The dead zones

When the ocean's inhabitants try to escape, you know there's a problem. Mark Schrope reports

THE Chesapeake Bay region on the US east coast defines itself largely by its seafood. Blue crab meat is ubiquitous, with the options ranging from crab cakes to crab-topped hamburgers. The watermen are fiercely proud of their fishing heritage, yet many are leery of seeing their children or grandchildren follow them into the business.

"My son, he got some sense into his head and started teaching school," says Jack Crockett, who has spent most of his life working the same waters that three generations of his family did before him. The son of another lifelong waterman, Don Pierce, has already followed him onto the water. "But I'm going to do my best to get my son's son to do something else," he says.

A key reason for the watermen's pessimism is that for many years they have watched a pernicious plague gradually taking over their bay. They know that on any given day, without warning, that plague can kill their entire catch. "It just makes it harder and harder to survive," says Larry Simns, head of the Maryland Watermen's Association.

The plague is a lack of the stuff of life, oxygen. In certain conditions, oxygen levels in the water can fall to dangerously low levels, creating what is commonly known as a dead zone. Fast-swimming creatures like fish can flee, but most bottom dwellers, such as shellfish, are likely to die. Some animals get so desperate to escape that they crawl or wriggle onto land in events called jubilees by the locals. Eels from a Danish fjord have done this, as have lobsters on a beach in South Africa. In the Chesapeake Bay it's the venerated blue crabs that sometimes make an ill-fated exodus attempt. Pierce remembers a jubilee two years ago at a creek near his hometown. "The crabs would hardly even go back in the water when you got close to them," he says.

NATALIE FOBES/CORBIS

NANCY RABALAIS

Nutrients carried by the waters of the Mississippi are suffocating the Gulf of Mexico

The oceans are complex systems, but it's safe to say that when the inhabitants start trying to escape there is a problem. At the last count, there were more than 200 dead zones around the world (see Map, page 40), ranging in size from a few square kilometres to a dead zone in the Baltic Sea that at its worst covered a staggering 120,000 square kilometres – roughly half the area of the UK. The number of dead zones has doubled every decade since the 1960s. In many places, they are occurring more frequently, covering larger areas or lasting longer. What's more, climate change could make matters even worse.

Extensive areas of low oxygen do occur naturally in the oceans (see "Adapting to the lows", page 41), especially in the deeper parts, but dead zones like the one in the Chesapeake certainly would not have grown to such an extent were it not for humans. While some of the details are debatable, the cause of the dead zones is fairly straightforward. "When you come right down to it it's too many people," says Robert Diaz, a researcher at the Virginia Institute of Marine Science in Gloucester Point who, along with colleagues, has maintained a global list of dead zones since the early 90s.

