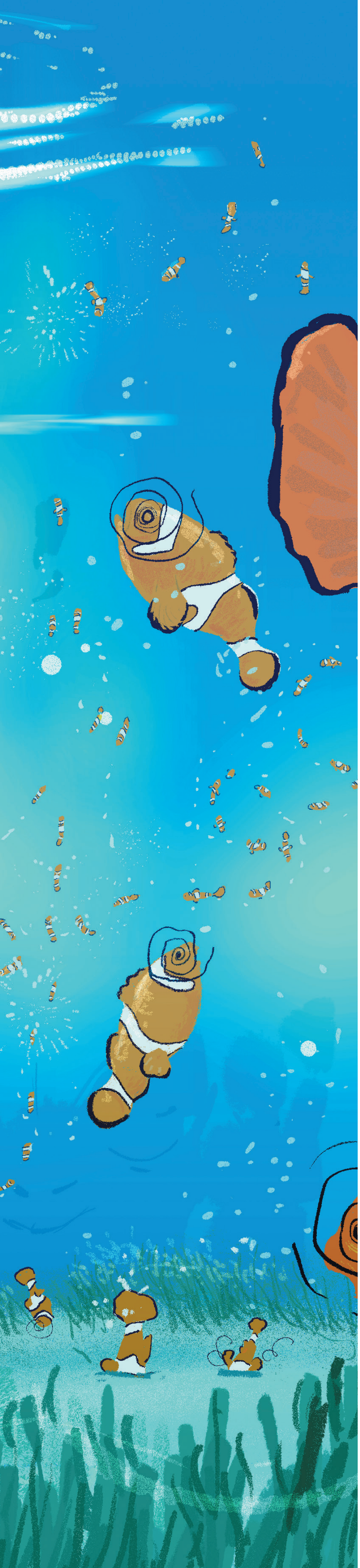
MARINE SCIENCE

LOST AT SEA



Ocean acidification may alter the behaviors of underwater creatures in disastrous ways

By Danielle L. Dixson

CLOWN FISHES LIVE THEIR ENTIRE ADULT LIVES nestled in the protective arms of a single sea anemone on a coral reef. Between birth and adulthood, however, the fishes have to complete a treacherous journey. After hatching, a larva—a tiny, partially formed version of an adult fish—swims out of the reef to the open sea to finish developing, presumably away from predators. After maturing for 11 to 14 days, the juvenile is ready to swim back to the reef and select an anemone to call home. But as it swims close, it has to cross a "wall of mouths"—all kinds of creatures, such as wrasses and lionfish, that lurk along the reef ready to gobble up the tiny fishes. Most successfully navigate the gauntlet by recognizing the smells of the predators and avoiding their grasp.

The sense of smell is really chemistry in action: detecting, understanding and responding to molecules in the water. Even a small shift in ocean chemistry could throw off this delicate survival mechanism. Scientists began to wonder what might happen when the water becomes more acidic, a trend that is occurring worldwide as the oceans absorb ever more carbon dioxide from the atmosphere. In 2010 my colleagues and I put 300 recently hatched clown fish larvae in a seawater tank in our laboratory and monitored them for 11 days. When we injected the scent of a friendly fish, they did not react. But when we injected the scent of a predator (a rock cod), they swam away.

We then repeated the experiment with 300 new hatchlings from the same parents, but this time the water was more acidic—adjusted to a level we can expect in certain parts of the world's oceans by 2100 if current trends continue. The young fish developed normally, yet not one avoided the predator odor. In fact, they preferred to swim toward the dangerous smell rather than plain seawater. When we introduced predator and nonpredator odors simultaneously, the fish seemed unable to make up their minds, spending equal time swimming toward one smell and the other. They were able to sense chemical signals but were unable to recognize the *meaning* of the signals. The reversal of behavior was surprising and concerning. We thought acidification might affect the chemical signaling slightly but never enough to prompt a fish to swim toward imminent death.

