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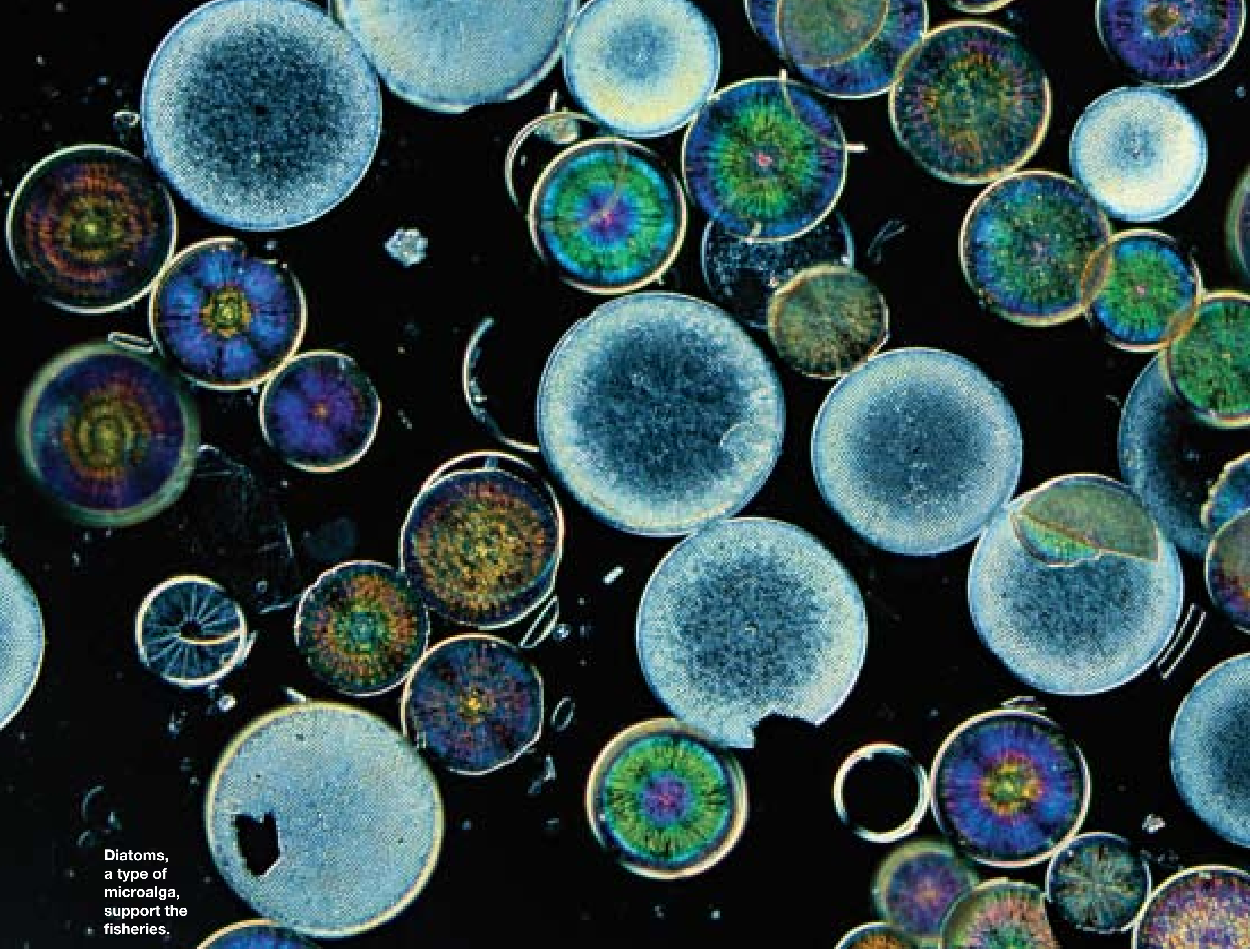
INVESTIGATIVE REPORT

OCEAN REFLUX

By soaking up carbon dioxide from industrial emissions, the oceans are becoming more acidic, threatening the foundation of life in the sea.

BY **KATHLEEN McAULIFFE** ARTWORK BY **ROBERT LONGO**



Diatoms, a type of microalga, support the fisheries.

