Harmful algal blooms: A threat to coastal ecosystems

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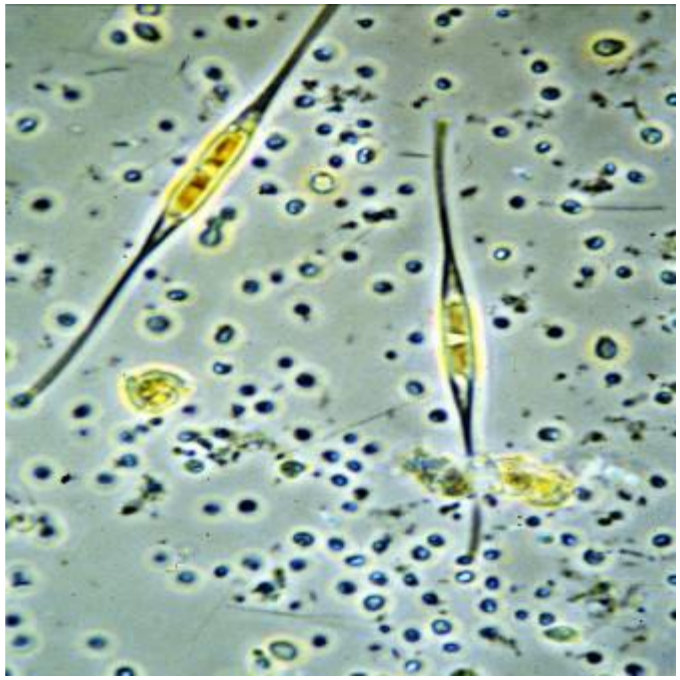
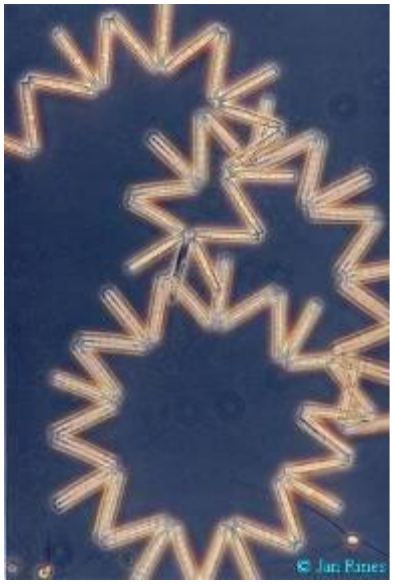
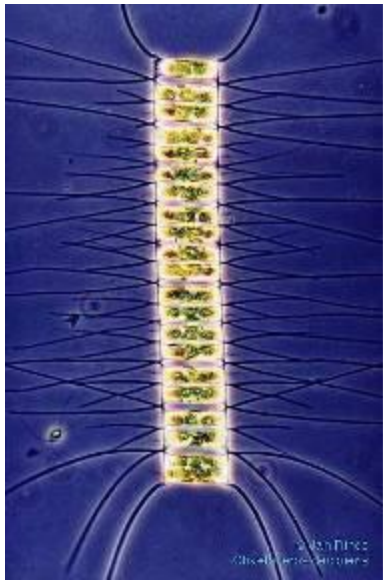
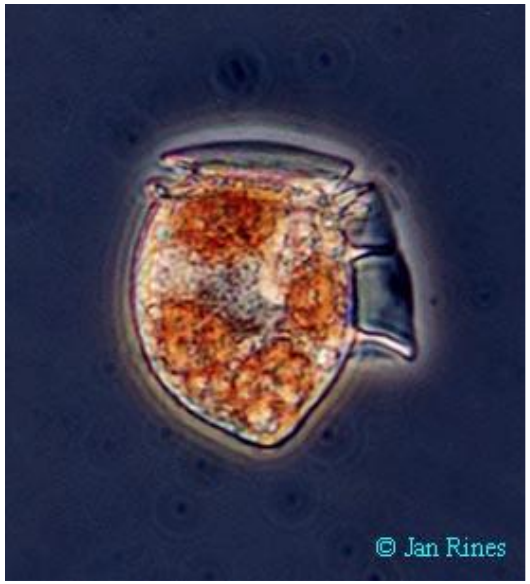
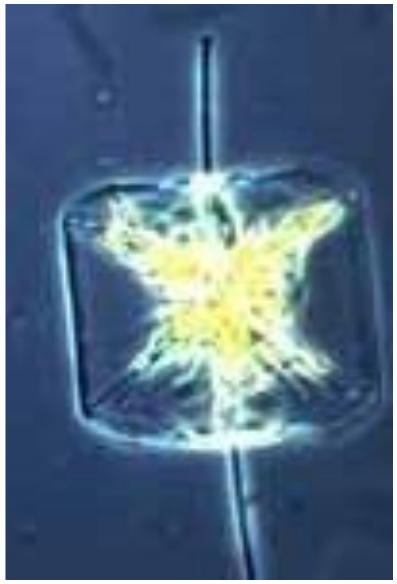


At the base of the food web, **phytoplankton** provide energy and oxygen to marine ecosystems and remove carbon dioxide from the atmosphere.









Harmful Algal Blooms (HABs)

- **Of the 5,000 documented phytoplankton species, several hundred are known to be harmful.**
- **Associated with elevated algal cell densities and/or toxins, leading to disruption of an ecosystem.**
- **Produce potent biotoxins, cause mass anoxic events, and/or shade seagrass (important habitat).**

www.biol.tsukuba.ac.jp

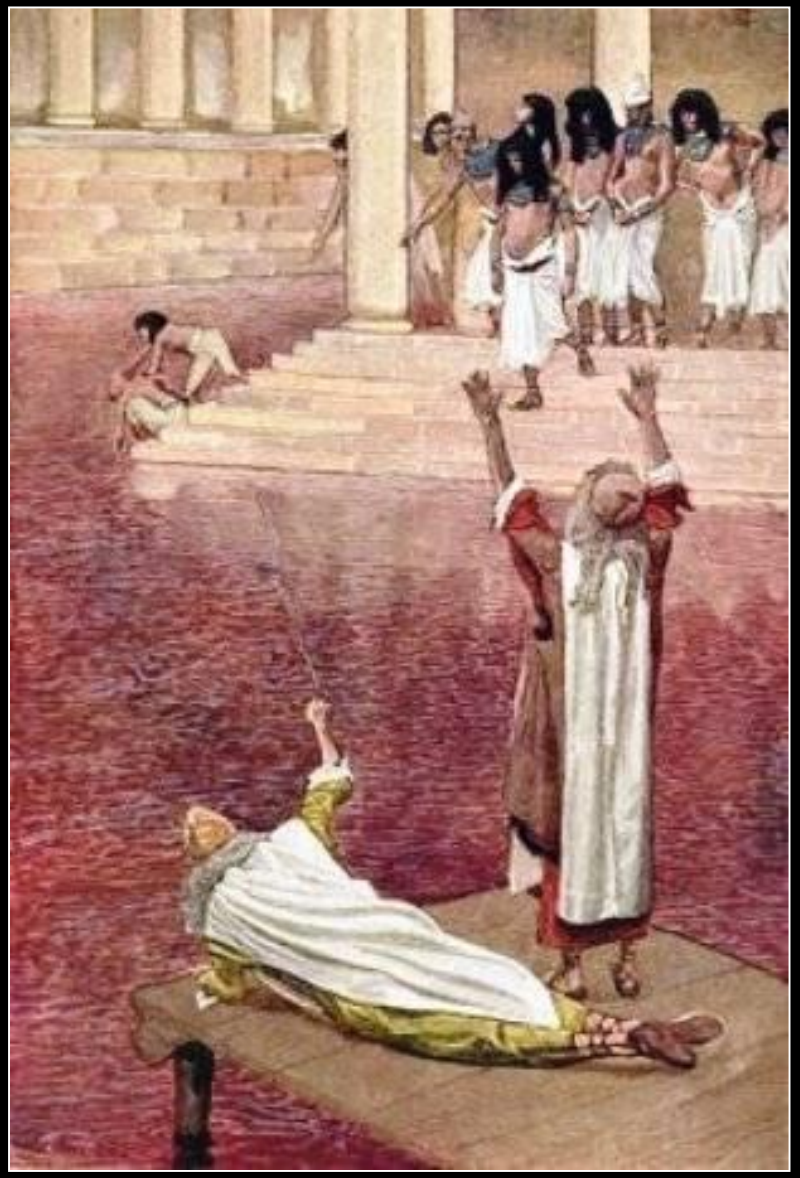
http://www.27east.com/story_detail.cfm?&id=167427

First documented harmful algal bloom?

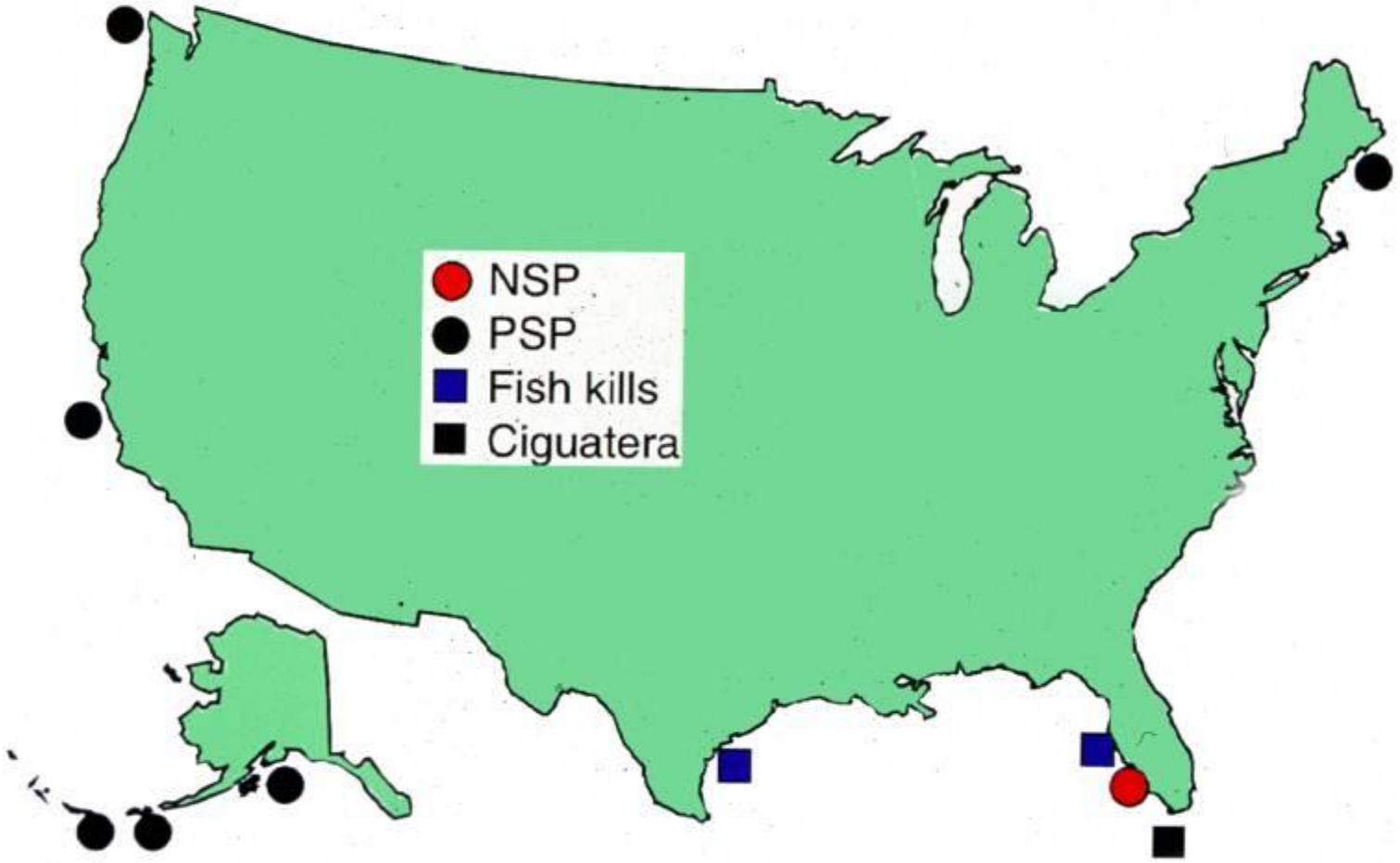
First Plague on the Egyptians

Exodus 7:14 - 7:25

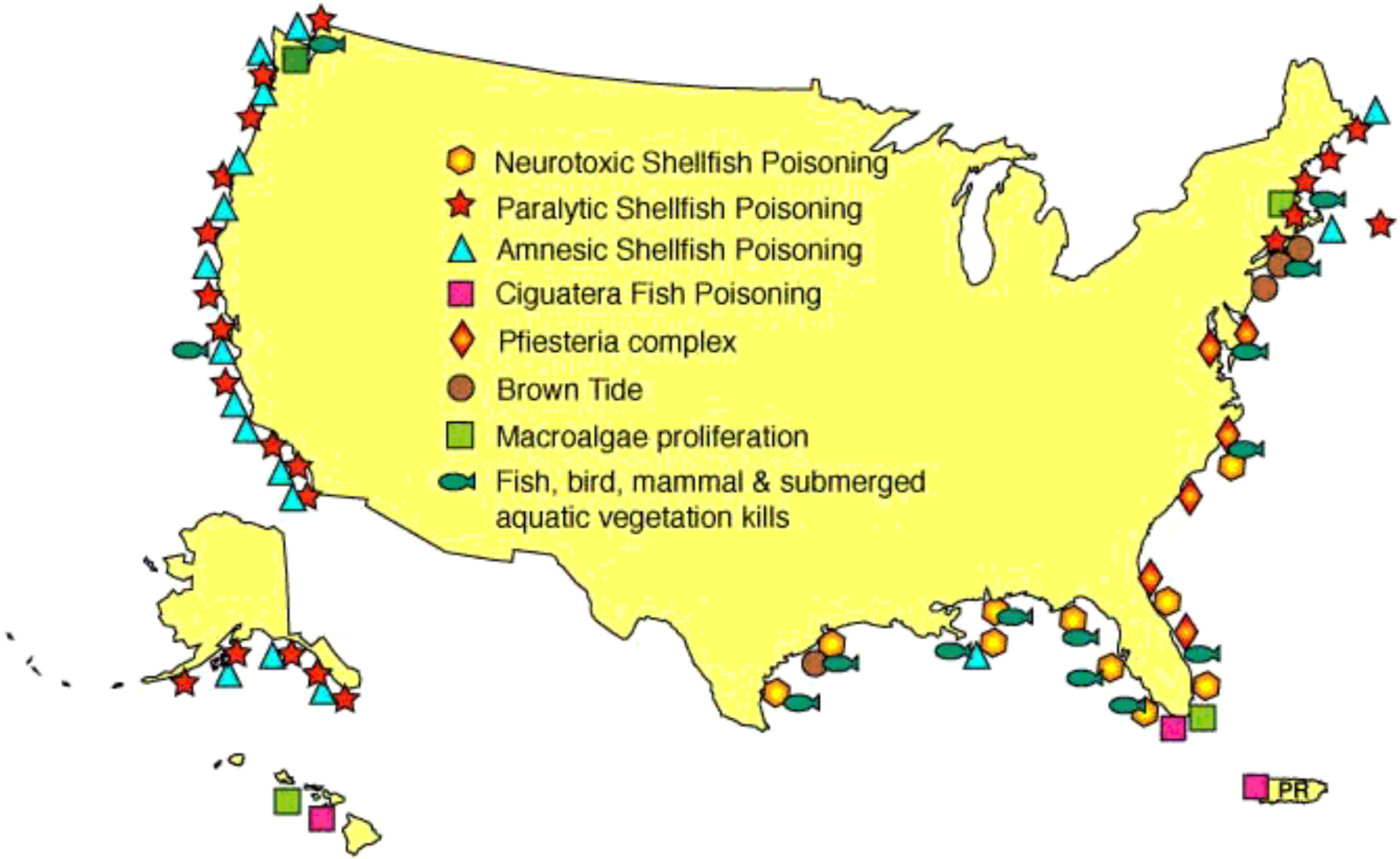
"God instructed Aaron to strike the **river Nile** with his staff; **all of its water turned into blood**. As a result of the blood, **the fish of the Nile died**, filling Egypt with an awful stench. This plague lasted for seven days."



Harmful Algal Blooms in the coastal US prior to 1972



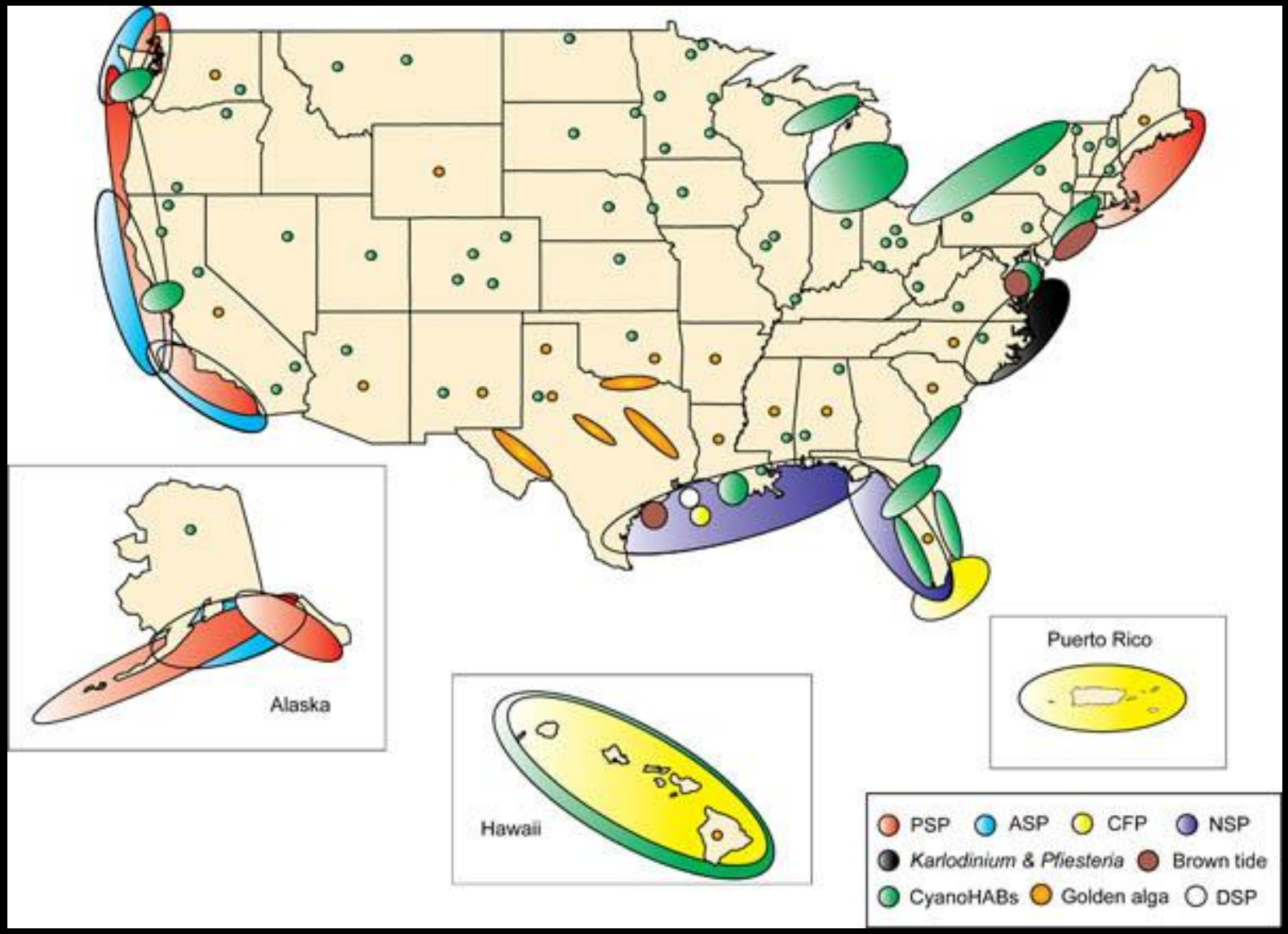
Major HAB-related Events in the Coastal U.S.



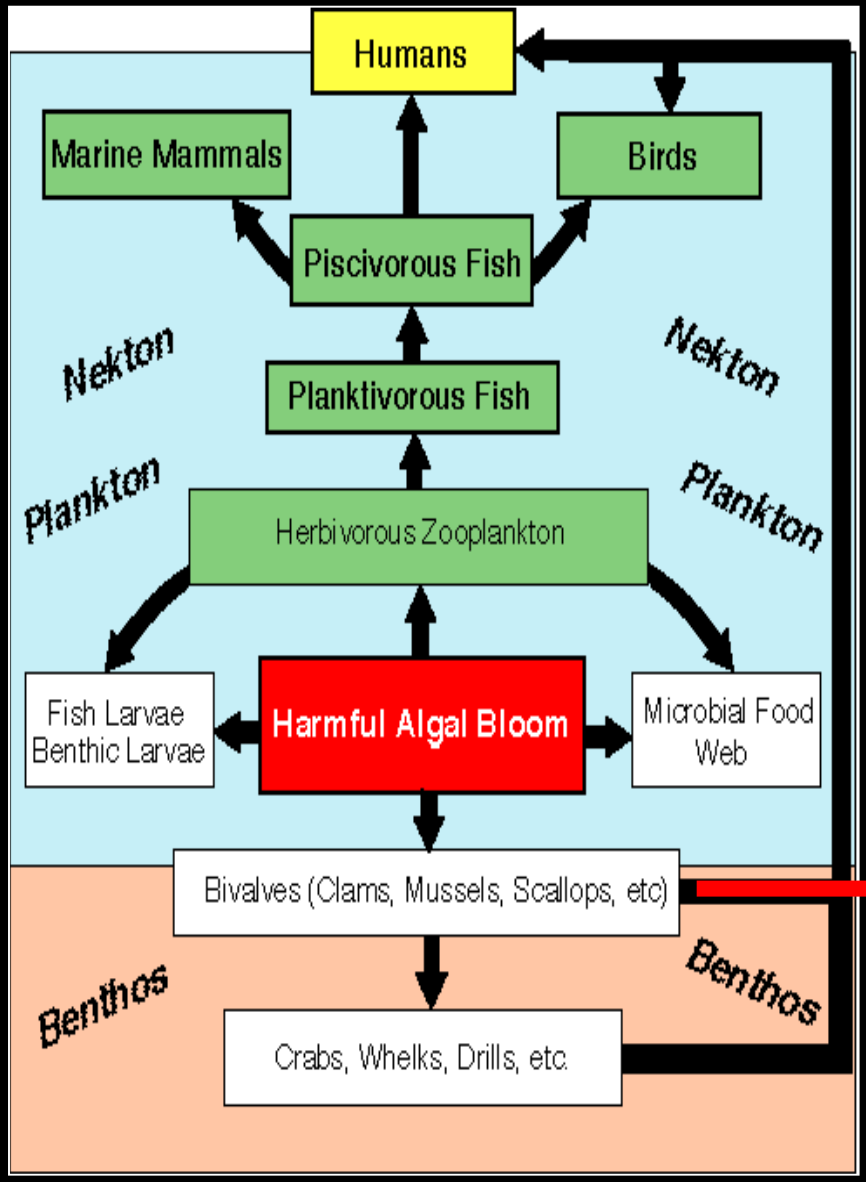
Source: NOAA COP/National HAB office-WHOI

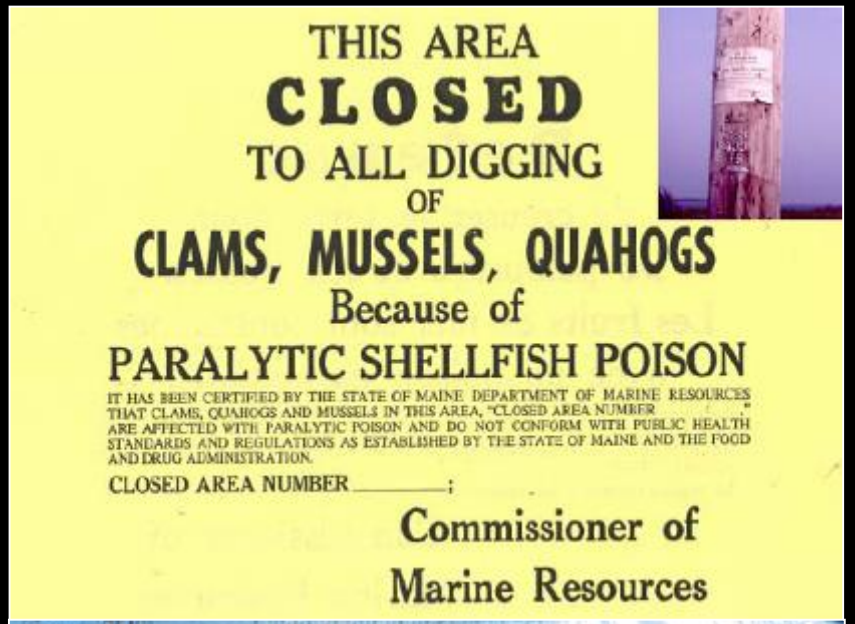
Region	Impact	Algae	Species
West coast	ASP	Diatoms	*Pseudo-nitzschia* sp.
Alaska	ASP	Diatoms	*Pseudo-nitzschia* sp.
Hawaii	Ciguatera	Dinoflagellate	*Gambierdiscus toxicus*
Florida	Ciguatera	Dinoflagellate	*Gambierdiscus toxicus*
ME, OR, CA	NSP	Dinoflagellate	*Dinophysis sp.* *Prorocentrum lima*
GOM, NC, SC	NSP	Dinoflagellate	*Karenia brevis*
Mid-Atlantic	Karlotoxins	Dinoflagellate	*Karlodinium venificum*
Gulf of ME	PSP	Dinoflagellate	*Alexandrium sp.*
Mid-Atlantic	Ecosystem disruption	Pelagophyte	*Aureococcus anophagefferens*
West coast	PSP	Dinoflagellate	*Alexandrium catenella*
Texas	Eco disrupt	Pelagophyte	*Aureoumbra lagunensis*
East Coast	Fish kills	Dinoflagellate	*Pfiesteria piscicida*
Nationwide	Cyanotoxin	Cyanobacteria	*Microcystis, Anabaena*
WA, RI	Fish kills	Raphidophyte	*Heterosigma akashiwo*

Distribution of US HABs



Many HABs contain toxic compounds which can impact all levels of marine food webs, including humans.

