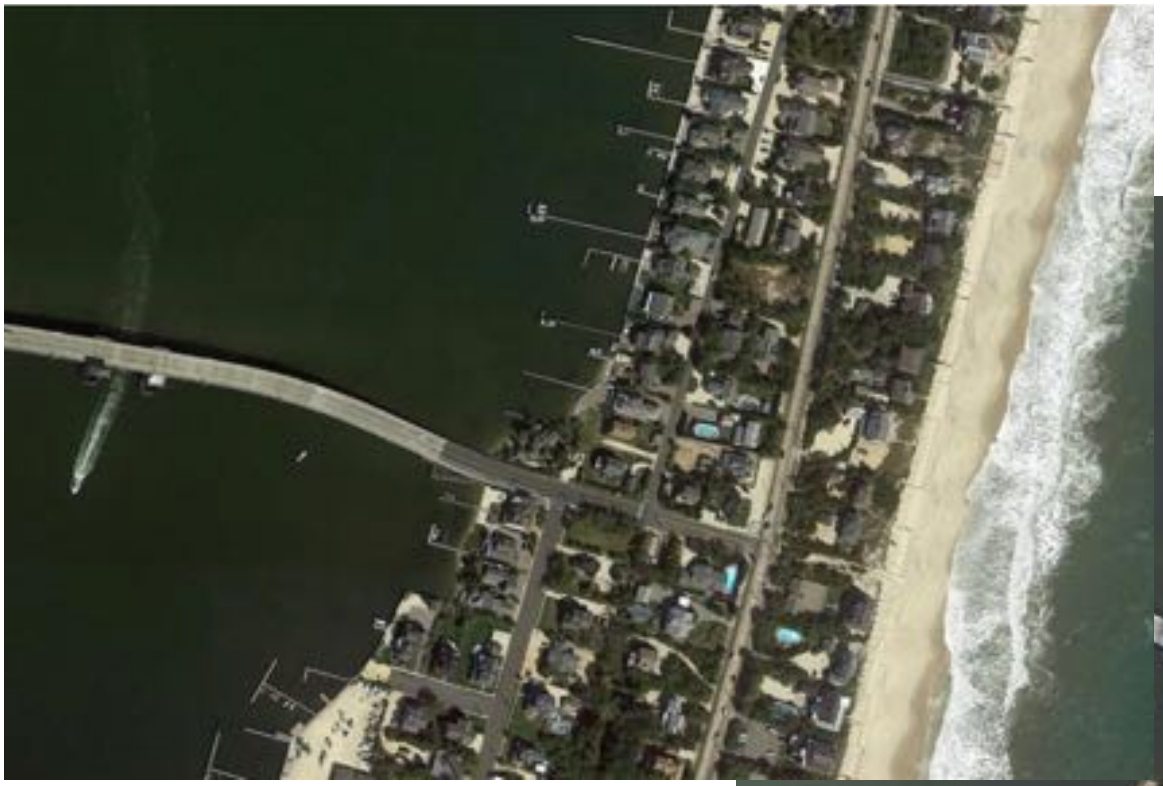
Toxins & Pollutants

ES 383

Colby at Bigelow, September 2018

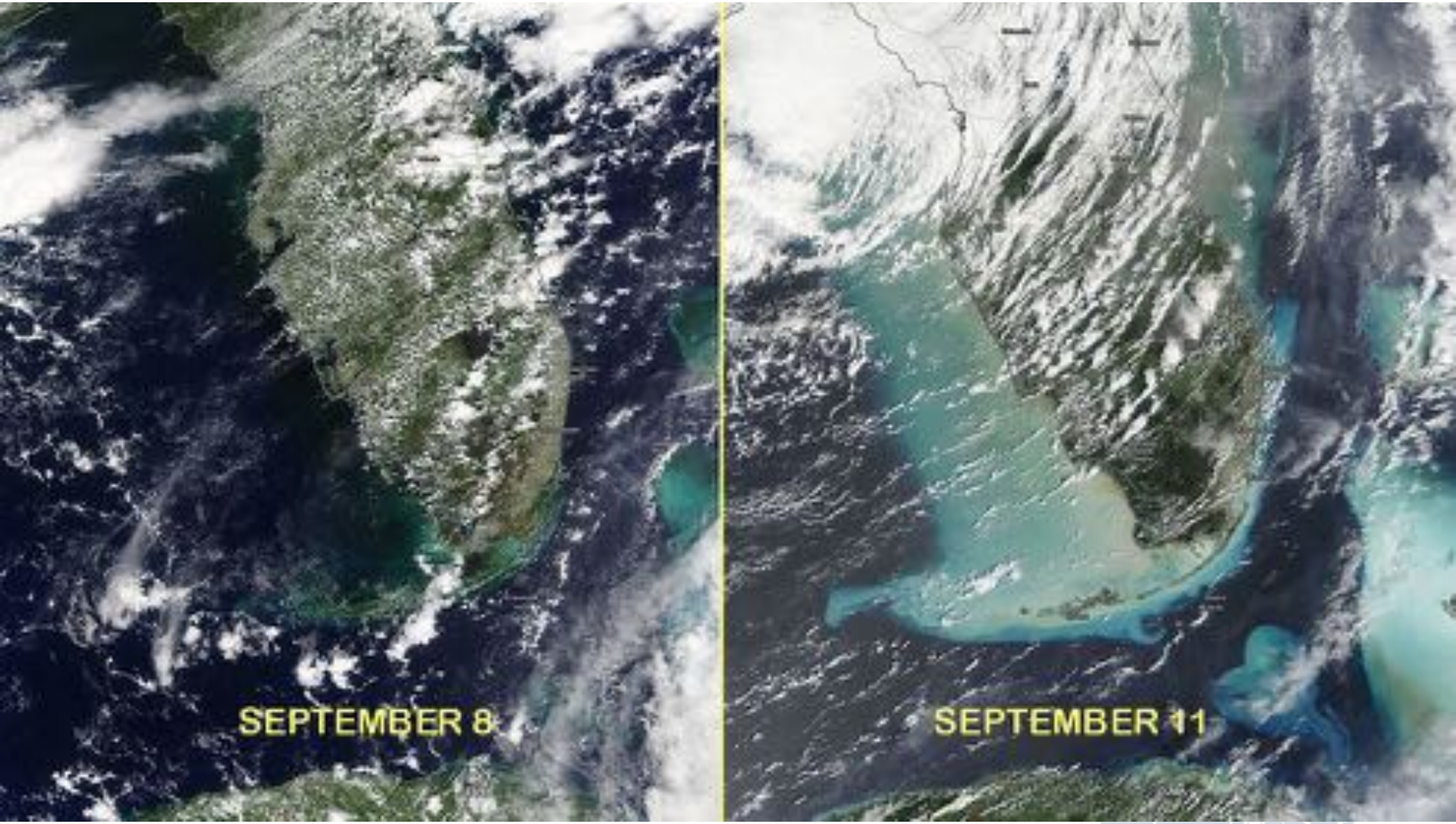
Bigelow | Laboratory for Ocean Sciences

Quick note on hurricanes



Hurricane Sandy (2012)

Quick note on hurricanes



Hurricane Irma (2017)

...onto toxins / pollutants

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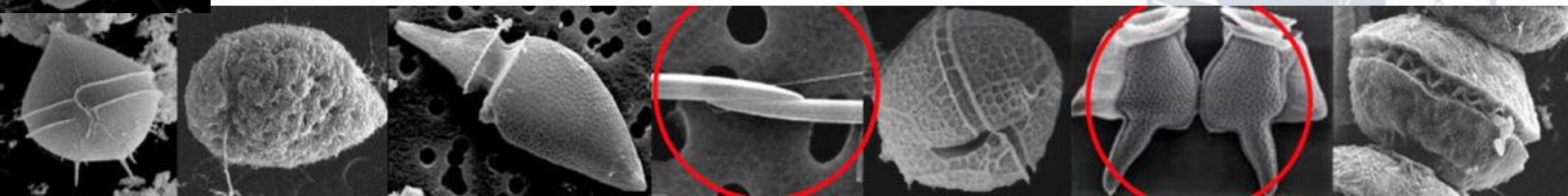
The basics: What is a 'HAB'?

