FINAL REPORT

Shell Bank: Improving oyster reef restoration through oyster shell recycling, education, and scientific inquiry

CMP Cycle 18 Final Report
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ACKNOWLEDGEMENTS

This project wouldn't have been possible without the strong community partnerships that support it. We'd like to thank our partners at the Port of Corpus Christi, Water Street Restaurants, and Groomer's Seafood, as well as the many volunteers who have participated in activities related to oyster shell recycling and habitat conservation and restoration. The support of these groups has been essential to the growth and continuing evolution of the Shell Bank Program.

INTRODUCTION

Eastern oysters (*Crassostrea virginica*) are valuable natural resources that provide many benefits to coastal environments. They filter and clean bay waters, create fish habitat, and protect shorelines from erosion. Oysters also provide an important source of revenue, with over 6.1 million pounds harvested and $23.5 million generated in Texas in 2013. However, oyster reefs are the most degraded marine habitat on earth, with estimates upwards of 90% lost globally. Because free-swimming oyster larvae depend on the hard shells of older generations for attachment and growth (Figure 1), when the shells of harvested oysters are not returned to bay waters, important habitat is lost.

Oyster reef restoration projects are ongoing across the U.S. Gulf of Mexico and Atlantic coasts to replace or enhance a variety of ecological functions provided by natural reefs, including: habitat provisioning for oysters, fish and macroinvertebrates; acting as a source of larval oyster spat to the surrounding area; improving water quality; protecting shorelines from erosion; and maintaining commercial harvest grounds. In substrate limited areas, where oyster reefs are limited by a lack of hard substrate, restoration efforts generally involve placing oyster shells or other hard substrates back into estuaries to support oyster attachment and growth. This process depends on having a reliable source of suitable substrate material. Shell is the natural substrate for restoring degraded oyster reefs—however, harvested oyster shells are often lost to landfills or competing uses, creating an obstacle to reef restoration success. The Shell Bank Program was developed to reclaim and recycle shells from restaurants and seafood wholesalers for use in reef restoration in the Texas coastal bend. Shells reclaimed from this program have been used to restore over 14 acres of oyster reef in the Mission-Aransas Estuary with funding from the Coastal Conservation Association, Fish America Foundation, Gulf of Mexico

Foundation, National Fish and Wildlife Foundation, Texas Parks and Wildlife Department, and the NOAA Community-Based Restoration Program.

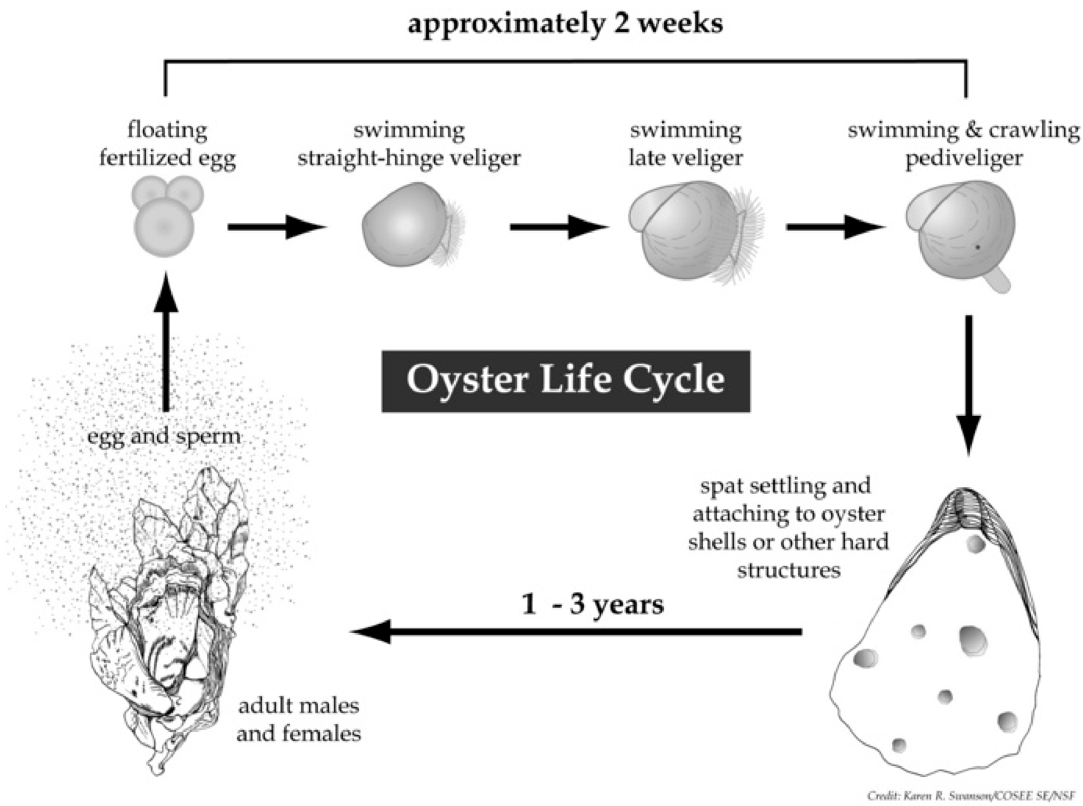

Figure 1. Oyster life cycle. Credit: Karen R. Swanson/COSEE SE/NSF

Project Goals, and Partners

The Shell Bank Project was created with support from the Coastal Management Program in 2009 as an innovative oyster shell reclamation, storage, and recycling program for the Texas Coastal Bend. Original project partners were: the Harte Research Institute for Gulf of Mexico Studies at Texas A&M University-Corpus Christi, the Port of Corpus Christi Authority, and Water Street Seafood Company in Corpus Christi, TX. For CMP Cycle 18, we expanded the program by focusing our efforts toward 4 principal project goals.

Goal 1: Expand substrate collection efforts.

Objective: We will continue to reclaim oyster shells from our partner restaurants/ wholesalers for restoring degraded reef. We will also expand our shell collection activities to new partners and work with the City of Corpus Christi to reclaim recycled porcelain from residential and commercial fixtures for reef restoration.

Goal 2: Establish community-based shell recycling program.

Objective: We will work with local municipalities to establish community drop off locations for shucked oyster shells to ensure these shells are recycled and placed at suitable locations in future reef restoration projects.

Goal 3: Outreach.

Objective: We will create interactive educational modules as part of a web based curriculum and internet-based kiosk to be placed within one of our partner restaurants. We will also work with community partners like the Texas State Aquarium and Moody High School to host volunteer shell bagging events.

Goal 4: Habitat assessment.

Objective: We will collect organisms on natural and restored reefs in the Mission-Aransas Estuary and perform food web analyses to determine how well the restored reefs mimic the habitat functions of natural reefs.

1. EXPAND SUBSTRATE COLLECTION EFFORTS

The Shell Bank Project works with Texas coastal bend restaurants, seafood wholesalers, and regional seafood festivals with the common goal of recycling oyster shells for use in reef restoration projects. To date, over 14 acres of oyster reef have been restored in the Mission-Aransas Estuary utilizing these reclaimed oyster shells. Recycling oyster shells for use in oyster reef restoration is a four-step process:

Step 1: Harvest. Oysters are harvested from bay waters by commercial oystermen, typically using an oyster dredge. The majority of these oysters are then sold to seafood wholesalers and restaurants. Seafood festivals also purchase large quantities of oysters that are then shucked on site to provide fresh plates of oysters on the half shell to festivalgoers.

Step 2: Collection. At restaurants and seafood festivals, the top shell of the oyster is collected in specially designated containers when oyster shuckers remove it at the shucking station to create oysters on the half-shell. After patrons consume raw oysters or other types of oyster platters, the bottom shell of each raw oyster is collected by bussers, separated from restaurant trash, and placed into similar collection bins. Shells from indoor collection bins are pooled into four 400 lb. capacity outdoor collection bins for pickup. At seafood wholesalers, oysters are completely removed from their shells on site to produce pint to gallon size containers of fresh shucked oysters. All shells are placed directly into the same collection containers and then transferred into two 5,000 lb. capacity dump trailers for pickup.

Step 3: Stockpiling. We visit each restaurant and seafood wholesaler regularly (daily-weekly, depending on shell production level) to collect the outdoor collection bins or trailers and transport them to the Shell Bank Repository at the Port of Corpus Christi. For seafood festivals, we typically provide outreach and educational opportunities for festival goers on site as well as collect oyster shells using buckets and trailers. These shells are also transported to the Port site. All shells are stockpiled at this location for at least 6 months of quarantine to eliminate potential diseases or invasive organisms.

Step 4: Restoration. After a large quantity of shells has been reclaimed, they are used in oyster reef restoration projects in Texas Coastal Bend bays (using external funding). This process involves site surveys, reef construction using large-scale (barges) small, community-scale methods, and monitoring to ensure restoration success.

In Corpus Christi, the largest majority of oyster shells are produced by Groomer's Seafood and Water Street Oyster Bar. These partners in the Shell Bank Program contribute 100% of their oyster shells for reef restoration. We were happy to add Groomer's Seafood as a new partner in November, 2014. They are Corpus Christi's largest fresh fish and fresh seafood wholesale and retail processor, as well as one of the largest fresh seafood suppliers in the U.S., servicing almost 2,000 restaurants, country clubs and retail stores, including Whole Foods and Sysco Foods. Their contribution to the program has been significant. As an example, we reclaimed between 2,800 and 8,800 pounds of oyster shells per month from October 2013 through November 2014, for an average of 5,657 pounds of oyster shells collected per month (Figure 2). After adding Groomer's, our monthly totals during the oyster season (Nov-April) jumped to an average of 40,500 pounds per month, with a maximum amount collected in May 2015 of 70,600 pounds of oyster shell in just 1 month! The amount of shells produced declined after the end of the oyster season but remains in line with pre-season totals. The total weight of oyster shells reclaimed from our partners during CMP Cycle 18 was 328,000 pounds, or approximately 248 cubic yards of shell.

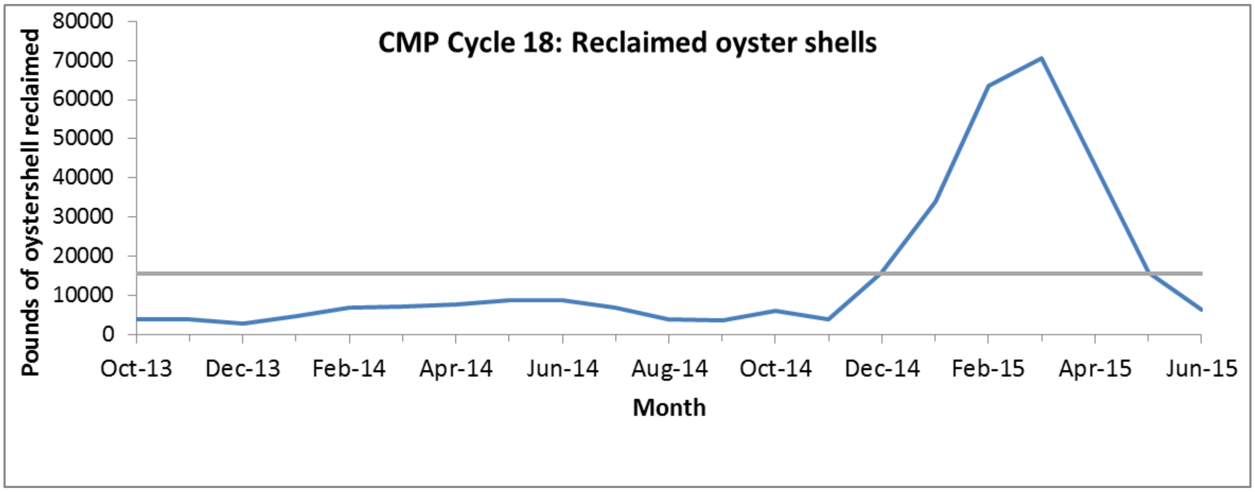

Figure 2. Pounds of oyster shell reclaimed (by month) as part of CMP Cycle 18 from October 2013-June 2015. The blue line illustrates monthly totals. The gray line illustrates the monthly average of 15,661 pounds.

