Toxins, Pollutants & Geoengineering

ES 383

Colby at Bigelow, September 2019

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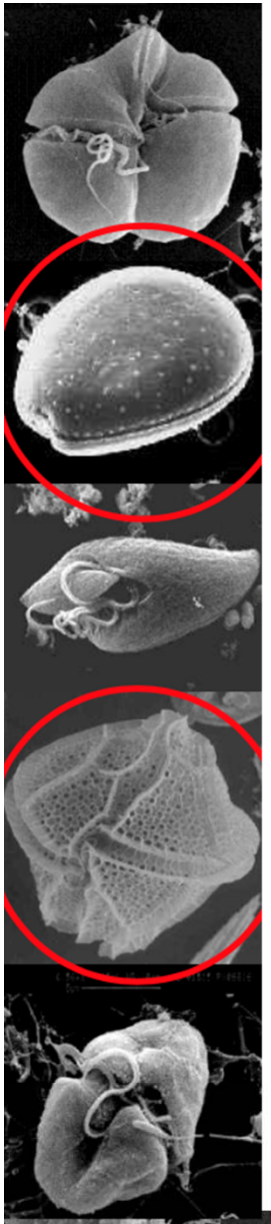
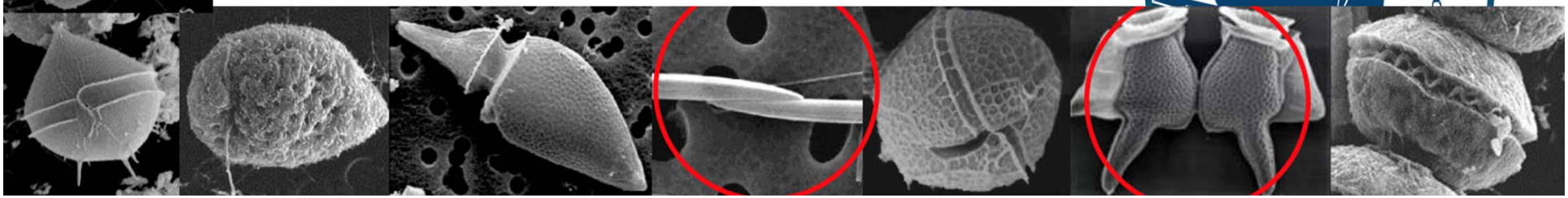


The basics: What is a ‘HAB’?

- 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 O_2 =hypoxia/anoxia), Physical damage (spines), or low Water Quality
- Who’s harmed:
  - Humans (ingestion, inhalation, contact)
  - Marine life and food web-based economies



Some Perspective

Globally

10,000-100,000 phytoplankton species

Typical coastal phytoplankton community

Globally

~300 species form 'blooms'

Globally

~100 species contain toxins

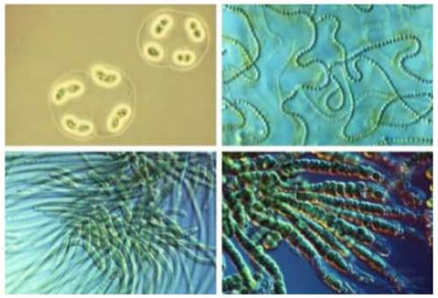
Locally

Maine

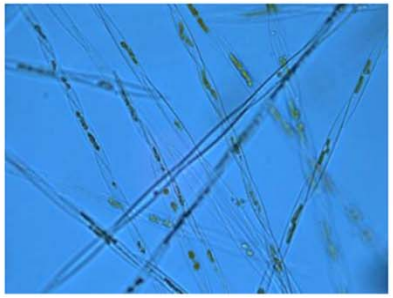
(~15 species of marine harmful algae)

dinofl
Maine Red Tide

Cyanobacterial Blooms Pond Scum

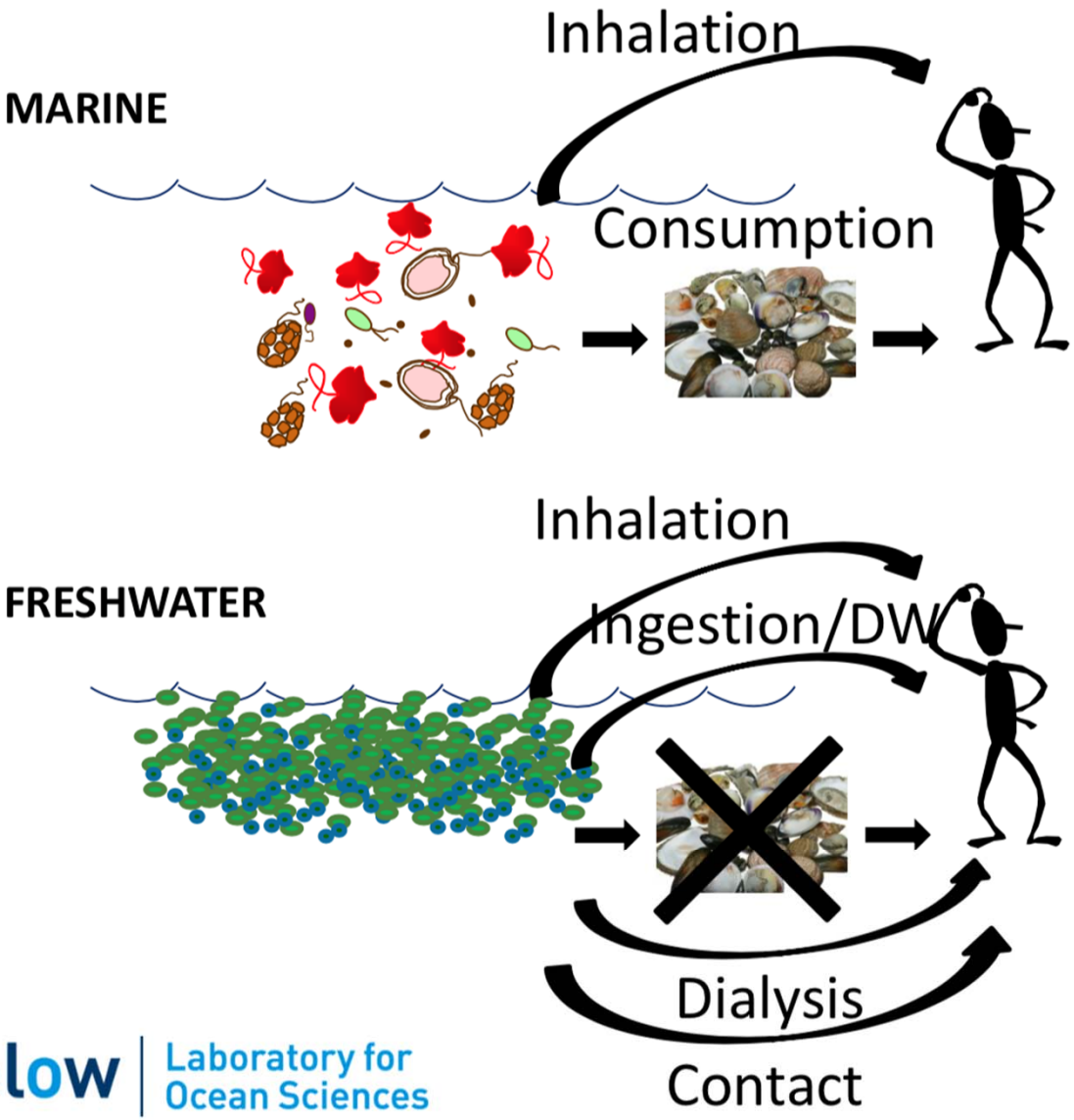


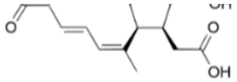
***Pseudo-nitzschia* Blooms**

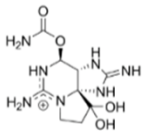


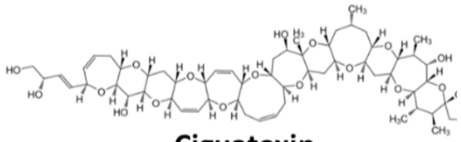
Why worry?

