Welcome to the C-CAN Ocean Acidification Roundtable!

Scientists
C-CAN OCEAN ACIDIFICATION ROUNDTABLE
Managers
Industry
Stakeholders

We will begin at 1:00 pm PT using the free VOIP (Voice Over Internet Protocol).

If you need technical assistance, please type your questions into the Question box in in the control panel on the right hand side of your screen.
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You will be charged for this call.
To connect you MUST HAVE the audio pin number shown after joining the seminar

Today's Webinar:

How ocean acidification works hand in hand with warming and other global change stressors to promote toxic Pseudo-nitzschia harmful algal blooms along the West Coast

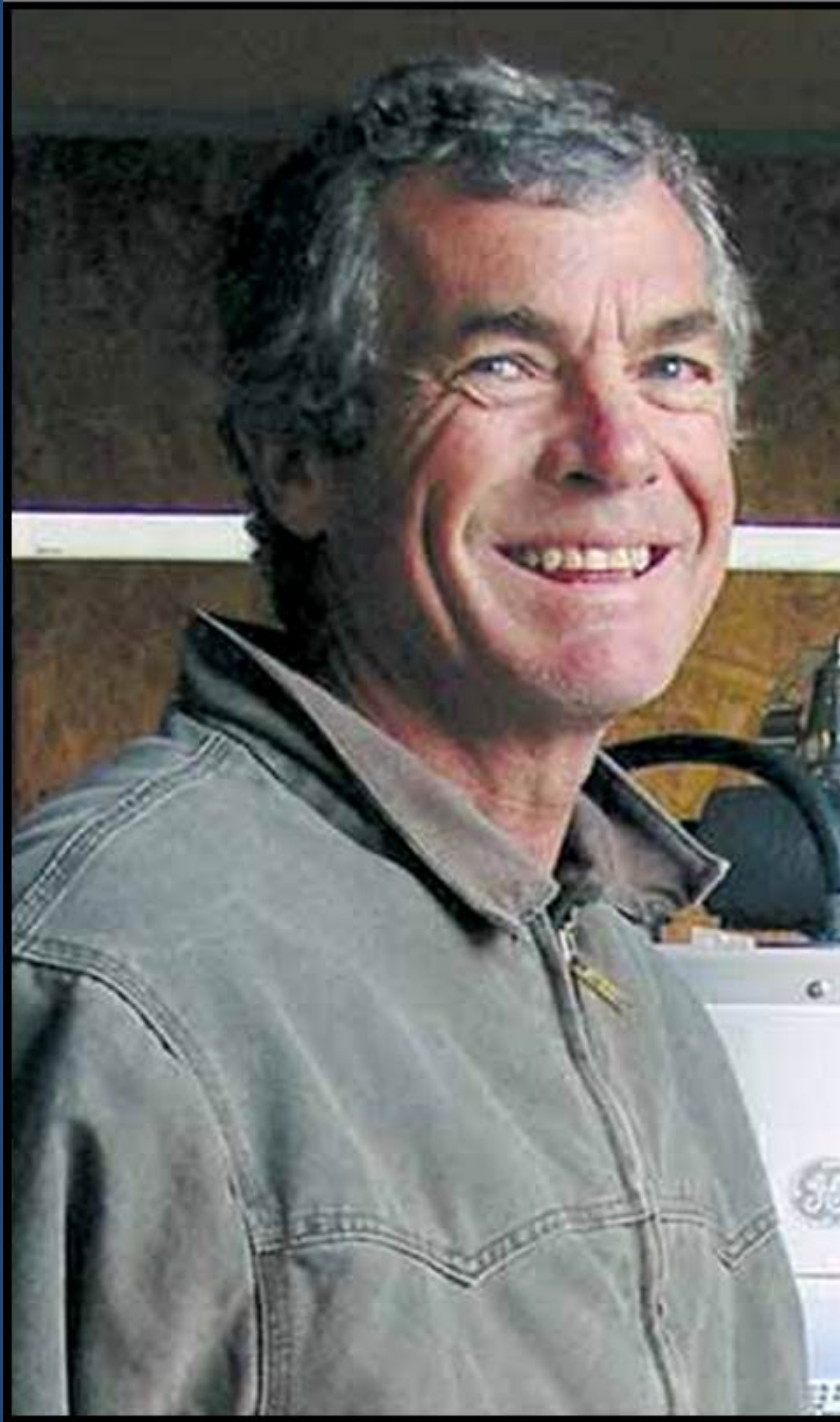
Hosted by:

Hosted by:

- Today's moderator:

Bruce Steele

C-CAN Steering Committee
Commercial diver/fisherman



Logistics coordinated by:

Washington Sea Grant

Teri King

Today's format:

Presentation by Dr. Dave Hutchins:

How ocean acidification works hand-in-hand with warming and other global change stressors to promote toxic *Pseudo-nitzschia* harmful algal blooms along the West Coast

Q&A

Adjourn

Introducing our Speaker

Dr. Dave Hutchins

Professor of Marine and Environmental Biology at the University of Southern California in Los Angeles.

~Ph.D. at UC Santa Cruz, followed by a postdoc at Stony Brook, and then worked for 10 years on the faculty of the Univ.of Delaware before moving to USC 12 years ago.

~ Fellow of the American Association for the Advancement of Science and of the Association for the Sciences of Limnology and Oceanography,

~ Chairman of the 1st Ocean Global Change Biology Gordon Research Conference,

~Associate Editor for Marine Climate Change and Ocean Acidification at the journal Proceedings B of the Royal Society.

Current research examines how global change processes affect ocean biology and biogeochemistry

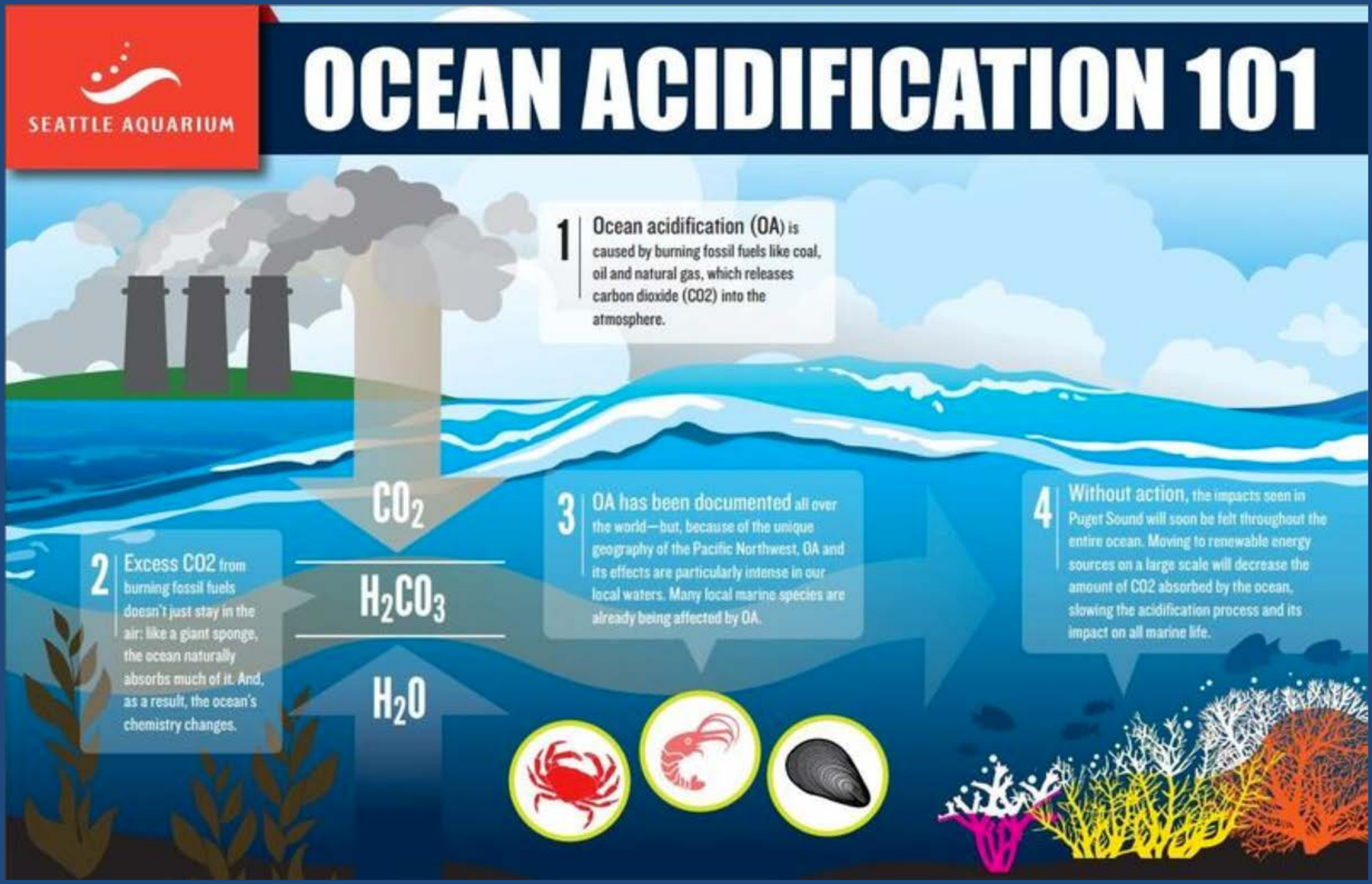
Including how future ocean acidification, sea surface warming, and changing ocean biology, chemistry and physics will impact toxic harmful algal blooms, carbon and nutrient cycling, iron and trace metal cycling, nitrogen fixation, and phytoplankton community structure in marine ecosystems ranging from California coastal waters, to the remote polar Southern Ocean and the open ocean subtropical gyres.

Dave Hutchins
Marine and Environmental Biology
University of Southern California

How ocean acidification works hand-in-hand with warming and other global change stressors to promote toxic *Pseudo-nitzschia* harmful algal blooms along the West Coast

Proposition 84

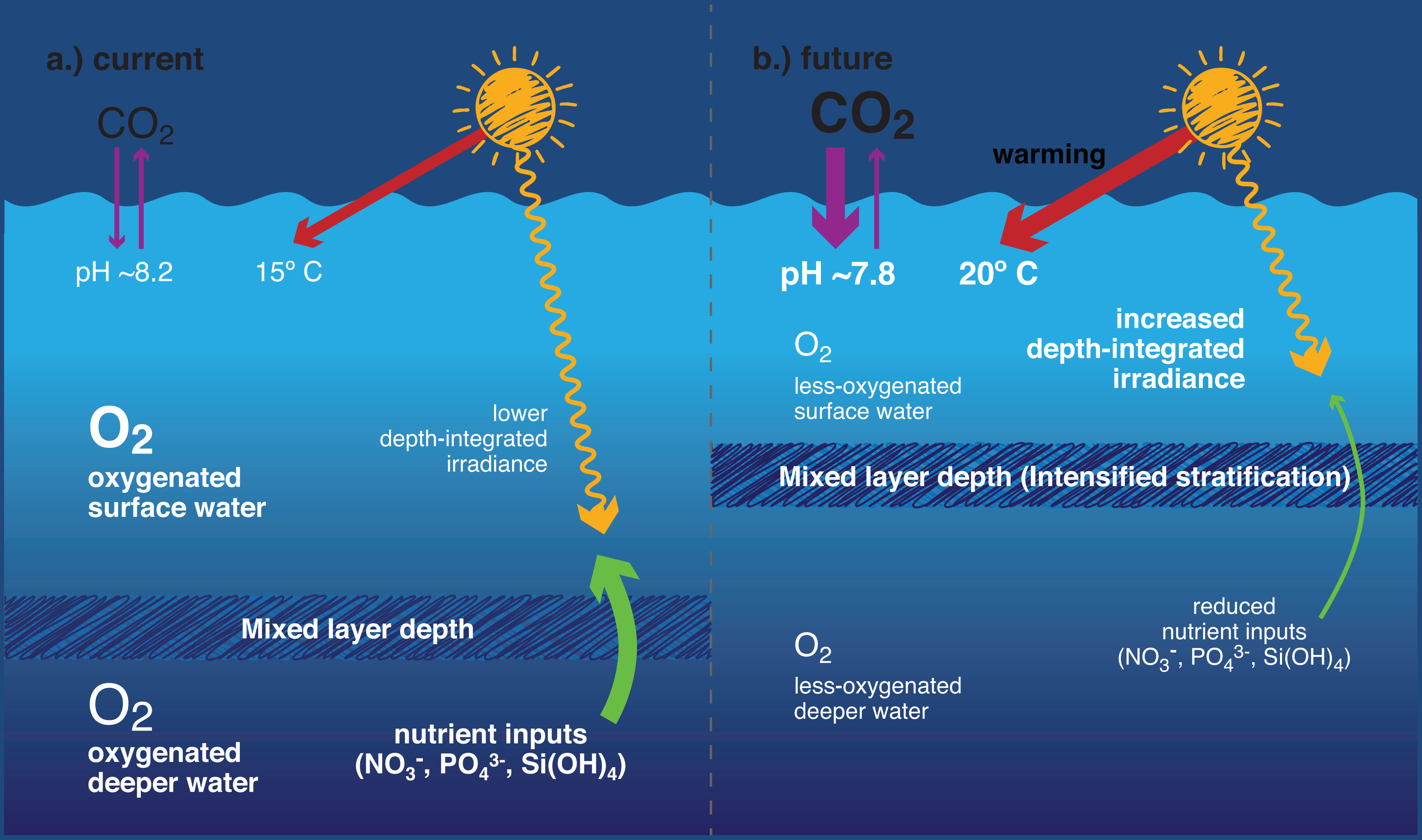
Sea Grant
University of Southern California
Science serving our urban coast



C-CAN

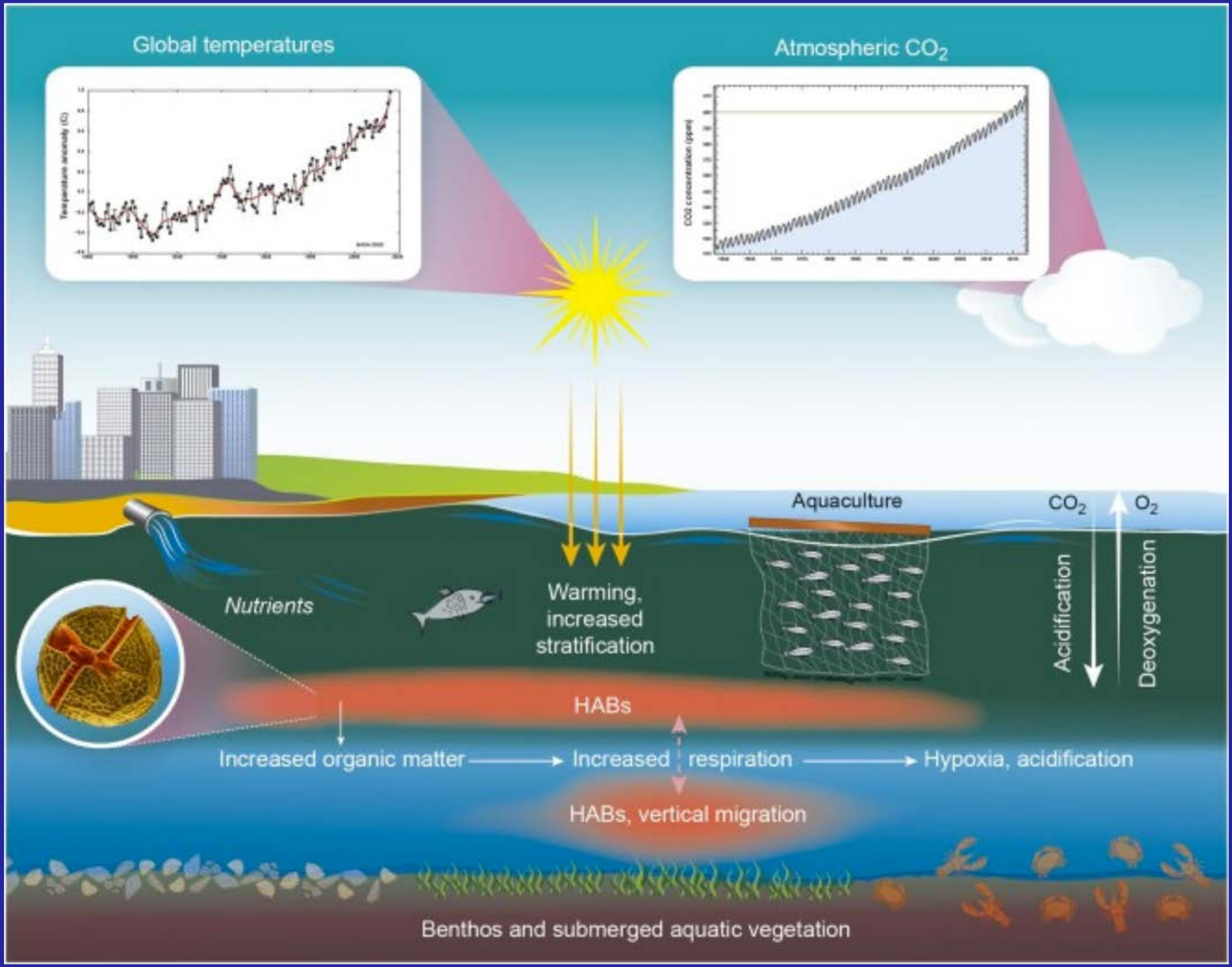
California Current Acidification Network