A second goal of this project was to work with the City of Corpus Christi to reclaim recycled porcelain that has been reclaimed from their waste stream (e.g. residential and commercial toilets, tubs, sinks) for use as an alternative substrate in oyster reef restoration projects. As part of CMP 17, we demonstrated the viability of using this material for oyster reef restoration; i.e. oyster spat successfully settled onto porcelain substrates and reef-associated fauna utilized this substrate as habitat. These results have now been published in the Journal of Coastal Conservation:

George LM, De Santiago K, Palmer TA, Beseres Pollack J (2015). Oyster reef restoration: Effect of alternative substrates on oyster recruitment and nekton habitat use. *Journal of Coastal Conservation* 19(1): 13-22. doi 10.1007/s11852-014-0351-y

In trying to scale up from small experimental reefs to large-scale reef restoration using reclaimed porcelain fixtures, we encountered two major issues: 1) finding a location where it would be acceptable to the public to restore a reef using these post-consumer materials, and 2) identifying a laboratory that could test the material to ensure the absence of human-related contaminants. Both of these activities were important to accomplish before this material could be used for large-scale restoration. We had numerous conversations with microbiologists both at Test America Inc. and Scientific Methods, Inc., and were initially advised to test for one potential human pathogen called male specific coliphage as an indicator of contamination. These viruses are commonly present in wastewater in relatively large numbers and their source is human feces. We were provided the following protocol of detection of coliphages and determination of source fecal contamination from Scientific Methods, Inc.:

> "SMI has developed a method to detect coliphages in large volume of water samples from 1 to 100 L using an encapsulated positively charged filter and modified USEPA Method 1602. After filtering desired volume of water samples, capsule filters are shipped back to SMI by an overnight carrier. Coliphages are eluted from filters using OptimaRE elution buffer, and followed by EPA Method 1602.
>
> When water samples are subjected to EPA method 1602, an overnight incubation allows viruses to infect the E. coli host cells and create lytic zones called 'plaques'. Viruses recovered from these lytic zones are subjected to oligoprobe hybridization using four separate enzymatically labeled probes that will bind with the genetic material of coliphages present within the enriched sample. Binding signatures make it possible to classify virus isolates into one of four distinct coliphage groups. Male-specific coliphages that correspond to human feces are statistically associated with phage groups

2 and 3, whereas animal coliphages are associated with groups 1 and 4. Depending upon the data requirements of the project, up to 10 male-specific coliphage isolates from each water sample can be subjected to hybridization."

However, following all of this groundwork, we had a particularly eye-opening conversation with Priuyni Patel, a microbiologist with Test America. Essentially she explained to us that there are innumerable potential human pathogens that could be associated with porcelain that has been recycled from the waste stream, which would necessitate testing for a greater suite of human pathogen indicators, including, but not limited to: total coliform, fecal coliform, E. coli, Enterococci, heterotrophic bacteria, bacterial identification, bacteriophage analysis, human bacteriodes, legionella, cryptosporidium, giardia, as well as a wide variety of protozoa, bacteria, fungi, viruses, etc. To just have the material tested for male specific coliphage was $175 per sample, and to add these additional tests quickly became cost prohibitive. Most importantly, we were advised that there was no way to ensure the material was free of human pathogens before placement in the water. Because we intended to use this material for oyster reef restoration, meaning that oysters would attach on grow on the porcelain and could then be harvested and consumed by people, we determined the risk to be too great and discontinued this approach.

Currently, Texas does not allow restoration in closed or 'restricted' waters due to potential water quality issues that could threaten human health. If this designation were to be changed in the future to allow for restoration in areas that could not be targeted for consumption, the use of this recycled material may become a viable option. In that case, oyster reefs could be used to filter and clean bay waters in these restricted areas, potentially improving local water quality conditions, but would not threaten human health because harvest and consumption would be forbidden.

One positive result of this partnership with the City of Corpus Christi was that Mr. Tom Tagliabue, Director of Intergovernmental Relations, contacted us about the possibility of the city seeking RESTORE Act funds to institutionalize the shell pickup and delivery portions of the Shell Bank Project, to assist with its sustainability. This project idea was submitted to the Phase IV early restoration funding mechanism for consideration.

On February 28, Gail Sutton, Jennifer Pollack, and 5 students participated in the 3rd Annual Austin Oyster Festival at the Carson Creek Ranch in Austin, Texas (Figures 3-5). We talked to festivalgoers about recycling their oyster shells and oyster reef restoration, and successfully reclaimed 3,000 pounds of oyster shells produced at the event.

Figure 3. Alex Austin, Kevin De Santiago, Mike Grubbs, Brittany Blomberg, and Kathryn Mendenhall at Austin Oyster Festival.

Figure 4. Inside the Austin Oyster Festival Tent showing the Oyster Shell Recycling Buckets at each table for festivalgoers to place their shells for recycling.

Figure 5. The collection trailer for recycling oyster shells at Austin Oyster Festival.

2. ESTABLISH COMMUNITY BASED SHELL-RECYCLING PROGRAM

This task was developed because community members from around the coastal bend have approached us with interest in recycling their own shucked oyster shells, but without a mechanism to do so. Instead, these shells are being thrown in the trash or dumped into non-ideal locations in the bay where they may sink into soft sediments or are out of reach of oyster populations. In order to meet this need and expand our shell collection efforts outside of restaurants/wholesalers, our goal was to work with local municipalities to establish community drop off locations for shucked oyster shells. This would allow our program to reclaim these additional shells that are being missed with our restaurant-based recycling program, and would ensure these shells are placed at suitable locations to restore reefs as part of future reef restoration projects.

Community meetings were held at the Rockport Aquarium October 16 and March 5 by Gail Sutton and Jay Tarkington. We utilized an existing community network to invite people from local seafood companies, community organizers, and officials from the city of Rockport. Feedback was that individuals who produce shells don't produce that much, and people are interested in the shells themselves, and they will just get taken from the bins. Very common to see them in driveways, yards, roofs. Also concerns with smell and health issues, as well as need to pick up this small amount of shell regularly.

After hearing the concerns from the local community it was decided we needed to collect shell from the larger producers like wholesalers. WaterStreet Restaurant Owner, Brad Lomax, introduced Jennifer Pollack and Gail Sutton to the owners of the largest seafood wholesaler in South Texas, Groomers Seafood in November 2014. Groomers Seafood physically expanded into the Corpus Christi area and was interested in recycling their shucked oyster shell. By December 2014, Groomers Seafood was provided bins for collecting shucked oyster shell. Their production was so high that within a month and a half we collected more shell in that period than the entire previous year. This production continued through May 2015. At that point the availability of oysters fell off so the production returned to our normal collection rate. The manager of Groomers Seafood stated that the numbers would increase again in the fall. For the calendar year of 2014 we collected 79,900 pounds of shell and for six months in 2015 we collected 207,200 pounds of shell. This confirms that our plan to collect from the wholesalers will have a bigger impact on the program overall with less expenses. We have also started discussions with the oldest and one of the largest seafood wholesalers (Quality Seafood) in Austin, Texas to collect their shucked shells. The City of Austin has enacted a law that all restaurants must compost all food waste starting in 2016. Quality Seafood is offering to collect shell from all of the restaurants they supply and send the shucked shell down to our collection site via the trucks that come to Austin to deliver fresh fish. We continue to work on this idea since Groomers Seafood has been such a success.

3. OUTREACH

The ultimate goal of the Shell Bank project is to provide information for education and outreach purposes to promote preservation and stewardship of coastal natural resources, including oysters. To this end, our goal was to create interactive educational modules as part of a web based curriculum and internet-based kiosk to be placed within one of our partner restaurants. The rationale is that the kiosk could provide animations and educational games to teach about oyster populations, oyster shell recycling, and reef restoration (See Appendix A for screen shots of the kiosk program). Information from the education modules could then be repurposed into videos and used at festivals and special events throughout the Coastal Bend, such as Bayfest, Sea Fair, Hummingbird Festival, and Earth Day Bay Day, reinforcing the larger role that oysters play in coastal ecosystems.

The kiosk has been installed at WaterStreet Oyster Bar (Figures 6-8). We are working with the restaurant owner to create a sign or banner that can be placed next to the kiosk explaining it to restaurant patrons and encouraging them to use it. Both adults and children like the content and now have a better understanding why we recycle oyster shell. Additionally, the importance of the oyster in the ecosystem is also conveyed to the restaurant clientele. The games reinforce the interaction between oysters and other sea life. The Oyster E-Book is on a platform that will allow us to take it to festivals and other venues. Our goal is to discuss the expansion of the E-Book into other restaurants.

Figure 6. Oyster e-book kiosk at Water Street Oyster Bar.

Figure 7. Oyster e-book kiosk located near the inside sign at Water Street Oyster Bar.

In addition to the kiosk, we updated the signage at Water Street Oyster Bar and at Groomer's to highlight their role in habitat restoration through participation in the Shell Bank Program. Two signs were placed outside of Water Street Oyster Bar, adjacent to the shell collection area to highlight the role of oyster shells in habitat creation (Figure 9). A similar sign was created for Groomer's Seafood wholesaler (Figure 10). One sign was also placed inside the restaurant with more of a restaurant-focused twist, highlighting not only shell recycling, but also the health benefits of eating oysters (Figure 11).

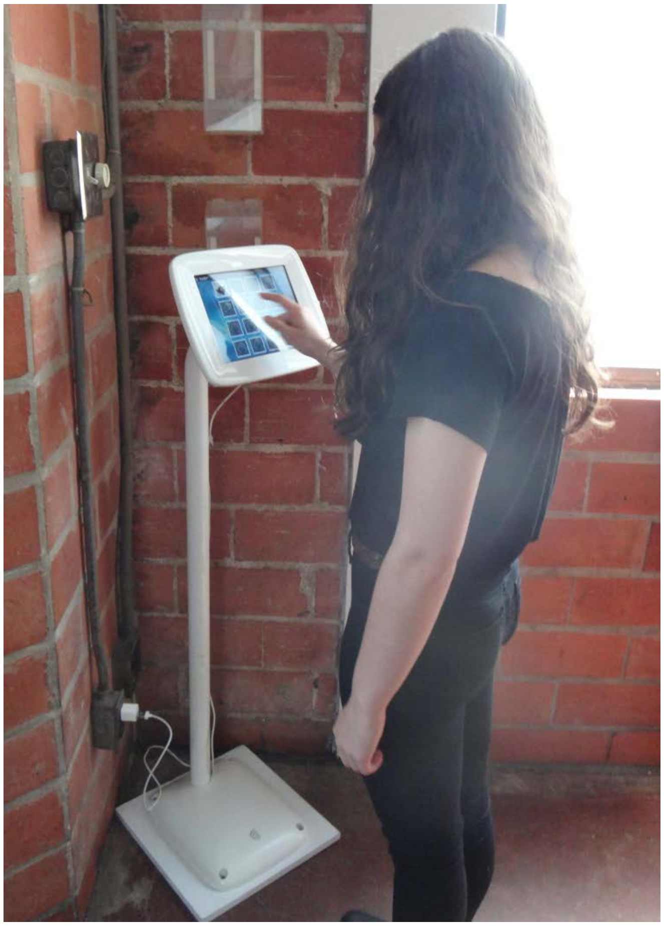

Figure 8. A restaurant patron explores the oyster e-book kiosk at Water Street Oyster Bar.

Figure 9. New signage outside of shell collection bin area at Water Street.

Figure 10. Signage at Groomer's Seafood wholesaler.

Figure 11. New signage inside of Water Street Oyster Bar promoting the oyster shell recycling program.