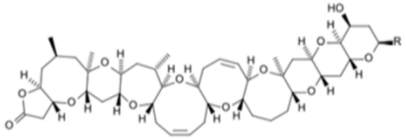
Toxin Transfer Routes

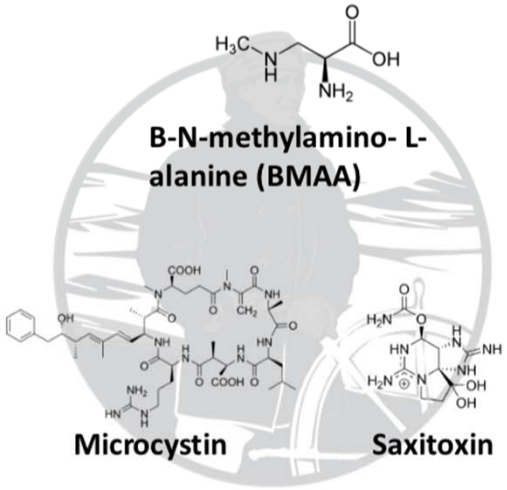



Domoic Acid


Saxitoxin


Ciguatoxin


Brevetoxin-A


B-N-methylamino- L-alanine (BMAA)

Microcystin

Saxitoxin

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Various toxins: from headaches/ nausea (mild) to paralysis/ death (extreme)

https://www.cdc.gov/habs/illness-symptoms-marine.html

Paralytic Shellfish Poisoning (PSP) – saxitoxin; dinofl
Domoic Acid/ Amnesic Shellfish Poisoning (D/ASP) – domoic acid; diatom
Neurotoxic Shellfish Poisoning (NSP) – brevetoxin; dinofl
Ciguatera Fish Poisoning (CFP) – ciguatoxin; dinofl
Diarrhetic Shellfish Poisoning (DSP) – 2 toxins; 2 dinofl
Azarpiracid Shellfish Poisoning (AZP) - ?; dinofl?

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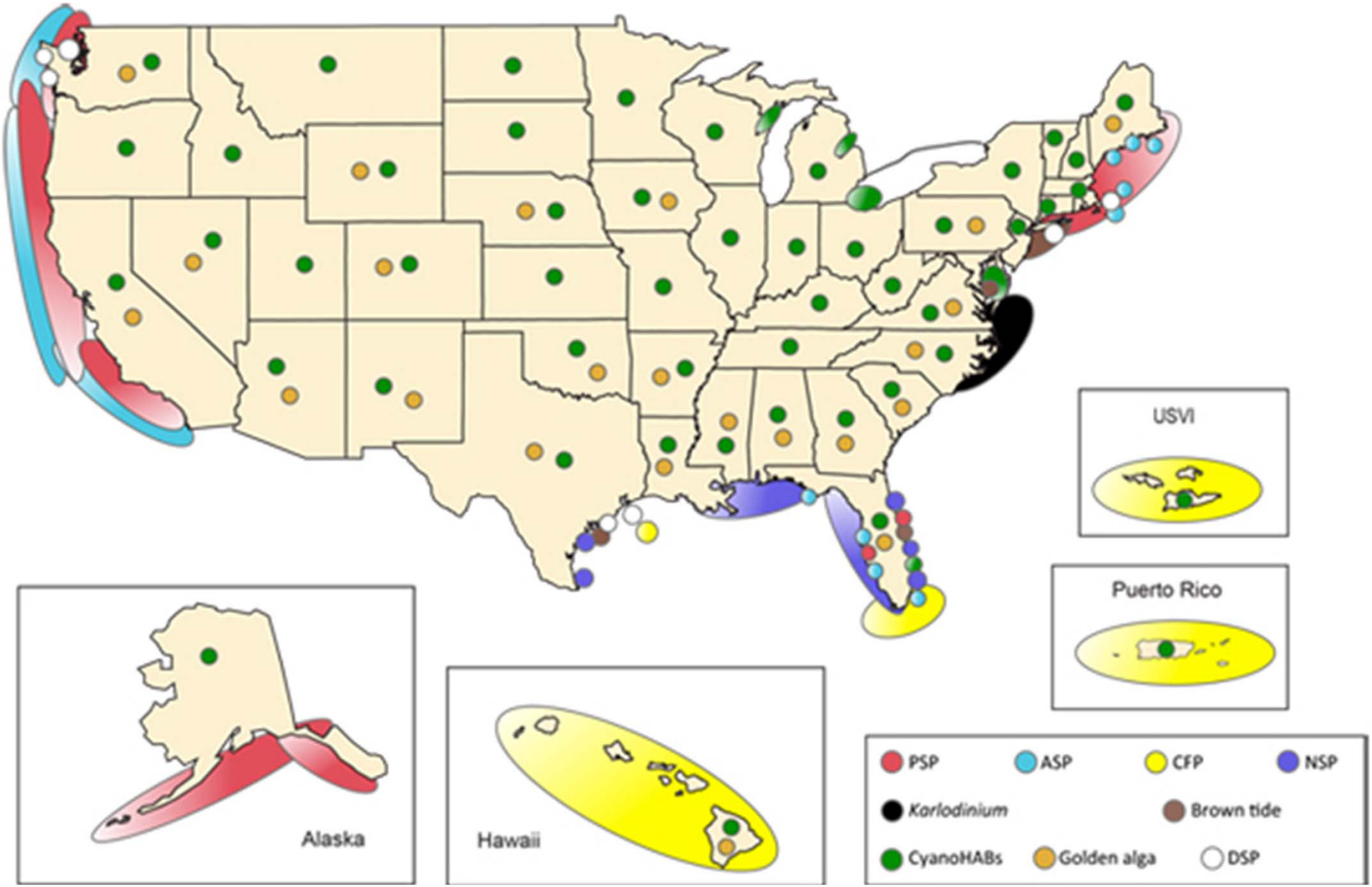
HAB distribution in the US

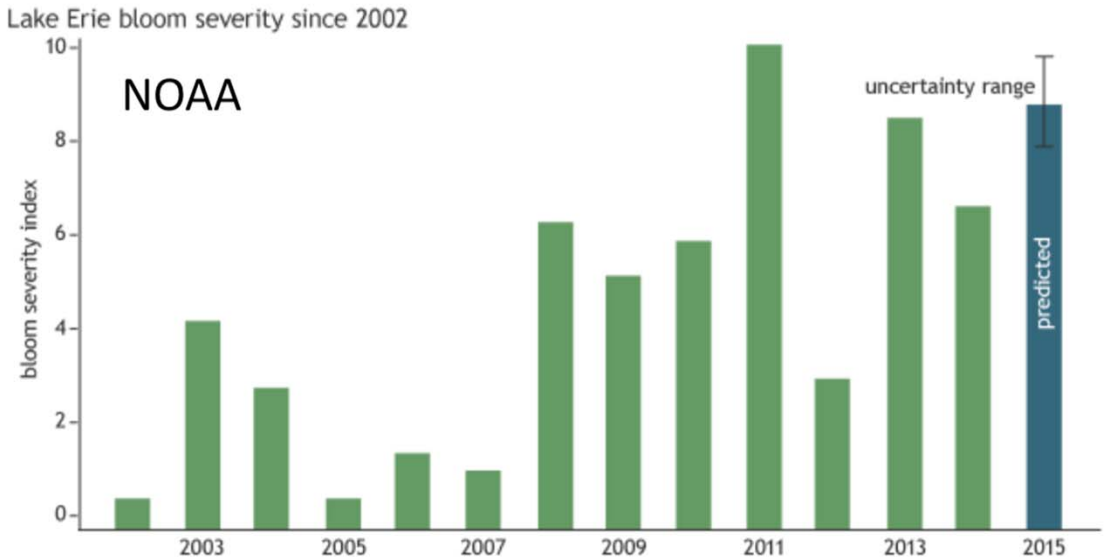
http://www.whoi.edu/redtide/page.do?pid=14898