Some of the physical and chemical changes expected in the future ocean



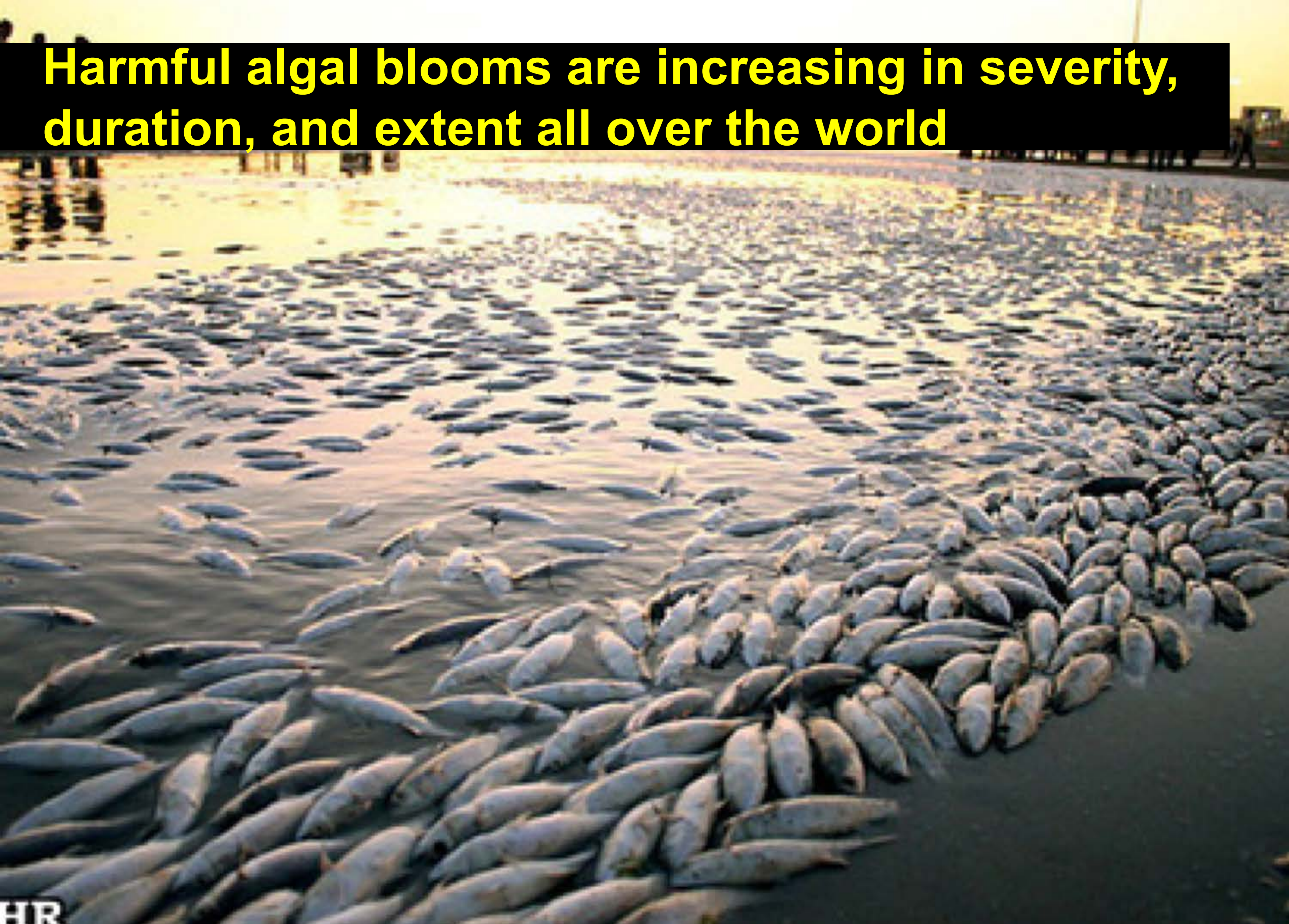
Hutchins and Fu 2017, Nature Microbiology

Numerous global change factors may be related to worldwide increases in the frequency and severity of Harmful Algal Blooms (HABs)



Griffith and Gobler 2019 Harmful Algae

Harmful algal blooms are increasing in severity, duration, and extent all over the world



Dinoflagellate range extensions in a warming ocean

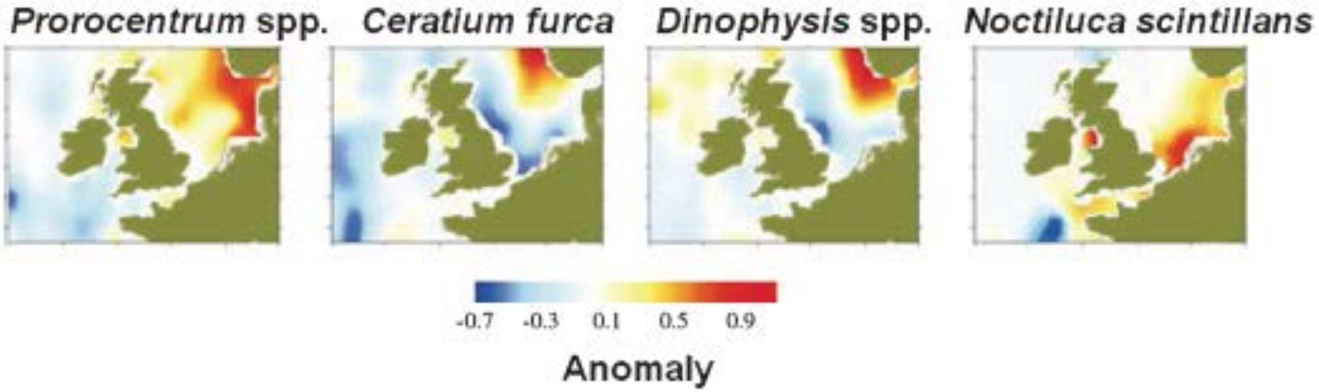


FIG. 5. Decadal anomaly maps (difference between long-term 1960–1989 mean and the 1990–2002 period) for four common HAB species (from left to right): *Prorocentrum*, *Ceratium furca*, *Dinophysis*, and *Noctiluca* in the North Atlantic. Note the increase in *Prorocentrum*, *C. furca*, and *Dinophysis* along the Norwegian coast, and increase in *Noctiluca* in the southern North Sea, reportedly associated with a contraction of the Subpolar Gyre to the west allowing subtropical water to penetrate farther north (adapted from Edwards et al. 2008, with permission).

Hallegraef 2010, J. Phycol 46

Effects of warming (1982-2016) on potential growth rates and bloom season length of the icthiotoxic dinoflagellate *Cochlodinium polykrikoides*

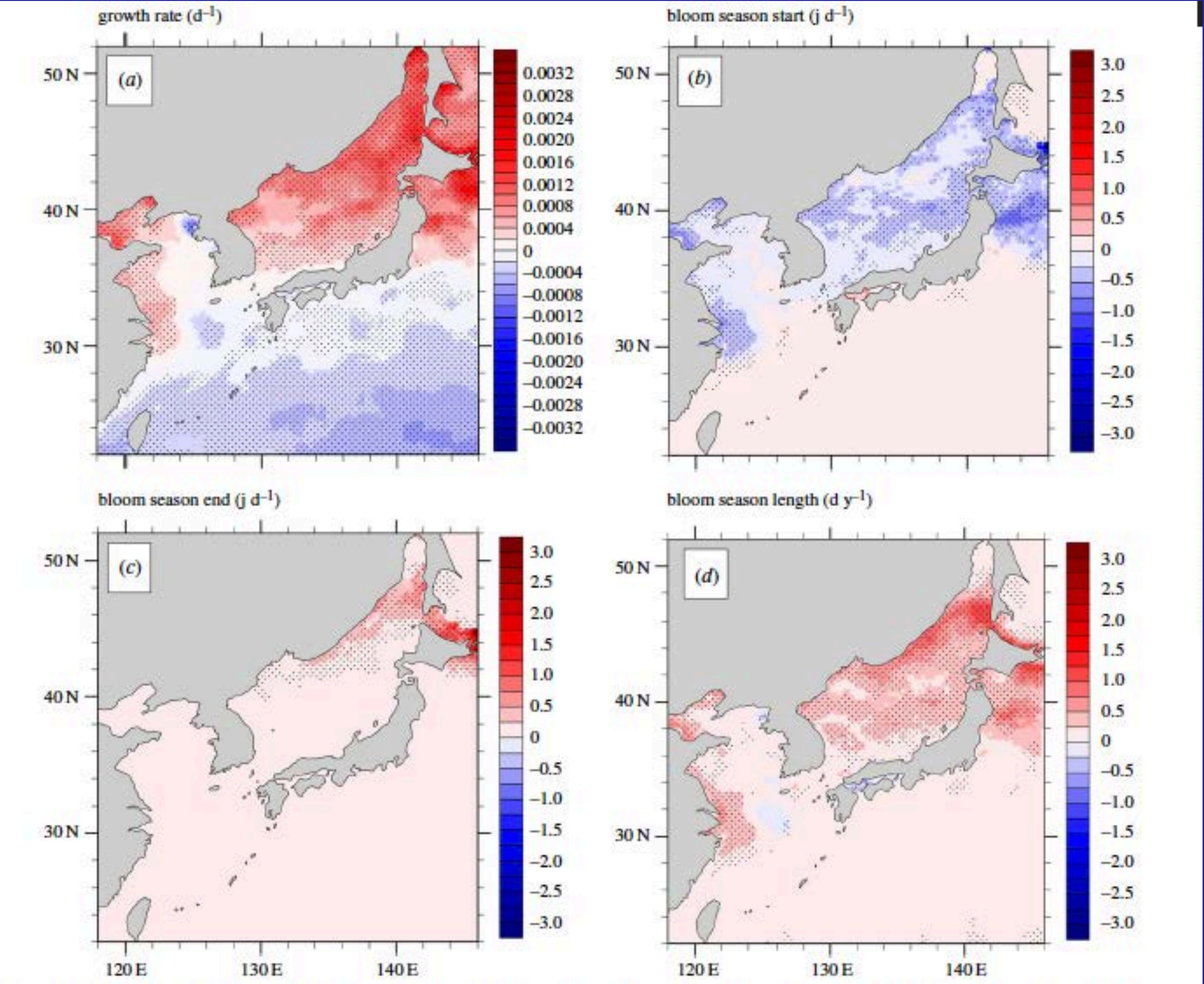
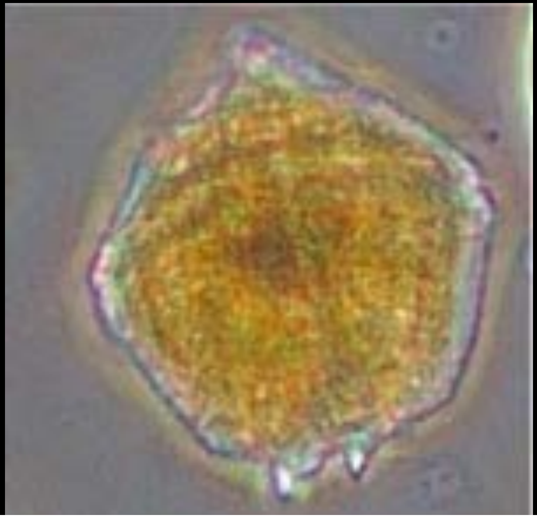


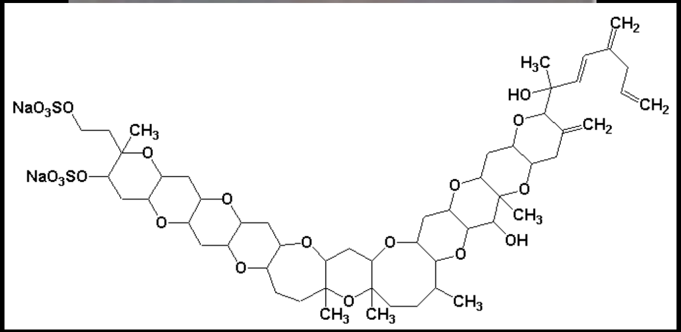
Figure 4. Trends (1982–2016) in the (*a*) growth rate, (*b*) beginning of bloom-favourable conditions, (*c*) termination of bloom-favourable conditions, and (*d*) bloom season length for *C. polykrikoides* (East Asian ribotype) in East Asia using standard resolution ($\frac{1}{4}$ degree) data product. Stippling indicates regions where trends are statistically significant ($p < 0.05$; Mann–Kendall test). (Online version in colour.)

Griffith et al 2019
Proceedings B

Massive mortality of red abalone, September 2011, Mendocino county, CA

Gonyaulax spinifera





Effects of a warming-induced extended growing season on *Alexandrium catenella*

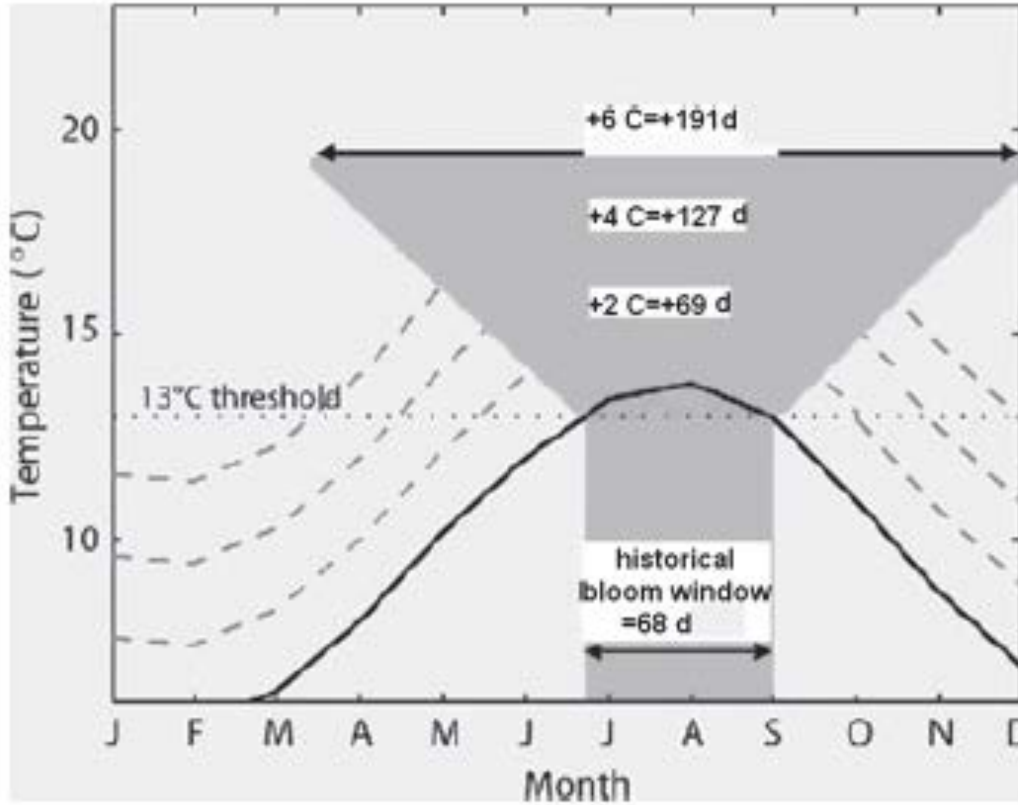
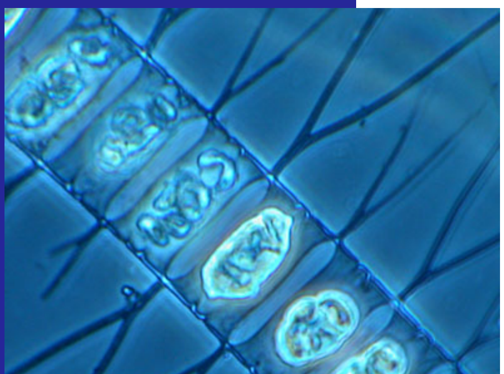


FIG. 7. Scenarios for warmer sea surface temperature conditions in Puget Sound by 2, 4, and 6°C would widen the >13°C window (in gray) of accelerated growth for the PSP dinoflagellate *Alexandrium catenella*. After Moore et al. (2008b). PSP, paralytic shellfish poisoning.

Moore et al. 2008, Environmental Health 7

Warming-induced shifts towards dinoflagellate blooms



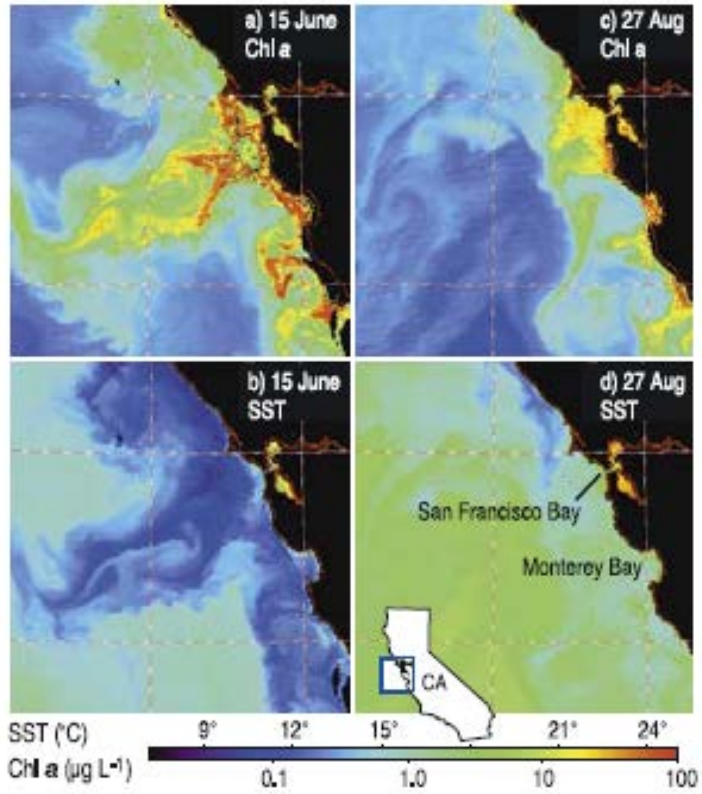
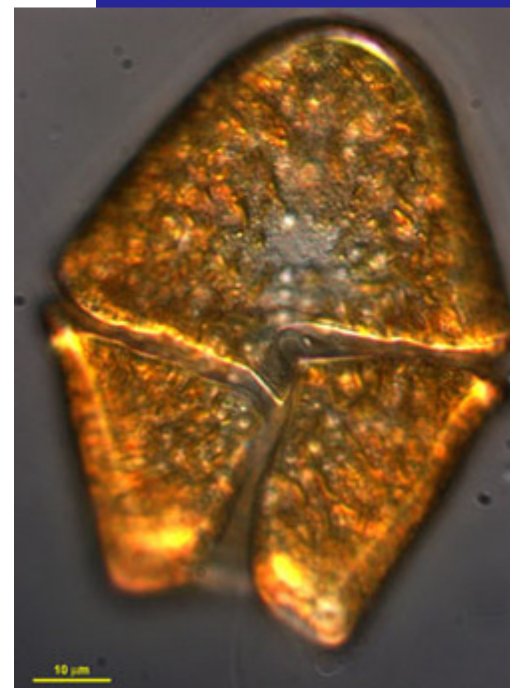


Figure 4. MODIS chlorophyll *a* (top) and surface temperature (bottom) images for 15 June (strong upwelling, left) and 27 August 2004 (weak upwelling, right).



