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The Oyster Reef Recruitment Game: An Example of Active Learning and Engineering in the Marine Science Classroom

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ABSTRACT

The inclusion of interdisciplinary, hands-on learning incorporated with engineering challenges is a great way to teach marine science content as well as foster collaborative problem-solving. To teach about oyster life cycles and the ecosystem engineering that oysters perform, and the role of oysters in southeastern salt marshes, we have developed a game to show the oyster life cycle. Starting with a rendition of musical chairs, students move on to investigating oyster reefs as physical barriers, calculating removal of particulates from the water column, then they mimic filter feeders, and design their own filtering machine.

INTRODUCTION

There are a lot of ways to teach marine science concepts, but current research is pointing to the inclusion of interdisciplinary, active, hands-on learning incorporated with engineering design challenges in the classroom as a way to teach content as well as foster problem-solving and communication skills (Vasquez 2014; Lesseig et al. 2017). In fact, the Next Generation Science Standards (NGSS) includes skills such as these in the 'Science and Engineering Practices.' As 'practices,' these skills need to be repeated, many times, in many ways, across the curriculum and throughout the K-12 grade levels (Bybee 2010; Bybee 2013; Lesseig et al. 2017). Younger students, in particular, need experiences with engineering and science, including data collection and analysis, collaboration, and experiences with non-traditional, non-cookbook exercises. As a teacher, I intentionally include data collection and experimental design in as many exercises as I can, especially with younger students who often don't get many science and engineering experiences because of the lack of teacher comfort with science and engineering at the elementary level (Bybee 2013; Draxler 2013). Also, students are often encouraged to memorize and regurgitate facts in order to boost test scores, when, really, it is harder to assess problem-solving skills that are of utmost importance. A teacher more comfortable with teaching science will increase the amount of science content and number of science and engineering activities in the classroom. To help, science educators are rapidly building an arsenal of ready-to-use and standards aligned (NGSS and Common Core) interdisciplinary STEM lessons and professional development opportunities. Here is one such lesson that middle school classroom teachers can use when teaching about the salt marsh.

This lesson is aimed at grades 4-6, incorporates NGSS science and engineering practices (Table 1), and discusses oyster reproduction and recruitment as well as how oysters act as ecosystem engineers. Students will actively "do" science and mathematics, collect data, and interpret results after engaging in a hands-on simulation of oyster recruitment and after modeling oysters as physical barriers. Lastly, these lessons are connected to real life, as many southeastern U.S. oyster reefs are in danger of drowning as sea levels rise. This, too, is an important facet of STEM education, the integration of science and technology with real-life problems (National Academy of Engineering and NRC 2014). Together, these oyster activities have the students asking questions, collecting and analyzing data, performing mathematical operations, and researching oyster natural history and the place of oysters in the culture and history of the Chesapeake Bay—and as a keystone species and ecosystem engineer. It is a focal topic that reaches out in a variety of ways and directions to integrate different learning strategies and skills.

BACKGROUND

The Nature Conservancy says that oysters are ecosystem engineers (The Nature Conservancy 2018), but what does that mean, exactly? And how can you teach this concept to students?

There are five species of oysters, a molluscan bivalve, found in the United States (two belong to the genus *Ostrea*, and three belong to *Crassostrea* (New World Encyclopedia 2017). Oysters are now cultivated on the Atlantic, Pacific, and Gulf coasts, and are important culturally (there are American Indian shell mounds, or 'middens', in the Southeast from 4,000 years ago) and economically (eastern oysters made up 70% of the commercial harvest of oysters, at about 22

TABLE 1. The *Next Generation Science Standards* (National Science Teachers Association 2013) science and engineering practices and disciplinary core ideas that are the focus of the oyster ecosystem engineer game