It all seemed so convenient: As our smokestacks and automobile tailpipes spewed ever more carbon dioxide into the air, the oceans absorbed the excess. Like a vast global vacuum cleaner, the world's seas sucked CO_2 right out of the atmosphere, mitigating the dire consequences of global warming and forestalling the melting of glaciers, the submergence of coastlines, and extremes of weather from floods to droughts. So confident were we in the seas' seemingly limitless capacity to absorb our gaseous waste that, by the turn of the millennium, the United States, Germany, and Japan were actually proposing to compress CO_2 from power plants into a gooey liquid and pipe it directly into the abyss.

The first tests of the plan were an eye-opener. When the compressed material was introduced into laboratory tanks, the spines of sea urchins and the shells of mollusks dissolved. Surprised, researchers launched studies to see how marine animals in laboratory tanks and in the wild would fare with CO_2 concentrations much lower than those in the original tests. They were stunned. "We found that mere absorption of CO_2 from the atmosphere into the ocean was enough to harm marine creatures," says Ken Caldeira, a chemical oceanographer now at the Carnegie Institution of Washington in Stanford, California.

The problem was that, having swallowed hundreds of billions of tons of greenhouse gases since the start of the Industrial Revolution, the oceans were becoming more acidic. And not just in a few spots. Now the chemistry of the entire ocean was shifting, imperiling coral reefs, marine creatures at the bottom of the food chain, and ultimately the planet's fisheries.

In 2003 Caldeira reported these findings in the journal *Nature,* coining the term "ocean acidification." One might think the news would spread around the world with the speed and force of a tsunami. But scientific discoveries take time to be digested and disseminated. Only recently have the far-flung implications of this development begun to register beyond the rarefied sphere of marine biologists.

"It's the most profound environmental change I've seen in my entire career, and nobody saw it coming," says Thomas E. Lovejoy, a biologist and president of the H. J. Heinz III Center for Science, Economics and the Environment in Washington, D.C.

Lovejoy is not the only one alarmed by the development. "It's just been an absolute time bomb that's gone off both in the scientific community and, ultimately, in our public policymaking," Rep. Jay Inslee (D-Wash.) told *The Washington Post* when first briefed on the matter in the spring of 2006. Congress is now scrambling to get up to speed by holding hearings on the issue and discussing federal legislation that could allocate roughly $100 million to study the

PREVIOUS PAGES: UNTITLED (GÖTTERDÄMMERUNG), 2005/COURTESY THE ARTIST AND METRO PICTURES. THESE PAGES: DR. DARLYNE A. MURAWSKI/GETTY IMAGES

After the FALL

Species evolve alongside each other in intricate relationships, so when one group is disrupted, another may flourish. Should ocean acidification proceed unfettered, we will be left with winners, losers, and a pile of rubble and slime.

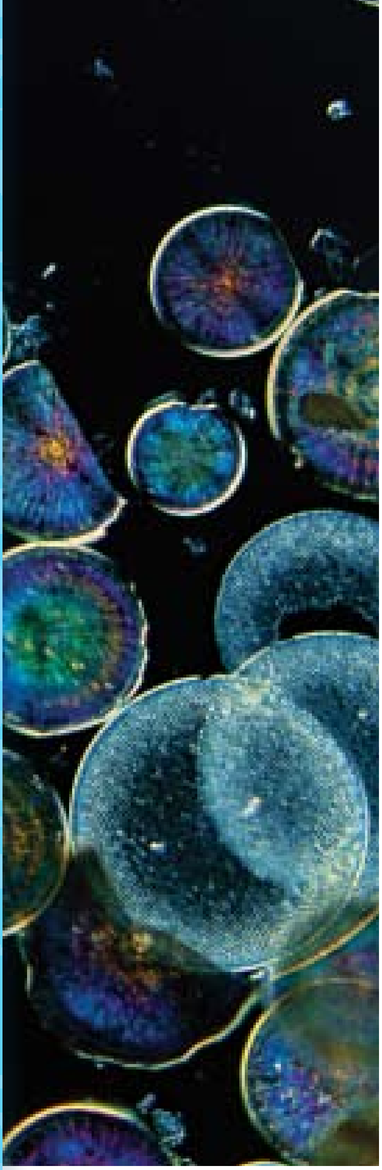
THE LOSERS

- **Coral:** the species. Unable to cope with the decrease in available calcium carbonate, these creatures will start to die.
- **Coral reefs:** the ecosystems. The demise of coral spells trouble for a million other species that feed near, live in, or derive protection from the reef environment: microalgae, also known as diatoms, sea urchins and other echinoderms, grazing fish, and foraminifera.
- **Shelled sea creatures.** Anything with a calcium carbonate shell, from microscopic plankton to clams and oysters to pteropods.