Cloern et al. 2005, GRL 32

HABs along the U.S. West Coast

Dangerous levels of Paralytic Shellfish Poison biotoxin found in many areas of central and south Puget Sound

Clam opener canceled due to high toxin count

OLYMPIA — The first razor clam dig of the fall season has been postponed due to elevated levels of marine toxins on Washington's

Beaches affected by the health closure include Long Beach, Twin Harbors, Copalis, Mocrocks and Kalaloch.

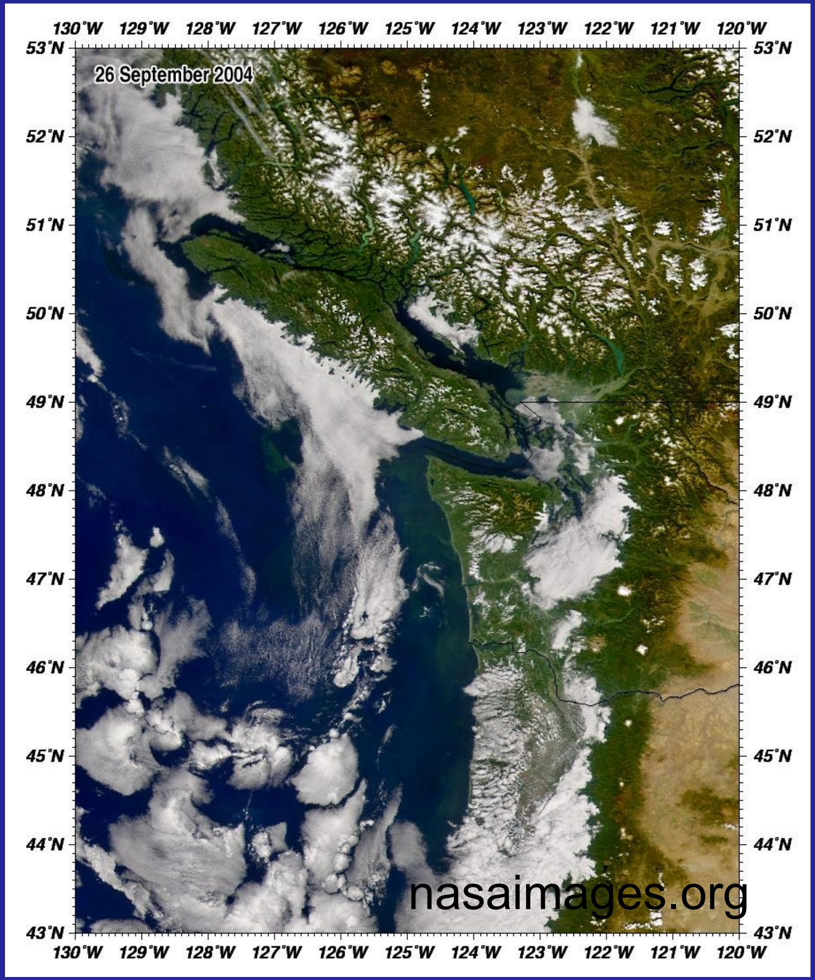
Santa Cruz Sentinel

Seabird Invasion Hits Coastal Homes

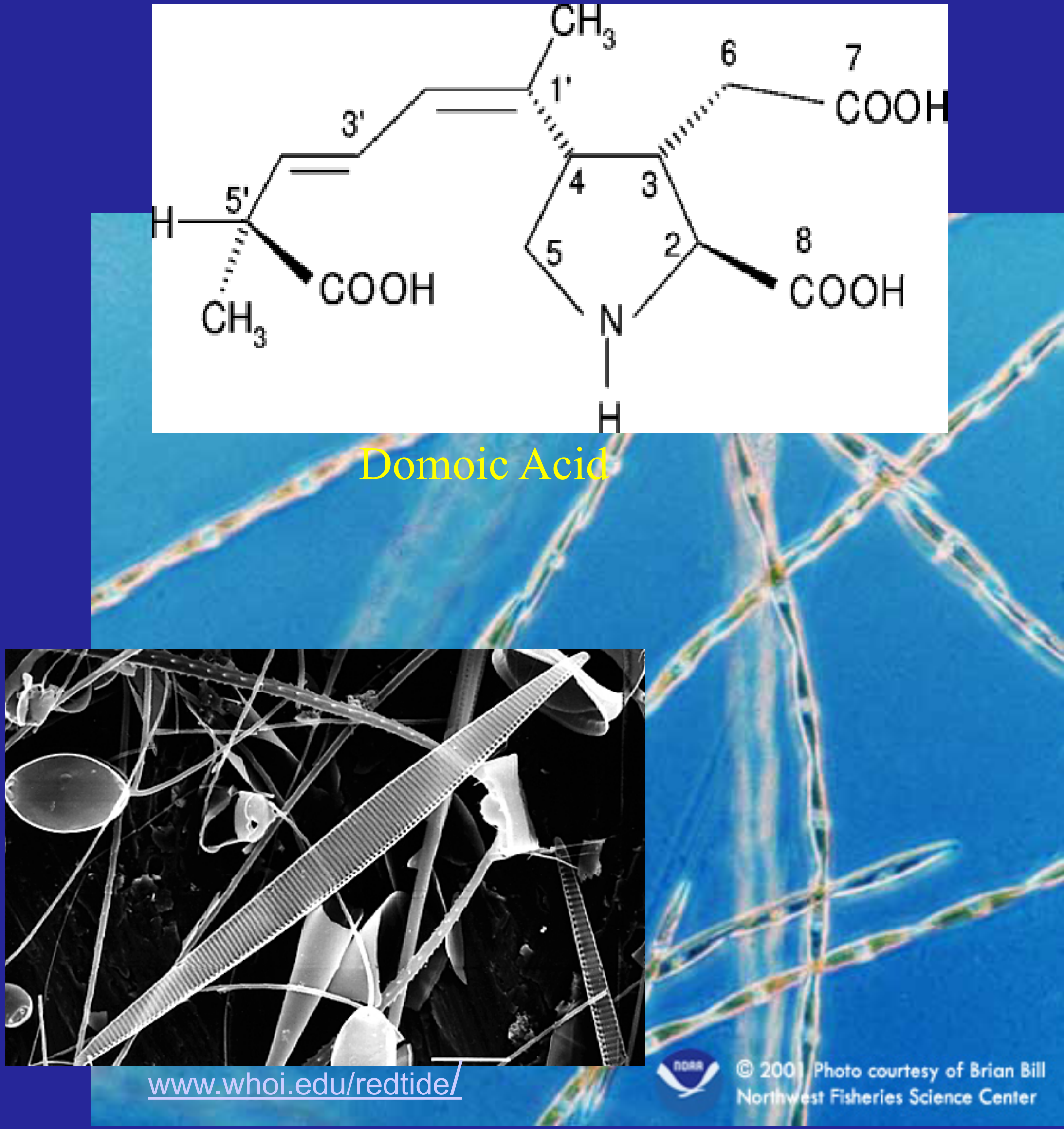
He Got The Bird—Or Was It Vice Versa

Thousands Of Birds Floundering In Streets

Pseudo-nitzschia blooms



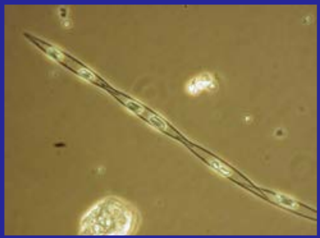
Pseudo-nitzschia bloom,
Juan de Fuca eddy

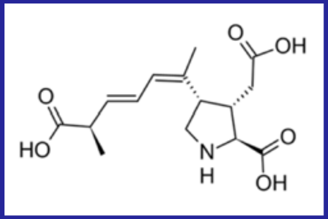


Domoic Acid

www.whoi.edu/redtide/

Pseudo-nitzschia and Domoic Acid

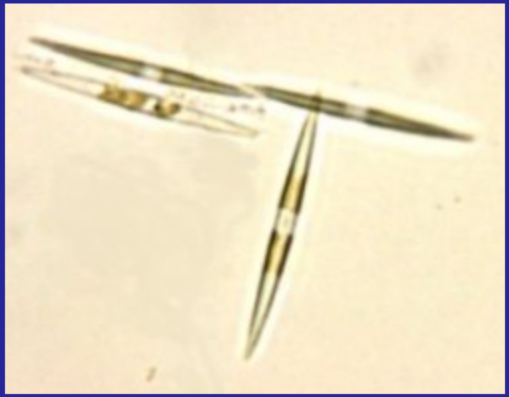




Effects of changing pCO_2 and phosphate availability on domoic acid production and physiology of the marine harmful bloom diatom *Pseudo-nitzschia multiseries*

Jun Sun,[a,b] David A. Hutchins,[a] Yuanyuan Feng,[a,b] Erica L. Seubert,[a] David A. Caron,[a] and Fei-Xue Fu[a,*]

Pseudo-nitzschia multiseries



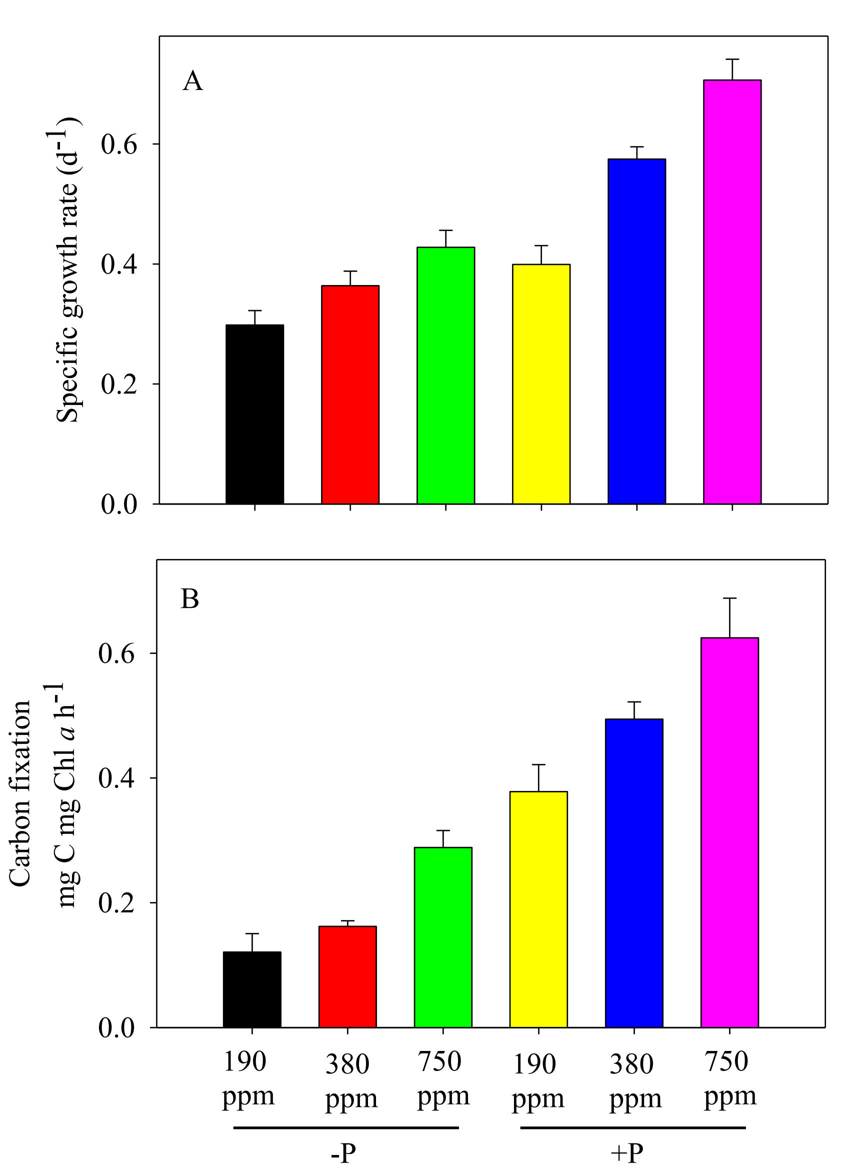
- CO_2 [190, 380, 750] ppm
- P-replete vs. P-limited
- Measurements of growth rates, physiology
- Domoic acid measurements using ELISA
- RNA samples for gene expression

Sun et al. 2011 Limnology & Oceanography 56

Pseudo-nitzschia multiseries- growth and carbon fixation rates

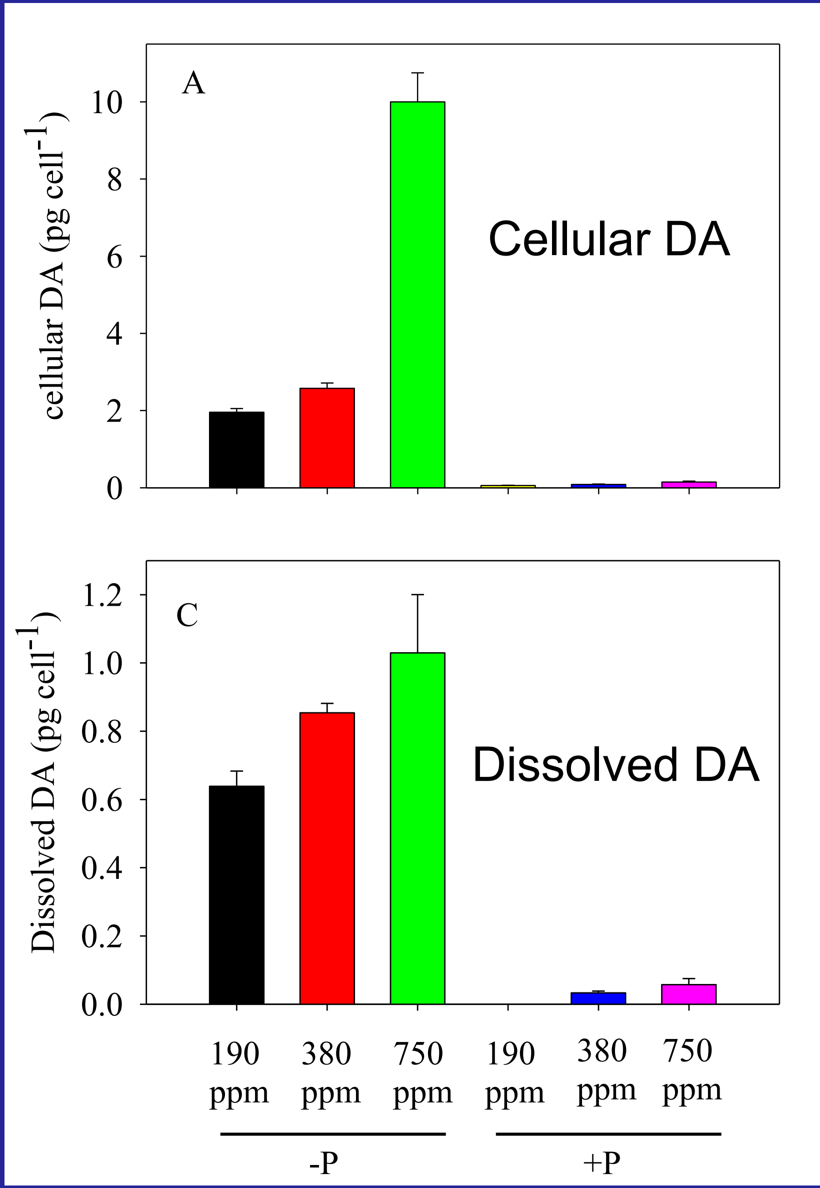
Growth rates

Carbon fixation rates



Sun et al. 2011
Limnology & Oceanography 56

Domoic acid production versus pCO_2 and P availability



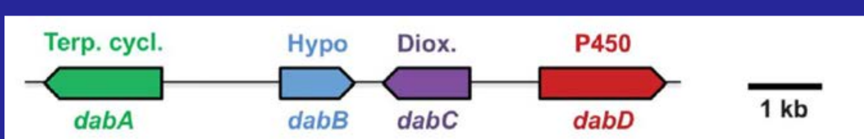
Sun et al. 2011 Limnology & Oceanography 56

Biosynthesis of the neurotoxin domoic acid in a bloom-forming diatom

John K. Brunson[1,2]*, Shaun M. K. McKinnie[1]*, Jonathan R. Chekan[1], John P. McCrow[2], Zachary D. Miles[1], Erin M. Bertrand[2,3], Vincent A. Bielinski[4], Hanna Luhavaya[1], Miroslav Oborník[5], G. Jason Smith[6], David A. Hutchins[7], Andrew E. Allen[2,8]†, Bradley S. Moore[1,9]†

Oceanic harmful algal blooms of *Pseudo-nitzschia* diatoms produce the potent mammalian neurotoxin domoic acid (DA). Despite decades of research, the molecular basis for its biosynthesis is not known. By using growth conditions known to induce DA production in *Pseudo-nitzschia multiseries*, we implemented transcriptome sequencing in order to identify DA biosynthesis genes that colocalize in a genomic four-gene cluster. We biochemically investigated the recombinant DA biosynthetic enzymes and linked their mechanisms to the construction of DA's diagnostic pyrrolidine skeleton, establishing a model for DA biosynthesis. Knowledge of the genetic basis for toxin production provides an orthogonal approach to bloom monitoring and enables study of environmental factors that drive oceanic DA production.

Brunson et al. 2018
Science 361, 1356–1358



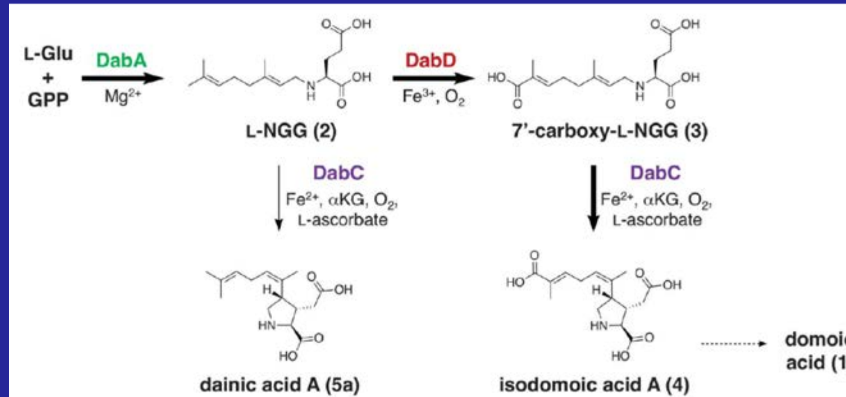


Fig. 2. Domoic acid (1) biosynthetic pathway based on *dab* gene annotations and in vitro enzyme activities.

How will knowing the genes involved in domoic acid synthesis help with our toxic *Pseudo-nitzschia* bloom crisis?

