FEATURE

In hot water

Five years ago, a marine heat wave began to wash across Pacific ecosystems. Researchers fear it is a preview of the oceans' future.

WARREN CORNWALL

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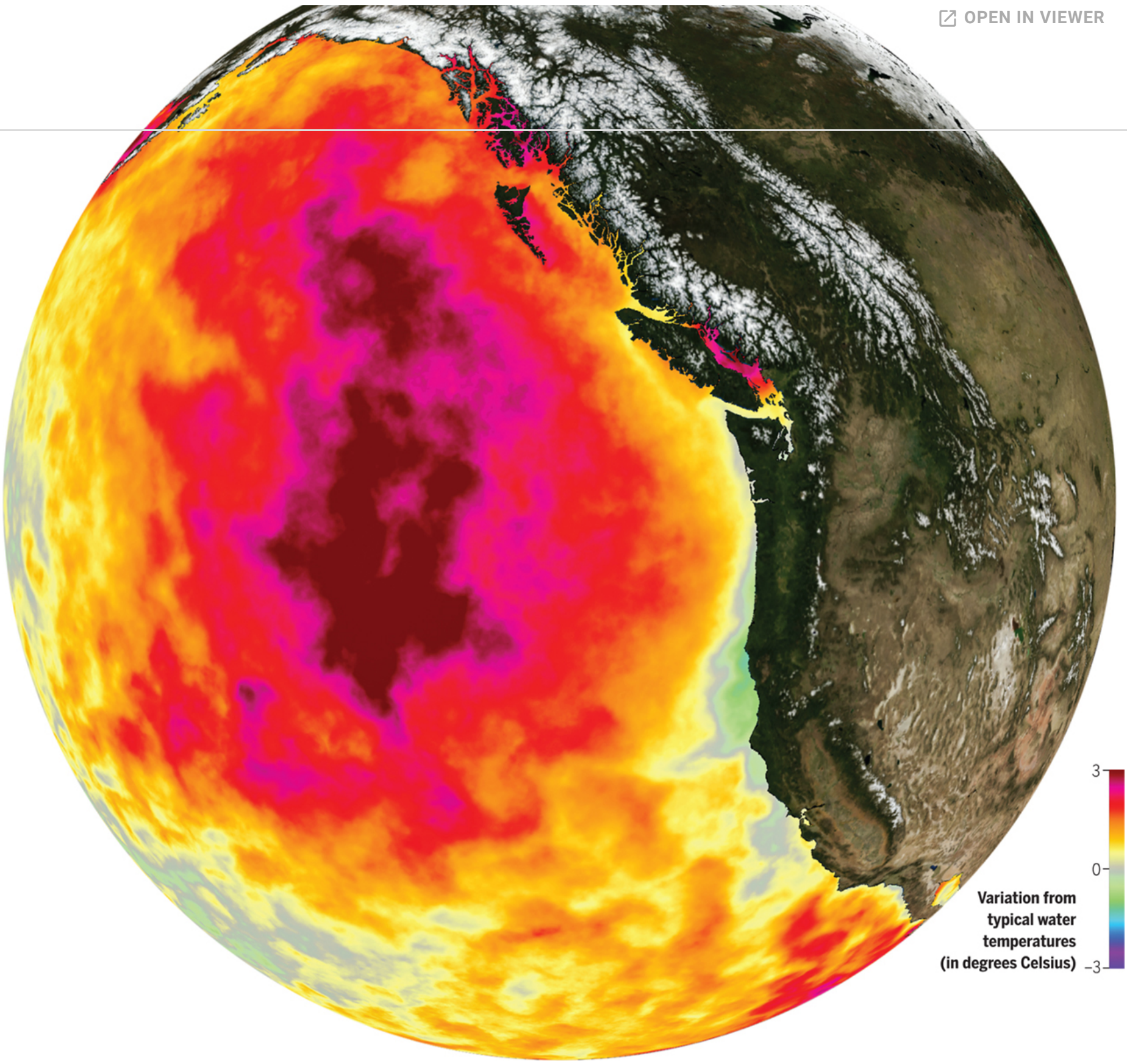


By early 2015, the unusually warm water known as The Blob covered a vast swath of the Pacific Ocean.

IMAGE: GENTEMANN, C., *ET AL. GEOPHYSICAL RESEARCH LETTERS* 44.1, 312, (2017)

When marine biologist Steve Barbeaux first saw the data in late 2017, he thought it was the result of a computer glitch. How else could more than 100 million Pacific cod suddenly vanish from the waters off of southern Alaska?