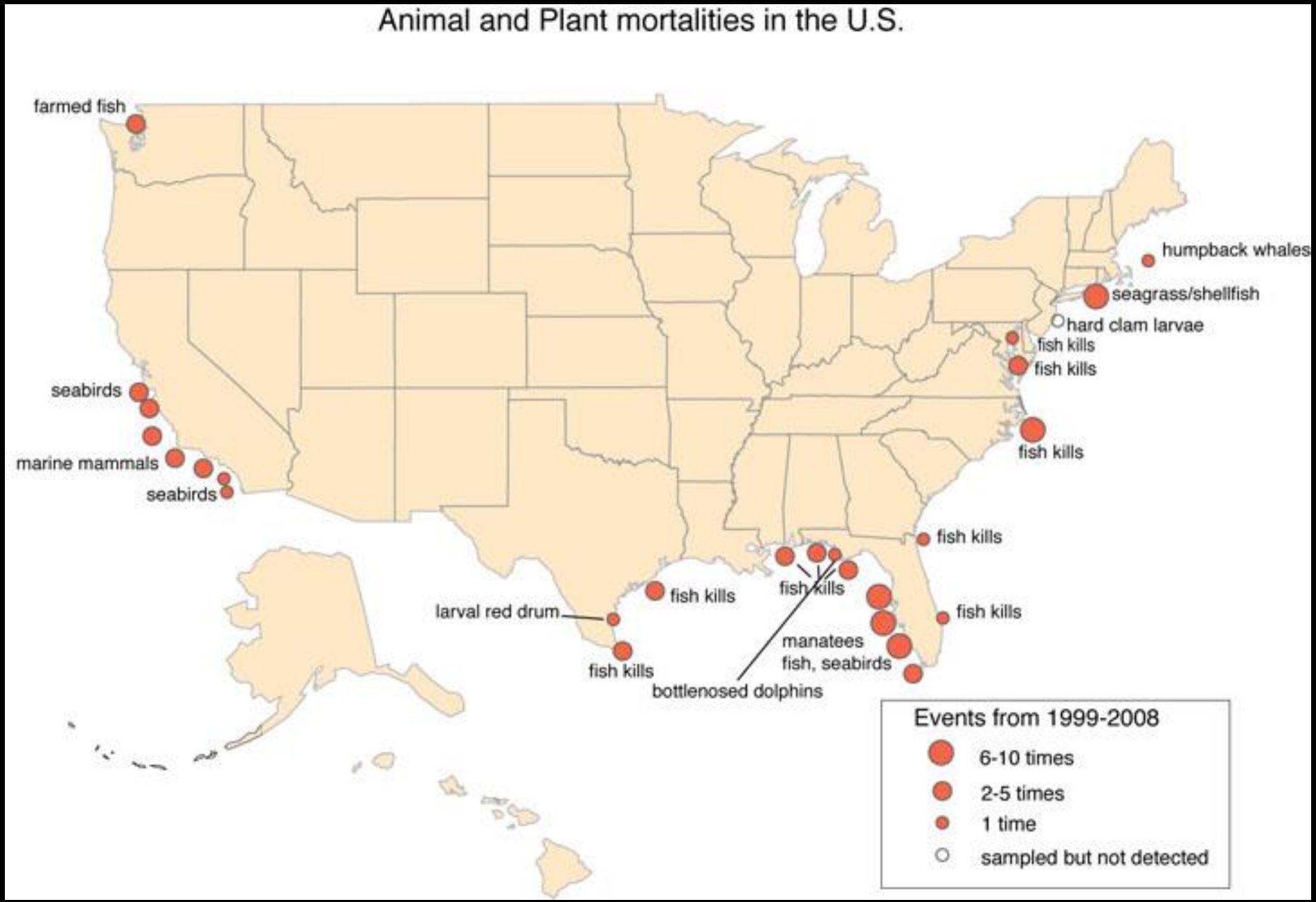




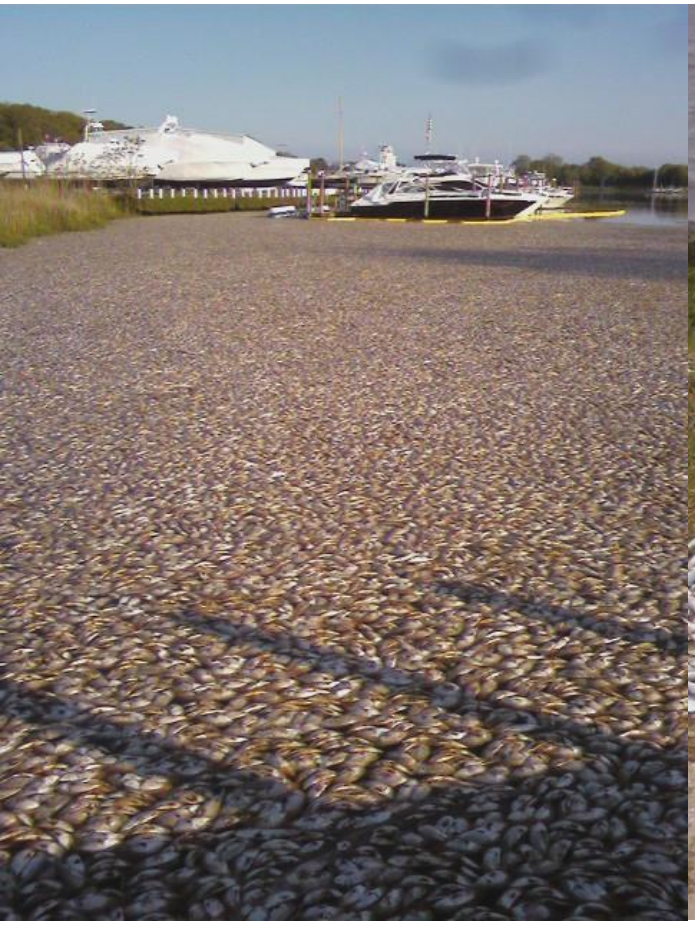
Human Health Syndromes

associated with phytoplankton

Name of Syndrome	Species and Toxin	Symptoms
Amnesic Shellfish Poisoning **(ASP)**	*Pseudo-nitzschia* **Domoic acid** 	Short term memory loss
Diarrhetic Shellfish Poisoning **(DSP)**	 *Dinophysis* **Okadaic acid** *Prorocentrum lima* 	Diarrhea Nausea Vomiting
Neurotoxic Shellfish Poisoning **(NSP)**	 *Karenia brevis* Brevetoxin	Respiratory problems
Paralytic Shellfish Poisoning **(PSP)**	*Alexandrium* Saxitoxin 	Loss of motor control


Animal and Plant mortalities in the U.S.
farmed fish
humpback whales
seagrass/shellfish
hard clam larvae
fish kills
fish kills
fish kills
seabirds
marine mammals
seabirds
fish kills
fish kills
fish kills
fish kills
larval red drum
fish kills
manatees
fish, seabirds
bottlenosed dolphins
Events from 1999-2008
6-10 times
2-5 times
1 time
sampled but not detected

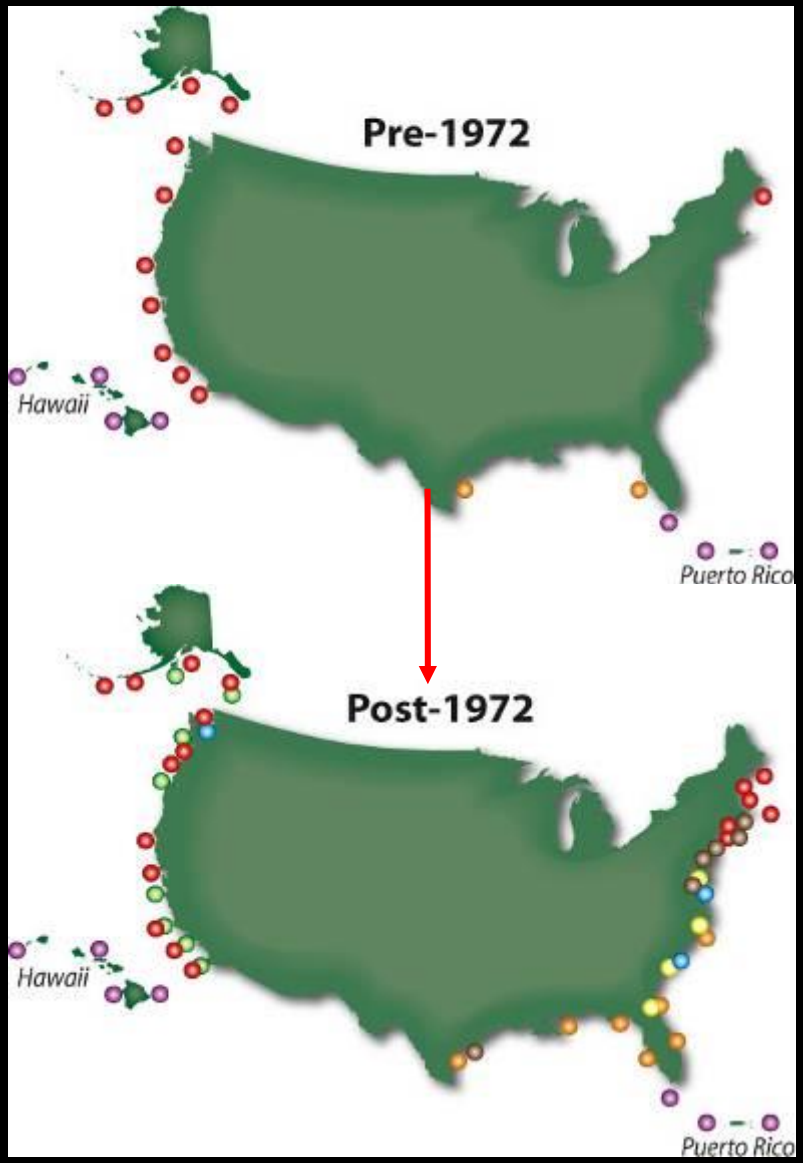
Ecosystem disruption by HABs: Death of marine life



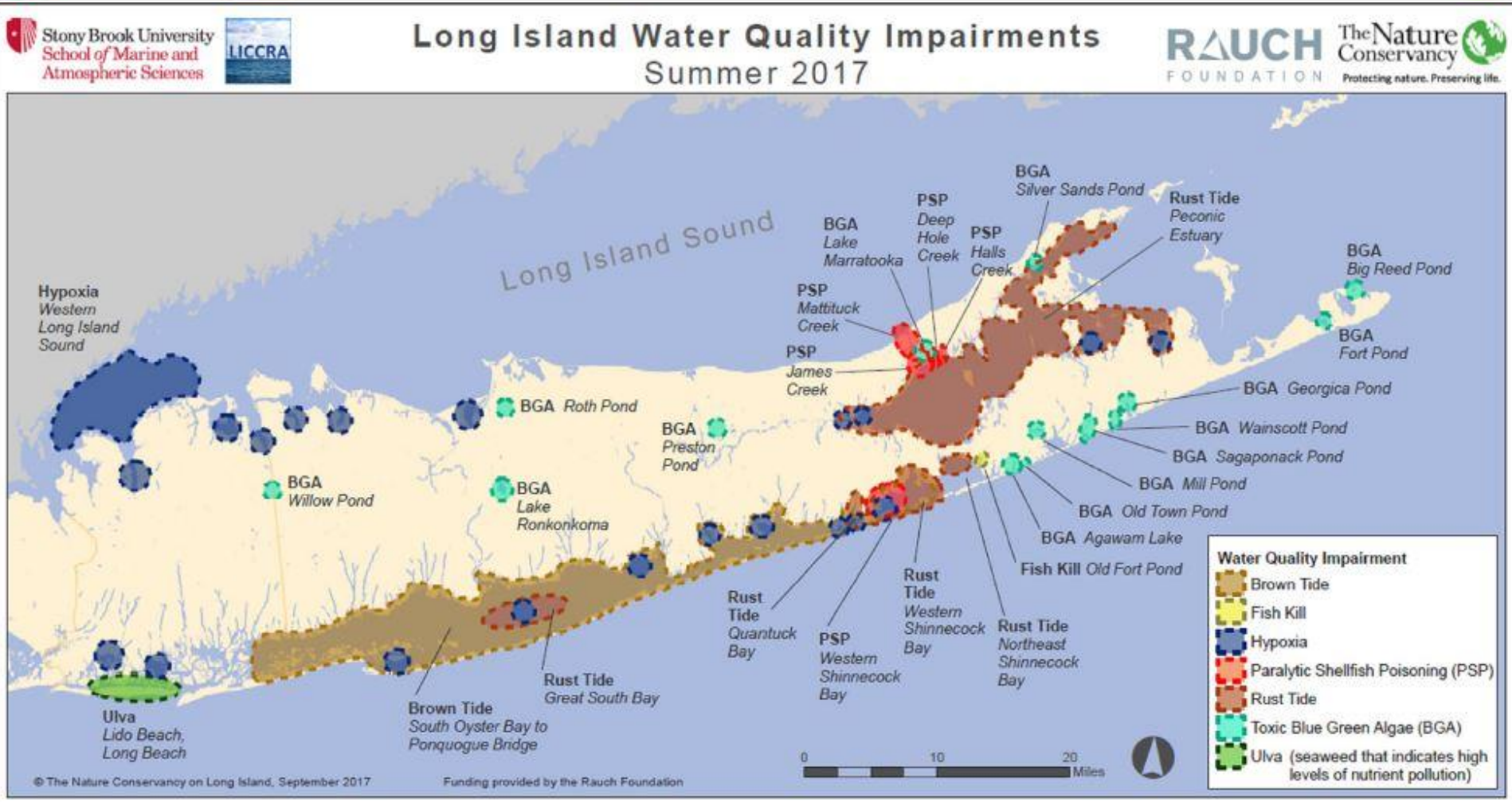
HABs cost the US ~$100sM annually

Why have HABs proliferated?

- Anthropogenic nutrient loading
- Loss of key food web predators in local ecosystems that may allow HAB species to thrive if introduced.
- Global climate change producing a wider range for some HABs.
- More comprehensive monitoring and reporting



Harmful algal blooms across Long Island

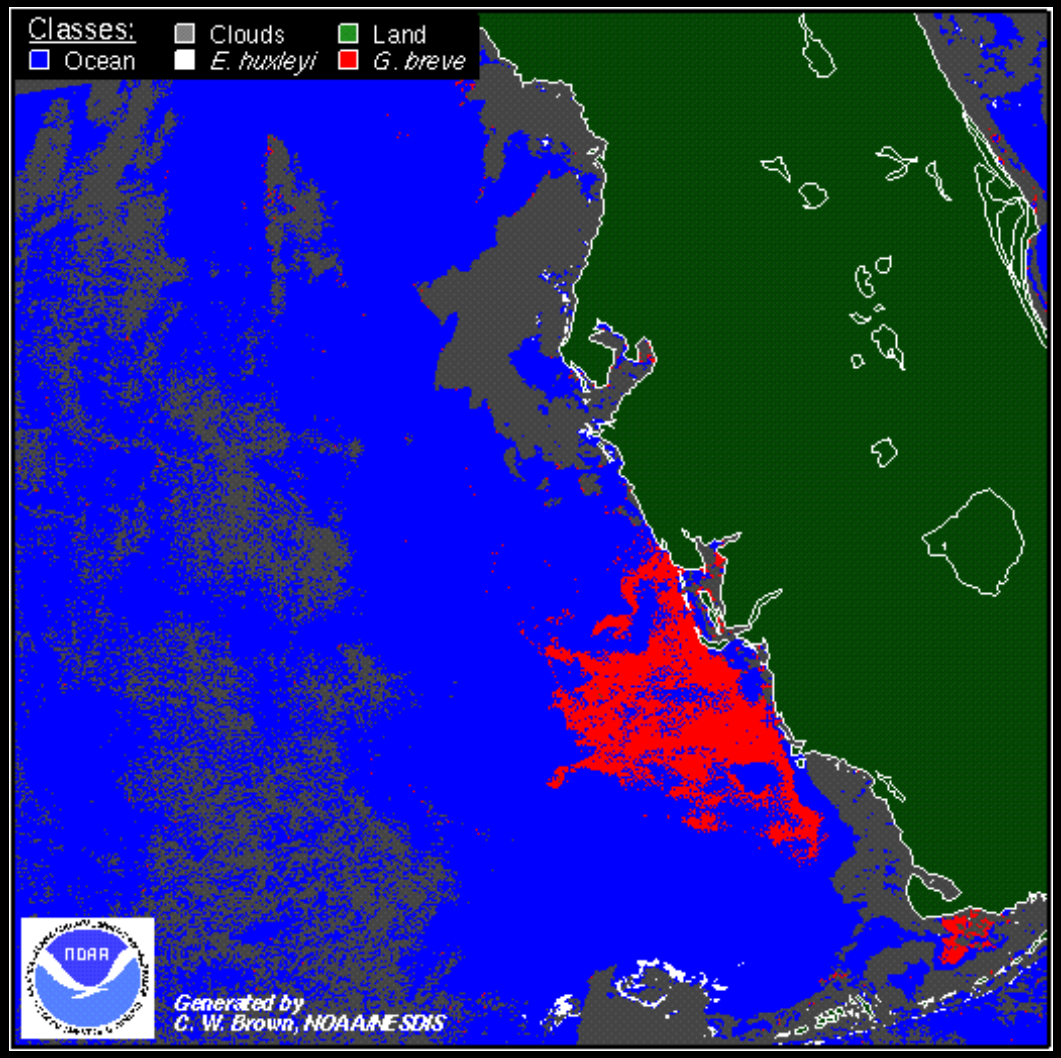


Some infamous US HABs…

Florida (and Texas) Red Tide blooms

caused by *Karenia brevis*

(formally known as *Gymnodinium breve*)



Brevetoxin can affect human health by….