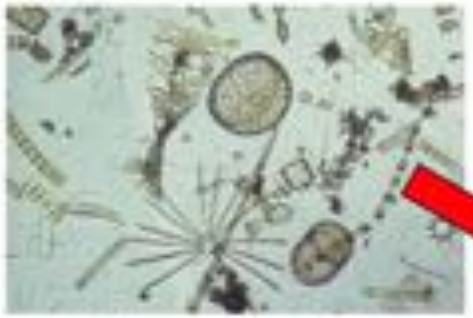
- A 'HAB' = Harmful Algal Bloom (= Red Tide)
  - A bloom (higher than normal concentration) of microscopic algae that cause harm due to:
    - Toxins, or
    - High Biomass (low/no O2 =hypoxia/anoxia) Physical damage (spines), or Water Quality
- Who's harmed:
  - Humans (ingestion, inhalation, contact)
  - Marine life and food webs Economies



Some Perspective

Globally

10,000-100,000
phytoplankton species



Typical coastal phytoplankton community

Globally

~300 species form 'blooms'

Globally

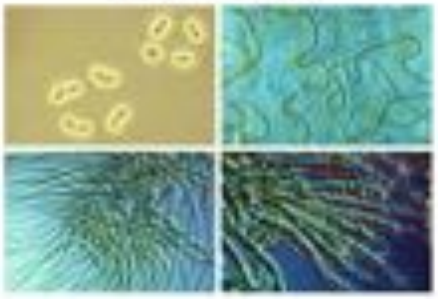
~100 species contain toxins

Locally

Maine
(~15 species of marine harmful algae)

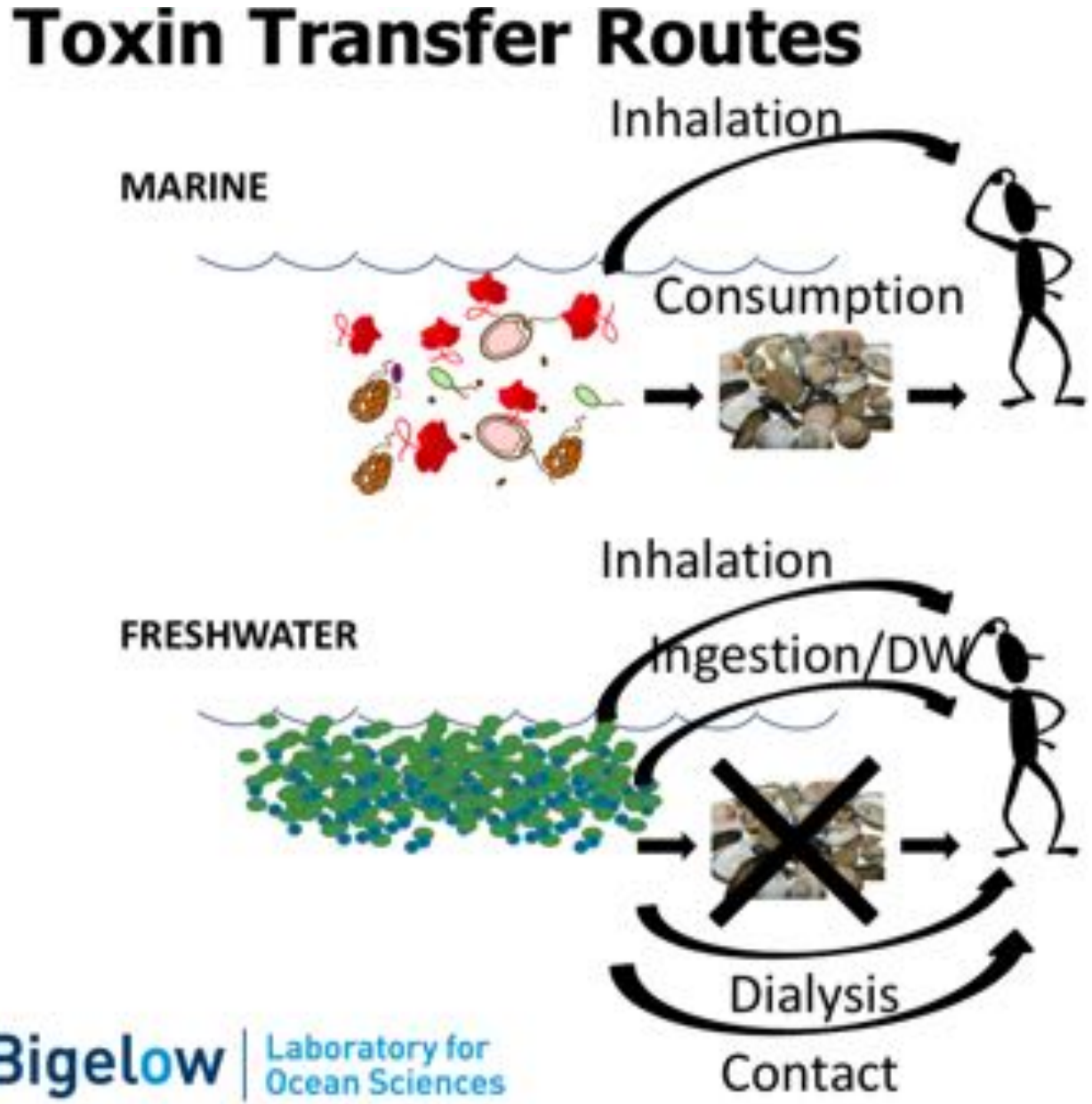
Maine Red Tide

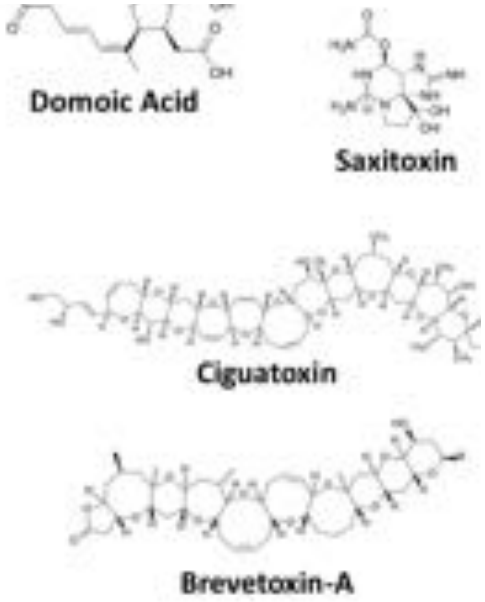
Cyanobacterial Blooms Pond Scum



***Pseudo-nitzschia* Blooms**

Why worry?





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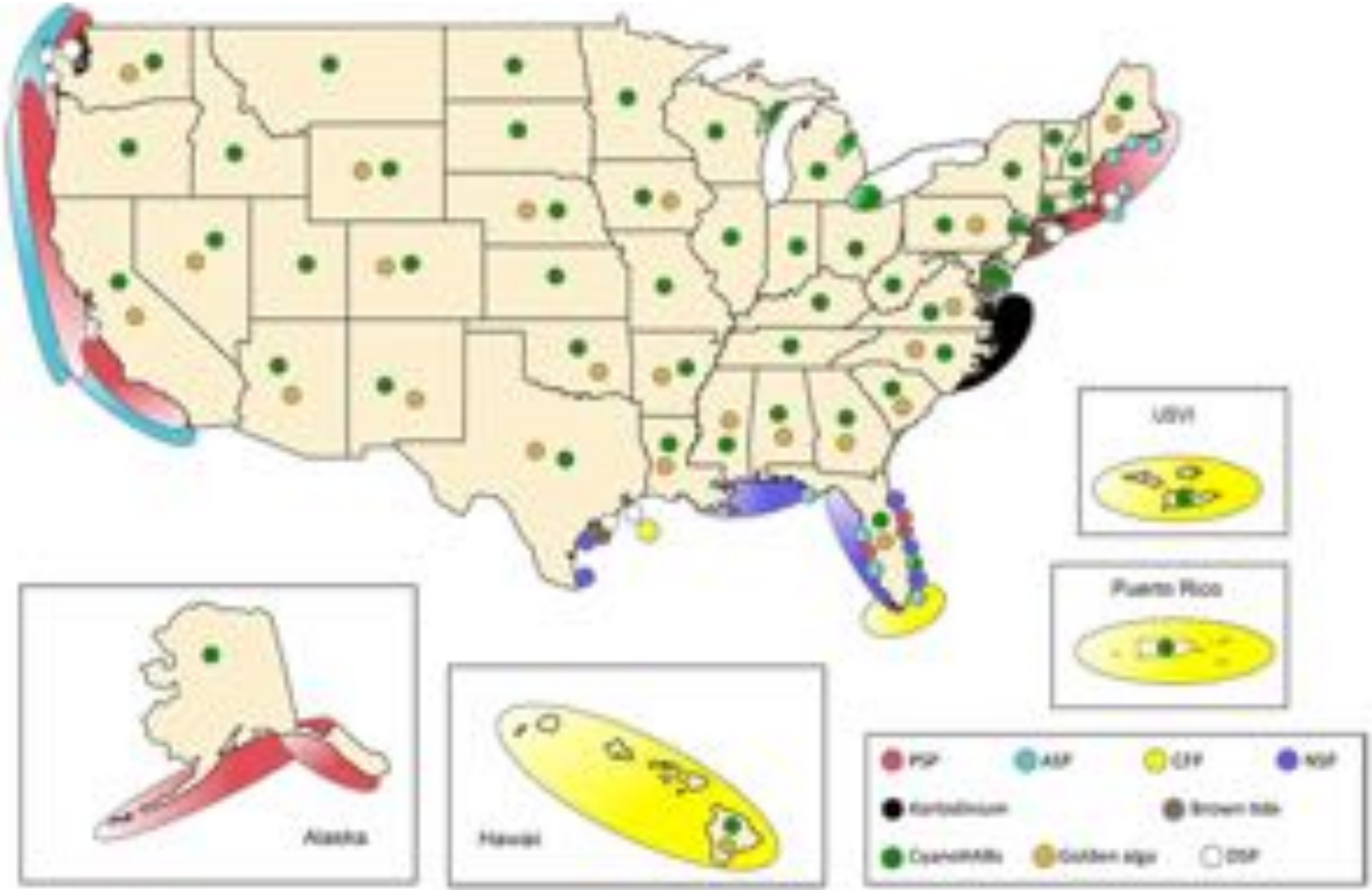
HAB distribution in the US