- **Allow us to understand how environmental factors like acidification, warming, eutrophication, deoxygenation etc. can act as triggers to control toxic bloom formation**

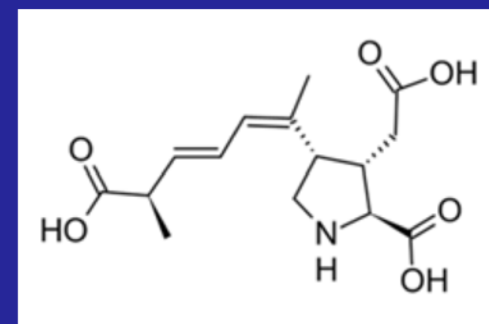
- **Potential genetic 'biomarkers' to detect and quantify actively or potentially toxic species**

- **Suggest possible targets for intervention and mitigation of toxic blooms**

High CO_2 and Silicate Limitation Synergistically Increase the Toxicity of *Pseudo-nitzschia fraudulenta*

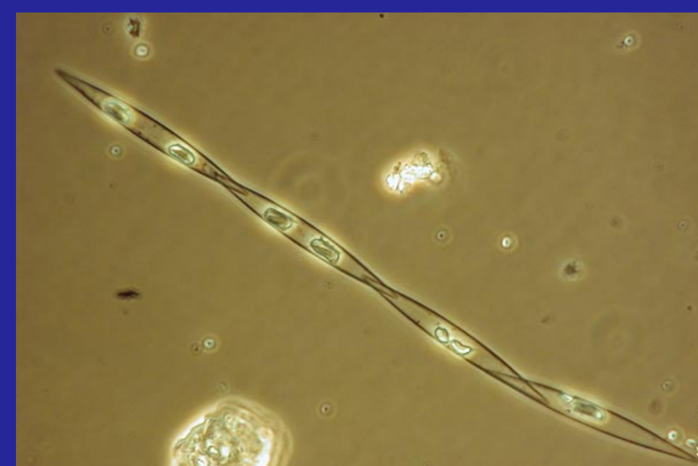
Avery O. Tatters, Fei-Xue Fu, David A. Hutchins*

- Si-replete vs. Si-limited
- CO_2 190, 380, 750 ppm
  - four months of pre-conditioning
  - Toxin measured with HPLC



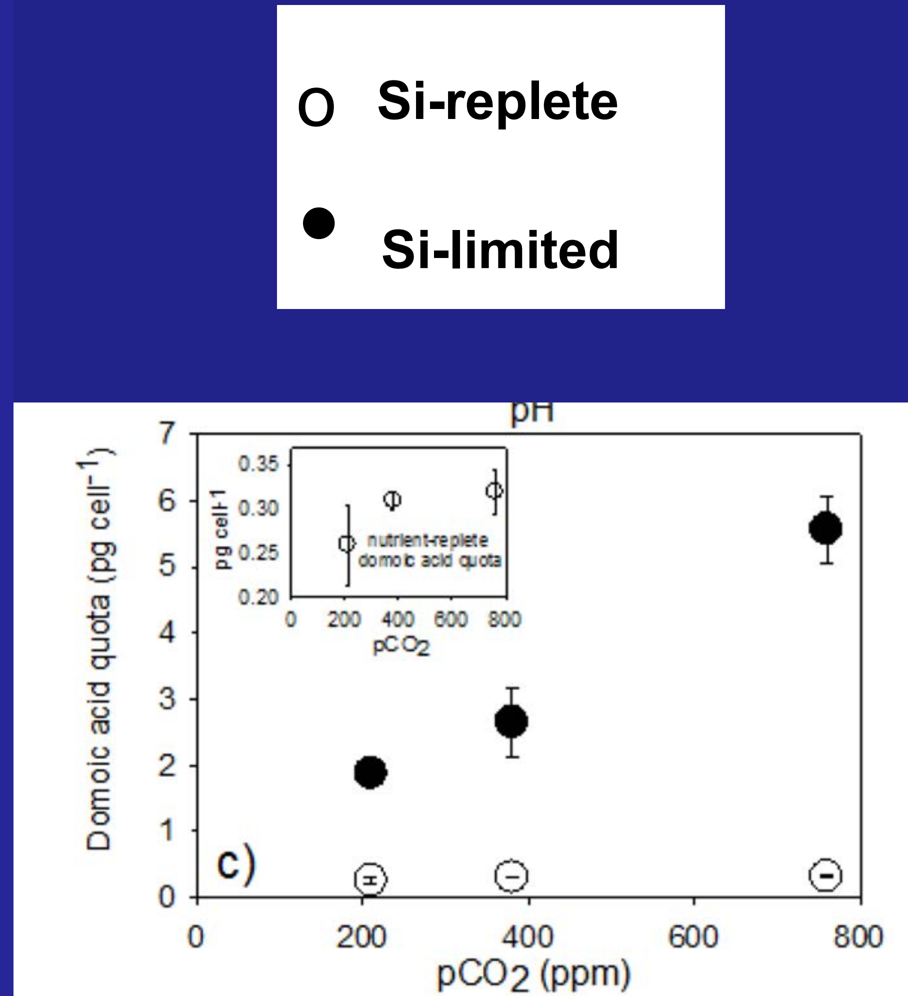
Pseudo-nitzschia fraudulenta

(from Southern California)



Tatters, Fu and Hutchins 2012
PLoS ONE 7

Domoic acid production increases dramatically with rising acidification- especially during Si-limited growth



Tatters et al. 2012

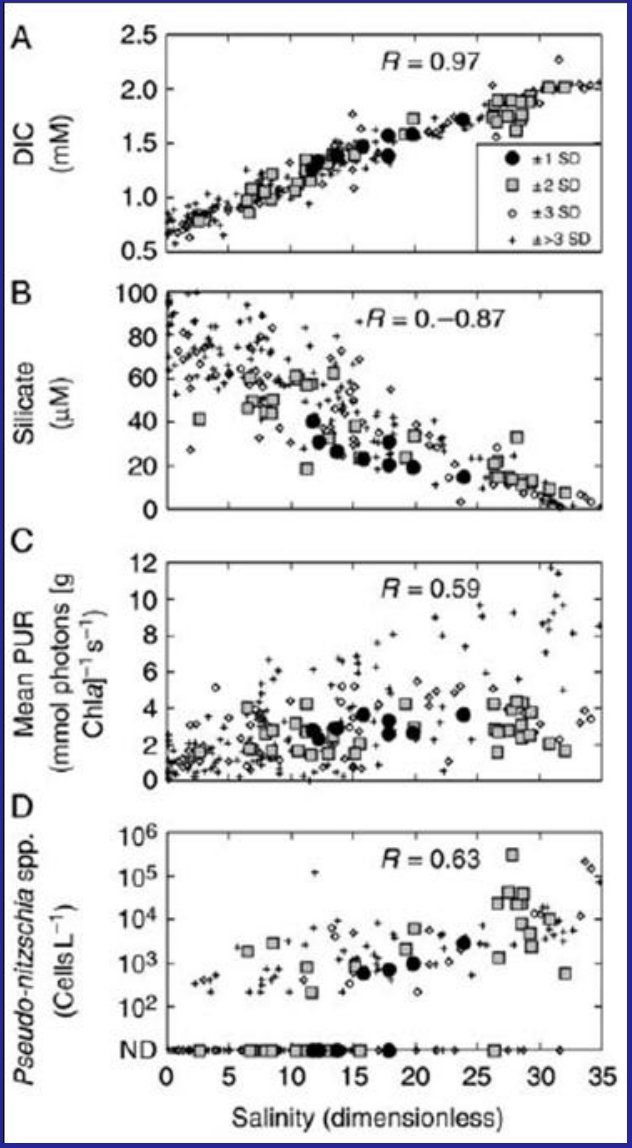
PLoS ONE 7

Supporting correlative field data from MacIntyre et al. (2011)

CO_2 concentrations

Si concentrations

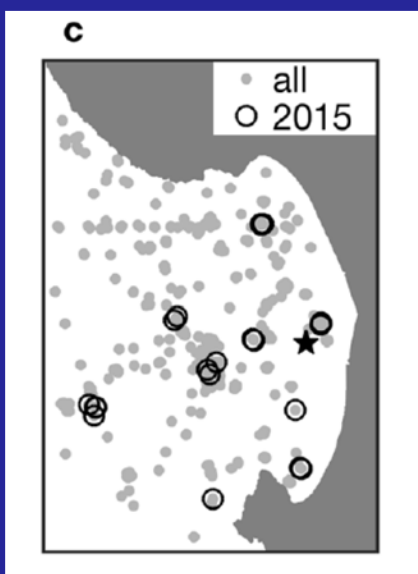
Pseudo-nitzschia abundance (also domoic acid levels)

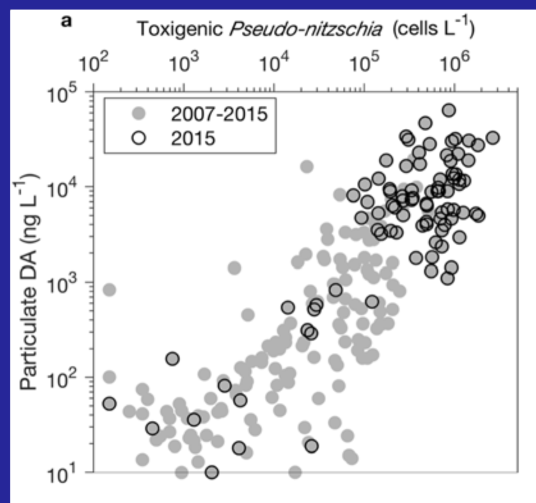


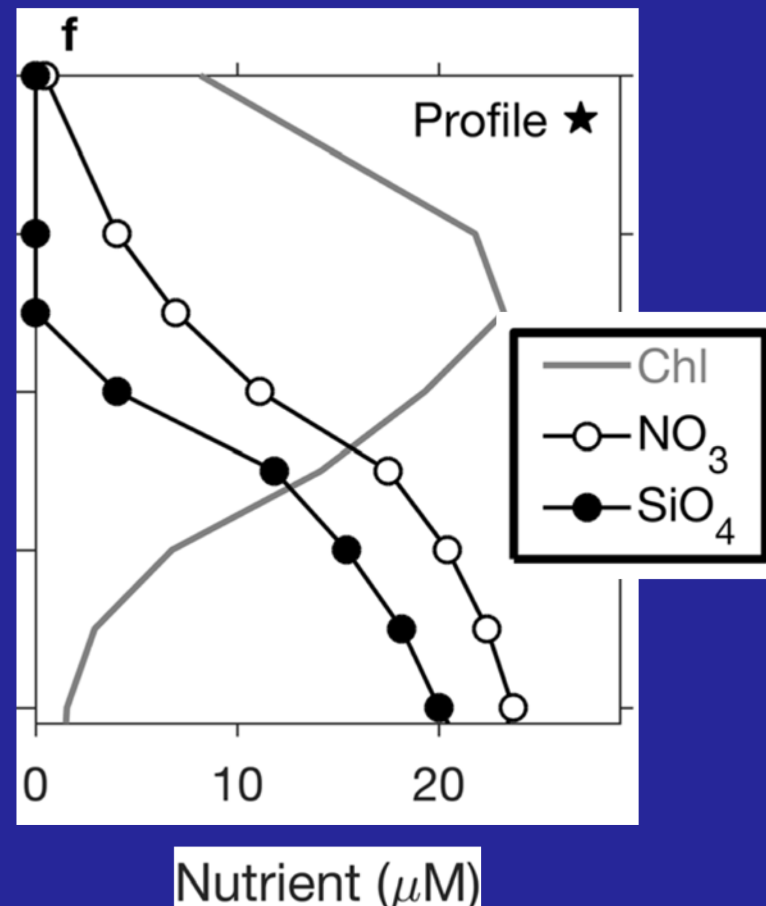
Si depletion increases the toxicity of a Monterey Bay bloom event during the 2015 heat wave event

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



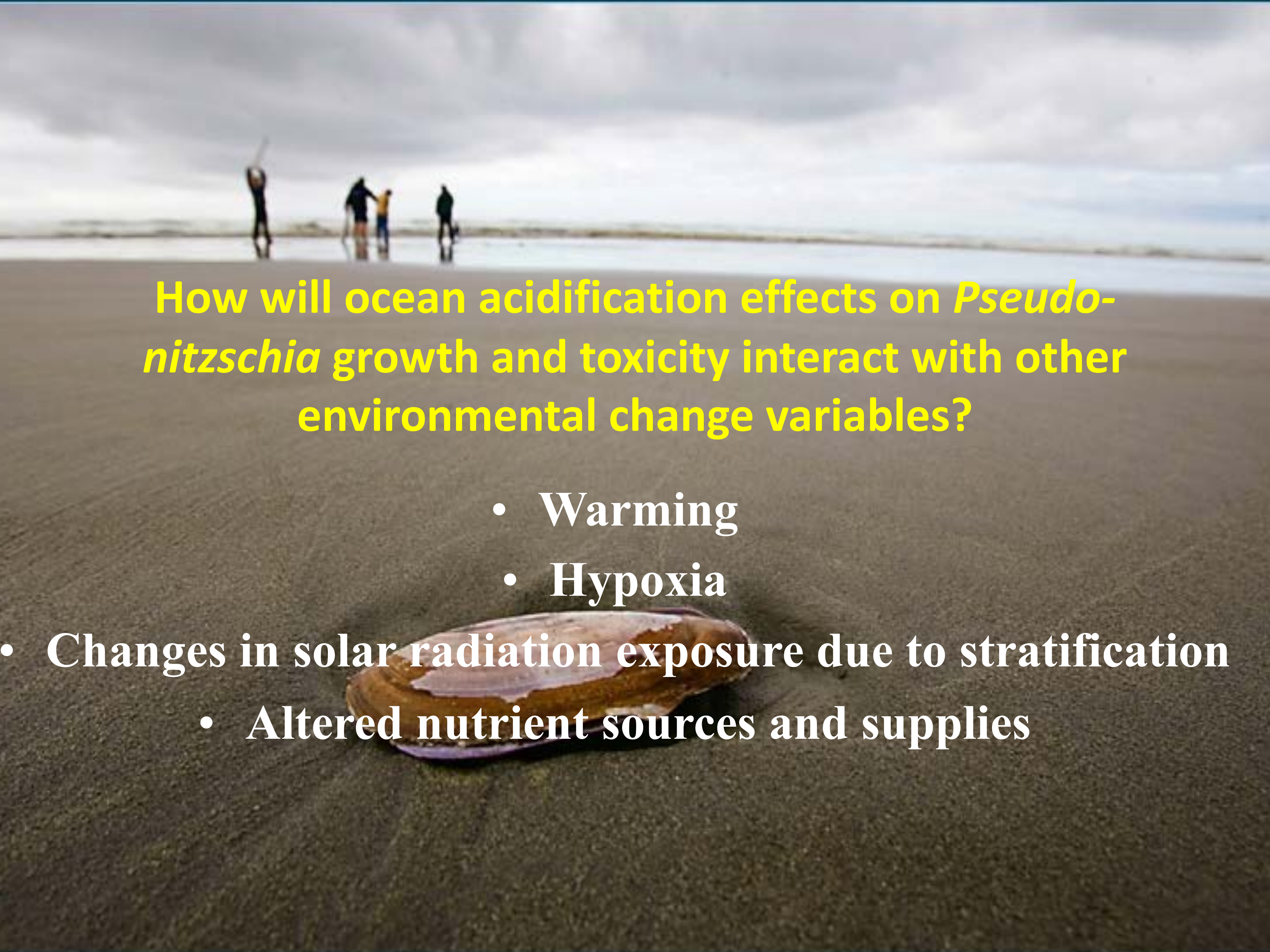




Take Home Message for Domoic Acid and CO_2

The toxicity of *Pseudo-nitzschia* spp. isn't increased that much by ocean acidification alone- but high pCO_2 can greatly magnify the increases in domoic acid production typically seen during limitation by the nutrients Si and P

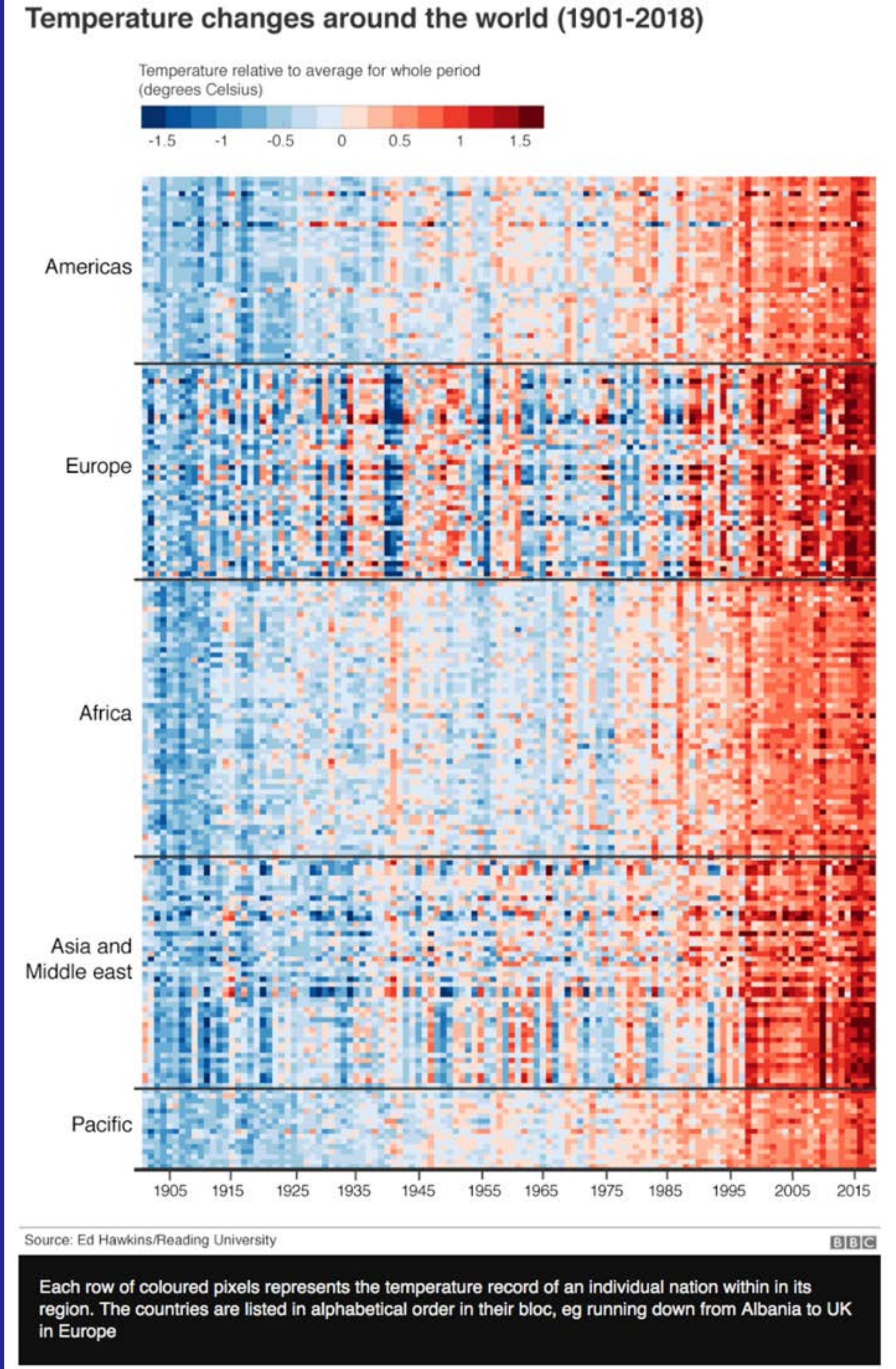
There is a synergistic effect between acidification and nutrient limitation