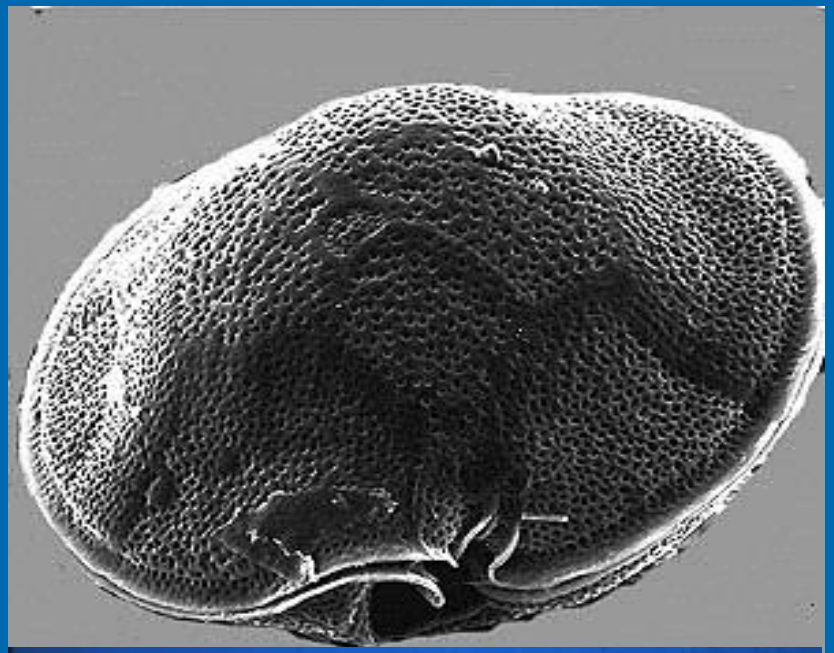
- Eating shellfish =NSP
  - Acute onset (minutes to hours)
  - Symptoms include:

    Gastrointestinal- abdominal pain, nausea, vomiting, diarrhea

    Neurological- headache, vertigo, numbness of lips, mouth and face, muscle pain, loss of coordination, partial paralysis, tingling sensations, convulsions, respiratory distress, temperature reversals
  - Rapid resolution (days)
- Skin contact
- Inhalation of aerosols

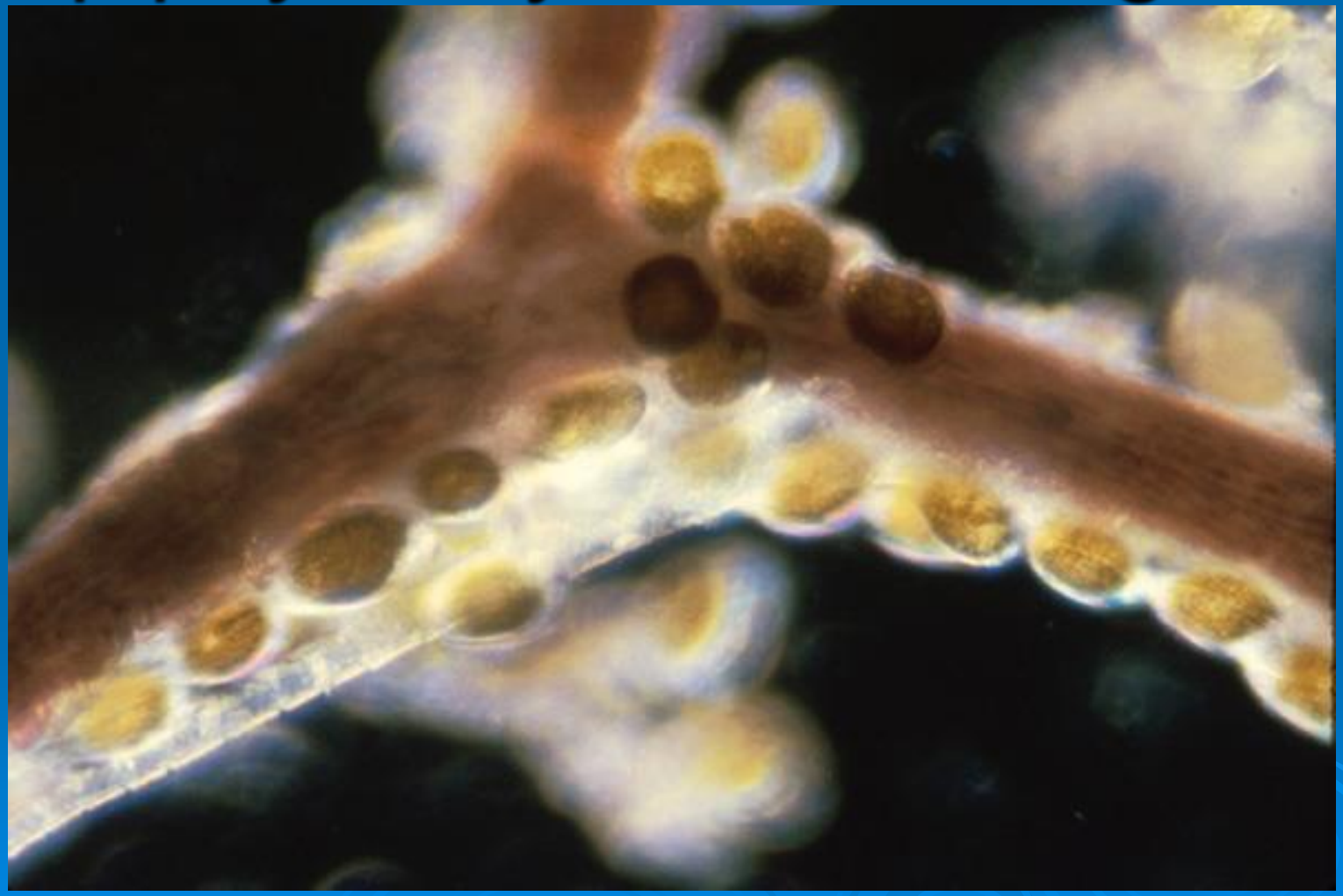
Ciguatera Fish Poisoning

- *Gambierdiscus toxicus*, an epiphytic dinoflagellate
- Associated with marcroalgae in tropical, coastal regions
- Optimum conditions: shallow waters, 25-34°C, 25-40 ppt
- Ciguatoxin concentrates up the food chain



Great Barracuda (Sphyraera barracuda)

Gambierdiscus cells grow epiphytically on macroalgae



Ciguatera Fish Poisoning: Symptoms

- Acute onset
- Early symptoms (24-48 h): Gastrointestinal
  - Pain, cramping, diarrhea, vomiting
- Late symptoms
  - Neurological
    - Headache, toothache
    - Temperature disturbance (hot-cold sensation reversal)
    - Respiratory paralysis and seizure in severe cases
  - Cardiovascular
    - Heart rate abnormalities (rare), usually bradycardia

Ciguatera Fish Poisoning

- ~ 50% of US seafood poisoning
  - 90% - Florida and Hawaii Usually large fish, bottom dwellers and reef fish
  - Red snapper, Grouper, Amber Jack, Sturgeon
- Toxins
  - Bioaccumulate
  - Stable and heat resistant
  - Lipid soluble
  - Highly potent (clinical effects from <1 mg)

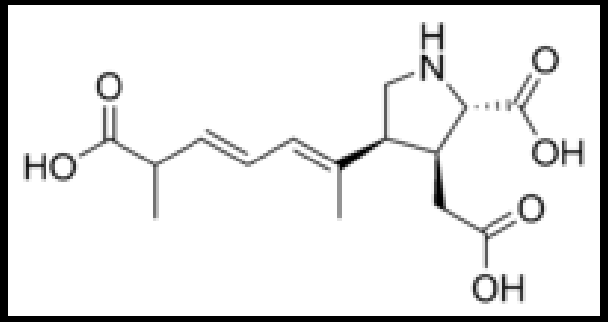
Not all HABs are Dinoflagellates

Pseudo-nitzschia

- Genus- Diatom
- Location-
  - along the Pacific Northwest coast of the United States and along the Atlantic Northeast coast of Canada and the Gulf of Mexico.
  - Around the world

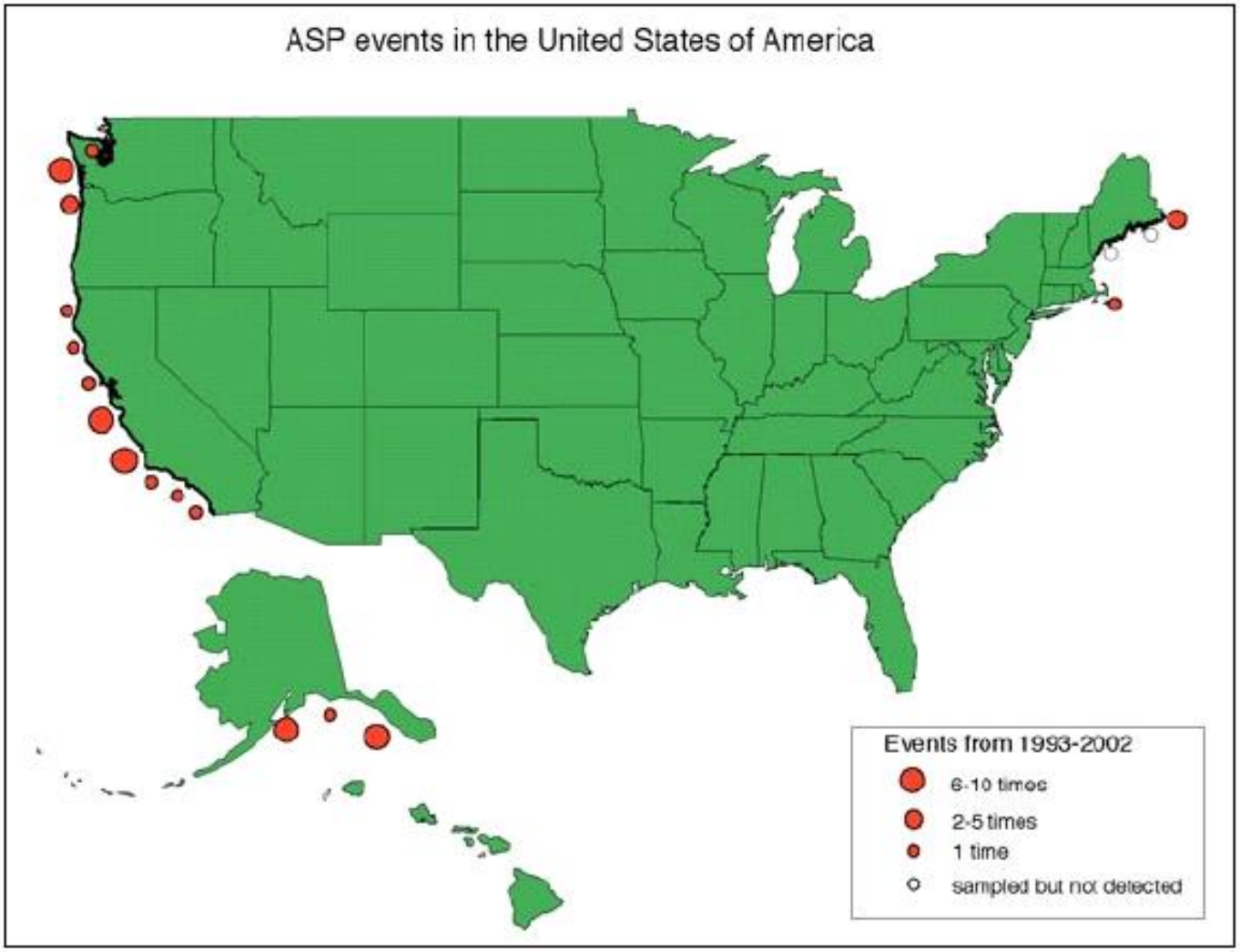
- Domoic acid, associated with ASP in humans.

Pseudo-nitzschia seriata - (Cleve) H. Peragallo *(400 x)*



Domoic acid Poisoning

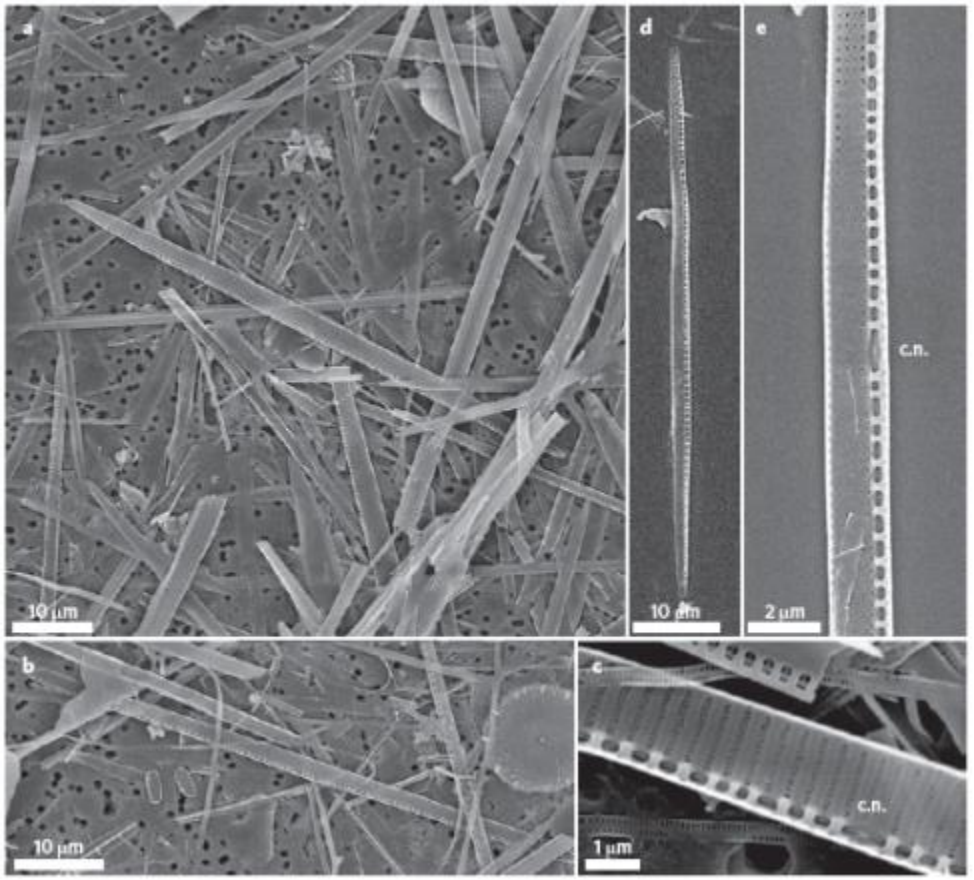
Shellfish beds closed to harvest at 20μg/g shellfish meat



Amnesic Shellfish Poisoning: Human Symptoms

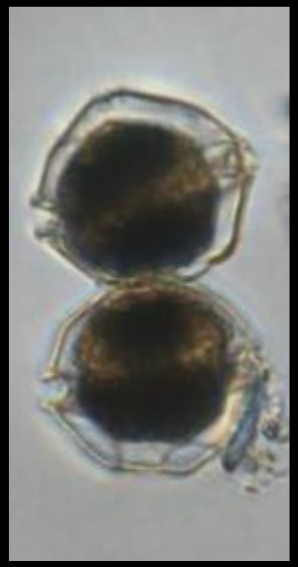
- Early symptoms: Gastrointestinal
  - Nausea, vomiting, diarrhea
- CNS symptoms
  - Dizziness
  - Cognitive effects
  - Disorientation
  - Memory loss
  - Delirium
  - Seizures
  - Agitation
- Highly variable course
  - 10% with permanent neurological damage

Amnesic Shellfish Poisoning: Cause of ‘The Birds’

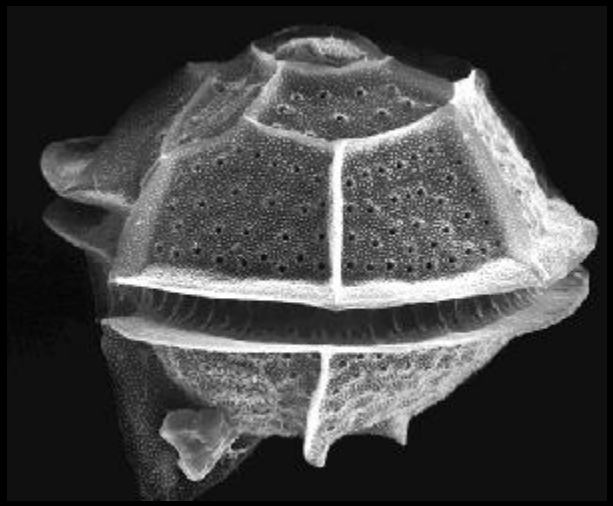


Scanning electron microscopy images of zooplankton gut contents collected in July–August 1961 from Monterey Bay, California.

Paralytic Shellfish Poisoning- PSP



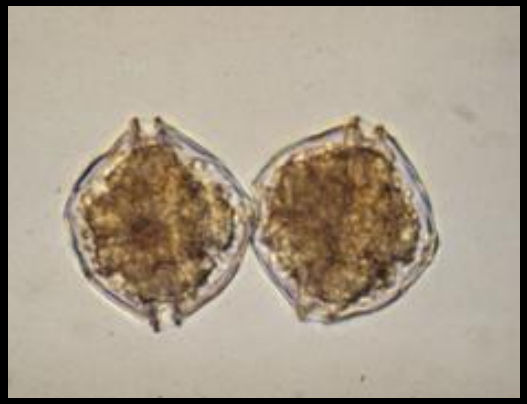
Alexandrium



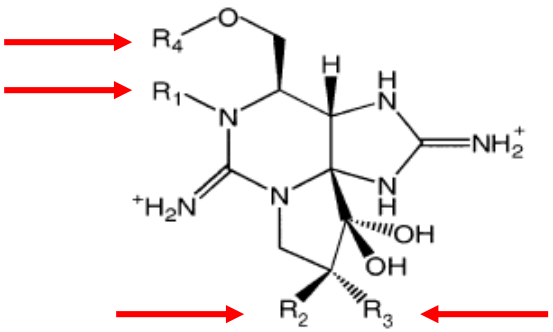
Pyrodinium

Gymnodinium

Paralytic Shellfish Poisoning (PSP): Globally significant human health syndrome caused by the saxitoxin producing dinoflagellates.



Saxitoxin blocks sodium channels; symptoms include: tingling sensation of mouth, lips and fingers→ muscular weakness→ death due to respiratory failure



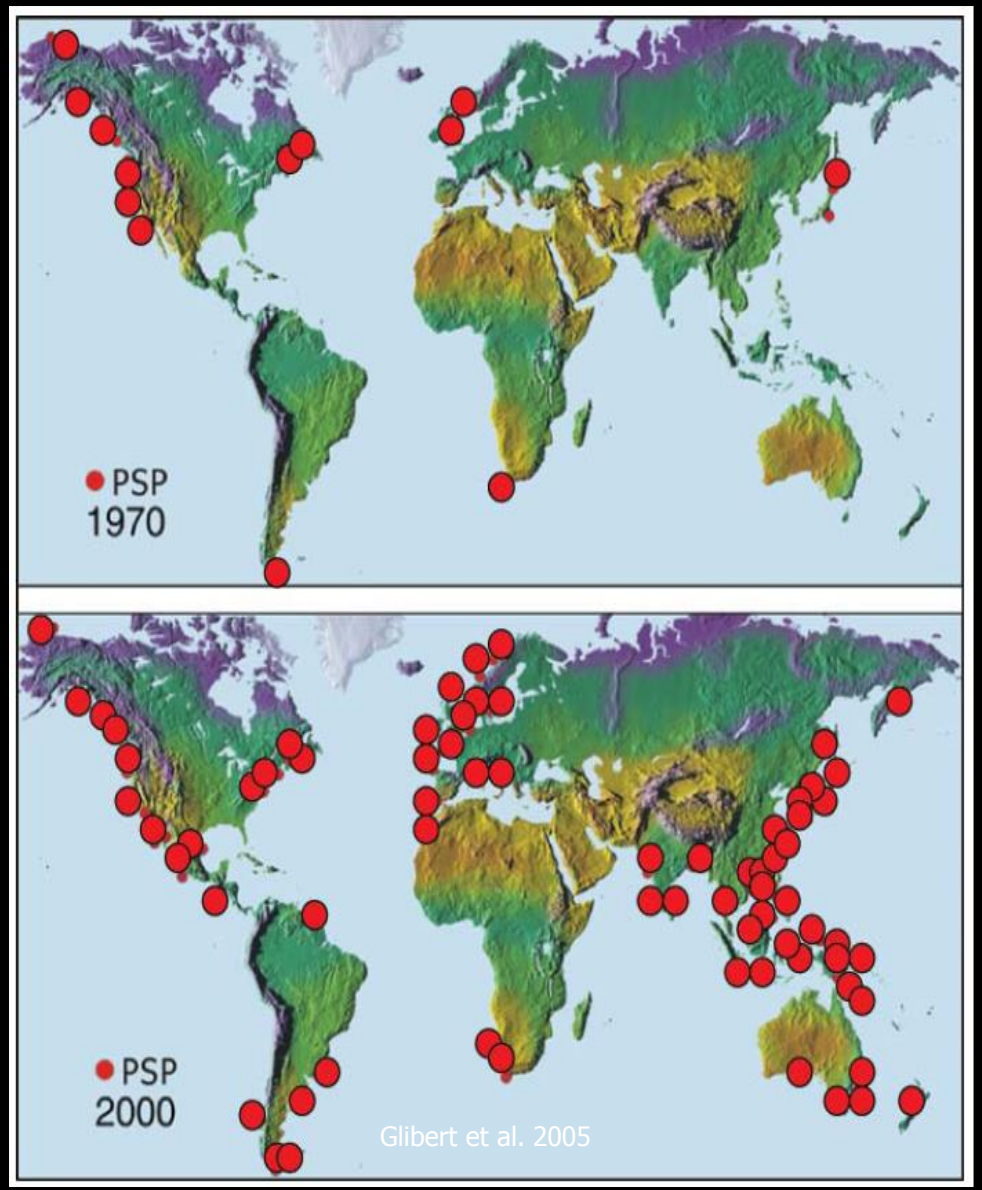
Heat Stable

R1	R2	R3	Carbamate toxins	*N*-sulfocarbamoyl toxins	Decarbamoyl toxins
			R4		
			-$CONH_2$	-$CONHSO_3^-$	H
H	H	H	STX (2,483)	GTX5 (160)	dcSTX (1,274)
OH	H	H	neoSTX (2,295)	GTX6 (180)	dcneoSTX (33)
OH	OSO_3^-	H	GTX1 (2,468)	C3 (33)	dcGTX1 (1,500)
H	OSO_3^-	H	GTX2 (892)	C1 (15)	dcGTX2 (1,617)
H	H	OSO_3^-	GTX3 (1,584)	C2 (239)	dcGTX3 (1,872)
OH	H	OSO_3^-	GTX4 (1,803)	C4 (143)	dcGTX4 (1,080)

C: C toxin; GTX: gonyautoxin; STX: saxitoxin; dc: decarbamoyl
Value in parenthesis: specific toxicity in MU/μmol

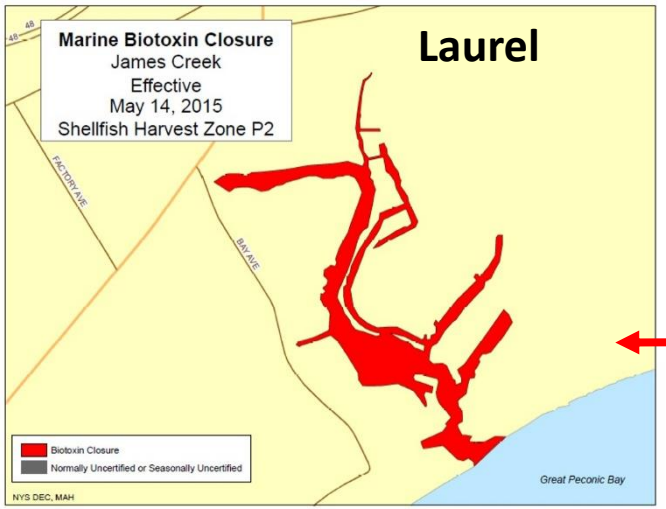
Samsur et al. 2006

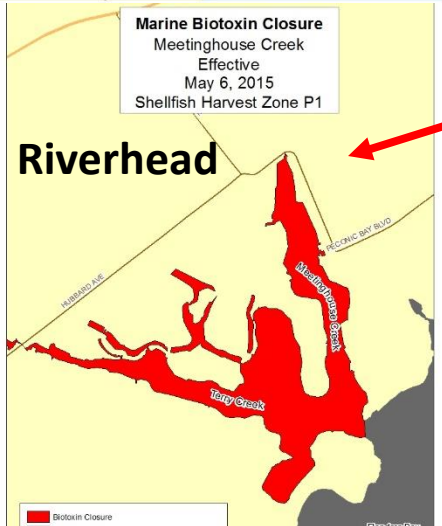
The global occurrence of PSP:

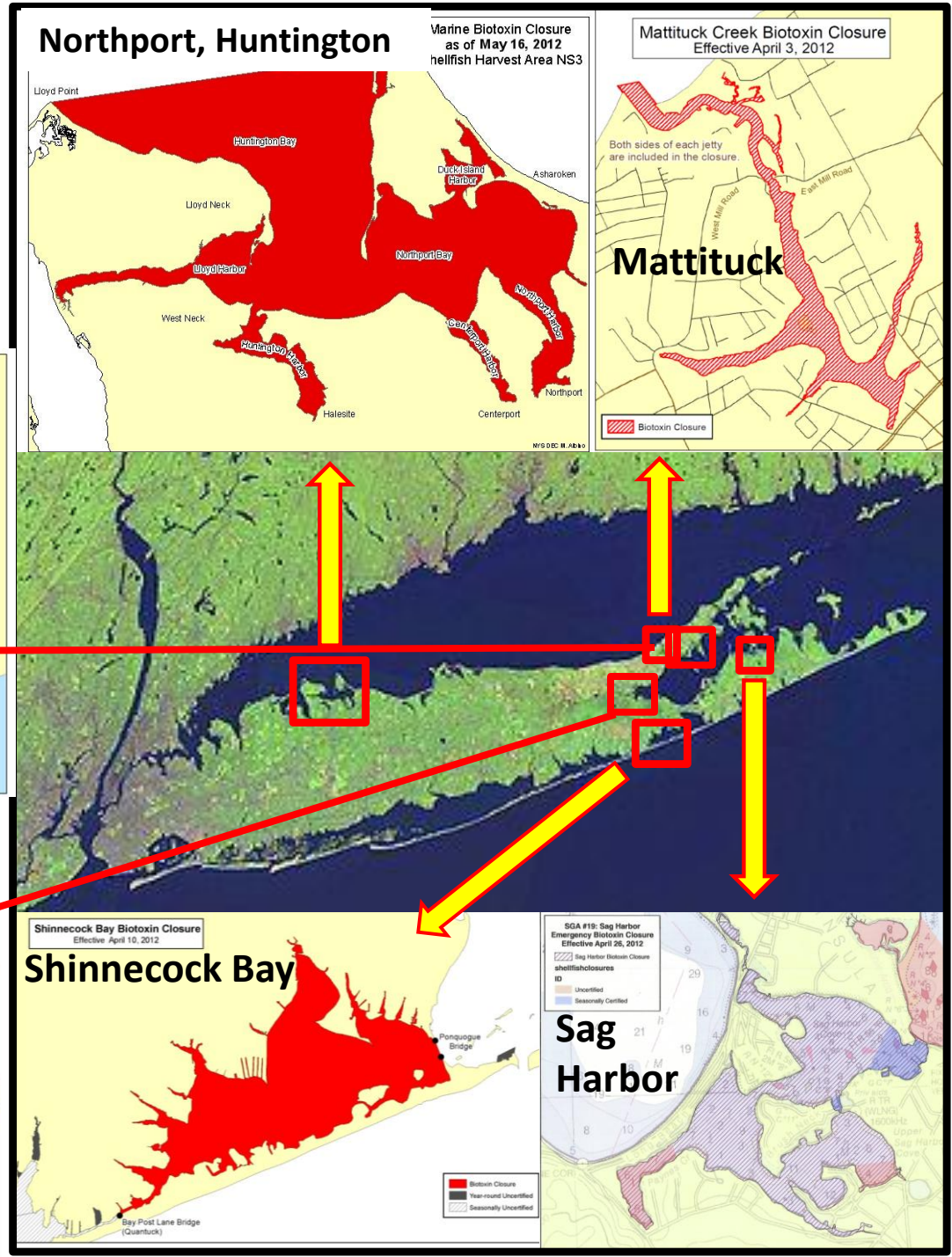


- PSP found worldwide with causative organisms varying
- Global expansion of blooms
- Increased coastal monitoring vs. anthropogenic nutrient loading?

