HAB Science in the classroom

Dr. Mindy Richlen

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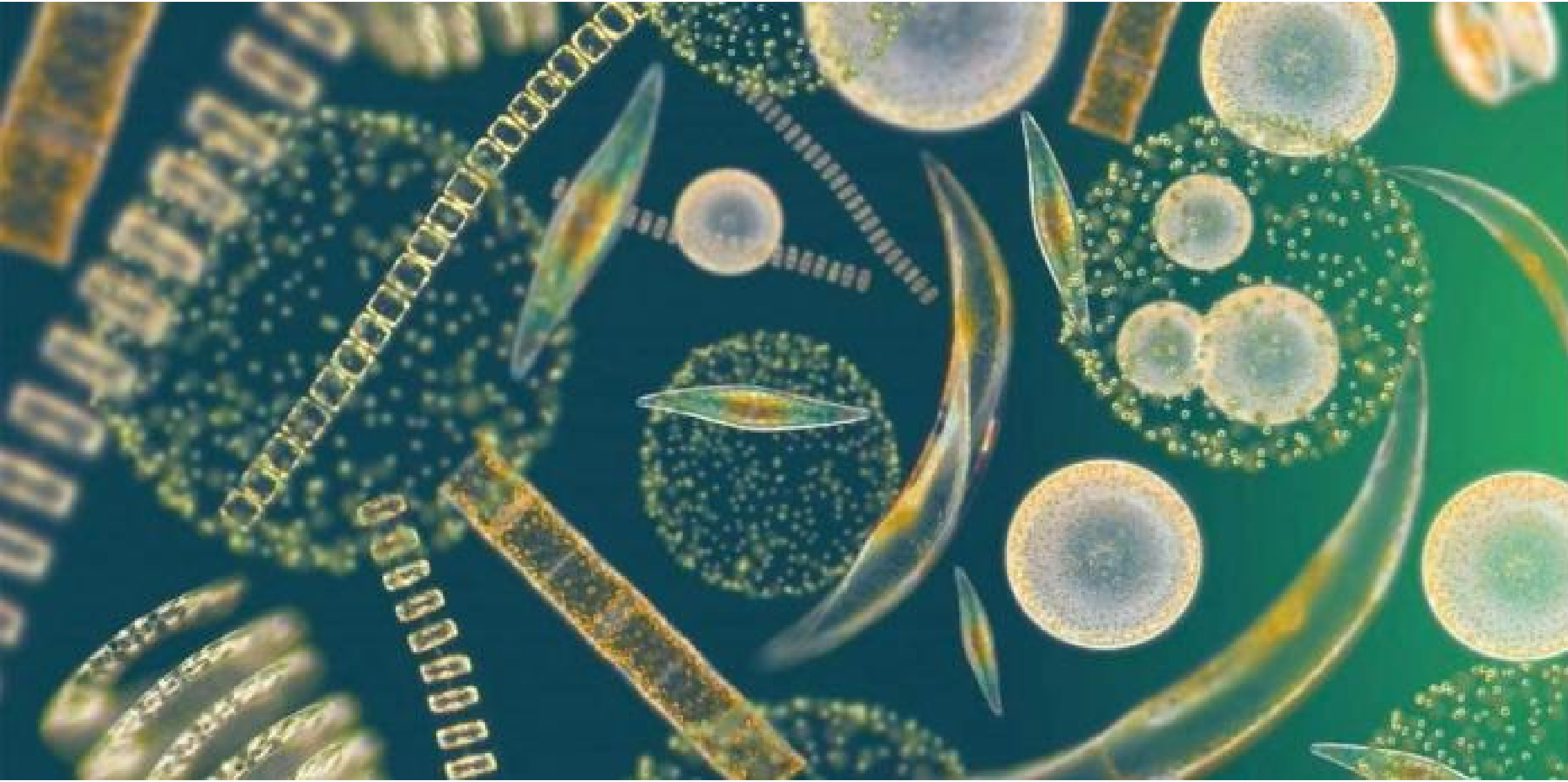
INSTITUTION



What are Harmful Algal Blooms?

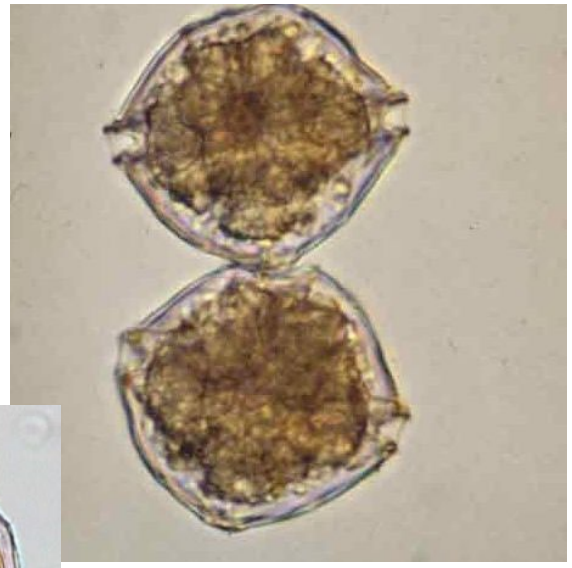
Excessive and rapid accumulations of algae in marine and freshwater environments to levels that can result in harmful impacts.

Categories of Impact:

- Toxins that HABs produce, which can kill fish or shellfish directly, or may sicken humans or wildlife following the ingestion of contaminated seafood or drinking water, or exposure via inhalation or dermal exposure
- Impacts associated with high biomass accumulation - light attenuation, oxygen depletion, clogging or damaging fish gills (i.e., their physical shape causes cells to lodge in gill tissues).

"Red tide" is inaccurate! Some species can cause harm at low concentrations (a thousand cells/L,) while other blooms that turn water red may not cause harm.

Toxins produced by bloom-forming microalgal species



Dinoflagellates

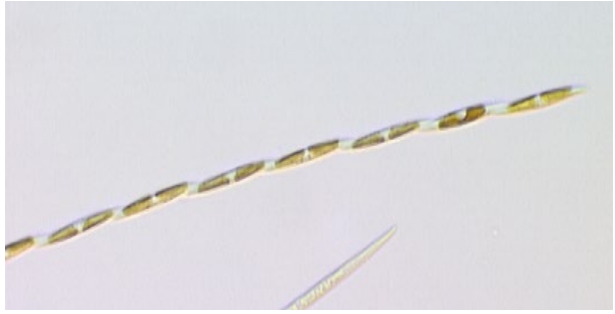
- saxitoxins
- brevetoxins
- okadaic acid
- ciguatoxins
- azaspiracid
- yessotoxin