NGSS SCIENCE AND ENGINEERING PRACTICES	NGSS DISCIPLINARY CORE IDEAS
Planning and Carrying Out Investigations • Include investigations that control variables and provide evidence to support explanations or design solutions. (4-ESS2-1) • Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon. (4-ESS2-1) • Conduct an investigation to produce data to serve as the basis for evidence that meet the goals of an investigation. (MS-LS1-1) **Analyzing and Interpreting Data** • Introduces quantitative approaches to collecting data and conducting multiple trials of qualitative observations. (4-ESS2-2) **Developing and Using Models** • Develop and use a model to describe phenomena. (MS-LS1-2) • Models of all kinds are important for testing solutions. (MS-ETS1-4) **MS ETS1.B: Developing Possible Solutions** • A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4) • There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3) • Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3)	**4 - LS1.A: Structure and Function** Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior, and reproduction. **5 - LS2.A: Interdependent Relationships in Ecosystems** The food of almost any kind of animal can be traced back to plants. Organisms are related in food webs in which some animals eat plants for food and other animals eat the animals that eat plants … A healthy ecosystem is one in which multiple species of different types are each able to meet their needs in a relatively stable web of life. Newly introduced species can damage the balance of an ecosystem. **MS - LS1.B: Growth and Development of Organisms** Animals engage in characteristic behaviors that increase the odds of reproduction. (MS-LS1-4) Genetic factors as well as local conditions affect the growth of the adult. (MS-LS1-5) **MS - LS2.C: Ecosystem Dynamics, Functioning, and Resilience** Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations. (MS-LS2-4) **MS - LS4.D: Biodiversity and Humans** Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling. (MS-LS2-5) **MS - ETS1.B: Developing Possible Solutions** There are systematic processes for evaluating solutions with respect to how well they meet the criteria. (MS-LS2-5)

million pounds of meat per year, worth about $4.3 million in 2001, according to the NRC [2004]). This article discusses *Crassostra virginica*, or the eastern oyster. These oysters are a food source and essential to a healthy and properly functioning marine ecosystem (Puglisi 2008).

Massive oyster reefs once dominated the shores of the southeastern United States (NOAA 2007). The eastern oyster (*Crassostrea virginica*), found from Canada through the Gulf of Mexico and south to the Yucatan Peninsula in Mexico, is considered a keystone species as they are food and habitat for many other species—and without the eastern oyster the species diversity of the estuary decreases (Puglisi 2008). They do more than serve as food and habitat; however, and are considered to be ecosystem engineers, maintaining shoreline and tidal creeks, filtering and cleaning water, and reducing erosion and turbidity (The Nature Conservancy 2018). Without the oyster reefs, the ecosystem changes.

Diversity drops (as it does when any keystone species is removed) and the water quality becomes poorer, the tidal creeks meander and change course, and marshes decrease in size. Present oyster reefs are responsible for the structure and functioning of the estuarine ecosystem.

As filter feeders, oysters draw water through their gills to capture nutrients (NOAA 2007). This has the effect of cleaning the water of pollutants and nutrients. Food is trapped in the mucus of their gills, so gills are used for both respiration and feeding. Mature oysters can filter five liters of water per hour (or 50 gallons per day), and thus oysters play a major role in the function of estuarine ecosystems (The Nature Conservancy 2018). Eastern oysters in the Chesapeake Bay could once filter a volume of water equal to that of the entire Bay (about 19 trillion gallons) in a week. Today, with fewer oysters in the Bay, it would take more than a year.

Adult eastern oysters reach about 115 mm in about two years, and can live for 20 years (Puglisi 2008; NOAA 2007). Oysters can breed at about four months of age, and they start breeding when the water temperature is about 15-20ºC (Puglisi 2008). Oysters breed when smaller males release millions of sperm and the larger females release millions of eggs; eastern oysters change sex from male to female as they grow larger (NOAA 2007). If all goes well, eggs get fertilized and the larvae drift on the currents, spiraling towards the ocean bottom, and, if lucky, they find a suitable hard surface on which to attach. Oyster larvae start out as microscopic trochophore larvae (feeding from a yolk sac) and then, by day two, change into a veliger larvae (with a shell and cilia for capturing planktonic food; Puglisi 2008; NOAA 2007). They fall prey to birds and fish, float for about three weeks feeding on algae, and grow the start of a calcium shell. Then, sometimes following pheromonal signals from benthic adults from the reefs below, they will descend and attach to a hard surface (usually other oysters) and metamorphose into spat (about 25 mm in size and generally male). Lots of spat bonded together form a reef. But this three-week cycle from egg to spat is fraught with danger, and many don't survive to 'recruit' or join a reef's adult population.