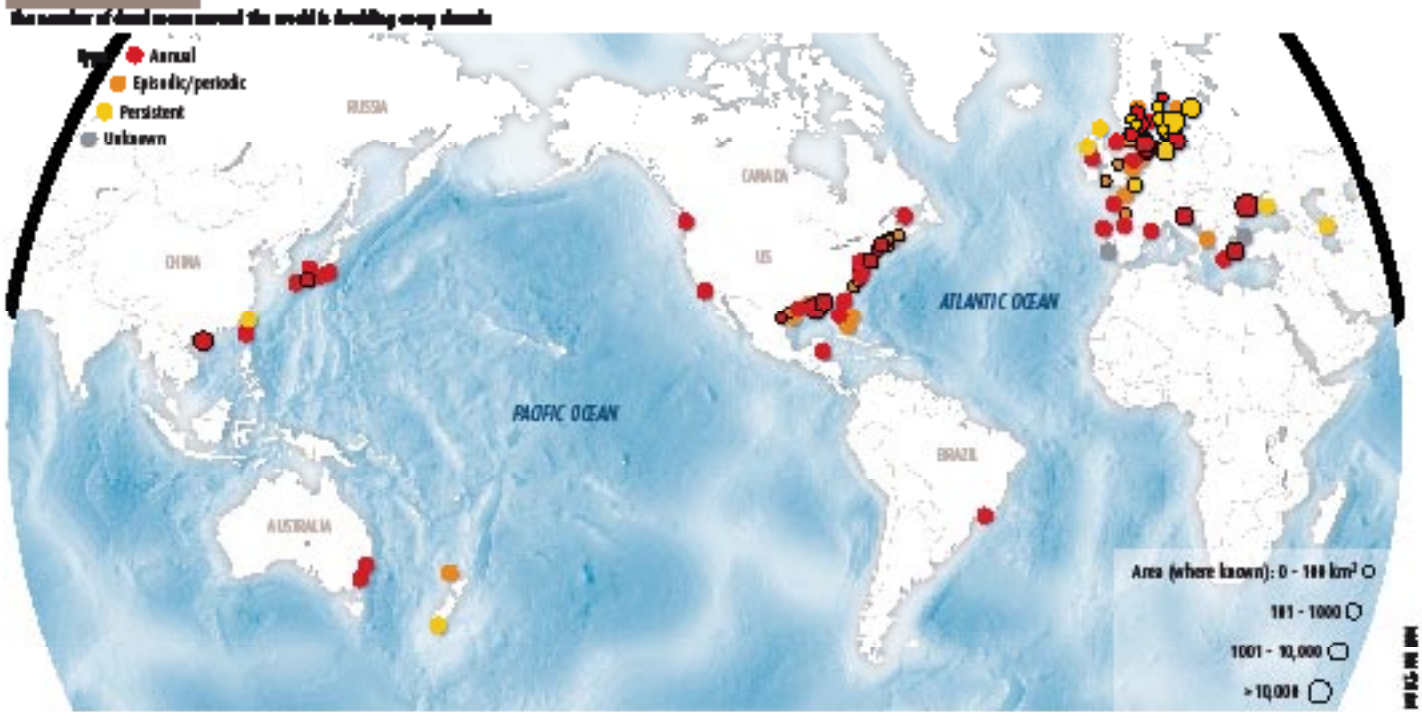
The story almost always goes something like this. A growing population leads to increasing levels of nutrients – mainly nitrogen and phosphorus – in coastal waters. The culprits include fertiliser-laden agricultural run-off, sewage and rainwater containing nitrous oxides from vehicle exhausts. The nutrients lead to blooms of algae that eventually die and fall to the bottom. Bacteria then gorge on this food, using up huge amounts of oxygen.

Such events have long been a problem in polluted rivers and lakes but in the sea, where nutrient-rich waters are rapidly diluted, and waves and currents help oxygenate and circulate water, it takes a special set of circumstances to create a dead zone. They are most common in places where water circulation is limited, such as estuaries and bays, or near the mouths of big, polluted rivers. Nitrogen is typically the main troublemaker in the ocean, whereas it is more likely to be phosphorus in fresh waters.

A dead zone also requires one more critical element: layering, or stratification, that stops oxygenated surface water mixing with deeper waters. This can be brought about by differences in temperature or salinity, effectively creating a sealed coffin in which wildly proliferating bacteria use up most of the available oxygen.

Nancy Rabalais of the Louisiana Universities Marine Consortium in Chauvin, who coined the term dead zone and discovered one of the world's largest in the Gulf of Mexico, has seen the results up close on numerous occasions. "There's just ▶

200 AND COUNTING



"There's just nothing. You just see dead organisms on the seafloor"

nothing," she says, "there are lots of fish at the surface, but once you get down into that layer you don't see any fish any more, you just see some dead organisms on the bottom."

Dead zones persist and spread until something happens to break the coffin seals and bring oxygenated water to the bottom, such as strong winds or storms. This is why many dead zones dissipate over the winter only to reappear in the summer.

For many, the devastation wrought by dead zones is enough to justify cleaning up our act. In economic terms, though, proving that cutting pollution is worth the cost can be challenging. While some shellfish or lobster fisheries have at times been completely destroyed, other dead zones have increased certain catches for a time by concentrating shrimp or fish into smaller areas. Improving fishing technology can also mask declining numbers of animals. If dead zones are allowed to persist, however, many valuable bottom-dwelling creatures, including some species of fish, disappear. Fishermen also have to travel farther and farther around the dead zone to get to suitable fishing grounds.

