MOVEABLE FEAST

As fish stocks move in response to warming, regulators struggle to keep pace

By **Marianne Lavelle**

In the early 2000s, trawler crews working the Celtic Sea off Ireland noticed something unusual. Small, spiny, bright orange fish, called boarfish, began appearing in their nets in huge numbers. Previously, the intruders had been a minor nuisance; their sharp spines jammed equipment and damaged the soft flesh of more valuable species, such as cod and hake. Irritated crews tossed them overboard.

As boarfish schools grew, however, the problem became an opportunity. Trawlers retooled to target the fish, which were turned into meal and oil. Boarfish went from trash to treasure, and they now generate more than $10 million annually for Irish fleets.

Scientists aren't exactly sure what is causing the boarfish boom, but there is evidence that a warming ocean is playing a role. And for fishery managers, the boarfish has become one symbol of an emerging global issue: the often surprising disruptions that climate change can create in the world's fisheries, as marine populations move, flourish, and wither as a result of warming seas.

PHOTO: © JEFFREY ROTMAN/CORBIS

Some stocks of Atlantic cod, long a mainstay of commercial fishing, have been hit hard by warming oceans, recent research suggests.

"Climate change is pushing whole [marine] systems to a state we haven't experienced before," says fisheries ecologist William Cheung of the University of British Columbia, Vancouver, in Canada. The reshuffling is creating challenges for scientists seeking to understand a rapidly changing ocean. It is also taxing fishery managers, who tend to view the oceans "as stable, or steady-state," instead of preparing for change, says Richard Merrick, chief scientist of the U.S. National Oceanic and Atmospheric Administration (NOAA) Fisheries in Silver Spring, Maryland. As a result, policymakers are scrambling to build management schemes that can cope with moving fish stocks and shifting ecosystems. The stakes are high, they note, given that ocean fisheries generate $195 billion annually in the United States alone and are a key food source for hundreds of millions of people.

IT HAS LONG BEEN A CHALLENGE to manage marine populations so that the ocean keeps on giving. In the early 1600s, when English explorer John Smith arrived in Jamestown, Virginia, he famously marveled at "more sturgeon than could be devoured by dog or man." Within a few centuries, however, people had severely depleted that species and many others.

Slowly, fishers and scientists learned how to set more sustainable catch limits, by combining a greater knowledge of the reproductive biology of marine species with improved surveying methods and economic data. By the late 20th century, many nations had imposed extensive controls on their fishing fleets, and even struck international agreements to prevent conflicts over stocks that swam across national borders. Such rules have helped many overfished stocks bounce back. Even relatively well-informed policies, however, have often proven difficult to implement, in part because of the ocean's great natural variability. Powerful currents can change course, huge water masses can shift, and fish and shellfish populations are prone to seemingly random booms and busts.

Now, fishery managers say climate change is making their job even more complicated. Oceans have helped moderate the impact of fossil fuel burning by absorbing an estimated one-third of the carbon dioxide that humans have added to the atmosphere, as well as much of the heat generated by greenhouse warming. But marine life is bearing the brunt of living in a giant sink for heat and carbon, which is acidifying as well as warming the waters.

Corals, crustaceans, seagrasses, and phytoplankton are among the many groups of organisms already showing effects from warming seas, researchers say. And fish are on the move, scientists have concluded in numerous studies, including a major survey led by ecologist Malin Pinsky of Rutgers University, New Brunswick, in New Jersey. After studying more than 40 years of census data on some 350 fish species found off North America, his team concluded that some 70% of the species were shifting their ranges, or moving to deeper or shallower waters, in response to changes wrought by warming. The researchers predicted in a 2013 *Science* paper that "rapid range shifts will fundamentally reorganize marine communities" and could "confound traditional management approaches."

AN OLD U.S. COAST GUARD STATION near Tuckerton, New Jersey, now a marine laboratory, holds an eerie record of those changes. More than 1 million translucent fish larvae float in glass vials, cataloged by species and the date they were captured.

Laboratory Director Ken Able, a biologist at the Rutgers University Marine Field Station, started methodically catching the hatchlings 26 years ago in a nearby estuary. Originally, the goal was to learn more about populations of summer flounder (*Paralichthys dentatus*), a much-prized catch. Ultimately, however, Able and his colleagues realized that the estuary is an ideal location for observing the transformation of the North Atlantic. Larvae spawned from Canada to the Caribbean and beyond ride to the region on two great currents—the Labrador Current from the north and the Gulf Stream from the south.