Reefs perform some really important functions, particularly in the Southeast United States (The Nature Conservancy 2018). The oysters are tolerant of a wide range of salinity and temperature (NOAA 2007). In the Southeast, oysters are intertidal. They are generally subtidal farther north in the Atlantic, but in the South a boring sponge (*Cliona* spp.) competes for space with the oyster and restricts it to the intertidal range (Hill 2002). The intertidal oyster reefs act as coastline buffers, holding tidal creeks in place and protecting the coast from sea-level rise and tropical storms. This quality in particular earns the eastern oyster the classification of "ecosystem engineer": by building reefs, they modify the physical environment to make it more suitable for their long-term survival, and by accumulating shell and debris they maintain their position relative to sea level (NOAA 2007). Acting as physical barriers, they physically remove larger material from the water even as they filter the water and remove small particles, thus reducing turbidity (The Nature Conservancy 2018). They also serve as habitat for many intertidal creatures, like mud crabs, amphipods, byozoans, barnacles, anemones, oyster drill snails, polychatetes, and, when submerged by the tide, even more organisms including fish and blue crabs (The Nature Conservancy 2018; NOAA 2007; Hill 2002). They are both food and shelter for other organisms, like wading birds who eat the worms and crabs, and racoons who like to eat the oysters. Oysters are food in themselves, but they also provide food to other organisms in the form of their fecal matter, eggs, sperm, larvae, and spat. Commercially important fish like the striped bass, black drum, croaker, and herring have been known to eat oysters and animals found on the oyster reefs (NOAA 2007).

As a way to teach about oyster life cycles (with planktonic larvae that don't get cared for by parent oysters), the ecosystem engineering that oysters perform and the role of oysters in the Southeastern salt marshes, we have developed a game to show the oyster life cycle.

In this game we start by discussing recruitment—or, the joining of the adult benthic community by the oyster larvae. Ask your students about the similarities and differences between oyster reproduction and human reproduction. Generally, as a homework assignment the students research the eastern oyster, and the next day, in class, we make a list, or a Venn diagram, using prompts when necessary. Students will be able to come up with two parents (male and female), males make sperm and females make eggs; however, with humans, the number of offspring are few (1-2 usually, per mother), and the offspring are taken care of (for years) as they are born unable to do anything for themselves. Oysters make millions of babies per oyster mom, and there is no parental care (and lots of larvae die). You also see that the smaller oysters are male and they change sex to females as they grow. Oyster babies look different than their parents and are called larvae (there are actually a couple different larval forms). After about three weeks, the larvae settle (leave the planktonic stage in the upper water column and head down towards the benthos) and become part of an adult population, or reef. Without parental care, oyster larvae survival is low, and many won't

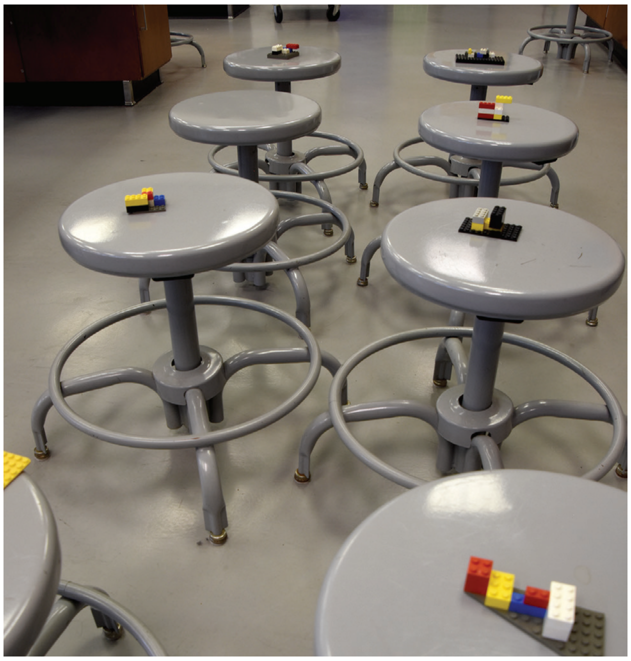

FIGURE 1. The oyster recruitment musical chairs game, with model Lego "reefs." Students in front of a chair with a Lego base add a Lego piece when the music stops. Courtesy of Lisa Pike