Creatures everywhere have three basic tasks in their lifetime: find food, reproduce and avoid becoming food in the process. In places such as coral reefs, where predators and prey densely pack a limited, complex habitat, natural selection strongly favors species that evade predators. Any disruption to this ability could have catastrophic consequences for the entire ecosystem.

If increasingly acidic water interferes with clown fish's sense of smell, it might also interfere with other senses and behaviors. And although we studied only one species of clown fish, smell is critical for a vast array of marine organisms. At a minimum, confusion and disorientation could place yet another stressor on fish already challenged by rising water temperatures, overfishing and changing food supplies. Further, if many ocean dwellers start to behave strangely, entire food webs, migration patterns and ecosystems could come crashing down. Although the science is still new, the results appear to be lining up: ocean acidification is messing with fish's minds.

THE ACID CHALLENGE

SINCE THE INDUSTRIAL REVOLUTION the atmospheric concentration of carbon dioxide has risen from 280 parts per million (ppm)

Illustration by Pascal Campion

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to just more than 400 ppm today. That number would be much higher without oceans, which absorb 30 to 40 percent of the CO_2 sent into our air. More CO_2 in seawater causes chemical reactions that increase acidity—measured as lower pH. Surface waters are roughly 30 percent more acidic today than in the late 1800s, and if current carbon emissions trends continue to the end of the century, they could be nearly 150 percent more acidic than back then.

Additional CO_2 in the water column breaks down calcite and aragonite—two minerals that are essential building blocks of the shells and exterior skeletons of certain sea creatures. Shellfish, urchins and plankton raised by other researchers in tanks with water that had high CO_2 levels developed incomplete or deformed shells and exoskeletons. Yet scientists thought that fish and other nonshelled organisms might escape the wrath of ocean acidification, in part because early research done in the 1980s showed that certain animals had an astonishing ability to regulate their internal chemistry by increasing or decreasing the amounts of bicarbonate and chlorine in their body. These studies, however, only looked at physiology—whether an animal could survive acidified water. Maintaining normal functions such as finding food and avoiding danger is a different challenge. Our research group was among the first to tackle the next logical question: Could acidification change behavior?

CONFUSING SMELLS AND SOUNDS

OUR CLOWN FISH EXPERIMENTS strongly suggested that acidification was indeed altering the animals' behavior. Other tests since then have been equally troubling. Because many reef predators commonly feed during the day, juvenile clown fishes that are returning to a reef to find an anemone tend to approach at night, when the predators are sluggish or sleeping, preferably under low moonlight. But navigation for a fish smaller than a dime in a dark, relatively featureless open ocean is not easy, so they use sounds produced by the reef and its inhabitants for guidance. A year after our smell experiment, we looked at whether acidifying water might interfere with hearing as well.

We tested young clown fish by putting them inside a box in a tank filled with seawater. When we pumped in daytime reef noise (which they would naturally avoid) through one side of the box, the fish spent almost three quarters of their time near the opposing wall, away from the sound source. But when we tested new fish that had spent their brief lives in water that was 60 percent more acidic—a level that we can expect in shallow oceans by 2030—they were not nearly as wary. More than half were actually attracted to the daytime sound.

We repeated the experiment twice more, with water that was 100 percent more acidic and 150 percent more acidic—levels that might arise by 2050 and 2100, respectively. In both situations, the clown fish spent around 60 percent of their time near the speaker playing daytime reef noise. We also ran separate tests to make sure none of them lacked a sense of hearing (they did not). Under the high acidity conditions, the clown fish were unable to recognize the meaning of auditory signals.

Ocean dwellers that have skewed senses may not avoid predators well. But the opposite effect could also occur: they might not be able to find food effectively.