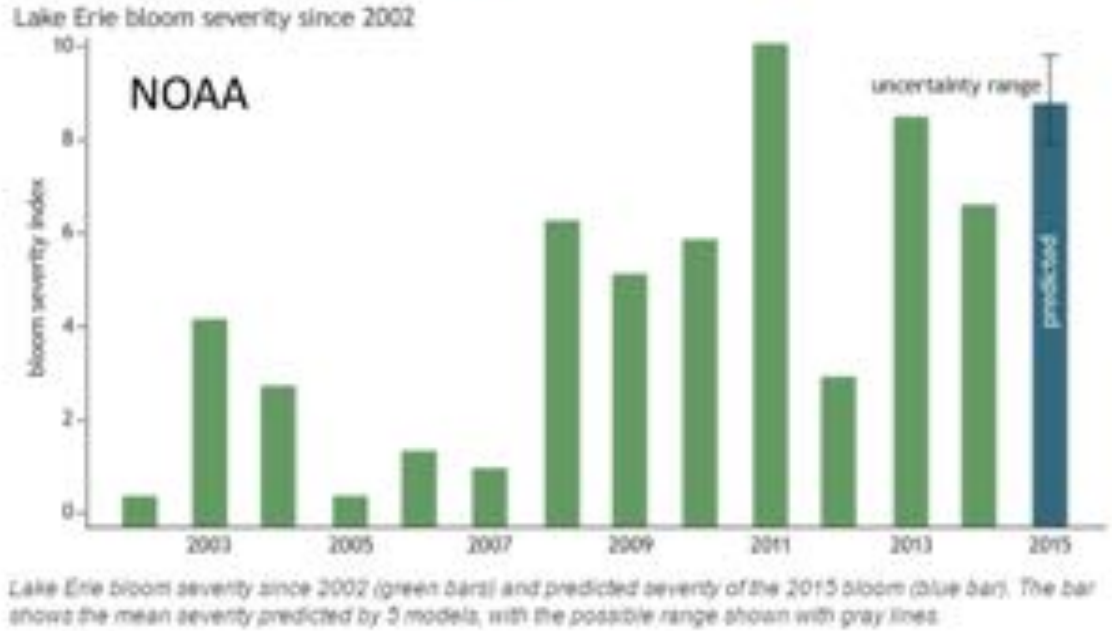
http://www.whoi.edu/redtide/page.do?pid=14898



Many HABs are increasing

Freshwater

Saltwater



Lake Erie bloom severity since 2002 (green bars) and predicted severity of the 2015 bloom (blue bar). The bar shows the mean severity predicted by 5 models, with the possible range shown with gray lines.

https://www.climate.gov/news-features/event-tracker/stay-out-scum-warns-noaa%E2%80%99s-latest-bulletin-lake-erie%E2%80%99s-harmful-algal

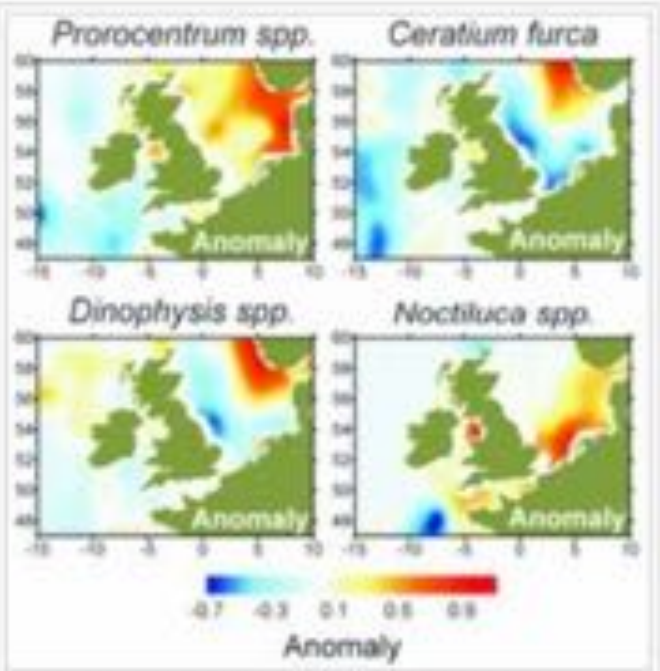


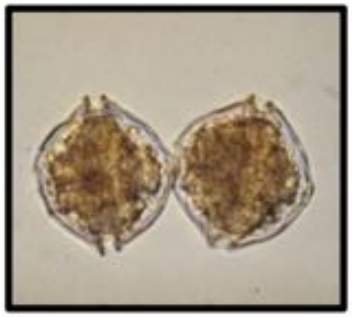
Fig. 3: Decadal anomaly maps for four common HAB taxa. Anomaly is the difference between the long-term mean (1960-1989) and post 1990s (1990-2002) (reproduced from Edwards M, Johns DG, Leterme SC, Svendsen E, Richardson AJ (2006) Regional climate change and harmful algal blooms in the northeast Atlantic. Limnology and Oceanography 51(2), 820-829).

Causes of increases

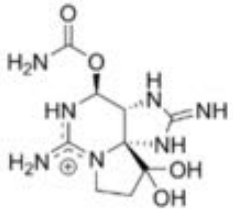
- Eutrophication = nutrient enrichment (pollution)
- Increased aquaculture operation
- Transport via ballast water and/or shellfish seeding activities: Kuwait red tides
- Long-term climate changes
- Improved scientific methodology & monitoring
- Shifting currents, storms and natural dispersal mechanisms

Gulf of Maine

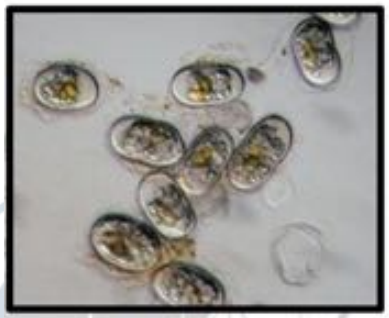
- Red Tide (Alexandrium) blooms
  - Can contain Saxitoxin,
  - Contaminates shellfish, can cause PSP (paralytic shellfish poisoning) if eaten
  - Blooms in late spring/early summer
  - Blooms initiate from cyst (=seed) beds in 2 regions: Casco Bay and Bay of Fundy regions
  - Blooms (and toxicity) move south along coast



Alexandrium vegetative cells



Saxitoxin



Alexandrium resting cysts

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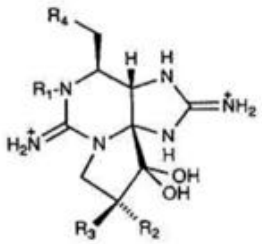
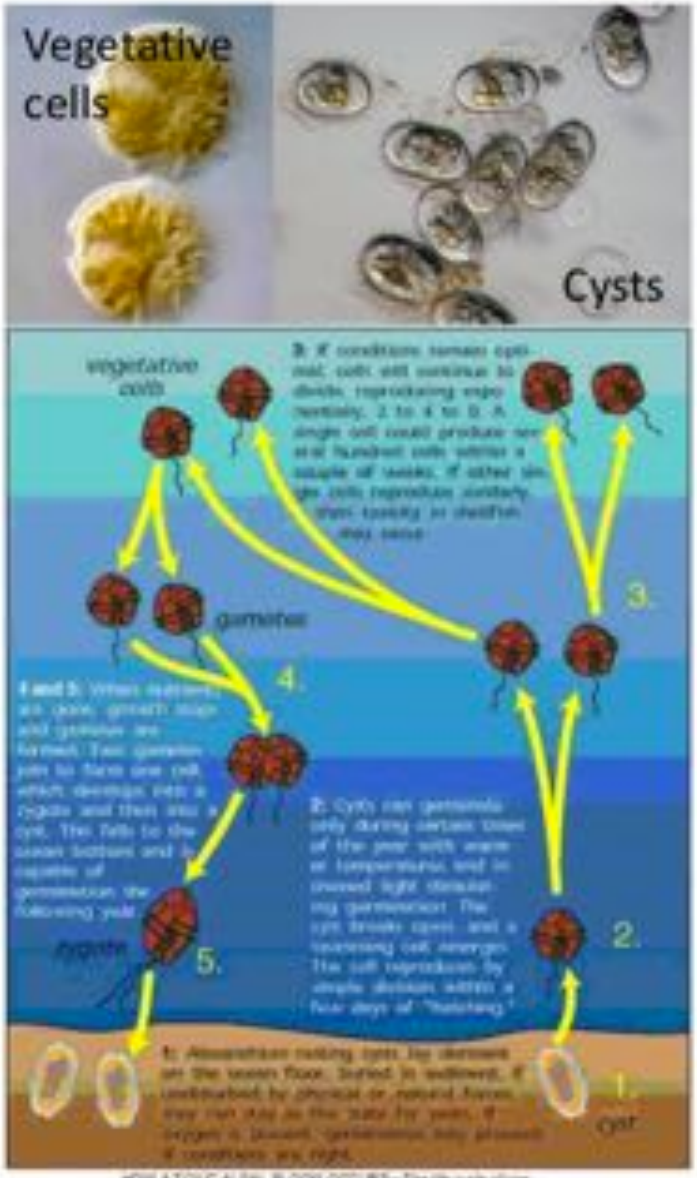
Paralytic Shellfish Poisoning (PSP)

