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Can Shellfish Adapt to Ocean Acidification?

Deirdre Lockwood

Scientists peer into oyster and clam genomes to help the shellfish industry prepare for a change in ocean chemistry.

In the Pacific Northwest, oyster aficionados have likely tasted Chris Langdon's scientific handiwork. Since 1996, his Molluscan Broodstock Program at Oregon State University has been breeding plump, fast-growing, and hardy oysters as stock for the $250 million West Coast oyster industry. But in the past several years, the program has taken on an additional goal: identifying oysters that are more resilient to ocean acidification.

In 2007, oyster hatcheries in Oregon and Washington began experiencing massive die-offs of their larvae that continued for several years. Eventually, managers and scientists realized that the larvae were dying during periods of strong upwelling, when deep waters rich in CO_2—and low in pH—come to the surface. These deep waters were even more acidified than in the past because of the oceans' growing uptake of CO_2 as its levels in the atmosphere increase.

When CO_2 dissolves in water, carbonic acid forms, releasing hydrogen ions that lower pH and convert carbonate ions to bicarbonate. The corrosive upwelling in 2007 dropped carbonate levels in the seawater enough that aragonite, the main form of calcium carbonate bivalves use to build shells, became undersaturated. Langdon and his colleagues showed that aragonite undersaturation ultimately drives oyster larvae to make smaller shells than usual or not to develop them at all. Both can spell death. Scientists, including Langdon's colleague Burke Hales, quickly began working with oyster growers to monitor carbonate chemistry in hatcheries and to buffer the water with sodium carbonate when aragonite became undersaturated during upwelling episodes. In 2010, the National Oceanic and Atmospheric Administration sponsored a $500,000 network of six monitoring systems at West Coast hatcheries.

Since 2011, this intervention, though costly, has helped avert major larval die-offs, Langdon says. But the experience made it clear that ongoing ocean acidification, which

Oysters and other shellfish are threatened by ocean acidification. Credit: Shutterstock

threatens marine organisms ranging from certain plankton at the base of the food chain to shellfish and corals, could endanger the shellfish industry worldwide.

Fortunately, there is evidence that some shellfish may be able to acclimate or adapt to these changes, thanks to the variable conditions these creatures experience and the wide genetic variation among individuals in a given species. As intertidal species, oysters see a lot of environmental change even on a daily basis, says Steven Roberts, a fisheries scientist at the University of Washington, Seattle.

In an effort to identify hardier shellfish stocks, Langdon, Roberts, and many other researchers are looking to determine the genetic and metabolic underpinnings of adaptability to acidification. They are on the hunt for biomarkers that could eventually help shellfish growers select more resilient stock or adjust hatchery conditions for improved survival and growth.

Langdon was inspired by University of Sydney researcher Laura Parker's work showing that stocks of the Sydney rock oyster bred for aquaculture grew shells better than wild oysters under acidified conditions—suggesting that the species has the genetic potential to adapt to acidification and that selective breeding for good hatchery performance could be a key to this. But Langdon's first attempt to repeat this experiment with his own stock of Pacific oysters from the Molluscan Broodstock Program did not show the same advantage.

So he and his colleagues are now testing the survival of a variety of different farmed oyster stocks at an acidified pH of 7.8, similar to that found during upwelling, and

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comparing them with stocks grown at the ambient seawater pH of 8.2. The team is sequencing the oysters' DNA and tracking gene expression to identify genes and metabolic pathways associated with better survival and growth under acidified conditions. The recent sequencing of the Pacific oyster genome has made this effort much easier, revealing the function of thousands of oyster genes. But many details are still unclear—including the exact cellular machinery oysters use to form their shells and how it becomes dysfunctional when the chemical environment around the oysters changes, says Pierre De Wit, an evolutionary biologist at the University of Gothenburg who is collaborating with Langdon. Before oysters' resilience can be understood, these questions will need answers.

For oysters, the first 24 hours of development are critical: They have to deposit a lot of shell quickly. In one of the earliest steps, proteins produced inside larval tissue are transported to an extracellular compartment to form a scaffold on which calcium carbonate crystals precipitate. Meanwhile, protease inhibitors prevent the breakdown of these proteins. De Wit has found that expression of both the scaffolding proteins and the inhibitors seems affected by acidified conditions. "In stressed larvae, this protein matrix could get disorganized and prevent larvae from forming proper shells," he says.

But this is only one of many factors that are involved in oysters' response to ocean acidification, it seems. So far, De Wit and Langdon have found about 50 genes whose expression is delayed in oyster larvae during the first 18 hours of development under exposure to lower pH. The genes are involved in shell matrix formation, transport within the cell, and transport of ions across cell membranes. "It may be possible down the road to develop genetic markers that will allow us to identify stocks that are more resistant to ocean acidification," Langdon says.

Other researchers are looking beyond aquaculture to wild shellfish for hallmarks of adaptation that growers might eventually exploit. Studies of sea urchins and rock oysters show that some organisms exposed to lower pH have offspring that are more resilient to these conditions, indicating some capacity for adaptation to acidification.

In Long Island Sound, where pH varies widely due to the effects of nutrient pollution, Bassem Allam of Stony Brook University is trying to detect adaptation in wild samples of Eastern oyster and hard clams. In previous studies on the clams, he and his team identified genetic variants called single nucleotide polymorphisms (SNPs) that are linked with resistance to the parasitic disease QPX. He's now using a similar approach to identify potential SNPs that confer tolerance to ocean acidification.

In addition to variations in DNA sequence like SNPs, epigenetic changes may also help shellfish tolerate stress. These are chemical modifications to DNA or proteins associated with it that influence gene expression—sometimes over generations—and that could preserve a memory of conditions the organisms encountered. To investigate this, Roberts and Hollie Putnam of the University of Rhode Island are working to jog the memory of giant clams of the Pacific Northwest called geoducks, which represent a $74 million industry in the U.S.

In one experiment, Putnam exposed juvenile geoducks to ambient and acidified pH treatments for about 3 weeks. Then she returned both groups to ambient conditions and tracked their growth for several months, before exposing them both to low pH. "They do seem to have a memory of what they experienced early on," she says. Geoducks exposed to low pH initially grew more slowly than control clams, but then made up for this by growing faster when switched to ambient conditions—and they also grew faster than control clams when re-exposed to low pH. "It suggests environmental history is important in how they respond to future stressors," she says. Eventually, hatcheries might carry out similar treatments to bolster the tolerance of their stocks, she says.

Juvenile geoducks' response to lower pH depends on their history. Credit: Hollie Putnam.

But it's early days for such solutions. In the short term, NOAA has expanded carbonate chemistry monitoring in shellfish hatcheries and coastal waters along the West Coast including Alaska, with a three-year, $1.5 million grant in 2015. And though the West Coast has been a sentinel for ocean acidification because of its upwelling, shellfish growers elsewhere are also facing change. Parts of New England, the Chesapeake Bay, the Gulf of Mexico, the East China Sea, the Baltic Sea, and more are considered ocean acidification hot spots for various reasons including coastal pollution and river input, which can dilute carbonate concentrations.

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In 2013, Maine oyster grower Bill Mook installed a similar monitoring system to those on the West Coast after larvae die-offs at his Mook Sea Farm. Developed by University of New Hampshire's Joe Salisbury with NOAA support, it's nicknamed the "black box"; more such systems may be needed in these hot spots before long.

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