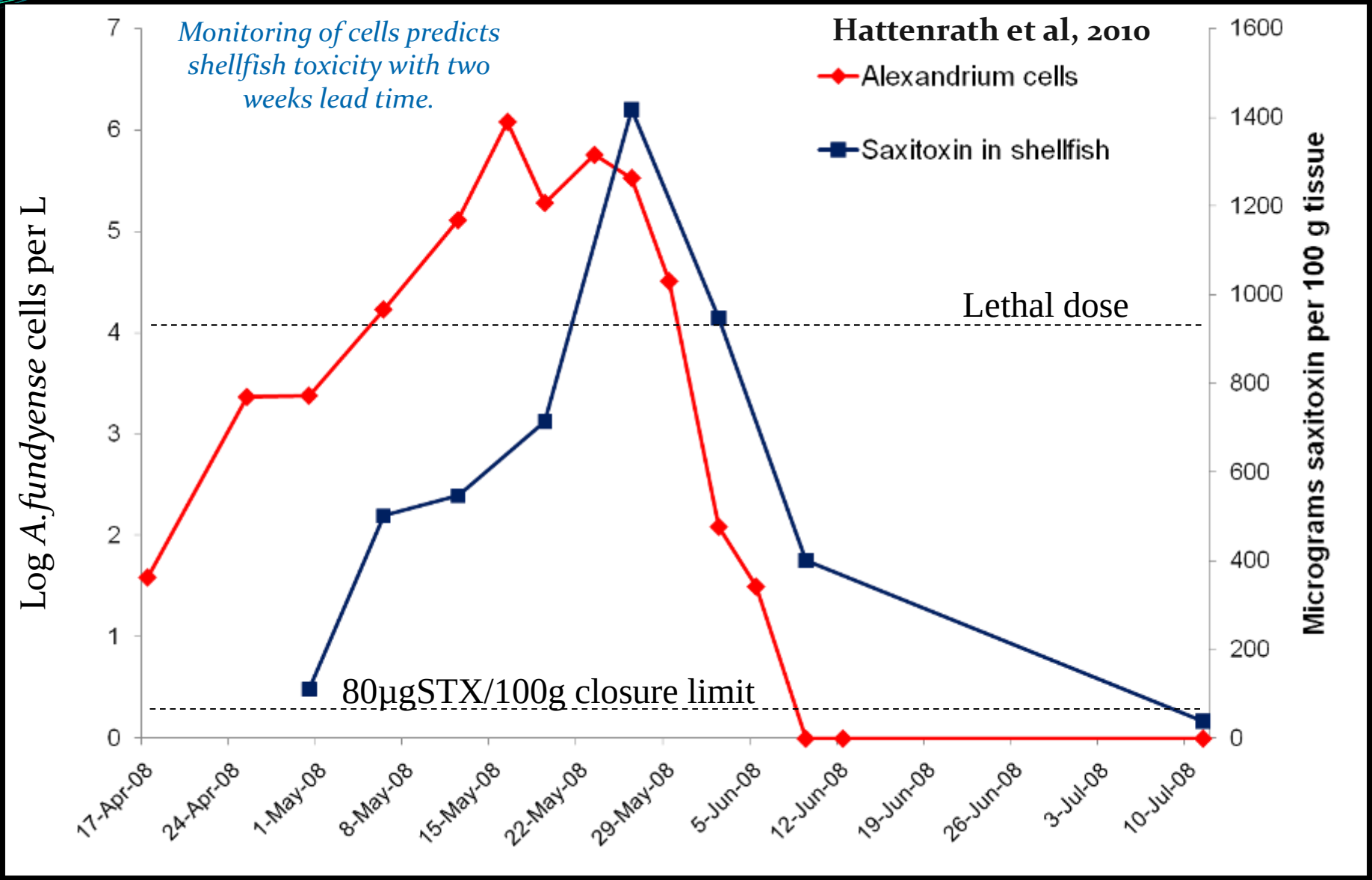
PSP-shellfish bed closures across Long Island



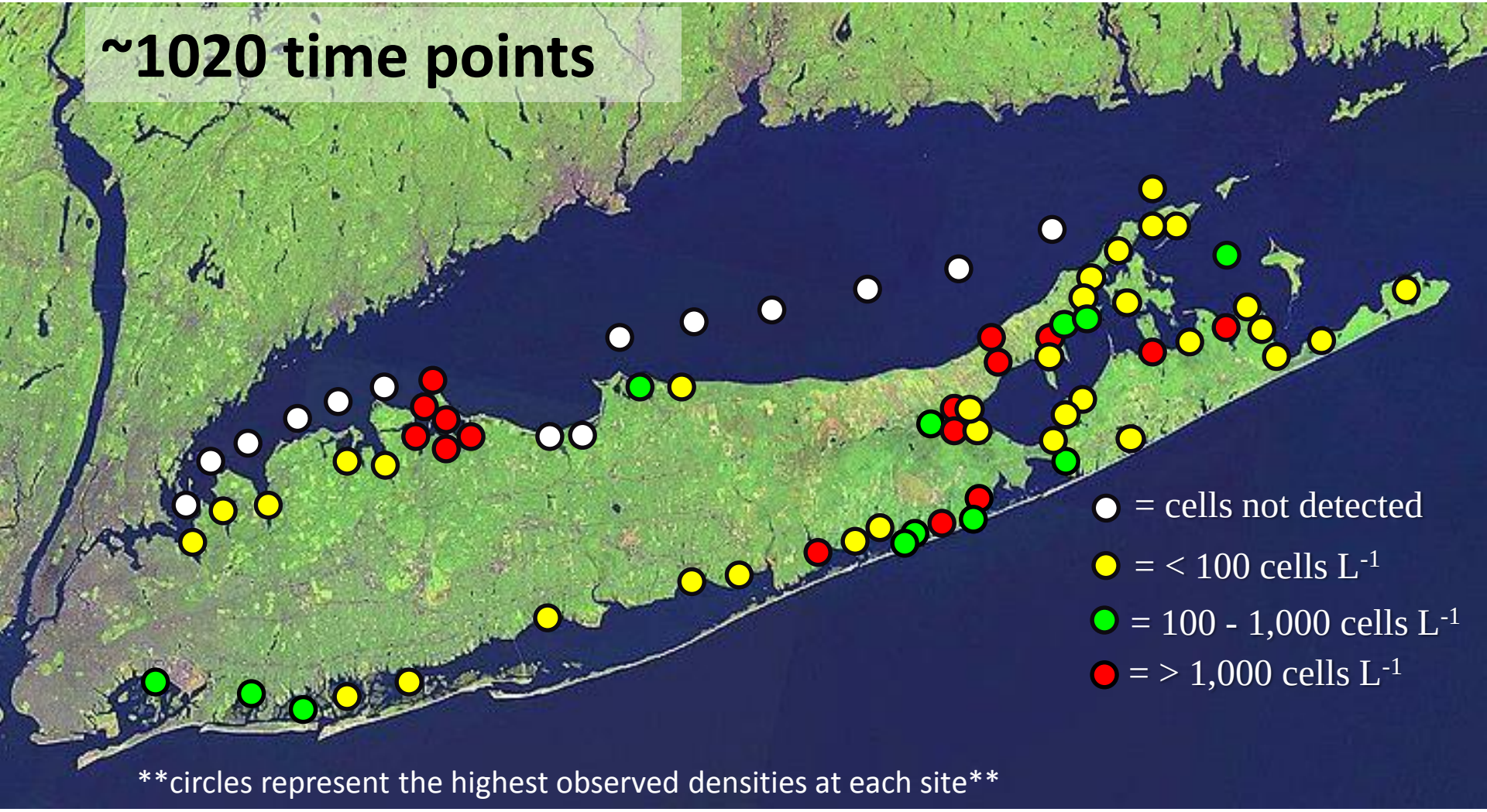




Alexandrium cells and shellfish toxicity: 2008



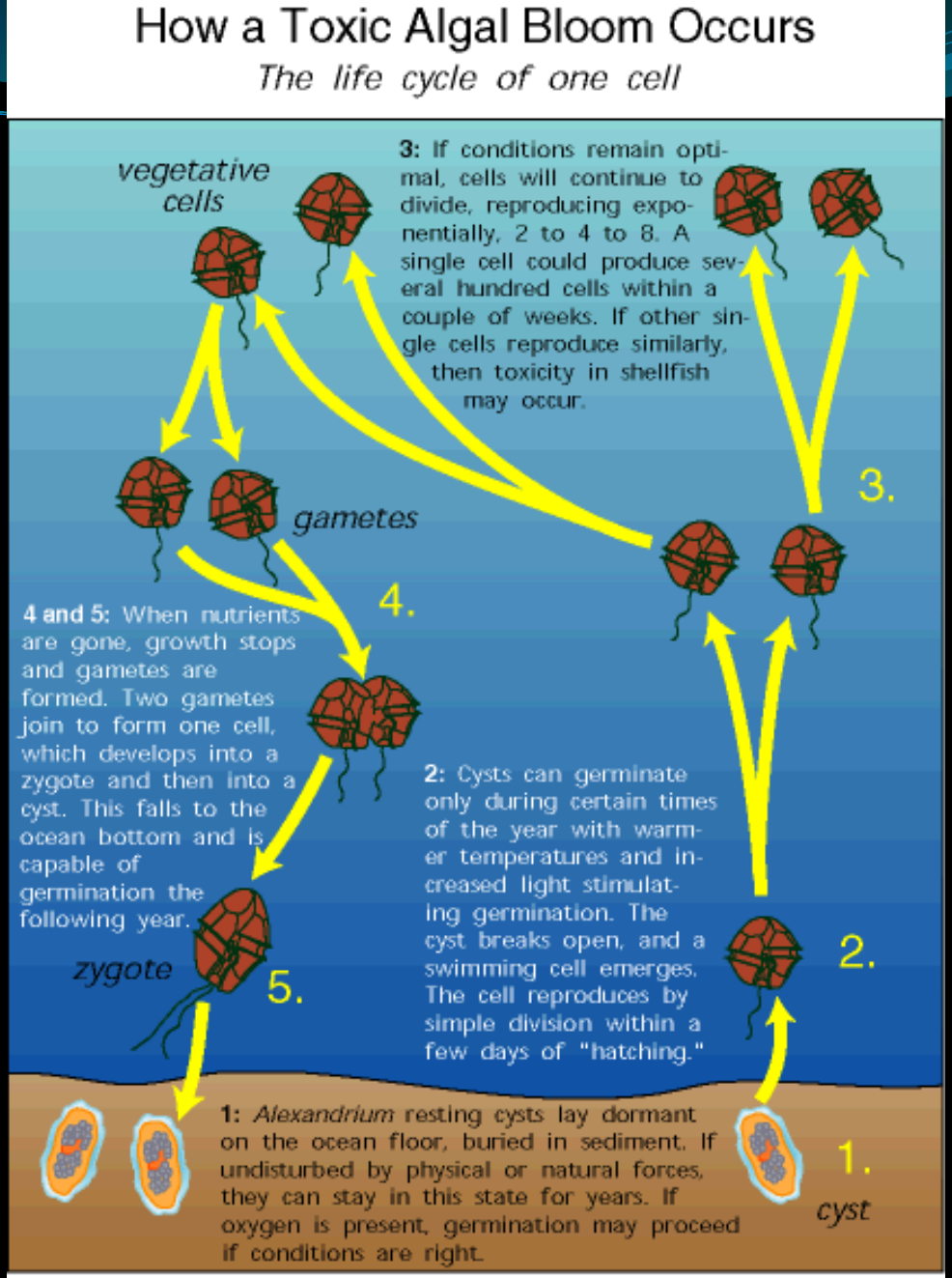
Presence of PSP-producing *Alexandrium* in LI: 2007-2015



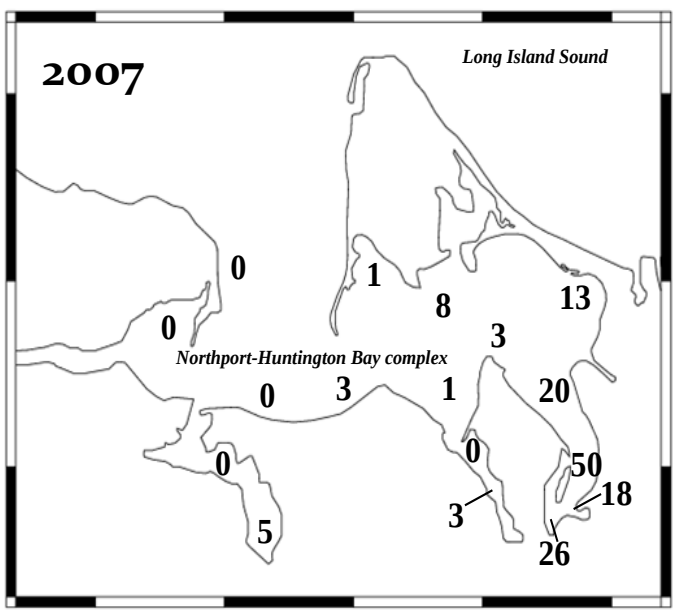
- *Alexandrium* found at 62 of 76 sites sampled (82%)

Alexandrium sp. Cysts

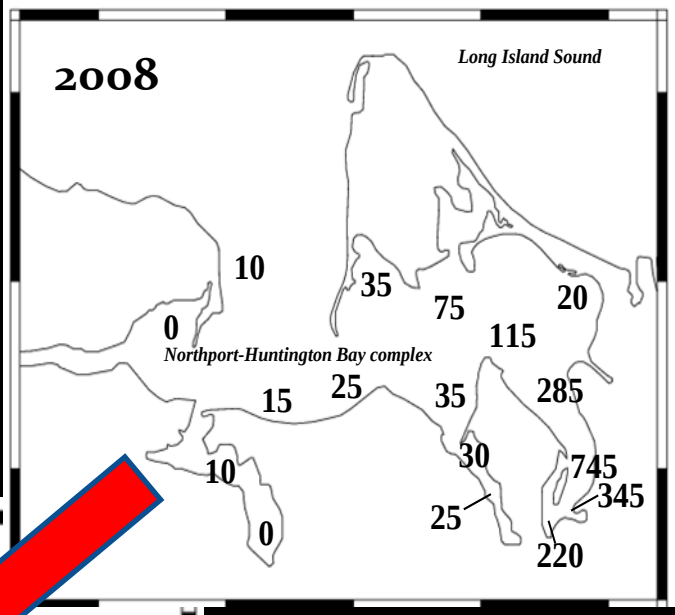
- Environmental stress cues sexual reproduction and cyst formation.
- Cysts deposited by the fall of a given year are predictive of blooms the following spring

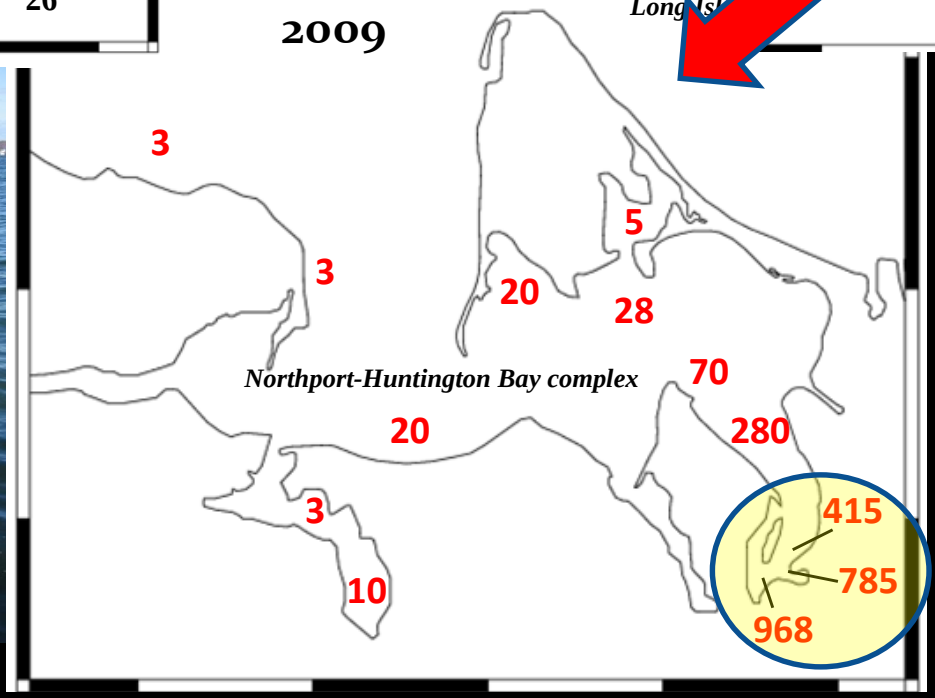


Northport cysts per cubic cm of sediment (2007-2009)



Large 2008 bloom

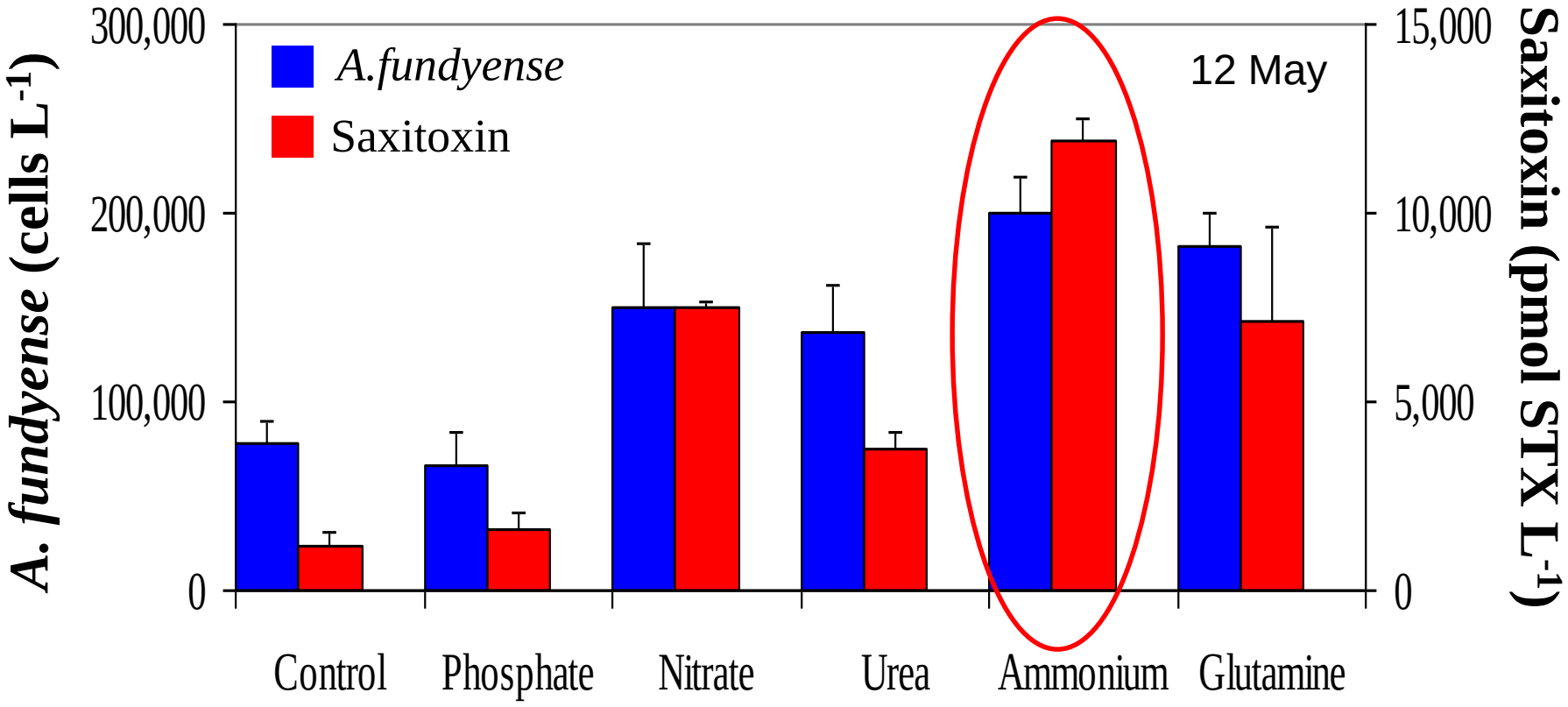




2009: Highest densities ever recorded in New York

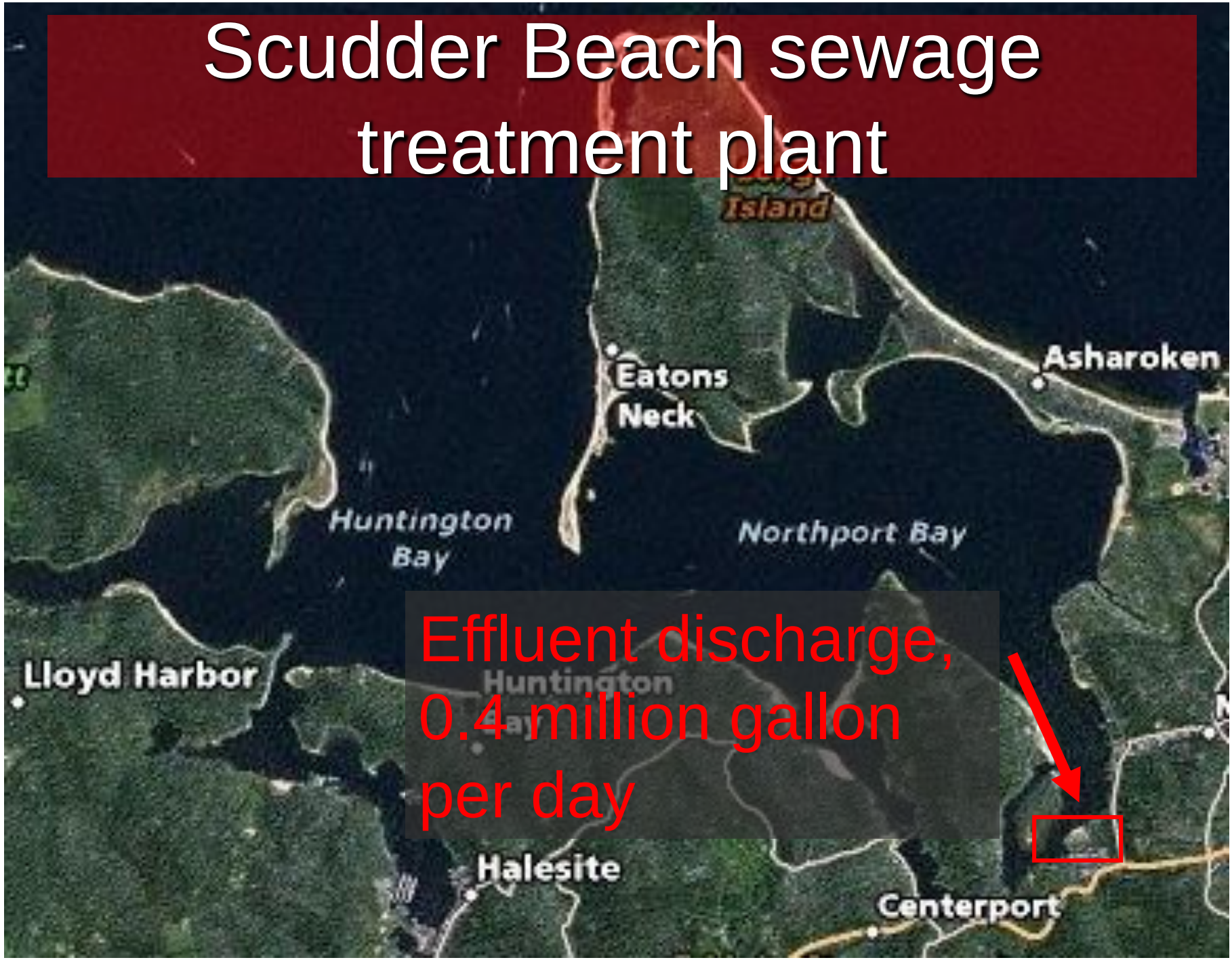
What drives New York blooms?