Alexandrium

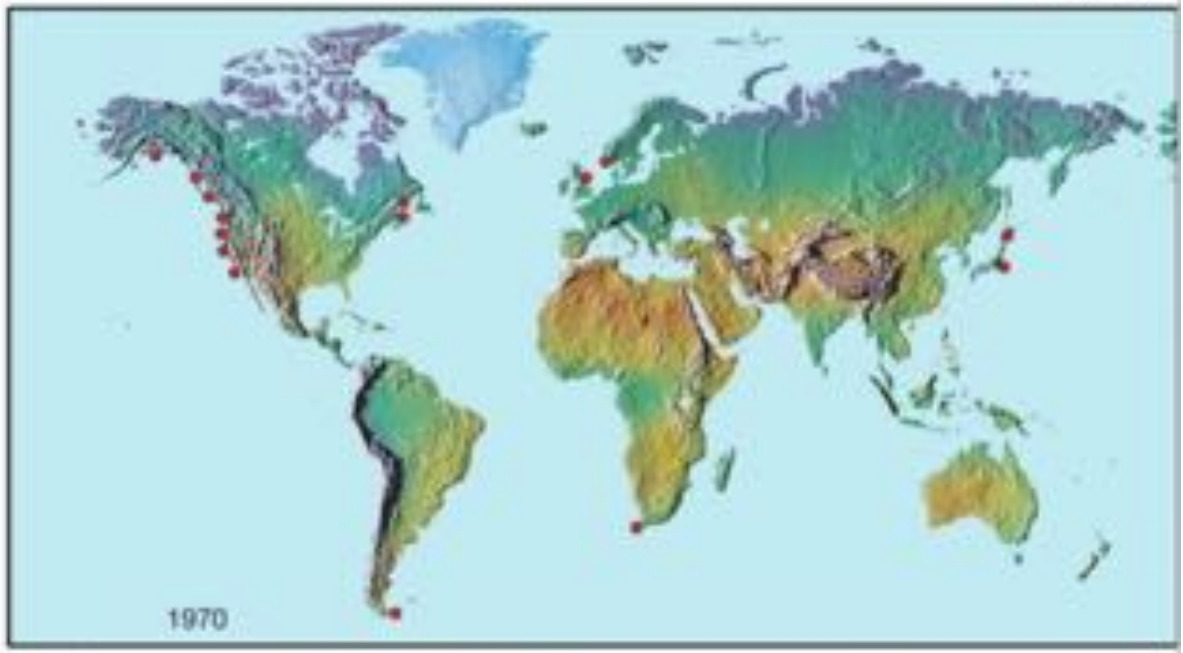


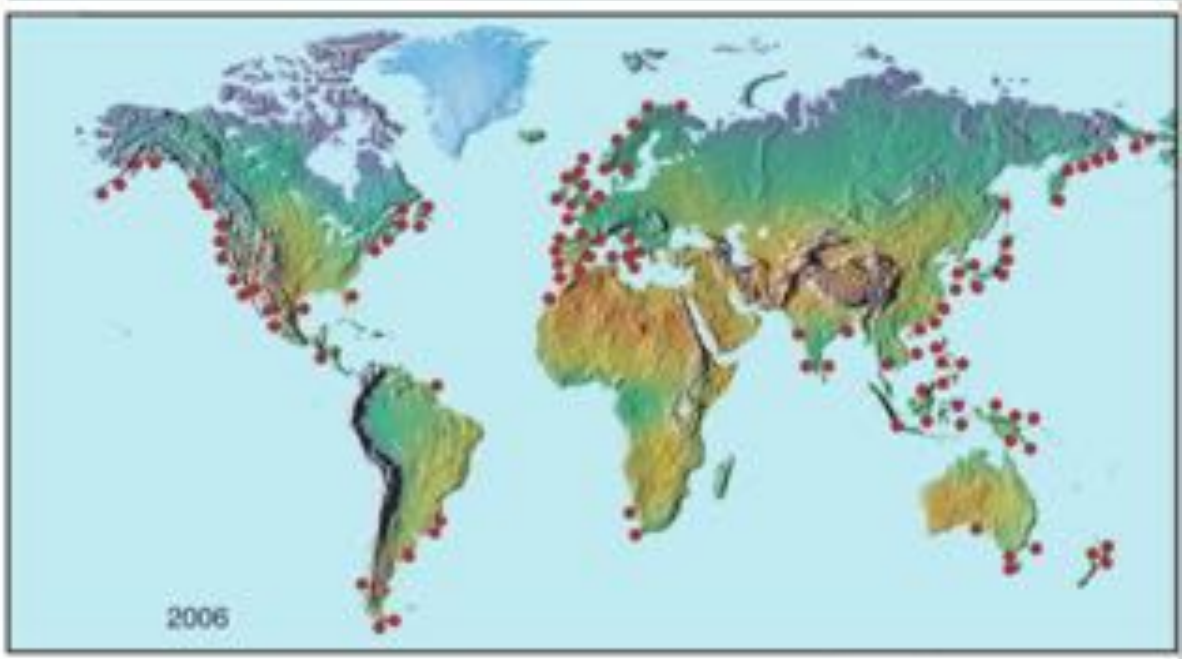
- Onset 5 to 30 minutes
- Mild Case
  - Headache
  - Nausea and vomiting
  - Dizziness
  - Numbness/tingling of mouth and lips, spreading to the face and neck Muscle weakness
- Extreme Case
  - Numbness/tingling of the arms and legs
  - Incoherent speech and light-headedness
  - Muscular paralysis
  - Difficulty breathing
  - *Death can result*