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

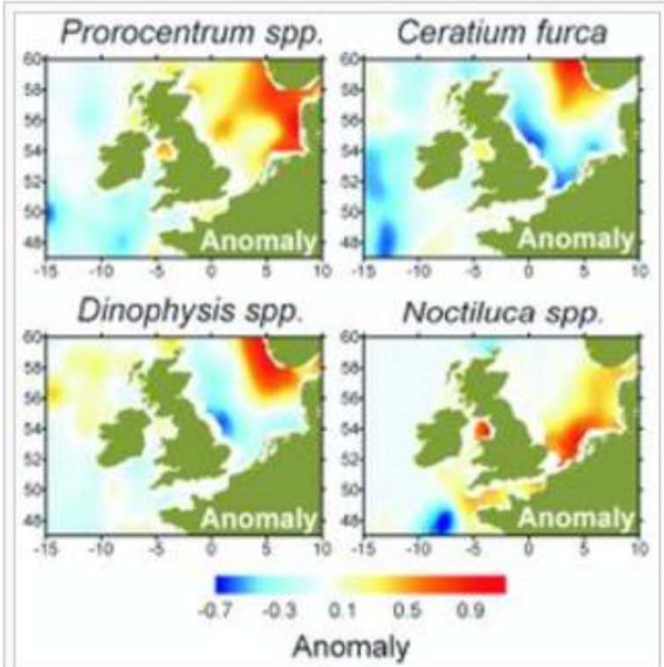


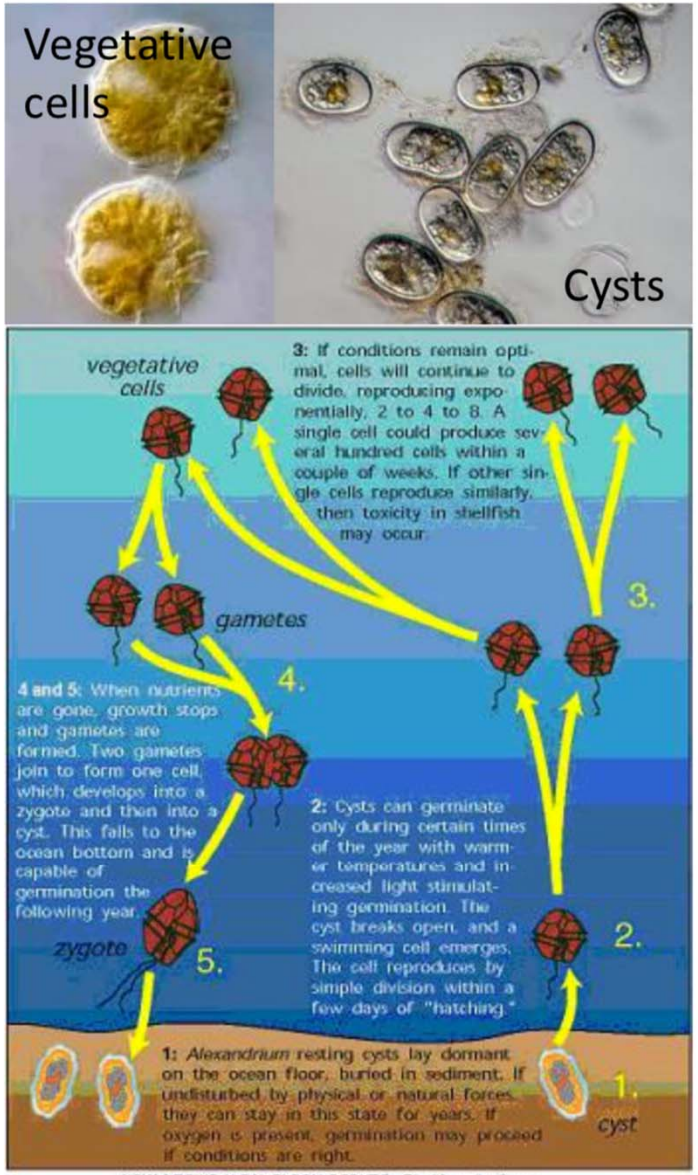
Fig. 3: Decadal anomaly maps for four common HAB taxa. Anomaly is the difference between the long-term mean (1960-1989) and post 1990s (1990-2002) (reproduced from Edwards M, Johns DG, Leterme SC, Svendsen E, Richardson AJ (2006) Regional climate change and harmful algal blooms in the northeast Atlantic.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

Causes of increases

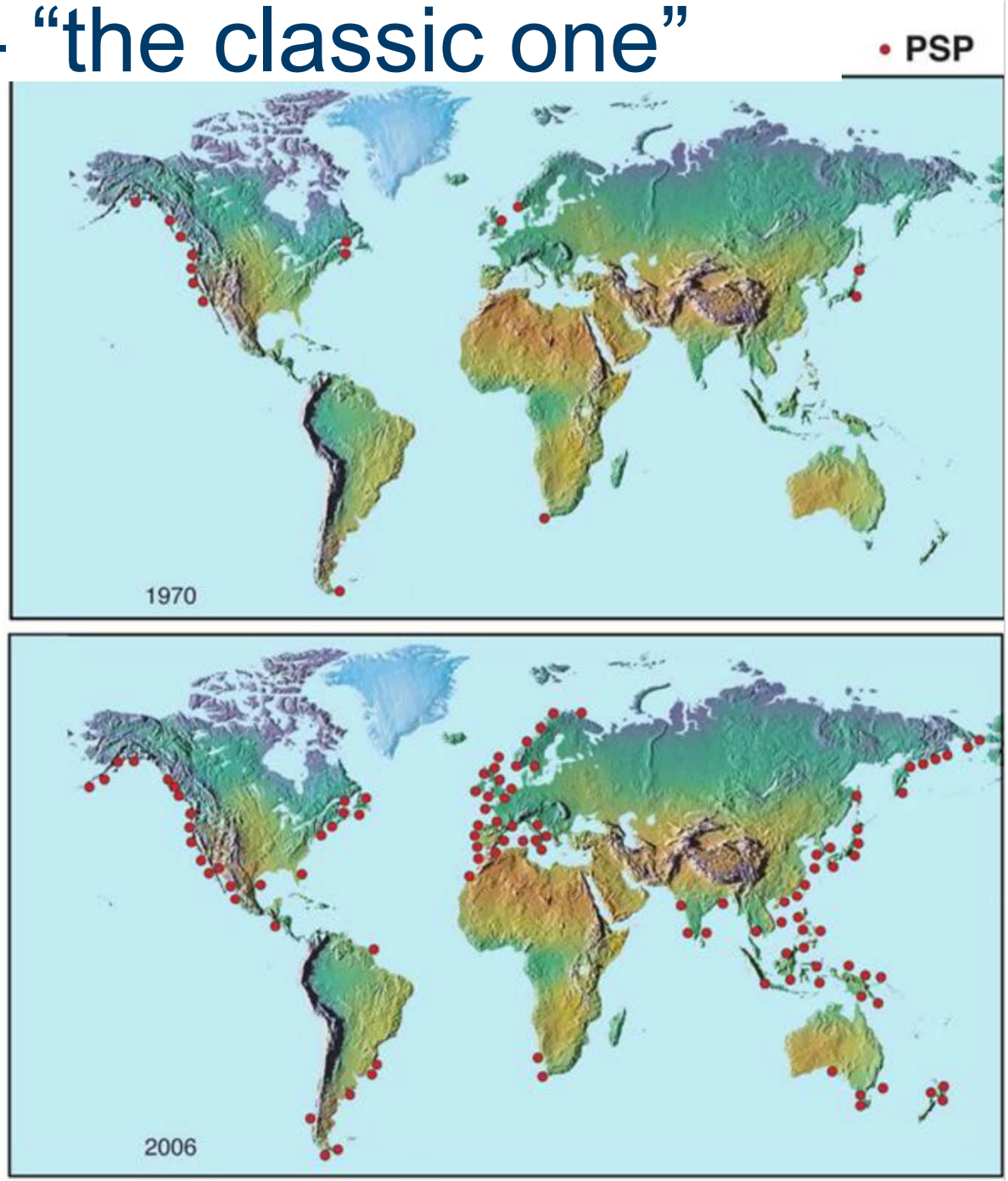
- Eutrophication = nutrient enrichment (pollution)
- Increased aquaculture operation
- Transport via ballast water and/or shellfish seeding activities: Kuwait red tides
- Long-term climate changes
- Improved scientific methodology & monitoring
- Shifting currents, storms and natural dispersal mechanisms