In addition, we continued to work with our colleagues at The Texas State Aquarium and Moody High School to host oyster shell bagging events at Goose Island State Park. These community-based restoration events allow the public to get involved in bagging oyster shells to create the building blocks oyster reef restoration. This project period we hosted two community events: April 5, 2014 and May 10, 2014 (Figures 12-13). For the April 5th event we hosted 61 volunteers that bagged 727 bags of shell for a total of 17,108. On May 10th event we hosted 150 volunteers that bagged 334 bags of shell for a total of 15,792.

Figure 12. Volunteers pass shell bags into the water at the community-based restoration event at Goose Island State Park.

Figure 13. Volunteers from our May 10, 2014 community oyster shell-bagging event at Goose Island State Park.

For the second year in a row, we continued our Oysters in the Classroom program at 10 local schools. In this program, each class is provided with the materials: aquaria, salt water mix, water quality test kits, oyster larvae and phytoplankton to grow, observe, and perform experiments on oysters in their classrooms (Figure 14). Students then observe the development and growth of oysters from larvae to adults, measure water quality, and design and perform numerous experiments. At the end of the school year, the oysters are placed back into the reef they originated from. Oysters in the Classroom generates meaningful education experiences for students and creates stronger connections to their local environment—the activities and materials assist teachers in better utilizing the local environment as a teaching and learning tool.

Figure 14. A fifth grader feeds the oysters in her classroom aquarium in Aransas Pass.

On July 10, 11, and 25th students associated with the Boys and Girls Club of America and students from the Rockport Aquarium were taught about oysters through our ongoing field based Wetland Explorer programs (50 students). On August 16, 30 and September 20th, the general public was able to learn about local oyster reefs and recycling through our traveling Wetland on Wheels exhibit. The Wetland On Wheels trailer exhibit highlights the journey of fresh water as it makes its way to the gulf. Along with other wetland flora and fauna, oyster importance and distribution are discussed. The traveling exhibit was able to reach 600+ people at the Rockport Aquarium's Aquafest, the Salty Aggie Fishing Tournament, and Rockport-Fulton's Hummingbird festival.

An oyster seminar was presented to 17 architecture students from the University of Texas at Goose Island on October 4. The students worked with Goose Island State Park building some structures out of shellcrete using recycled shells (Figure 15). The highlight of the seminar was a journey to the historic port of El Copano where the students were able to view and study some vintage 1830-1860 vintage shellcrete structures. The shellcrete structure is another educational tool to teach park visitors about the ecological, economic, and cultural importance of oyster shells.

Figure 15. Shellcrete structure created from recycled oyster shells at Goose Island State Park.

Lastly, the "Oysters in the Classroom" and ongoing oyster recycling was discussed October 7-8th at the Open Space Science, Technology, Engineering and Math (STEM) conference at the Harte Research Institute Texas A&M University-Corpus Christi. Over 50 people were in attendance from State agencies and educators.

The Shell Bank Program was selected as a finalist for the second year in a row for the Texas Environmental Excellence Award from the Texas Commission on Environmental Quality—the highest environmental award in the state.

4. HABITAT ASSESSMENT

As oyster reef restoration becomes more common for replacing degraded reefs, it is important to understand how well these restored systems mimic the important functions, such as fish habitat, provided by natural reefs. We collected oysters, fish and crustaceans associated with restored and natural oyster reefs in the Mission-Aransas Estuary and used stable isotope techniques in the laboratory to evaluate the food webs (who is present and what is eating what) of restored versus natural oyster reefs. The goal was to determine how well the restored reefs in this bay system mimic the habitat functions of natural reefs and, if necessary, to provide recommendations to improve the habitat value of restored reefs to closer match that provided by natural reefs.

Six sampling sites were chosen within the restored and natural oyster reefs (Figure 16). Oysters and the reef-associated faunal community were sampled using trays (dimensions 45x30x11cm) filled with reef substrate corresponding to reef type: either reclaimed oyster shell (restored reef) or natural reef material (including live oysters; natural reef). Trays were collected seasonally (winter, spring, summer, fall), and we assessed the abundance and biomass of oysters, fish and crustaceans. Additionally, we collected tissue samples from all organisms as well as suspended particulate organic matter and sediment organic matter for stable isotope analysis and food web assessments.

Figure 16. Restored oyster reef (purple polygons) and natural oyster reef study area in the Mission-Aransas Estuary. Green squares designate sample sites.

Oyster densities were significantly higher in the natural reef than in the restored reef during our first sampling season in the winter (Figure 17). During the spring and summer, there was a decline in oyster densities on the natural and restored reefs, and there was no longer a difference in oyster density between reef types. Oyster densities increased in both the restored and natural reefs in the fall, reflecting oyster spat recruitment and growth throughout the summer months. Oyster densities remained similar between the natural and restored reef.

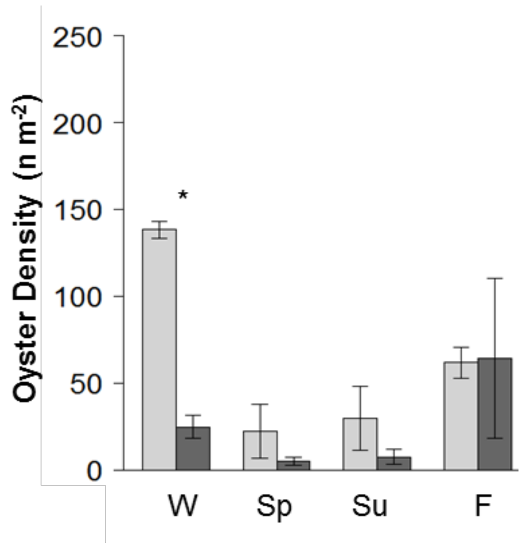

Figure 17. Oyster density (shell height ≥ 25mm) measured in restored (dark bars) and natural (light bars) oyster reef sites during seasonal sampling periods in the Mission-Aransas Estuary, Texas.

Oyster sizes were initially greater on the natural reef during our first (winter) sampling period (Figure 18). This was to be expected, as the restored reef had not yet had sufficient time to recruit and grow large oysters. By the summer sampling period, oyster size on the restored reef had come within range of that on the natural reef, and this pattern remained through our final fall sampling period.

The reef-associated fish and crustacean community also fluctuated over time. The density of reef- associated fauna was similar during our very first sampling period and remained that way except for during the spring where the density of reef-associated fauna on the restored reef exceeded that on the natural reef (Figure 19). This was primarily due to an abundance of porcelain crabs on the restored reef.

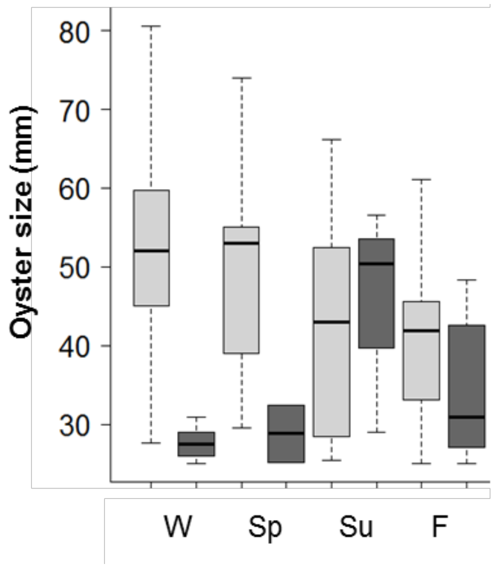

Figure 18. Oyster shell height (mm) measured in restored (dark bars) and natural (light bars) oyster reef sites during seasonal sampling periods in the Mission-Aransas Estuary, Texas.

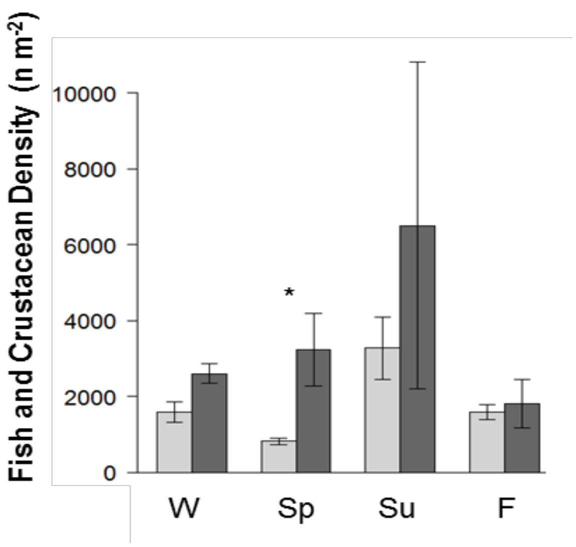

Figure 19. Density of reef-associated fish and crustaceans in restored (dark bars) and natural (light bars) oyster reef sites during seasonal sampling periods in the Mission-Aransas Estuary, Texas.

Species richness, or the number of reef-associated species, was higher on the natural reef starting during our first sampling period and persisting through the summer (Figure 20). During our final sampling period in the fall, both reef types had similar numbers of reef-associated fish and crustacean species.

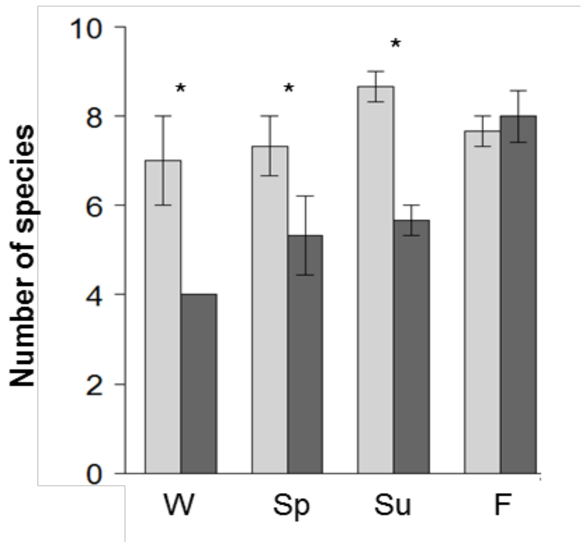

Figure 20. Species richness of reef-associated fish and crustaceans in restored (dark bars) and natural (light bars) oyster reef sites during seasonal sampling periods in the Mission-Aransas Estuary, Texas.

To examine the potential food resources and trophic complexity of the food webs on the restored and natural oyster reefs, we examined the stable isotopes of carbon and nitrogen (Figure 21). Briefly explained, $\delta^{13}C$ is used to trace organic matter back to its primary producer source while the $\delta^{15}N$ values indicate the trophic level of consumers, with higher values indicating higher trophic levels. The suspended particulate organic matter pool was dominated by C3 plant detritus (likely originating from row crops in the Mission-Aransas watershed such as cotton or soybeans) and phytoplankton, while sediment organic matter is dominated by trapped or dead phytoplankton material and what we believe is microphytobenthos (benthic algae) based on C/N ratios.

We focused on 2 filter feeding primary consumers—the oyster and the hooked mussel—to determine if there were dietary shifts between reef types due to food availability (Figure 21). Phytoplankton appears to be the primary food resource in both reef types, and microphytobenthos may become important during summer months. We also looked at the $\delta^{15}N$ values of 2 secondary consumers—the naked goby and the snapping shrimp--to determine if there were any differences in food chain lengths between reef types. The higher $\delta^{15}N$ values show these species are feeding at a higher trophic level, indicating a carnivorous or omnivorous diet. We drew ellipses around the primary and secondary consumer values as a reference between the natural and restored reefs, and it is evident that a similar diet is being utilized across both reef types by the organisms we examined. The secondary consumers also appear to be feeding at a similar trophic level, indicating similar food chain lengths between reef types.

In conclusion, the oyster density as well as the reef-associated faunal density and diversity became similar between the natural and restored reef during the monitoring period, indicating the restored reef is providing similar habitat function for these organisms as would a natural reef. Additionally, the stable isotope data indicate similar primary food resource availability between reef types, as well as similar food chain lengths. Therefore, the restored reef is generally providing similar food web functions as the reference natural reef during the period of monitoring. In combination, these data are very encouraging because they indicate restored reefs can successfully replace, in some part, targeted ecosystem functions that were formerly provided by healthy reefs.