As a result, Able's larvae library has become a record of change. Over time, southern-dwelling species, such as the Atlantic croaker (*Micropogonias undulatus*), have become more abundant. Northern species, including

the Atlantic herring (*Clupea harengus*) and three-spined stickleback (*Gasterosteus aculeatus*), have begun to disappear.

U.S. East Coast fishery managers are still grappling with how their approach should change to address the ebb and flow of these species, some of which is due to fishing practices rather than climate change. But the issue has become urgent for managers in the eastern North Atlantic. Over the past decade, large schools of mackerel (*Scomber scombrus*) began appearing in the waters off Iceland, signaling a northward expansion of the fish's range linked to warmer waters. In 2009, amid a financial crisis, Iceland unilaterally increased its mackerel catch, prompting outrage from competing fleets in the European Union and Norway, which traditionally have had rights to the majority of the catch. They complained that Iceland's expanding fishery (and another in the Faroe Islands) was imperiling their own mackerel stocks.

The science underlying such claims became the focus of fierce debate, with the parties disagreeing over the size of the whole population—a key to setting safe catch limits—and whether the competing fleets were exploiting the same or distinct populations. Opponents even had trouble agreeing on what waters should be included in the mackerel's range, and how best to count the fish.

In a bid to clarify matters, researchers have launched efforts "to make sure that they're discussing the same stocks, using the same methodology … [but] it's quite difficult to maintain a standard that compares apples to apples," says Manuel Barange, director of science at the Plymouth Marine Laboratory in the United Kingdom.

In the meantime, the political impasse has continued, meaning that Iceland has been setting its own catch quotas, instead of working with other nations to establish regionwide catch limits that reflect the changing mackerel distribution.

THE MACKEREL DEADLOCK highlights the difficulty of using traditional fishery surveys to track and predict climate-induced population shifts. Current methods, including the use of dedicated research trawlers to make periodic but limited hauls, may not allow researchers to "adequately capture the future population dynamics in a changing ocean," NOAA officials noted earlier this year in a report. What's more, "a large percentage of the ocean is not being surveyed, let's face it," says Jeff Kaelin of Cape May, New Jersey, a commercial fishing executive and member of regional council that helps set U.S. catch quotas. That means plenty of blind spots where scientists aren't able to see and react to sometimes subtle shifts.

To help fill the gaps, some fishery managers and fishers would like to see more systematic use of commercial fishing vessels to gather information. In the United States, for example, the South Atlantic Fishery Management Council, which sets fishing quotas in federal waters from South Carolina to Florida, is exploring the idea of equipping fishing boats to measure environmental variables, such as temperature. That would allow researchers to study how changes in those conditions affect catches.

The bigger dream, however, is to use such information—combined with real-time data from satellites, buoys, and other platforms—to predict future marine changes, much as weather services now forecast droughts and floods. Such a capability might have enabled fishery managers in New England, for instance, to give fishers advance warning of a record ocean heat wave in 2012 that brought warm-water squid as far north as the Gulf of Maine, and caused lobster catches to rise. Local fishers were unable to take advantage of the squid windfall because there wasn't enough notice to retool their boats with the proper gear, and lobsters rotted in trucks because processors weren't ready.

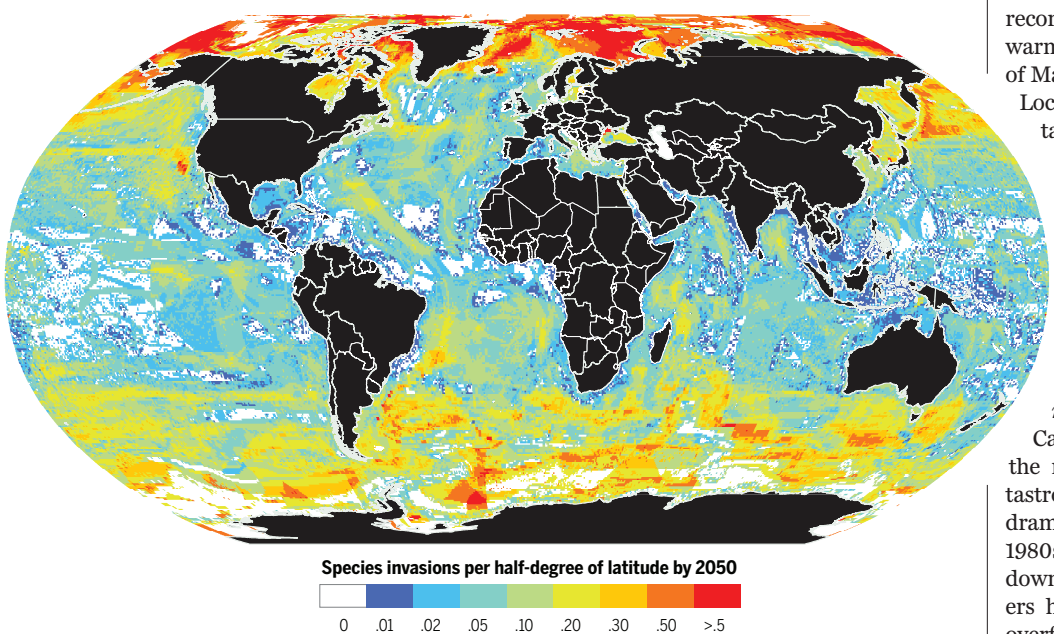
BETTER OCEAN CLIMATE monitoring systems might also help prevent fishery calamities, a recent study suggests. The collapse of cod (*Gadus morhua*) stocks off New England and Canada's eastern coast has been one of the most studied and debated fishery catastrophes in the world. In both nations, dramatic cod population declines since the 1980s have led officials to essentially shut down once lucrative fisheries. Researchers have long laid much of the blame on overfishing, but have suspected that changing ocean conditions—including warmer waters—also played a role.