Within hours, however, Barbeaux's colleagues at the National Oceanic and Atmospheric Administration (NOAA) in Seattle, Washington, had confirmed the numbers. No glitch. The data, collected by research trawlers, indicated cod numbers had plunged by 70% in 2 years, essentially erasing a fishery worth $100 million annually. There was no evidence that the fish had simply moved elsewhere. And as the vast scale of the disappearance became clear, a prime suspect emerged: “The Blob.”

In late 2013, a huge patch of unusually warm ocean water, roughly one-third the size of the contiguous United States, formed in the Gulf of Alaska and began to spread. A few months later, Nick Bond, a climate scientist at the University of Washington in Seattle, dubbed it The Blob. The name, with its echo of a 1958 horror film about an alien life form that keeps growing as it consumes everything in its path, quickly caught on. By the summer of 2015, The Blob had more than doubled in size, stretching across more than 4 million square kilometers of ocean, from Mexico's Baja California Peninsula to Alaska's Aleutian Islands. Water temperatures reached 2.5°C above normal in many places.

By late 2016, the marine heat wave had crashed across ecosystems all along North America's western coast, reshuffling food chains and wreaking havoc. Unusual blooms of toxic algae appeared, as did sea creatures typically found closer to the tropics (see sidebar, p. 445). Small fish and crustaceans hunted by larger animals vanished. The carcasses of tens of thousands of seabirds littered beaches. Whales failed to arrive in their usual summer waters. Then the cod disappeared.

A fin whale found on an Alaskan beach in 2015 might have been among the victims of The Blob.

PHOTO: BREE WITTEVEEN

The fish “basically ran out of food,” Barbeaux now believes. Once, he didn't think a food shortage would have much effect on adult cod, which, like camels, can harbor energy and go months without eating. But now, it is “something we look at and go: ‘Huh, that can happen.’”

Today, 5 years after The Blob appeared, the waters it once gripped have cooled, although fish, bird, and whale numbers have yet to recover. Climate scientists and marine biologists, meanwhile, are still putting together the story of what triggered the event, and how it reverberated through ecosystems. Their interest is not just historical.

Around the world, shifting climate and ocean circulation patterns are causing huge patches of unusually warm water to become more common, researchers have found. Already, ominous new warm patches are emerging in the North Pacific Ocean and elsewhere, and researchers are applying what they've learned from The Blob to help guide predictions of how future marine heat waves might unfold. If global warming isn't curbed, scientists warn that the heat waves will become more frequent, larger, more intense, and longerlasting. By the end of the century, Bond says, “The ocean is going to be a much different place.”

EVEN AS OMINOUS HEADLINES warned of what *National Geographic* dubbed “The blob that cooked the Pacific,” researchers scrambled to decipher what was happening. They consulted satellite readings; crisscrossed the Pacific on research ships, sometimes dredging the depths with nets; picked through the carcasses of birds and whales; and huddled over microscopes and lab aquariums.

The Blob was spawned, experts say, by a long-lasting atmospheric ridge of high pressure that formed over the Gulf of Alaska in the fall of 2013. The ridge helped squelch fierce winter storms that typically sweep the gulf. That dampened the churning winds that usually bring colder, deeper water to the surface, as well as transfer heat from the ocean to the atmosphere—much like a bowl of hot soup cooling as a diner blows across it. As a result, the gulf remained unusually warm through the following year.

But it took a convergence of other forces to transform The Blob into a monster. In the winter of 2014–15, winds from the south brought warmer air into the gulf, keeping sea temperatures high. Those winds also pushed warm water closer to the coasts of Oregon and Washington. Then, later in 2015 and in 2016, the periodic warming of the central Pacific known as El Niño added more warmth, fueling The Blob's growth. The heat wave finally broke when La Niña—El Niño's cool opposite number—arrived at the end of 2016, bringing storms that stirred and cooled the ocean.

Satellites and instrumented buoys made it relatively easy for scientists to track The Blob's bloom and fade. But the vast sweep of its ecological impact was harder to see.

That story starts with some of the ocean's tiniest inhabitants, which sit at the base of the marine food chain. In the Gulf of Alaska, phytoplankton blooms shrank during the warm years, a trend scientists trace to a lack of the nutrients that the winds usually churn to the surface with colder, deeper water. The decline in phytoplankton appears to have rippled out to copepods—fat-rich crustaceans the size of a sesame seed—that feed on the algae, says Russell Hopcroft, a zooplankton ecologist at the University of Alaska in Fairbanks. During Blob years, the copepods grew leaner at the same time as phytoplankton ebbed and water temperatures climbed, he says. When warmer water moved north to Alaska, it also carried in different, less nutritious copepod species.