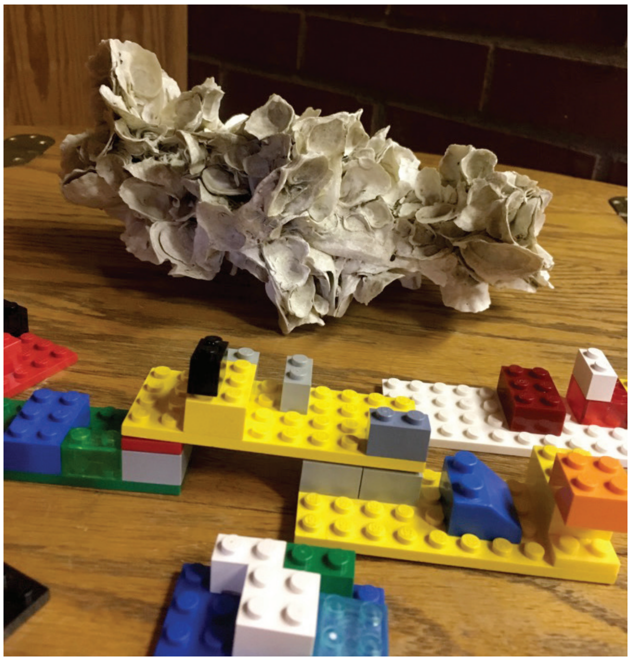

FIGURE 2. Completed oyster reefs after several rounds. Courtesy of Lisa Pike

make it to adulthood and recruitment (the settling down and joining the adult population stage). So, we've just talked about a lot of vocabulary words, especially 'recruitment,' 'settle,' 'plankton,' 'larvae,' and 'metamorphosis' and we are now ready to model oyster reproduction and recruitment.

Oyster life cycles and recruitment can be taught using a variation on musical chairs. Set it up by placing one chair for each student in a back to back double line (Figure 1). On some of the chairs (leaving 3-6 chairs empty), have a small, flat Lego base. Give students a handful of small Lego pieces and have students add one piece to each reef whenever the music stops (Figure 2). They may add a piece to a reef (this is oyster larval recruitment) only if they are in front of a chair that has a Lego base—and only one student per chair. For each succeeding round (or 'year'), the teacher rolls a die (with numbers corresponding to recruitment issues), and can add/remove one or more bases (leaving chairs in place) for reasons such as "cold winter, lots of oysters died," or "hurricane rain led to an influx of freshwater, lowering the salinity—lots of oysters died," and so on. Reefs thrive when the temperature and salinity are good, predators are few, and sea levels remain constant; they fail to thrive with freshwater, cooler (or hotter) temperatures, sea-level rise, flooding, predators, changes in ocean currents that move larvae (or their food) off shore instead of onshore, and so forth.

Students who don't get to add a piece will take their Lego pieces to a shoebox-sized bin on the side—these pieces are larval oysters who were not able to recruit and end up being eaten or dying, decomposing, and re-entering the food chain as nutrients for phytoplankton (or sinking to depths which helps to sequester carbon).

Why couldn't the larvae recruit? Well, being a larva is dangerous. Larvae are small, planktonic (can't make much headway against the currents and waves), and tasty. A lot of larvae get eaten. Some get washed ashore and dry up, others get flushed into waters that are too cold, the wrong salinity, or polluted (and they die). Some get taken by currents to areas where they can't make it to the bottom, or there is no hard surface on which to attach (larvae can't attach to shifting sands, they need something hard to cement to). What this really means is that some years recruitment is good, and there are lots of baby oysters—and some years it is not good; further, these poor recruitment years aren't due to oyster misbehavior, but rather random chance events like weather or currents. In the end, larvae that are successful in recruitment (joining the benthic oyster reef) have been able to head down to the bottom after about three weeks in the plankton and find a hard surface, preferably other oysters. Adult oysters may release pheromones which are chemical signals to the larvae that there are reefs below to which they

Trial	# oyster larvae that successfully recruit	# oyster larvae that die	total # oyster larvae (= # successful + # dead)	% successful recruitment $= \left(\frac{\text{\# successful}}{\text{total number}}\right) \times 100$	Time Allocated
1	20	5	25	80%	-2
2	18	7	25	72%	+1
3	19	6	25	76%	-2
4	17	8	25	68%	+2
5	19	6	25	76%	+1
6	20	5	25	80%	

FIGURE 3. Oyster recruitment game worksheet. This is sample data from a class of 25 students, starting with 20 Lego bases.

can attach (Bussarawit and Cedhagen 2012; NOAA 2007). Students will visually see that not all larvae recruit, and there will be an increasing number of larvae that are either eaten or decompose and thus return nutrients to the system in the shoebox. Students can quantify this on their student worksheet (Figure 3).