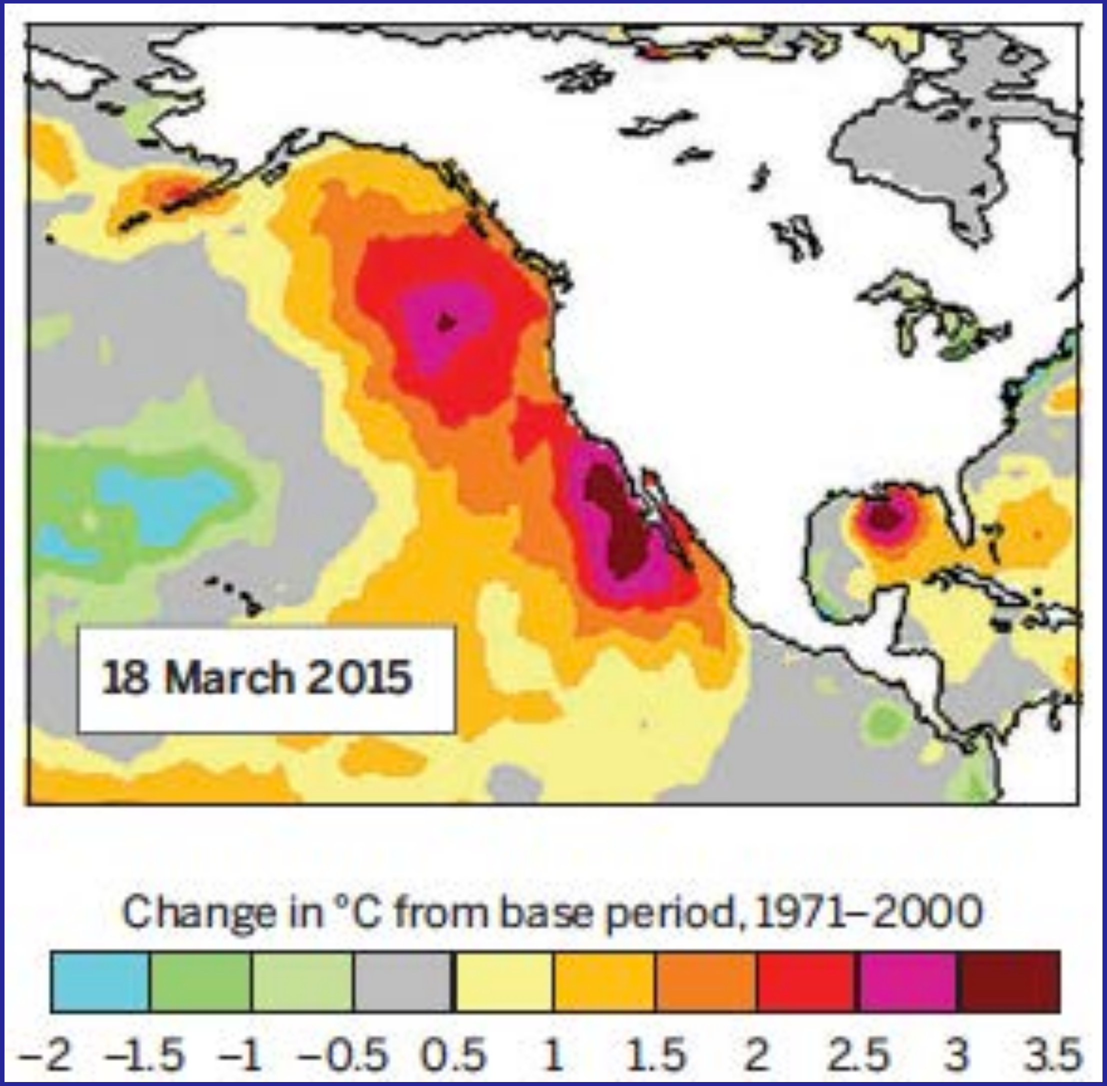
How will ocean acidification effects on *Pseudo-nitzschia* growth and toxicity interact with other environmental change variables?

- Warming
- Hypoxia
- Changes in solar radiation exposure due to stratification
- Altered nutrient sources and supplies

The Earth is getting warmer…



Pseudo-nitzschia and warming: The Blob bloom



Kintisch 2015 Science

Geophysical Research Letters

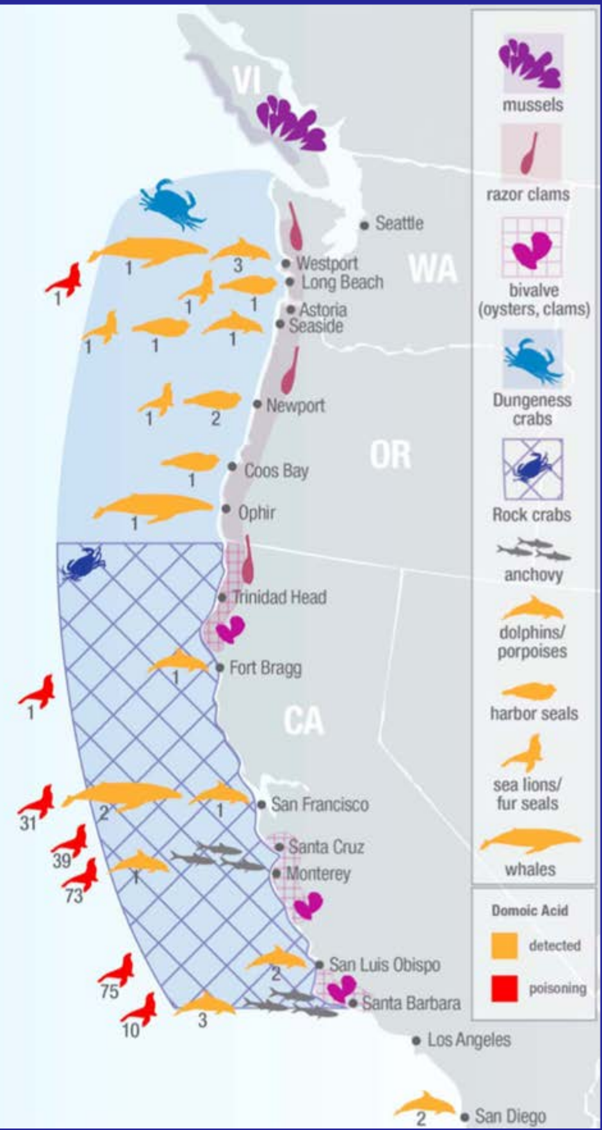
RESEARCH LETTER
10.1002/2016GL070023

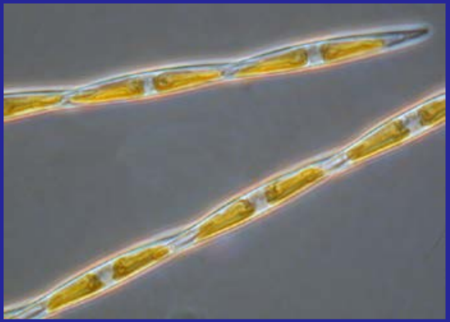
Special Section:
Midlatitude Marine Heatwaves: Forcing and Impacts

An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions

Ryan M. McCabe[1], Barbara M. Hickey[2], Raphael M. Kudela[3], Kathi A. Lefebvre[4], Nicolaus G. Adams[4], Brian D. Bill[4], Frances M. D. Gulland[5], Richard E. Thomson[6], William P. Cochlan[7], and Vera L. Trainer[4]

2015	Shellfish Harvest and Fishery Closures with Maximum Domoic Acid Values
7-May	Quinault tribe razor clam harvest closure (WA)
8-May	Commercial, tribal & recreational razor clam harvest closure (WA)
9-May	Razor clam harvest closure (northern OR)
14-May	State wide razor clam harvest closure (OR)
15-May	Shellfish harvest closure (BC Canada)
29-May	Anchovy viscera maximum 1671 ppm (CA)
1-Jun	Anchovy, sardine fishery closure (CA)
3-Jun	Dungeness crab maximum 65 ppm (WA)
5-Jun	Dungeness crab fishery closure (WA)
3-Jul	Anchovy, sardine, mussel, & clam closures expanded to southern CA
11-Sep	Dungeness crab maximum 140 ppm (northern CA)
27-Oct	Razor clam maximum 170 ppm (southern OR)
3-Nov	Dungeness crab & rock crab warning for recreational harvest (CA)
6-Nov	Commercial rock crab fishery closed (CA)
8-Nov	Dungeness crab maximum 70 ppm (southern OR)
11-Nov	Dungeness crab & rock crab recreational & commercial fishery closure (CA)
22-Nov	Dungeness crab maximum 270 ppm (northern CA)
23-Nov	Rock crab maximum 1000 ppm (southern CA)
23-Nov	Delayed opening of commercial Dungeness crab fishery (WA, OR, CA)
9-Feb-2016	CA seeks federal disaster declaration for commercial crab fishery





McCabe et al. 2016

Domoc acid closures cost the West Coast Dungeness crab fishery ~$50-100 million

The Verge

Who's to blame for the neurotoxin that's poisoning the Pacific?

Why a Pacific coast fishing organization is suing 30 fossil fuel companies

THE VERGE

By Rachel Becker | Mar 19, 2019, 10:00am EDT

Photos by Vjeran Pavic

SHARE

GOOD DEALS

SimpliSafe's 11-piece home security s
is $100 off at Best Buy

https://www.theverge.com/2019/3/19/18271856/crabs-domoic-acid-climate-change-big-oil-fossil-fuels-pacific-harmful-algal-bloom

Fishermen Sue Big Oil For Climate Change Damages

PCFFA

The Pacific Coast Federation of Fishermen's Associations

versus

ExxonMobil

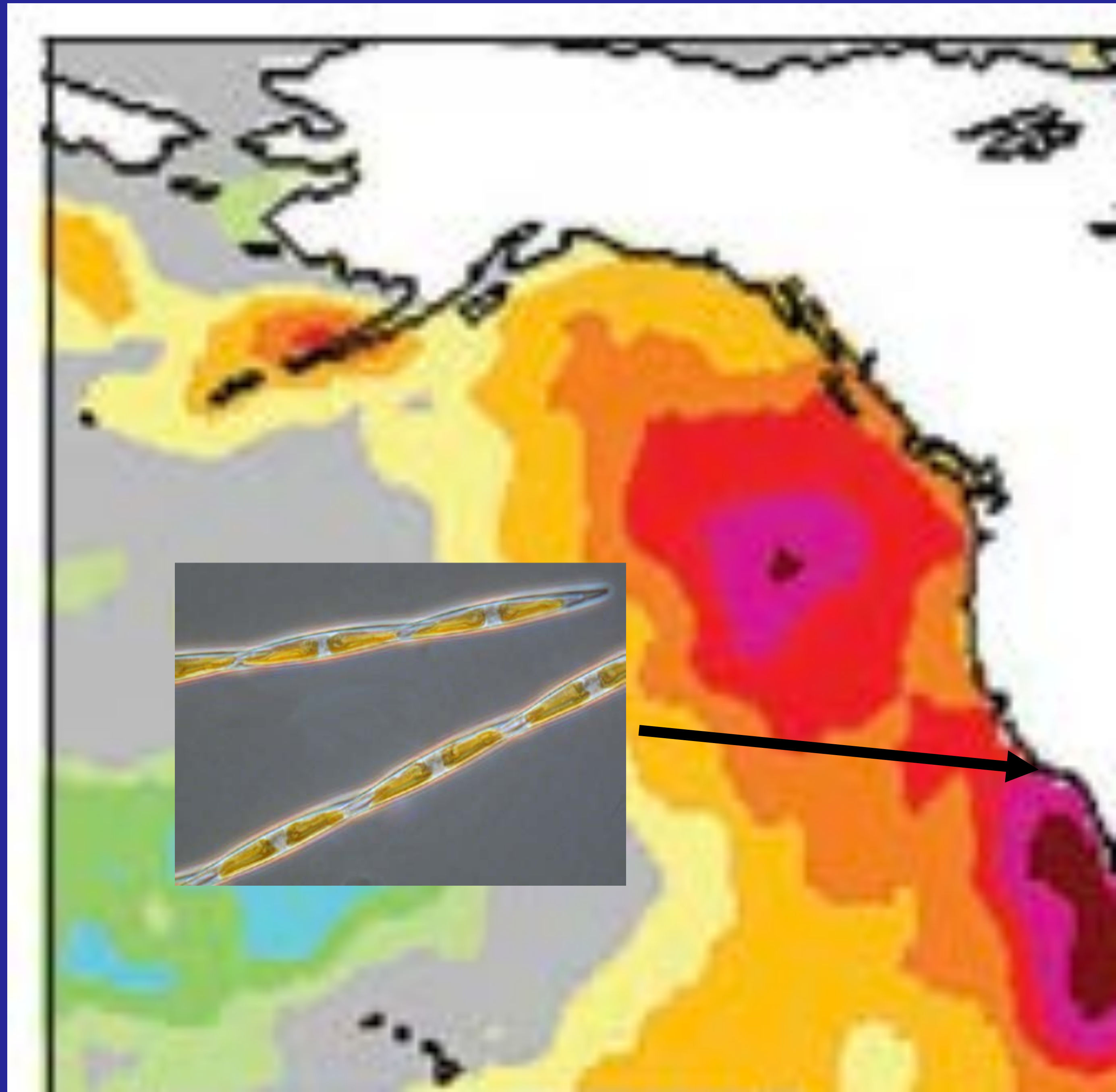
bp

Chevron

Shell

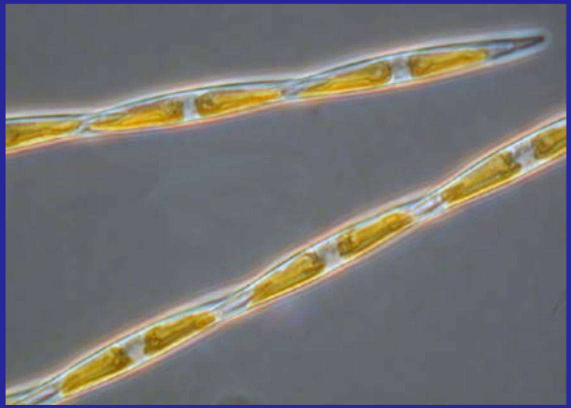
ConocoPhillips

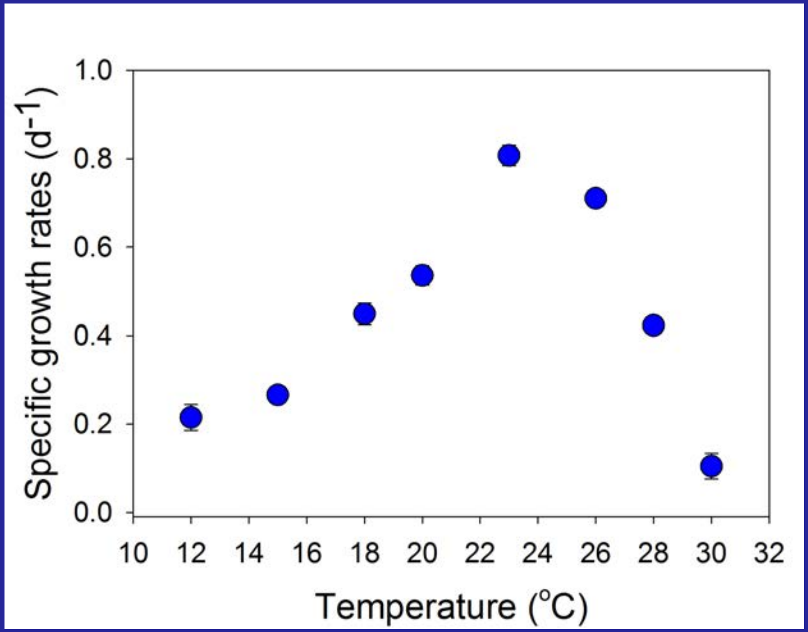
We used a *Pseudo-nitzschia australis* culture isolated locally near the beginning of the Blob bloom to investigate the relationship between temperature and domoic acid production



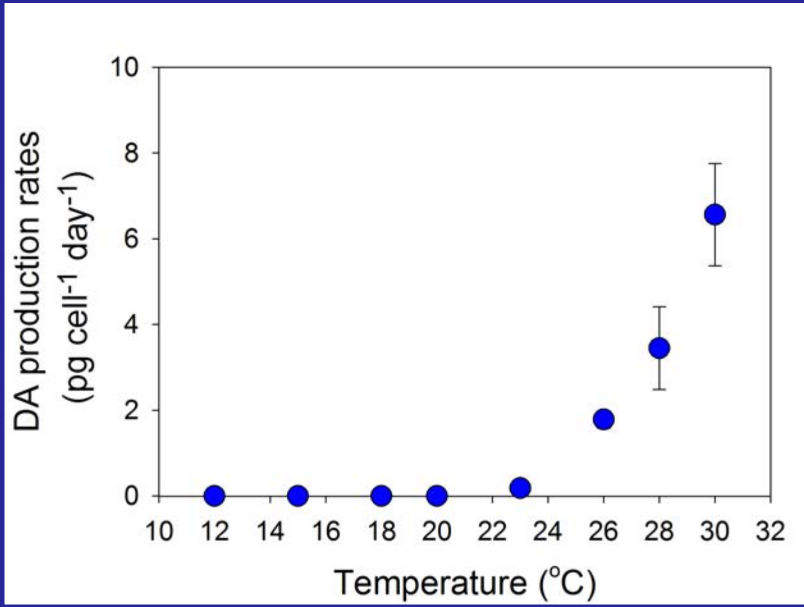
Pseudo-nitzschia australis temperature responses

