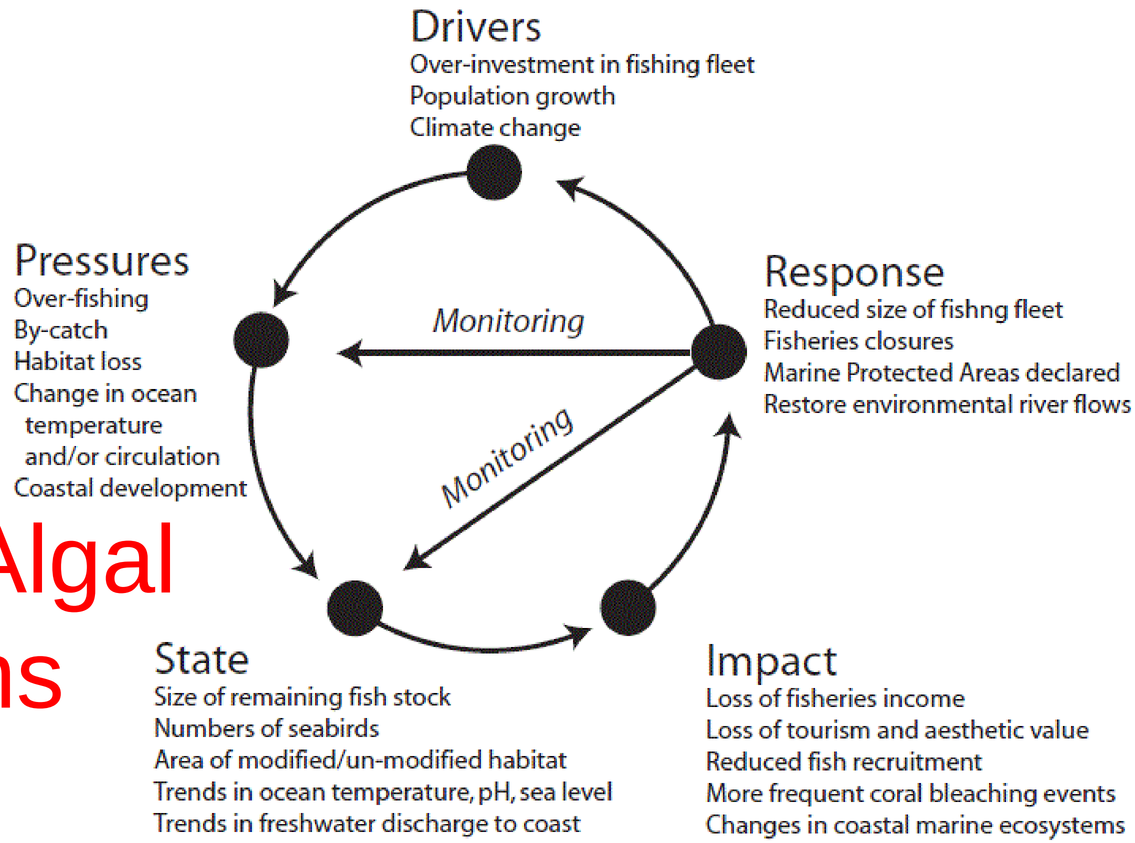

Economic Benefits of Reducing Harmful Algal
Blooms in Lake Erie
Submitted to the International Joint Commission
October 2015
VERITAS
Economic Consulting


OCEANS AND SOCIETY
BLUE PLANET
Edited by Samy Djavidnia, Victoria Cheung, Michael Ott and Sophie Seeyave

HABs are a worldwide phenomenon requiring international understanding leading ultimately to local and regional solutions