Next we talk about the oyster as an ecosystem engineer, an organism that modifies the environment to aid in their future survival.

With the ecosystem engineer part, students create a model oyster reef on a Lego flat base (make sure that it isn't solid, but has two-by-two Lego brick-sized gaps and holes [Figure 4]). Tilt it into a shoebox (representing a tidal creek). This can also be done with cardstock, in the absence of a prolific supply of Legos. Take a pitcher with different sized plastic beads (the size of a one-by-one brick or smaller), and slowly pour it through the reef into the shoebox. The reef, which is intertidal and submerged at high tide, will capture and keep many of the beads from entering the shoebox, or tidal creek. In this way oyster reefs act as a physical barrier, holding large particles in place, helping maintain tidal creek positions and flow. Challenge the students to try it again, with a reef that has more gaps, or larger/smaller gaps. Ask the students to design, using cardstock and scissors, different reef formations and test them scientifically. What variables need to be controlled? The tilt of your bucket (with reef cover)? The number of beads you pour over the reef? Holes need to be at least as large as the beads you use (so a bead can pass through), and you can give them a total amount of open space each reef should have. What size holes/placement of holes will give the best retention (long and narrow? several small versus one large?). If you were an engineer tasked with designing an artificial oyster reef, what would it look like and why? The key is not having a solid reef that's just a seawall, or a groin. Reefs have gaps and allow water and some particles through. Finish by asking students why it is beneficial to trap sediments and to maintain the shape and flow of tidal creeks.

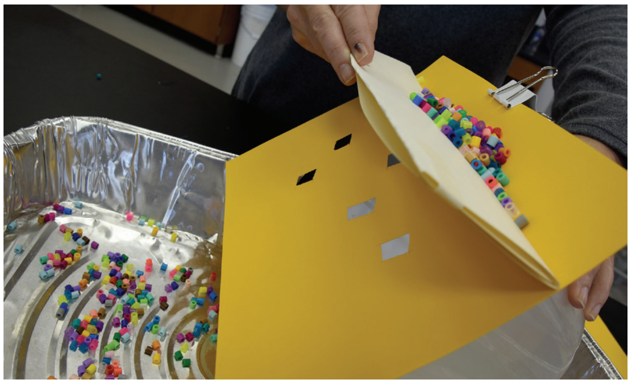

FIGURE 4. Oysters as ecosystem engineers—a Lego oyster reef and a cardstock oyster reef showing solid portions and gaps. Courtesy of Lisa Pike

Discuss how the oysters perform an essential ecosystem service by filtering and cleaning the water of microscopic particulates, such as harmful red tide algae or pollutants like nitrogen or phosphorous, or the industrial chemicals in the PCB group, or the herbicide atrazine (Luna-Acosta et al. 2015). Students can test this, too, using a fish tank with water. Place something that floats in the water (styrofoam or plastic beads, cut up kitchen sponge, plastic confetti, etc.). Take a small fish net (found in aquarium supply stores) and teach students how to put the net in, move it 2 inches forward, and lift it out

(Figure 5). Challenge the students to be "filtering machines" like oysters. Students stick the net in, move it forward 2 inches (through the floating objects), and lift the net up; oysters suck water over their gills and trap small particles with the mucus that covers their gills. How many times do they have to repeat this movement to filter all of the plastic (representing phyto-plankton or algae, which is the food of the oyster, or some sort of toxin or pollutant) from the tank? Students can collect data on this and can determine, by systematic experimentation (i.e., trying a method multiple times and averaging the number of particles removed), if there is a method of filtering that cleans the water more quickly. For example, should they dip the net in the same spot time after time, move the net forward each time, use a circular motion? Lastly, challenge students to engineer their own filtering device, given parameters (not larger than 1/10th the size of the tank surface area) and craft supplies. You can ask them to factor in that oysters can't move—can they make a design that traps particles without moving laterally? What movements will cause a current that returns the particles to the oyster machine?

