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

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

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

ABSTRACT
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 plant-like organisms inhabiting our oceans that photosynthesize, thereby producing oxygen. In fact, a large percentage of the world's oxygen is produced by marine organisms that photosynthesize. Dinoflagellates are one of the major groups of phytoplankton (see vocabulary insert). They have two tail-like appendages called flagella (singular flagellum) that are used for locomotion (Figure 1; Figure 2a). These organisms are unicellular (one celled) but can form chains (Figure 2b), and are transported by ocean currents.

Most dinoflagellates are beneficial, but a small number of species are capable of producing potent toxins (reviewed by Backer and McGillicuddy 2006; Anderson et al. 2012). Marine organisms such as shellfish (oysters, clams, mussels, and scallops) as well as other invertebrates and fish can accumulate these toxins when they consume these organisms during filter feeding. This often occurs when conditions are favorable for dinoflagellate growth, leading to the formation of high algal densities that appear to discolor the water, also known as harmful algal blooms, or "red tides." Eating shellfish collected from a location where HABs are occurring can be dangerous. However, when the bloom diminishes, shellfish will gradually excrete the toxin, and will once again be safe to eat.

One of the most prominent HAB problems worldwide is Paralytic Shellfish Poisoning, or PSP, caused by the dinoflagellate *Alexandrium catenella*. PSP is a life-threatening illness caused by eating shellfish that are contaminated with neurotoxins known collectively as saxitoxins. Symptoms of PSP include numbness, tingling, dizziness, paralysis, as well as difficulty breathing and respiratory arrest. In severe cases, PSP can be fatal. In addition to causing illness in humans, the consumption of saxitoxin-carrying shellfish, fish, and invertebrates can sicken other organisms that eat them, such as marine mammals and birds (Landsberg et al. 2014).

CONTACT Mary Carla Curran CurranC@SavannahState.edu Marine Sciences Program, Department of Marine and Environmental Sciences, Savannah State University, Box 20467, Savannah, GA 31404, USA
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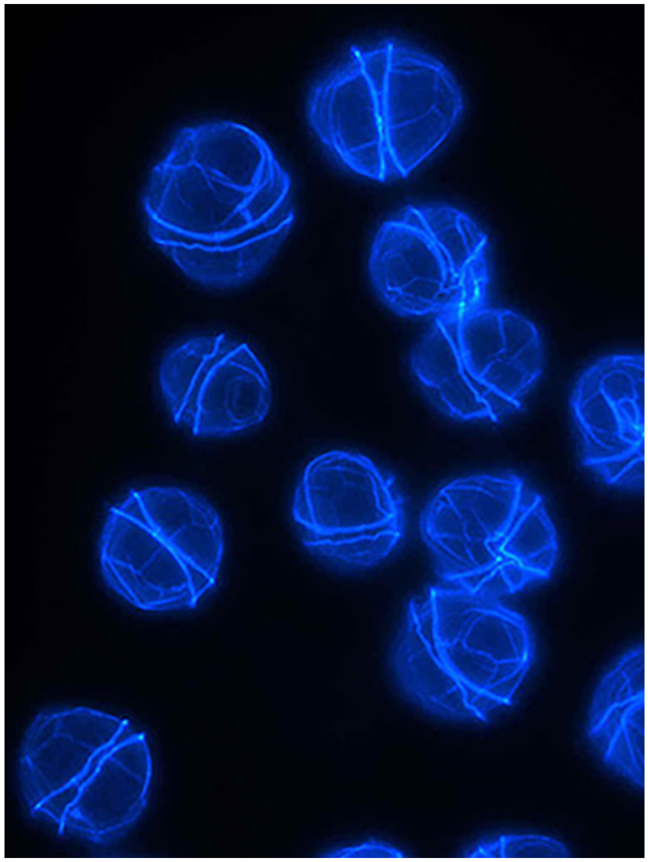

Figure 1. Fluorescent microscope image of *Alexandrium catenella* cells. Photo courtesy of G. Usup.

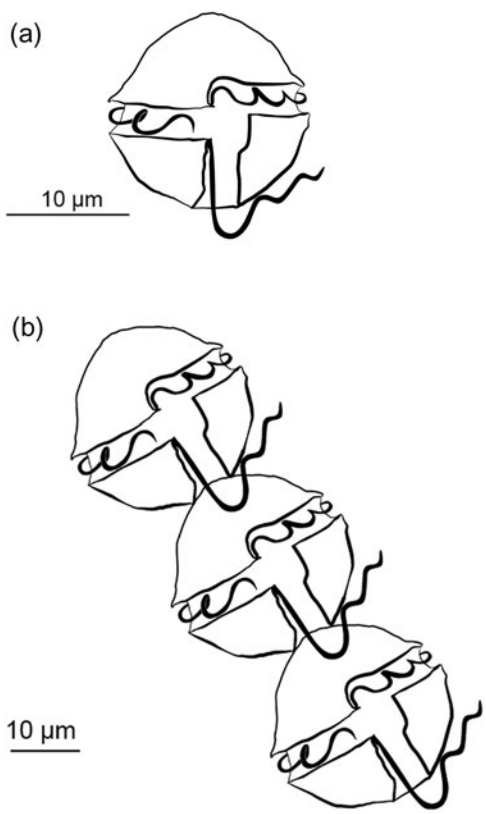

Figure 2. Diagram of a dinoflagellate as a single cell (A) and as a chain (B).