THE WINNERS

- **Cyanobacteria.** These nitrogen-fixing, photosynthetic bacteria, also known as blue-green algae, are found in numerous habitats—in soil and lakes as well as the oceans. Unlike calcifying ocean species, they will very likely benefit from an increase in marine CO_2, which provides them with more raw material for manufacturing chemical energy.
- **Dinoflagellates.** Like cyanobacteria, these generally single-celled organisms draw energy through photosynthesis, with many living as symbionts inside coral. Temperature-stressed corals will discharge their dinoflagellate partners, resulting in coral "bleaching," but the organisms can also live independently and may do so more easily in an ocean where CO_2 is becoming more readily available.
- **Seaweed.** Otherwise known as macroalgae, seaweed competes with coral for light and space. Since most seaweed grows much more rapidly than coral, once the balance is tipped, any chance of coral recovery is all but completely choked off.

Carl Brenner



impact of industrial emissions on marine ecosystems.

Even the fishing industry has been caught off guard. Fisheries are "the ultimate canary in the coal mine of ocean acidification," says Brad Warren, the former editor and publisher of *Pacific Fishing* magazine, who recently launched the nonprofit Sustainable Fisheries Partnership to encourage seafood enterprises to confront the problem through policy initiatives.

While the existence of global warming was fiercely debated for decades, ocean acidification has been rapidly accepted by the scientific community as a real and imminent hazard. "It is very complicated to pin the heating of the planet on a single gas, but ocean acidification involves straightforward chemistry," says Robert B. Dunbar, professor of geological and environmental sciences at Stanford University. Since it is easy to chart the step-by-step progression of the problem, there is widespread consensus that we are marching toward disaster at a pace that is impossible to ignore.

An analysis of CO_2 preserved in ice cores shows that for more than 600,000 years the ocean had a pH of approximately 8.2 (pH is the acidity of a solution measured on a 14-point scale, with a pH below 7 being acidic and above 7, basic). But since 1800, the beginning of the Industrial Revolution, the pH of the ocean has dropped by 0.1 unit. That may not sound like much, but pH is a logarithmic scale, so the decline in fact represents a whopping 30 percent increase in acidity. With the oceans now absorbing man-made CO_2 at a rate of 22 million tons a day and climbing, the situation is certain to worsen rapidly. More than a dozen projections by the International Panel on Climate Change indicate that ocean pH by the end of the century could drop as low as 7.8, which would correspond to a 150 percent increase in acidity since preindustrial times. "A drop of that magnitude is more than we've seen in 20 million years," says Richard A. Feely, supervisory oceanographer at the National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Laboratory in Seattle. "That's going to profoundly change the ecology of the sea as we now know it, in ways that could potentially be devastating."

OSTEOPOROSIS UNDER THE SEA

Most vulnerable to the assault of higher acidity, scientists say, is any creature that makes a calcium carbonate shell. A look at the chemistry of ocean acidification explains why. When CO_2 from the atmosphere combines with water, it produces carbonic acid (the ingredient that gives soft drinks their fizz) and decreases carbonate ions, a key building block of marine animals' shells. As the oceans become more acidic, this material will become increasingly scarce, hindering the ability of shelled organisms to make and maintain their homes. Like human bones whittled by osteoporosis, their exoskeletons will grow thin and brittle or—mirroring what happened to the test animals at CO_2 injection sites—dissolve.

The range of creatures in imminent danger from this hazard includes mollusks and crustaceans such as clams, oysters, lobsters, and crabs; large sea creatures for which shellfish is a dietary staple, notably seals, otters, and walruses; and most worrisome of all, plankton and other microscopic organisms that sustain mighty whales and fish big and small.

To make matters worse, German and Japanese researchers recently increased CO_2 levels in seawater and found that the greenhouse gas can damage some marine organisms directly: Squid slowly asphyxiated as the excess CO_2 crowded out oxygen in their blood, and fish embryos and larvae were abnormally small and less likely to survive.

DISSOLVING THE CORAL REEFS

Also endangered by rising acidity are coral reefs, home to an astonishingly diverse range of aquatic life. Though reef resembles rock, it is actually made up of a teeming city of anemone-like creatures known as polyps. These tiny organisms wave their tentacles in the currents to snatch tidbits of food, all the while secreting shells to anchor their trunks. After the animals die, layer upon layer of their skeletons create the exotic structures we call coral reefs, but according to scientists, they will begin to crumble as corrosive waters undo the work of countless generations of polyps.