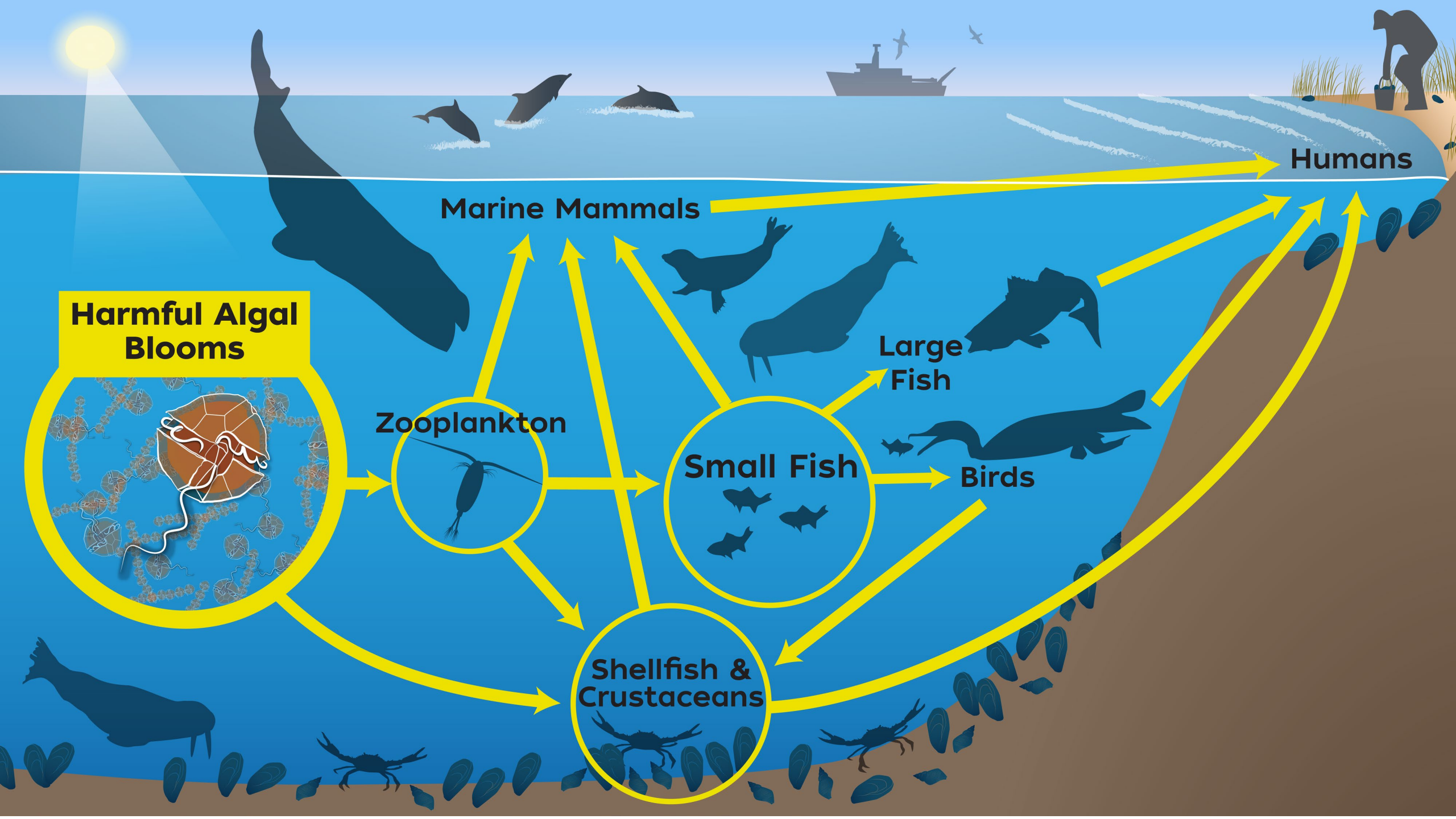
Diatoms

- domoic acid

Cyanobacteria

- saxitoxins
- anatoxins
- microcystins
- nodularins

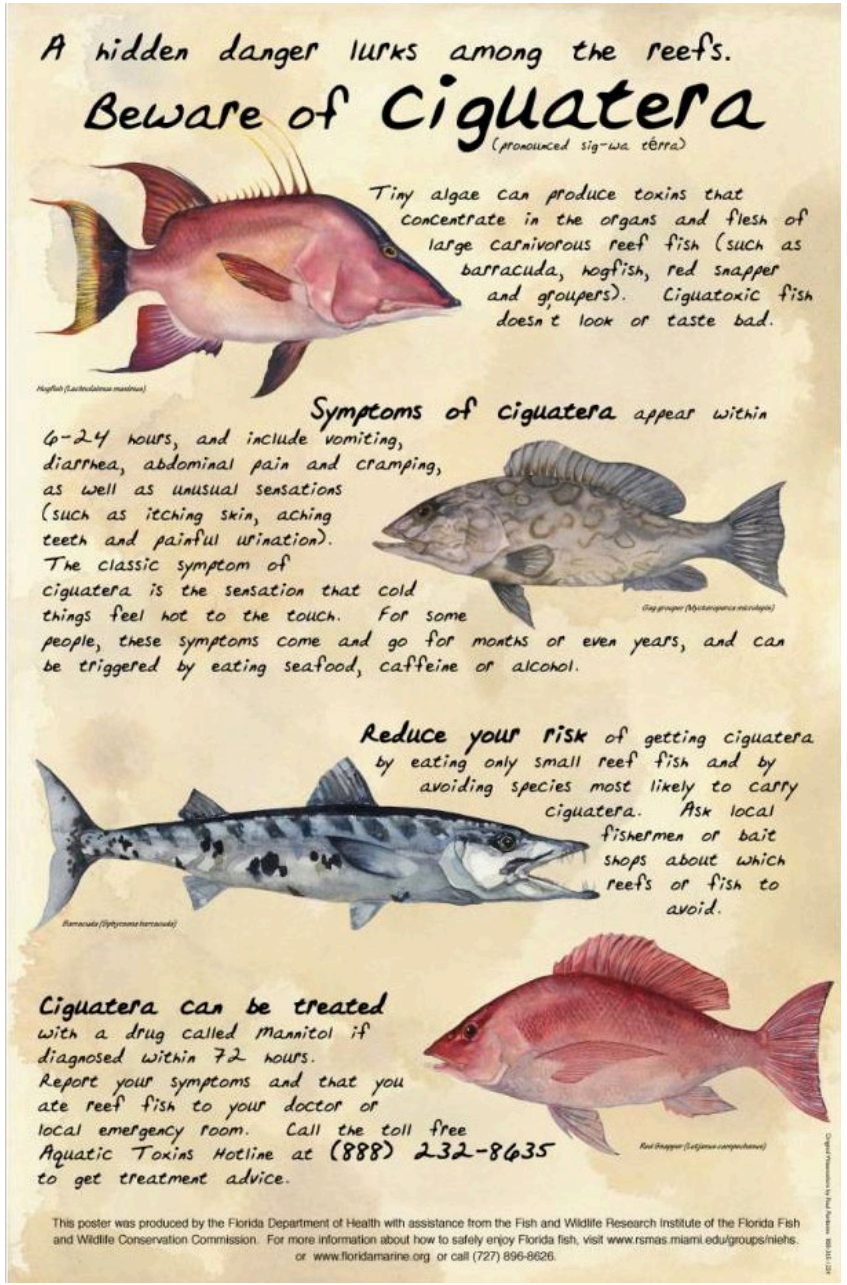



Humans
Marine Mammals
Harmful Algal Blooms
Zooplankton
Large Fish
Small Fish
Birds
Shellfish & Crustaceans

HAB Impacts – Human Health

- Poisoning syndromes caused by toxin accumulation in seafood (shellfish, fish)
  - Paralytic Shellfish Poisoning (PSP)
  - Amnesic Shellfish Poisoning (ASP)
  - Diarrhetic Shellfish Poisoning (DSP)
  - Neurotoxin Shellfish Poisoning (NSP)
  - Ciguatera Poisoning (CP)
- Respiratory irritation and other symptoms in residents/beachgoers (blooms of NSP-causing dinoflagellate *Karenia brevis*)
- Harmful cyanobacteria blooms (also known as CyanoHABs) are potential public health threats in nearly every state due to their presence in drinking and recreational waters.

Occur in New England



HAB Impacts – Wildlife and Ecosystems

- HAB events have caused mass mortalities of domestic animals and wildlife, including fish, sea turtles, manatees, birds, and dolphins.
- Aquaculture and farmed fish vulnerable to effects of toxins and/or high algal biomass (e.g., mechanically clogging fish gills)
- Ecosystem impacts include habitat loss (e.g., from reduced light availability), displacement of other species, hypoxia, altered food web interactions
- Impacts from long-term chronic exposure can include reduced or impaired immunity, growth, and reproduction; altered behavior

Rehabilitation of sea lions recovering from domoic acid intoxication in 2017. During that stranding season, the Pacific Marine Mammal Center rescued 60 sea lions that displayed classic symptoms of domoic acid intoxication.

Socio-Economic Impacts

- Public Health impacts (medical treatment, lost wages)
- Closure of shellfish harvesting & economic losses for fishermen, aquaculture operations, seafood processors, and restaurants
- Economic losses from shellfish recalls
- Long-term reductions in fishery yields
- Community impacts due to disruptions to recreational and subsistence harvesting
- Event response and management expenses
- Socio-ecological crisis and unrest following severe blooms (e.g., 2016 in Chile)

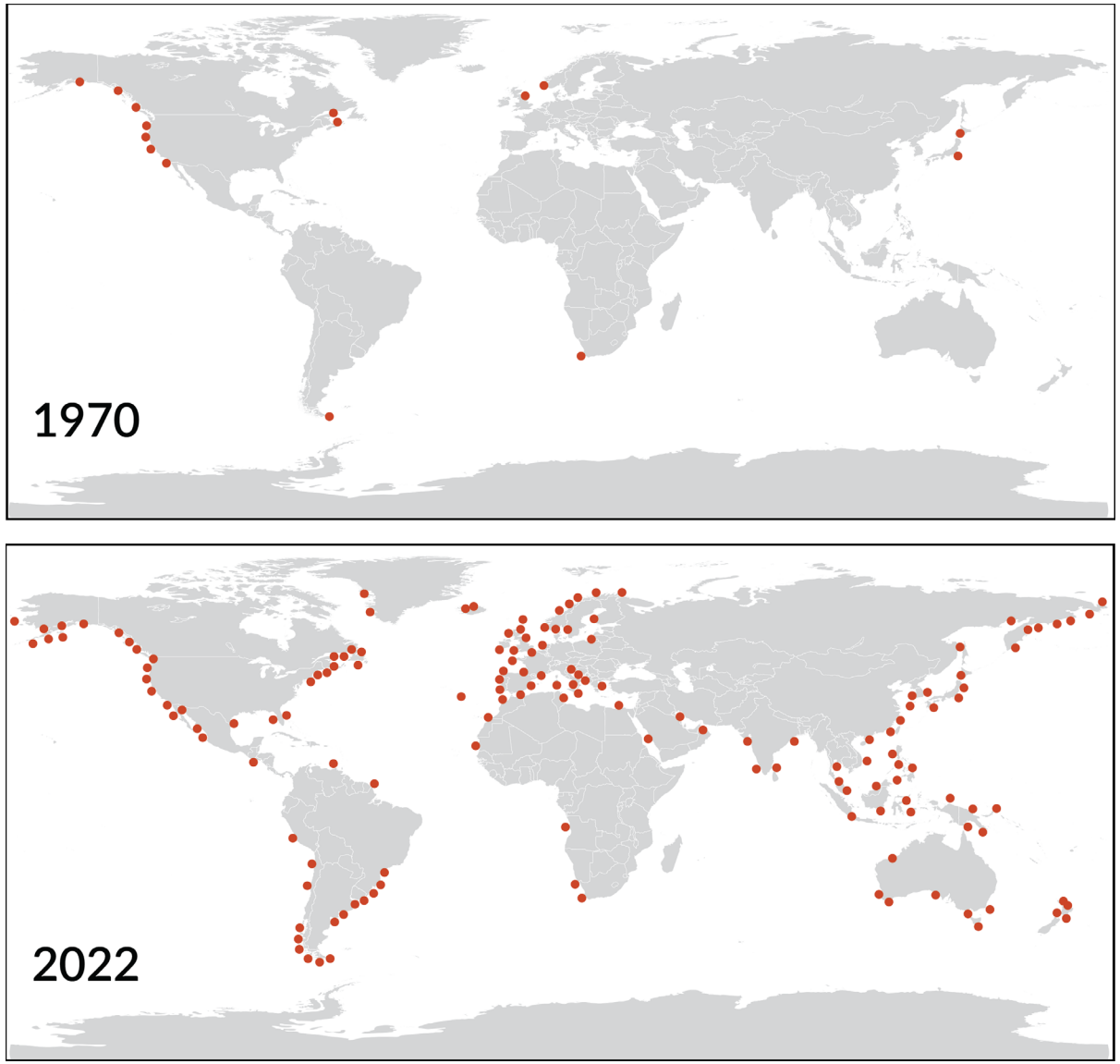
Digging razor clams in WA (image by D. Ayres)

Shellfish harvest closure due to unsafe PST levels.

Protests and social upheaval following the 2016 red tide crisis in Chile (Fig 1f; Armijo et al. 2020)

Global Expansion

- Apparent expansion of marine HABs over the past several decades
- Many coastal countries are faced with disturbing trends of increasing bloom incidence, larger areas affected, more fisheries resources impacted, and higher economic losses
- Causes behind expansion likely include natural species dispersal as well as human-related phenomena such as nutrient inputs, coastal development, aquaculture development, and climatic shifts.
- Also reflects improved monitoring and detection capabilities, and increased scientific scrutiny and awareness.



Map of Paralytic Shellfish Poisoning (PSP) history and global expansion: 1970 (top panel) compared with 2022 (bottom panel). Data from IOC-UNESCO: https://data.hais.ioc-unesco.org/

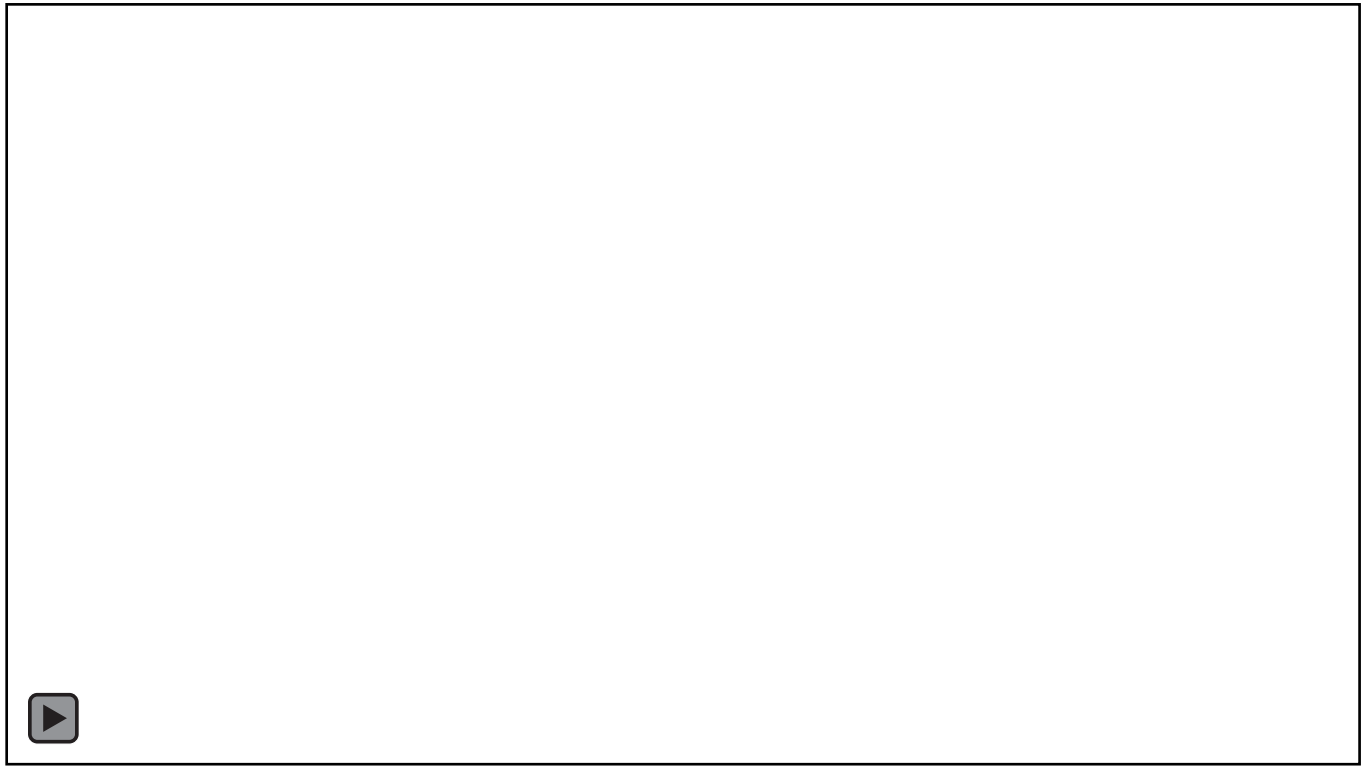
What is Paralytic Shellfish Poisoning?