Maine Red Tide
Alexandrium



• PSP

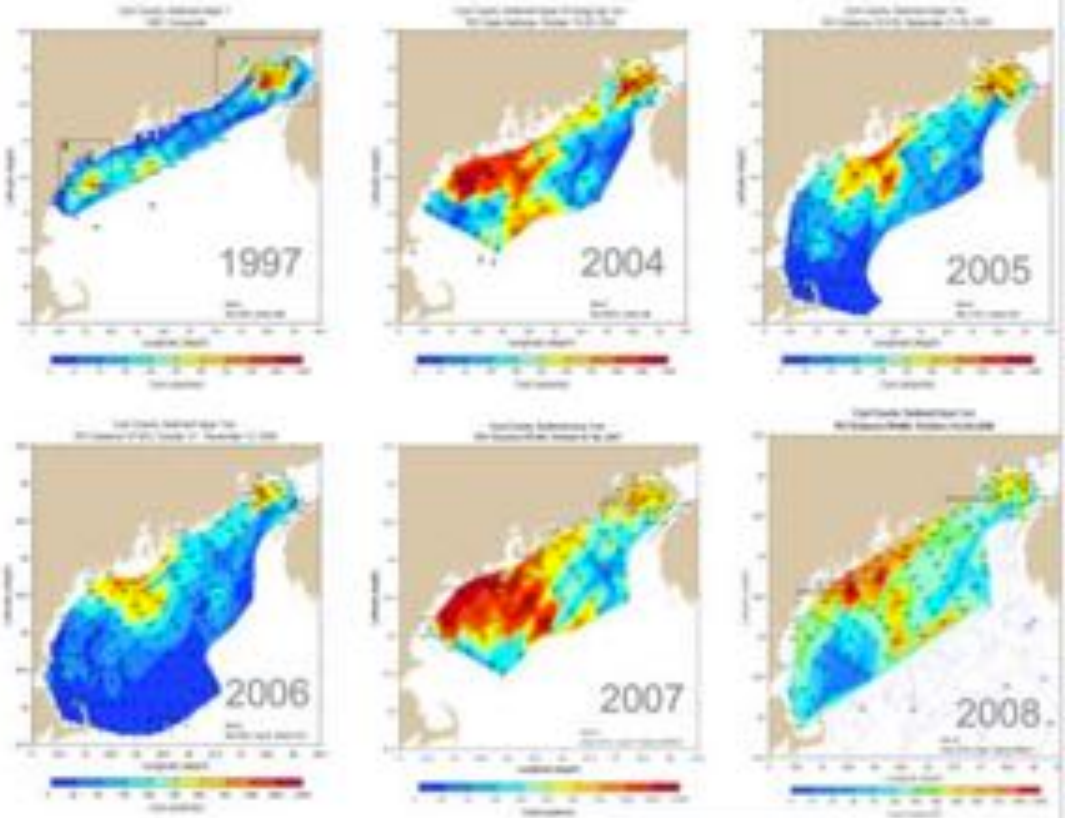




Main *Alexandrium* bloom dynamics

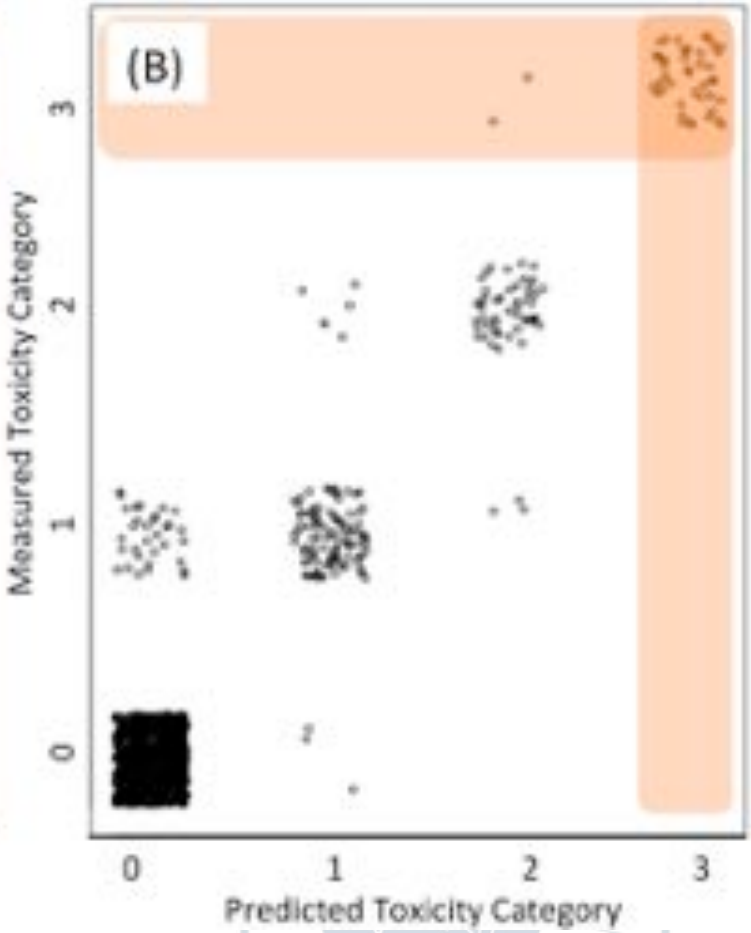
Fig. 1. Map illustrating the general counterclockwise circulation pattern in the Gulf of Maine associated with major *A. fundyense* habitats (adapted from Anderson 1997). The GOM is bordered by Canada—Bay of Fundy (BOF) and Nova Scotia (NS)—to the north and east and the United States—Maine (ME), New Hampshire (NH), Massachusetts (MA), and Massachusetts Bay (MB)—to the west. The major segments of the Maine coastal current (MCC) are highlighted as the western segment (WMCC) and the eastern segment (EMCC). Outflow from the Penobscot, Kennebec and Androscoggin, Saco, and Merrimack Rivers are indicated with arrows. This freshwater outflow produces a buoyant plume that is associated with the WMCC.

(From Anderson et al 2005)



(www.whoi.edu)

Alexandrium forecasting



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New bloom on the block: *Pseudo-nitzschia*

Portland Press Herald

Portland Press Herald
Oct. 6, 2016

BUSINESS

Brain-damaging toxin closes Down East shellfish industry

A bloom producing 'very nasty' domoic acid, a biotoxin that can cause illness, memory loss, brain damage and possibly death in humans, is unprecedented for Maine.

BY PETER MCGUIRE STAFF WRITER

An unusual bloom of toxic algae has closed a third of Maine's coastline to clam and mussel harvesting and triggered a widespread shellfish recall.

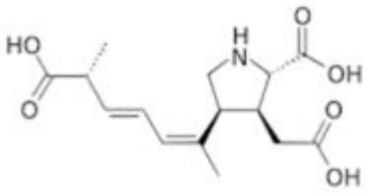
Last week, the Department of Marine Resources issued a recall of mussels, clams and quahogs caught in Down East Maine after samples tested positive for domoic acid, a

Courier Gazette & Camden Herald
Feb 25, 2017

Mysterious toxic algae that shut down RI shellfishing last fall is back

Providence Journal
March 3, 2017

Pseudo-nitzschia blooms



Domoic acid

- 1st bloomed, 1983, PEI Canada
- Common off west coast
- Can contain domoic acid
- Contaminates shellfish, can cause ASP (amnesic shellfish poisoning) if eaten
- Blooms in fall
- Can impact marine mammals & birds
- New phenomena, closures in 2016, 2017

P. Countway, Bigelow Laboratory

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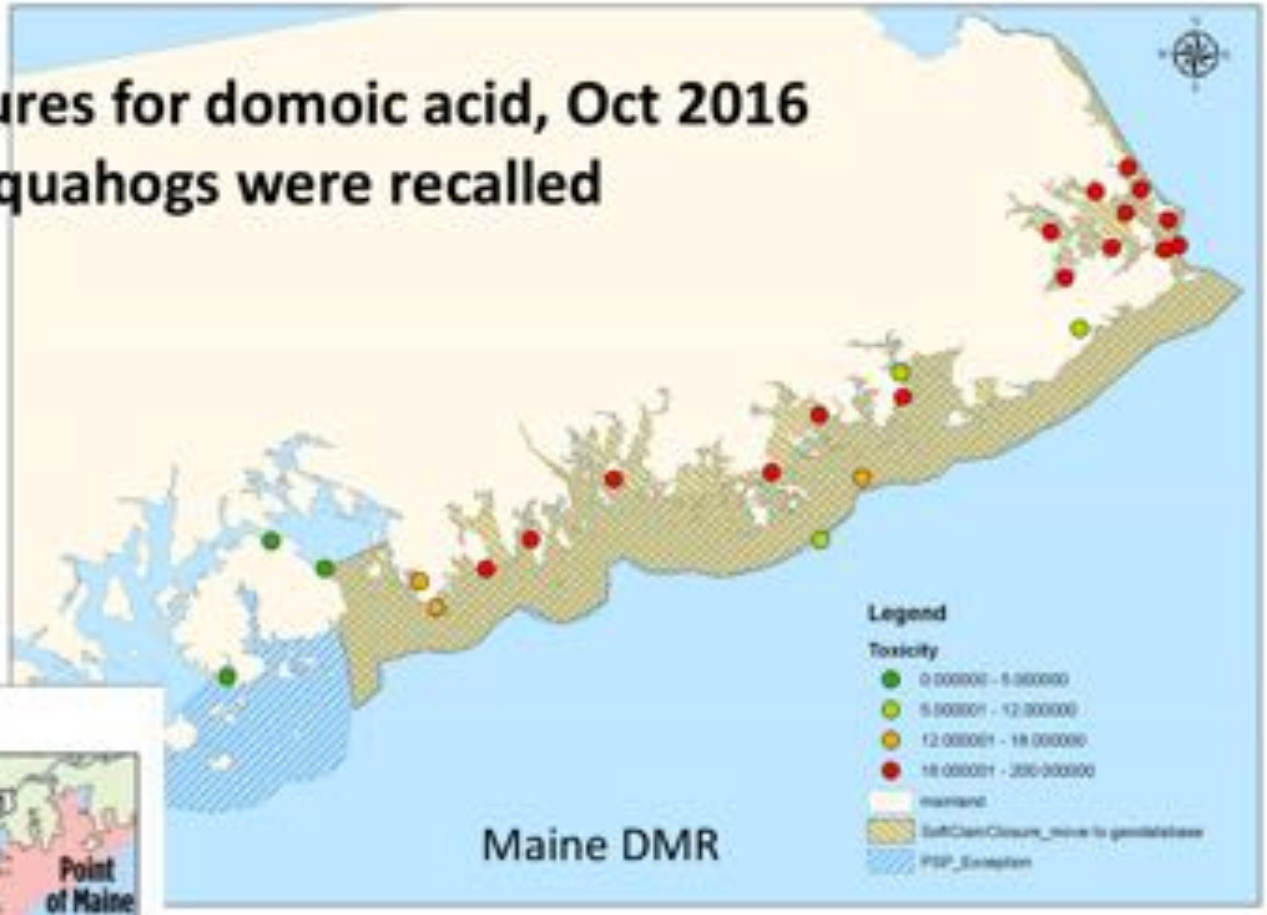
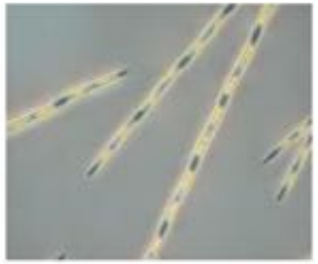
Maine shellfish closures for domoic acid, Oct 2016
5 tons of mussels & quahogs were recalled



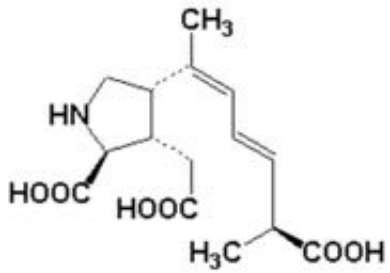
Portland Press Herald, Sept 14, 2017

Amnesic Shellfish Poisoning (ASP)

- Onset 5 to 30 minutes
- Mild Case
  - Nausea and vomiting
  - Diarrhea
  - Abdominal cramps
- Extreme Case
  - Headaches
  - Hallucinations, confusion, dizziness
  - Short-term memory loss
  - Respiratory problems
  - Cardiac arrhythmias
  - Motor weakness, seizures
  - Coma
  - *Death can result*



Pseudo-nitzschia



Domoic Acid Structure
Source: http://www.cfsan.fda.gov/~mow/domoic.html

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Demonic Domoic

Alarming outbreak of acid in the ocean is poisoning hundreds of aquatic birds and mammals....