Impact of nutrient loading on *Alexandrium* densities and toxicity, 2008



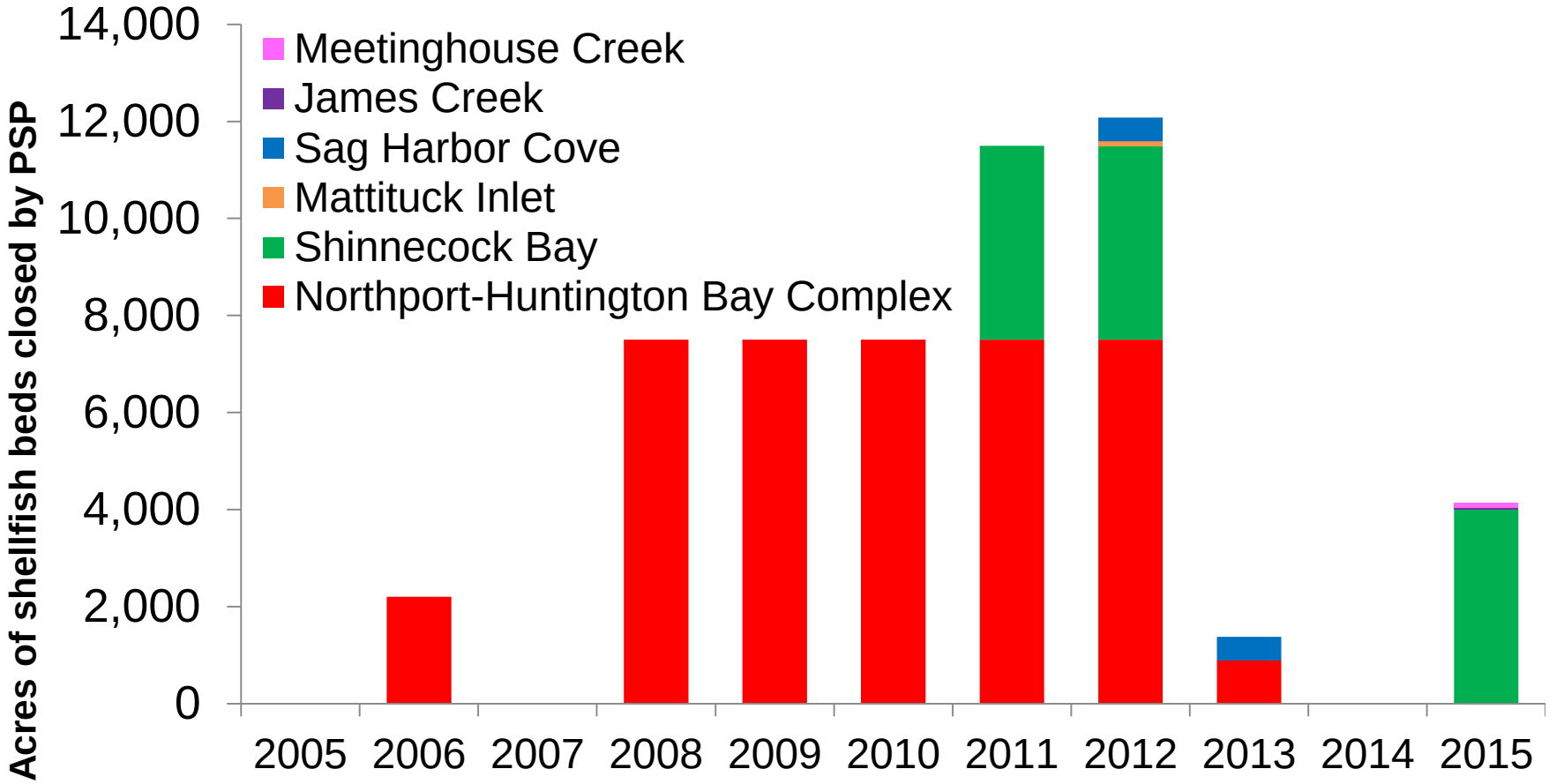
- N significantly increased cell densities in 66% of experiments ($p<0.05$; $n=6$)
- N significantly increased toxin levels in 50% of experiments ($p<0.05$; $n=6$)

Scudder Beach sewage treatment plant



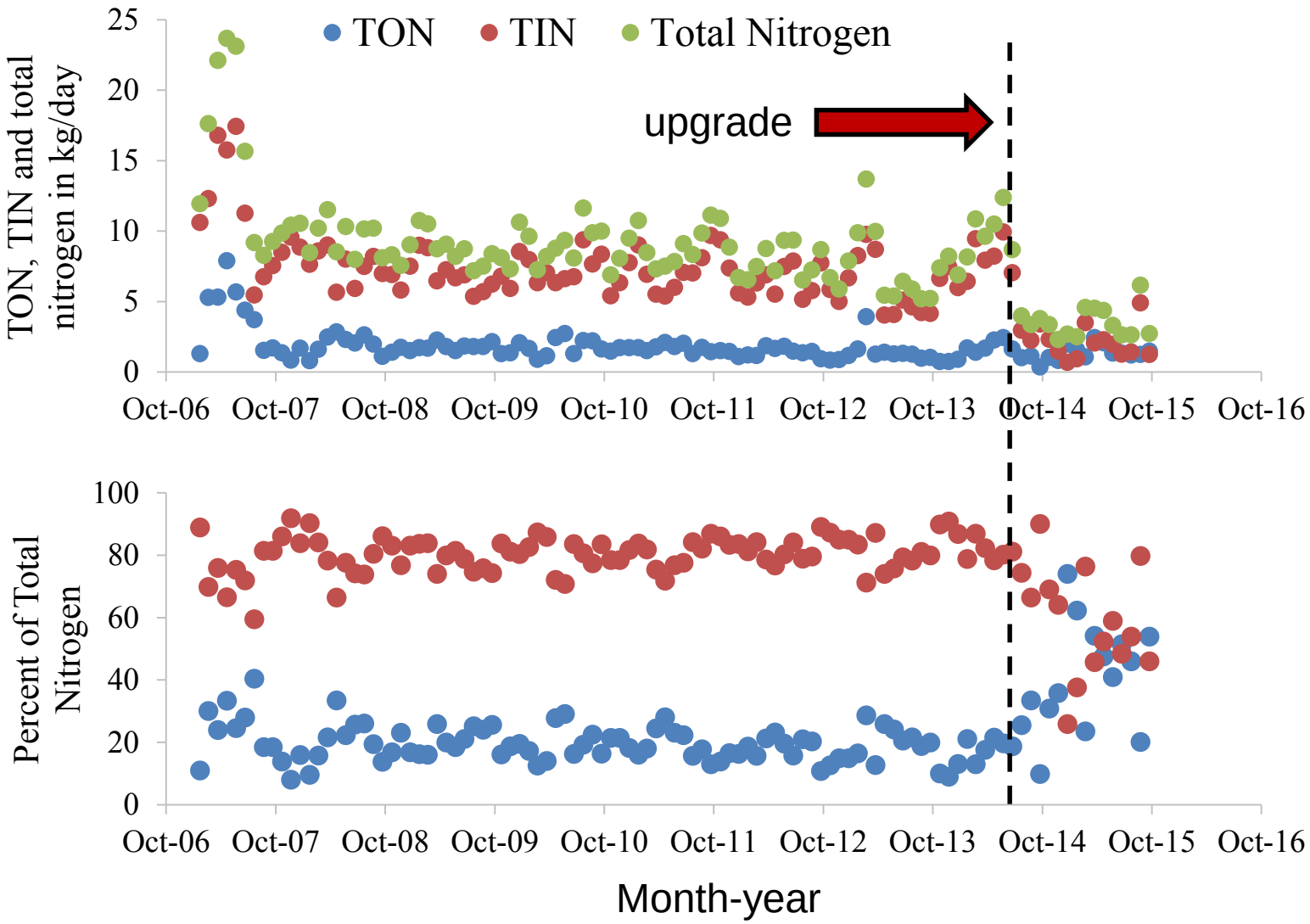
Expansion of PSP-induced shellfish bed closures on Long Island, 2005 – 2015

Prior to 2006, Long Island had never experienced a PSP event



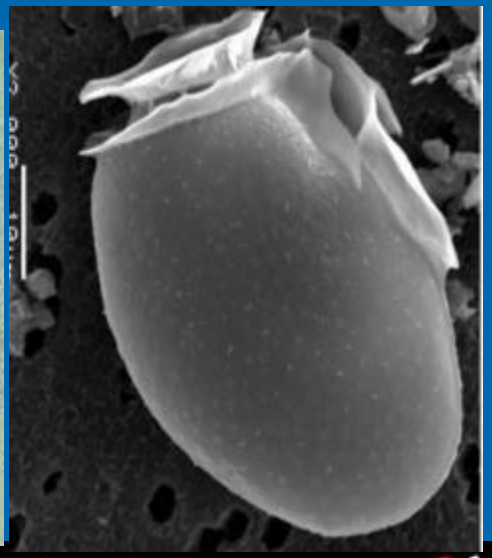
Data collected from NYSDEC website

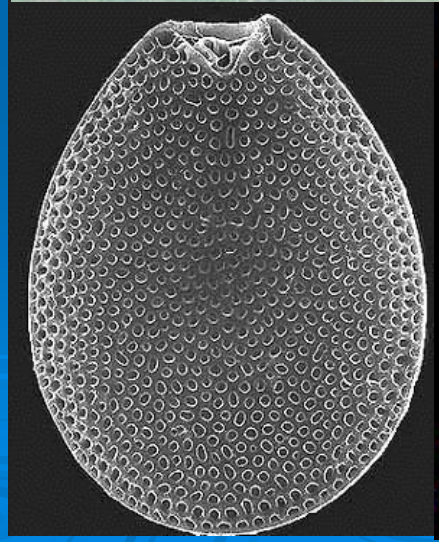
Changes in Northport Bay STP effluent

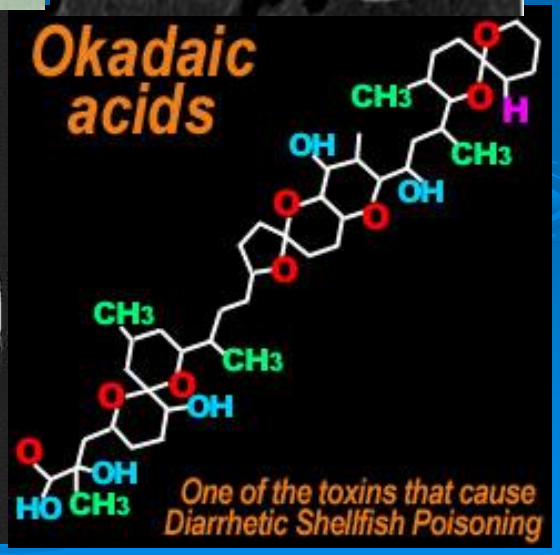


Diarrhetic Shellfish Poisoning

- Dinoflagellates
  - *Dinophysis spp.*
  - *Prorocentrum lima* (epiphytic brown macroalgae)
- Species reported in the US but associated illnesses not reported until summer 2011
- Okadaic acids and dinophysistoxins







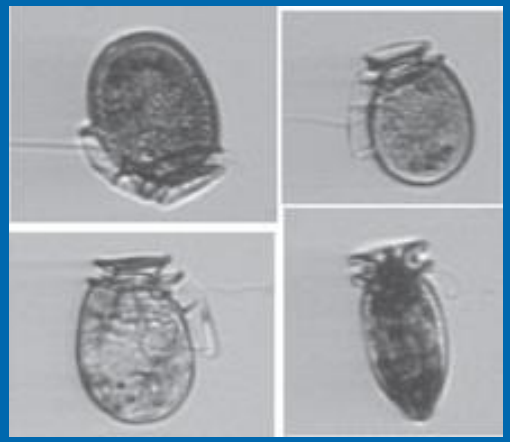
Diarrhetic Shellfish Poisoning: Human Symptoms

- Gastrointestinal illness
  - Diarrhea, nausea, vomiting
  - Rapid onset, rapid resolution
  - No neurotoxic effects
  - Long-term effects? (Possibly tumorigenic)
- FDA level in shellfish – 0.16 ppm okadaic acid plus 35-methyl-okadaic acid =160 ng/g shellfish tissue

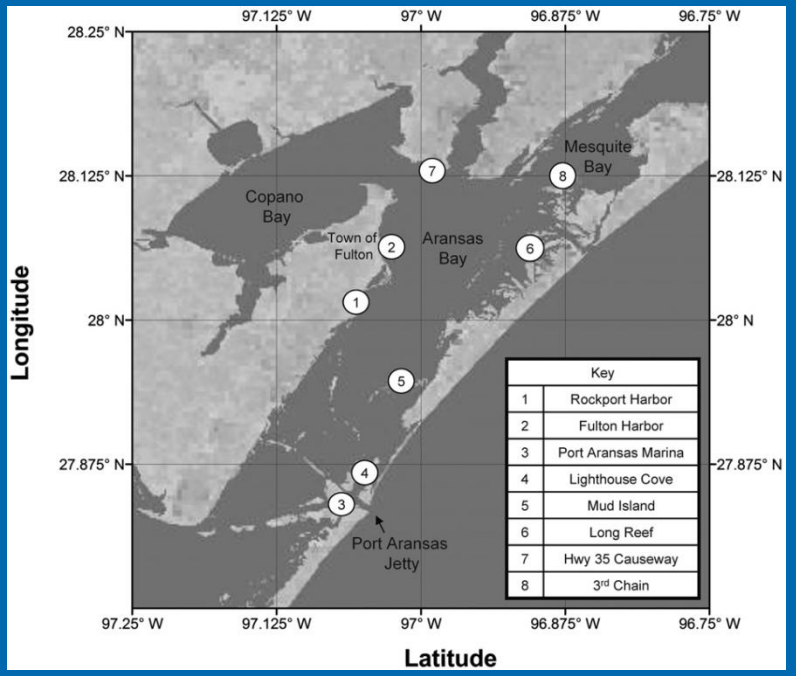
FIRST HARMFUL *DINOPHYSIS* (DINOPHYCEAE, DINOPHYSIALES) BLOOM IN THE U.S. IS REVEALED BY AUTOMATED IMAGING FLOW CYTOMETRY[1]

Lisa Campbell[2] et al., 2010

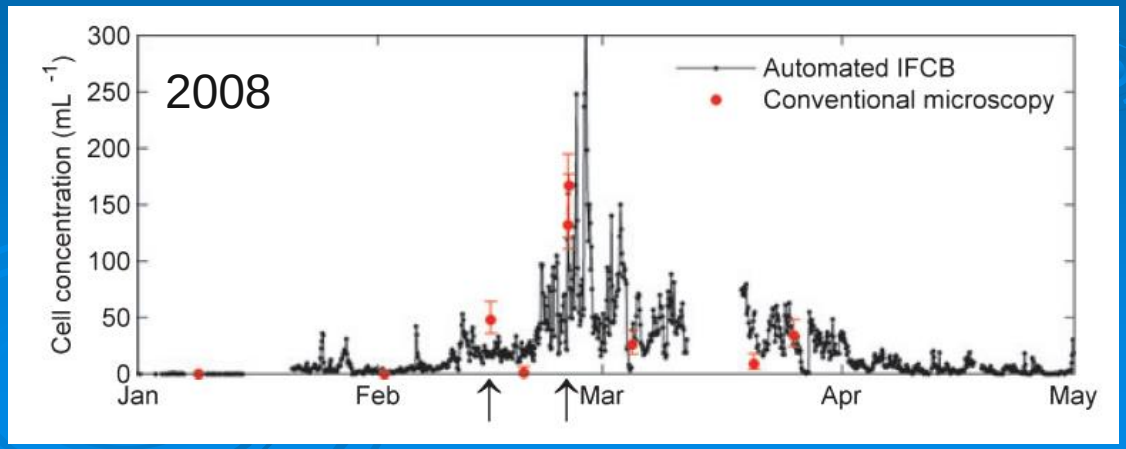
Dinophysis ovum



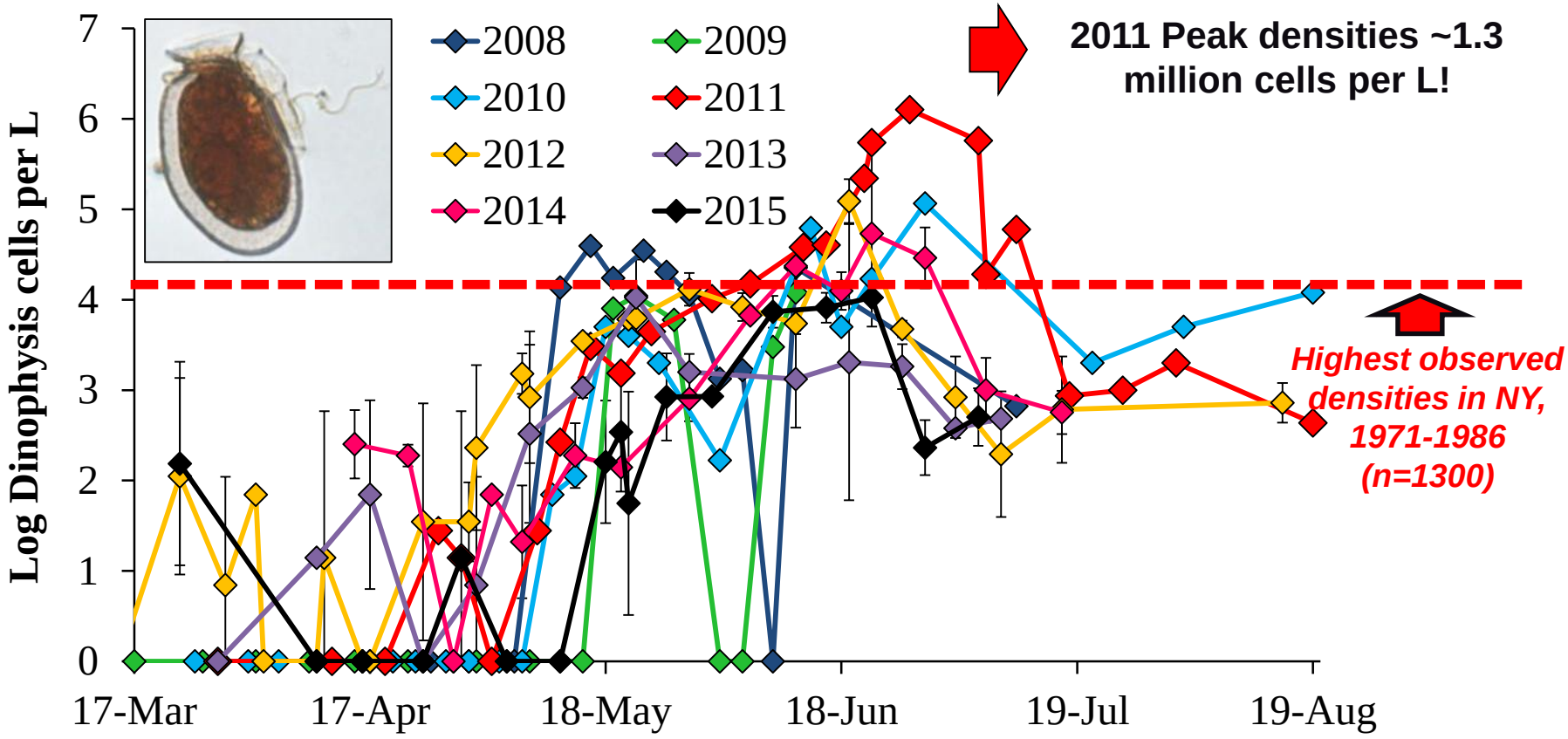
Oysters = 470 ng/g OA



Deeds et al., 2010



Northport *Dinophysis* blooms, 2008 - 2015



- Every year except 2009, 2013 and 2015 had higher bloom densities than those previously reported in New York.
- The largest bloom occurred in 2011 ($>10^6$ cells L^{-1}).