"Today's reefs are as much as 5,000 years old, and they will start to fall apart within a decade or so if we don't radically change how we do business," contends Christopher Langdon, a biological oceanographer at the University of Miami's Rosenstiel School of Marine and Atmospheric Science.

The first hint that this might happen emerged more than a decade ago, when Langdon, working in Biosphere 2, grew corals in a swimming pool–size tank. The corals thrived when calcium carbonate was added to the water but did poorly without it. Ocean acidification wasn't a recognized threat at the time, so Langdon's findings just sat there. But today, pulled up from the void, they are sounding alarms. Working from his Biosphere data, Langdon calculates that the rise in CO_2 pollution since 1850 is stunting the growth of today's tropical corals by 10 to 15 percent.

Meanwhile, warming seas, human poaching, agricultural runoff, and other forms of pollution have also been taking a toll on coral, as documented by just-published measurements of Australia's Great Barrier Reef between 1988 and 2003. In that time frame—a mere 15 years—the world's oldest and largest reef showed an alarming 21 percent decline in growth. This steep downward trend is far greater than even Langdon expected and makes him wonder whether ocean acidification may be acting synergistically with the other destructive forces to greatly compound the damage.

With so many environmental stresses clouding the future of our fragile reefs, the emergence of yet another threat has marine biologists badly shaken. "When I first realized that ocean acidification was happening and the scale of the problem, I was sick about it," admits Joan Kleypas, a coral expert at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. The insidious, creeping nature of the threat has her particularly concerned. "Bleaching, caused when rising temperatures lead corals to expel the algae that give them their color, often kills corals outright," she says. "It's shocking. But ocean acidification is an invisible, chronic stress that's hard for people to believe. It's like hypertension in a person, slowly getting worse and worse without any visible symptoms."

Lest there be any doubt about the fate that awaits coral in a corrosive world, a recent paper published in the journal *Science* provides a stark warning. The authors of the report, marine biologists Maoz Fine and Dan Tchernov, raised coral specimens in tanks of water with a pH of 7.3, roughly as acidic as the oceans are expected to become sometime in the next century. In response, the hard coral did a vanishing act, and the polyps that once resided in it reverted to a naked existence. "If seeing is believing," Kleypas observes, "that picture says it all."

Should the reefs vanish, the vast populations of aquatic life they support will not be the only casualties. Islands that are atolls, with foundations of coral sediment, could crumble into more acidic seas, experts say. Reefs also form a barrier between land and ocean, preventing beach erosion and creating sheltered sanctuaries for mangroves, birds, and other wildlife. And coral may have still other important functions, as yet unrecognized.

Just two decades ago, scientists discovered that colorful tropical reefs have ghostly counterparts in deep, cold waters throughout the world's oceans. White as bone, they live as much as three miles down where no light penetrates, feeding off dead marine matter that sinks from above. These corals grow in dense thickets, some of them 30 feet tall, off the coasts of Scotland, Norway, Alaska's Aleutian Islands, and many other places. Indeed, cold-water reefs turn out to be 10 times as abundant as their much better-known tropical cousins. Yet for all their prevalence, these cold-water varieties have barely been explored because of their inaccessibility. Should corrosive waters soon claim them, we may realize their value only in hindsight.

PERIL AT THE POLES

Coral may be the poster child in the effort to rouse public concern about ocean acidification, yet many scientists worry even more about how the sea's smallest and least familiar denizens will adapt to the change. Biological oceanographer Victoria Fabry of California State University at San Marcos has spent years studying pteropods, thumbnail-size creatures that flutter through frigid polar and subpolar waters using flaplike wings. When startled they retract into shells that are normally smooth and translucent. But Fabry found that in water as corrosive as their aquatic habitat may be in 2100, the shell of at least one pteropod species turns opaque and begins to dissolve. To Fabry this suggests that pteropods may become vulnerable to predation in a more acidic world and dwindle in number or, in some regions, even die out. Indeed, she says, they may already be suffering adverse consequences, a possibility she is currently investigating.

"Pteropods in Peril" is not the stuff of headlines, nor have Fabry's findings grabbed our attention like the plight of the polar bears. Yet the loss of pteropods would impact our lives much more directly. Puny though they are, pteropods are a major food source of some of the biggest cash cows in the sea—salmon, herring, cod, and pollack. A significant decline in their population, Fabry says, could have grave economic consequences.