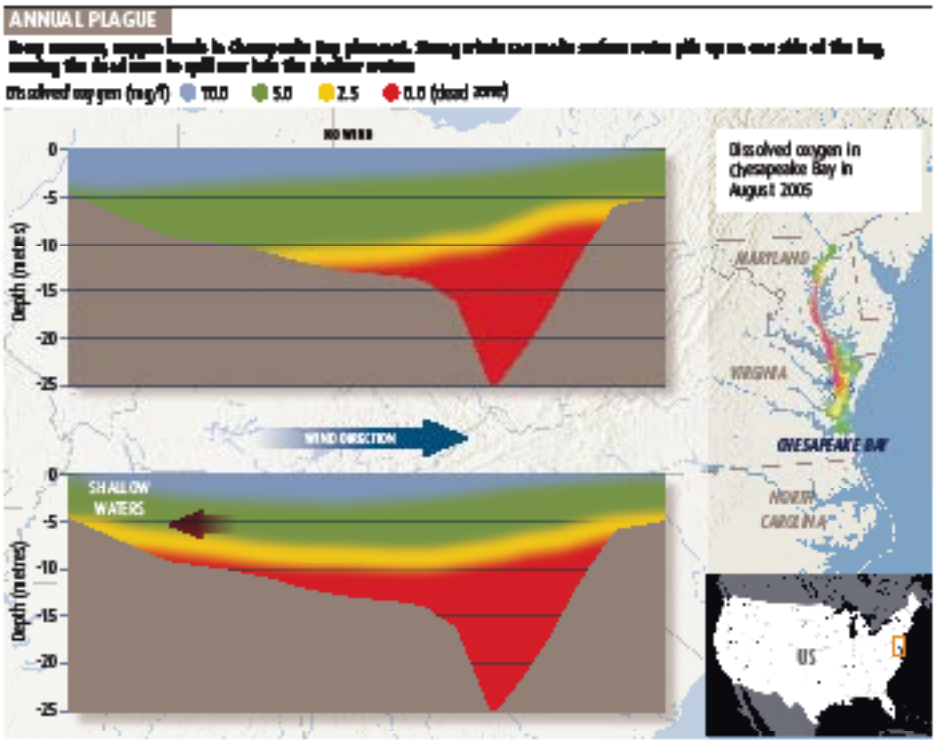
In the Chesapeake, for instance, the striped bass, or rockfish, is an important part of the catch. As the dead zone expands in the summer, the large fish head for the oxygenated mouth of the bay, making it far too costly for most boats to reach them. But the watermen do still catch some fish and sometimes also switch to other activities, such as crabbing. Most, though not all, of the "dead" water is below the depth of the crab traps. However, winds can blow across the bay piling water on one side. The weight of this water squeezes a "burp" of hypoxic water out the other side into shallower areas (see Diagram, right). When it happens, watermen find their traps filled with dead crabs, meaning days of work wasted and income lost. "You'll have one good day and the next day the dead water gotcha," says Pierce.

Road to recovery

While the dead zone in the Chesapeake has been studied for decades, in other locations such as the East China Sea, details are only just emerging, though low oxygen was first documented there in 1981. In 2003, Chung-Chi Chen, a marine ecologist at the National Taiwan Normal University in Taipei, and his team chanced upon a dead zone, probably seasonal, that encompassed around 12,000 square kilometres. "It has definitely hurt the area, which is a major fishing ground," Chen says. For now, the problem does not appear to be on the Chinese government's list of concerns, he says.

If the amount of nutrients is reduced enough, ecosystems can recover to some extent, though completely restoring them may be impossible. One of the greatest dead zone recovery stories was not so much a triumph of political will as a serendipitous benefit of the fall of communism.

Like the Baltic, the enclosed Black Sea is prone to low oxygen. The deeper reaches of the sea have for at least the last 8000 years



Adapting to the lows

Low-oxygen zones existed long before humans started polluting the oceans. In the depths of the ocean, over a million square kilometres of the seafloor are starved of oxygen.