Krill—tiny shrimp that, like copepods, are a key food for many fish—felt the heat, too. In 2015 and 2016, as The Blob engulfed the coasts of Washington and Oregon, the heat-sensitive creatures vanished from biologists' nets.

As the base of the food chain crumbled, the effects propagated upward. One link higher, swarms of small fish that dine on copepods and krill—and in turn become food for larger animals—also became scarce as warm waters spread. On a remote island in the northern gulf, where scientists have tracked seabird diets for decades, they noticed that capelin and sand lance, staples for many bird species, nearly vanished from the birds' meals. In 2015, by one estimate, the populations of most key forage fish in the gulf fell to less than 50% of the average over the previous 9 years.

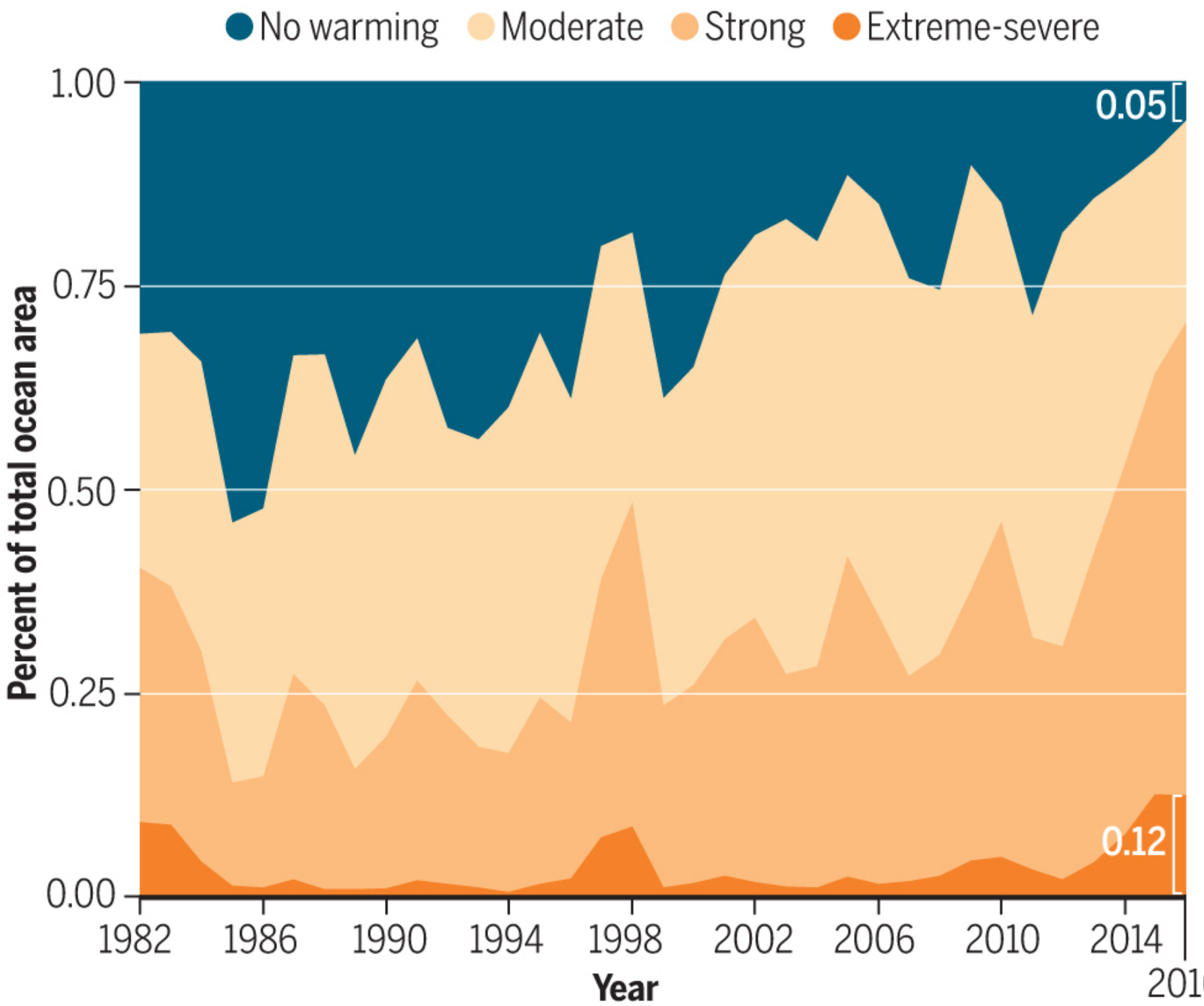
Of the fish that remained, some offered little nourishment. Sand lance caught in 2016 were so stunted that Yumi Arimitsu, a fisheries ecologist with the U.S. Geological Survey (USGS) in Juneau, thought she was holding fish that had recently hatched. But a check of their ear bones showed they were a year old. The fish had so little fat that each one provided just a tenth of the energy content of one average fish from other years.