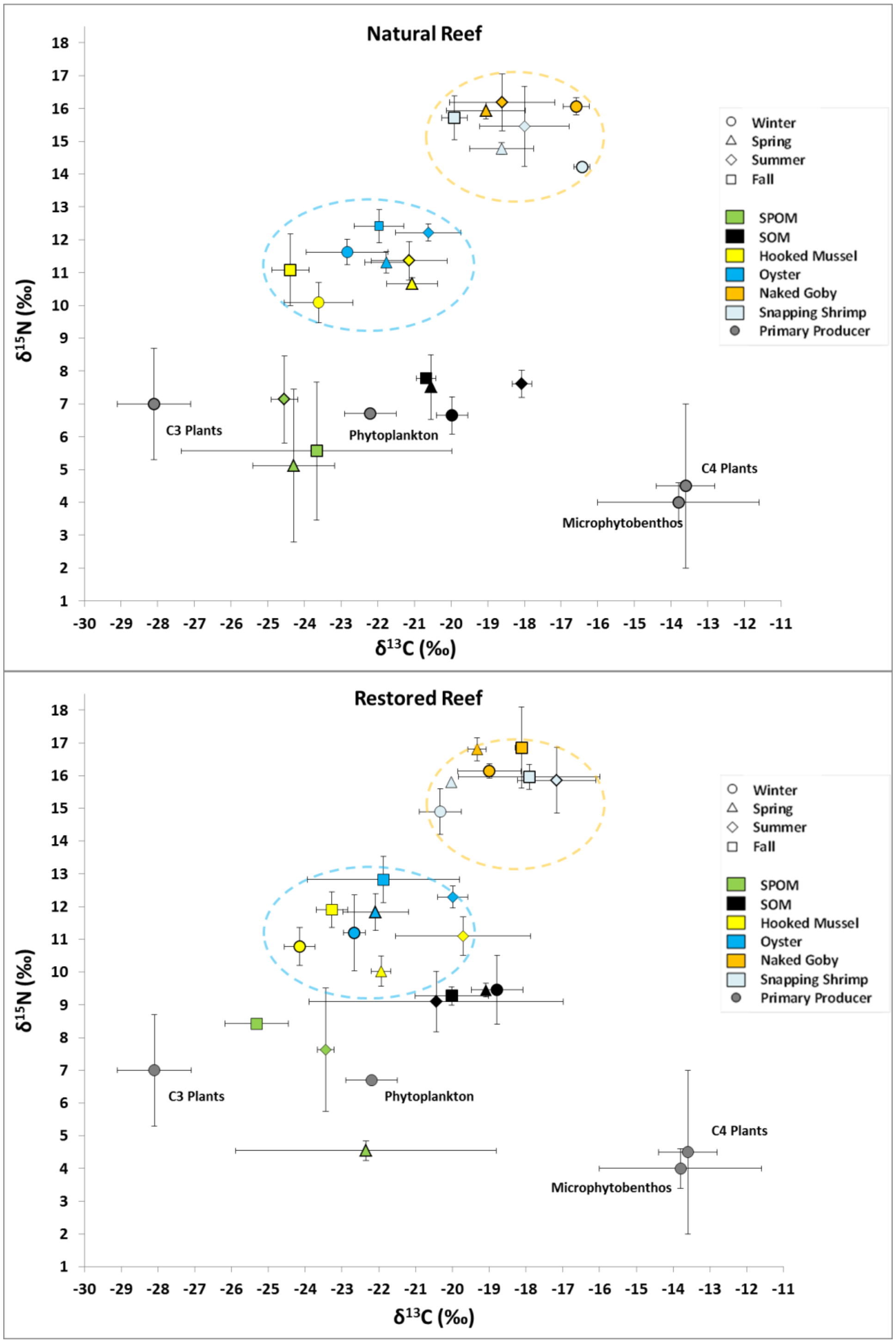

Figure 21. Stable-isotope signatures (d13C and d15N) of primary producers (gray circles) and potential food sources (green and black shading), primary consumers (yellow and blue shading) and secondary consumers (yellow and light blue shading) on natural reef (top) and restored reef (bottom).

CONCLUSION

The Shell Bank oyster shell recycling program continues to grow and thrive and make meaningful contributions to habitat restoration, thanks support from the Texas Coastal Management Program. We continue to expand our partner base, create important opportunities for community involvement in habitat restoration, increase our outreach and educational footprint, and make great strides at better understanding the functioning of restored oyster reef habitats. The Shell Bank Program will strive to continue educating the public, providing oyster shells for oyster reef restoration, and seeking science-based solutions to improve the sustainability of oysters, a key ecological, economic, and cultural resource for our state and the Gulf of Mexico as a whole.

Appendix A. Screenshots from oyster e-book kiosk at Water Street Oyster Bar

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WELCOME TO THE REEF!

This book explores the mysterious world of oysters, their neighbors, and the coastal waters they call home. Enjoy puzzles, games, and a comic. **Begin by swiping to the next page.**

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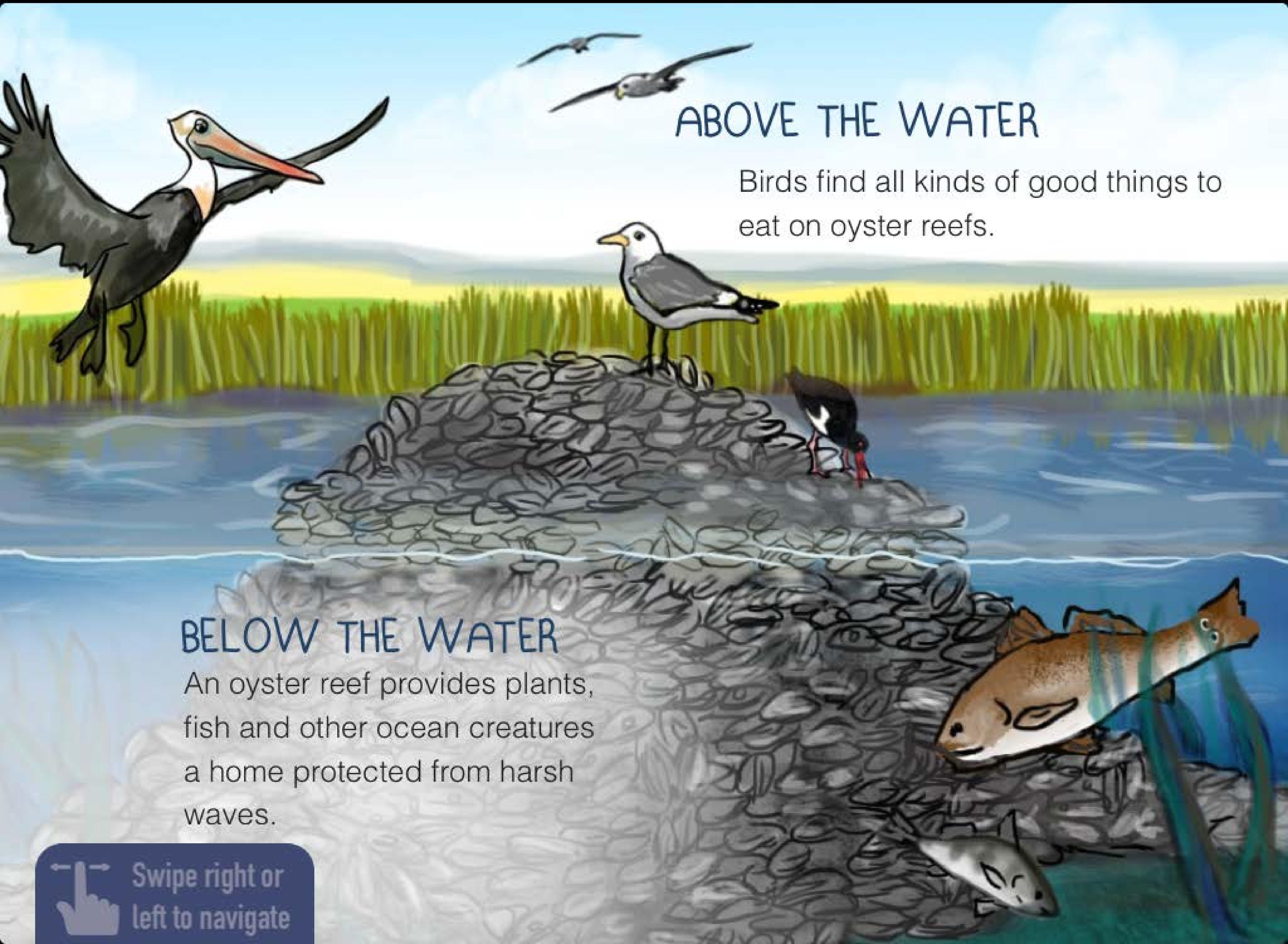
ABOVE THE WATER
Birds find all kinds of good things to eat on oyster reefs.
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ENTER THE AMAZING WORLD OF THE OYSTER!

OYSTER GAMES

Explore life in and around an oyster reef through:

- a memory game
- a special photo gallery
- a coloring activity
- a word find challenge

Swipe to get started.

Swipe right or left to navigate

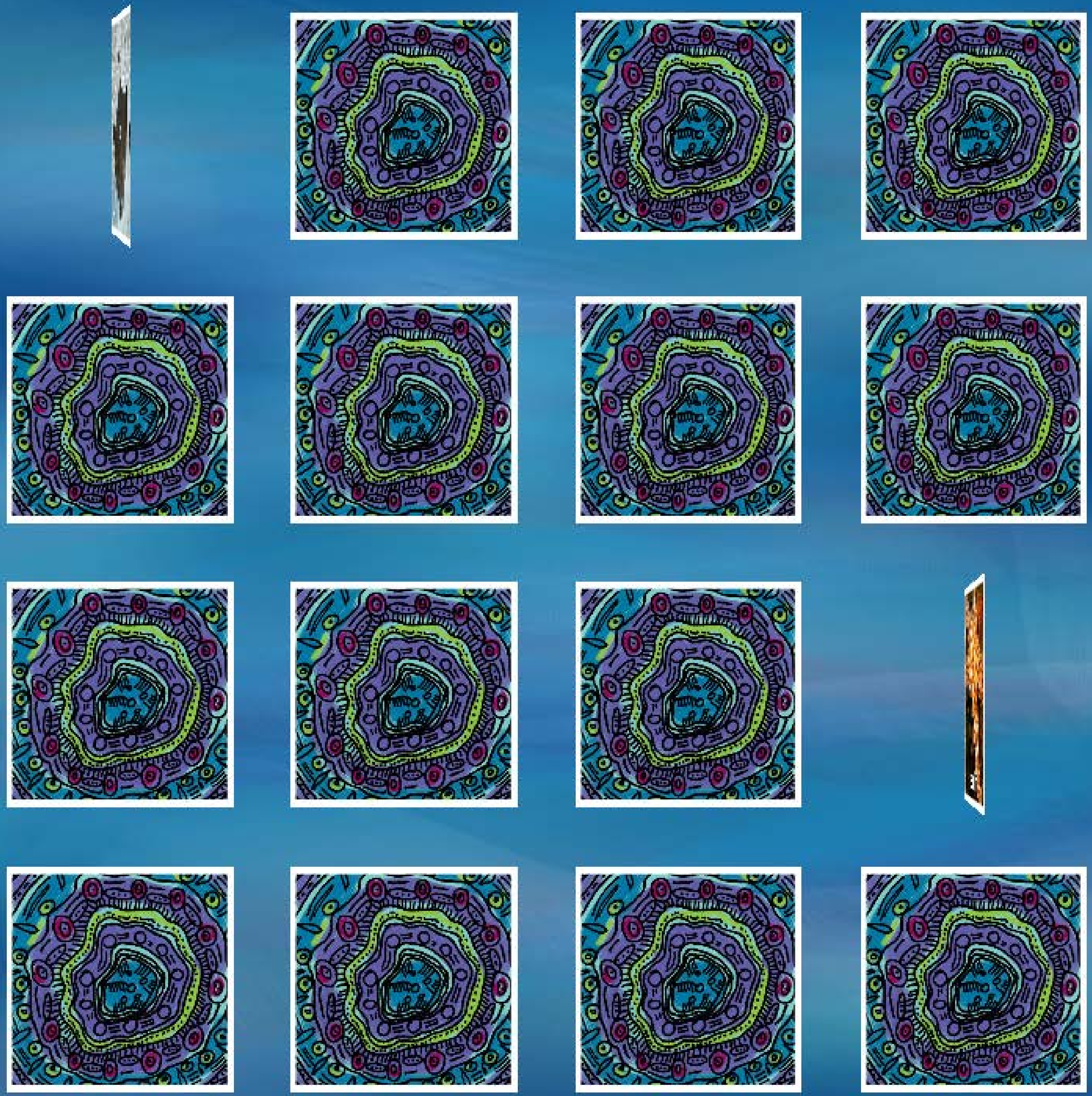
WHO ELSE LIVES HERE?