Growth rates



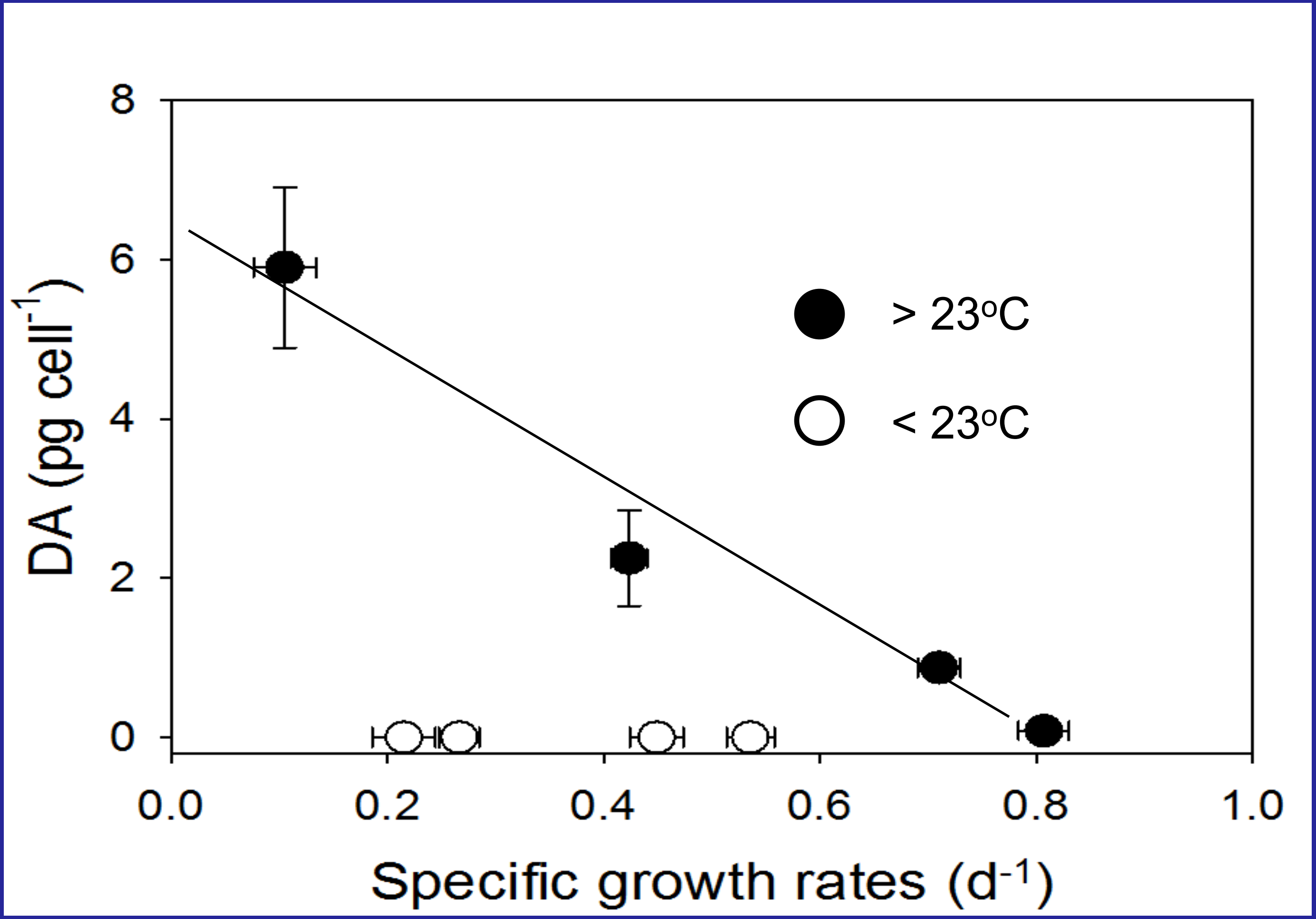


Domoic acid production rates

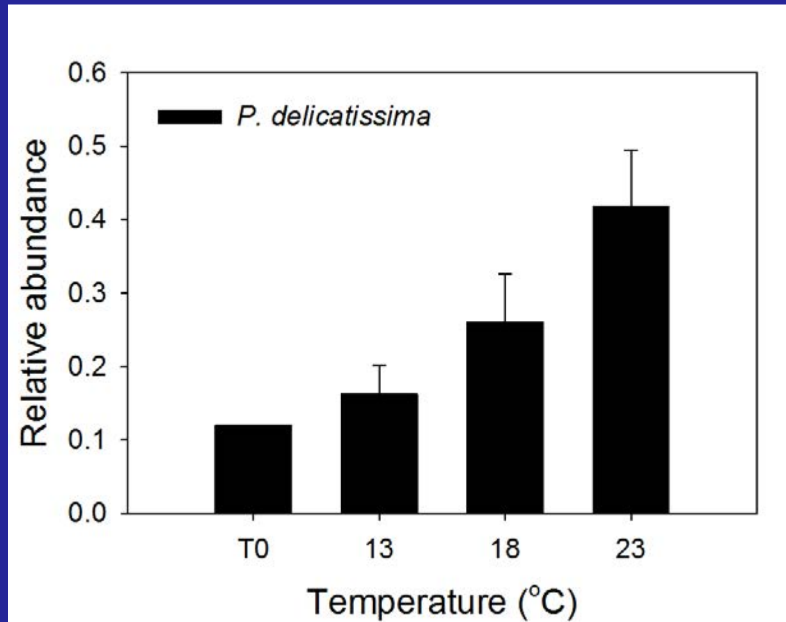


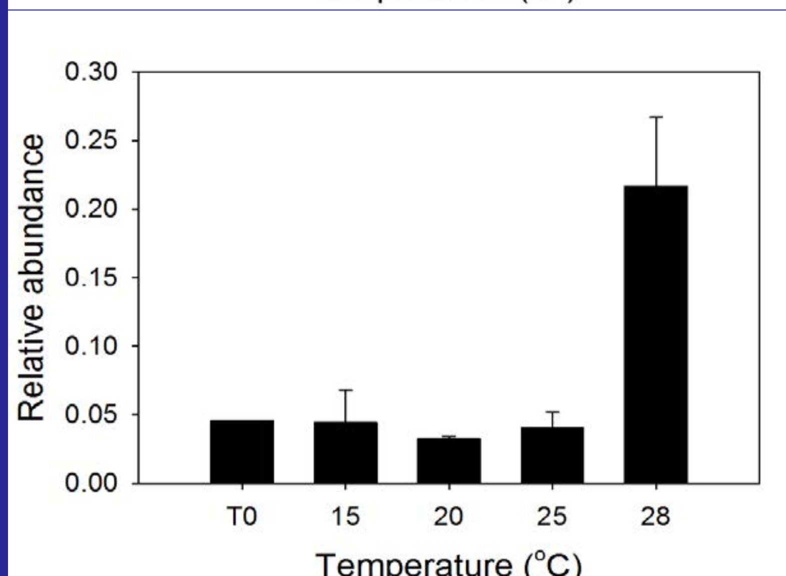
Zhu et al. 2017, Harmful Algae

Cellular toxin content versus growth rate

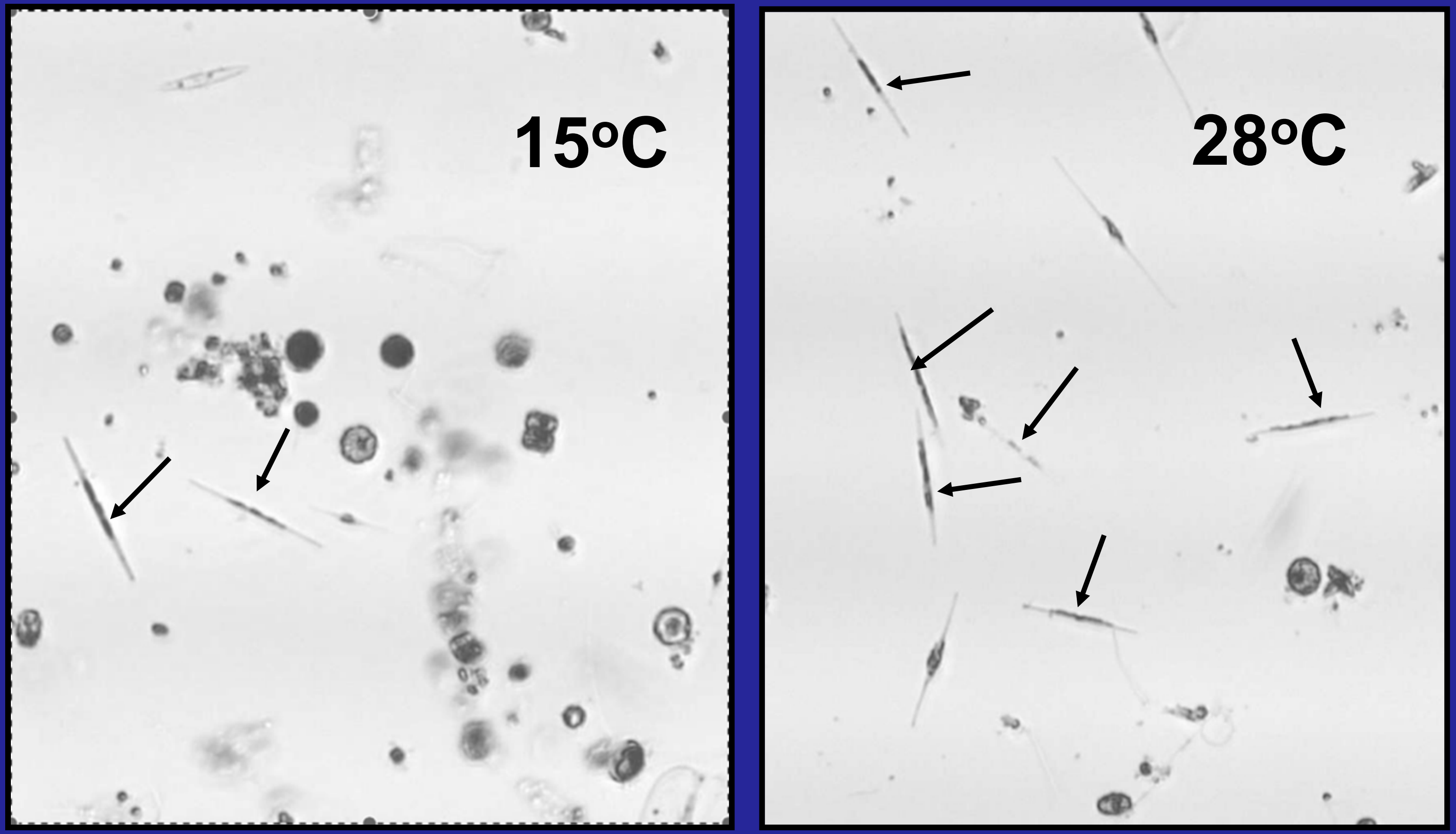


Natural community experiments:
P. delicatissima abundance increases with temperature



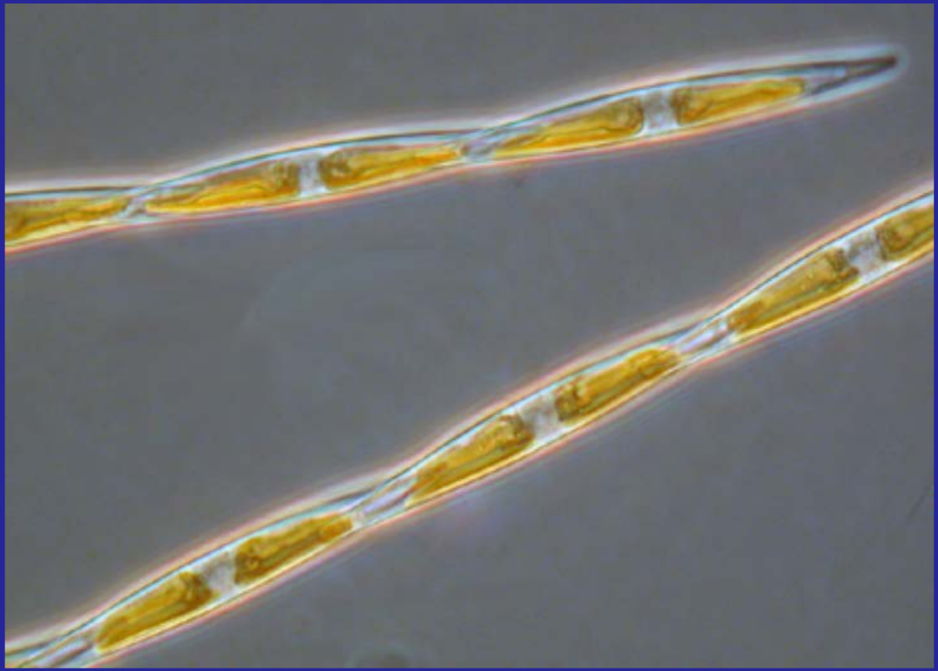


Natural community experiments:
P. delicatissima abundance increases with temperature

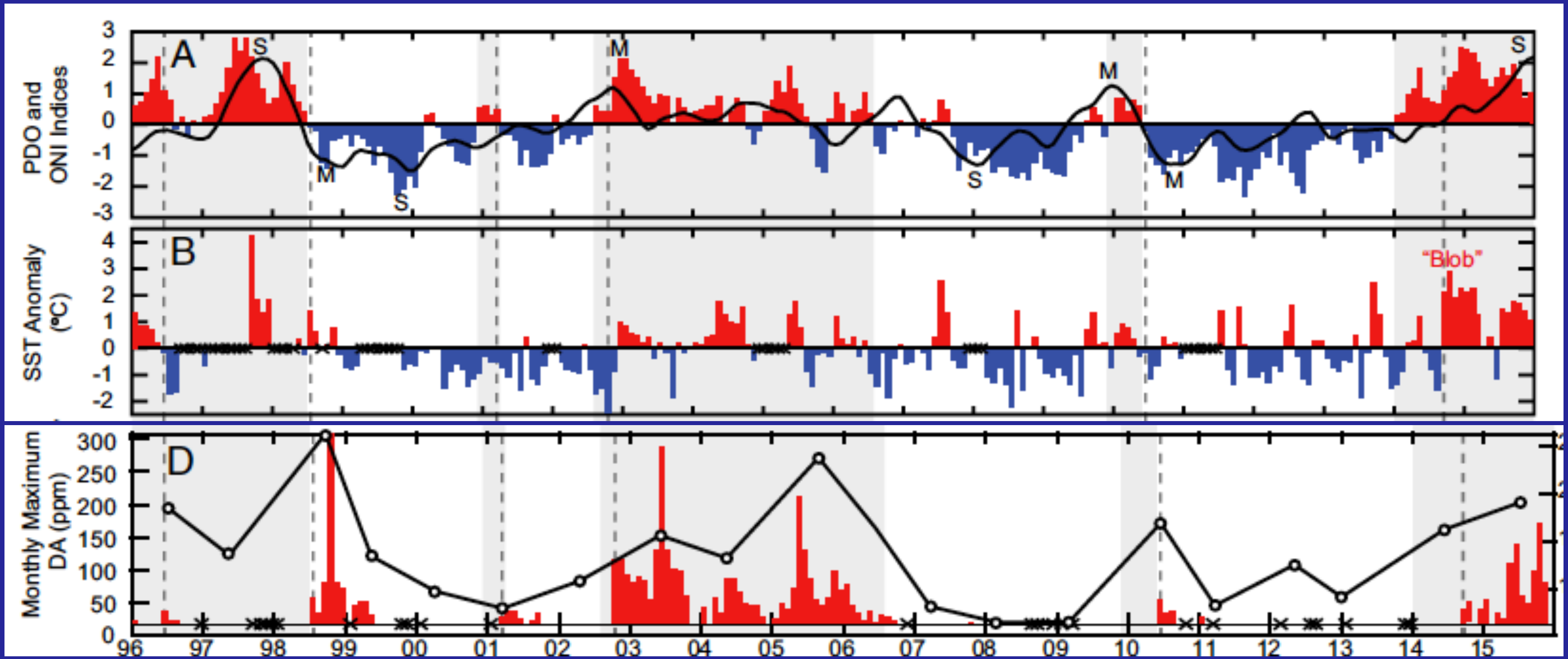


Domoic Acid and Warming

Both the toxicity and the abundance of some toxic *Pseudo-nitzschia* spp. can be greatly increased by warming