Finger-length juvenile cod that spend their first summer feeding in the gulf 's shallow waters also disappeared. In 2014, when NOAA researchers on an annual survey cast their nets into two bays off Kodiak Island in Alaska, they came up almost empty. There were “no fish around,” recalls Ben Laurel, a NOAA fisheries ecologist based at the agency's lab in Newport, Oregon. “There's just this big hole.”

Even as these food stocks declined, the warmer water delivered a second blow to the cold-blooded creatures there, from copepods to adult cod. The heat dialed up the metabolism of the animals, forcing them to eat more to keep their bodies fueled—just as prey became scarcer.

It's getting warm in here

The portion of the world's oceans experiencing moderate to extreme marine heat waves has been growing since the 1980s.



CREDITS: (GRAPHIC) V. ALTOUNIAN/*SCIENCE*; (DATA) HOBDAY *ET AL.*, *OCEANOGRAPHY*, 31 (2), 2018

Barbeaux thinks that one-two punch is what did in Pacific cod, gray-flanked fish that can grow to more than a meter. After his initial shock at discovering the 2017 cod crash, he started to assemble a picture of a creeping underwater famine. Looking back, researchers noticed adult cod caught in 2015 and 2016 were skinnier than normal. The stomachs of cod caught in 2015 were half-empty compared with boom years, and contained few energy-rich capelin and tanner crabs.

Despite their ability to go months without eating, the cod could not withstand this double whammy. Computer simulations developed by federal scientists suggest that, as warm waters lingered, the fish ran a deep caloric deficit. Barbeaux suspects the weakened fish became more vulnerable to disease and predators, such as salmon sharks.

THE COD'S DEMISE wasn't easily observed. But other changes occurring in the ocean's depths became visible in sudden, morbid convulsions on beaches and in bays. In late 2014, thousands of starved Cassin's auklet seabirds be-

gan to wash ashore in Washington and Oregon. On New Year's Day 2016, a retired bird biologist in Whittier, Alaska, stumbled across the white and gray bodies of 8000 common murres lining a beach, like so many abandoned buoys. In the following days, people found the normally hardy seabirds—known for their ability to fly hundreds of kilometers in a day to find fish—dead and dying across much of southern Alaska. They piled up on beaches and staggered along highways like little zombies. As many as half a million died, scientists estimate.

Then there were the disappearing whales. In the summer of 2015, 2 years into The Blob, just 166 humpback whales returned to Alaska's Glacier Bay from their winter calving grounds near Hawaii and Mexico, a 30% drop from 2013. All the humpback calves seen in Glacier Bay that year disappeared later and are presumed dead. And the bodies of 28 humpback and 17 finback whales washed up on beaches in Alaska and British Columbia in Canada.

Toxic algae blooms that stretched along much of the west coast in 2015 might have played a role in the seabird and whale deaths. But some of the animals might have simply starved because competing predators had vacuumed up available forage fish. The seabird die-off, for example, peaked in the winter of 2015–16, just as warmer waters would have revved up the appetites of fish like cod, notes John Piatt, a USGS marine ecologist based in Port Townsend, Washington. “If murres and whales are dying en masse everywhere, what does it tell you?” Piatt asks. “That there's no food anywhere.”

Researchers are still puzzling over many Blob mysteries. Even as common murres suffered, for example, tufted puffins that feed on the same fish showed few problems, notes Heather Renner, a wildlife biologist for the U.S. Fish and Wildlife Service in Homer, Alaska. And although the cod story seems to fit together neatly, there are still unknowns, such as exactly how warmer water temperatures affected baby cod. Laurel hopes some answers will emerge from ongoing laboratory experiments that involve raising young cod in aquariums with different water temperatures. The findings could help illuminate how tiny temperature shifts influence growth and survival, particularly during crucial winter months when the fish live largely on fat reserves.

Other clues could come from the bodies of baby cod that researchers have collected from Kodiak Island beaches every year since 2006, then packed into lab freezers. Laurel has long wanted to study the collection to see how climate, ocean conditions, and diet shape development. Now, the urgency of understanding The Blob has unlocked money for that work.