Many other animals call the oyster reef their home. See if you can match them!

Swipe right or left to navigate

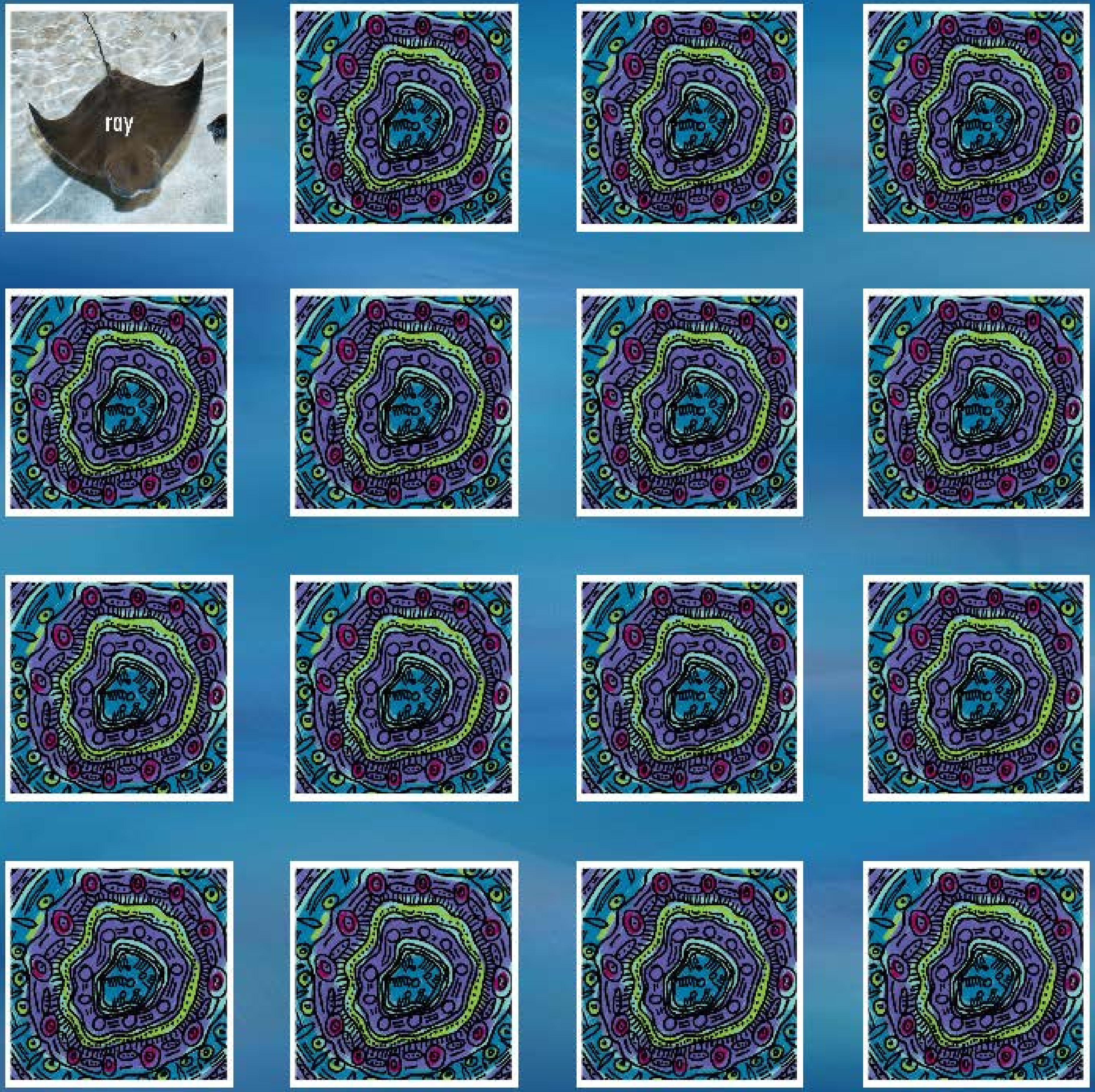
Close Window to Continue

Who lives in the reef



Close Window
to Continue

Who lives in the reef



MORE THAN MEETS THE EYE

Young oysters are not babies like you or I were. They go through many changes over their lives. In some of those stages, they are very very tiny. Can you find Sheldon?

Swipe right or left to navigate

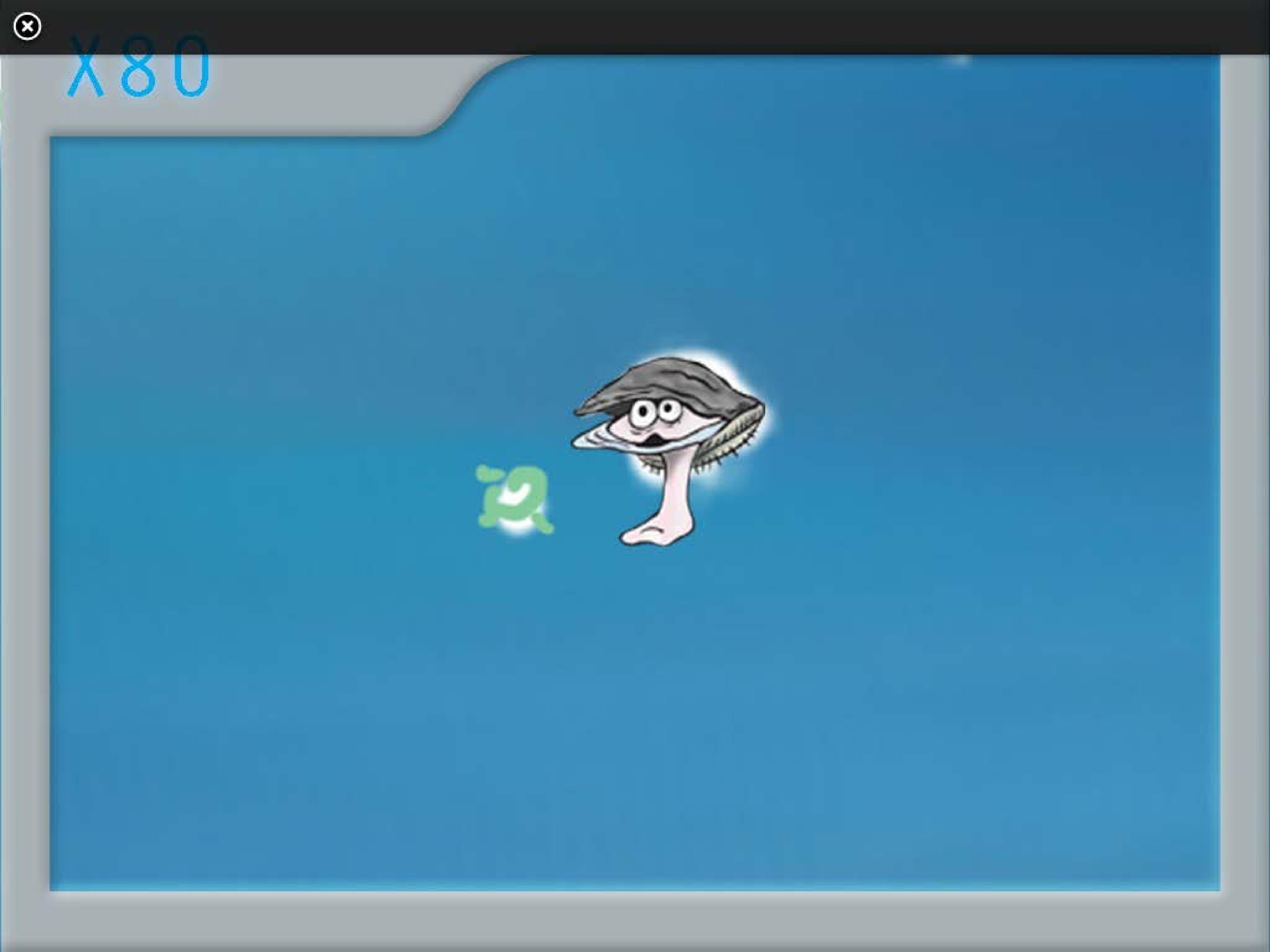

Hey! Here I am!
I am very small!
Tap to look closer!
Then **swipe**.

X10


X20


X40


X50


X80

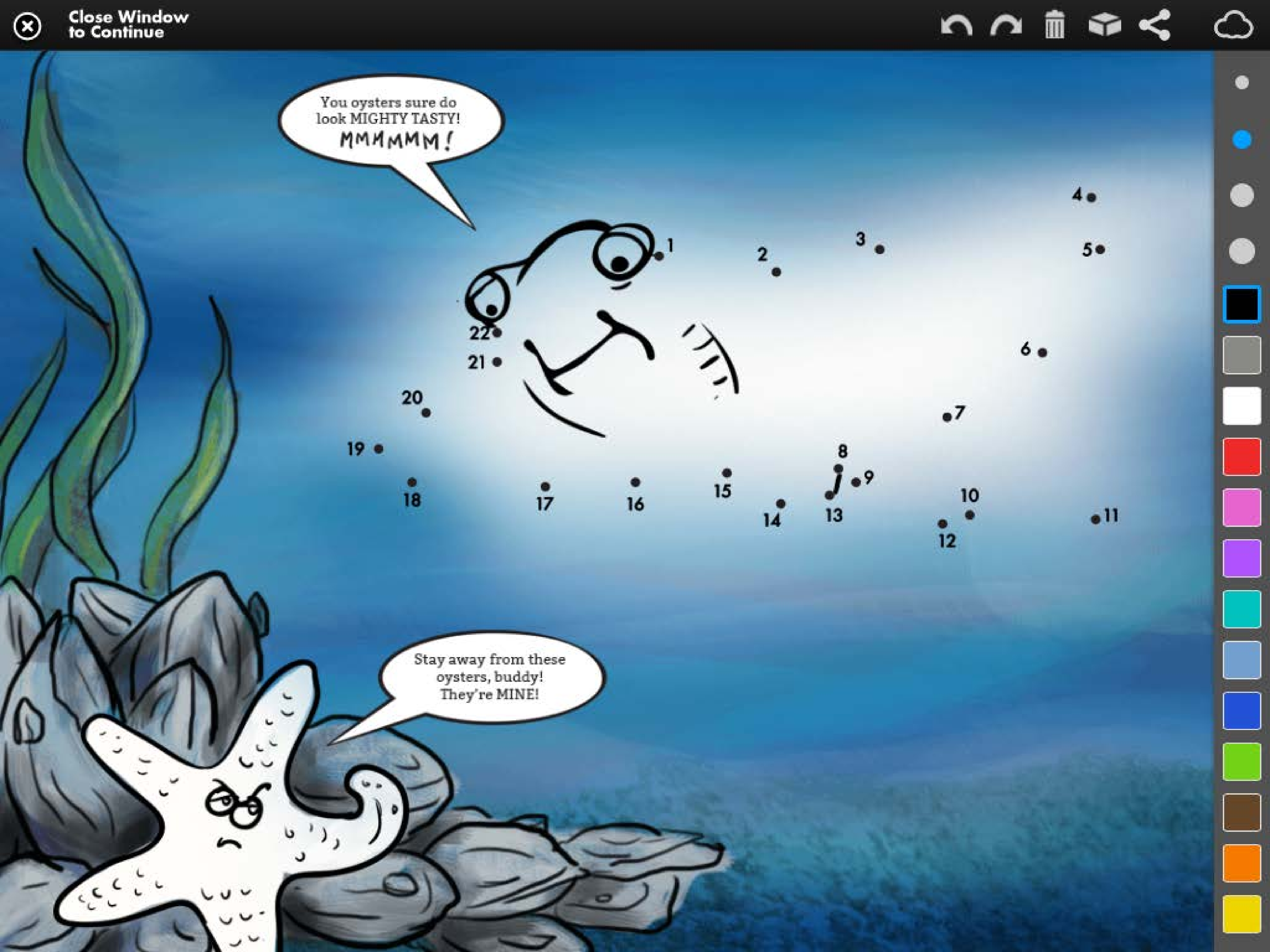

X100
Hi! I'm Sheldon. One day, I will be an adult oyster.