DSP toxins ng/g

FDA action level = 160 ng/g

=shellfish sampling site

2011

Mytilus edulis

total OA	PTX2
165	5

Mytilus edulis

total OA	PTX2
1245	115

Mytilus edulis

total OA	PTX2
142	9

Mya arenaria

total OA	PTX2
957	66

Geukensia demissa

total OA	PTX2
1137	71

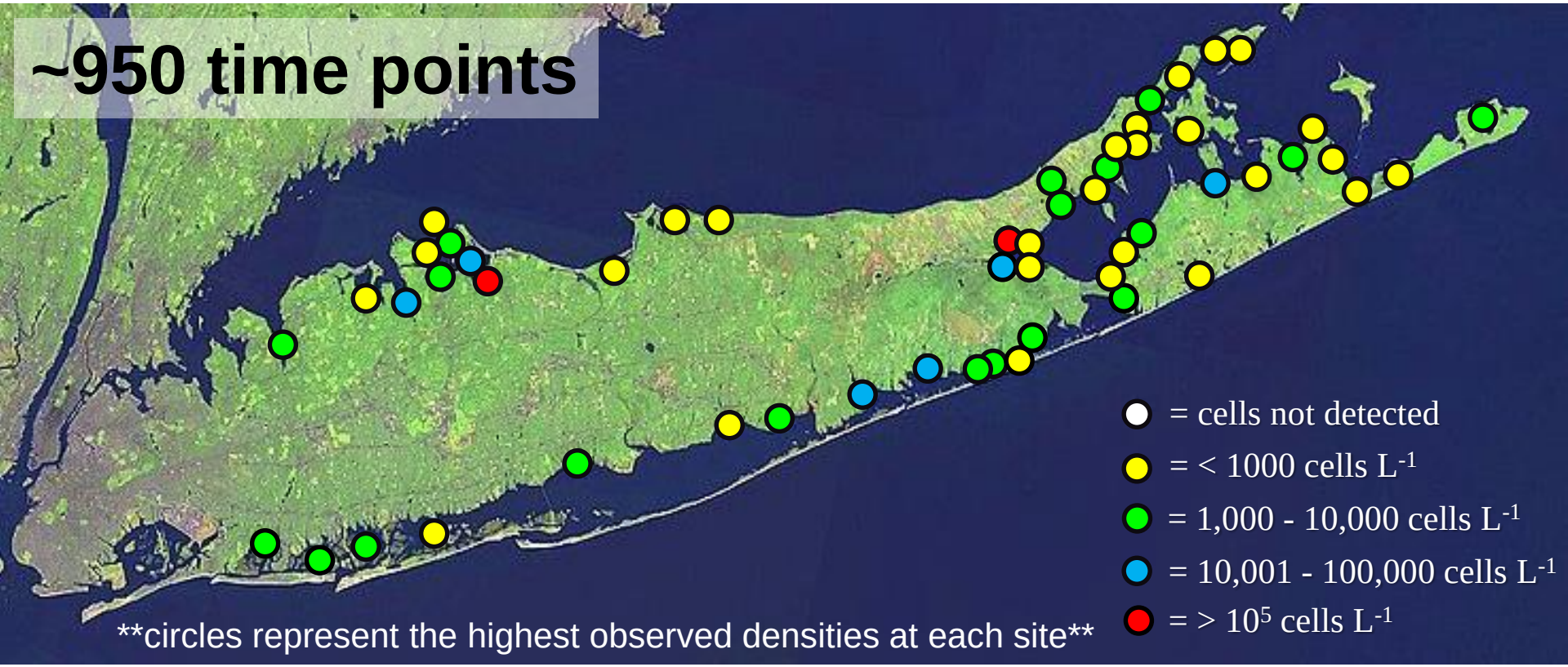
Key

Mytilus edulis = blue mussel

Mya arenaria = soft shell clam

Geukensia demissa = ribbed mussel

Presence of DSP-producing *Dinophysis* in LIS: 2008-2015

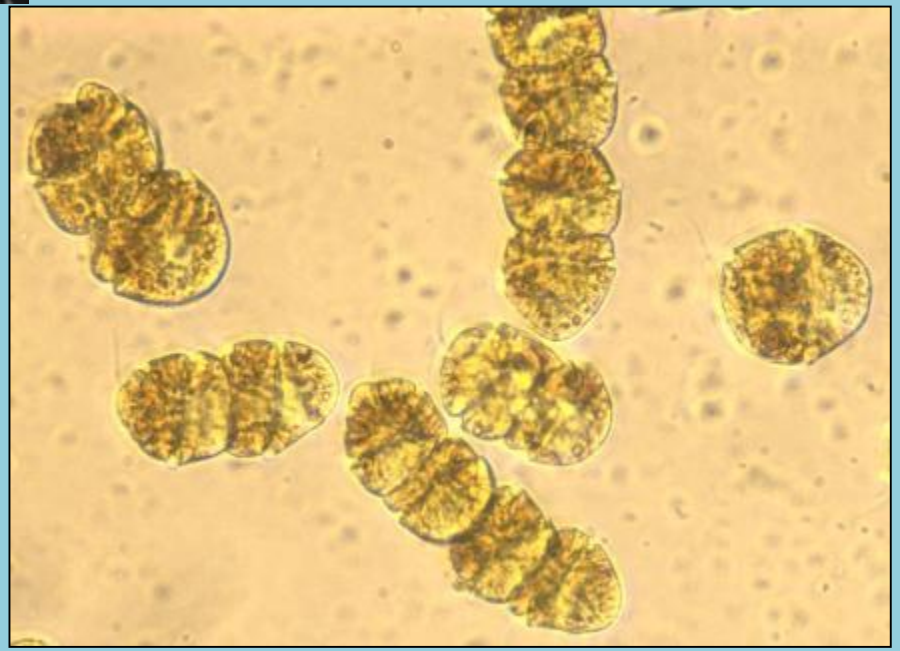


- *Dinophysis* was observed at 54 of 54 sites sampled, and 17% of those sites had higher densities than those reported ~30 years ago (Freudenthal and Jijina, 1988).
- The largest blooms occurred in Northport Bay and Meetinghouse Creek.

Cochlodinium polykrikoides

- Dinoflagellates
- Chain-forming
- “Rust tide”

- Approximately 20-40 µm in size
- Perform diel vertical migration
- Cysts observed in cultures (Tang and Gobler 2012)

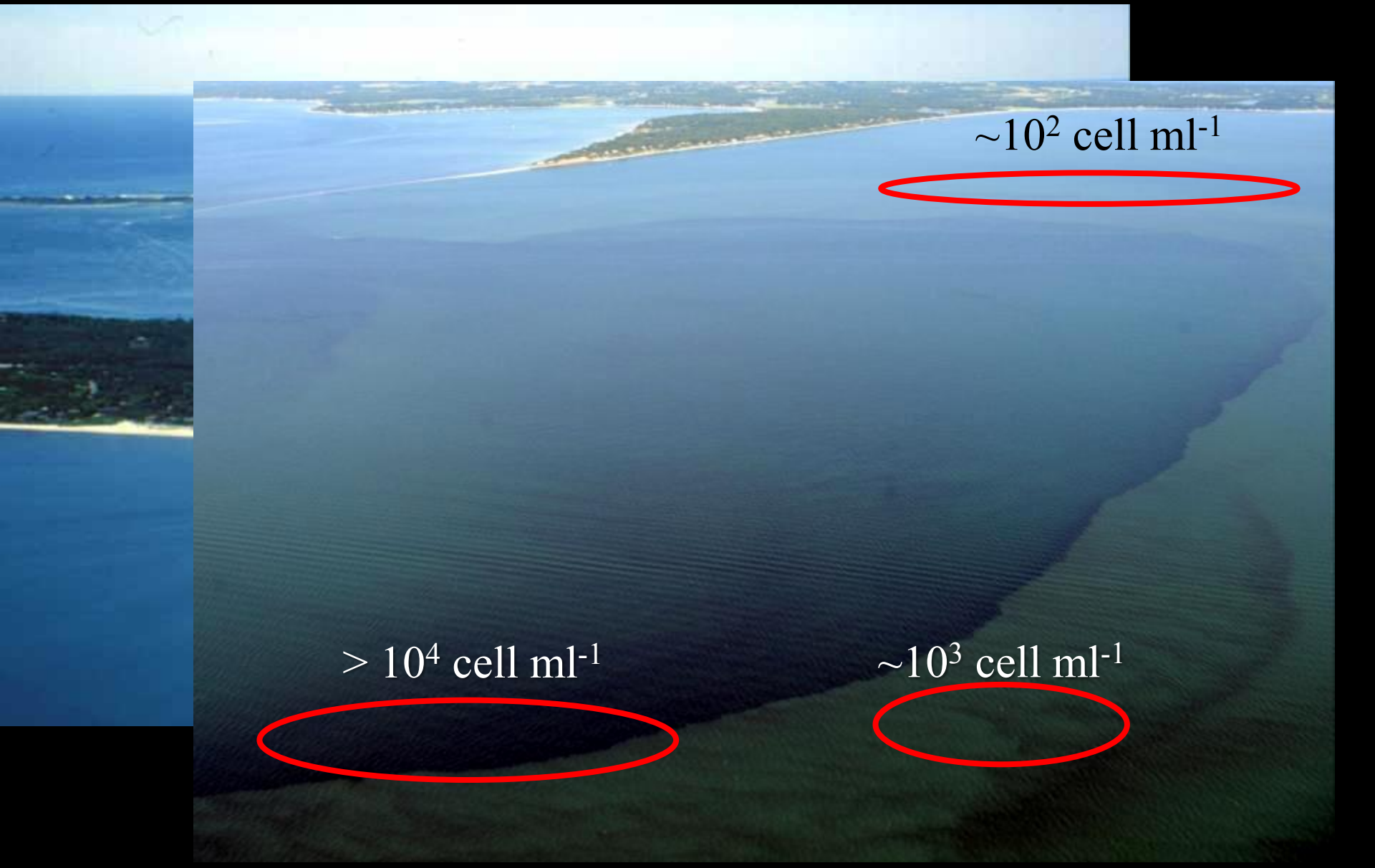


Cochlodinium rust tides

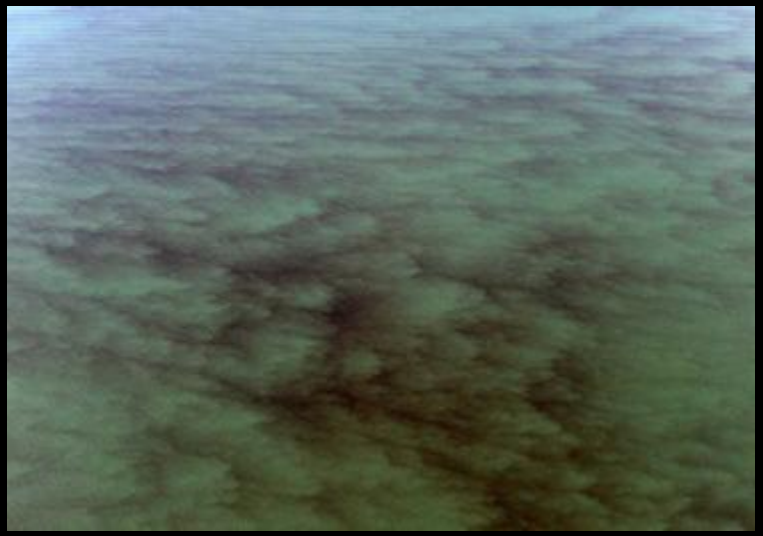
Cochlodinium

- An East End phenomenon: Peconics, Shinnecock
- Typically occurs in August and September
- Forms distinctive, large patches

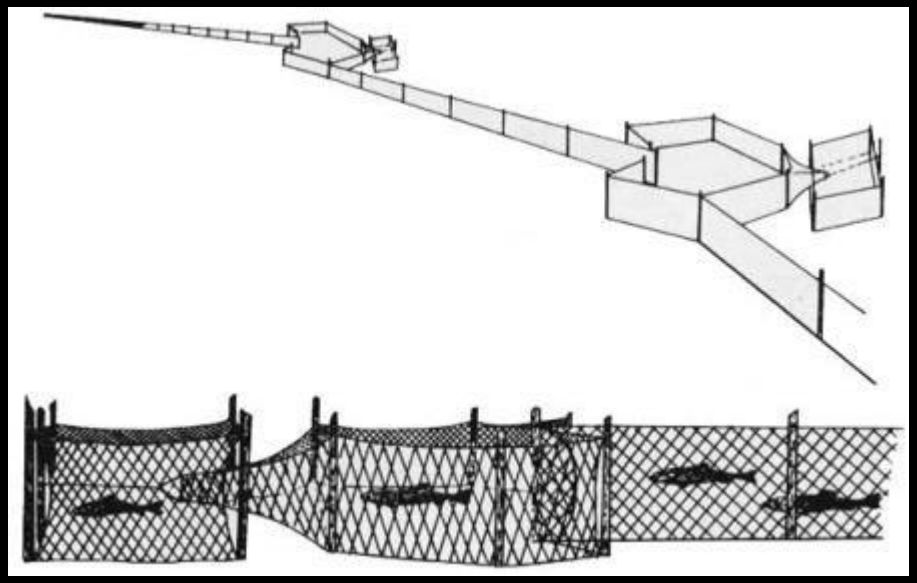
Cochlodinium polykrikoides blooms in NY, USA



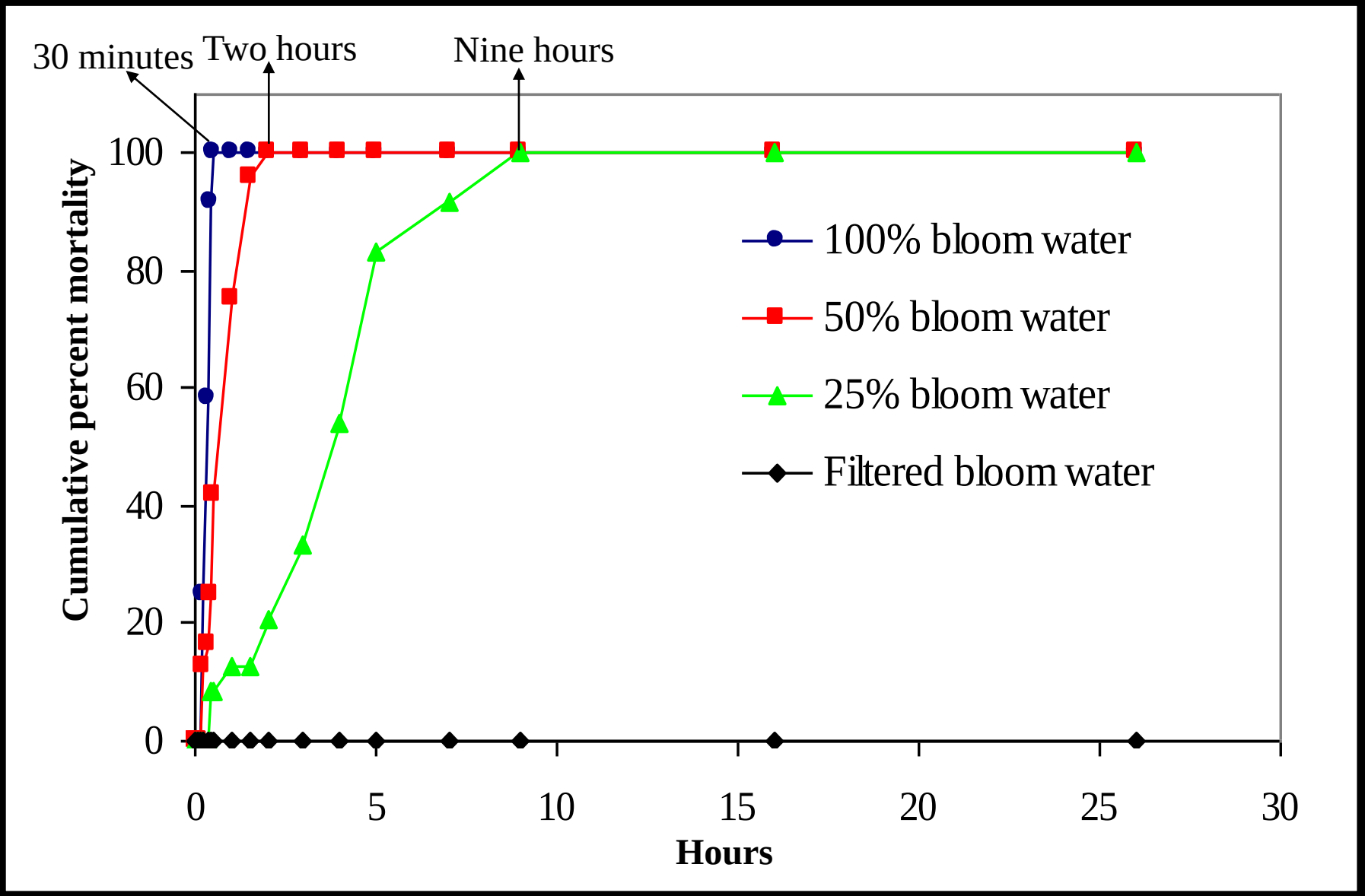
Cochlodinium polykrikoides blooms in New York, 2004 - 2010



Cochlodinium impacts on planktivorous fish

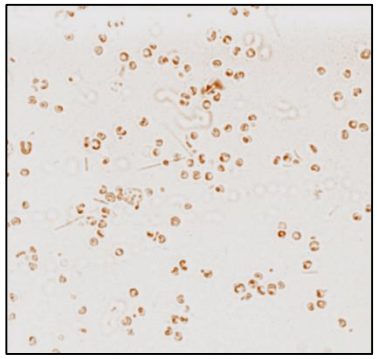


Impacts of *Cochlodinium* on sheepshead minnows (fry)



Long Island Brown tide blooms

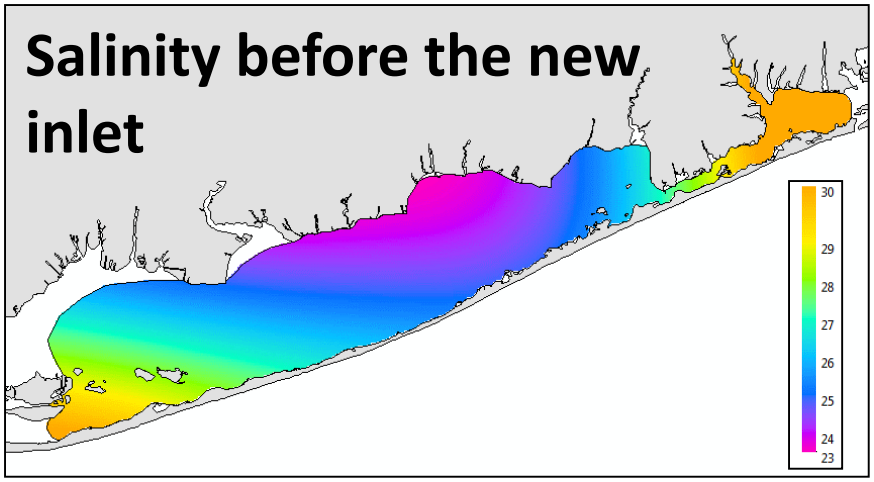
- A south shore phenomenon: Great South Bay, Moriches, Quantuck, Shinnecock Bay
- Typically occurs in June – July, September - November
- Turns bays dark-to-light brown

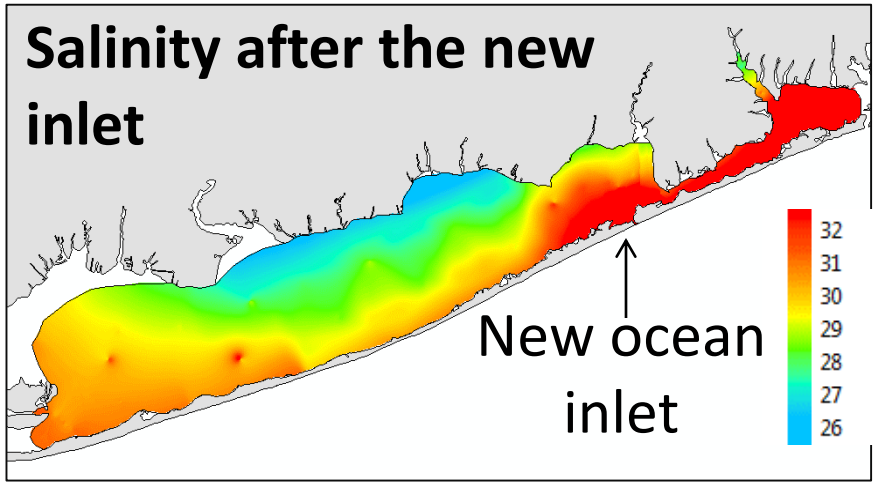


Brown tide

Ocean flushing and brown tides

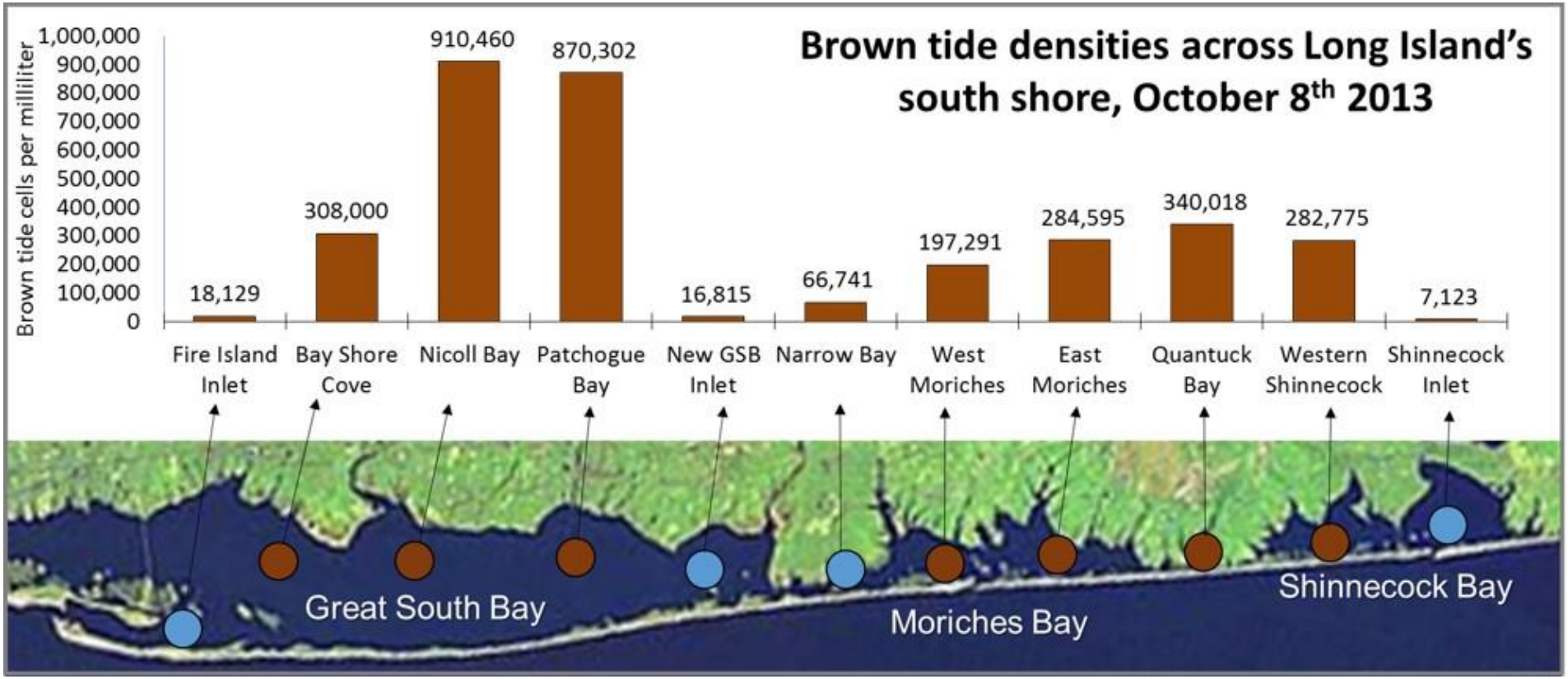
New inlet in Great South Bay following Hurricane Sandy





Flushing time week to months

Flushing time one daily


Brown tide densities across Long Island's south shore, October 8th 2013
Brown tide cells per milliliter
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
18,129
308,000
910,460
870,302
16,815
66,741
197,291
284,595
340,018
282,775
7,123
Fire Island Inlet
Bay Shore Cove
Nicoll Bay
Patchogue Bay
New GSB Inlet
Narrow Bay
West Moriches
East Moriches
Quantuck Bay
Western Shinnecock
Shinnecock Inlet
Great South Bay
Moriches Bay
Shinnecock Bay

Toxic cyanobacteria ecology and health effects

•Cyanobacteria blooms usually occur in eutrophic freshwater lakes during warmer months (peak recreational period)

•Many strains of freshwater cyanobacteria synthesize potent hepatotoxins and neurotoxins, such as microcystin and anatoxin-a, respectively

• The World Health Organization (WHO) has set a 1µg per liter concentration for microcystin as a guideline level for safe drinking water.