Like human-induced dead zones they can be caused by high concentrations of algae in surface waters, often due to the upwelling of nutrient-rich water. When the algae die, bacteria feeding off this material consume the oxygen.

In the open ocean, however, oxygen levels are unlikely to fall to a damaging degree unless the water is already somewhat oxygen depleted. Deep ocean currents are usually very slow, and it can be hundreds or thousands of years before this water returns to the surface, by which time it is often very low in oxygen. The Pacific generally has the oldest deep water because it is the last stretch on the deep part of the ocean current known as the global conveyor belt. Natural low oxygen zones are common between 100 and 1200 metres down in the eastern Pacific along the continental margin, from Chile to Alaska, where this water wells up, and in a few other scattered areas.

These natural low-oxygen zones are not dead zones. In the open deep water, many free-swimming creatures such as jellyfish survive. In places where these low-oxygen bands meet the continental margin or other features such as seamounts, the seabed, too, is far from lifeless. While some species such as sea urchins and starfish cannot cope with the conditions, worms, molluscs and even a few species of fish can be found.

"Because they are permanent and evolution has had time to do its magic, quite a large number of animals have adapted to these conditions." says Lisa Levin of the Scripps Institution of Oceanography in La Jolla, California.

been home to the world's largest permanent zone that is completely devoid of oxygen. On the shallower north-west shelf, however, low oxygen did not start to become a problem until the 1970s. A decade later the Soviet Union collapsed; state funding for fertiliser faded away and several huge animal farms shut down. The nutrient input to the Black Sea halved. "Suddenly the pressure was off," says Laurence Mee, an oceanographer at the University of Plymouth in the UK. By the late 1990s, dead zones on the shelf had almost completely disappeared.

But while the ecosystem is recovering, it is not returning to the way it was. On a recent research cruise, Mee and his team brought along scientists who had dived in the Black Sea in the 1960s. "It was a fascinating comparison," says Mee. "The Black Sea system has recovered a lot. If you go to an area where there were algal beds before, there are algal beds now, but by and large they are not the same species." A species of red seaweed once covered an area the size of the Netherlands, sheltering and nurturing around 40 species specially adapted to it, such as crabs with red camouflage. Now other species, some invaders from outside the Black Sea, have largely replaced the red seaweed and the creatures that depended on it.

Regime collapse is not the only way to get rid of dead zones. Long Island Sound, the stretch of water between Connecticut and New York, is considered a cautious success story. The dead zone there, which once covered hundreds of square kilometres, has shrunk considerably, probably thanks to improved sewage treatment.

Around the Baltic and Black seas nearly every country is now a member of European Union and so subject to EU pollution directives that require countries to reduce nutrient inputs to waterways to set levels. Most governments around the Black Sea and the river Danube that feeds it have also committed to an additional resolution to maintain nutrient inputs at mid-1990s levels.

"The issue now is to stick to it," says Mee. "It's a costly business and you've got to really convince people it's worth doing. It's not an easy sell." He and others are concerned that as economies improve in the Black Sea region, governments and the public may forget the former dead zone scourge. "We've been trying to say, 'look guys, look over your shoulder – all of this could come back again'," he says.

In some areas, though, reducing the nutrient input does not seem to be working. Denmark has dead zones in its coastal waters and estuaries covering up to 2000 square kilometres. "There has been a commitment to reduce nutrients and I think that is fantastic. I'm very proud of that actually," says Dan Conley, a marine ecologist at the National ▶

Red tide

In 2005, a 135-kilometre stretch of water off Florida's south-west coast turned into a dead zone. The cause, however, was rather unusual.

Toxin-producing "red tide" algae somehow became trapped in cool, denser water cut off from the warmer surface layer, according to Carl Beaver of the Florida Fish and Wildlife Research Institute in St Petersburg. The toxins killed fish and other organisms, whose carcasses in turn fed growing bacterial populations that reduced oxygen to lethally low levels. Corals, sponges and other organisms died.