LOOK OUT!

A predator, an animal that hunts other animals,
has been spotted on the reef!
Can you connect the dots to see who
has been eating the oysters?

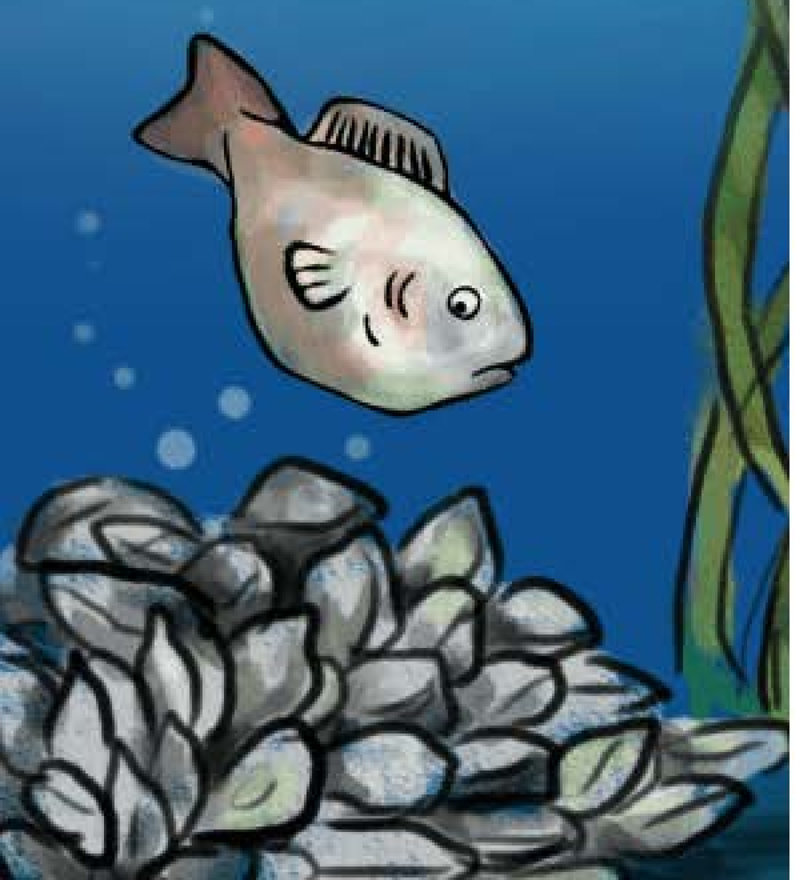
Tap here to start

Swipe right or left to navigate

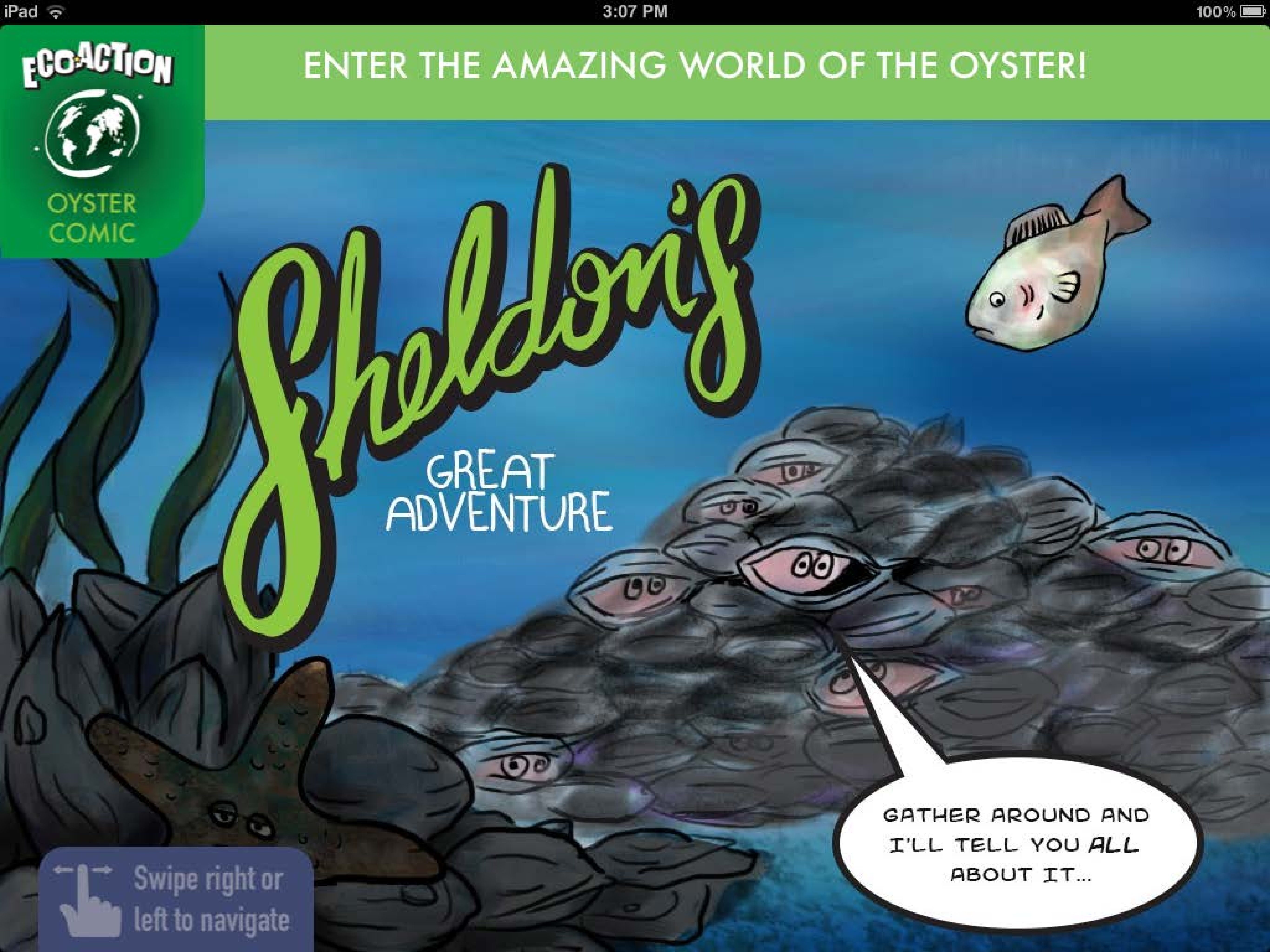

Close Window to Continue
You oysters sure do look MIGHTY TASTY! MMMMMM!
Stay away from these oysters, buddy! They're MINE!

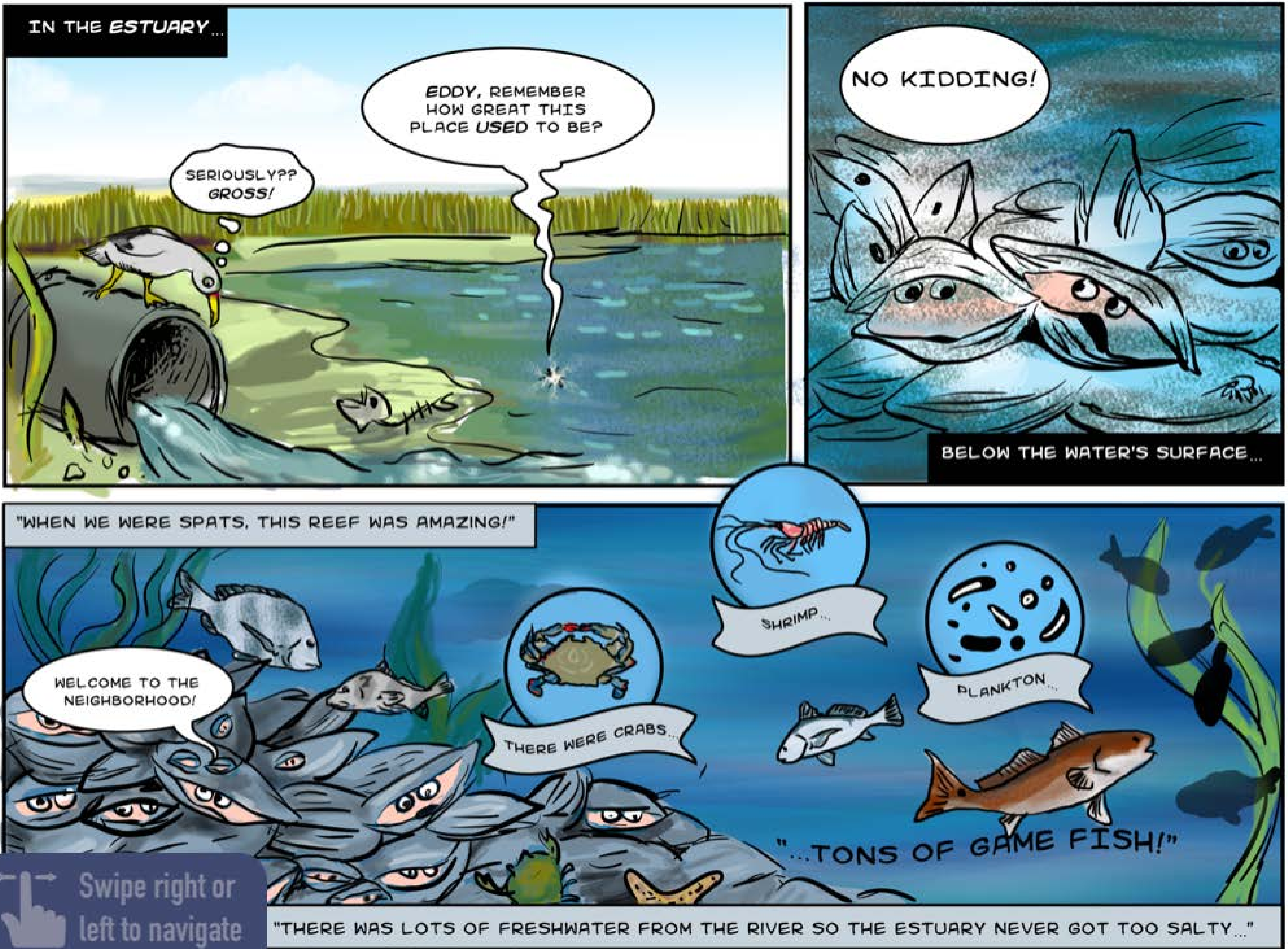

iPad
3:07 PM
100%
Use your sharp eyes to find the oyster vocabulary words!
Reef Search
Tap here to start
Swipe right or left to navigate