Domoic acid in shellfish correlates with climate trends



McKibben et al. 2017 PNAS

The future- predictions of a warmer eastern Pacific Ocean

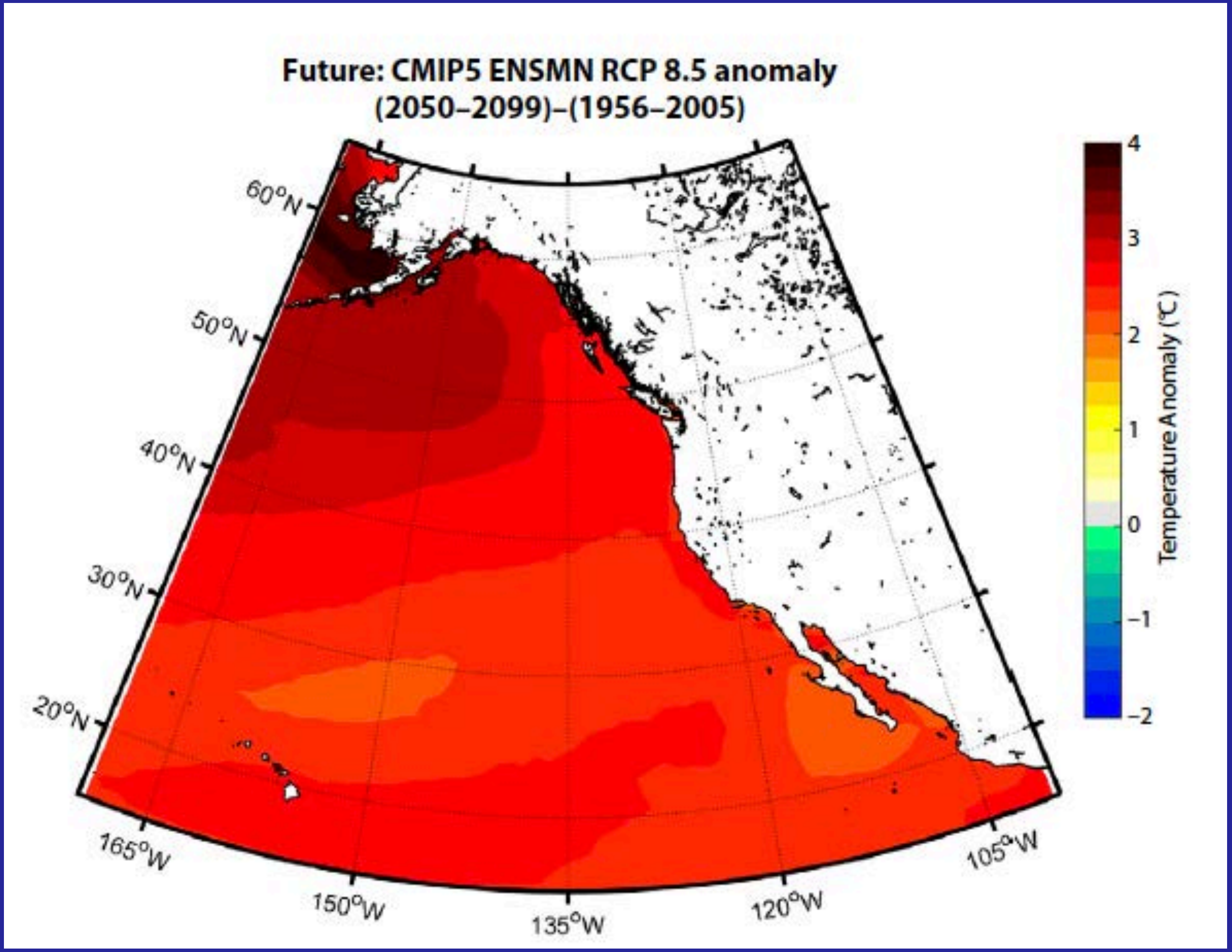
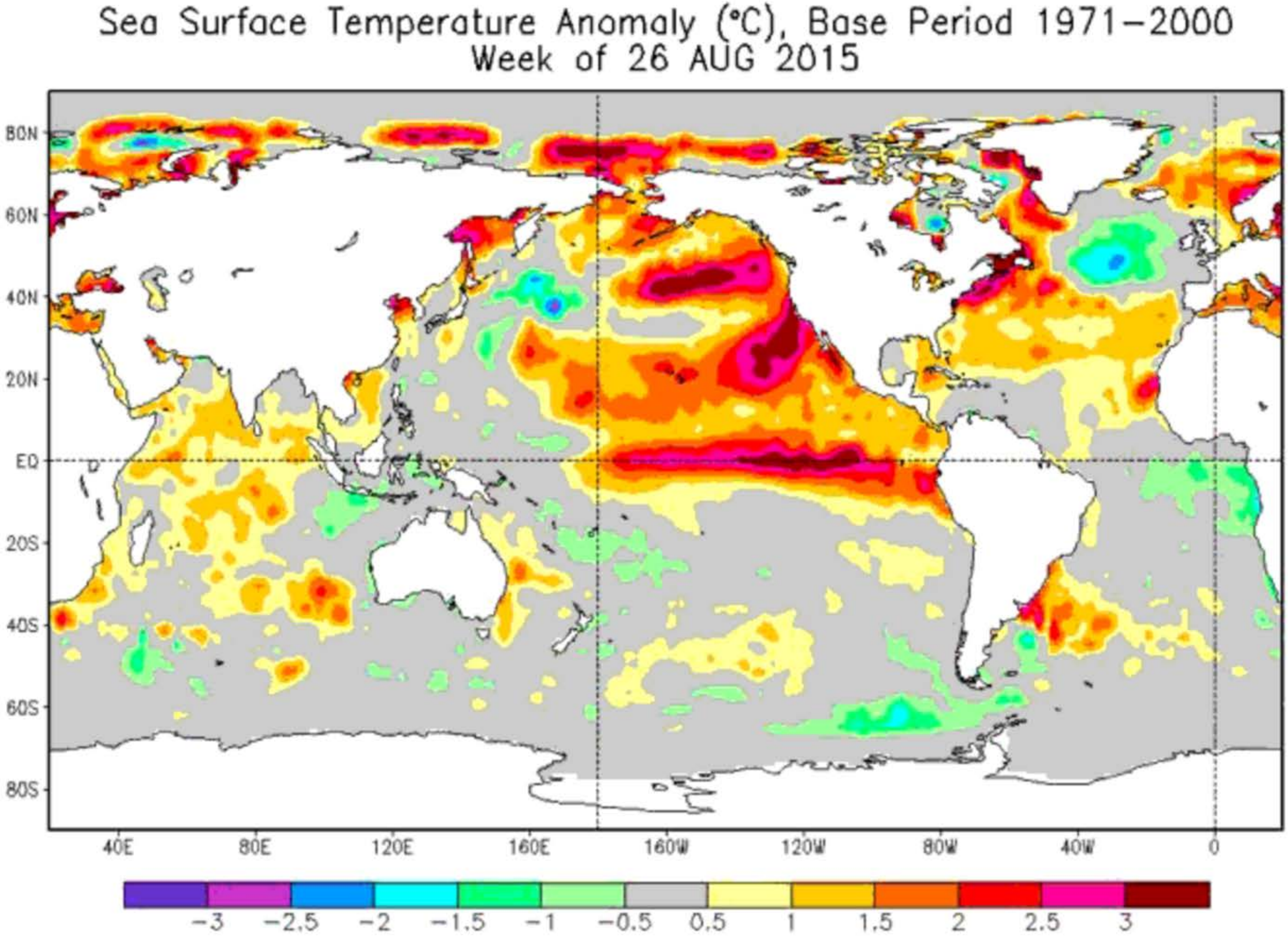
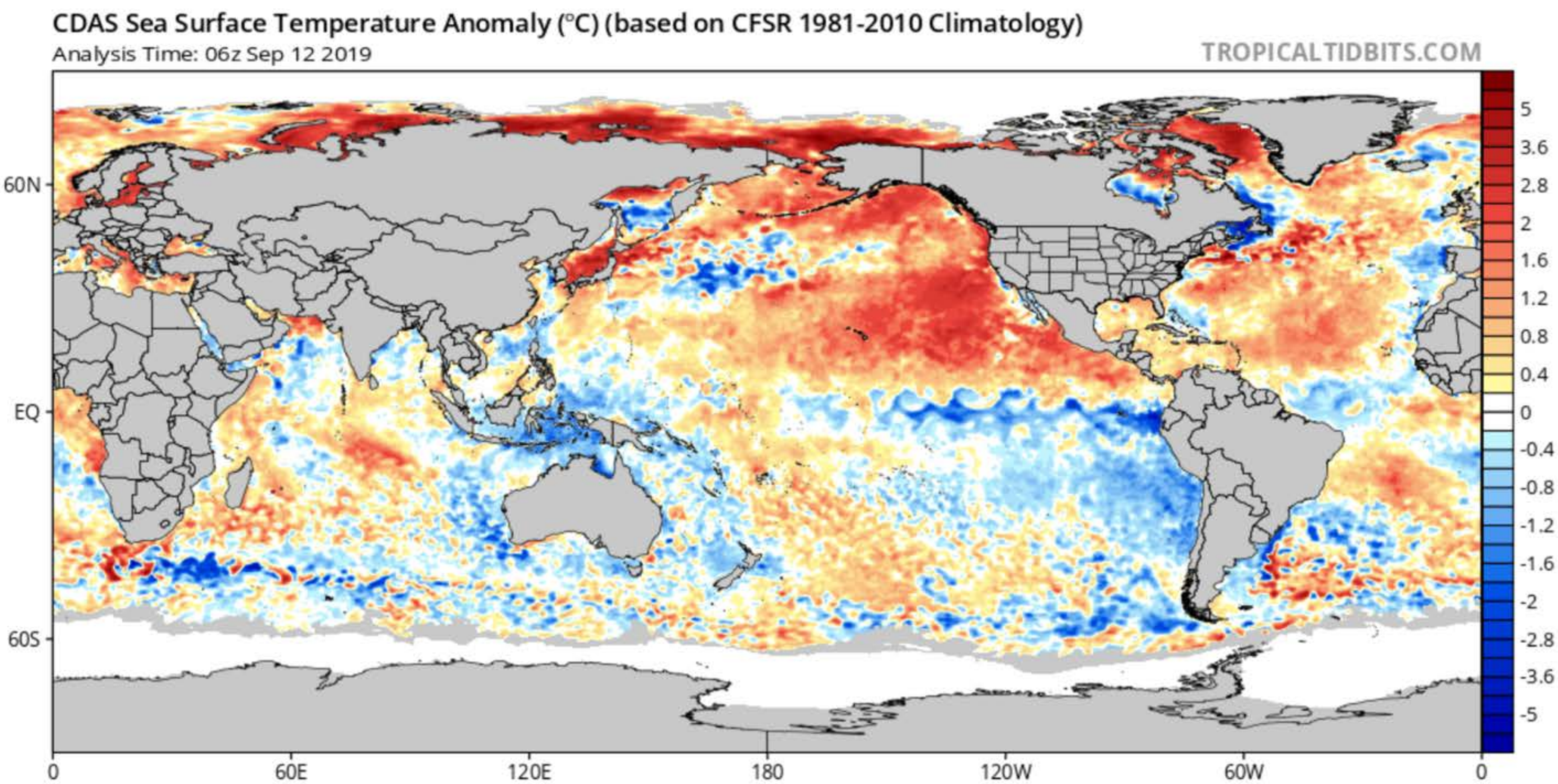


FIGURE 4. Temperature anomalies predicted for 2050–2099 using the RCP8.5 climate 368 model, calculated relative to temperature records from 1956–2005. Data were obtained from the NOAA climate change Web portal (NOAA, 2016a).

Cavole et al. 2016 Oceanography


Sea Surface Temperature Anomaly (°C), Base Period 1971–2000
Week of 26 AUG 2015
80N
60N
40N
20N
EQ
20S
40S
60S
80S
40E
80E
120E
160E
160W
120W
80W
40W
0
−3
−2.5
−2
−1.5
−1
−0.5
0.5
1
1.5
2
2.5
3

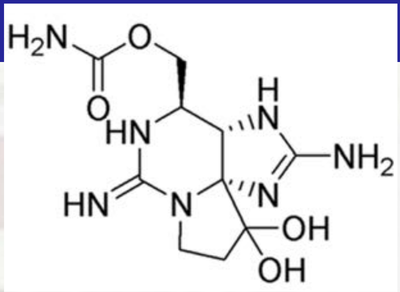


Sea surface temperature differences, compared to the average from 1981-2010, in the Pacific Ocean on September 12, 2019. (Data from NOAA, via TropicalTidbits.com)

How will long-term warming trends and transitory heat wave events interact with other global change factors like acidification and stratification to affect toxic *Pseudo-nitzschia* blooms?

The interactive effects of acidification, warming and nutrient limitation on toxic *Alexandrium*

Alexandrium catenella

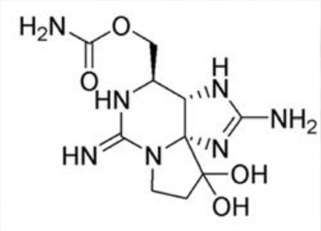


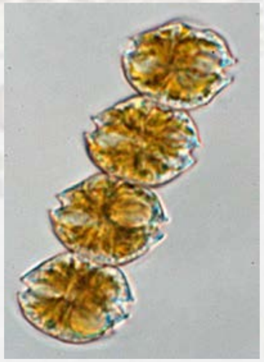
- produces saxitoxin and derivatives, collectively known as Paralytic Shellfish Poisoning Toxins (PSPs)
- Phosphate limitation increases toxicity
- growth and toxicity were measured in a local clone of *Alexandrium catenella*
- eight months of conditioning in an experimental matrix of:

Two CO_2 concentrations

Two temperatures

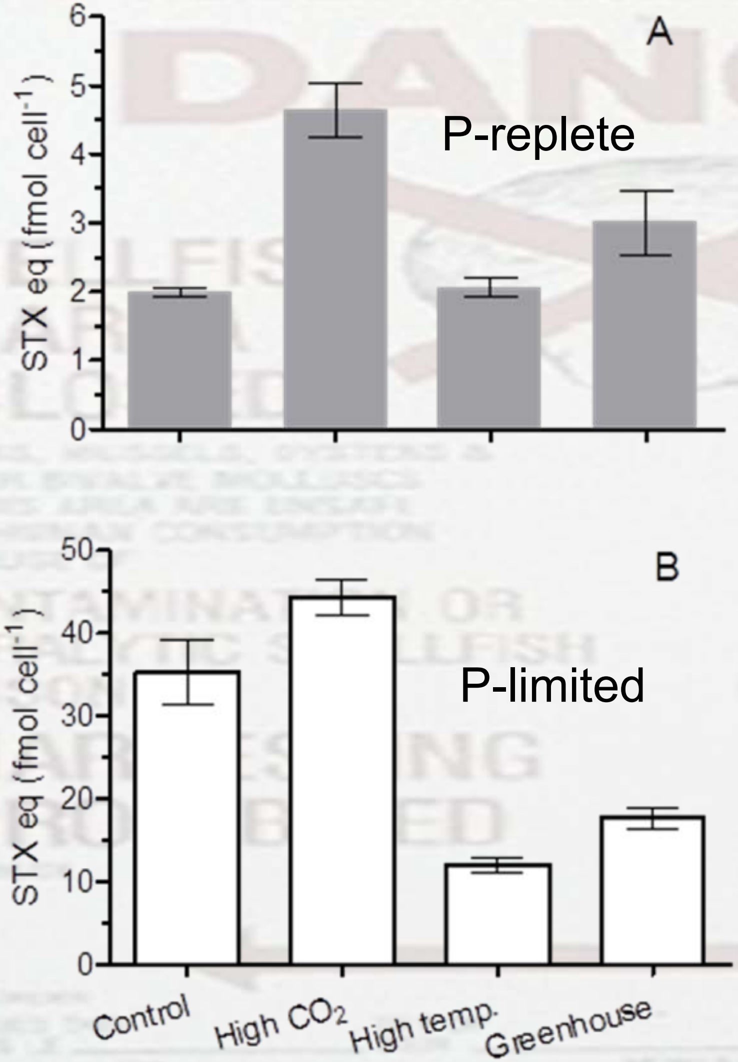
Two phosphate concentrations



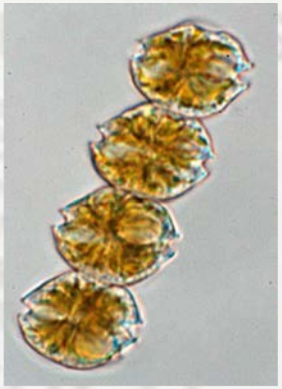


High CO_2 promotes the production of paralytic shellfish poisoning toxins by *Alexandrium catenella* from Southern California waters

Avery O. Tatters [a], Leanne J. Flewelling [b], Feixue Fu [a], April A. Granholm [b], David A. Hutchins [a,*]



High CO_2 led to increased cellular toxin levels, regardless of temperature or phosphate status examined.



Warmer temperatures reduced toxicity

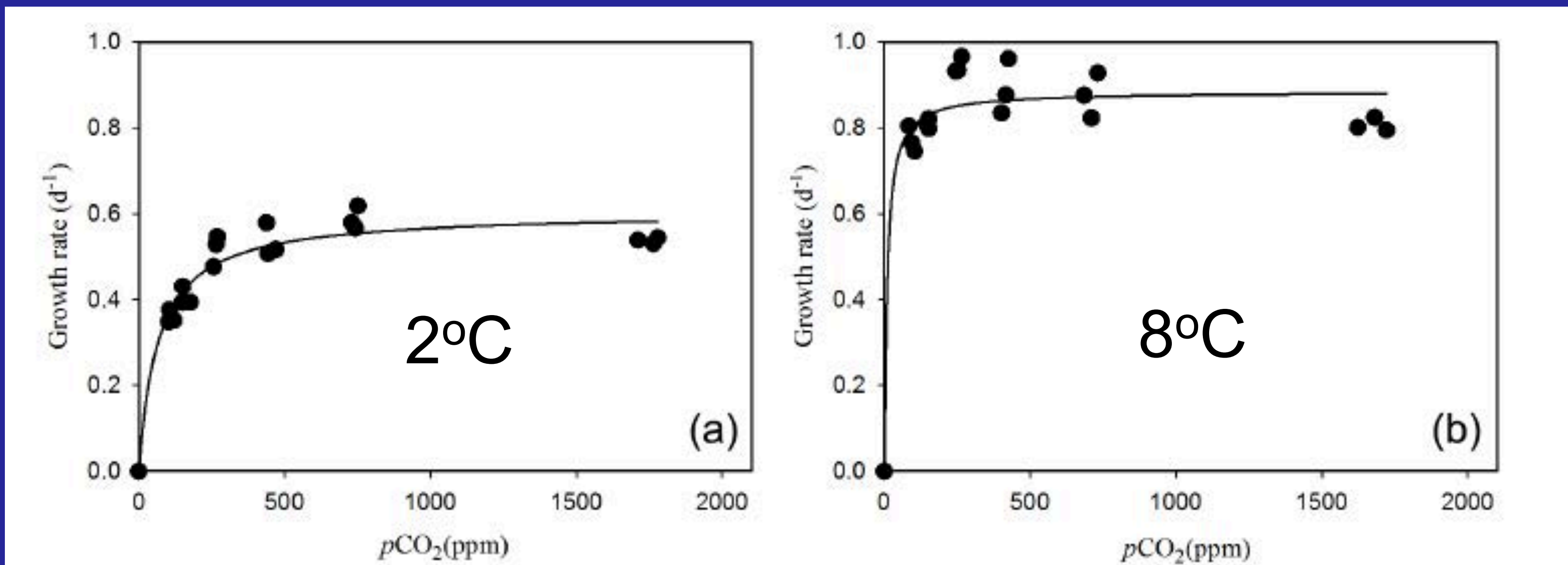
High CO_2, P-limited, low temperature conditioned cells- most toxic

Tatters et al. 2013 Harmful Algae

Interactions between acidification and warming in a polar *Pseudo-nitzschia*

Individual and interactive effects of warming and CO_2 on *Pseudo-nitzschia subcurvata* and *Phaeocystis antarctica*, two dominant phytoplankton from the Ross Sea, Antarctica

Zhi Zhu, Pingping Qu, Jasmine Gale, Feixue Fu, and David A. Hutchins



1) Maximum growth rates are almost 50% higher under acidified conditions at the warmer temperature

2) Half-saturation constants for CO_2 are 6X lower (11 ppm vs 66 ppm) under acidified conditions at the warmer temperature

Zhu et al. 2017, Biogeosciences

Our current project is supported by California Proposition 84 funds, administered by the Urban Ocean Sea Grant program

How will interactions between multiple global change stressors affect *Pseudo-nitzschia* growth and toxicity?