In the U.S., PSP primarily impacts northern Atlantic and Pacific coasts, including Alaskan coastal waters, and is of particular concern in the Northeast, where PSP toxins and health risks have been a recurring problem for many years (Anderson et al. 2005, Bean et al. 2005, Anderson et al. 2014a). To protect human health, public health managers in shellfish-producing states impacted by PSP closely monitor shellfish for toxins to ensure that they are safe to eat. If toxins reach a certain level (0.8 ppm, or 80 μg 100 g^{-1} of shellfish meat), managers will close an area to shellfishing by posting signs along the impacted coastal areas where people may collect shellfish recreationally (Figure 3), and will circulate notices to notify commercial shellfishers, county and town offices, and seafood sellers. Closures are enacted well before toxins reach levels that might sicken human consumers. Managers will continue to monitor a particular area until toxin levels decrease to the point where shellfish is safe to eat, and only then will the closure be lifted.

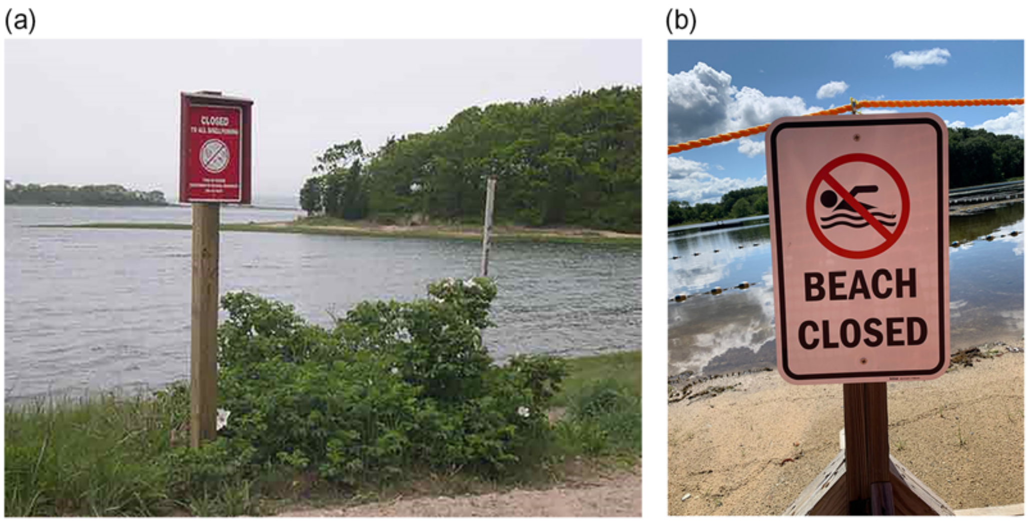

Figure 3. Example of signage used for A) shellfish bed closures and B) beach closure due to marine and freshwater harmful algal blooms, respectively. Shellfish bed closure photo courtesy of J. Kleindinst; beach closure photo taken by M. Richlen.

Researching Harmful Algal Blooms

To learn more about why and when PSP-causing blooms of *A. catenella* occur, scientists routinely collect both seawater and sediment samples from shore, using small boats, or during surveys aboard larger research vessels. These samples are analyzed using light and fluorescence microscopy to quantify concentrations of dinoflagellate cells in the water column, as well as their resting stages (similar to a seed, called "cysts") in bottom sediments. The cyst stage is an important part of the life cycle that enables them to survive unfavorable conditions (e.g., low temperature) and is described in more detail below (also see Figure 5). Data on the abundance and distribution of cysts are used to determine when and where blooms occur, identify the conditions that might promote bloom formation, and to develop models of bloom dynamics that can be used to predict blooms. These data have also been used to identify locations of cyst "seedbeds"; e.g., extremely high concentrations of cysts that might initiate blooms in subsequent years (McGillicuddy et al. 2005). To visualize these data, scientists may construct what resembles a "heatmap" depicting dinoflagellate concentrations across a study region (Figure 4 depicts dinoflagellate cysts in the Gulf of Maine region). Note that the map's color coded shading is based on dinoflagellate concentrations, and is not related to the temperature/heat measured in the region.

Dinoflagellate life cycle

The life cycle of the dinoflagellate *Alexandrium catenella* is complicated and includes an asexual phase (during which organisms reproduce by binary fission) and a sexual phase (during which two cells fuse to form a life-cycle stage called a planozygote that has a mix of genetic material from both parents), followed by a resting cyst phase (Figure 5). The cyst stage is an inactive life-cycle stage during which the dinoflagellate remains dormant in ocean sediments, and this enables them to survive unfavorable conditions (e.g., low temperature). When conditions are suitable for growth (increased light availability and water temperature), the cyst germinates and commences cell division. This organism can reproduce quickly during the asexual phase, and under certain conditions can form blooms.