ALTHOUGH THE BLOB has dissipated, its impact lingers. Of five common murre colonies in the gulf surveyed in 2018, only two seem to be breeding at normal levels. Just 99 humpback whales returned to Glacier Bay last year, with only one new calf in tow, far below the 3-decade average of more than eight calves per year. Cod numbers this year are projected to be even lower than they were last year. That means more tough times for cod fishers. Federal officials cut the allowable catch by 80% after the 2017 collapse, and the 2019 limits are even lower.

But a recovery may be in the offing. With cooler waters, tiny cod filled the bays at Kodiak Island in the summer of 2018. Larger, high-fat copepods showed an uptick, as did forage fish. Seabirds have resumed breeding in some places. Krill have rebounded off the west coast. “It indicates that to some extent the ecosystem is able to restabilize once [more typical] conditions return,” says Janet Duffy-Anderson, a NOAA fisheries ecologist based in Seattle.

Now, scientists are ramping up efforts to study similar firestorms that are gathering strength in other corners of the ocean. Warmer temperatures are threatening corals in the Red Sea, kelp forests in southern Australia, and fisheries off the coasts of New England and eastern Canada. Rising temperatures are also affecting ecosystems near New Zealand, the Mediterranean, and the coast of Argentina. In northern Australia, record air temperatures late last year sparked warnings of more damage to the Great Barrier Reef. Back-to-back marine heat waves in 2016 and 2017 are estimated to have killed half the reefs there.

“Marine heat wave” became a common part of scientific parlance in just the past decade. Now, research on the waves “is kind of taking off,” says Eric Oliver, a physical oceanographer and marine heat wave expert at Dalhousie University in Halifax, Canada. In 2016, he and a group of Australian, U.K., and U.S. scientists moved to give the field some common metrics by proposing that a marine heat wave be defined as a string of five or more days in which ocean water temperatures are in the top 10% compared with the previous 3 decades. Last year, recognizing that ocean warming might soon get public attention like other natural disasters, some of the same scientists sug-

gested ranking their severity much like hurricanes, ranging from Category I to Category IV. They also proposed naming marine heat waves based on their location and year—so The Blob might have been called Northeast Pacific 2013.

Each heat wave has its own constellation of causes. But there is one common and increasingly potent factor, researchers say. As oceans soak up more heat from a warming planet, heat waves are becoming more common and more intense. The number of days with a marine heat wave somewhere on the globe has doubled since 1982, according to a 2018 study by Swiss scientists published in *Nature*. Those researchers warned that, if warming continues on the current trajectory, marine heat waves will become 41 times more frequent by the end of the century. They will also be longer and bigger. Heat waves would typically last more than 100 days, with maximum temperatures 2.5°C above average. The western tropical Pacific and Arctic oceans would be the hardest hit. The changes, the authors wrote, would probably push "marine organisms and ecosystems to the limits of their resilience."

That scenario fits with what Bond foresees for the northeast Pacific. The climate and ocean models he uses produce sobering scenarios. By 2050, without major curbs on planetary warming, average ocean temperatures in that region will likely be between 1°C and 2°C above historic levels—meaning Blob-like temperatures will become typical. As a result, Bond says, "When we have a marine heat wave in 2050, it's going to be way out there—in the uncharted territory."

Other tastes of that future might be just around the corner. Even as researchers close the book on The Blob, they are keeping a close watch on new heat waves off Alaska. In the winter of 2017–18 the northern Bering Sea was devoid of ice for the first time on record. And last summer, a warming trend that started in 2014 turned feverish. Water temperatures in the Bering Sea, where walleye pollock support one of the world's biggest fisheries, hit 4°C above normal in some regions. Already, the heat appears to be having an impact. Late last year, researchers found that numbers of fatty copepods—a favorite of young pollock—were 90% below average. The big question is what impact the copepod shortage will have on fish trying to survive their first winter, Duffy-Anderson says. That won't be known until later this year.

Meanwhile, in the Gulf of Alaska, calm, warm weather this past fall has spawned a new patch of unusually warm water, one that is eerily like the baby Blob. In October 2018, Barbeaux logged into Facebook to share a news story warning The Blob might have a sequel. His comment succinctly captured what many scientists are thinking as they probe the effects of the last heat wave: "Oh, crap."

Correction (12 February 2019): The credit for the image of Earth's temperatures has been updated.

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MAR. 22, 2019

RE: Geothermal heat in oceans

WYSS YIM Retired professor, Department of Earth Sciences, The University of Hong Kong

Based on the analysis of observation records there is an alternative explanation for the Blob. The main cause identified was the eruption of the Nishino-shima volcano 940 km south of Tokyo.
The Volcanic Explosivity Index (VEI) based on the volume of subaerially erupted materials from November 20, 2013 to

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