Kyla Kelly

- Acidification
- Warming
- Nitrogen source
- Light
- UV radiation

Pseudo-nitzschia multiseries

Our first set of experiments examined *Pseudo-nitzschia multiseries* growth and domoic acid production in an interactive experimental matrix of:

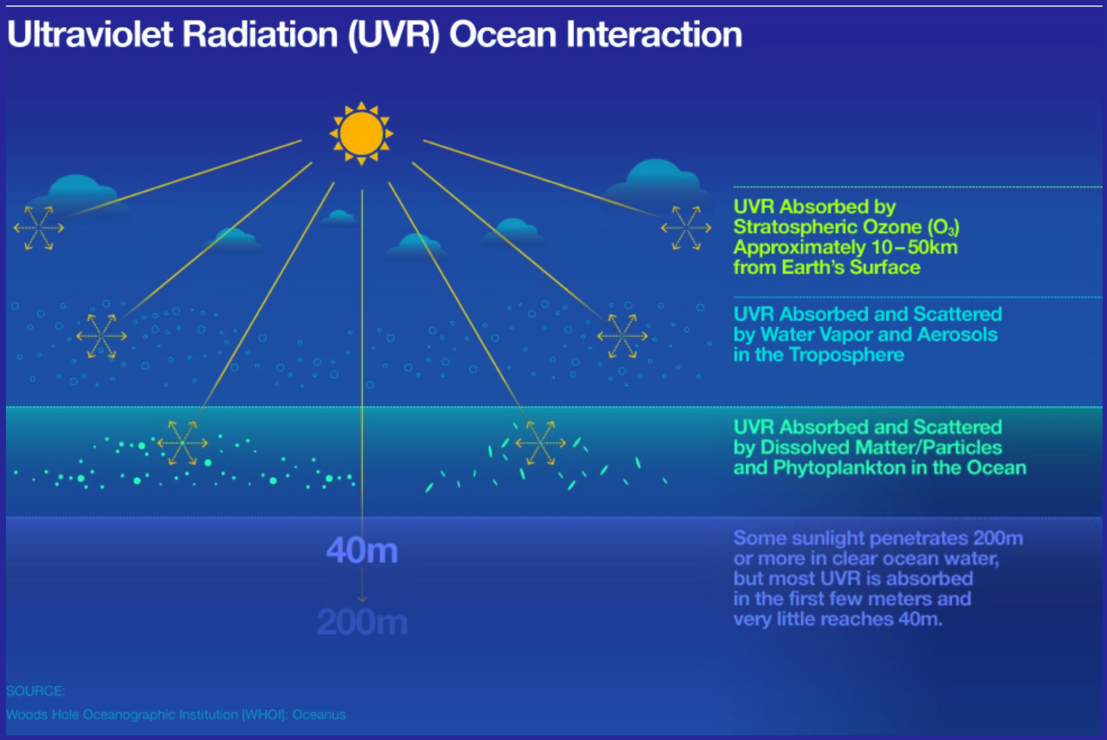
Temperature (20C and 25C)

Nitrogen source (Nitrate and urea)

Solar radiation (Photosynthetically active radiation (PAR) alone, and PAR plus UV radiation)

Our early results suggest that *Pseudo-nitzschia multiseries* is very sensitive to UV radiation

It's growth is almost completely inhibited at UV levels that are easily tolerated by other algae we have examined



UVR only penetrates into the top few meters of the ocean

Does this unusual sensitivity to UV radiation help explain the common observation that *Pseudo-nitzschia* often forms sub-surface 'thin layer' blooms?

Cryptic Blooms: Are Thin Layers the Missing Connection?

Margaret A. McManus · Raphael M. Kudela · Mary W. Silver · Grieg F. Steward · Percy L. Donaghay · James M. Sullivan

Thin layers and camouflage: hidden *Pseudo-nitzschia* spp. (Bacillariophyceae) populations in a fjord in the San Juan Islands, Washington, USA

J. E. B. Rines[1,*], P. L. Donaghay[1], M. M. Dekshenieks[2], J. M. Sullivan[1], M. S. Twardowski[3]

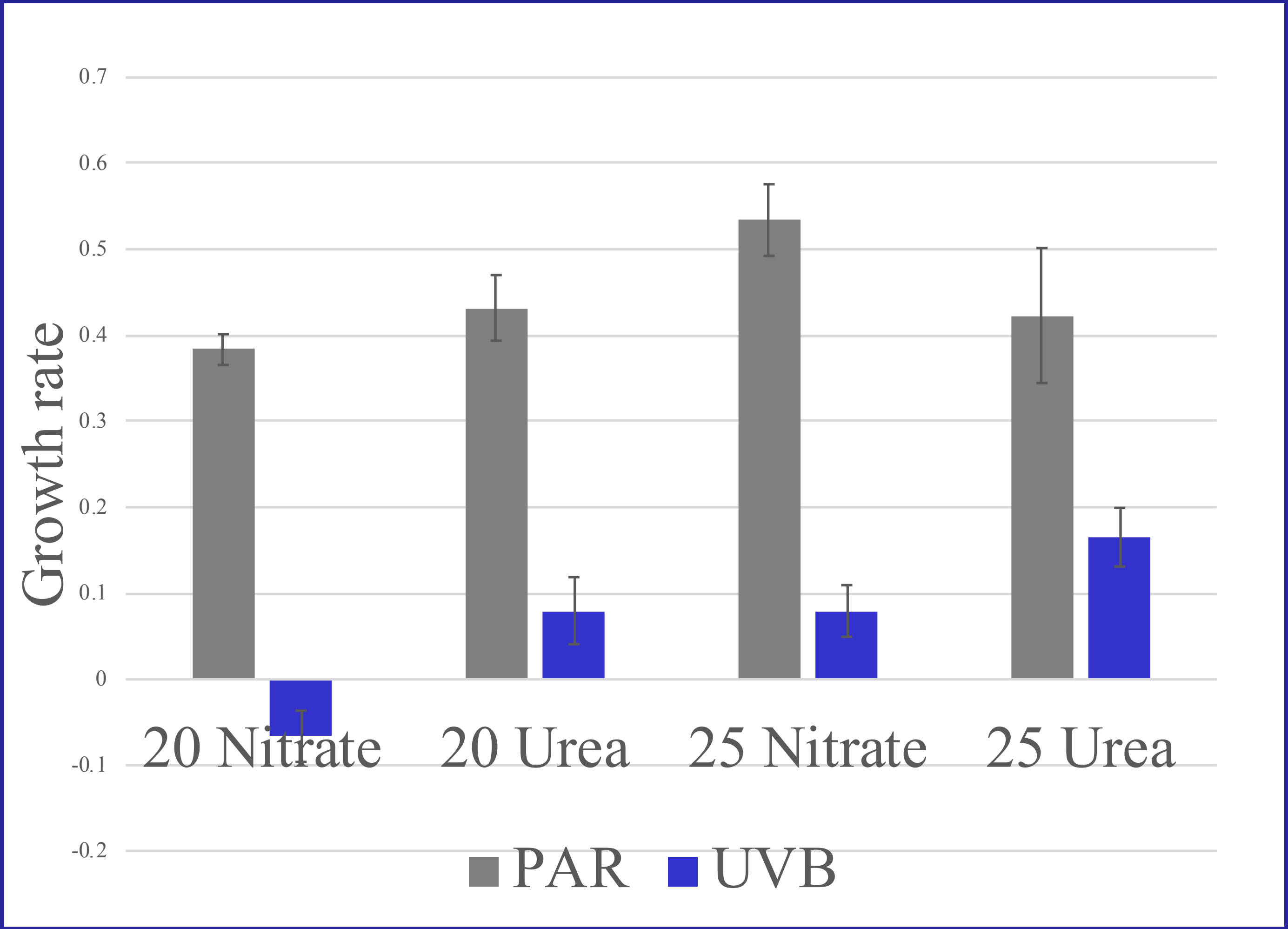
Limnol. Oceanogr., 53(5), 2008, 1816–1834

Thin layers of *Pseudo-nitzschia* spp. and the fate of *Dinophysis acuminata* during an upwelling–downwelling cycle in a Galician Ría

L. Velo-Suárez and S. González-Gil
Instituto Español de Oceanografía, Centro Oceanográfico de Vigo, Subida a Radiofaro 50-52, Cabo Estay, Canido, 36390 Vigo, Spain

What are the implications for toxic blooms if the surface mixed layer is getting shallower due to climate change, as predicted by many models?

Early results of our first multiple stressor experiment



1) This toxic species is very sensitive to UV

2) Highest growth rates are in the PAR, warming and nitrate treatment

3) The combination of warming and growth on urea seems to confer some resistance to UV

Global change and harmful *Pseudo-nitzschia* blooms

Many global change factors have the potential to affect our already serious problem with toxic *Pseudo-nitzschia* blooms, including ocean acidification, warming, stratification, deoxygenation, and changes in nutrient supplies and solar radiation.

Many of these environmental changes can individually promote *Pseudo-nitzschia* growth and/or toxicity, but it is the *interactions* between multiple factors that are likely to be far more important than any single factor alone.

We need to start considering global change holistically, as it is the combination of *all* these simultaneous changes together that will determine the future of harmful *Pseudo-nitzschia* blooms along the West Coast.

Acknowledgements

Senior collaborators

Feixue Fu, Andy Allen, Jun Sun, Dave Caron, Bradley Moore

Students

Avery Tatters, Kyla Kelly, Zhi Zhu, Pingping Qu, Jasmine Gale

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USC Urban Ocean Sea Grant

California Proposition 84

NSF Polar Programs

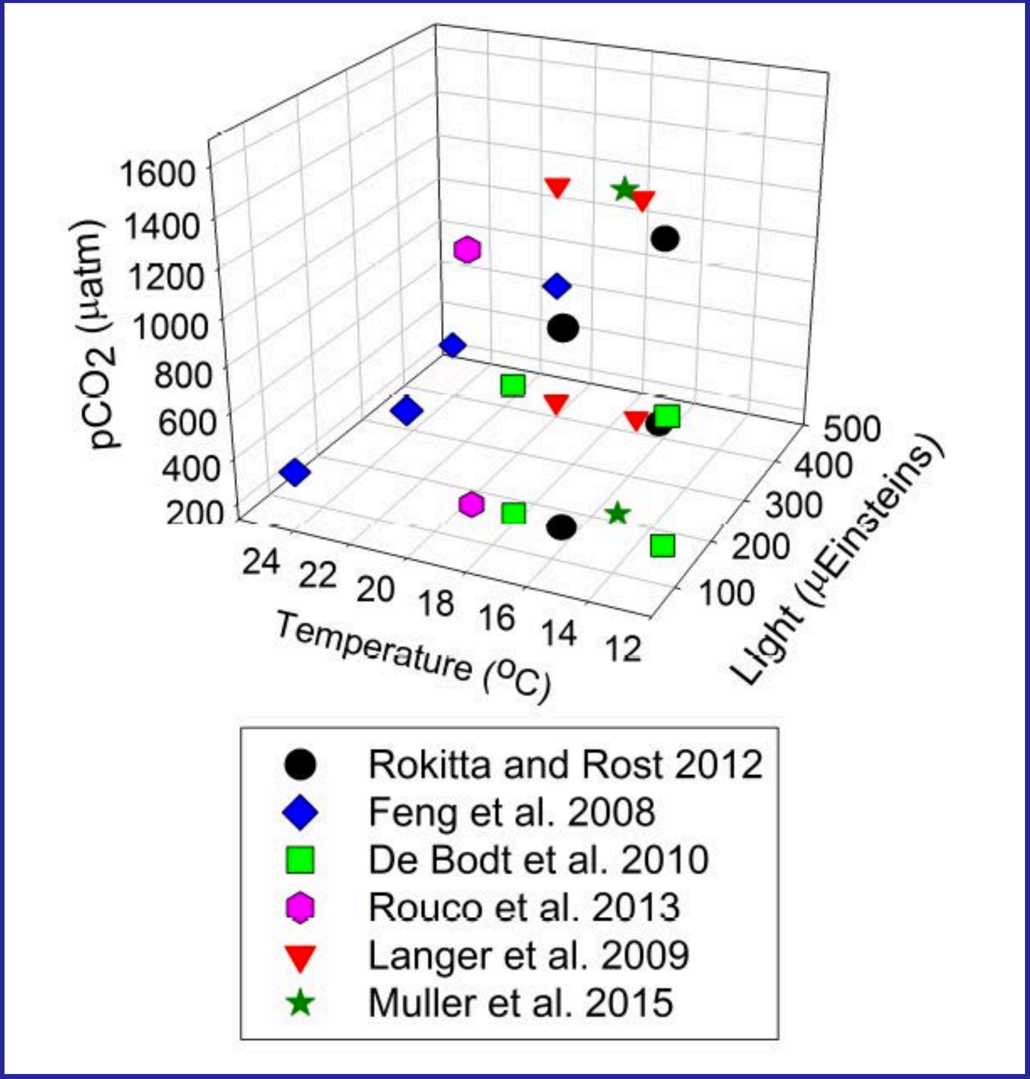
Sea Grant
University of Southern California
Science serving our urban coast

Proposition 84

Designing multiple variable global change experiments can be tricky!

Growth rates of phytoplankton in six published global change studies:

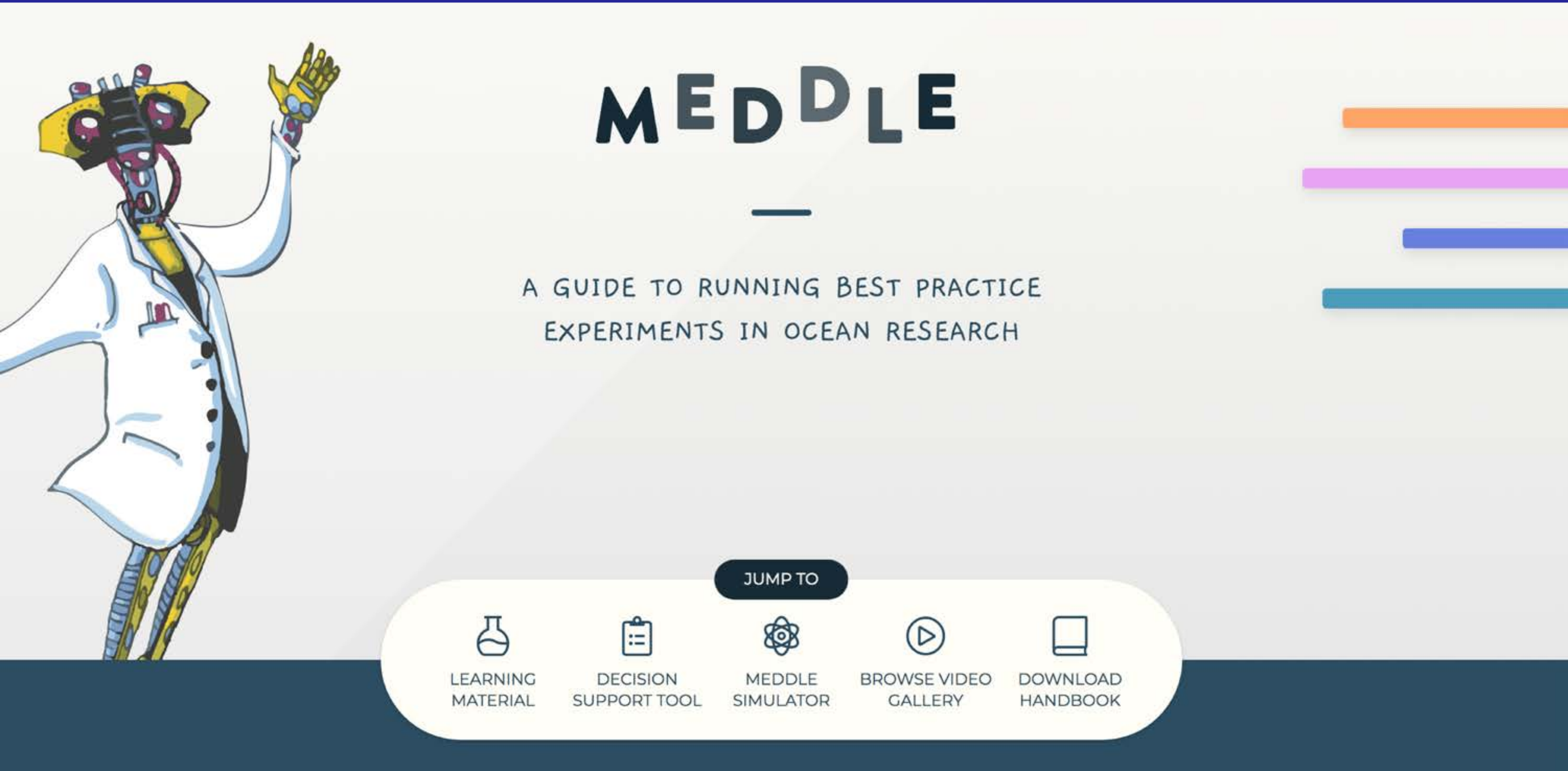
Experimental outcomes vary, at least partly because different experimental matrices were used



Hutchins and Fu 2017 Nature Microbiology

A digital Best Practices Guide on how to design and carry out complex multiple variable global change experiments

- https://meddle-scor149.org



You can design and run an online simulated global change experiment of your own

M

SIMULATOR

Time to experiment! MEDDLE lets you design single and multi driver experiments and produce simulated data that you can analyze. Happy meddling!

Have fun designing a better experiment!

A video archive and pdf of this webinar will available on the C-CAN website in the "workshop" page

- http://c-can.info/workshopswebinars/

Please contact Diane Pleschner-Steele at dplesch@gmail.com with any questions about C-CAN

Next Roundtable Discussion!

October 16, 2019 at 1 PM Pacific Time

To be announced

Registration and more info will be distributed via the C-CAN listserv shortly. You can sign up by visiting the C-CAN News page

http://c-can.info/category/news/