Activity Introduction

This activity focuses on a particular species of bloom-forming dinoflagellate that can produce toxins that are harmful to humans and wildlife, and depicts how scientists collect and interpret data to better understanding bloom dynamics. The purpose is to engage students in plotting data over a large geographic area and over time to identify potential locations where HABs are prevalent, which is important information for managers charged with protecting citizens from PSP. Students will plot real data (Figure 6) to determine where and when high

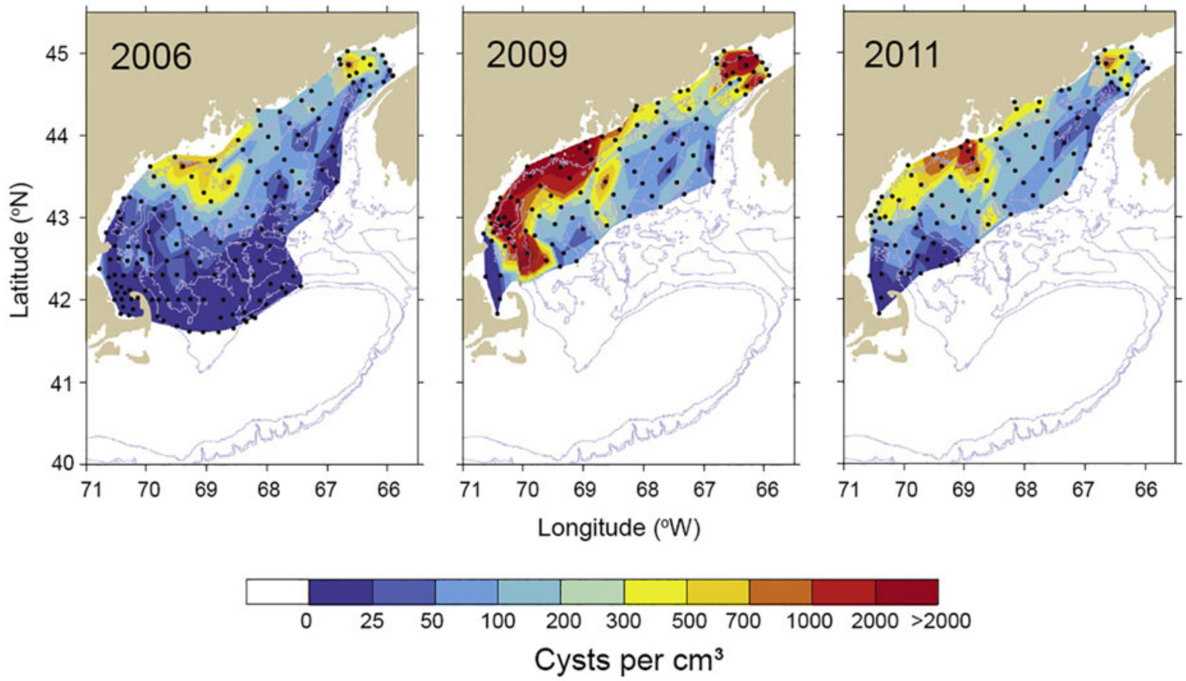

Figure 4. A-C. Heat maps of dinoflagellate cyst concentrations in the Gulf of Maine from three different years. Figure adapted from Anderson et al. 2014b.

accumulations of dinoflagellate cysts are found and develop their own ideas about sampling strategies. This activity includes modifications for the visually impaired. For example, the sketches are provided with thick black lines with high visual contrast that can be seen by students who have some vision, and/or can be printed out on a Pictures in a Flash (PIAF) machine, which elevates black ink when printed on a special paper. Students can then feel the outline (Figure 7).

Vocabulary

bivalve – a type of mollusk such as a clam, mussel, oyster, or scallop

cyst stage – an inactive or resting life cycle stage of an organism

dinoflagellate – a type of phytoplanktonic organism in aquatic systems.

flagellum – appendage that allows microorganisms to swim

harmful algal bloom – rapid growth of a particular algal species, leading to toxic or harmful effects on people, shellfish, fish, marine mammals, and birds

invertebrate – an animal without a vertebral column (backbone)

phytoplankton – passively drifting photosynthetic organisms such as dinoflagellates

saxitoxin – neurotoxin produced by *Alexandrium* and the best-known paralytic shellfish toxin

shellfish – general term including a variety of species of clams, mussels, oysters, scallops, crab, lobster, shrimp, and sea urchins.

shellfisher – person who harvests shellfish to eat (recreational shellfisher) or sell (commercial shellfisher)

unicellular organism – an organism that is only one cell

Standards

Middle-school standards are provided below, although this activity has been shared with high school students as well.

Next Generation Science Standards (NGSS Lead States 2013)

MS-LS1-6 From Molecules to Organisms: Structures and Processes

Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.

MS-LS2 Ecosystems: Interactions, Energy, and Dynamics

Performance Expectations: MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

Science and Engineering Practices: MS-LS2-1: Interdependent relationships in ecosystems.

Crosscutting Concepts: MS-LS2.5: Science addresses questions about the natural and material World.