Gulf of Maine – “the classic one”

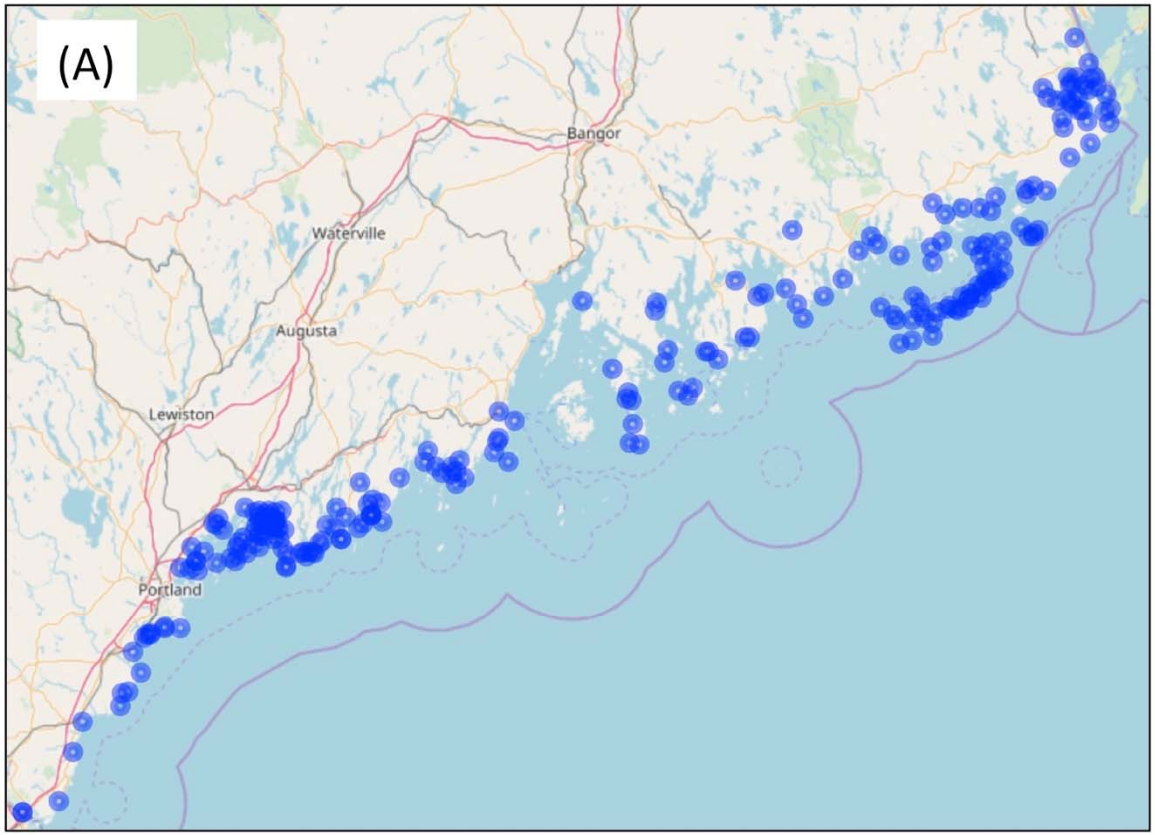
Alexandrium

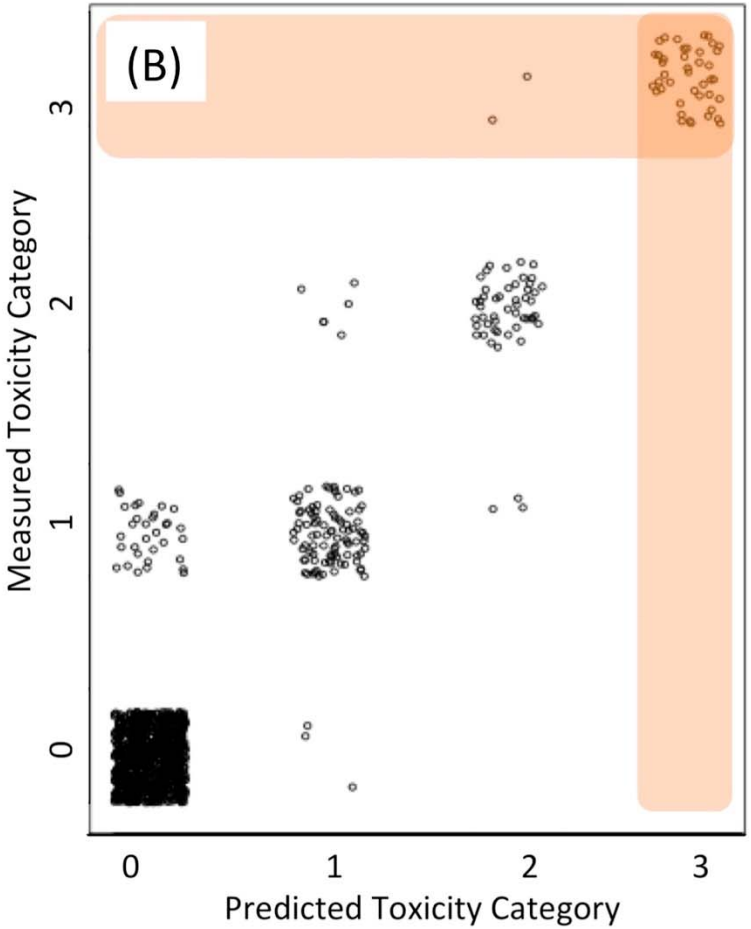


HOW A TOXIC ALGAL BLOOM OCCURS—The life cycle of one cell. (Don Anderson, Woods Hole Oceanographic Institution)



Alexandrium forecasting





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New bloom on the block: *Pseudo-nitzschia*

Portland Press Herald

What are you looking for? LOG IN S

Portland Press Herald
Oct. 6, 2016

BUSINESS Posted October 6, 2016 | Updated October 7, 2016 INCREASE FONT SIZE

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

Share 8 Comments

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 biotoxin that can cause illness, memory loss, brain damage and possibly death in