- Life-threatening syndrome associated with eating seafood contaminated with paralytic shellfish toxins (PSTs)
- Rapid onset (<3h) of neurological symptoms:
  - Tingling, numbness, and burning
  - Ataxia, giddiness, drowsiness, fever, rash, and staggering.
  - Abdominal pain, nausea, vomiting, and diarrhea.
  - Severe cases result in respiratory arrest
- There is no antidote, supportive therapy aids in recovery

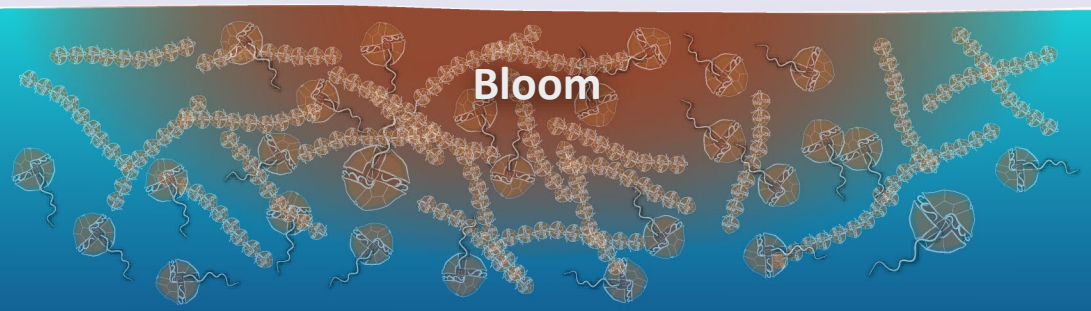
Image by KGBO, Wikimedia Commons

What causes Paralytic Shellfish Poisoning?

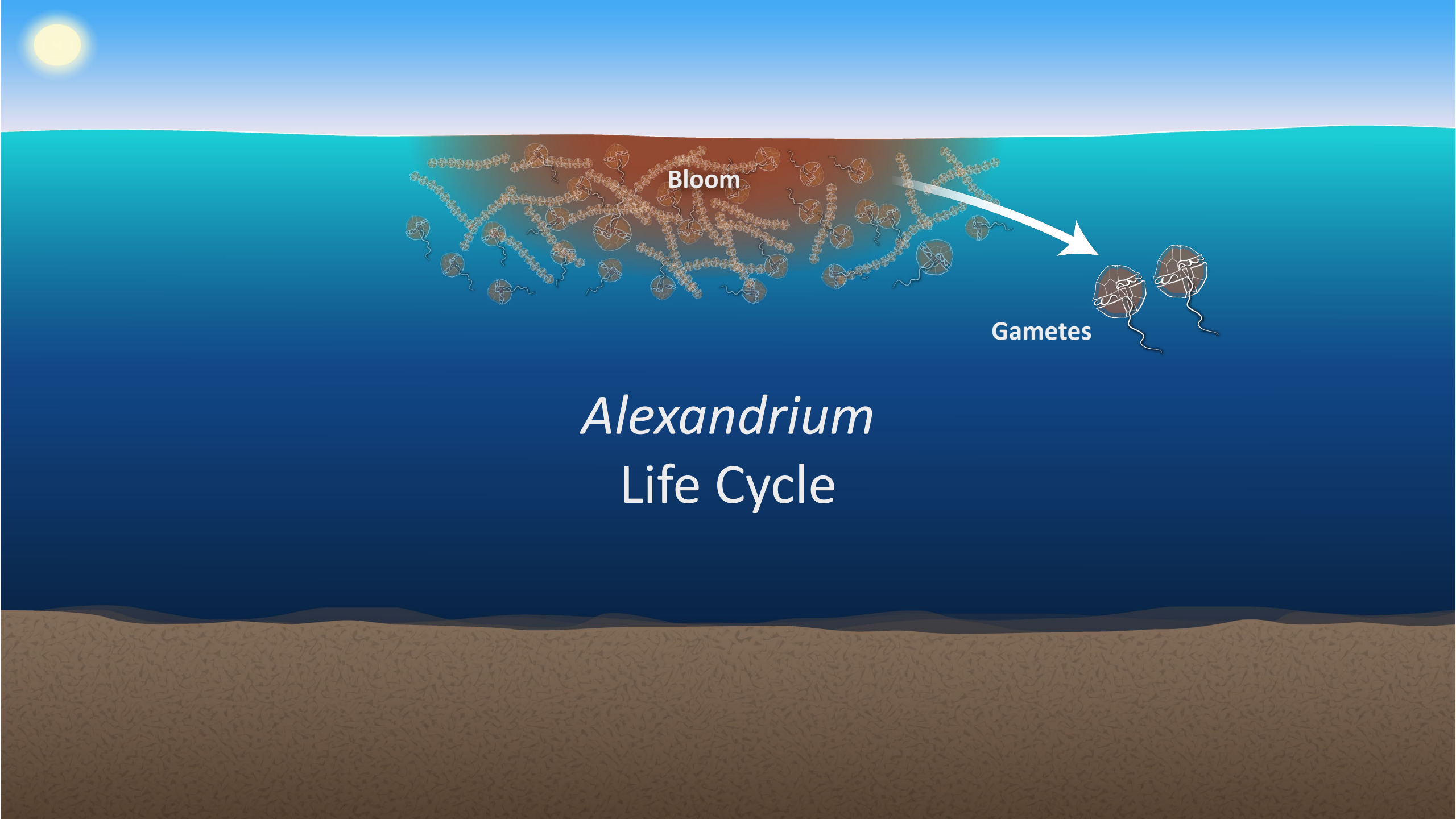
- Bloom forming dinoflagellate species in the genera ***Alexandrium*** and ***Pyrodinium***
- Found globally in coastal waters
- Produce suite of toxic compounds, of which saxitoxin (STX) is most potent
- Cooking seafood does not eliminate the risk of illness
- Human illness caused by PSTs is prevented by large-scale proactive monitoring programs