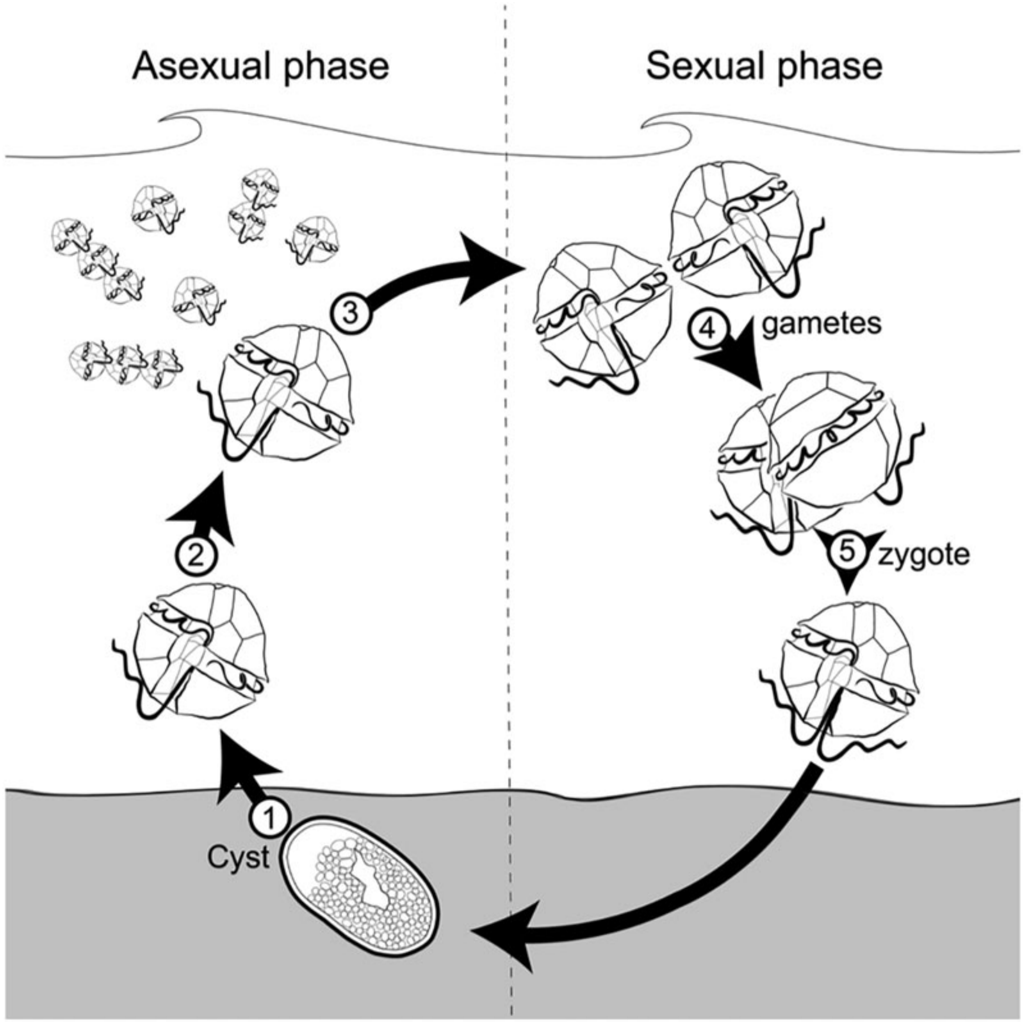

Figure 5. Life cycle of a dinoflagellate that includes a dormant resting phase (1), asexual cell division (2-3) and gamete production (4), and planozygote formation (5). The cyst stage is an inactive life cycle stage during which the dinoflagellate remains dormant in ocean sediments, and this enables them to survive unfavorable conditions (e.g., low temperature). When conditions are suitable for growth (increased light availability and water temperature), the cyst germinates and commences cell division. This organism can reproduce quickly during the asexual phase, and under certain conditions can form blooms.

Specifics for each stage are: 1) Cysts of dinoflagellates lay dormant on the ocean floor buried in sediment. Left undisturbed, they can stay in this state for years; 2) When environmental conditions are favorable for growth, cysts germinate and a germling cell called a planomeiocyte emerges. Cyst germination is controlled by a variety of external factors including temperature, light, and oxygen concentrations. Some species have an internal "clock" control; 3) Within a few days of germination, the swimming cell reproduces by simple division. With abundant nutrients and optimal conditions, cells will reproduce exponentially. A single cell can divide into several hundred cells within weeks. If enough cells "bloom," shellfish can become contaminated with paralytic shellfish poisoning toxins, poisoning humans and the other animals that eat them; 4) Growth stops when conditions are no longer favorable for growth and gametes are formed; and 5) Two gametes fuse, and develop into a planozygote. The planozygote will then thicken its cell wall and condense its cytoplasm to become a cyst. This dormant cyst falls to the ocean floor for germination in subsequent years.

MS-LS2-1 Ecosystems: Interactions, Energy, and Dynamics

Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.

Grade:

Middle School (6-8)

MS-LS2-3 Ecosystems: Interactions, Energy, and Dynamics

Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.

Grade:

Middle School (6-8)

MS-LS2-4 Ecosystems: Interactions, Energy, and Dynamics

Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

Grade:

Middle School (6-8)

Figure 6. Visually impaired student works on graphing exercise. The 3D dinoflagellate model and plush toy are on the left.

Figure 7. Visually impaired student feels a raised example of the dinoflagellate life cycle. The raised print is made with a Picture in a Flash (PIAF) machine. The dinoflagellate plush toy is on the left and the model dinoflagellate made with a 3D printer is on the right. A mussel, a consumer of dinoflagellates, was placed in the center of the page.

MS-LS2-5 Ecosystems: Interactions, Energy, and Dynamics

Evaluate competing design solutions for maintaining biodiversity and ecosystem services.

Grade:

Middle School (6-8)

MS-LS4-1; HS-PS1-2: Patterns: Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.

MS-ESS3-3 Earth and Human Activity: Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.

Common Core State Standards

(http://www.corestandards.org/Math/)

Grade 5 Measurement and Data

Convert like measurement units within a given measurement system.

CCSS.MATH.CONTENT.5.MD.A.1

Convert among different-sized standard measurement units within a given measurement system (e.g., convert 5 cm to 0.05 m), and use these conversions in solving multi-step, real world problems.

Represent and interpret data.