Historical records suggest similar events may have happened in this region in the distant past, but human pollution is not off the hook. Debate is now raging about whether red tides are more frequent due to fertilisation by nutrient inputs, such as the massive amounts of polluted water reaching the sea each year from Lake Okeechobee in the Everglades.

It's not just polluted water flowing into the sea that can cause red tides. A massive coral-killing red tide around Indonesia in 1997 appears to have been triggered by iron fertilisation from the smoke from forest fires in the archipelago (*Science*, vol 301, p 952).

LYNDA RICHARDSON/CORBIS

Up the coast in the Chesapeake, times are bad for crabs and fishermen alike

Environmental Research Institute in Roskilde, Denmark. Despite substantial reductions, though, the dead zone there has not shrunk. "It's a bit of a mystery," says Conley.

One explanation is that a "backlog" of nutrients can build up, maintaining a dead zone long after remedial action is taken. Nutrients can accumulate in groundwater that may not reach rivers and oceans for years, for instance, while organic matter can build up on seabeds where the lack of oxygen reduces bacterial activity. This means any oxygen reaching these waters will quickly be consumed as bacteria resume feeding. Where this happens, nutrient inputs might have to be drastically reduced to get some dead zones on the road to recovery. "It's what you might call a tipping point in reverse," says Donald Boesch of the University of Maryland Center for Environmental Science in Cambridge.

Teetering on the edge

How much of a problem this tipping point in reverse will be in other areas of the world remains to be seen. In most areas of the US, for instance, pollution has yet to be reduced to low enough levels to make much difference. In 1987 a Chesapeake Bay task force set a target of reducing the nutrient flow from some – but not all – surrounding states by 40 per cent by 2000. One of its members, Michael Burke, says that while that target has now almost been reached, if a few years late, it has long been clear that far greater reductions are needed. In 2003, the task force set a new target of reducing the nutrients entering the bay from all contributing states to 80 million kilograms per year by 2010.

Many question whether anything like this target will be reached. "They're not publicly admitting they won't make the deadline," says Boesch, "but it's clear to everyone that the goals won't be met."

Then there's the question of how much nutrient reduction will be required to get the Gulf of Mexico's dead zone, which averages about 17,000 km^2 for parts of each year, past the tipping point and on the way to recovery. A task force made up of nine federal agencies, nine states and two Native American tribes, established an action plan in 2001 that aimed to reduce the size of the dead zone to 5000 km^2.

The task force is now supposed to be reviewing the progress to date, but some fear the entire plan is instead being questioned. "It's disappointing," says Boesch, who helped create the 2001 plan. "I don't know whether people in the White House now are saying, let's debunk hypoxia, but I think the message comes across that they're not interested in any type of more aggressive enforcement."

Even if the task force does come up with new measures to reduce pollution, these will likely be low on the list of funding priorities for the Bush administration. This is especially disheartening to some given that recent analyses of US marine policy by both the federal government and the non-profit Pew Foundation highlighted the need for special attention for the Gulf of Mexico dead zone and other pollution-related problems.

There's also another potential complication on the horizon: global warming. One proposed target for the Gulf of Mexico is to reduce the nitrogen influx from the Mississippi by 30 per cent. A study by Dubravko Justic at Louisiana State University in Baton Rouge, however, concluded that increased Mississippi flow along with rising sea temperatures, as predicted by one climate model, would negate any benefit by increasing stratification and nutrient delivery. On the other hand, if there's no temperature rise and, as predicted by another climate model, a decrease in river flow, dead zones would occur far less frequently. "The question now is, which way it will go?" Justic says. His findings also apply to many other dead zones around the world.

Back in Chesapeake Bay, the watermen face an uncertain future. Crockett sees little that's encouraging. "There are so many things working against the bay that I don't think it's going to get any better," he says. Simns fears that the dead zone could spread further in the bay. "We're right here teetering on this cliff," he says. "We just have to convince the public to pay now instead of later."

Despite his fears, Simns is encouraged by measures such as a "flush tax" in Maryland for funding better water treatment. "I've got to be optimistic," he says. "I can't believe man is so stupid as to let this bay die." ●

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