What do pteropods eat? Put a drop of seawater on a slide under a microscope and you will see: amoebas, tiny crustaceans, and plankton, many of which also sport shells. A major thrust of current research is to understand how creatures like these at the bottom of the food chain respond to ocean acidification. Toward that goal, scientists have scooped samples of seawater from a variety of latitudes and studied the rich broth of microorganisms they contain in simulator tanks built into the decks of ships. "The idea is to keep the specimens as fresh as possible in their natural habitat," explains David Hutchins, a biological oceanographer at the University of Southern California in Los Angeles. Then the simulation trials begin: The temperature, pH, and CO_2 levels of the tank are adjusted to mimic conditions expected a century from now.

What can Hutchins discern about the future from these simulations? There will be winners and losers, but the overall picture is, he says, "frightening."

As the temperature and acidity of a test tank climb, diatoms that dominate the cold northern oceans fall off steeply in number—an ominous sign, given that they currently support by far the richest fisheries in the world. The Bering Sea alone generates about 30 percent of the global harvest of seafood. In the frigid southern

A pteropod with wings extended. **Below:** Aerial view of the Great Barrier Reef.

TOP: RUSS HOPCROFT/UAF/COML. BOTTOM: DAVIDWALLPHOTO.COM

oceans, plankton species are different, but some have shells, and the trend is the same: Their populations rapidly decline. At both poles, organisms in decline are being replaced by plankton called flagellates. According to Hutchins, flagellates are not nearly as good at passing their stored energy up the food chain to fish and other higher life forms. "That's going to disrupt food chains that sustain the kinds of creatures we're used to seeing at the poles—sea lions, penguins, and whales—and instead promote a microbe-dominated community," he says.

THE GREAT BELCH OF DESTRUCTION

The anticipated impact on wildlife resembles a game of dominoes: After acidification has destabilized one species or ecosystem, the damage could ripple up and down the food chain. Especially worrisome is the fact that the shelled plankton under threat are efficient at storing CO_2. When the creatures that eat the plankton die, their shells and organic remains fall to the ocean floor, sequestering carbon in the deep water and sediments. "Cold-water planktons are powerful allies in preventing atmospheric CO_2 from climbing higher than it already is," Hutchins says.

Therefore, their rapid decline could quickly turn the planet hotter. "Currently the ocean is a sink for CO_2—that is, it takes in more CO_2

The Cost on the STREET

The oceans will pay a devastating price for acidification, but we will be pummeled on land as well. Sectors at risk include:

Tourism. In Australia, almost 2 million visitors a year flock to the Great Barrier Reef, spending $4.8 billion, a significant percentage of the country's tourism income. Worldwide, so-called reef tourism is increasing at a rate of 20 percent a year, providing up to 25 percent of total gross domestic product for numerous island nations, particularly in the Caribbean.

Coastal communities. Studies have shown that reefs shield people, infrastructure, and lagoon ecosystems from wave and storm surges. With the disappearance of the reefs, hurricanes and other tropical storms will result in even greater loss of life and resources than is the case today.

Pharmaceuticals. Acidification's assault on marine biodiversity means fewer chances to derive drugs like AZT, which came from the sea. Today dozens of ocean-derived drugs are in the research and development pipeline, including at least 30 for the treatment of cancer. If acidification proceeds, "we may never get a chance to develop the next wonder drug," Canadian coastal economist Jack Ruitenbeek says.

Fisheries. Globally, 38 million people are directly employed by fisheries or fish-related industries, and more than a billion people—mostly in the developing world—rely on fish as their main source of protein. Within the next two decades, marine biologist Robert Cowen says, the continued loss of fish from poor management and overexploitation "could translate into the starvation of 100 million or 200 million people—and that's without ocean acidification." The added insult of more corrosive waters on already-depleted fish stocks, he says, could have reverberations for poor coastal inhabitants that are frankly alarming. **C. B.**

from the atmosphere than it releases," Hutchins explains. "But a warming and acidifying ocean could become a net source of CO_2." In other words, the world's seas could begin belching the gas into the atmosphere, just as our cars and factories do. In his opinion, that could unfold within a few centuries. "It's hard not to be negative about this," Hutchins says. "Frankly, ocean acidification is apocalyptic in its impact."