CCSS.MATH.CONTENT.5.MD.B.2

Make a line plot to display a data set of measurements in fractions of a unit (1/2, 1/4, 1/8). Use operations on fractions for this grade to solve problems involving information presented in line plots. *For example, given different measurements of liquid in identical beakers, find the amount of liquid each beaker would contain if the total amount in all the beakers were redistributed equally.*

Grade 6 Statistics and Probability

Develop understanding of statistical variability.

CCSS.MATH.CONTENT.6.SP.A.1

Recognize a statistical question as one that anticipates variability in the data related to the question and accounts for it in the answers. *For example, "How old am I?" is not a statistical question, but "How old are the students in my school?" is a statistical question because one anticipates variability in students' ages.*

CCSS.MATH.CONTENT.6.SP.A.2

Understand that a set of data collected to answer a statistical question has a distribution which can be described by its center, spread, and overall shape.

Summarize and describe distributions.

CCSS.MATH.CONTENT.6.SP.B.4

Display numerical data in plots on a number line, including dot plots, histograms, and box plots.

CCSS.MATH.CONTENT.6.SP.B.5

Summarize numerical data sets in relation to their context, such as by:

CCSS.MATH.CONTENT.6.SP.B.5.A

Reporting the number of observations.

CCSS.MATH.CONTENT.6.SP.B.5.B

Describing the nature of the attribute under investigation, including how it was measured and its units of measurement.

CCSS.MATH.CONTENT.6.SP.B.5.C

Giving quantitative measures of center (median and/or mean) and variability (interquartile range and/or mean absolute deviation), as well as describing any overall pattern and any striking deviations from the overall pattern with reference to the context in which the data were gathered.

Grade 7 Statistics and Probability

Draw informal comparative inferences about two populations.

CCSS.MATH.CONTENT.7.SP.B.3

Informally assess the degree of visual overlap of two numerical data distributions with similar variabilities, measuring the difference between the centers by expressing it as a multiple of a measure of variability. *For example, the mean height of players on the basketball team is 10 cm greater than the mean height of players on the soccer team, about twice the variability (mean absolute deviation) on either team; on a dot plot, the separation between the two distributions of heights is noticeable.*

Grade 8 Statistics and Probability

Investigate patterns of association in bivariate data.

CCSS.MATH.CONTENT.8.SP.A.1

Construct and interpret scatter plots for bivariate measurement data to investigate patterns of association between two quantities. Describe patterns such as clustering, outliers, positive or negative association, linear association, and nonlinear association.

CCSS.MATH.CONTENT.8.SP.A.2

Know that straight lines are widely used to model relationships between two quantitative variables. For scatter plots that suggest a linear association, informally fit a straight line, and informally assess the model fit by judging the closeness of the data points to the line.

Grade 8 Expressions and Equations

Understand the connections between proportional relationships, lines, and linear equations.

CCSS.MATH.CONTENT.8.EE.B.5

Ocean literacy principles (National Marine Educators Association 2013)

Principle 5: The ocean supports a great diversity of life and ecosystems

5F. Ocean ecosystems are defined by environmental factors and the community of organisms living there. Ocean life is not evenly distributed through time or space due to differences in abiotic factors such as oxygen, salinity, temperature, pH, light, nutrients, pressure, substrate, and circulation. A few regions of the ocean support the most abundant life on Earth, while most of the ocean does not support much life.

Principle 6. The ocean and humans are inextricably interconnected.

6D. Humans affect the ocean in a variety of ways. Laws, regulations, and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (point source, nonpoint source, and noise pollution), changes to ocean chemistry (ocean acidification), and physical modifications (changes to beaches, shores, and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

6G. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Climate literacy principle

Principle Seven: Climate change will have consequences for the Earth system and human lives.

Materials list

- Printout of Figure 2 and Figure 5 to show students
- Plush toys or 3D printed models of dinoflagellates (The code for producing 3D models is publicly available here: https://sites.google.com/site/drjeffreywkrause/diatom-models)
- Activity sheet (provided below; one per person)
- Colored pencils (1 package per group)
- Printout of heatmaps after students complete their own
- Raised print PIAF handout (optional)

Supplemental material for visually impaired students

- Braille writer and paper
- Stick-on gems for students to place data points on the graph

Note that the 3D printed models and raised print figures were designed to accommodate visually impaired students, but were appreciated by sighted students and teachers so were included in the materials list above.

Safety

Students will be handling paper and pencils and any models the teacher has available. Some objects might be sharp, smelly (shells), or heavy.

Procedure

Time requirement: approximately one class period (50 min) unless more background is provided or assigned at the beginning.

Before beginning the activity, the teacher may want to ask students some background questions to gauge what they already know about photosynthesis and its importance, such as:

- What kinds of organisms photosynthesize?
- Why is it important?
- Do you know any marine plants that photosynthesize?
- Do you know that there are microscopic organisms called plankton, specifically phytoplankton, that photosynthesize (they probably know the word “plankton” from the cartoon Spongebob Squarepants)?

Distribute some of the examples of dinoflagellates such as: a copy of Figure 2; plush toy; or model from 3D printer (Figure 2 is approximately 5,000 times larger than actual dinoflagellate size). Share any of the information provided in the Background section before getting started.

Follow along with the instructions provided in the HAB Handout. In brief, students will be working in groups of 2-3 and answering questions after making a heat map using actual data provided by scientists monitoring the Gulf of Maine. They will then generate a line graph using the time series of data from four of the sites from 2006-2011.