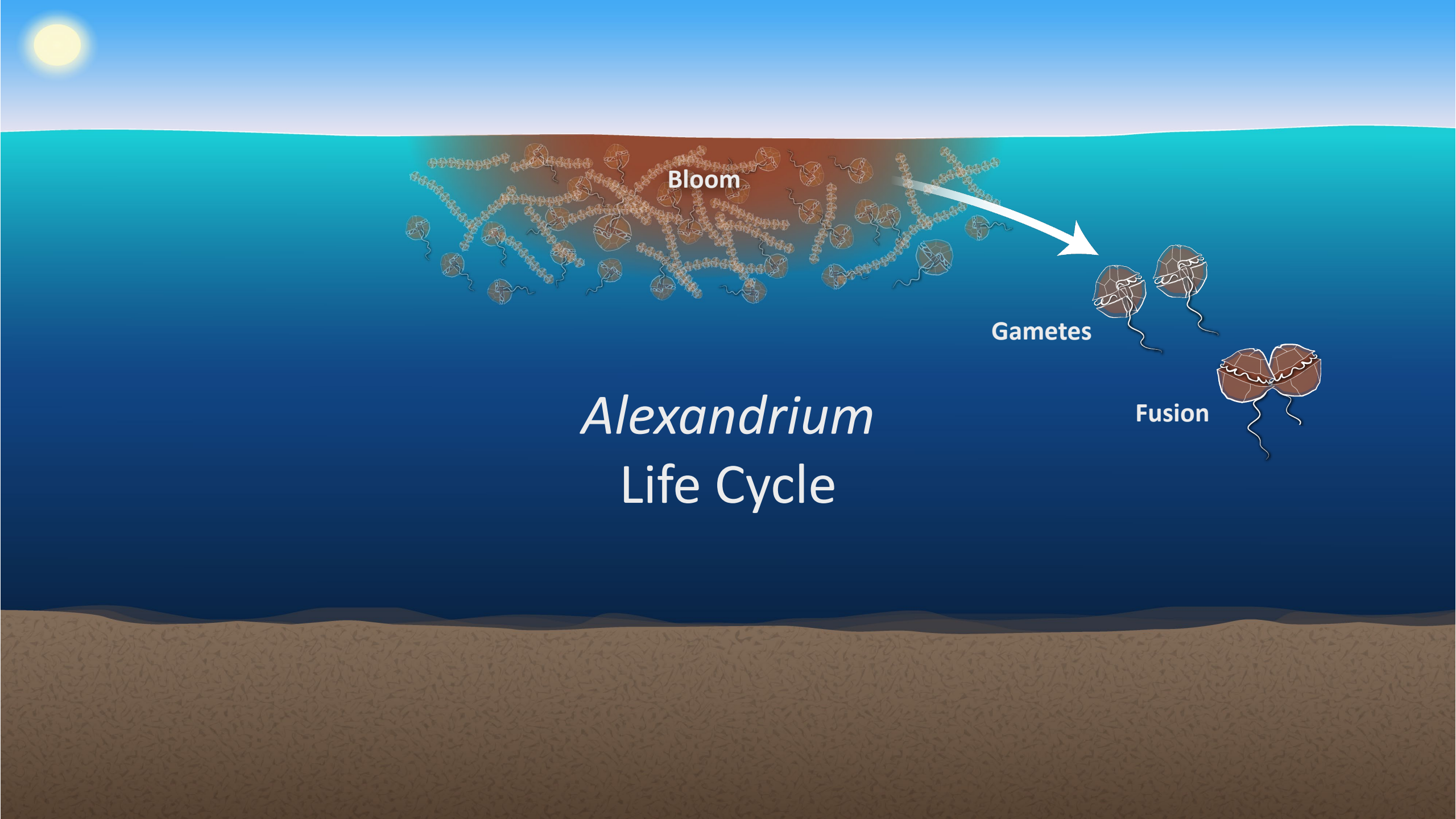
Video by E. Fachon, WHOI

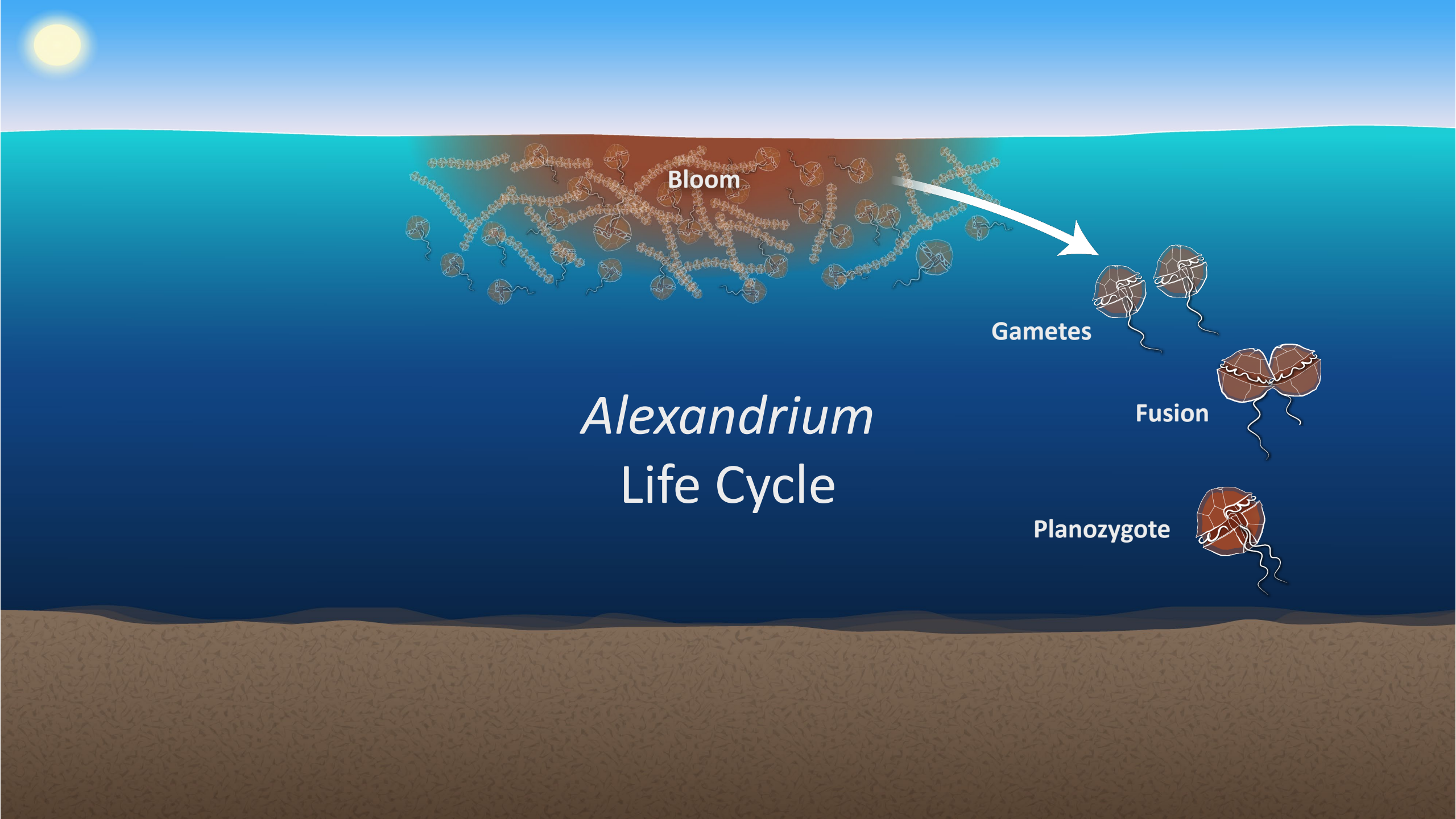


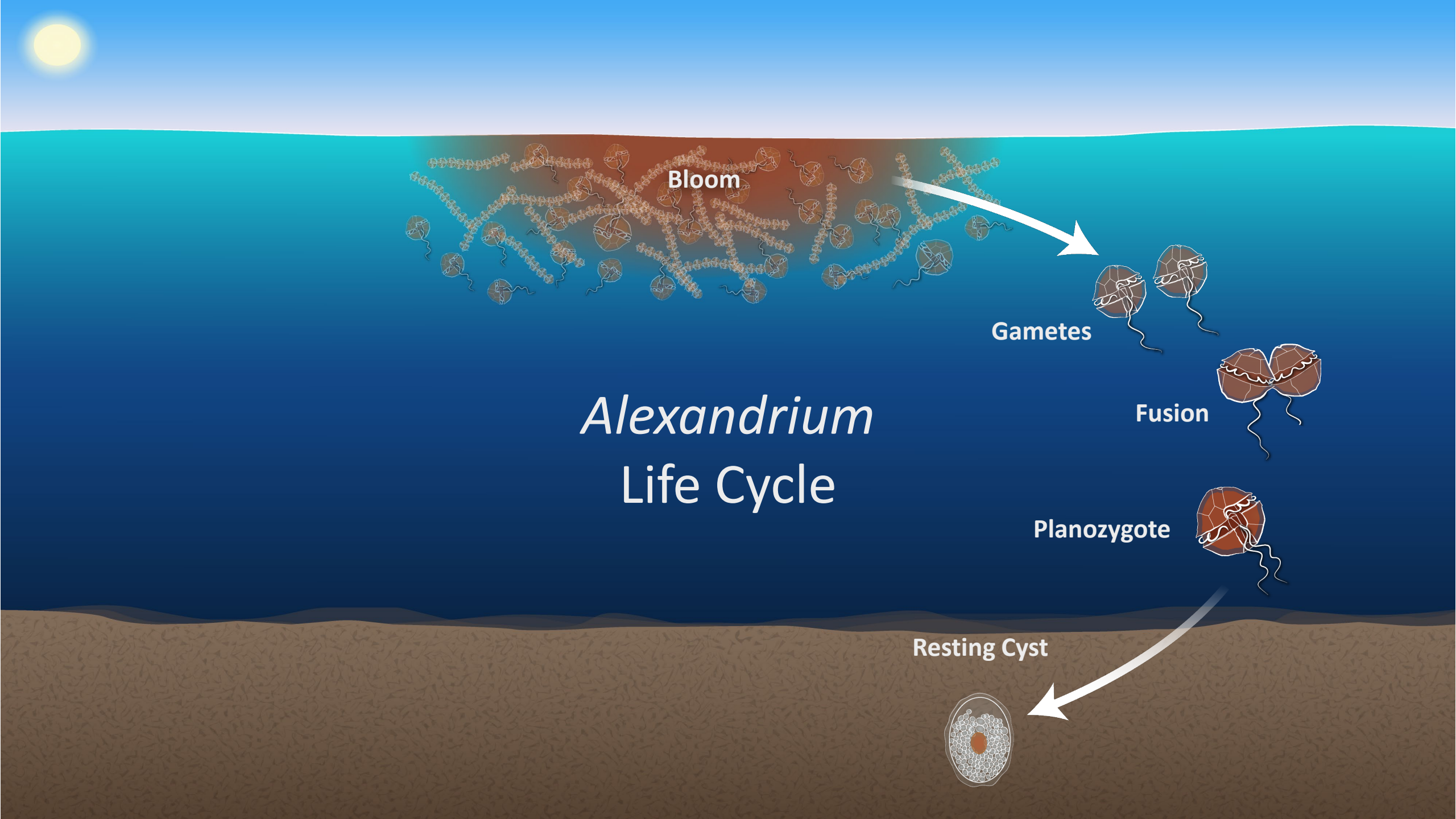
Alexandrium
Life Cycle

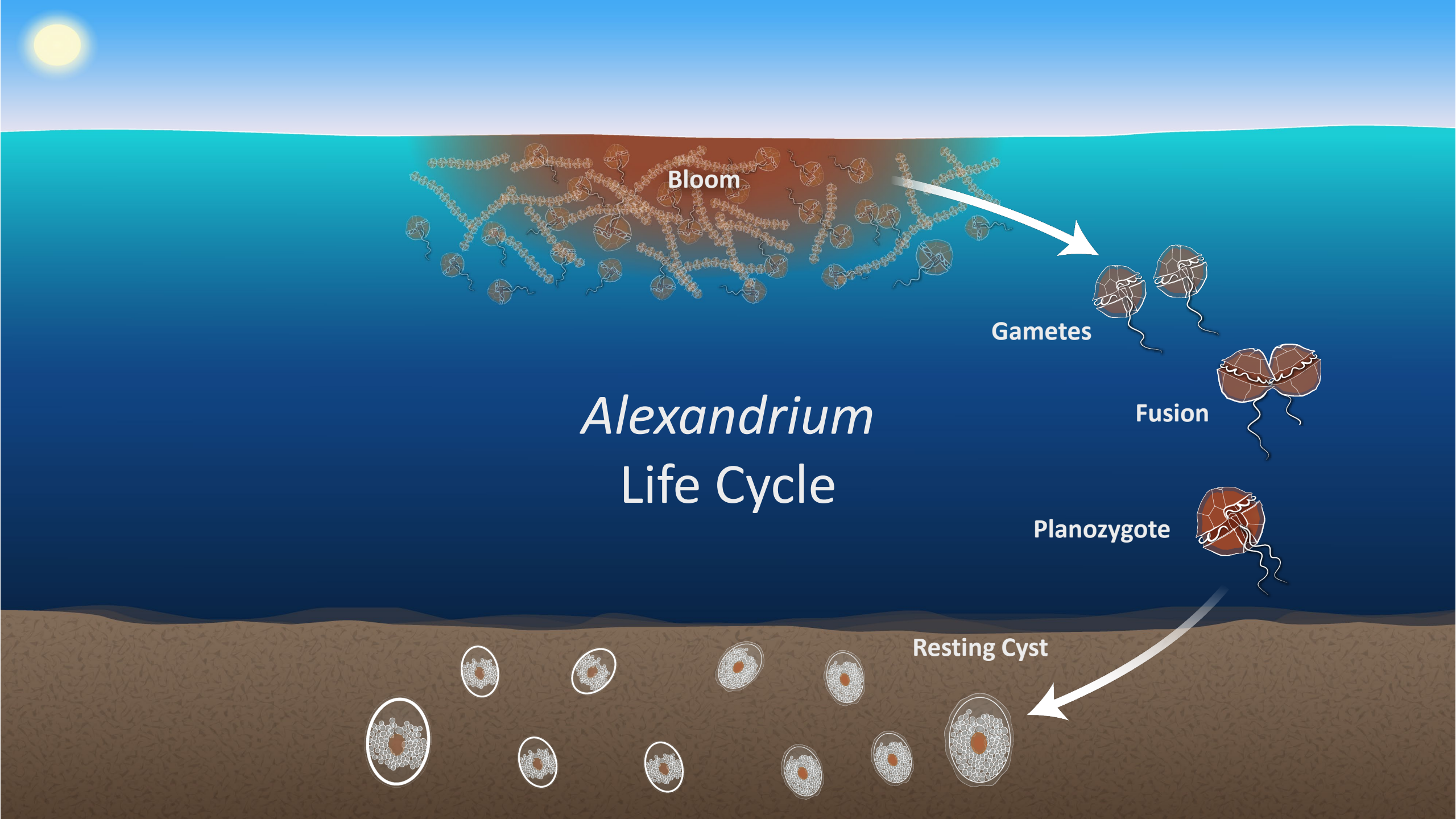


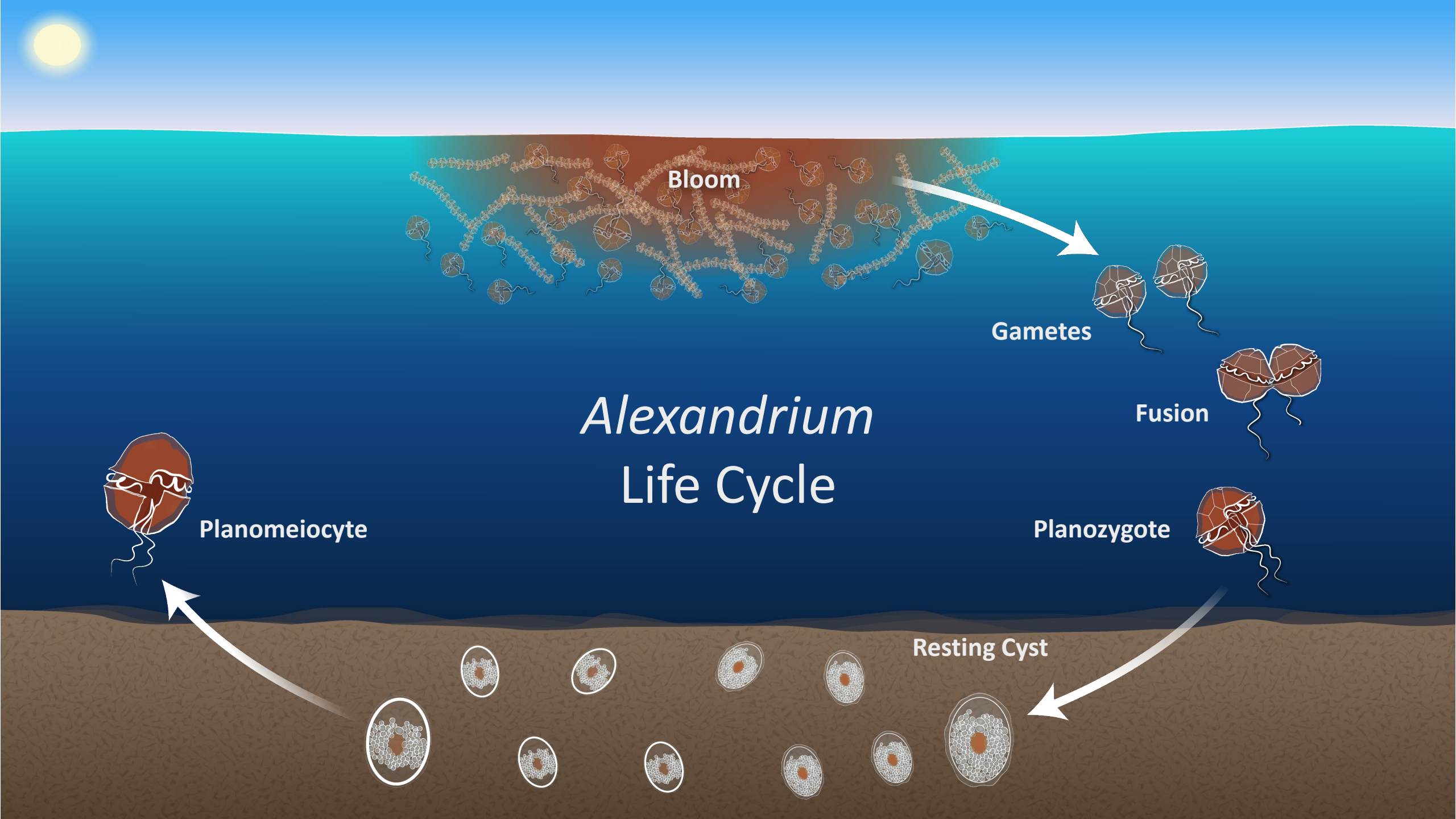
Alexandrium Life Cycle

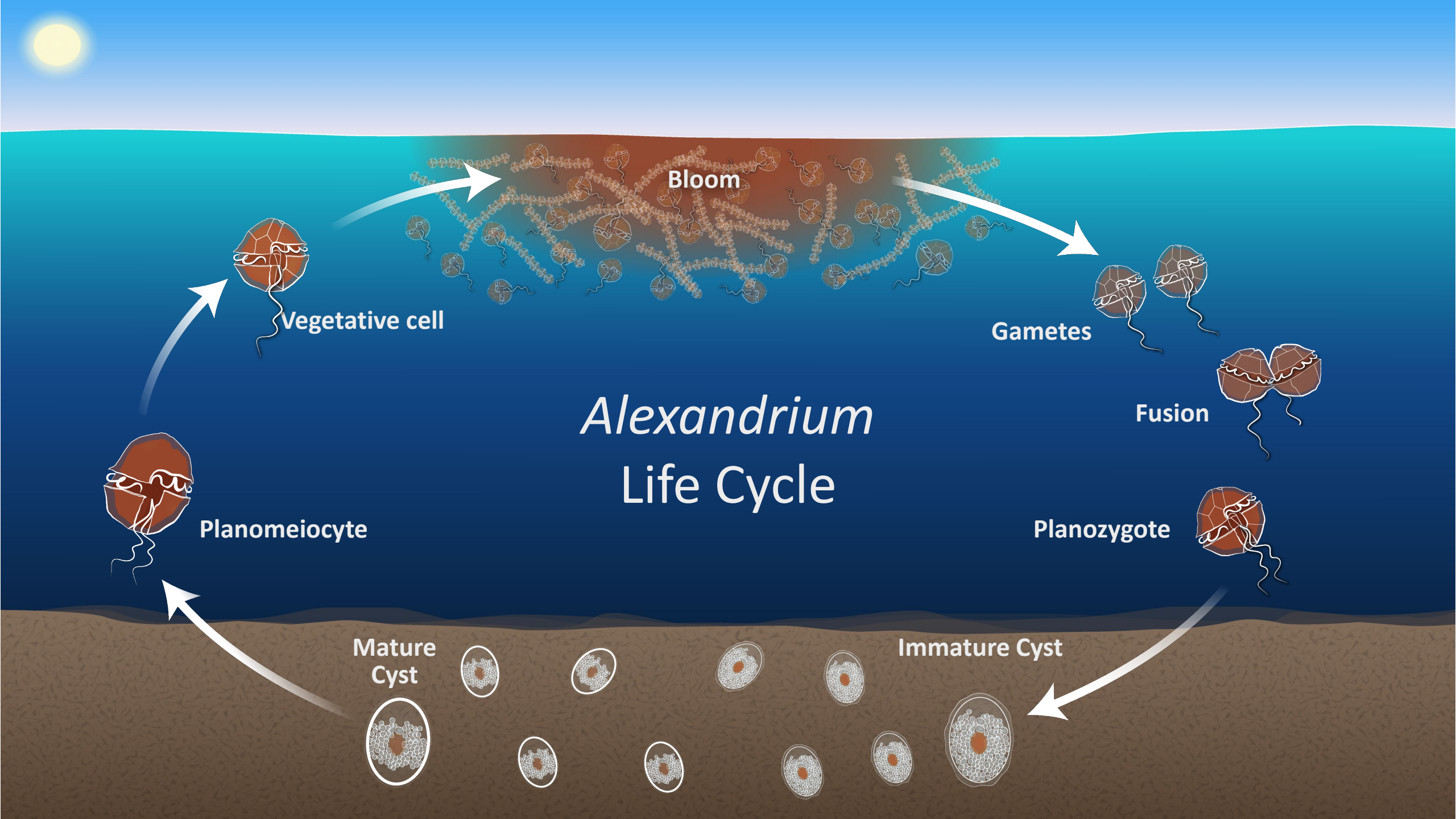

Bloom
Gametes
Fusion
Alexandrium
Life Cycle


Bloom
Gametes
Fusion
Planozygote
Alexandrium
Life Cycle


Bloom
Gametes
Fusion
Planozygote
Resting Cyst
Alexandrium
Life Cycle

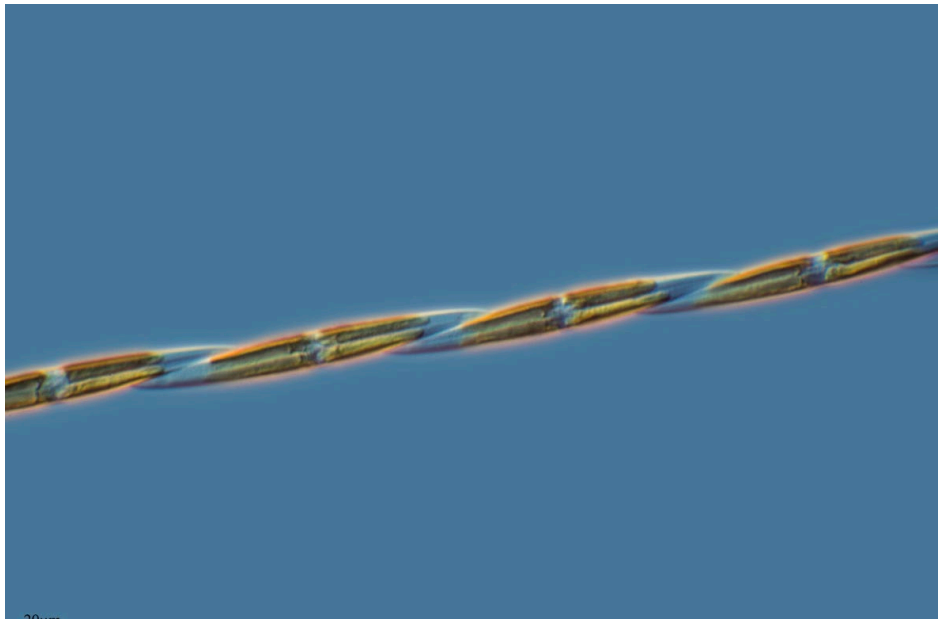

Bloom
Gametes
Fusion
Planozygote
Alexandrium
Life Cycle
Resting Cyst


Bloom
Gametes
Fusion
Alexandrium
Life Cycle
Planomeiocyte
Planozygote
Resting Cyst


Bloom
Vegetative cell
Gametes
Fusion
Alexandrium
Life Cycle
Planomeiocyte
Planozygote
Mature
Cyst
Immature Cyst

Amnesic Shellfish Poisoning (ASP)

- Caused by certain diatom species in the genus *Pseudo-nitzschia* that produce domoic acid
- Impacts both people and wildlife, particularly on the West Coast