These small exercises illustrate the importance of oysters, and lead to a good discussion on the issues of overharvesting oysters. What happens when the oysters aren't as abundant as they used to be? Disease and toxins (from dispersants to clean up oil spills, for example), are causes of the decline of oysters (Freeman et al. 2010). Sea-level rise is also taking a toll on oyster reefs, as are hurricanes, development, and fishing methods like dredging or bottom trawling. Overharvest of oysters is another big issue; for example, in the Chesapeake Bay, oyster populations started declining in the 1890s due mostly to overharvest (when 20 million bushels per year were extracted) and have not recovered, with only 3-5 million bushels per year being harvested today (NRC 2004). Harvesting oysters can be as simple as gathering them by hand or with rakes, or as harmful as using dredges, which really damages the reefs and the habitat. When oyster habitat decreases, so does fish habitat, and coastal erosion increases.

Is there a way to help oyster reefs recover, or to add new oyster reefs to the ecosystem? Different states are trying different methods to restore oyster reefs, such as specialized mats in Florida; bagged oyster shells and chain link baskets of shells in Georgia; interlocking steel cages in Alabama; and oyster "castles" in South Carolina (South Carolina Sea Grant Consortium 2018). Oyster farming (mariculture) is also becoming profitable and widespread, and can increase the number of oysters in natural ecosystems and the number of oyster larvae ready to recruit. The biggest issue along the southeastern coast is sea-level rise drowning out our inter-tidal oyster reefs.

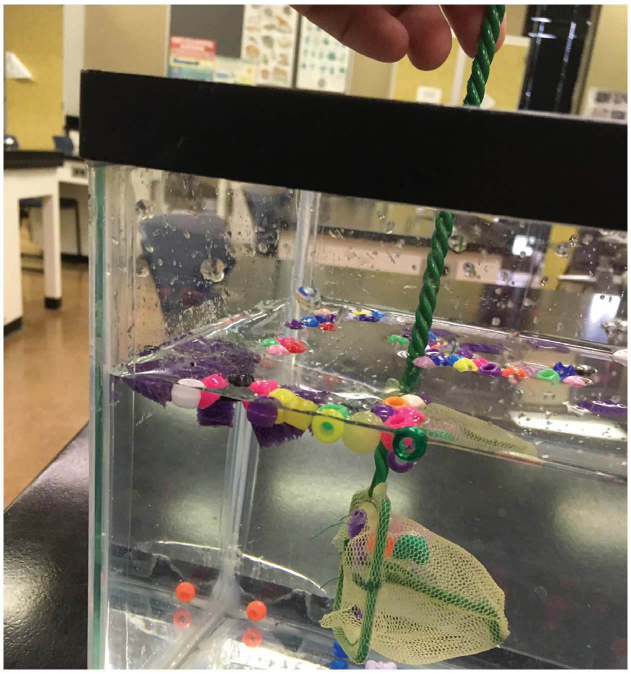

FIGURE 5. Calculating filtering efficiency and engineering a filtering machine. Courtesy of Lisa Pike

One way to assess this lesson on oysters is to ask students to draw an oyster reef both as a pre- and post-lesson assessment (this is similar to the draw a saltmarsh lesson available at SC Sea Grant Consortium). Ask students to draw where it is found in the marsh, and what organisms live there. They should use labels and notations to describe the oyster reef. You can also ask students to draw a plan for a machine that cleans up ocean trash (like oyster's filter plankton, humans can filter seawater). Students may also research oysters, oyster reefs, artificial reefs, oyster mariculture techniques, or impacts of climate change on oysters, and present reports to the class.

Access the complete Oyster Recruitment Game, along with all the resources used in the implementation of the activity, online at https://static1.squarespace.com/static/5b4cecfde2ccd188cfed8026/t/5d5a23e6cb97dc00012b2334/1566188518854/The-Oyster-Reef-Recruitment-Game-Resources.pdf.

RESOURCES

COSEE NOW Marine Lesson Plans - Fish Biology and Ecology, Shellfish Recruitment and Reproduction: http://coseenow.net/education-resources/lesson-plans/

East Coast MARE - Oysters and Oyster Reefs in Your Classroom: http://coseenow.net/mare/ oysters-in-your-classroom/

South Carolina Sea Grant Consortium - Curriculum Connection (Summer 2018): http://www.scseagrant.org/Content/?cid=1017

Salt Marsh Drawing Pre and Post Assessment. South Carolina Sea Grant Consortium. Authors: Ben Weiss and E.V. Bell.

The South Carolina Oyster Restoration and Enhancement (SCORE): Estuaries 101 Curriculum (The Great Oyster Mystery and An Ode to the Oyster).

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