Observation and discussion

This activity was tested on both sighted and visually impaired students. It was designed to be accessible to visually impaired students through modifications using raised features (Picture in a Flash tactile graphic maker), gem stickers (Figure 8) and/or braille writers (Figure 9) to produce the graphs. The time needed to complete the activity depends on the visual acuity and dexterity of the students, but should be 1-2 class periods. We received positive comments from teachers regarding the use of real data and the opportunity for student participants to generate their own models, as this is often excluded from activities for the visually impaired. Examples of the graphs students produced are in Figures 10 and 11. In general, teachers working with visually impaired students should plan on needing more time to complete the graphs and/or should have an aide assist these students or possibly have them work in pairs. The heat map colors could be substituted with different textures (cloth, sandpaper, glitter, aluminum foil) to produce a tactile map of the HAB distribution. The physical models of the dinoflagellates (3-D printed model, plush toy, PIAF pictures) were particularly helpful when working with the visually impaired but were appreciated by all.

Conclusions

Students learned about the importance of HABs and how they impact human health, as well as how coastal

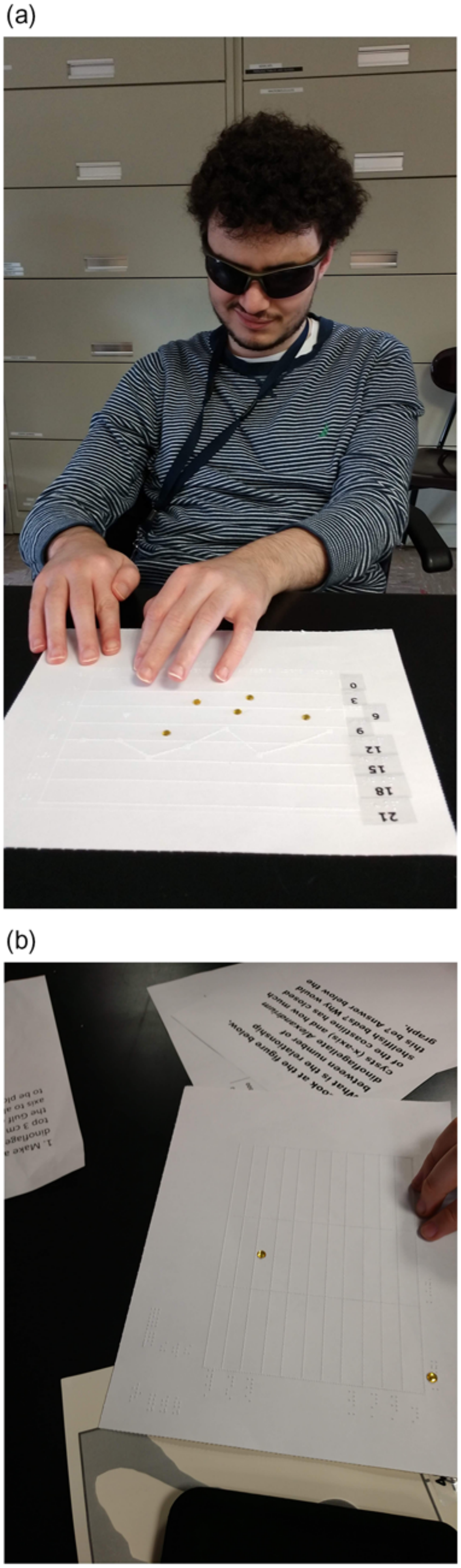

Figure 8. Visually impaired students place stick-on gem data points onto an earlier version of the graph provided in braille.

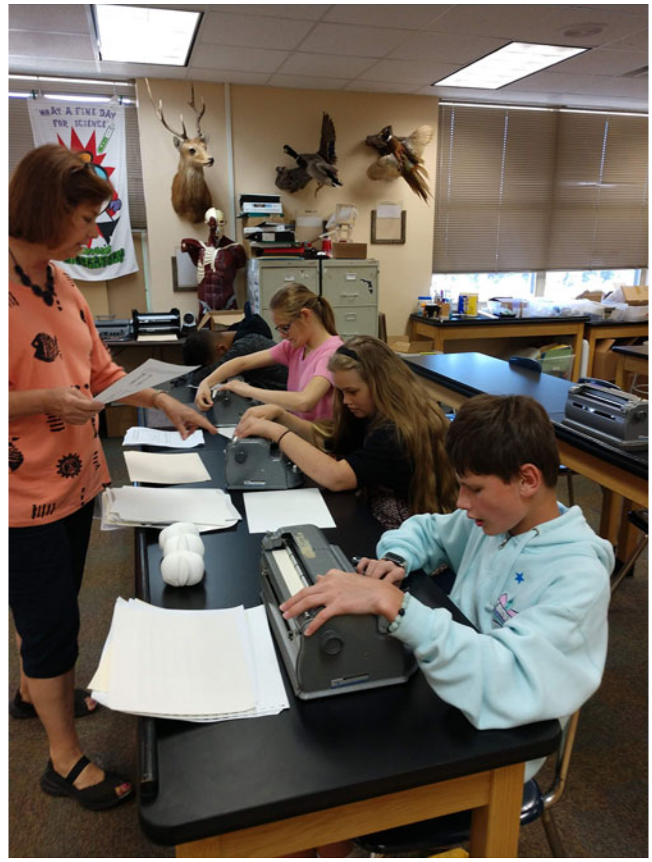

Figure 9. Students at the Florida School for the Deaf and Blind create their own graphs using a braille writer.

waters are routinely monitored to ensure the safety of the seafood we eat. The data plotting exercises familiarize students with different ways that scientists visualize and interpret data, and illustrate the importance of adequate temporal and spatial sampling. Students learned from making both types of graphs and were proud of their accomplishment. They enjoyed the creative element of making the heatmap especially since they were constructed from "real" data collected by scientists studying and modeling HABs in the Gulf of Maine. The students also enjoyed comparing their heat map with those generated by students for other sampling years, which helps to illustrate patterns in cyst distribution that were consistent over time and across geography.