- Weird fact: Alfred Hitchcock's "The Birds" was inspired by a real-life event in CA when hundreds of strangely behaving seabirds were observed in coastal communities of Monterey Bay.
- An emerging issue in New England; first domoic acid-related closures occurred in Maine in 2016, with additional subsequent fishery closures and periodic toxicity – presents a challenge for managers



Pseudo-nitzschia chain (Virtual Biodiversity Project)

Diarrhetic Shellfish Poisoning (DSP)

- Caused by *Dinophysis* dinoflagellates – have a global distribution, with closures occurring around the country
- Produces toxins (okadaic acid, dinophysistoxins, pectenotoxin) that cause DSP
- DSP is not fatal, but causes severe gastrointestinal distress - symptoms include diarrhea, nausea, vomiting, and abdominal pain
- The first *Dinophysis*-driven fishery closure in New England was in Maine in 2016, the first MA closure occurred in 2017

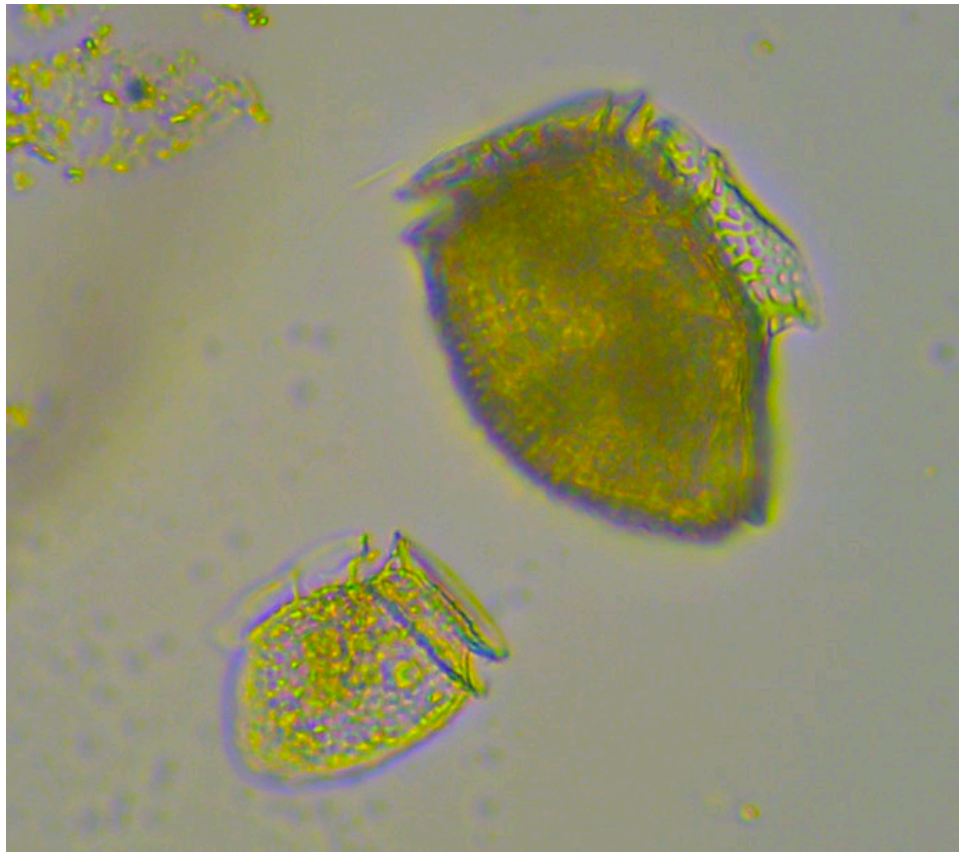


Image by C. Heil.