•Cyanotoxins can cause serious neurological and gastrointestinal disorders and have been associated with gastrointestinal cancers.

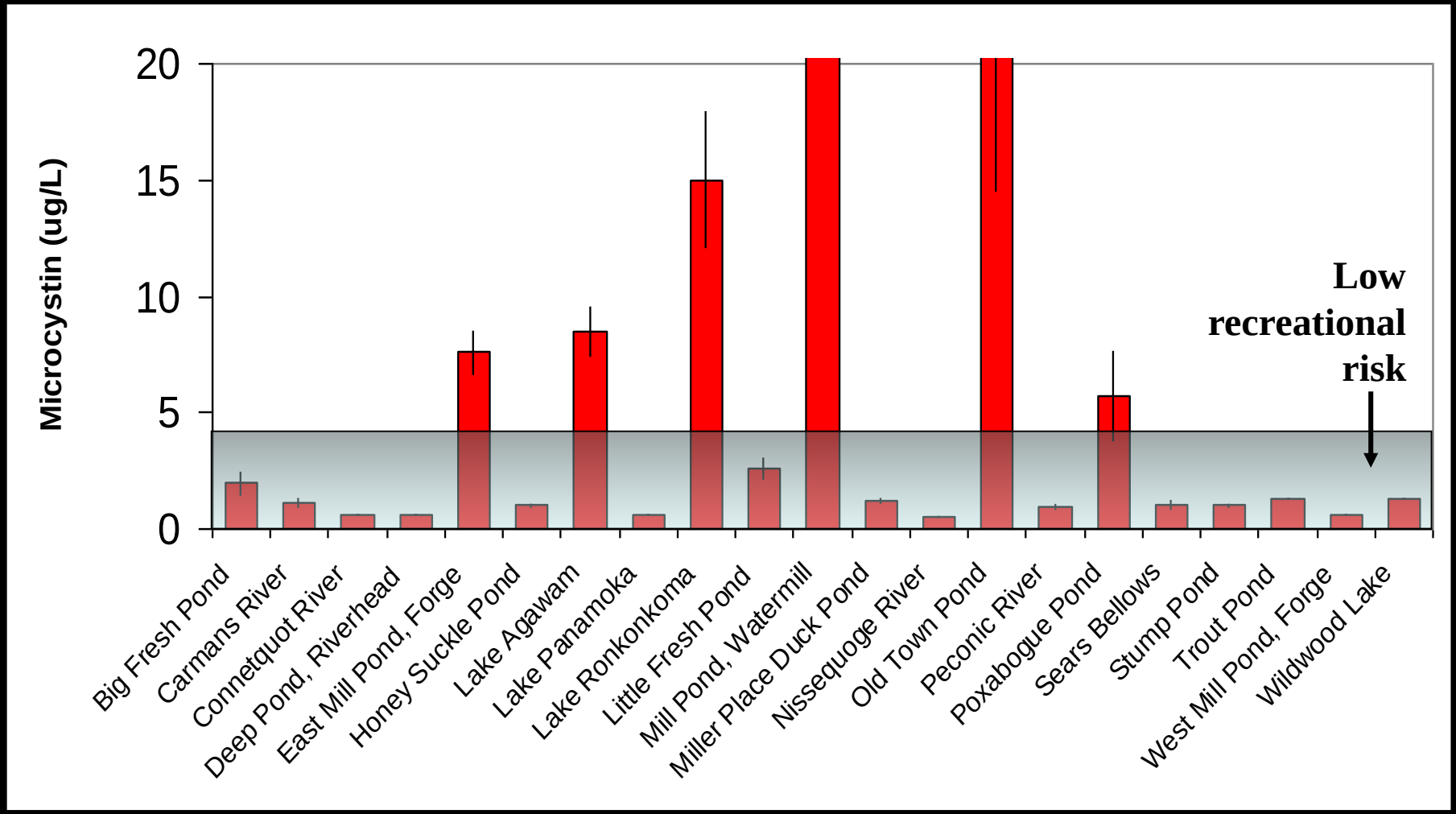
•Cyanotoxins have been linked to deaths in waterfowl, cattle, and dogs

Bloom Formation

Mechanisms for bloom formation include:

- **Poorly flushed waters (high residence time)**
- **Excess nutrient concentrations (eutrophication)**
- **Decreased grazing pressure**
- **Higher water temperatures: >15˚C**

Suffolk County Lake Survey



Lake Agawam, Southampton

EASTERN EDITION

The Southampton Press

THURSDAY, SEPTEMBER 25, 2008

Scientists Puzzled by Fish Kill in Mill Pond

Algae bloom might be the primary culprit

By Beth Young

A massive fish kill in Water Mill's Mill Pond was discovered on Monday by scientists who have been monitoring algae blooms in the freshwater pond over the past several years.

Dr. Chris Gobler, an associate professor at Stony Brook University, said he received several phone calls Monday morning from residents who live near the pond, reporting that thousands of fish of at least six different species were floating dead in the pond.

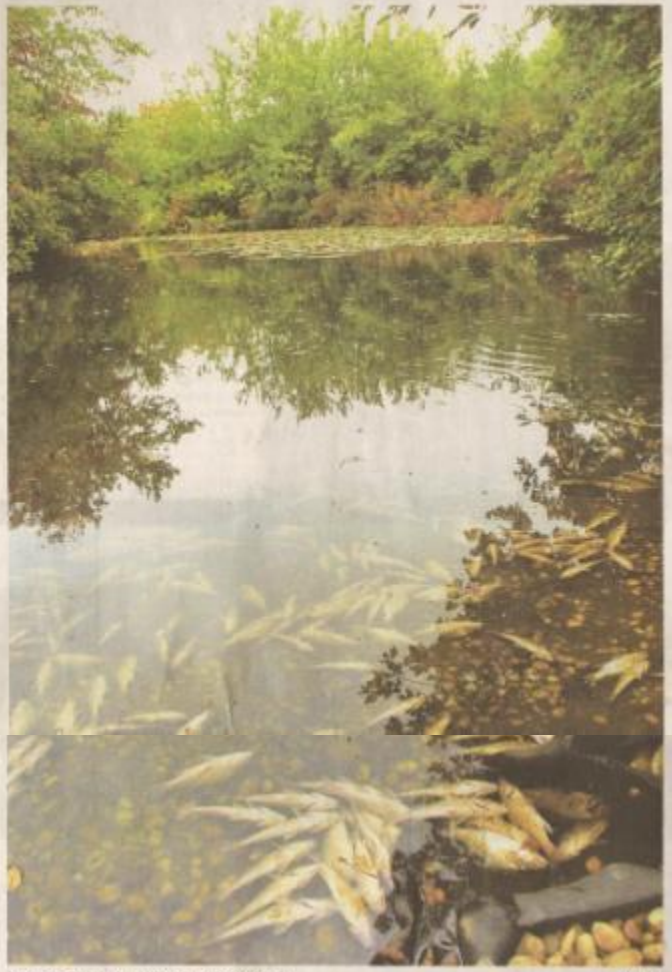
Oxygen levels had returned to normal levels by Tuesday morning.

Dr. Gobler and his laboratory group have been monitoring the levels of blue-green algae blooms in the pond since 2005. He said that last week the group recorded one of the largest blooms ever observed in the pond. At least six different species, including white perch, catfish, eels and bass, have been collected by Stony Brook students, who will continue to monitor algae blooms, the algae consume much of the oxygen in the water, asphyxiating the fish. Such a situation occurred in Lake Agawam in Southampton Village in 2006, when a large number of white perch were found dead in the lake after an algae bloom. White perch are known to be very sensitive to oxygen deprivation.

"It wasn't as extensive as this," Dr. Gobler said, comparing the Lake Agawam fish kill to Monday's in Mill Pond. "There are more fish and a greater diversity of fish than we saw there."

Adding to the mystery of the current die-off, Dr. Gobler said that he was puzzled after his research group took tests at

See POND, Page A11

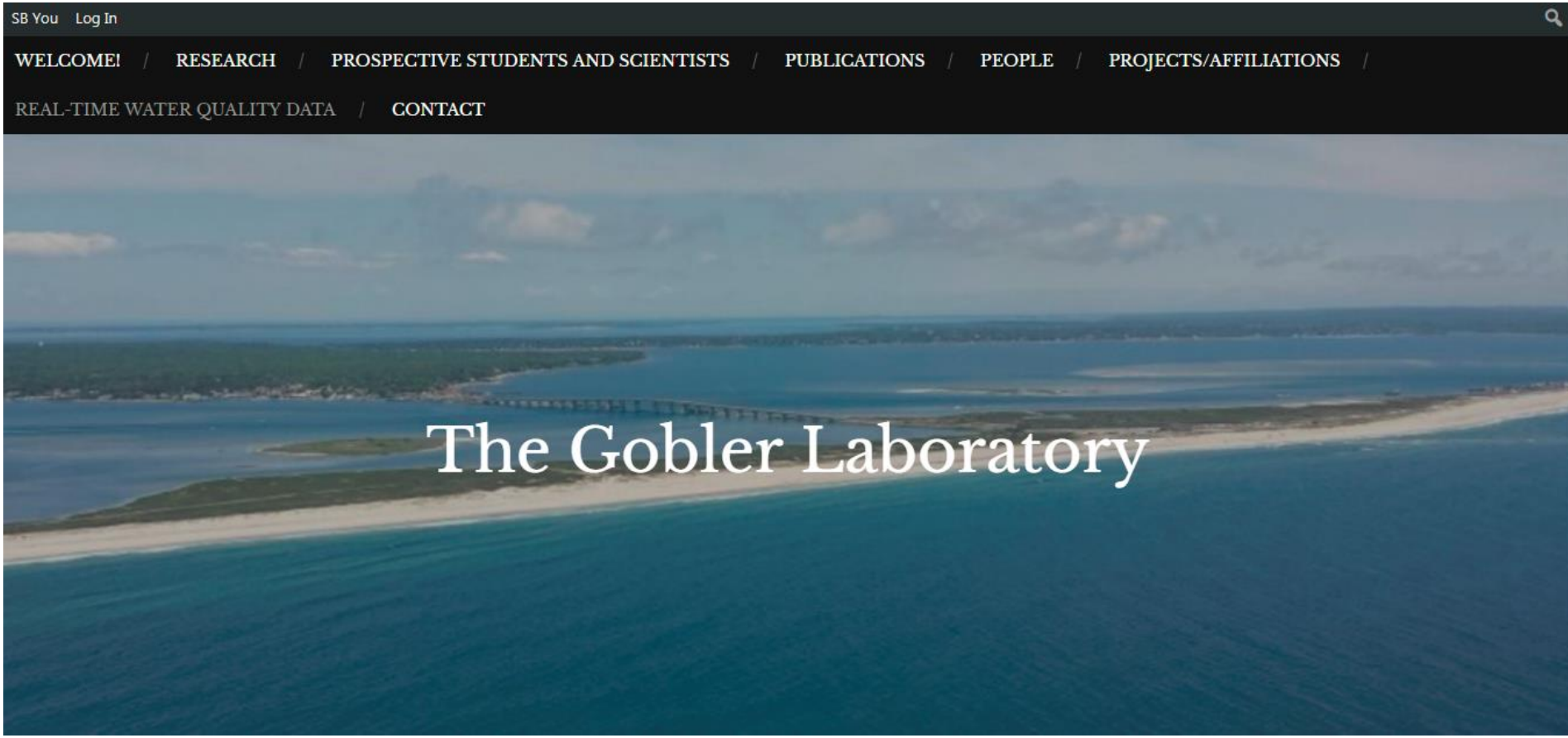


A massive fish kill recently occurred in Mill Pond.

Long Island Marine Monitoring Network (LIMMN)

How?

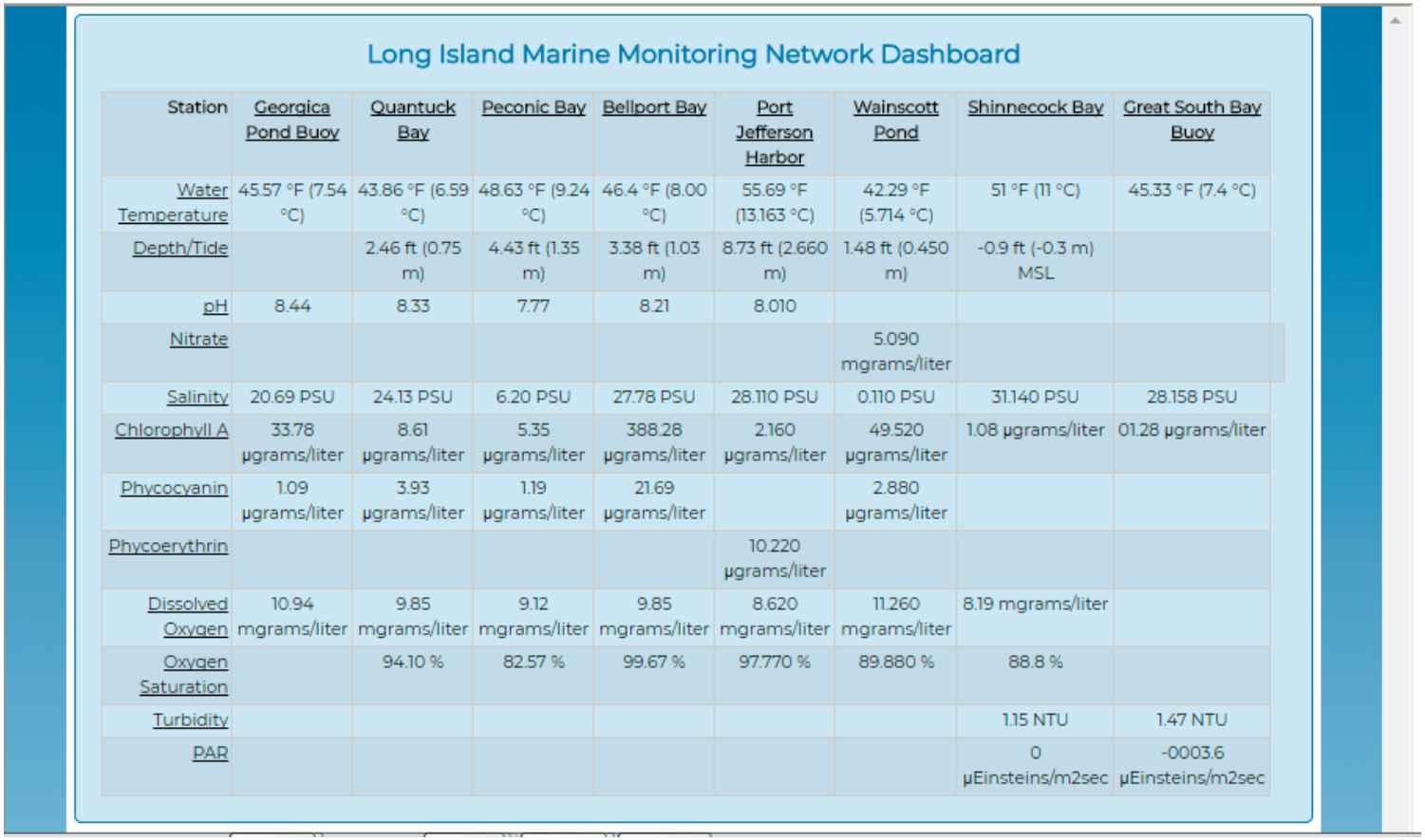
- The monitoring program utilizes both continuous logger data and discrete sampling data.
- At each location, an autonomous sensor (Onset HOBO U26) measuring temperature and DO is deployed and these sensors collect and store data at 10 minute intervals.
- **New this year – telemetry data.**



https://you.stonybrook.edu/goblerlab/

RT-map.php was last modified: September 21 2017 15:48:36.

Real-Time Water Quality Data

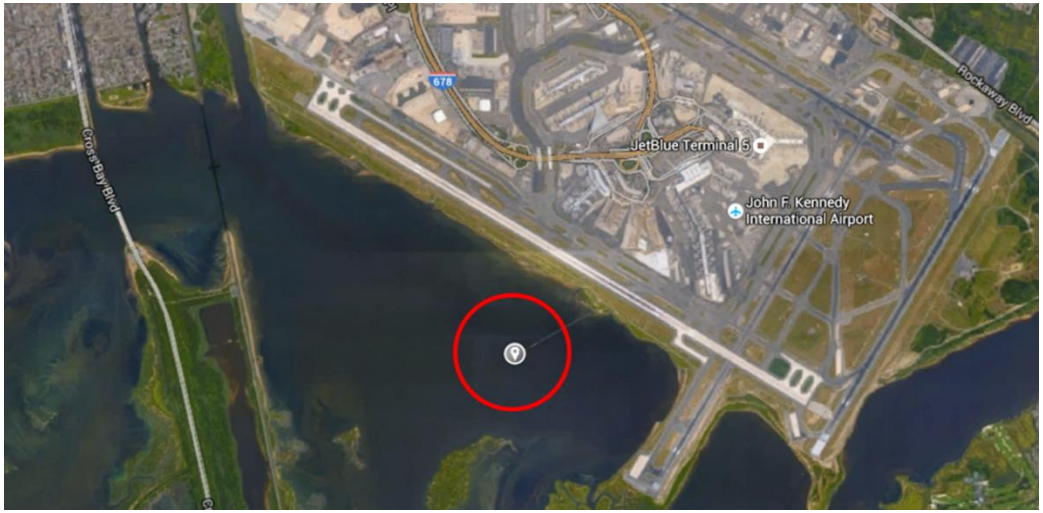


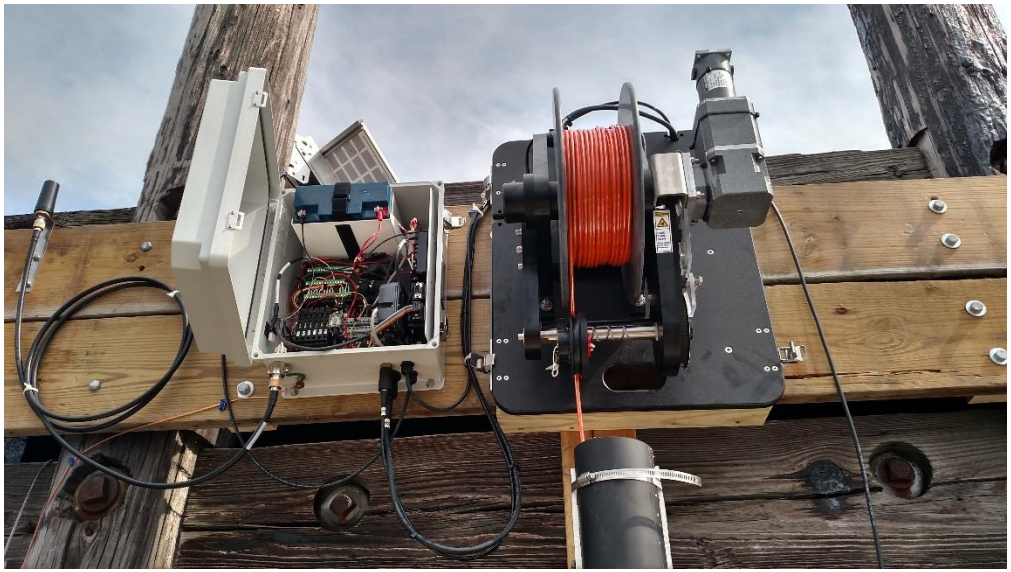
Long Island Marine Monitoring Network Dashboard

Station	Georgica Pond Buoy	Quantuck Bay	Peconic Bay	Bellport Bay	Port Jefferson Harbor	Wainscott Pond	Shinnecock Bay	Great South Bay Buoy
Water Temperature	45.57 °F (7.54 °C)	43.86 °F (6.59 °C)	48.63 °F (9.24 °C)	46.4 °F (8.00 °C)	55.69 °F (13.163 °C)	42.29 °F (5.714 °C)	51 °F (11 °C)	45.33 °F (7.4 °C)
Depth/Tide		2.46 ft (0.75 m)	4.43 ft (1.35 m)	3.38 ft (1.03 m)	8.73 ft (2.660 m)	1.48 ft (0.450 m)	-0.9 ft (-0.3 m) MSL	
pH	8.44	8.33	7.77	8.21	8.010			
Nitrate						5.090 mgrams/liter		
Salinity	20.69 PSU	24.13 PSU	6.20 PSU	27.78 PSU	28.110 PSU	0.110 PSU	31.140 PSU	28.158 PSU
Chlorophyll A	33.78 µgrams/liter	8.61 µgrams/liter	5.35 µgrams/liter	388.28 µgrams/liter	2.160 µgrams/liter	49.520 µgrams/liter	1.08 µgrams/liter	01.28 µgrams/liter
Phycocyanin	1.09 µgrams/liter	3.93 µgrams/liter	1.19 µgrams/liter	21.69 µgrams/liter		2.880 µgrams/liter		
Phycoerythrin					10.220 µgrams/liter			
Dissolved Oxygen	10.94 mgrams/liter	9.85 mgrams/liter	9.12 mgrams/liter	9.85 mgrams/liter	8.620 mgrams/liter	11.260 mgrams/liter	8.19 mgrams/liter	
Oxygen Saturation		94.10 %	82.57 %	99.67 %	97.770 %	89.880 %	88.8 %	
Turbidity							1.15 NTU	1.47 NTU
PAR							0 µEinsteins/m2sec	-0003.6 µEinsteins/m2sec