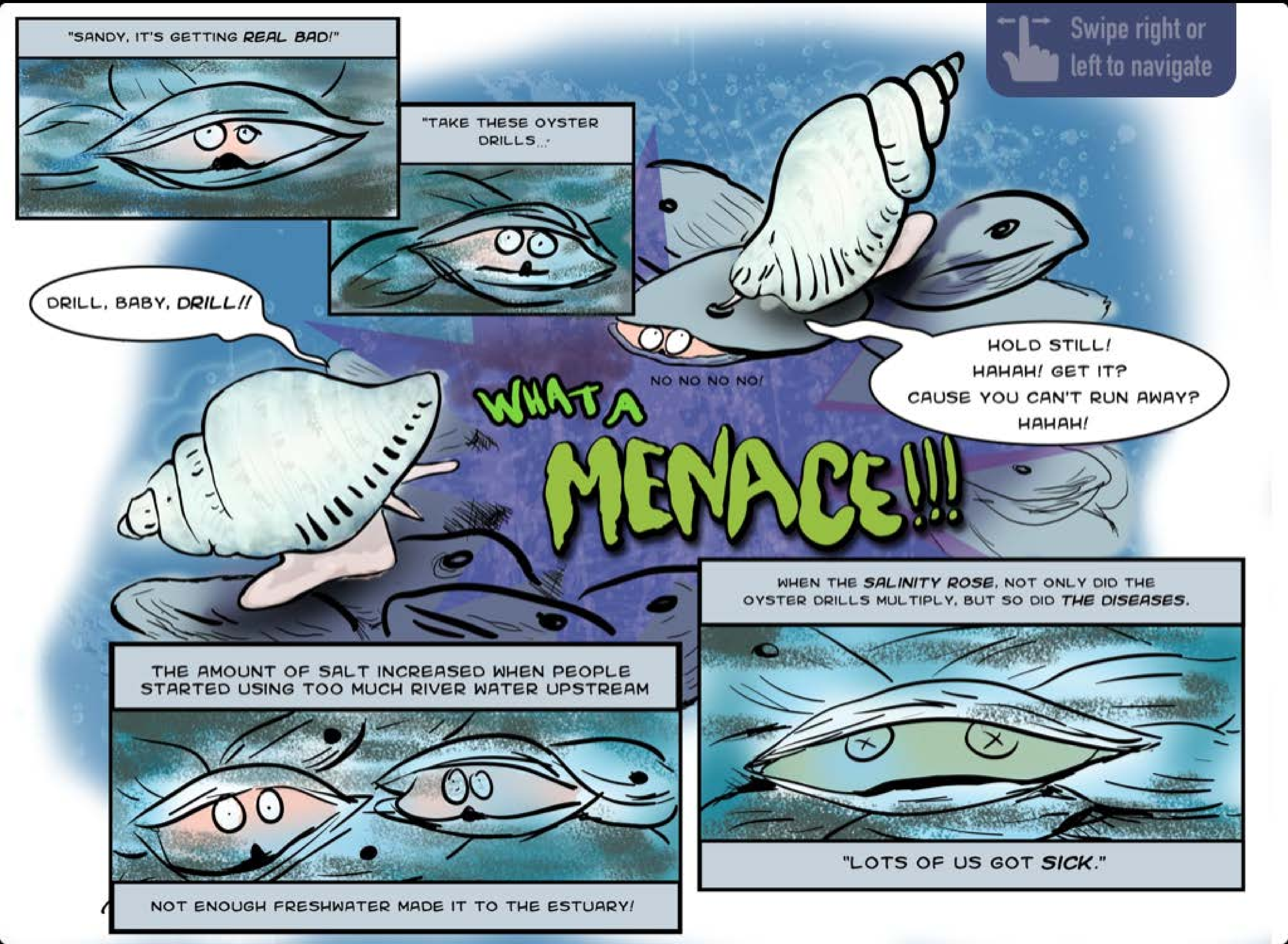
oyster
spat
reef
~~habitat~~
fish
food
salt
plants

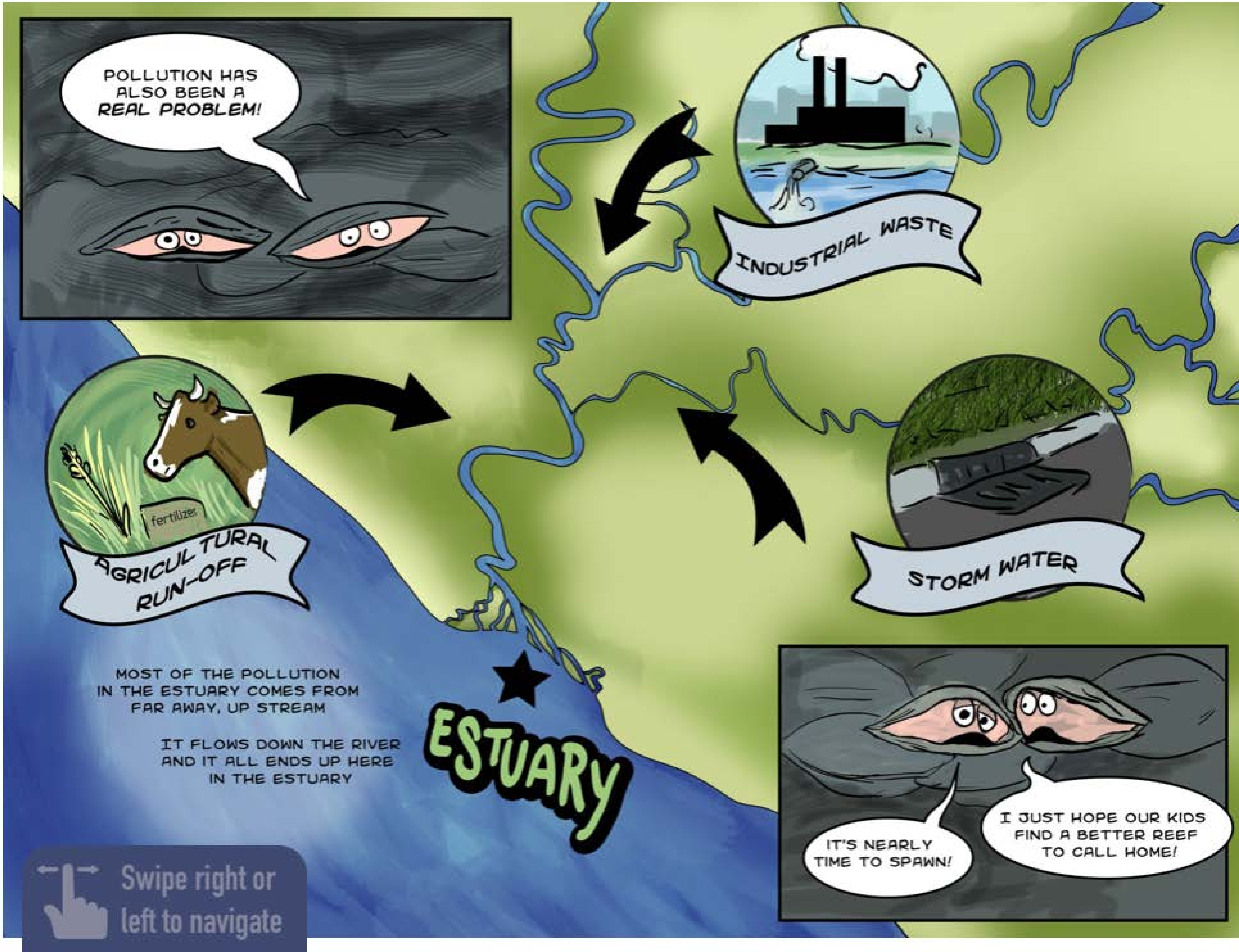


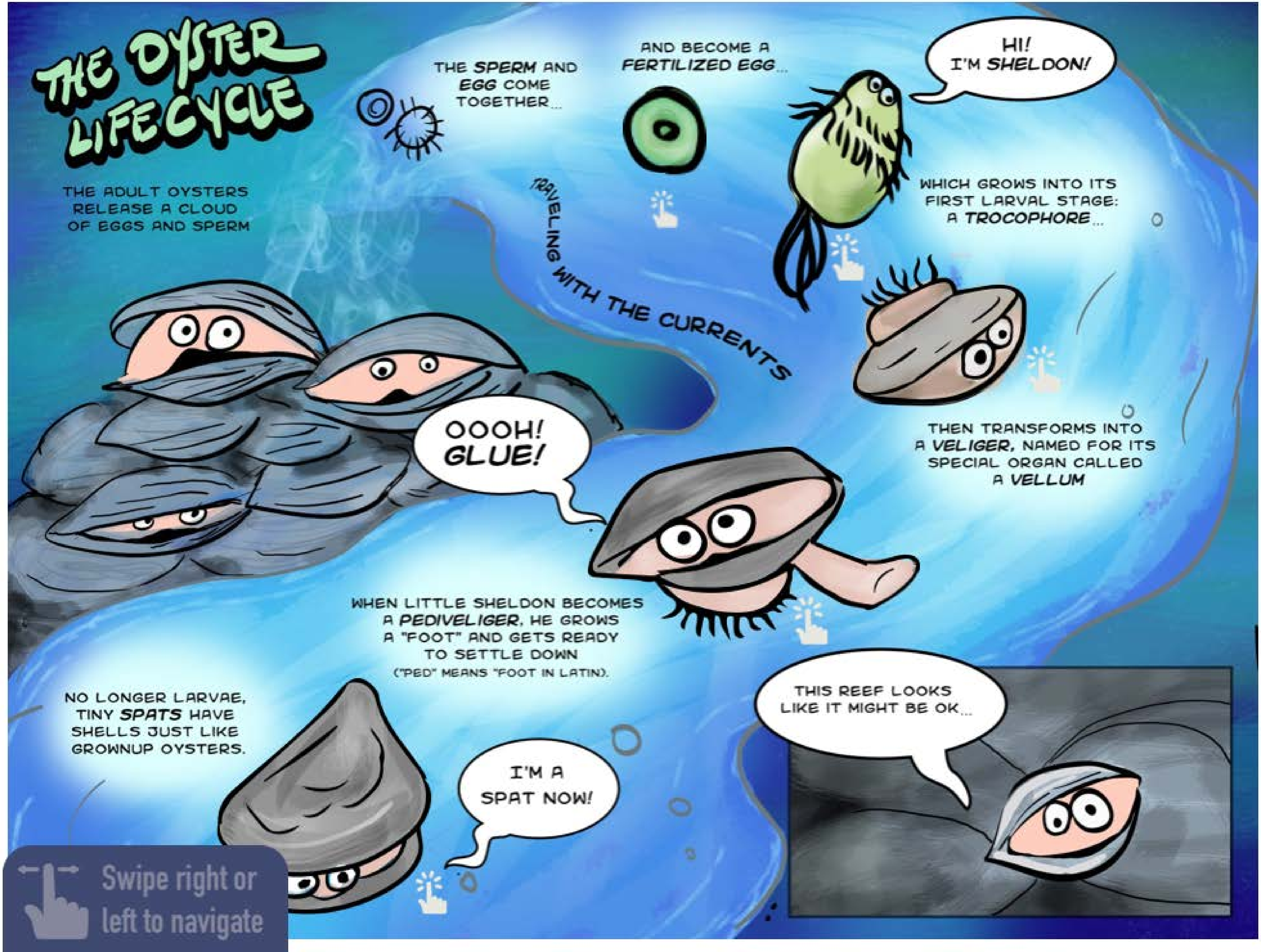
T	H	A	B	I	T	A	T
S	O	P	L	A	N	T	S
F	A	Y	A	L	C	W	I
W	I	L	S	R	E	E	F
F	S	S	T	T	C	J	W
O	W	P	H	A	E	L	C
O	Q	M	A	F	N	R	T
D	Q	F	N	T	P	M	R