Robert Cowen, chairman of the division of marine biology and fisheries at the Rosenstiel School of Marine and Atmospheric Science, agrees, but for a different reason. His chief concern is fish populations, which were in steep decline even before ocean acidification was recognized. In just the past 40 years, overfishing, destructive trawling, and poor management of the seas have depleted 75 percent of our commercially important fish stocks, with almost one-third of them—including tuna, marlin, and shark—under particular threat. "We're hammering fish from the top down and now from the bottom up as more acidic oceans erode the base of the food chain," Cowen says.

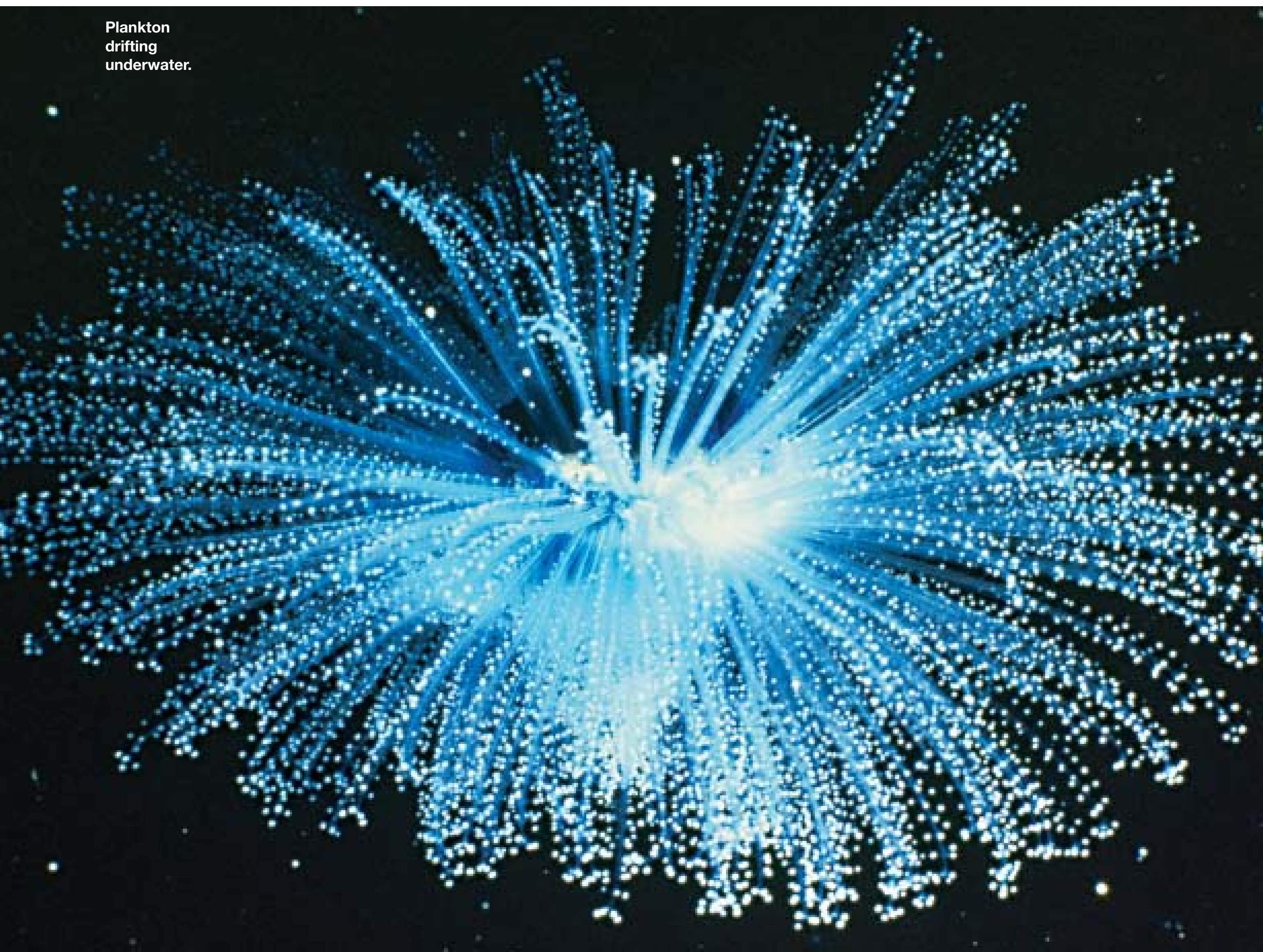
It was at a conference two years ago, Cowen adds, that the scale of the disaster unfolding at sea really hit him. Deeply disturbed, he and his wife, Su Sponaugle, also a marine biologist at Rosenstiel, soon realized they would have to tone down how they talked about the research in front of their adolescent twins. "They overheard one of our conversations and started asking questions like 'What's going to happen?'" Sponaugle recalls. "We could see their distress and hear the agitation in their voices, and then they wanted to know, 'Is it too late?' and we're like, 'Hmm…well…'"