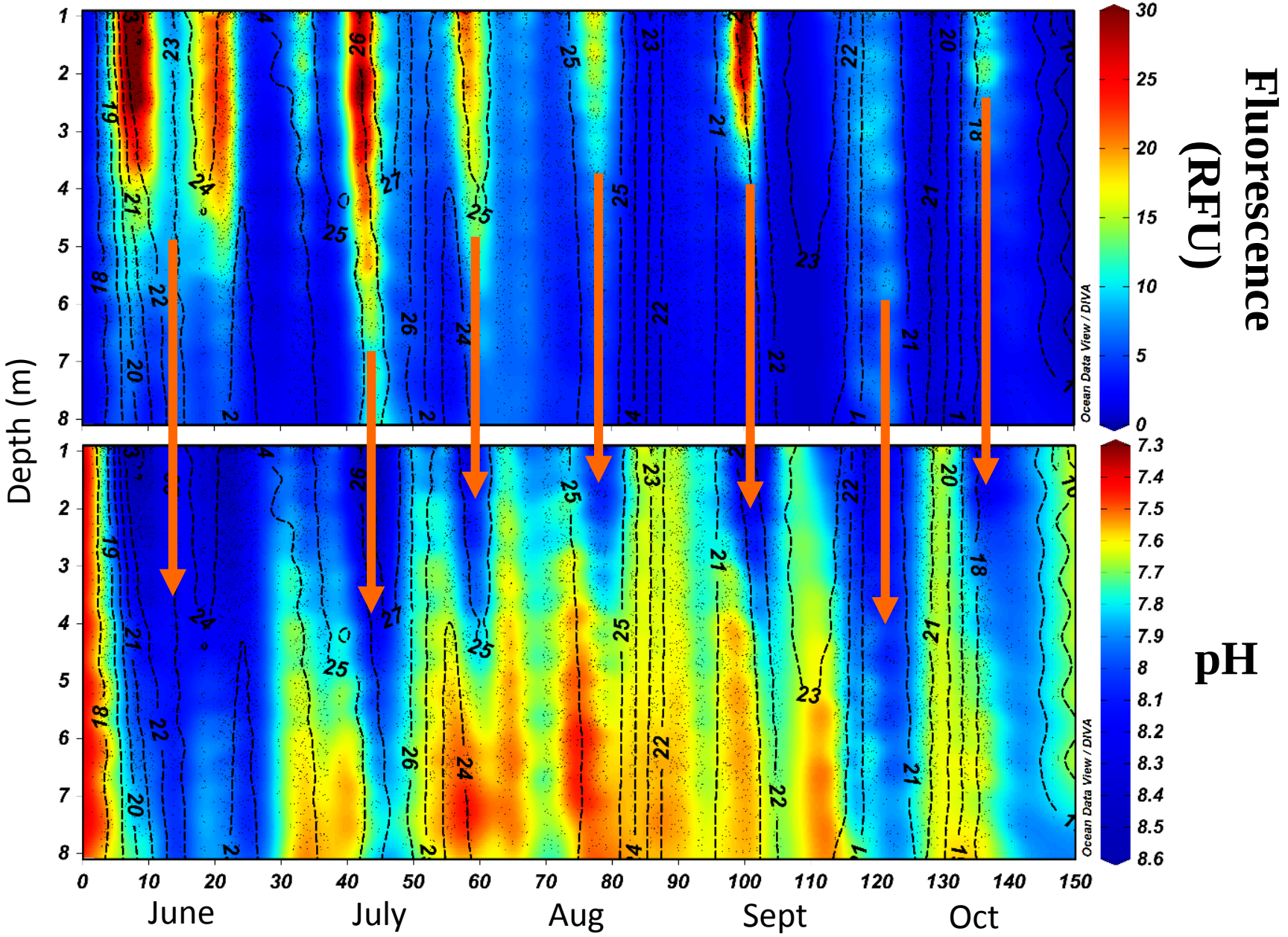
https://you.stonybrook.edu/goblerlab/real-time-water-quality-data/

Automated telemetered profiler

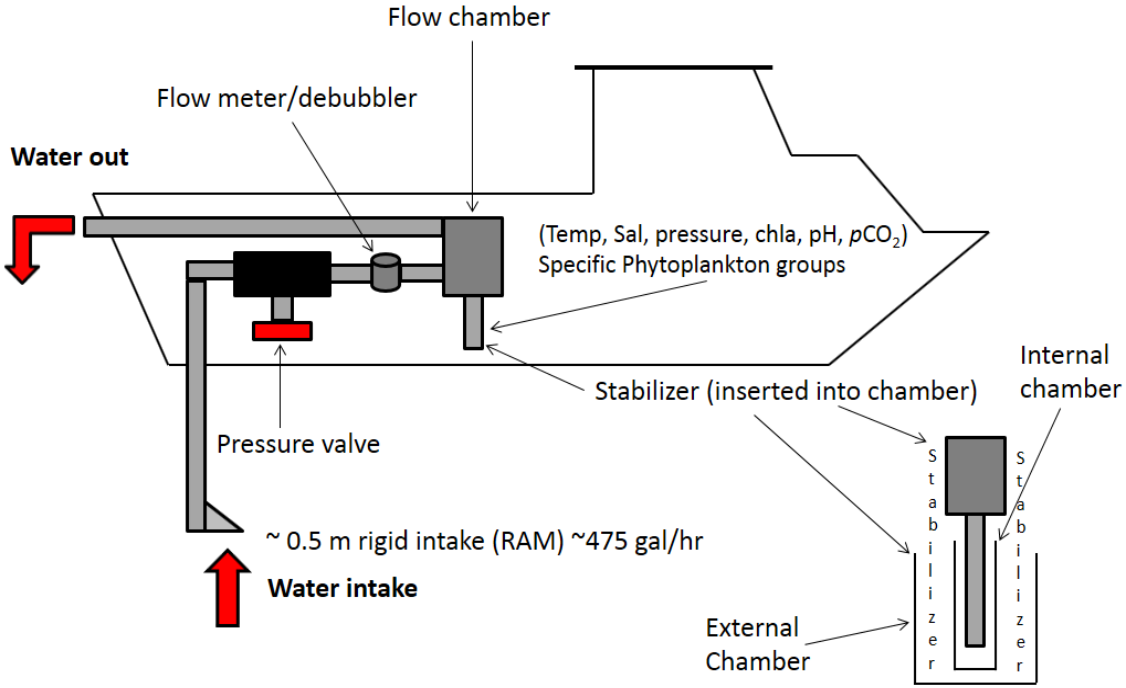




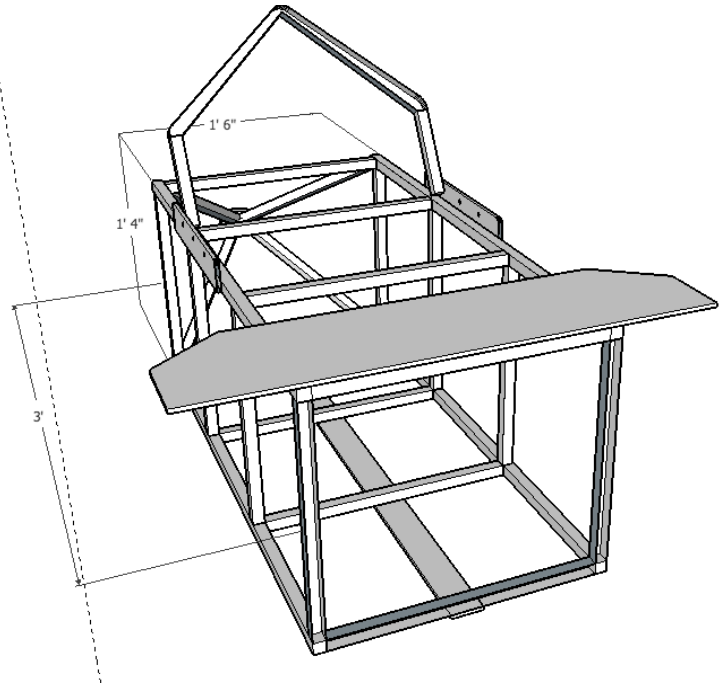
150 days of vertical profiling in Jamaica Bay, 2017

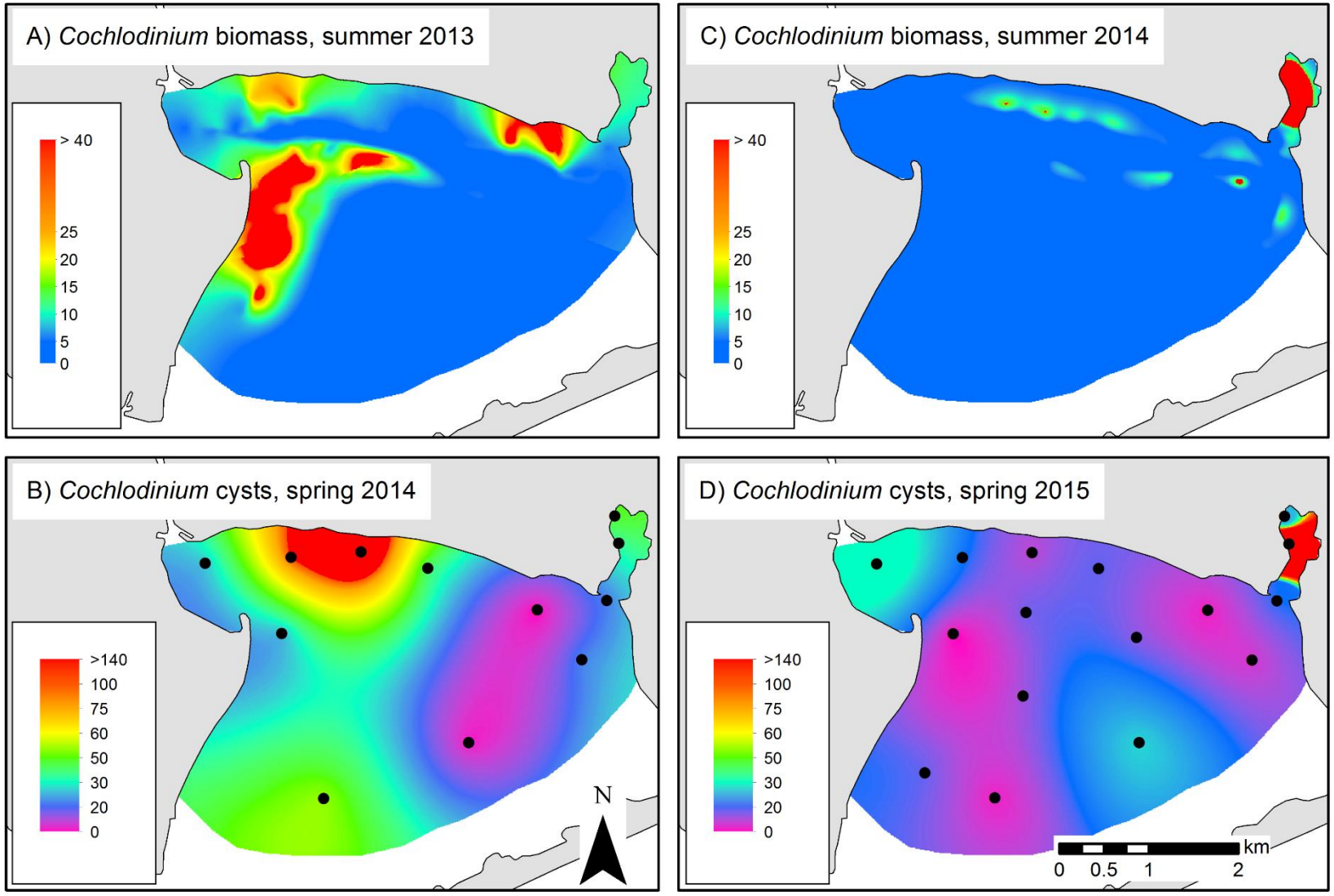


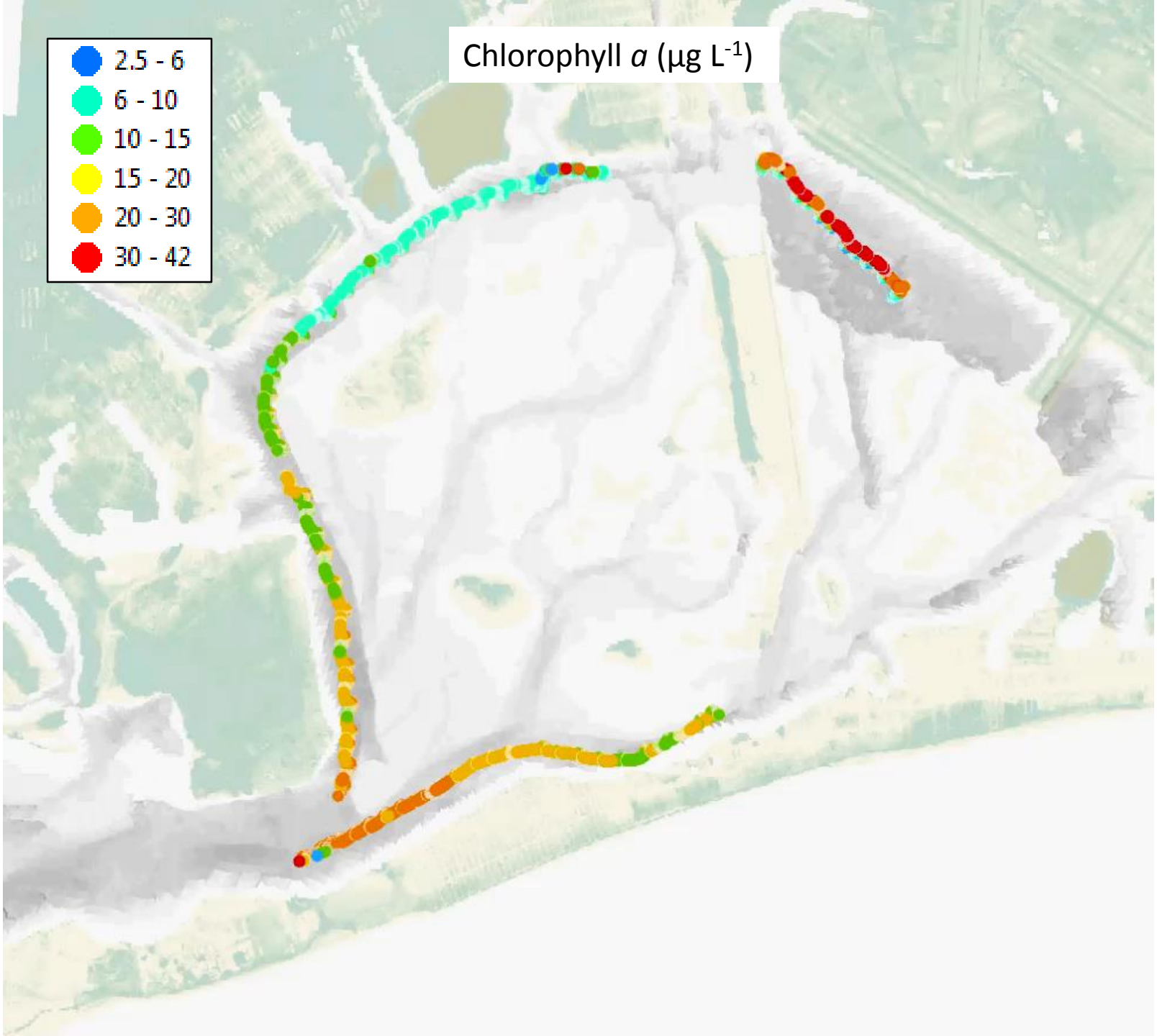
High resolution surface mapping



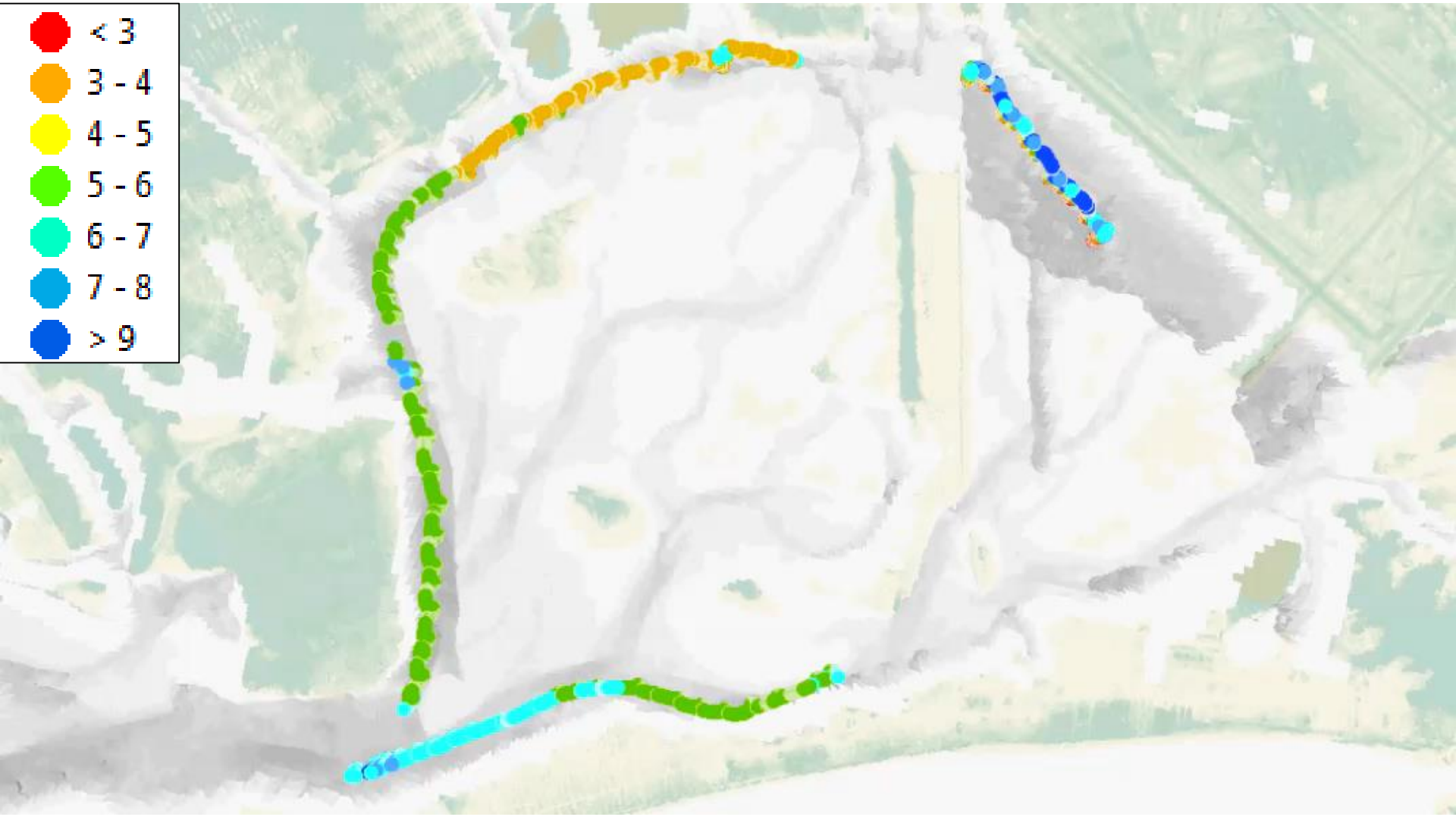
Underway towing profiler

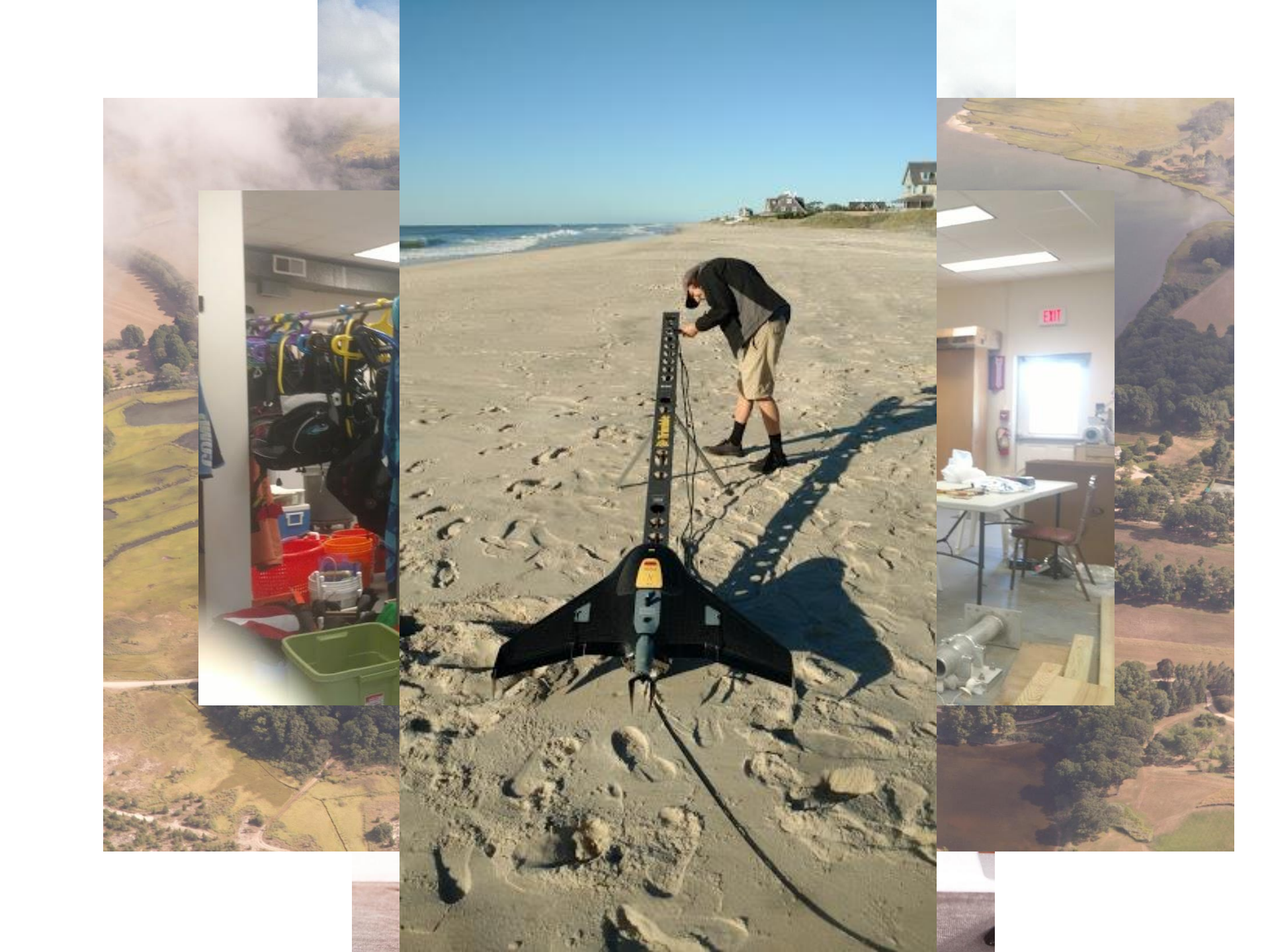



A) *Cochlodinium* biomass, summer 2013
> 40
25
20
15
10
5
0
C) *Cochlodinium* biomass, summer 2014
> 40
25
20
15
10
5
0
B) *Cochlodinium* cysts, spring 2014
>140
100
75
60
50
30
20
0
N
D) *Cochlodinium* cysts, spring 2015
>140
100
75
60
50
30
20
0
km
0
0.5
1
2


Chlorophyll *a* (µg L^{-1})
2.5 - 6
6 - 10
10 - 15
15 - 20
20 - 30
30 - 42

Three-dimensional profiling of DO (mg L^{-1}) in Jamaica Bay
August, 2015




EXIT

Conclusions

- Harmful algal blooms are an increasingly common phenomenon in coastal ecosystems.
- Better detection methods, climate change, over-fishing and enhanced nutrient loading are leading to more frequent HABs.
- HABs can harm humans and/or marine life.
- HABs can be caused by dinoflagellates, diatoms, cyanobacteria, and others.