(Daily Breeze, April 2007)

THE LOG
SoCal's #1 Boating & Fishing Newspaper

Poisoned, 'Drunken' Pelicans Fall From Sky

Thursday, July 13, 2006

Mystery behind Hitchcock's birds

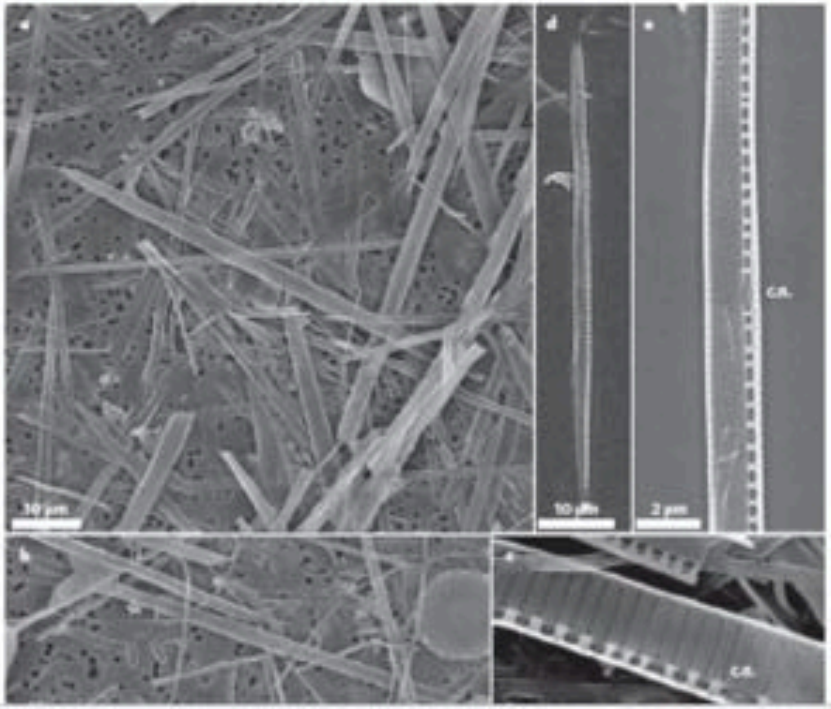
To the Editor — On 18 August 1961, a Californian newspaper reported that thousands of "crazed seabirds pelted the shores of North Monterey Bay, California" regurgitating anchovies. Soon after reading the report (Supplementary Fig. S1), local visitor Alfred Hitchcock was inspired to produce his famous thriller *The Birds*. Three decades later, in 1991, another mass poisoning occurred in the same area — this time, of fish-eating, disoriented and dying brown pelicans. But on this occasion the culprit was identified: the pelicans had ingested domoic acid, a neurotoxin that is produced by the diatom *Pseudo-nitzschia*. Large quantities of this diatom, and the associated toxin, were found in the stomachs of fish in the region. It has been suggested that diatom-generated domoic acid was also responsible for the 1961 event[1], but direct evidence has been lacking. Here we show that plankton samples from the 1961 poisoning contained toxin-producing *Pseudo-nitzschia*, supporting the contention that these toxic diatoms were responsible for the bird frenzy that motivated Hitchcock's thriller.

Algal toxins such as domoic acid are increasingly recognized as the cause of marine poisoning events. Domoic acid is a chemical analogue of glutamate and, as such, binds with high affinity to glutamate receptors in the brain[2]. When domoic acid passes through the blood–brain barrier and binds to these receptors in birds and mammals, it causes symptoms such as confusion, disorientation, scratching, seizures, coma and even death[3].

Over the past decade, Monterey Bay, a productive coastal environment in the California Current upwelling system, has been affected by recurrent blooms of *Pseudo-nitzschia* species that produce domoic acid. These blooms have led to the death or stranding of brown pelicans, Brandt's cormorants and sea-lions[4–7]. Although *Pseudo-nitzschia* has resided in the waters off California for millennia, domoic acid was only detected in diatoms in the region in 1991[8]. Prior to this, episodes of seabird mortality off the shores of California were attributed to other factors such as fog, infectious diseases, oil spills and fishing practices[9]. One such event was that involving the influx of disorientated seabirds into Monterey Bay in the summer of 1961, which entered into cinematic history.

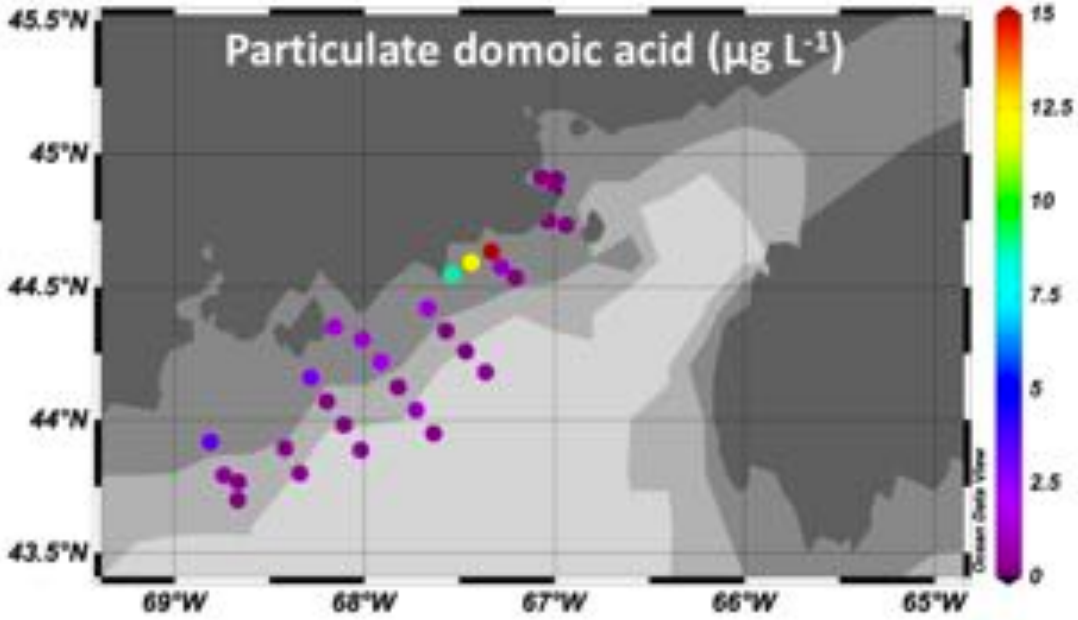
Sooty shearwaters, *Puffinus griseus*, are common visitors to Monterey Bay. These birds travel from their breeding grounds in the south-west Pacific to the productive waters of the north-east Pacific, including the California Current, during the summer and early autumn to feed[10]. In Monterey Bay, huge flocks of sooty shearwaters feed on krill, squid and fish[11]. In the summer of 1961 the birds were found regurgitating anchovies, flying into objects and dying on the streets, capturing the attention of summer resident Alfred Hitchcock; *The Birds* was released two years later.