What Sponaugle and Cowen didn't want to say—or couldn't find the way to say—was yes, it might be too late. You can't turn an ocean liner on a dime, and in their view, it will take a complete about-face in society's profligate use of fossil fuels to avert a catastrophe. Nor are they alone in that opinion. "If we were to begin to reduce man-made emissions this year," NOAA's Feely says, "it would take decades before we'd see CO_2 levels and acidity start to go down instead of up and hundreds or thousands of years to return to pre-industrial levels."

Very simply, the process by which the ocean normally maintains its chemical equilibrium is glacially slow, severely limiting its capacity to adjust to an extreme shock. And make no mistake: The massive influx of industrial emissions is just that.

Over the history of the planet, there have been many sudden peaks in CO_2 related to volcanic eruptions, releases from hydrothermal vents, and other natural events. When the pH of the ocean dips as a result of absorbing this excess gas, bottom sediments rich in calcium carbonate begin to dissolve, countering the increase in acidity. This buffering process occurs over 20,000 years, roughly the

LARRY MADIN/GETTY IMAGES



Plankton drifting underwater.

Three Bold Plans to Save the SEAS

The bleak prognosis for marine species—and ultimately humans—in an environment of unchecked ocean acidification has prompted scientists to suggest a number of mitigation strategies.

1. One proposal, first suggested in the late 1980s by oceanographer John Martin of the Moss Landing Marine Laboratories in California, involves seeding ocean surfaces with iron to promote phytoplankton blooms that will soak up carbon dioxide, eventually exporting it into the deep ocean. The plan has the added theoretical benefit of reducing atmospheric carbon. The first part of the process, the phytoplankton bloom, has already been demonstrated in small-scale tests in the South Pacific and the equatorial Pacific Ocean. But no one has ever shown that a carbon drawdown will persist over time, making many scientists fear that the effort could send the ocean's biochemical systems careering in unforeseen directions.

2. A second tactic under consideration at places like the Carnegie Institution of Washington and the University of California at Santa Cruz is to neutralize the seas—possibly with limestone from, say, the White Cliffs of Dover. But there are problems here as well: The scale of the mining and transportation effort to harvest these minerals would be enormous and extremely expensive. Moreover, it would itself involve the expenditure of large amounts of energy and thus the emission of additional carbon dioxide into the atmosphere.

3. Last year a team of scientists led by Kurt Zenz House, a doctoral candidate at Harvard University, proposed something they call engineered weathering, inspired by a natural process in which slightly acidic freshwater is neutralized by exposure to alkalizing minerals. Under House's proposal, hydrochloric acid would be harvested from the ocean by a specialized electrochemical treatment and then exposed to silicates, resulting in a net alkalizing shift.

When it comes to saving the seas, of course, the kind of technological fixes suggested here would be measures of last resort. Bärbel Hönisch, a marine biologist and geochemist at Columbia University's Lamont-Doherty Earth Observatory, points out that "none of these strategies has been tested over the long term, and the potential effects on the ecosystem are uncertain." In the end, she adds, the best solution might be the most obvious one: Dramatically reduce our carbon emissions. **C. B.**

TOP: DEXCHAMPS/ANDIA.FR/DRR.NET. BOTTOM: INTERNETWORK MEDIA/GETTY IMAGES

Can the White Cliffs of Dover (above) save the seas? If not, the plankton bloom seen in the Atlantic, below, might become a thing of the past.

time it takes for water to circulate along the bottom from the Atlantic to the Pacific and back up to the surface several times. Currently, however, we are pouring man-made CO_2 into the atmosphere at 50 times the natural rate. "That overwhelms the natural buffering system for maintaining balance in ocean chemistry," the Carnegie Institution's Caldeira says. "To find any parallel in the earth's history you would have to look to a sudden violent shock to the system far in the geologic past."