Monitoring and Prevention

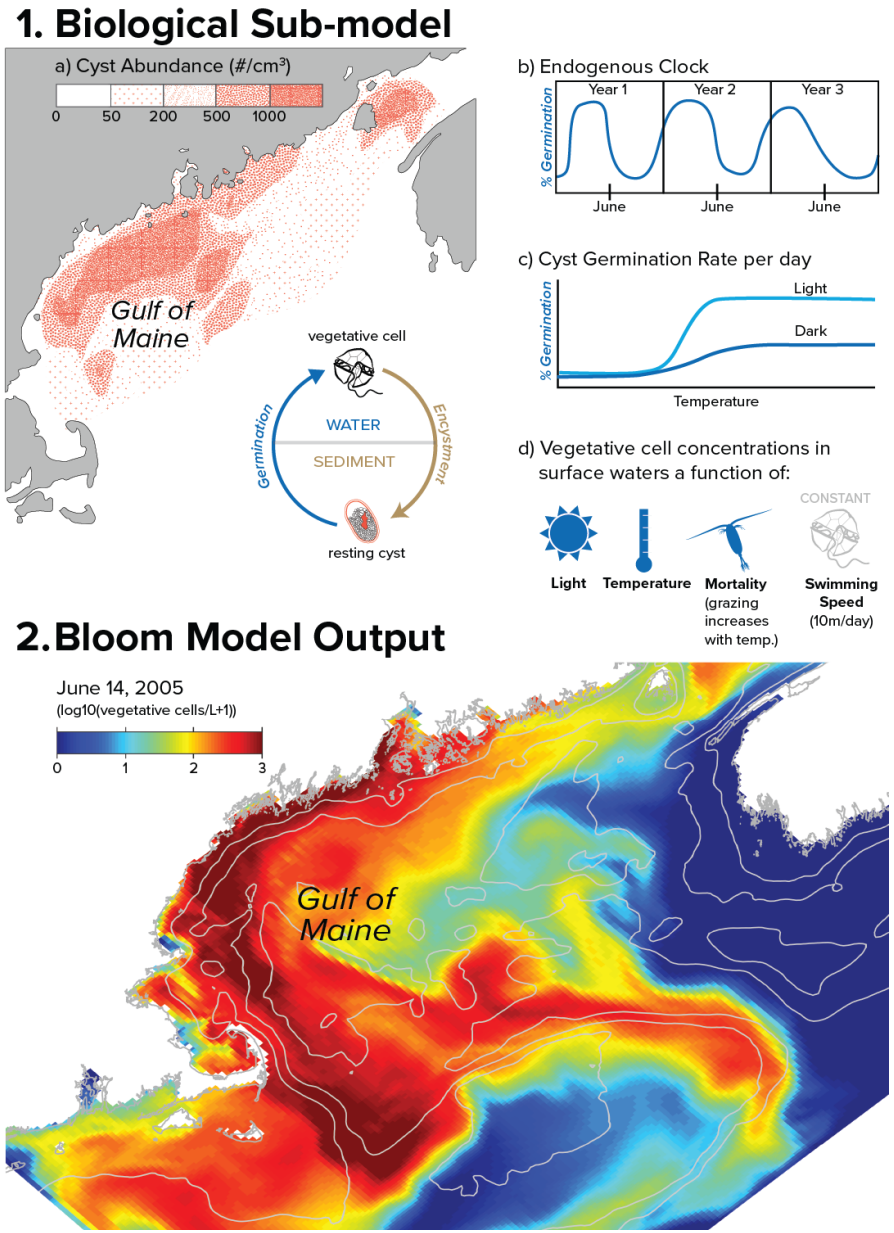
- Cooking seafood does **NOT** eliminate toxicity
- Human illness prevented by large-scale, proactive monitoring programs in many coastal areas that assess toxin levels in shellfish, and plankton communities in water samples
- Subsistence/recreational harvesters can be vulnerable if harvesting from unmonitored areas

USFDA regulatory limits for algal toxins:

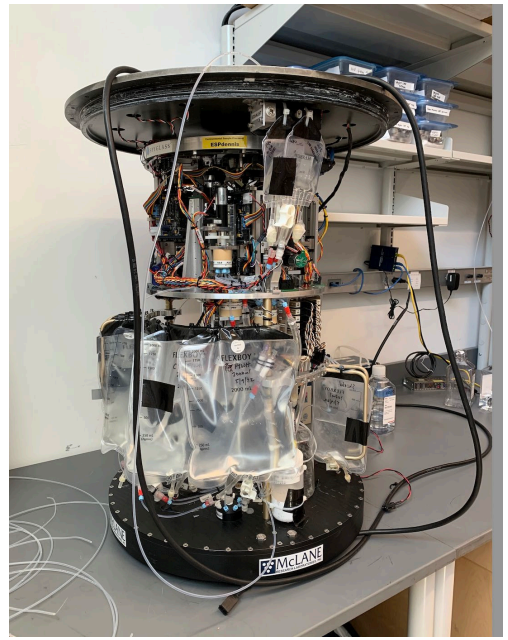
- Domoic Acid (ASP): ≥ 20 mg/kg domoic acid
- Brevetoxin: ≥ 0.8 mg/kg brevetoxin-2 equivalent or 5,000 cells/L
- Saxitoxin (PSP): ≥ 0.8 mg/kg saxitoxin eq.

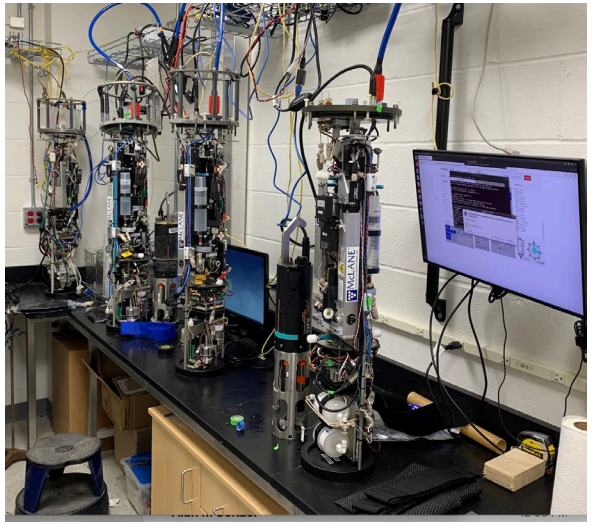
Emerging Monitoring and Forecasting Approaches

- Novel technologies for providing *in situ* data – autonomous sensors deployed using stationary & mobile platforms
  - ImagingFlow Cytobot (IFCB)
  - Environmental Sample Processor (ESP)
- Site or region-specific models for bloom forecasting; e.g., Gulf of Maine biological submodel coupled with hydrodynamics



Gulf of Maine *Alexandrium* population dynamics model that couples hydrodynamics with a biological submodel. (Illustration by Natalie Renier, WHOI)





K-12 educational enrichment

- Multiple Oceans and Human Health (OHH)-focused activities developed for middle school and high school classrooms:
  - *Alexandrium* blooms (Curran & Richlen, 2019)
  - *Pseudo-nitzschia* community dynamics (Richlen et al. 2021)
  - Chemical ecology (Curran & Robertson, 2020)
  - HAB species growth & climate change impacts (in prep)
  - Analyzing ocean observing data (in prep)
- Evaluation and assessment: classroom testing, solicit teacher feedback, publication in peer-reviewed science education journals

SCIENCE ACTIVITIES
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https://doi.org/10.1080/00368121.2022.2106172

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Slicing the pie: Interpreting harmful algal blooms one pie chart at a time

Mindy L. Richlen[a], Mary Carla Curran[b], Christina Chadwick[c] and Katherine A. Hubbard[a,c]

[a]Biology Department, Woods Hole Oceanographic Institution, Falmouth, Massachusetts; [b]Marine Sciences Program, Savannah State University, Savannah, Georgia; [c]Florida Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission, St. Petersburg,Florida

ABSTRACT
The Earth's oceans are home to a diverse array of life, from large marine mammals to microscopic organisms. Among the most important are the marine phytoplankton, which comprise the basis of marine food webs, and also produce a large percentage of the Earth's

KEYWORDS
Harmful Algal Bloom (HAB); phytoplankton; diatoms; visual impairment; accommodations/ adaptations

SCIENCE ACTIVITIES
https://doi.org/10.1080/00368121.2019.1691968

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Harmful Algal Blooms (HABs): track them like a scientis

Mary Carla Curran[a] and Mindy L. Richlen[b]

[a]Marine Sciences Program, Department of Marine and Environmental Sciences, Savannah State
[b]Biology Department, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA

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Marine phytoplankton comprise the foundation of oceanic food webs and generate
Earth's oxygen. Of the many phytoplankton species in the ocean, a few dozen prod
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tides" that can discolor marine waters. Managers and scientists have been monitor
waters and shellfish resources for HABs and their toxins to ensure seafood safety and
why blooms occur. This educational activity focuses on a prominent HAB species
paralytic shellfish poisoning (PSP). Students will learn about the importance of HABs
well as how scientists collect and use data to understand and predict blooms. Studen

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Activities and Program Models

Chemistry Made Easy: Teaching Students about the Link Between Marine Chemistry and Coral Reef Biodiversity

Authors: Mary Carla Curran, Alison Robertson

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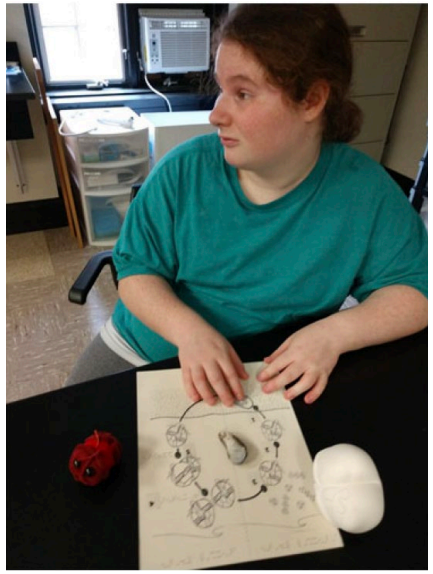
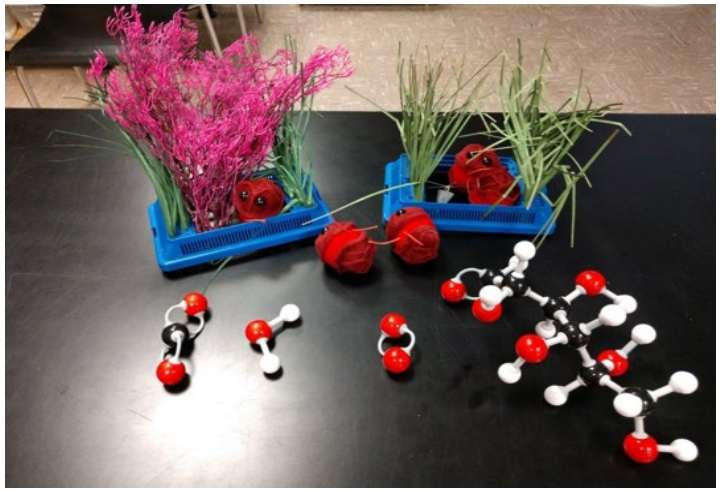
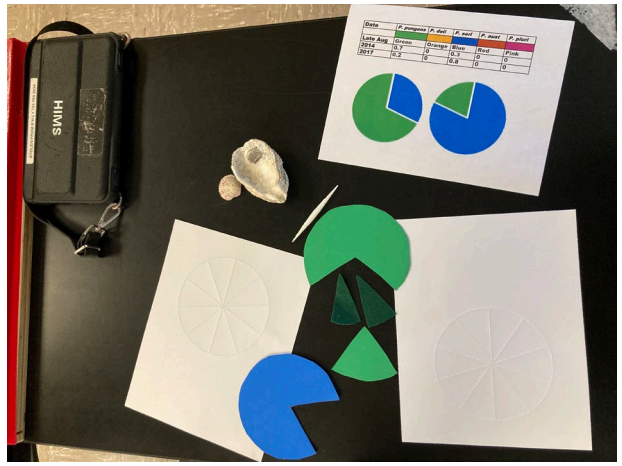
Presentation at NMEA meeting, 2019