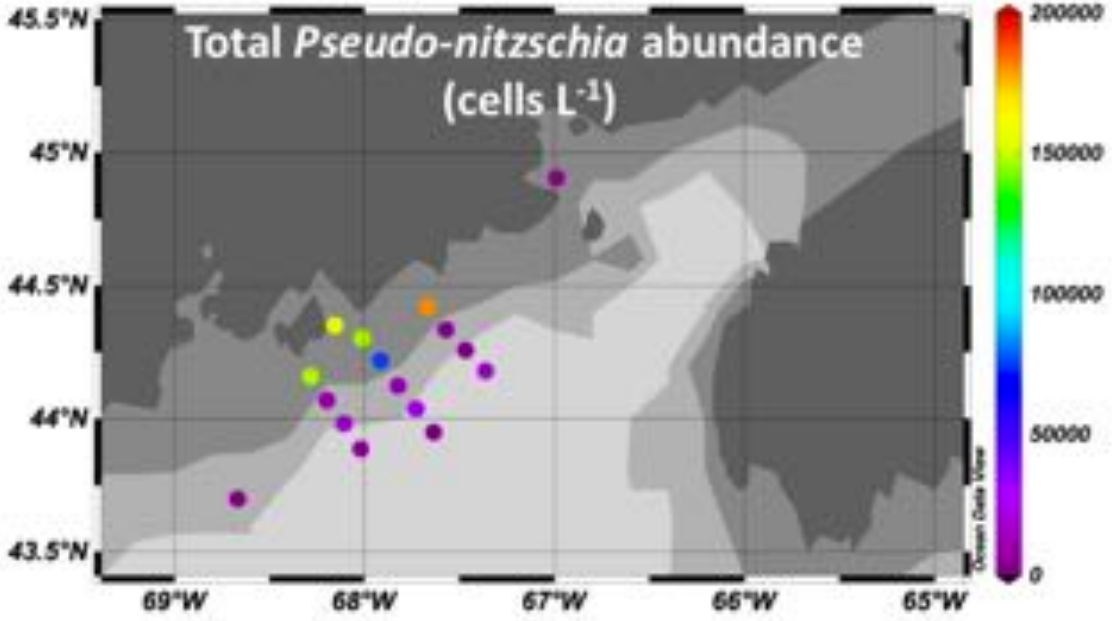
Here, we show that toxin-producing species of *Pseudo-nitzschia* were indeed present in high numbers at the time of the 1961 bird frenzy. In the absence of water samples, we examined archival samples of herbivorous zooplankton — which feed on diatoms, and are preyed on by sea turtles and some fish and birds — collected during ship surveys at the time[12] (Supplementary Fig. S2). By analysing the gut contents of these animals, we were able to reconstruct regional flora (Supplementary Information). Toxin-producing species of *Pseudo-nitzschia* accounted for 79% of the diatoms present in the guts of these organisms (Fig. 1a). Species included *P. turgidula* (Fig. 1b,c), *P. pseudodelicatissima* (Fig. 1d,e; Supplementary Fig. S3), *P. pungens*, *P. delicatissima*, *P. australis* and *P. multiseries* (Supplementary Table S1); the latter two dominated blooms during the 1991 poisoning of brown pelicans. The most abundant *Pseudo-nitzschia* species identified



Bargu et al (2012)
Nature Geoscience

ASP Rapid Event Response 2016: Bigelow & WHOI

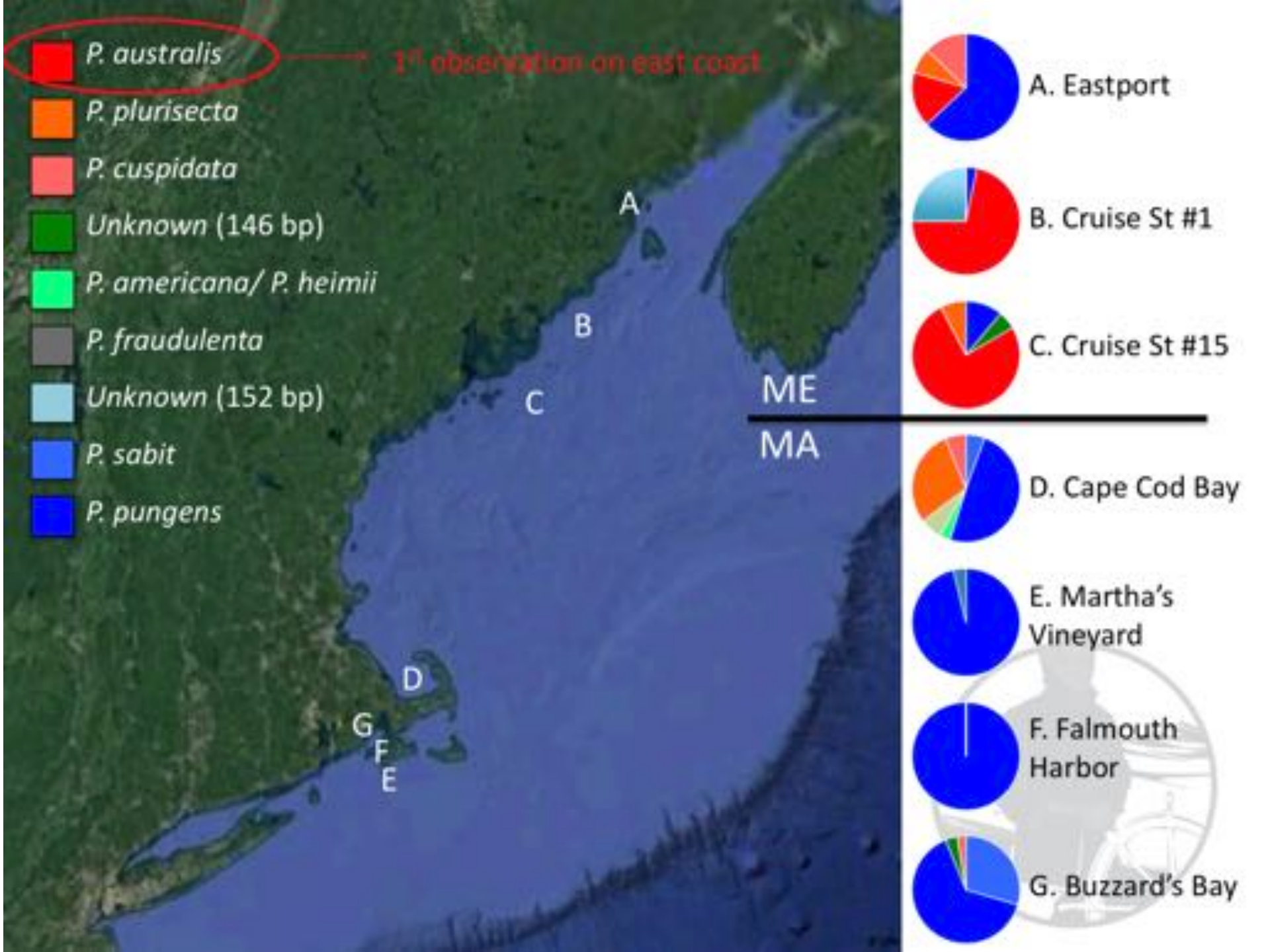




Pseudo-nitzschia cells & DA surveyed 10/5-10/8/16

Kate Hubbard & Steve Archer

(and many others including: M. Robert, E. Olesin, D. Kulis, B. Keafer, D. Anderson, D. McGillicuddy, L. Flewelling, J. Disney, A. Farrell, C. Villac, P. Countway, C. Heil, ME DMR, MA DMF, and others from state/federal management agencies


P. australis
1st observation on east coast
P. plurisecta
P. cuspidata
Unknown (146 bp)
P. americana/ P. heimii
P. fraudulenta
Unknown (152 bp)
P. sabit
P. pungens
A
B
C
D
E
F
G
ME
MA
A. Eastport
B. Cruise St #1
C. Cruise St #15
D. Cape Cod Bay
E. Martha's Vineyard
F. Falmouth Harbor
G. Buzzard's Bay

Why change in *Pseudo-nitzschia* status quo?

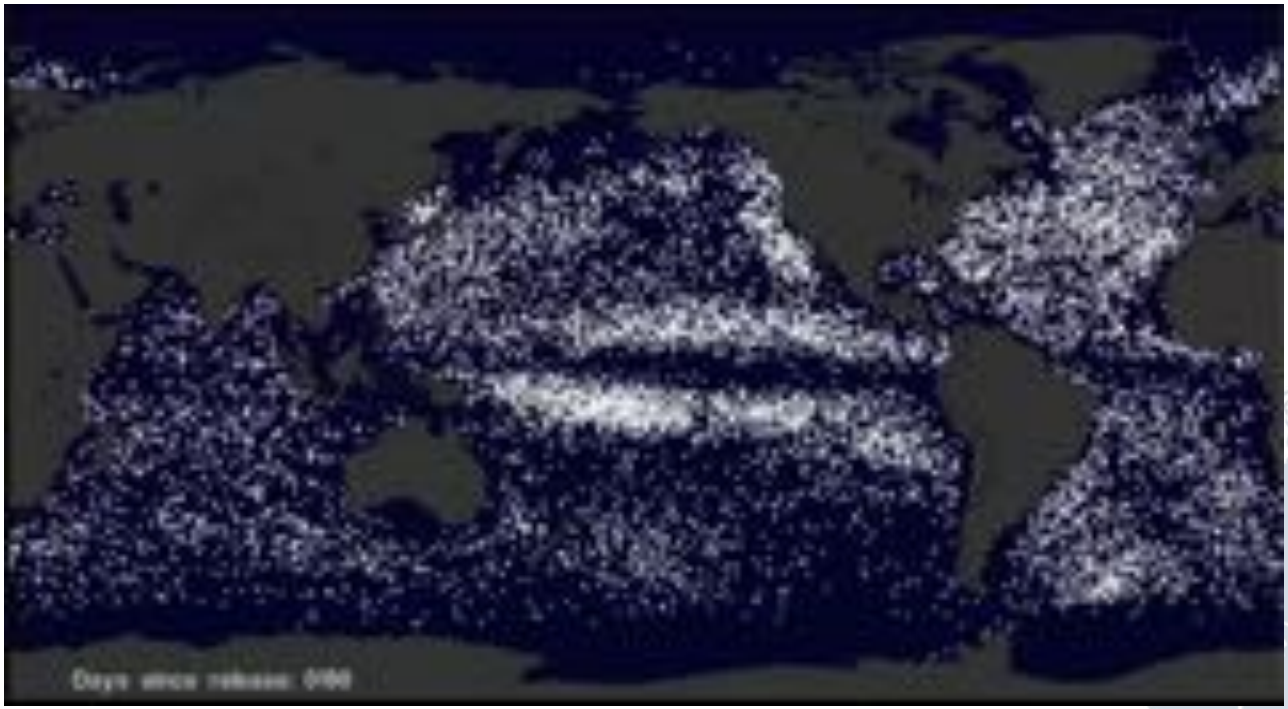
- Introduction of new species (P. australis)?
- Toxicity related to population nutrient (Si, P, trace metal) status?
- *Pseudo-nitzschia* blooms linked to eutrophication
  - Riverine inputs high in N & P relative to SiO4 decreases the Si:N ratio, favoring Pseudo-nitzschia blooms (Bates et al., 1998)
- Climate change related?
- Or all of these?