Courier Gazette & Camden Herald
Feb 25, 2017

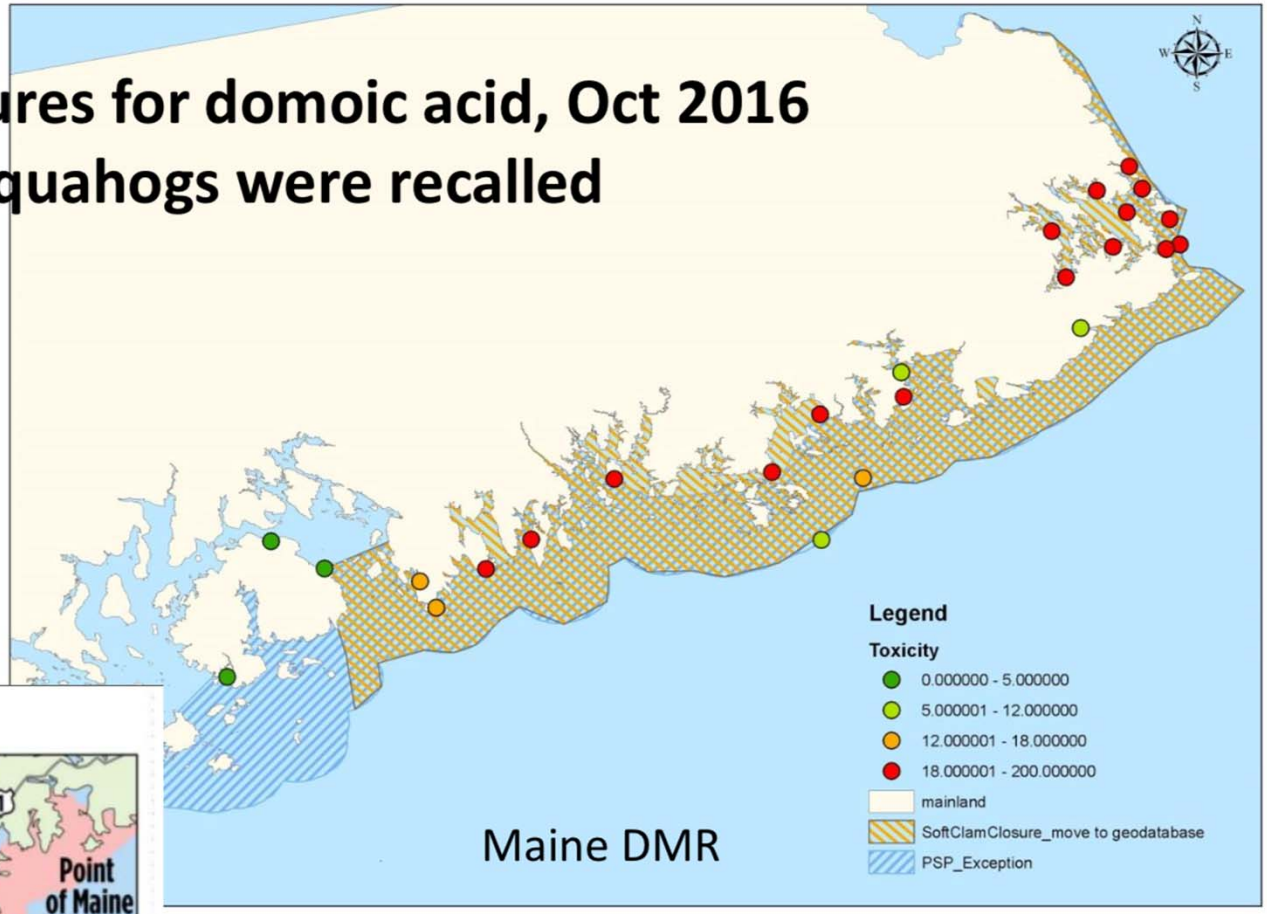
Mysterious toxic algae that shut down RI shellfishing last fall is back

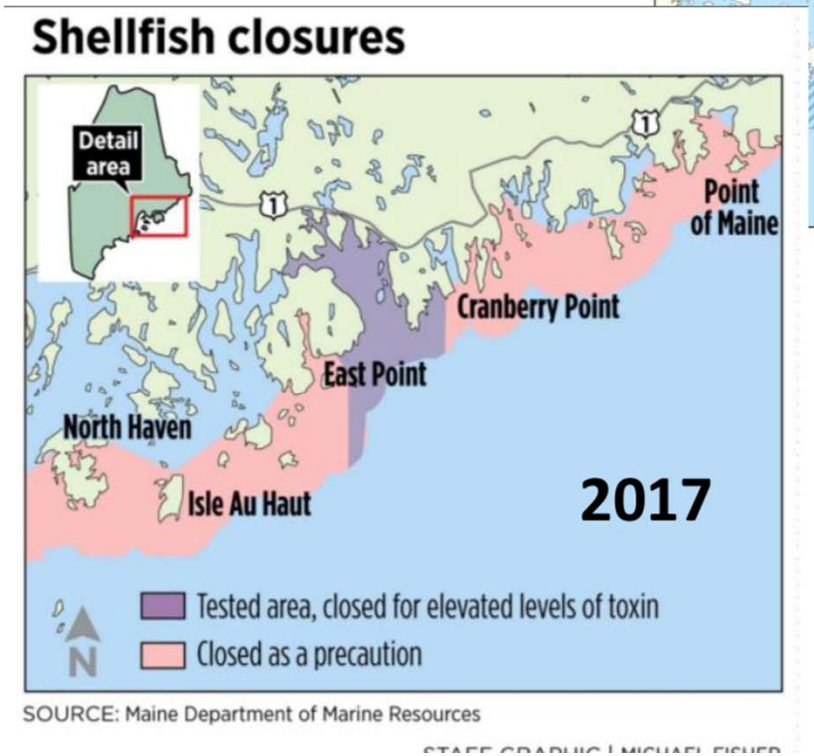
Providence Journal
March 3, 2017

HIDE CAPTION

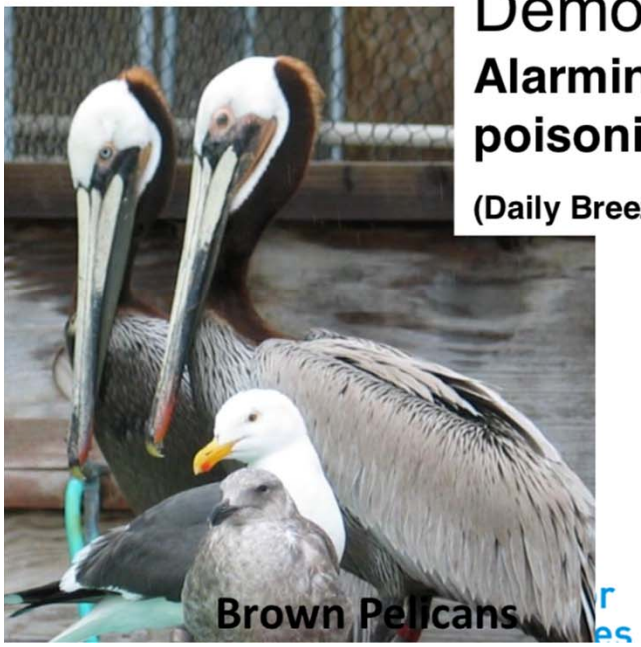
Gregory Velleca sorts oysters that were pulled up in oyster racks with his boss Russell Blank who has oyster beds off Wickford, R.I. - [The Providence Journal/Steve Szydlowski]