Sharks have an infamously keen sense of smell, which they rely on to navigate, locate mates and track prey. Given the sensory confusion we found in clown fish, we wondered how sharks might react to acidified waters. We collected 24 adult smooth dogfish—small sharks that migrate in temperate waters between the Carolinas and southern New England—from the coast near Woods Hole, Mass. We split them into three groups and held each group in small, round swimming pools. The sharks in group 1 simply swam around in water taken from the ocean near Woods Hole. We put group 2 sharks in water treated to mimic ocean acidity in 2050 and group 3 sharks in water simulated for 2100. Meanwhile we created a concentrated "squid rinse" by soaking squid in seawater and straining the water through a cheesecloth. (Sharks love squid.)

After five days we let each shark swim in a flume tank 10 meters long and two meters wide. The acidity matched that of the pool in which they had been held. The flume tank had two nozzles that each pushed a mild plume of water from front to back. One plume flowed along the left side of the tank, and the other plume did so along the right. After the sharks started swimming, we infused some of the squid water through one of the nozzles. We later reversed the plumes in case the sharks had a natural preference to swim along one side.

Overhead cameras and tracking software recorded what happened next. Sharks in group 1—regular seawater—spent over 60 percent of their time swimming in the plume that smelled like their lunchtime squid. Sharks in group 2 did the same. But sharks in group 3 actively avoided the scent of prey, spending less than 15 percent of their time in the squid-treated water. We saw other differences. Group 1 sharks repeatedly bumped and bit at a brick held in front of the nozzle emitting the squid water. They hit it more than twice as many times as the sharks in group 2 and more than three times as often as sharks in group 3.

It is surprising to see a predator lose interest in, and even avoid the smell of, its food. Reef fishes tested in other experiments seem to exhibit similarly odd behavior. Given the importance of sharks as top predators to ecosystems and their known vulnerability to environmental changes, ocean acidification could be a major threat to these animals and the ecosystems where they live.

IN BRIEF

Increasingly acidic ocean water created by climate change might be undermining important behaviors that sea creatures need for survival.

Experiments show that damselfishes, sharks and crabs raised in or exposed to highly acidic water may fail to smell predators or to find food or may uncharacteristically wander into dangerous places.

It is unclear whether ocean dwellers can adapt to increasing acidity if the rise is slow or if they can pass along adaptive traits to their offspring. Tests at volcanic reefs that are naturally more acidic might provide some answers.

BOLD IS BAD

IT IS ALWAYS TRICKY to say that behaviors seen in a lab would also be seen in the wild. So we went to a sandy lagoon near one of the Great Barrier Reef's northern islands to examine another trait: boldness. There we tested how wild-caught juvenile damselfishes would react to predator smells after exposing them to acidic water for four days. In a flume tank, about half of them held in water with acidity expected by 2050 were attracted to a predator plume and half were not, but 100 percent of them held in water anticipated by 2100 were attracted to the predator odor.

We tattooed the damselfishes so we could identify them and then let them loose on a small reef we made in the lagoon. The fishes that had been held in the most acidic water demonstrated risky behavior: instead of staying close to a protective coral, they wandered farther away and did so more often than the fishes that had been held in untreated seawater. After a research diver scared them back into the coral, those that had been held in the higher CO_2 levels came back out quicker than the other fishes did. And sure enough, the bold ones exposed to the seawater for 2100 were nine times more likely to be eaten by a predator. Fishes exposed to the seawater for 2050 were not quite as bold but still wandered and were five times more likely to die.

Scientists like to use reef fishes for experiments because their behaviors are consistent and easy to observe. But experiments on other sea creatures have shown disturbing behaviors as well. Researchers at the Monterey Bay Aquarium Research Institute raised hermit crabs in highly acidic conditions. The crabs did not show the significant increase in boldness that damselfishes did, but they took much longer than normal to reemerge from their shells when they were attacked by a simulated predator (a toy octopus).

Investigators in Chile worked with the Chilean abalone, a mollusk that adheres to rocks along wave-swept shores. Typically when rough waves dislodge the abalones from their perches, they quickly reattach themselves so they do not drift around, making them an easy catch for predators. When CO_2 levels were raised by about 50 percent, some abalones took less time than usual to right themselves. Some held in more acidic water took wrong turns while trying to avoid crab predators lurking nearby, and some actually turned *toward* the crabs' claws instead of away from them.