Extensions

Students interested in researching the topic further can prepare a brochure on the topic as described in Fogleman and Curran (2006). Another activity about toxic algae, with details chemistry including

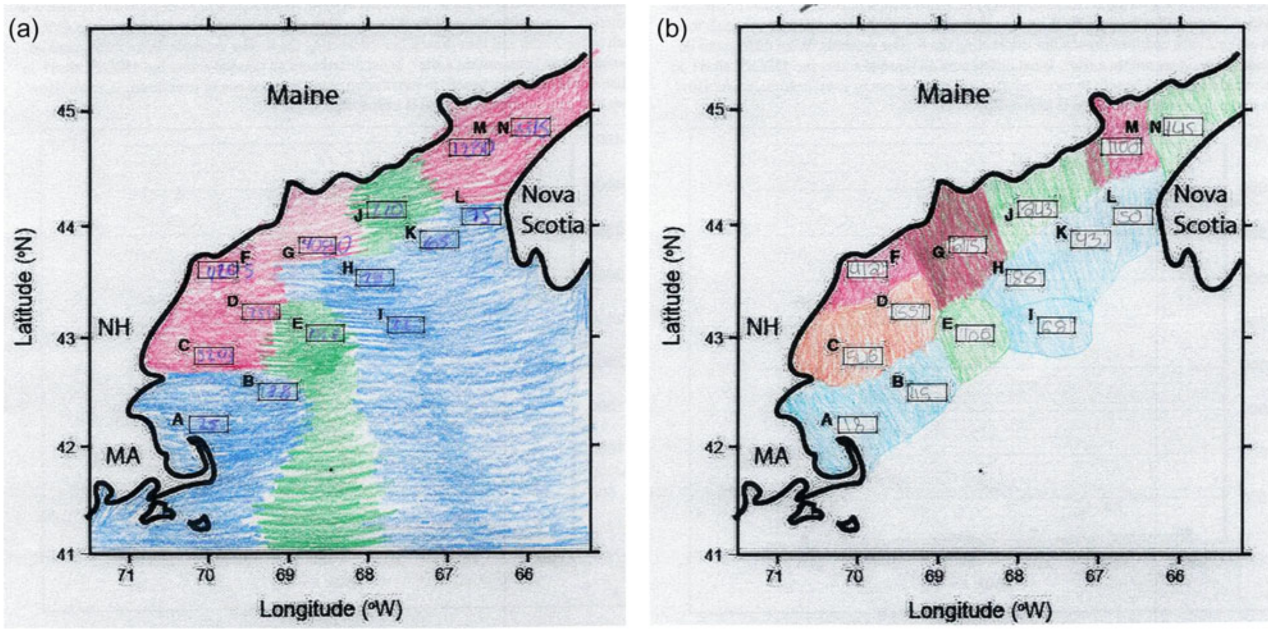

Figure 10. Two examples of heat maps generated by students. A) 2009 and B) 2011.

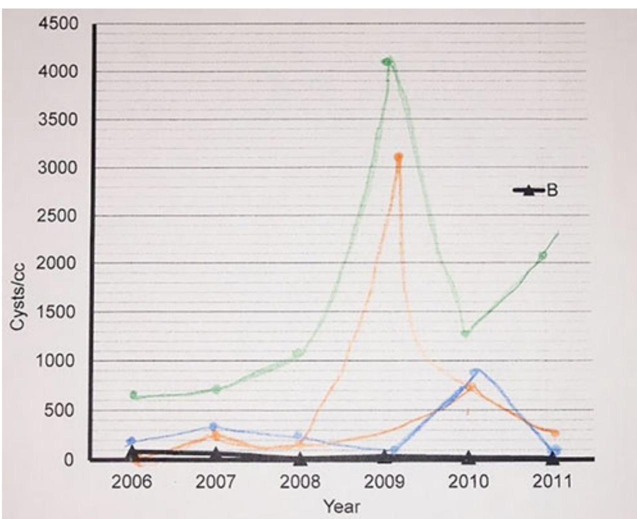

Figure 11. Example of student-generated line graph.

photosynthesis (Curran and Robertson, forthcoming). Students who are more interested in the socioeconomic aspect of the problem of HABs could create a mock townhall meeting similar to one described in Williams et al. (2016). This activity enables students to pick or be assigned different stakeholders as they try to resolve a problem that impacts people's livelihoods. Students could also research what government entities are responsible for monitoring the safety of the environment or the exploited resources, which enhances language arts skills. In the present activity, data were only presented using metric units. If teachers feel that more background is needed on the metric system, they could incorporate the activity described in Curran (2003) or add an exercise converting imperial units to metric ones.

Other activities with modifications for the visually impaired include Curran et al. (2019), Sukkestad and Curran (2012), Thompson et al. (2016), and Curran et al. (2017).