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





Portland Press Herald, Sept 14, 2017



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

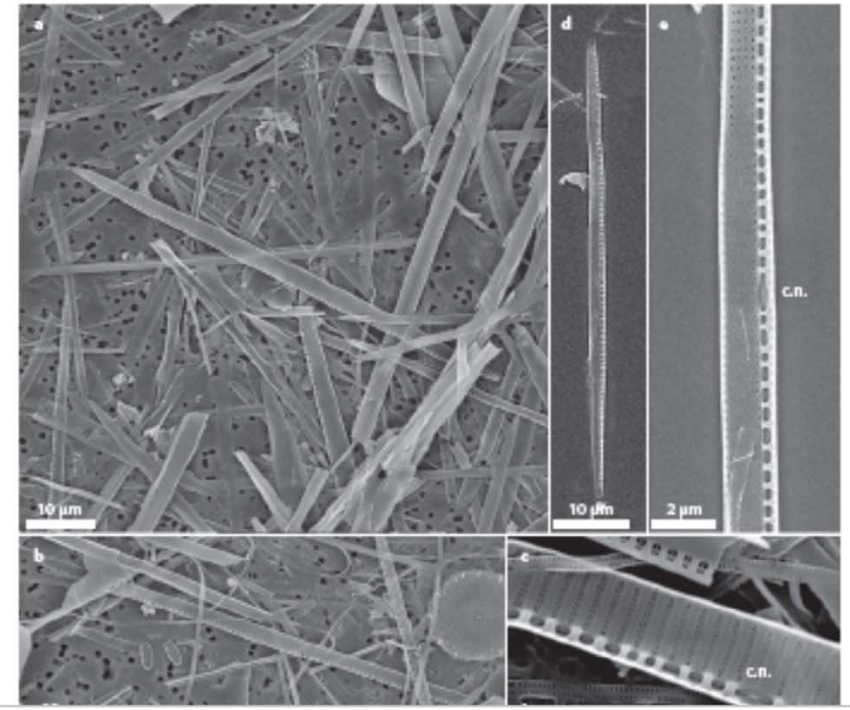
To the Editor — On 18 August 1961, a Californian newspaper reported that thousands of "crazed seabirds pelted the shores of North Monterey Bay, California" regurgitating anchovies. Soon after reading the report (Supplementary Fig. S1), local visitor Alfred Hitchcock was inspired to produce his famous 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

Marine Pollution

Mostly land-based, mostly non-point source

- Dumping: trash, sewage
- Noise: shipping, transportation, mining, warfare practice
- Direct discharge: warm industrial cooling water
- Runoff: agricultural, industrial wastewater, urban
- Atmospheric: industrial chemicals, urban smog; (some natural)
- Mining: deep sea, oil
- Ships: accidents, spills

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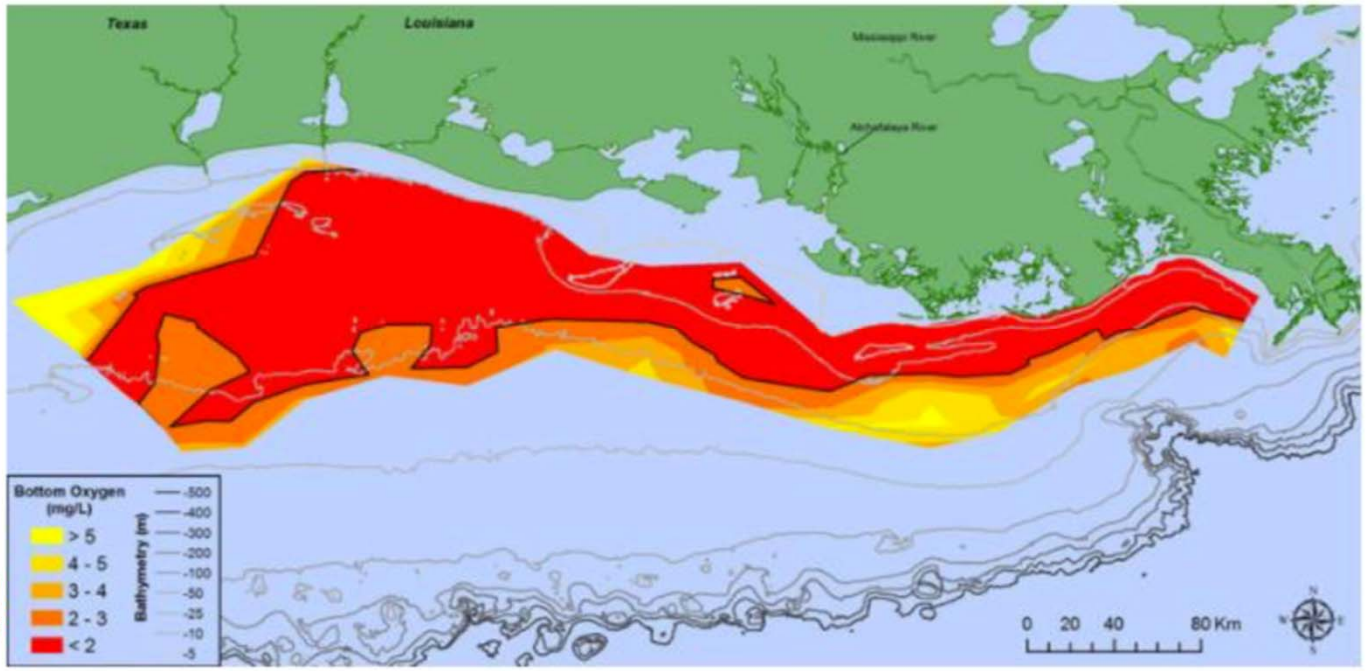
Plastics

- “[M]ore weight in plastics than fish by the year 2050” .. UN Ocean Conference
- Most plastic in the ocean is microplastics

https://www.youtube.com/watch?v=mGzlz9Ld-sE

Dead Zones

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



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Geoengineering?

- Definition = “intentional large scale manipulation of the environment”
- Can we buy time by cooling the planet artificially?
- Initially ‘taboo’ idea for scientists… but is getting more attention…
  - Slow progress of mitigation effort to reduce CO_2 emissions (Paris Climate Accord)
  - Evidence for increasing climate impacts (sea-ice, Greenland ice sheet)
  - Maybe we should think about an ‘emergency brake’
  - In 2006: Notorious scientists (Paul Crutzen, Ralph Cicerone) reignited the idea of examining geoengineering feasibility and impacts from a scientific point of view