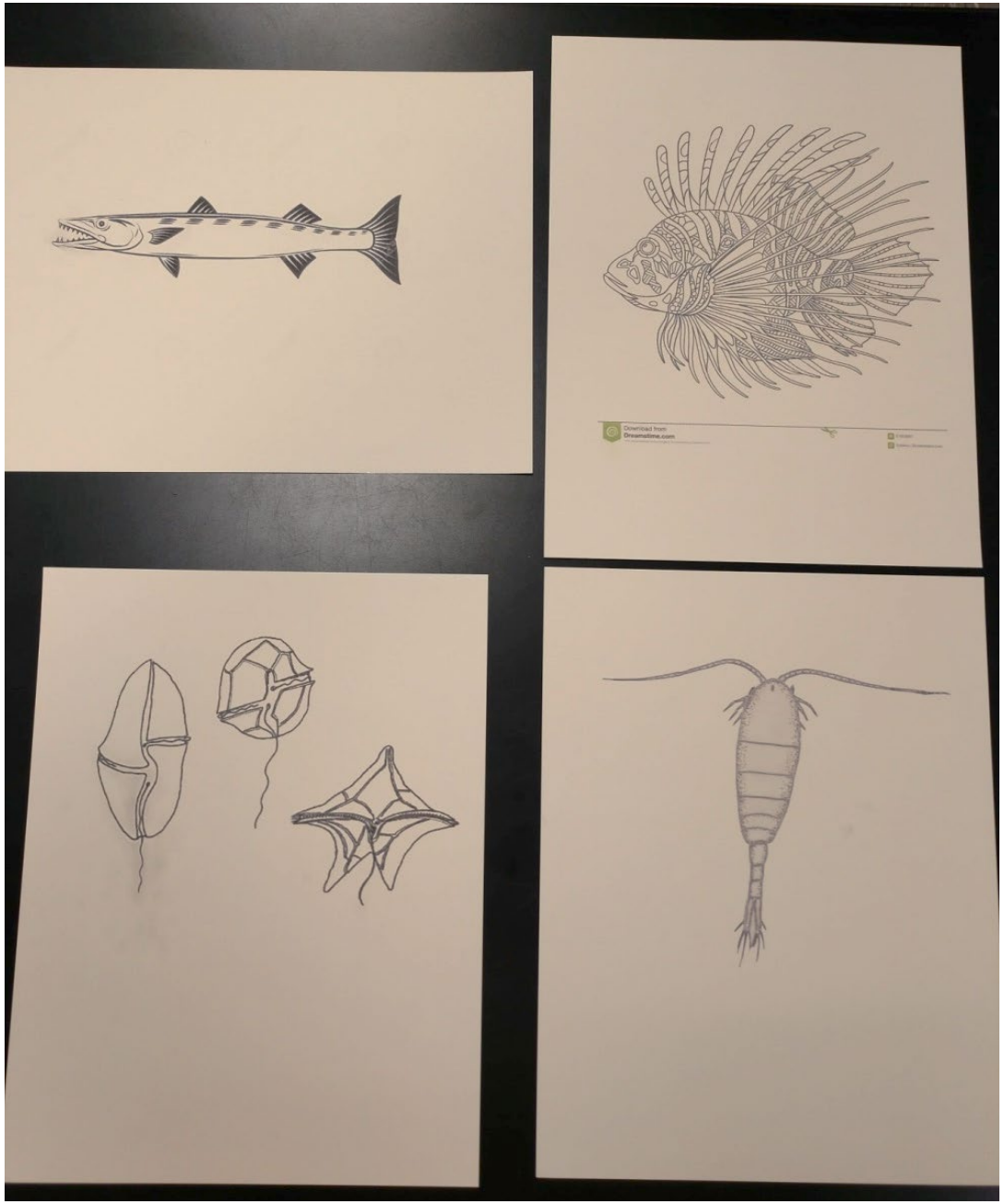
Modifications for the visually impaired

BUT including multi-sensory educational tools improves learning for all students

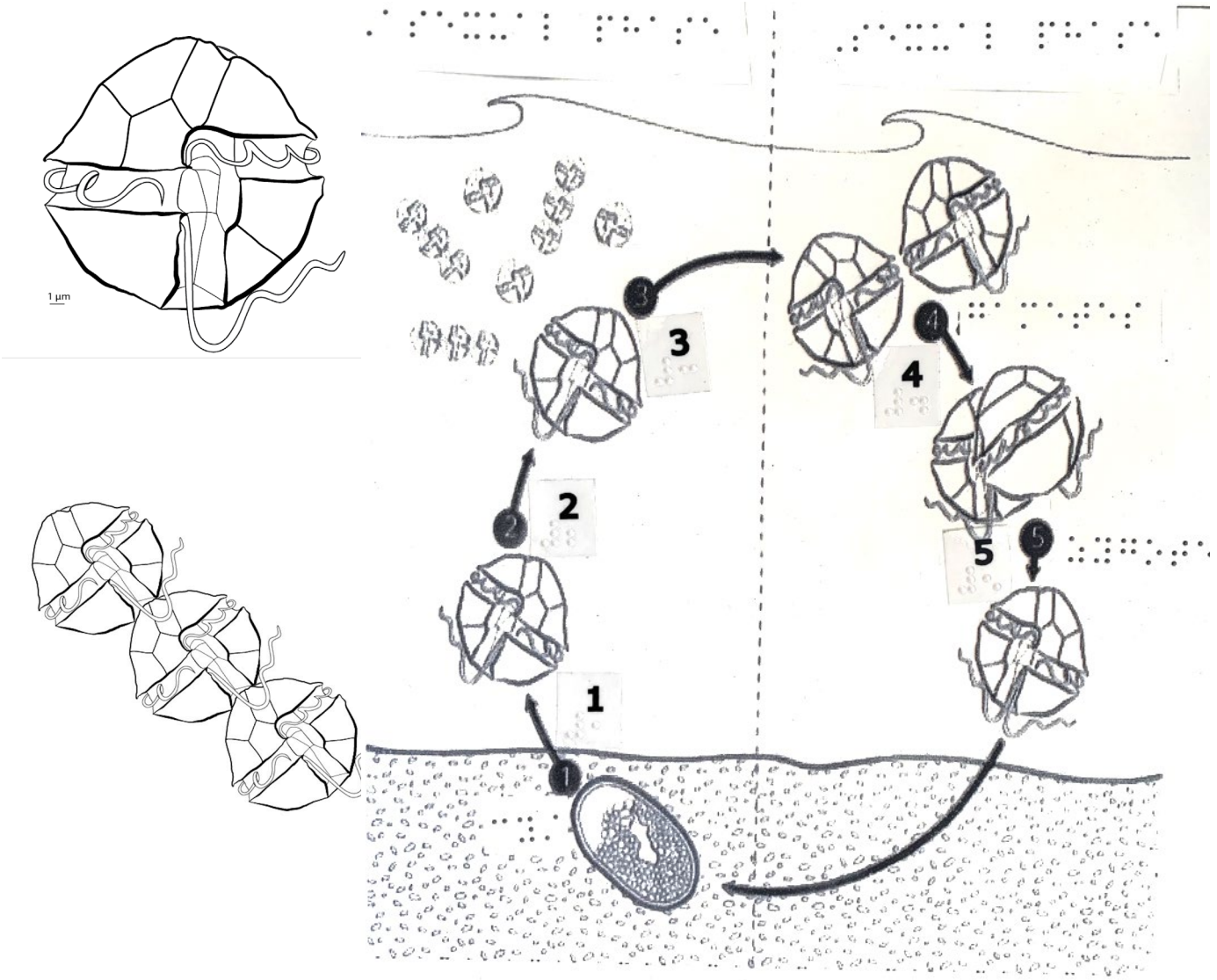








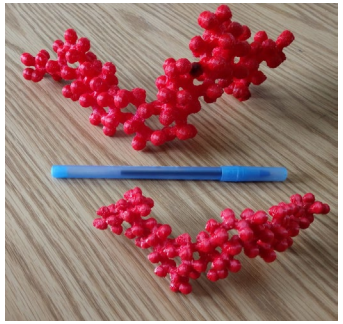
Examples of graphics printed using raised ink from a Pictures in a Flash device (PIAF)

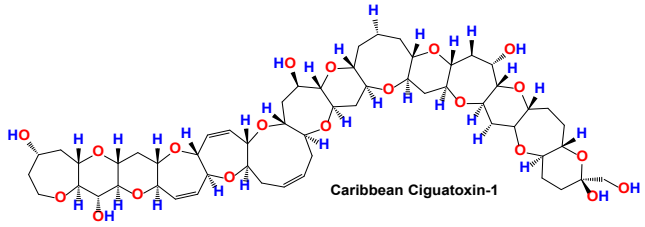


Activities published; others underway

Marine chemistry and coral reef diversity

Focused on tropical food webs and the role of chemistry in the bioaccumulation of toxins in seafood

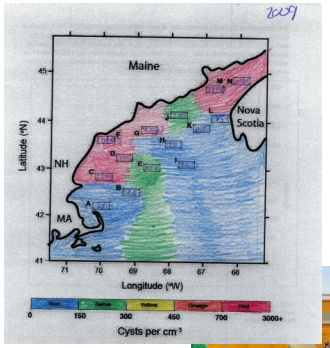


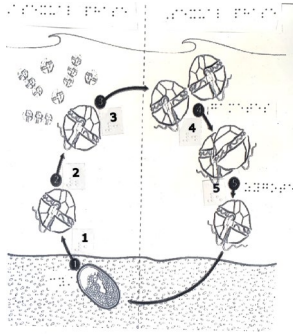


Curran & Robertson (2020)

Alexandrium dinoflagellate cyst dynamics in the Gulf of Maine (GOM)

Students learn about *Alexandrium* blooms in the GOM, and how cell/cyst data are used to model and predict blooms

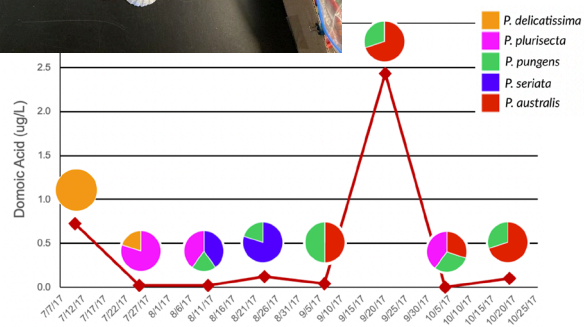




Curran & Richlen (2020)

Community structure of *Pseudo-nitzschia* diatom blooms

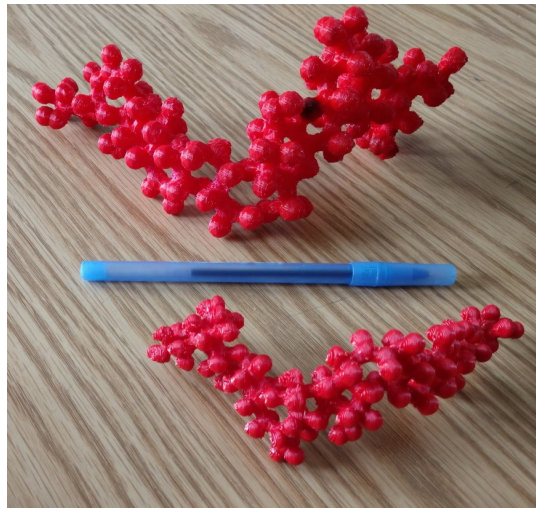
Tracking temporal changes in community structure of *Pseudo-nitzschia* diatom blooms and domoic acid concentrations

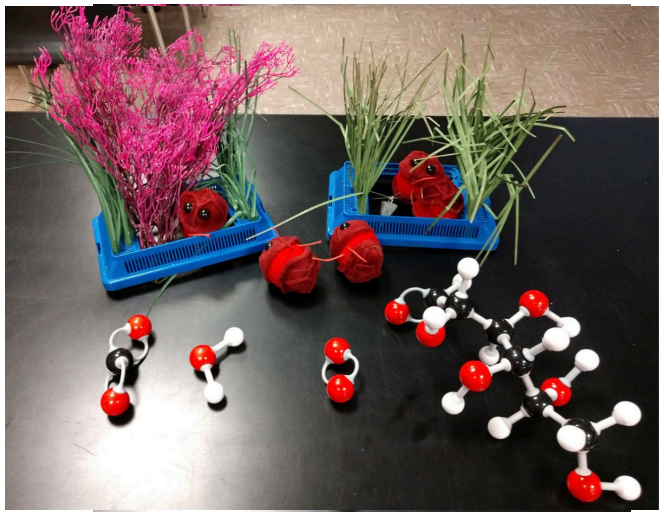


Richlen et al. (2021)

Marine Chemistry & Coral Reef Diversity

- Activity focused on tropical food webs and the role of chemistry in the bioaccumulation of toxins in seafood
- Students use pipe cleaners and beads in classroom exercises to construct the molecules used in photosynthesis





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Reading: Chemistry Made Easy: Teaching Students about the Link Between Marine Chemistry and Coral Ree...