Plastics

- "[M]ore weight in plastics than fish by the year 2050" .. UN Ocean Conference
- Most plastic in the ocean is microplastics
  - Larger plastics breaking down
  - Microplastic products (beads)
  - Ingested by plankton

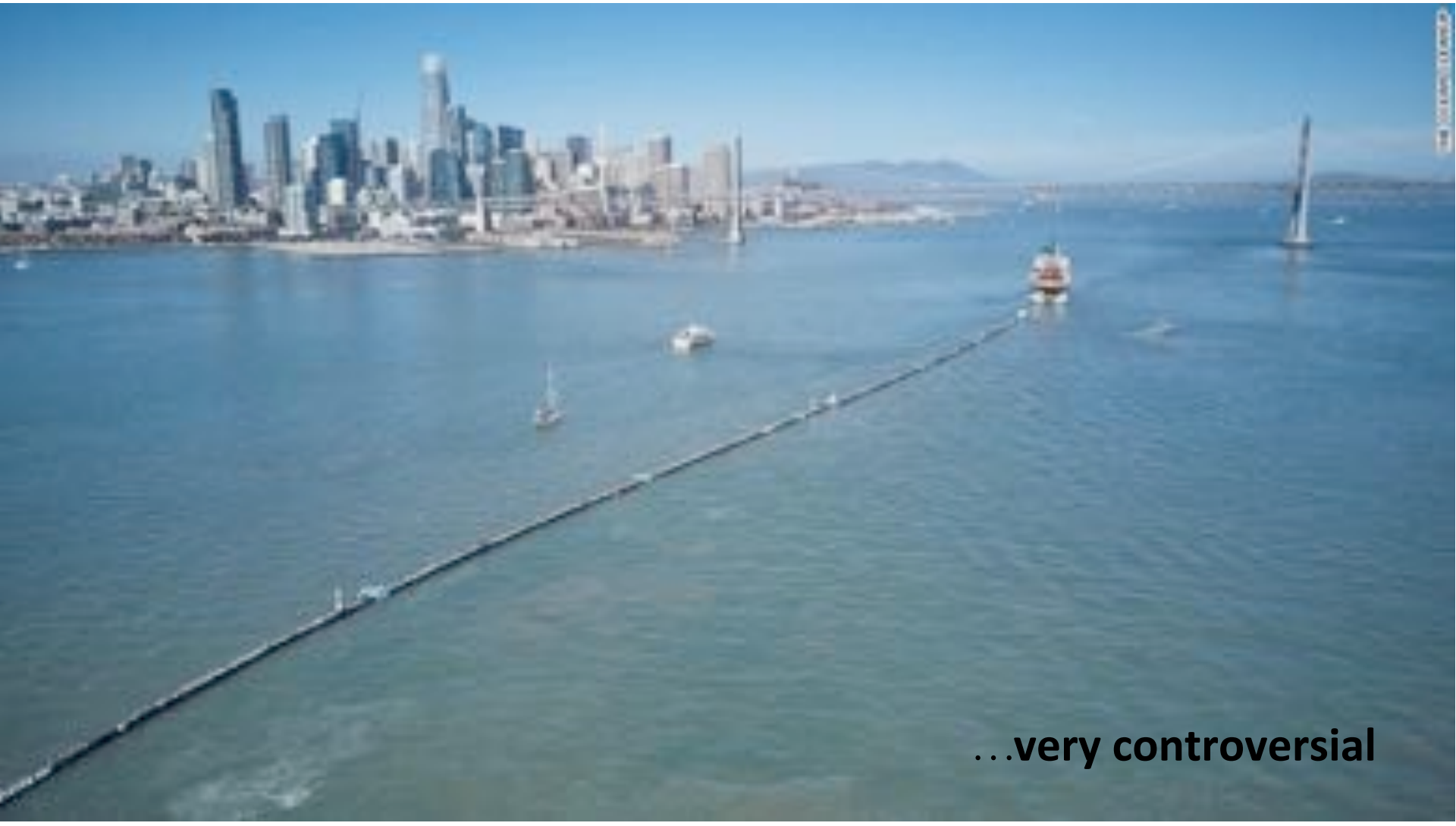
Plastics

- "Garbage patches" of debris concentrated by ocean currents



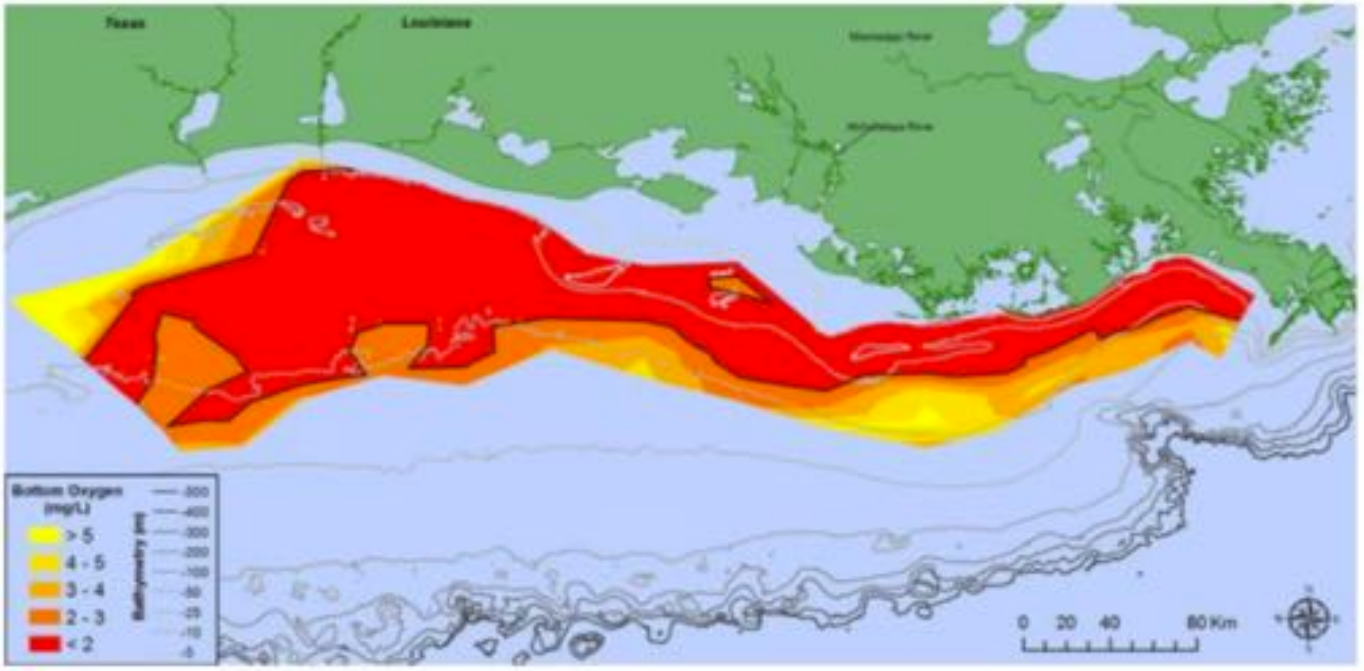
Plastics

- The Ocean Cleanup System 001



Dead Zones

- Nutrient runoff from agriculture
- Excess planktonic production
- Lead to excess bacterial heterotrophy
- Leads to depleted oxygen



Other Topics

- Plastics
  - http://www.pnas.org/content/pnas/113/9/2331.full.pdf
- Dead zones
  - https://yosemite.epa.gov/sab/sabhap.nsf/e1853c0b6014d36585256dbf005c5b71/ab0b29e73b45c22085257206004b5d07/$FILE/Rabalais2002DeadZone.pdf
- Noise pollution
  - http://whitelab.biology.dal.ca/lw/publications/Weilgart%202007%20CJZ%20noise%20review.pdf
- Coastal pollution, oil spills, radioactive materials, many others