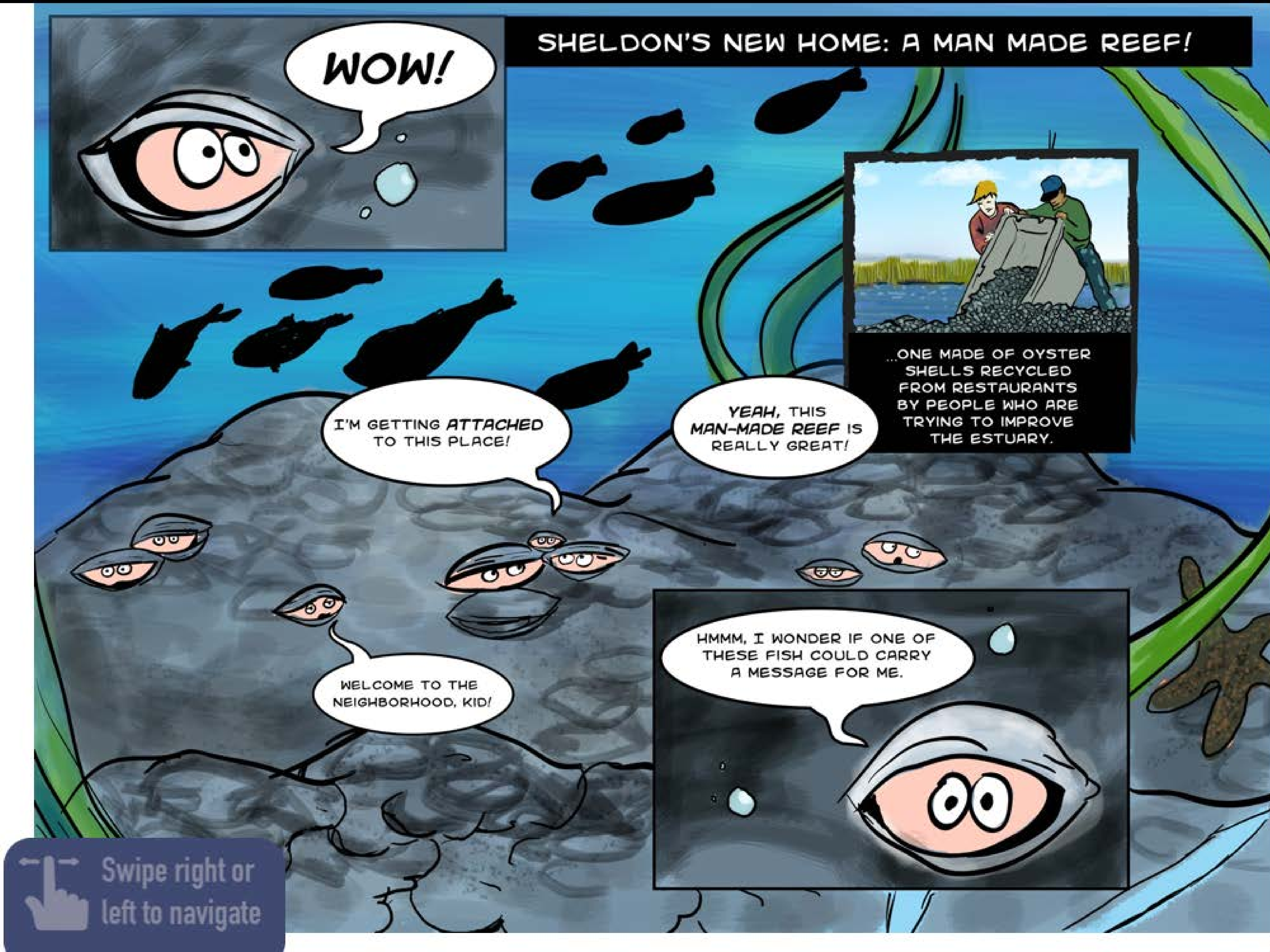


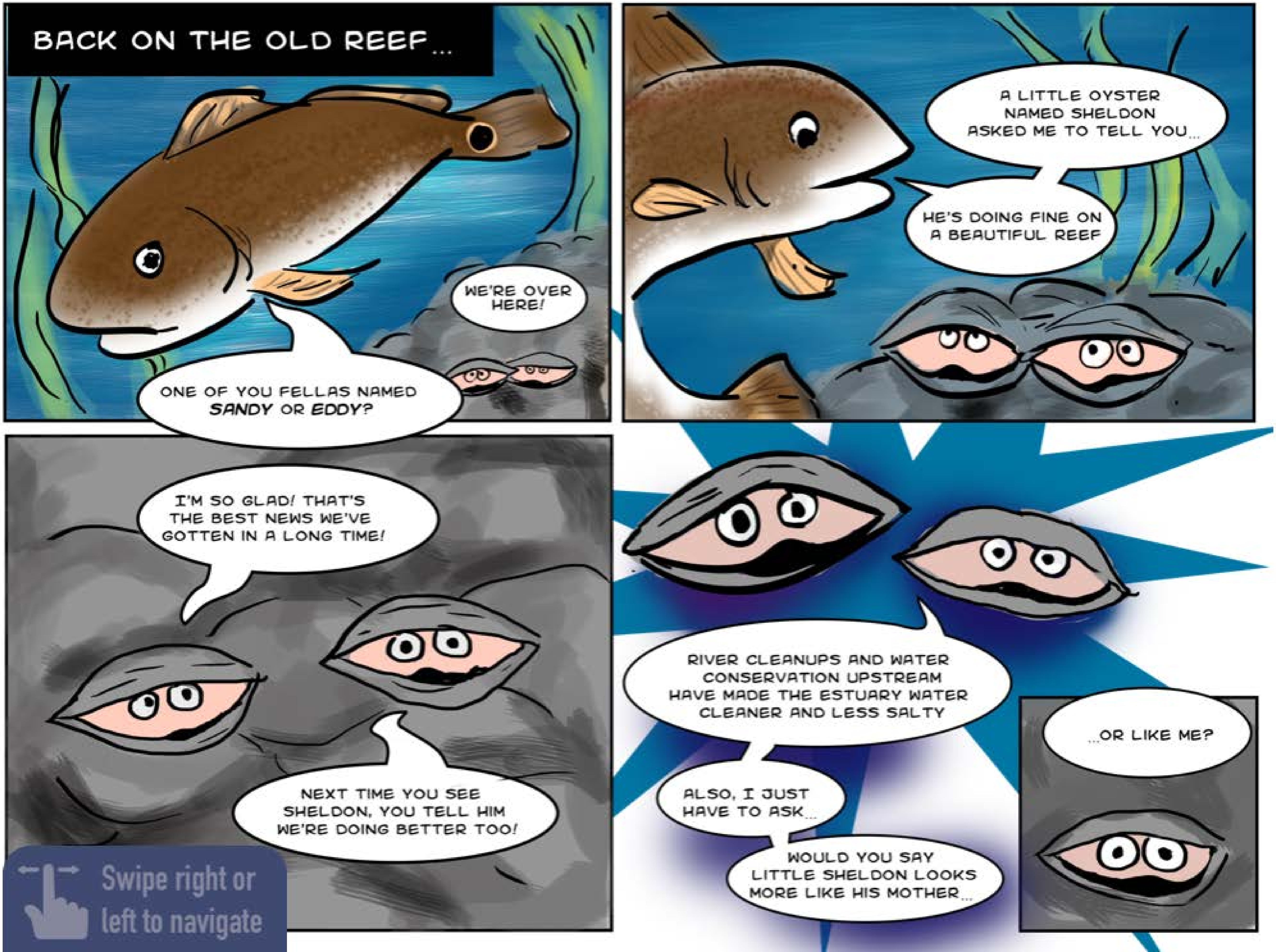

IN THE ESTUARY...
EDDY, REMEMBER HOW GREAT THIS PLACE USED TO BE?
SERIOUSLY?? GROSS!
NO KIDDING!
BELOW THE WATER'S SURFACE...
"WHEN WE WERE SPATS, THIS REEF WAS AMAZING!"
WELCOME TO THE NEIGHBORHOOD!
THERE WERE CRABS...
SHRIMP...
PLANKTON...
"...TONS OF GAME FISH!"
"THERE WAS LOTS OF FRESHWATER FROM THE RIVER SO THE ESTUARY NEVER GOT TOO SALTY..."


Swipe right or left to navigate
"SANDY, IT'S GETTING REAL BAD!"
"TAKE THESE OYSTER DRILLS..."
DRILL, BABY, DRILL!!
NO NO NO NO!
HOLD STILL! HAHAH! GET IT? CAUSE YOU CAN'T RUN AWAY? HAHAH!
WHAT A MENACE!!!
THE AMOUNT OF SALT INCREASED WHEN PEOPLE STARTED USING TOO MUCH RIVER WATER UPSTREAM
NOT ENOUGH FRESHWATER MADE IT TO THE ESTUARY!
WHEN THE SALINITY ROSE, NOT ONLY DID THE OYSTER DRILLS MULTIPLY, BUT SO DID THE DISEASES.
"LOTS OF US GOT SICK."


POLLUTION HAS ALSO BEEN A REAL PROBLEM!
INDUSTRIAL WASTE
AGRICULTURAL RUN-OFF
fertilizer
STORM WATER
MOST OF THE POLLUTION IN THE ESTUARY COMES FROM FAR AWAY, UP STREAM
IT FLOWS DOWN THE RIVER AND IT ALL ENDS UP HERE IN THE ESTUARY
ESTUARY
IT'S NEARLY TIME TO SPAWN!
I JUST HOPE OUR KIDS FIND A BETTER REEF TO CALL HOME!
Swipe right or left to navigate


THE OYSTER LIFECYCLE
THE ADULT OYSTERS RELEASE A CLOUD OF EGGS AND SPERM
THE SPERM AND EGG COME TOGETHER...
AND BECOME A FERTILIZED EGG...
HI! I'M SHELDON!
WHICH GROWS INTO ITS FIRST LARVAL STAGE: A TROCOPHORE...
TRAVELING WITH THE CURRENTS
THEN TRANSFORMS INTO A VELIGER, NAMED FOR ITS SPECIAL ORGAN CALLED A VELLUM
OOOH! GLUE!
WHEN LITTLE SHELDON BECOMES A PEDIVELIGER, HE GROWS A "FOOT" AND GETS READY TO SETTLE DOWN
("PED" MEANS "FOOT IN LATIN).
THIS REEF LOOKS LIKE IT MIGHT BE OK...
NO LONGER LARVAE, TINY SPATS HAVE SHELLS JUST LIKE GROWNUP OYSTERS.
I'M A SPAT NOW!
Swipe right or left to navigate


SHELDON'S NEW HOME: A MAN MADE REEF!
WOW!
...ONE MADE OF OYSTER SHELLS RECYCLED FROM RESTAURANTS BY PEOPLE WHO ARE TRYING TO IMPROVE THE ESTUARY.
I'M GETTING ATTACHED TO THIS PLACE!
YEAH, THIS MAN-MADE REEF IS REALLY GREAT!
WELCOME TO THE NEIGHBORHOOD, KID!
HMMM, I WONDER IF ONE OF THESE FISH COULD CARRY A MESSAGE FOR ME.
Swipe right or left to navigate


BACK ON THE OLD REEF...
ONE OF YOU FELLAS NAMED *SANDY* OR *EDDY*?
WE'RE OVER HERE!
A LITTLE OYSTER NAMED SHELDON ASKED ME TO TELL YOU...
HE'S DOING FINE ON A BEAUTIFUL REEF
I'M SO GLAD! THAT'S THE BEST NEWS WE'VE GOTTEN IN A LONG TIME!
NEXT TIME YOU SEE SHELDON, YOU TELL HIM WE'RE DOING BETTER TOO!
RIVER CLEANUPS AND WATER CONSERVATION UPSTREAM HAVE MADE THE ESTUARY WATER CLEANER AND LESS SALTY
ALSO, I JUST HAVE TO ASK...
WOULD YOU SAY LITTLE SHELDON LOOKS MORE LIKE HIS MOTHER...
...OR LIKE ME?

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Swipe right or left to navigate