Clearly, ocean acidification is meddling with sea creatures' minds. But how? A few researchers wonder if the cues themselves—the smells and sounds—are altered by the changing pH. But experiments show that fish can readily identify chemical cues in high-CO_2 water. Other scientists hypothesize that the altered behavior could be a stress response in fish that are trying to regulate changing acidity in their body, but that requires further investigation.

On a different hunch, Philip L. Munday of James Cook University in Australia and I decided to collaborate with Göran E. Nilsson of the University of Oslo. Nilsson suspected that acidification interferes with a neurotransmitter called $GABA_A$, which modulates signals in the brains and nervous systems of many animals, including humans. Among other tasks, $GABA_A$ inhibits signals by conducting chlorine and bicarbonate across nerve cell membranes. When fish are exposed to elevated CO_2 levels, they excrete chlorine from their body to accumulate more bicarbonate—an attempt to minimize pH change inside their body. This shift in chemistry, however, causes $GABA_A$ receptors to become excited, impairing signals. When fish exposed to high CO_2 are later placed in water with gabazine, a chemical that reduces the excitation, normal behavior resumes after only 30 minutes. Yet $GABA_A$ sensitivity may differ among species, so it is not clear if this is the primary cause for behavioral changes.

CAN FISH ADAPT?

THE MAIN QUESTION I receive when speaking about ocean acidification is, What are the chances that marine life can adapt? Nature has an astounding capacity to heal itself. Predicting how an organism might adapt is difficult, and predicting how well complex ecosystems can adapt is nearly impossible.

Experiments do indicate some common trends. For example, smell was altered for adult sharks as well as juvenile clown fish. There also seems to be a tipping point for coral-reef fishes: about half exhibited troubling behavior when acidity was raised to levels expected by 2050, but virtually all showed the behaviors at levels anticipated for 2100.

We have to ask, however, if the rate of acidification in experiments is a complicating factor. Most studies have bred or habituated fish to elevated CO_2 conditions over a few days or months—an extremely short time frame. The animals are not given a realistic opportunity to acclimate or adapt. We will have to investigate fish in the wild as the ocean gradually becomes more acidic.

To gain insight, scientists have turned to reefs near volcanic gas seeps, where CO_2 comes up through the reef floor at spots, naturally acidifying the water there to levels anticipated by 2100. When we visited volcanic reefs in Papua New Guinea, we found that juvenile damselfishes at a seep site were attracted to a predator odor, did not distinguish between predator and nonpredator odors, and exhibited bolder behavior—the same oddities shown by our lab fishes. At nonseep reefs, the same damselfish species did detect and avoid predators and was less bold.

We also do not know if the behaviors might be passed on to future generations. Researchers are just beginning to investigate. In one study, the offspring of coral-reef fishes raised under high-CO_2 conditions showed no advantage in adapting to higher levels.

Ocean acidification is one of many stressors. Overfishing, increased water temperature, greater pollution, the removal of top predators such as sharks, and habitat destruction all hurt the sea. Although local issues such as shark finning can be stopped by authorities, broader insults such as increased temperature and acidification could be the straws that break the backs of many species. As we examine how stressors physically affect ocean dwellers, we should also investigate how they might affect cognitive abilities, which are just as important to survival. SA

MORE TO EXPLORE

Behavioural Impairment in Reef Fishes Caused by Ocean Acidification at CO_2 Seeps. Philip L. Munday et al. in *Nature Climate Change,* Vol. 4, pages 487–492; June 2014.

Odor Tracking in Sharks Is Reduced under Future Ocean Acidification Conditions. Danielle L. Dixson et al. in *Global Change Biology,* Vol. 21, No. 4, pages 1454–1462; April 2015.

FROM OUR ARCHIVES

The Dangers of Ocean Acidification. Scott C. Doney; March 2006.

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