That idea got a major boost last month with the publication of a study concluding that rapid ocean warming appears to have catalyzed the decline of one major cod stock living in the Gulf of Maine. Satellite data show that from 2004 to 2013 the ongoing warming of surface waters in the gulf greatly accelerated, a team led by oceanographer Andrew Pershing of the Gulf of Maine Research Institute in Portland, Maine, reported in *Science*. Over the past decade, the Gulf of Maine became the fastest warming spot in the world's oceans, making it hard for young cod to survive. At the time, says Pershing, fishery managers didn't understand what was happening, and so allowed catch quotas to remain too high.

The moral of the story, Pershing says, is

Polar invasion

If greenhouse gas emissions remain high, the Arctic and Southern oceans could see the arrival of up to two new species per half-degree of latitude by 2050 (red areas), according to one study of how more than 800 exploited fish and shellfish stocks might respond to climate change. At the same time, many marine species would disappear from waters closer to the equator.



GRAPHIC: WILLIAM CHEUNG, ADAPTED FROM CHEUNG *ET AL. / ICES JOURNAL OF MARINE SCIENCES* **72**, (10 OCTOBER 2014) © ACS

For more than 25 years, biologist Kenneth Able has been collecting fish larvae (below) from an estuary in New Jersey, providing clues to a changing ocean.

that "as ecosystems around the world begin to encounter these conditions that are really changing, using history as your guide is not going to be very effective." Gib Brogan, an advocate with the conservation group Oceana in Boston, says the study also underscores the need for fishery regulators to "put a buffer in [management plans] for the uncertainty that comes with climate change."

THAT'S ADVICE that Ireland's emerging boarfish fishery is trying to heed. As catches boomed—reaching 144,000 metric tons in 2010, Ireland's second biggest catch behind mackerel—European fishery managers began to worry. Nobody, they realized, knew much about the little orange fish: how many there were, how quickly they reproduced, or even how long they lived. The managers feared that unregulated fishing could wipe out the stock before the industry even established itself.

Some of the more than 1 million larvae collected by Able's group.

To buy time, the E.U. fisheries commission imposed new rules that reduced catches—and boarfish captains and others began raising money to fund the needed science. In a collaboration that some fishery managers will envy, scientists conducted the first sonar surveys of boarfish schools from commercial fishing boats, with guidance from fishermen on where to find the fish. By analyzing growth rings in fish ear bones, Danish scientists determined boarfish live as long as 30 years. Biologists also calculated how quickly they reproduce, and learned that they have few natural predators. Using old fishing records and new genetic testing methods, they determined that Irish boarfish are homebodies—they didn't migrate from another location to the North Atlantic. And they realized the species has been there a long time, albeit in smaller numbers. That suggests that some change in the environment—an increased food supply, perhaps—boosted boarfish reproduction. And warming waters are a likely catalyst, many scientists believe.

Now, E.U. fishery managers are drawing on that information to devise a long-term management plan for the boarfish. Researchers hope it will acknowledge the possibility of future ocean changes and ecosystem shifts. And the experience could become a model for how other fishing communities can work with scientists to adapt to the changes that climate change will bring, says Kari Stange, a social scientist at Wageningen University in the Netherlands.

Stange recalls one Irish fisherman who was preparing to travel to E.U. headquarters in Belgium to discuss how the new fishery would be managed. He said: "We can't just go to Brussels and say that a lot of fishermen think there's a lot of fish out there," Stange recalls. "They knew they had to come with science." ■

Marianne Lavelle is a freelance journalist in Arlington, Virginia.

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