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Activities and Program Models

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Authors: Mary Carla Curran, Alison Robertson

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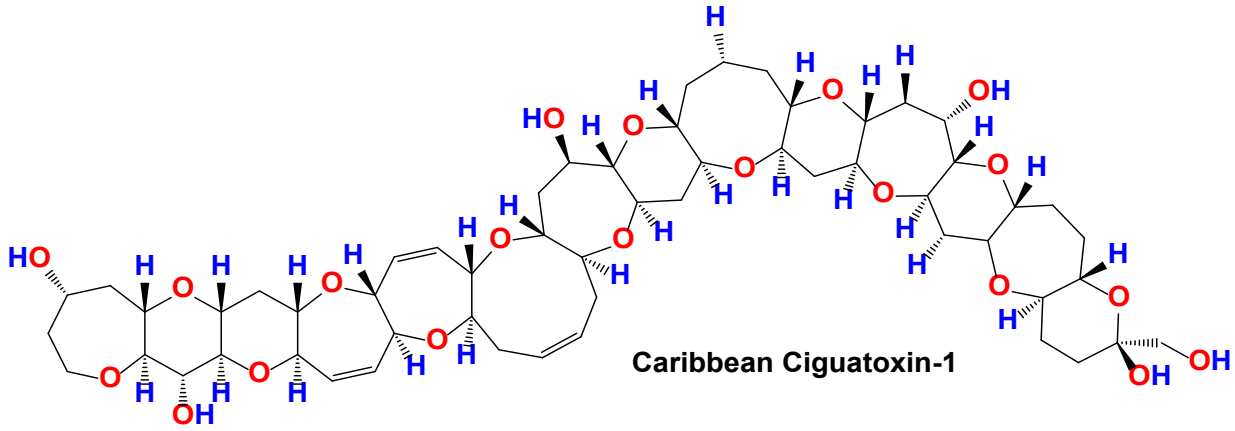
Teaching students about chemistry can be fun. Here, students learn that chemistry is linked to all marine life and affects where they live, the community that they live in, and what eats them. Some chemicals made by organisms have negative effects on humans and marine life, and these toxins and venoms can bioaccumulate in fish and affect human consumers who rely on critical marine resources for food. After learning about the role of chemistry in this food web and how humans might be affected by contaminated seafood, students can brainstorm about ways to increase food safety whilst considering community needs in regions of the world that may have economic difficulties. This activity has modifications for the visually impaired.



Curran & Robertson, 2020

Alexandrium cyst dynamics in the Gulf of Maine

- Focusing on *Alexandrium* in the GOM, and how cell/cyst data are used to model and predict blooms
- Students create heat maps using *Alexandrium* cyst distribution data collected over multiple years

SCIENCE ACTIVITIES
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Marine phytoplankton comprise the foundation of oceanic food webs and generate most of the Earth's oxygen. Of the many phytoplankton species in the ocean, a few dozen produce potent toxins, and at high concentrations can form what are called Harmful Algal Blooms (HABs) or "red tides" that can discolor marine waters. Managers and scientists have been monitoring coastal waters and shellfish resources for HABs and their toxins to ensure seafood safety and understand why blooms occur. This educational activity focuses on a prominent HAB species that causes paralytic shellfish poisoning (PSP). Students will learn about the importance of HABs and PSP, as well as how scientists collect and use data to understand and predict blooms. Students will plot data on HAB species collected by scientists over multiple years of sampling. Students will also plot results over time and across regions, report on observed patterns, and complete grade-appropriate calculations. Lastly, group discussion will focus on determining whether geographic patterns exist that might influence where shellfish beds are closed. This activity is timely given the widespread wildlife mortalities and beach closures due to Florida red tide in 2017-2018, as well as widely publicized dog deaths in 2019 caused by exposure to freshwater cyanobacteria (blue-green algae) blooms.

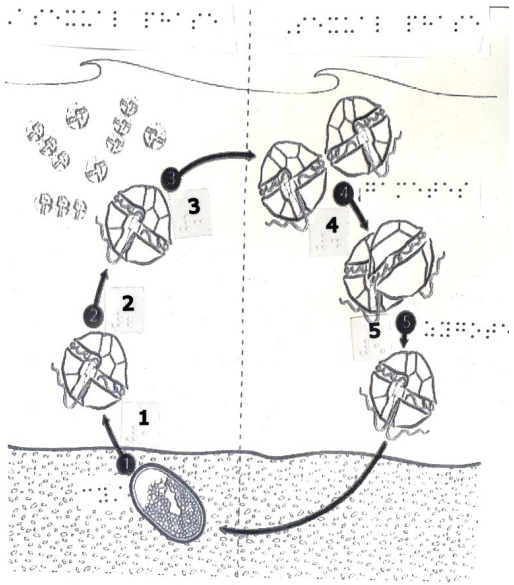
KEYWORDS

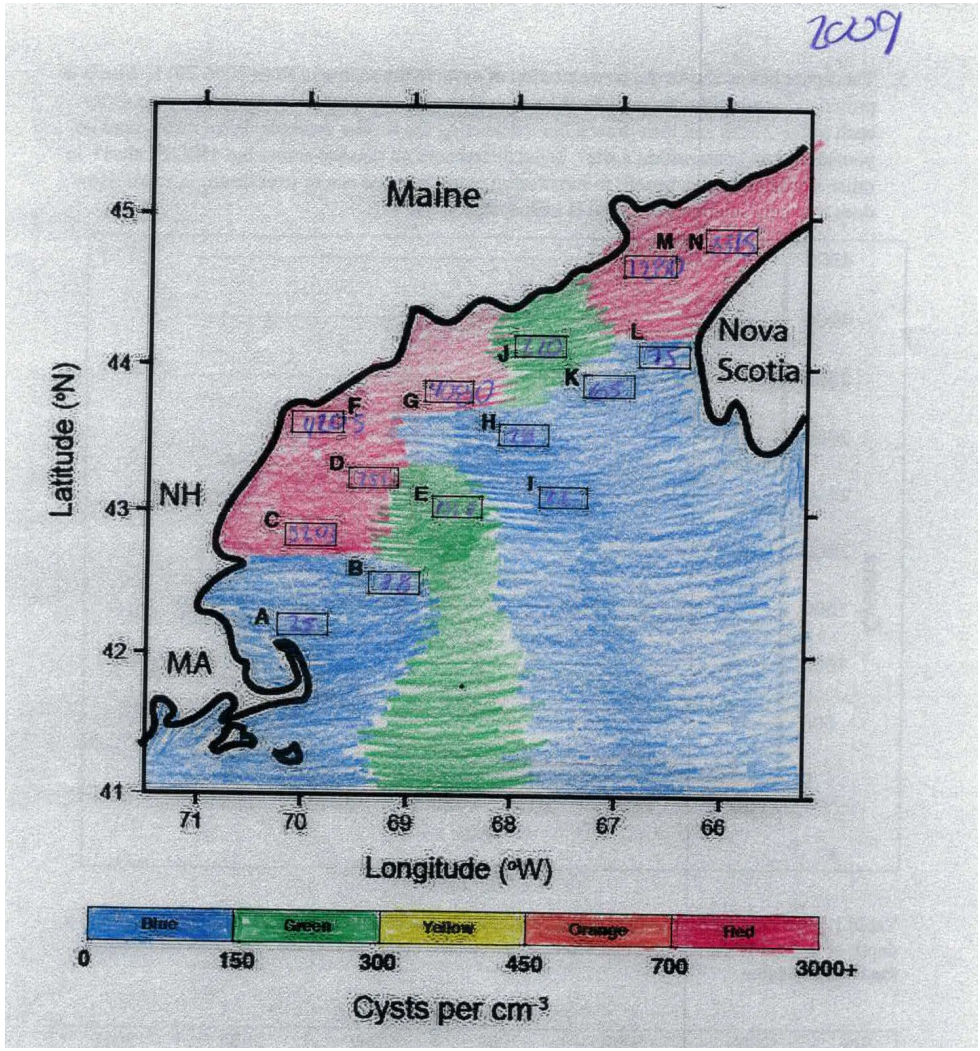
Harmful Algal Bloom (HAB); red tides; dinoflagellate; Paralytic Shellfish Poisoning (PSP)

Background

Just like plants in terrestrial systems, there are

when conditions are favorable for dinoflagellate growth, leading to the formation of high algal densities that appear to discolor the water, also known

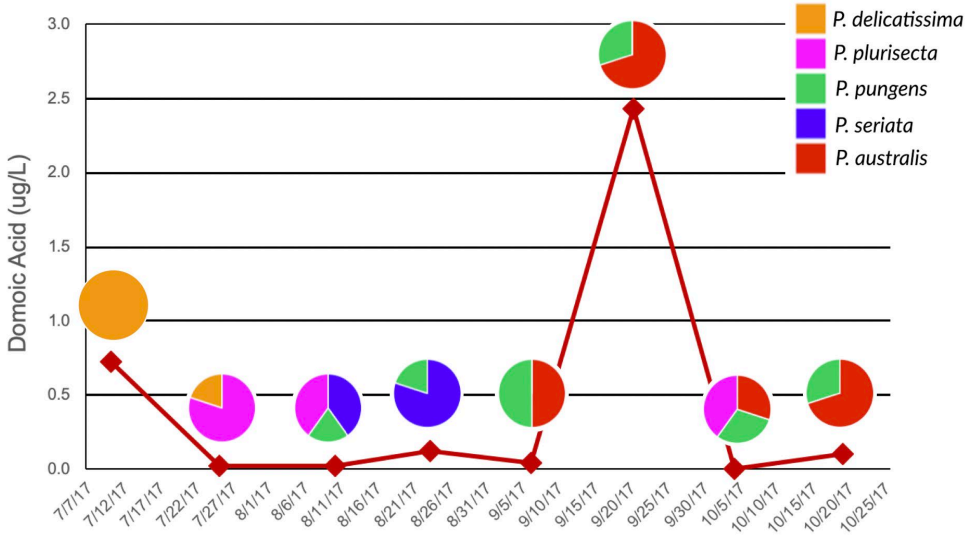


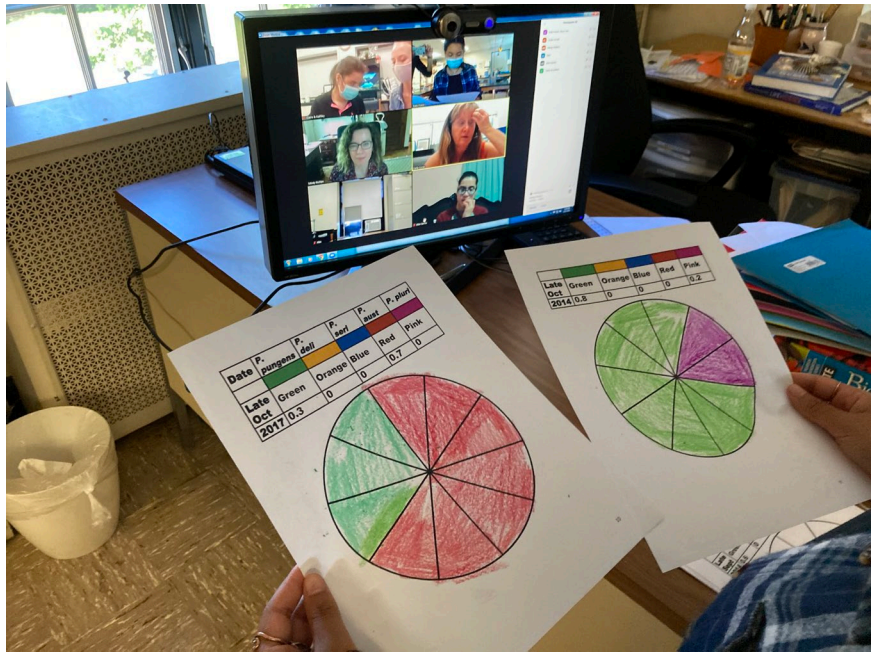


Curran & Richlen, 2019

Community structure *of* *Pseudo-nitzschia* diatoms

- Focusing on *Pseudo-nitzschia* and domoic acid; tracking temporal changes in community structure and domoic acid (pre and post *P. australis)*
- Students calculate proportional abundance of different species and plot data over time.





Richlen et al. (2021)

Resources

- U.S. National Office for Harmful Algal Blooms:
  https://hab.whoi.edu/
  https://hab.whoi.edu/regions-resources/resources-for-educators/
- Northeast HAB Webpage:
  www.northeasthab.whoi.edu
  https://northeasthab.whoi.edu/for-educators/
- NOAA Harmful Algal Blooms Resources and Information:
  https://oceanservice.noaa.gov/hazards/hab/
- CDC Harmful Algal Bloom (HAB) Associated Illnesses:
  https://www.cdc.gov/habs/index.html
- IOC-UNESCO Harmful Algae Information System (HAIS)
  https://data.hais.ioc-unesco.org/

Thank you!