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References

Anderson, D. M., C. A. Stock, B. A. Keafer, A. Bronzino Nelson, B. Thompson, D. J. McGillicuddy, Jr., M. Keller, P. A. Matrai, and J. Martin. 2005. *Alexandrium fundyense* cyst dynamics in the Gulf of Maine. *Deep Sea Research*

Part II: Topical Studies in Oceanography 52 (19–21): 2522–42. doi: 10.1016/j.dsr2.2005.06.014.

Anderson, D. M., A. D. Cembella, and G. M. Hallegraeff. 2012. Progress in understanding harmful algal blooms: Paradigm shifts and new technologies for research, monitoring, and management. *Annual Review of Marine Science* 4 (1):143–76. doi: 10.1146/annurev-marine-120308-081121.

Anderson, D. M., D. A. Couture, J. L. Kleindinst, B. A. Keafer, D. J. McGillicuddy, Jr., J. L. Martin, M. L. Richlen, J. Michael Hickey, and Andrew R. Solow. 2014a. Understanding interannual, decadal level variability in paralytic shellfish poisoning toxicity in the Gulf of Maine: The HAB Index. *Deep Sea Research Part II: Topical Studies in Oceanography* 103:264–76. doi: 10.1016/j.dsr2.2013.09.018.

Anderson, D. M., B. A. Keafer, J. L. Kleindinst, D. J. McGillicuddy, Jr, J. L. Martin, K. Norton, C. H. Pilskaln, J. L. Smith, C. R. Sherwood, and B. Butman. 2014b. *Alexandrium fundyense* cysts in the Gulf of Maine: Long-term time series of abundance and distribution, and linkages to past and future blooms. Deep Sea Research Part II: *Topical Studies in Oceanography* 103:6–26. doi: 10.1016/j.dsr2.2013.10.002.

Backer, L. C., and D. J. McGillicuddy, Jr. 2006. Harmful algal blooms: At the interface between coastal oceanography and human health. *Oceanography* 19 (2):94. doi: 10.5670/oceanog.2006.72.

Bean, L. L., J. D. McGowan, and J. W. Hurst, Jr., 2005. Annual variations of paralytic shellfish poisoning in Maine, USA 1997–2001. *Deep Sea Research Part II: Topical Studies in Oceanography* 52 (19–21):2834–42. doi: 10.1016/j.dsr2.2005.06.023.

Landsberg, J. H., K. A. Lefebvre, and L. J. Flewelling. 2014. Effects of toxic microalgae on marine organisms. *Toxins and Biologically Active Compounds from Microalgae.*, Vol. 2: 379e449. New York: CRC Press.

McGillicuddy, D. J., D. M. Anderson, Jr., D. R. Lynch, and D. W. Townsend. 2005. Mechanisms regulating large-scale seasonal fluctuations in *Alexandrium fundyense* populations in the Gulf of Maine: Results from a physical–biological model. *Deep Sea Research Part II: Topical Studies in Oceanography* 52 (19–21):2698–714. doi: 10.1016/j.dsr2.2005.06.021.

Resources

Curran, Mary C. 2003. Learning the metric system: Calculating fish distributions, densities, and means using candy fish. Current: The Journal of Marine Education 18(4):28–31.

Curran, Mary C., Amy S. Bower, and Heather H. Furey. 2017. Detangling spaghetti: Tracking deep ocean currents in the Gulf of Mexico. Science Activities. http://dx.doi.org/10.1080/00368121.2017.1322031

Curran, Mary C., Laela S. Sayigh, and Kathleen Patterson. 2019. Eavesdropping on marine mammal conversations: An activity suitable for the visually impaired. Current: The Journal of Marine Education 33(2):33–42.

Curran, Mary C., and Alison Robertson. Forthcoming. Chemistry made easy: Teaching students about the link between marine chemistry and coral reef biodiversity. Submitted Current: The Journal of Marine Education.

Fogleman, Tara and Mary C. Curran. 2006. Save our salt marshes! Using educational brochures to increase student awareness of salt marsh ecology. Current: The Journal of Marine Education 22(3): 23–25.

Sukkestad, Kathryn and Mary C. Curran. 2012. Noodling for mollusks. NSTA: The Science Teacher 79(8): 38–42.

Thompson, Coral A., Sue C. Ebanks, and Mary C. Curran. 2016. Shrimp Socktail: The shrimp you feel instead of peel. Current: The Journal of Marine Education 30(1): 35–47.

Williams, J. T., J. Gut, M. Sherman, and M. C. Curran. 2016. Hear ye, Hear ye: Mock town hall meeting on human-induced impacts on the ecosystem. Current: The Journal of Marine Education 30(1):13–24.

Biosketches

Mary Carla Curran is a Full Professor in the Department of Marine and Environmental Sciences at Savannah State University. She is an active member of the National Marine Educators Association and has extensive experience translating scientific research into peer-reviewed K-12 activities. She is passionate about outreach activities and hopes to encourage students to remain interested in the sciences. Her areas of research include fish biology, parasite-host interactions, and estuarine ecology.

Mindy Richlen is a Research Specialist at the Woods Hole Oceanographic Institution. Her research interests focus on the ecology, physiology, and molecular biology of phytoplankton taxa responsible for harmful algal blooms (HABs). In addition to her research, she is actively engaged in coordinating the interests of HAB stakeholders at the national level through her involvement in the U.S. National Office for Harmful Algal Blooms and the National HAB Committee. As lead of the Community Engagement Core for the Woods Hole Center for Oceans and Human Health, she is involved in fostering data sharing and communication, and translating research findings for diverse audiences.