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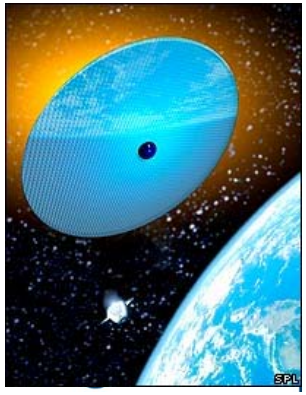
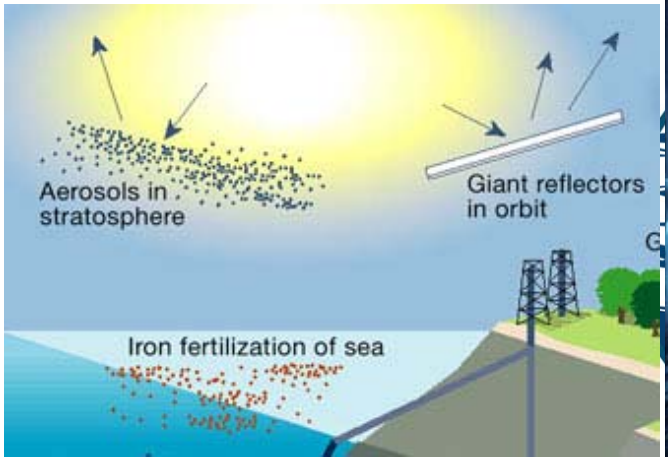
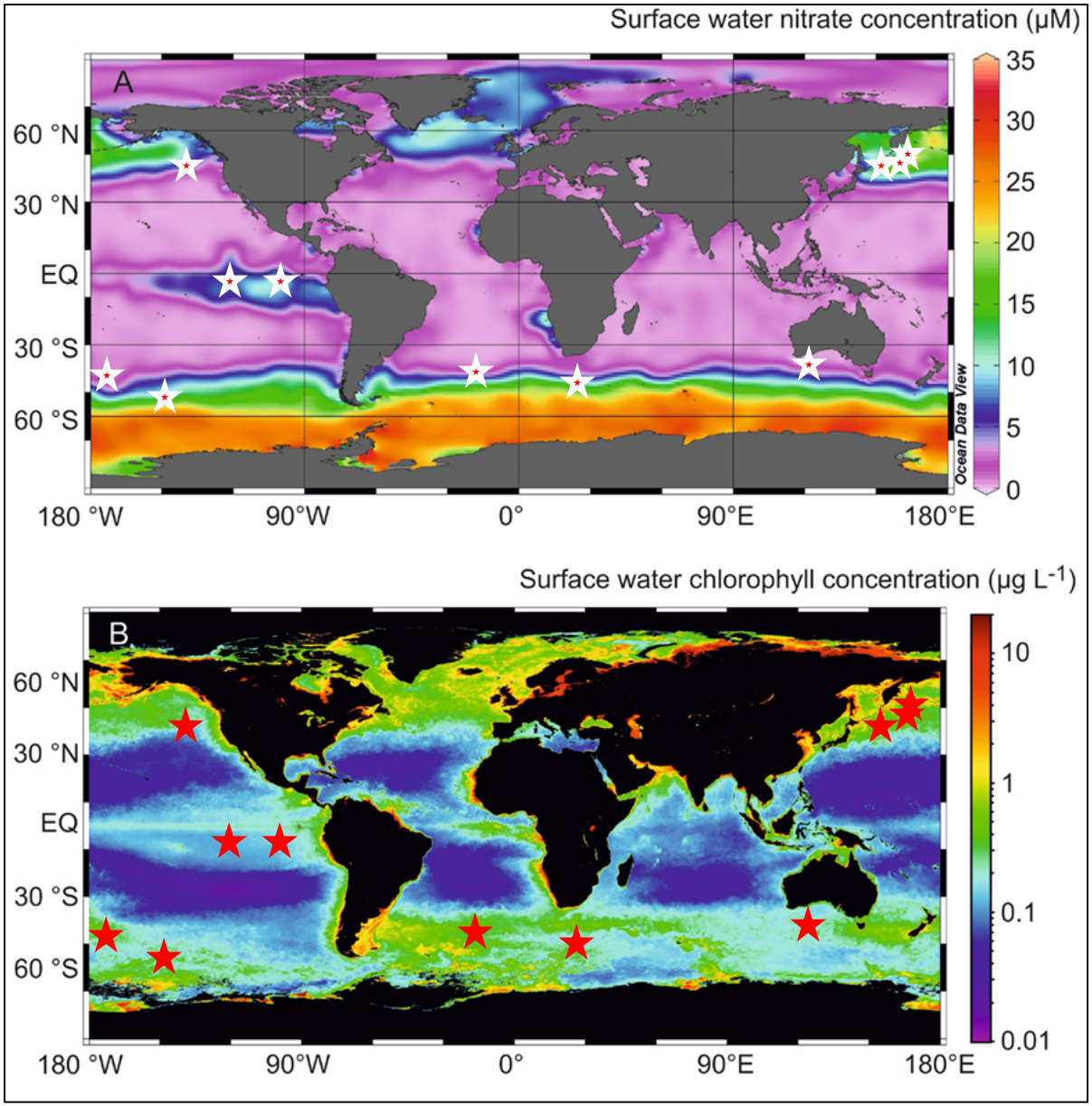
Two main solutions

- Remove CO_2 from the atmosphere (sequestration in ocean and/or land)
- Reduce solar radiation (increase Earth's albedo or reduce incoming solar radiation)







Iron Fertilization Experiments

The stimulated higher surface productivity should result in enhanced and sustained carbon export and sequestration to depth

Locations of **12 iron fertilization** experiments (1993 to 2005): 1–3 metric tons of iron (liquid iron sulfate) dispensed from tankers dispersed in 100-km^2 patches

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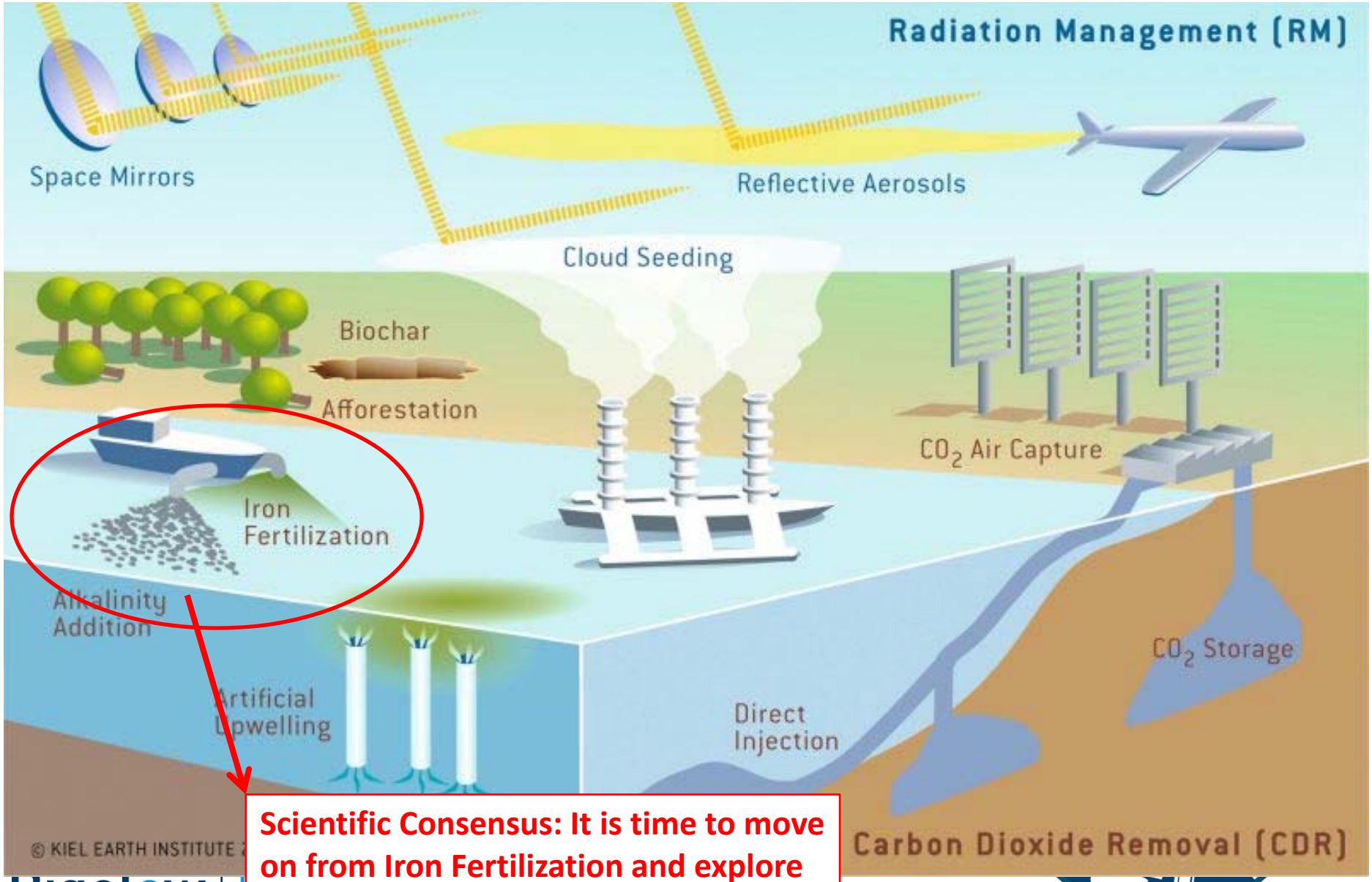
Other geoengineering strategies



Scientific Consensus: It is time to move on from Iron Fertilization and explore other, more effective options!