One such event occurred 55 million years ago at the so-called Paleocene-Eocene Thermal Maximum (PETM), when 4.5 million tons of greenhouse gases were released into the atmosphere. Just what triggered this enormous emission is not known, but scientists suspect volcanic activity may have begun the process. That may in turn have caused the planet to heat up enough to melt deposits of methane frozen in sediments on the ocean floor (something, incidentally, that could happen again), discharging even more potent greenhouse gases into the atmosphere and further heating the planet in an escalating feedback loop.

Whatever the exact cause of the CO_2 release at the PETM, the

Rescuing the REEFS!

With reefs so endangered, you might think there is little you can personally do to help. But according to reef specialist Meaghan Johnson of the Nature Conservancy, individuals can make a difference here. "Anything we can do to reduce stress on coral reefs is a step in the right direction, and there is definitely a role for the public," she says. To that end, the conservancy and other groups suggest that you:

- Reduce your personal carbon footprint. The less fossil fuel you use, the less carbon you release into the atmosphere and the less you contribute to the twin threats of global warming and ocean acidification. Take public transportation instead of a car, and, if possible, opt for green power like solar or wind at home.
- Eat low on the food chain (we use less energy producing a salad than a steak).
- Conserve water, creating less runoff and wastewater to pollute the ocean.
- Use organic fertilizers in your garden. The chemicals from commercial fertilizers will eventually find their way into the ocean, further harming the reefs.
- Plant trees. They absorb carbon dioxide and reduce runoff.
- Visit a reef, but don't consume it. If you vacation at a reef resort, patronize businesses that manage the reefs responsibly (ask about the groups' eco policies), and don't buy souvenirs plundered from the reef ecosystem. Also, practice responsible diving and snorkeling: Don't touch the reef or anchor your boat on the reef, acts that can damage or even kill these ecosystems.

While you are doing your part, scientists like Johnson, a participant in the Florida Reef Resilience Program, hope the reefs can be restored through careful monitoring and protection of reef nurseries. Another effort, called Biorock, comes from the late architect Wolf Hilbertz and coral scientist Tom Goreau. To restore the reefs, latticed steel structures are lowered into flagging reef habitats like the one at right and exposed to electric current. The current promotes the crystallization of dissolved minerals, forming limestone deposits that cling to the structure. Natural reef fragments are transplanted onto the lattice, and coral larvae flock to the limestone. They are quickly followed by the rest of the usual reef denizens—urchins, crabs, fish, and lobsters. The technique has so far been successfully deployed in Panama, Thailand, Indonesia, French Polynesia, and the Philippines. **C. B.**

Above: An artificial reef off the Bali coast. **Below:** Bleached coral in the South China Sea.

TOP: WOLF HILBERTZ/GLOBALCORAL.ORG. BOTTOM: NEWSCOM

earth warmed faster than at almost any other time in its history. The average temperature soared 9 degrees Fahrenheit, entire ecosystems shifted to higher latitudes, and massive extinctions occurred on land and, most telling, at sea. The abrupt rise of CO_2 acidified the oceans. James Zachos, a paleo-oceanographer from the University of California at Santa Cruz, analyzed sediment cores obtained from deep drilling in the ocean and discovered that bottom-dwelling creatures with shells disappeared from the fossil record for a period of more than 40,000 years corresponding to the PETM. And once the oceans turned more acidic, Zachos says, they did not recover

quickly: It took another 60,000 years before sediments again began to show a thick white streak indicative of fossilized shells.

Drastic as the PETM was, the event is tame compared with acidification today. “Back then,” Zachos says, “4.5 million tons of CO_2 were released over a period of 1,000 to 10,000 years. Industrial activities will release the same amount in a mere 300 years—so quickly that the ocean’s buffering system doesn’t even come into play.”

This is not to imply that current CO_2 emissions are likely to kill off all life in the sea. Microbes, with their rapid generation times, should evolve and ultimately persist in altered seas. But slower-to-reproduce creatures such as fish and other higher organisms will struggle to survive. “The marine ecosystem will adapt,” USC’s Hutchins believes. Life may be different, but it will go on.

Kleypas of NCAR stands out among marine biologists in her optimism that we will be able to stop the output of man-made CO_2 in time to prevent irreparable harm to the marine ecosystem. To do that, she acknowledges, will take incredible sacrifice and an overhaul of infrastructure on an unprecedented scale. “I know people think I’m crazy,” she says, “but we’re the only species that can change our behavior overnight.” ■