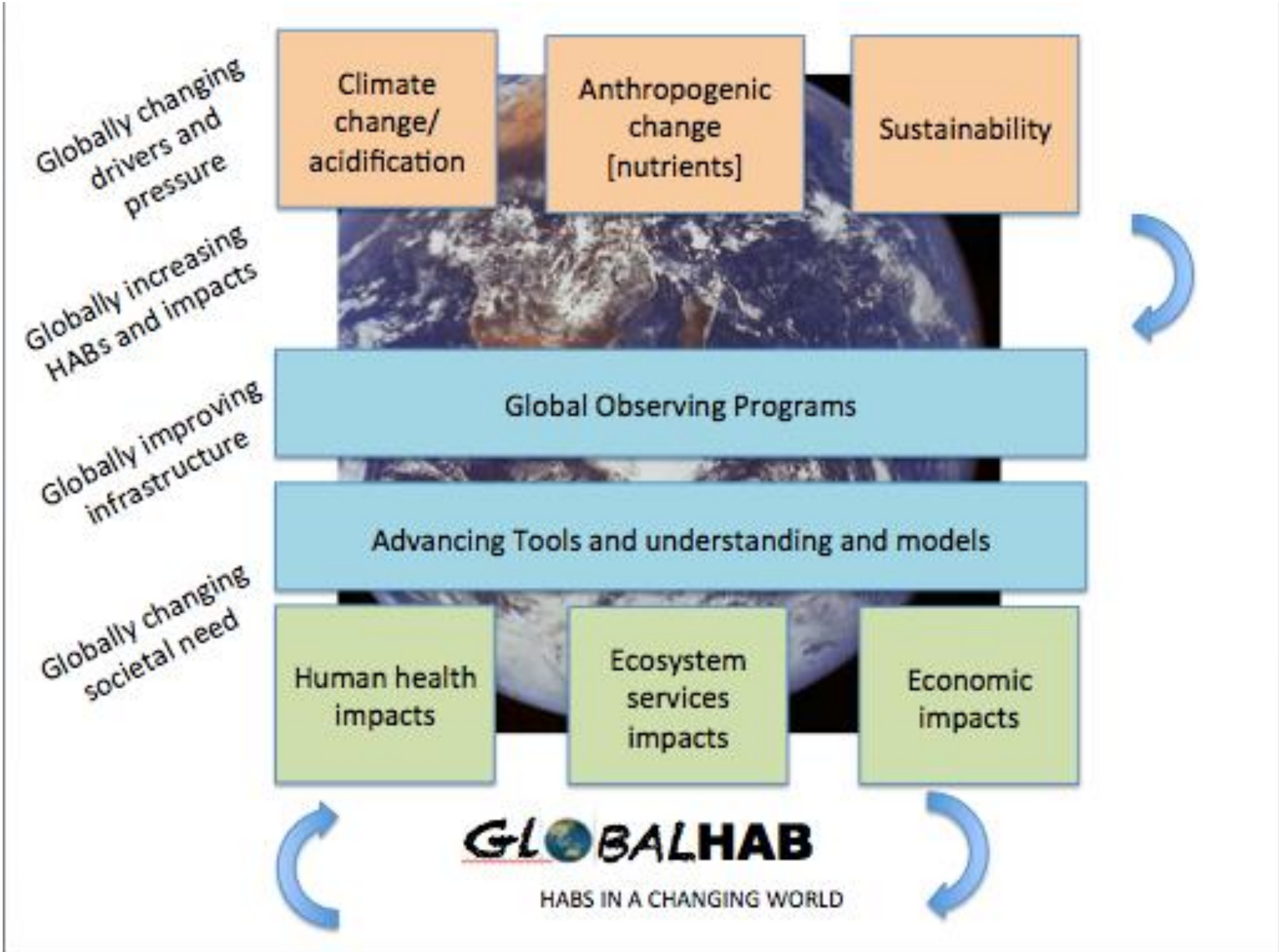


Harmful Algal Blooms



US IOOS Biology Task Team:
HABs (and phytoplankton species) identified as Essential Ocean Variable

Global Ocean Observing System Biology & Ecosystem Panel
HABs identified as an Essential Ocean Variable


Globally changing drivers and pressure
Globally increasing HABs and impacts
Globally improving infrastructure
Globally changing societal need
Climate change/ acidification
Anthropogenic change [nutrients]
Sustainability
Global Observing Programs
Advancing Tools and understanding and models
Human health impacts
Ecosystem services impacts
Economic impacts
GLOBALHAB
HABS IN A CHANGING WORLD

MISSION

To improve understanding, prediction, management and mitigation of HABs in aquatic ecosystems.

Global HAB IOC - SCOR

GOALS

• **GlobalHAB** will address the scientific and societal challenges of HABs, including the environmental, human health and economic impacts, in a rapidly changing world.

• **GlobalHAB** will involve participants from related fields of natural and social science, and will link with other regional and international organizations and initiatives relevant to HABs.

• **GlobalHAB** will foster intercalibration among existing methods, as well as promoting the development and adoption of new technologies.

• **GlobalHAB** will promote training, capacity building and communication of knowledge about HABs to society.

• **GlobalHAB** will serve as a liaison between the scientific community, stakeholders and policy makers, promoting science-based decision making.

GlobalHAB Target Areas (DRAFT)

- **Benthic HABS (from GEOHAB Programme)**

- **HABs & Human Health**
  - To determine long term effects of low level exposure to aquatic biotoxins on human health, animal health and aquatic organisms.
  - To determine the synergistic or antagonistic effects of multiple aquatic biotoxins on human and marine organism health.
  - To improve coordination between algal biotoxin monitoring and public health surveillance activities.

- **HABs in Fresh & Brackish Water**
  - To synthesize and share information on mitigation with managers
  - To improve communication between scientists and managers working on freshwater and cyanobacterial HABs
  - To identify emerging issues for cHABS across freshwater, brackish and marine habitats, both benthic and pelagic

- **Economics of HABs**
  - To develop cross community understanding of the economic impacts of HABs and hence to define methodologies and criteria capable of robustly assessing (at both regional and local levels) the economic costs of HAB and methods to predict and mitigate them.

GlobalHAB Target Areas (DRAFT)

- **Toxins**

Applied goal: Development, evaluation and regulatory validation of toxin analysis (better, faster, cheaper)
Fundamental goals: Characterize genetic and environmental basis for toxin production and determine mode of action of toxins.

- **HABs in a Changing World**

To understand global patterns in HAB responses to common drivers (thermal windows, stratification, nutrients).
Key questions: are windows of opportunity expanding, or simply shifting in space and time? Are the common drivers moving into novel combinations, or shifting coherently?

- **HABs & Aquaculture**

- To determine the potential effects of nutrients, shifting nutrient ratios, and/or organic matter from aquaculture in promoting HABs.
- To identify modes of impact and mechanisms in HAB interactions with aquaculture

Summary

- We have a good understanding of the MAIN toxins/organisms… but it is also clear that the details matter (species, strains, unanticipated effects)
- Globalization and climate change are leading to new issues, new impacts
- We have a very poor understanding of the interactive effects of multiple organisms/toxins
- We need to move beyond “simply” doing science, and justify HAB research/monitoring within a societal context
- Now is the time! We’ve never had so much opportunity to engage beyond the HAB community