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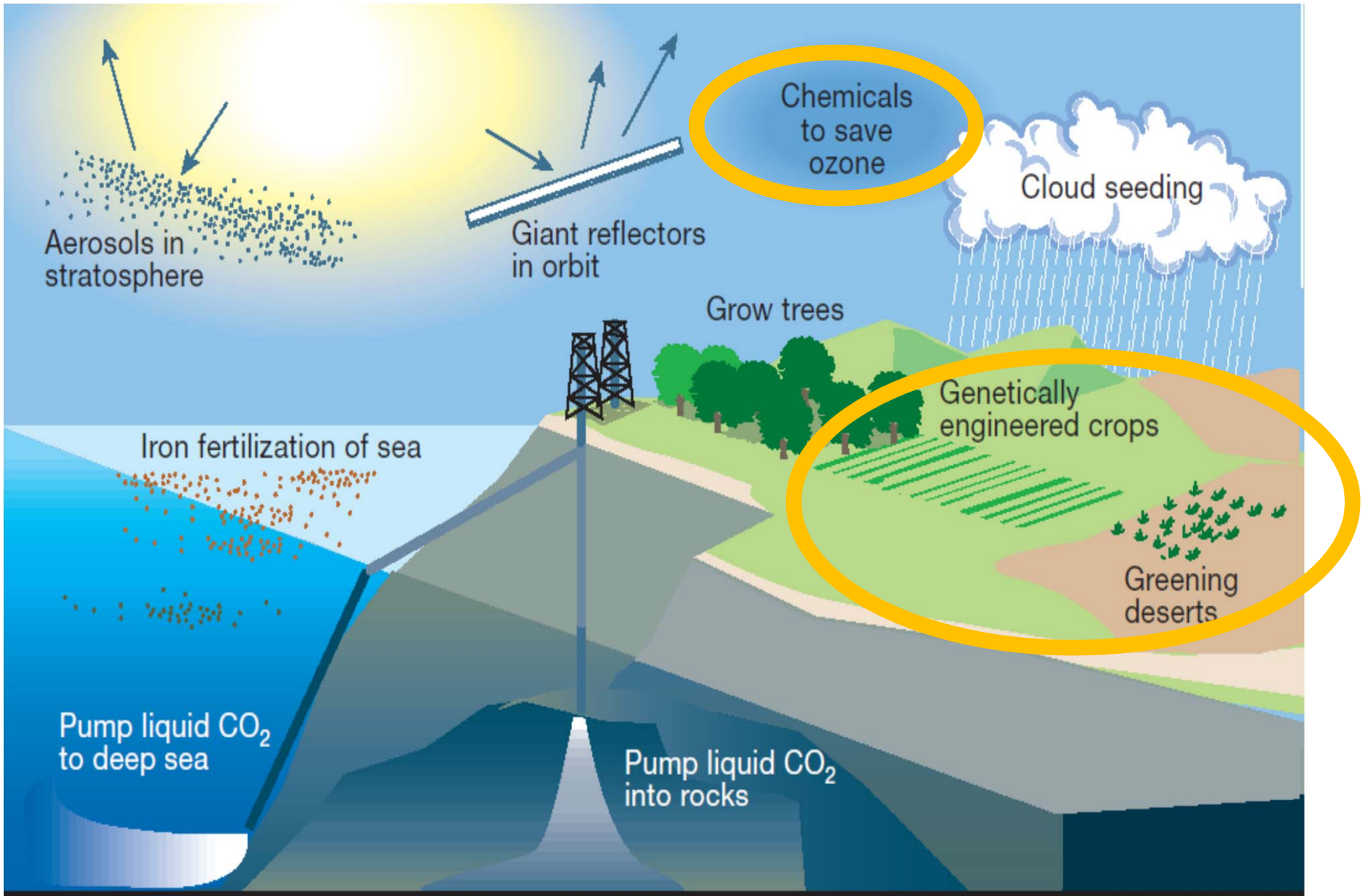


Schematic representation of various climate-engineering proposals (courtesy B. Matthews).

Geoengineering – the good and the bad

- Arguments for…
  - Quick fix to rapid warming (melting ice caps, rising sea levels…) effectively reversing CO_2 warming.
  - Some ideas not that expensive.
- Against…
  - Negative impacts on hydrological cycle, ozone layer…
  - Once started we need to maintain it for centuries
  - Failure of implemented GEO would be catastrophic
  - No cure for ocean acidification
  - Treat symptoms not cause. Excuse not to reduce GHG?
  - Too cheap… country or rich individual could do it unilaterally
  - Uncertainties in science…are models good enough ?
  - Ethical/political questions: how would it be implemented? How do we decide what the temperature should be? Who would decide?…

More in: Robock (2008) 20 reasons why geoengineering may be a bad idea. *Bull. Atomic Scientists*, **64**, No. 2, 14-18, 59

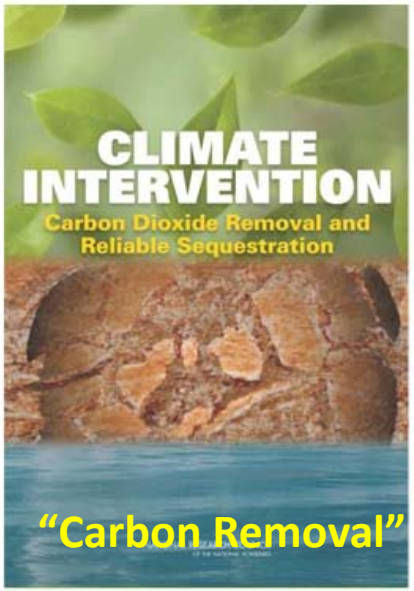
Where from here….. future recommendations?

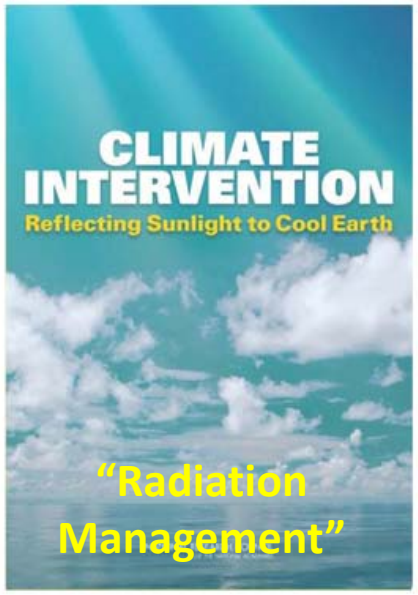
Policy studies are conducted through the National Research Council (NRC). Access information about current and recently completed studies, including more than 5,000 publications available free online.

"Geoengineering and its consequences are the price we may have to pay for failure to act on climate change."

"Used irresponsibly or without regard for possible side effects, geoengineering could have catastrophic consequences similar to those of climate change itself."

John Shepherd, University of Southampton,





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