

PART ONE  
ALTERED OCEANS

## **A Primeval Tide of Toxins**

**Runoff from modern life is feeding an explosion of primitive organisms. This 'rise of slime,' as one scientist calls it, is killing larger species and sickening people.**

By Kenneth R. Weiss, Times Staff Writer  
July 30, 2006

The fireweed began each spring as tufts of hairy growth and spread across the seafloor fast enough to cover a football field in an hour.

When fishermen touched it, their skin broke out in searing welts. Their lips blistered and peeled. Their eyes burned and swelled shut. Water that splashed from their nets spread the inflammation to their legs and torsos.

"It comes up like little boils," said Randolph Van Dyk, a fisherman whose powerful legs are pocked with scars. "At nighttime, you can feel them burning. I tried everything to get rid of them. Nothing worked."

As the weed blanketed miles of the bay over the last decade, it stained fishing nets a dark purple and left them coated with a powdery residue. When fishermen tried to shake it off the webbing, their throats constricted and they gasped for air.

After one man bit a fishing line in two, his mouth and tongue swelled so badly that he couldn't eat solid food for a week. Others made an even more painful mistake, neglecting to wash the residue from their hands before relieving themselves over the sides of their boats.

For a time, embarrassment kept them from talking publicly about their condition. When they finally did speak up, authorities dismissed their complaints — until a bucket of the hairy weed made it to the University of Queensland's marine botany lab.

Samples placed in a drying oven gave off fumes so strong that professors and students ran out of the building and into the street, choking and coughing.

Scientist Judith O'Neil put a tiny sample under a microscope and peered at the long black filaments. Consulting a botanical reference, she identified the weed as a strain of cyanobacteria, an ancestor of modern-day bacteria and algae that flourished 2.7 billion years ago.

O'Neil, a biological oceanographer, was familiar with these ancient life forms, but had never seen this particular kind before. What was it doing in Moreton Bay? Why was it so toxic? Why was it growing so fast?

The venomous weed, known to scientists as *Lyngbya majuscula*, has appeared in at least a dozen other places around the globe. It is one of many symptoms of a virulent pox on the world's oceans.

In many places — the atolls of the Pacific, the shrimp beds of the Eastern Seaboard, the fiords of Norway — some of the most advanced forms of ocean life are struggling to survive while the most primitive are thriving and spreading. Fish, corals and marine mammals are dying while algae, bacteria and jellyfish are growing unchecked. Where this pattern is most pronounced, scientists evoke a scenario of evolution running in reverse, returning to the primeval seas of hundreds of millions of years ago.

Jeremy B.C. Jackson, a marine ecologist and paleontologist at the Scripps Institution of Oceanography in La Jolla, says we are witnessing "the rise of slime."

For many years, it was assumed that the oceans were too vast for humanity to damage in any lasting way. "Man marks the Earth with ruin," wrote the 19th century poet Lord Byron. "His control stops with the shore."

Even in modern times, when oil spills, chemical discharges and other industrial accidents heightened awareness of man's capacity to injure sea life, the damage was often regarded as temporary.

But over time, the accumulation of environmental pressures has altered the basic chemistry of the seas.

The causes are varied, but collectively they have made the ocean more hospitable to primitive organisms by putting too much food into the water.

Industrial society is overdosing the oceans with basic nutrients — the nitrogen, carbon, iron and phosphorous compounds that curl out of smokestacks and tailpipes, wash into the sea from fertilized lawns and cropland, seep out of septic tanks and gush from sewer pipes.

Modern industry and agriculture produce more fixed nitrogen — fertilizer, essentially — than all natural processes on land. Millions of tons of carbon dioxide and nitrogen oxide, produced by burning fossil fuels, enter the ocean every day.

These pollutants feed excessive growth of harmful algae and bacteria.

At the same time, overfishing and destruction of wetlands have diminished the competing sea life and natural buffers that once held the microbes and weeds in check.

The consequences are evident worldwide.

Off the coast of Sweden each summer, blooms of cyanobacteria turn the Baltic Sea into a stinking, yellow-brown slush that locals call "rhubarb soup." Dead fish bob in the surf. If people get too close, their eyes burn and they have trouble breathing.

On the southern coast of Maui in the Hawaiian Islands, high tide leaves piles of green-brown algae that smell so foul condominium owners have hired a tractor driver to scrape them off the beach every morning.

On Florida's Gulf Coast, residents complain that harmful algae blooms have become bigger, more frequent and longer-lasting. Toxins from these red tides have killed hundreds of sea mammals and caused emergency rooms to fill up with coastal residents suffering respiratory distress.

North of Venice, Italy, a sticky mixture of algae and bacteria collects on the Adriatic Sea in spring and summer. This white mucus washes ashore, fouling beaches, or congeals into submerged blobs, some bigger than a person.

Along the Spanish coast, jellyfish swarm so thick that nets are strung to protect swimmers from their sting.

Organisms such as the fireweed that torments the fishermen of Moreton Bay have been around for eons. They emerged from the primordial ooze and came to dominate ancient oceans that were mostly lifeless. Over time, higher forms of life gained supremacy. Now they are under siege.

Like other scientists, Jeremy Jackson, 63, was slow to perceive this latest shift in the biological order. He has spent a good part of his professional life underwater. Though he had seen firsthand that ocean habitats were deteriorating, he believed in the resilience of the seas, in their

inexhaustible capacity to heal themselves.

Then came the hurricane season of 1980. A Category 5 storm ripped through waters off the north coast of Jamaica, where Jackson had been studying corals since the late 1960s. A majestic stand of staghorn corals, known as "the Haystacks," was turned into rubble.

Scientists gathered from around the world to examine the damage. They wrote a paper predicting that the corals would rebound quickly, as they had for thousands of years.

"We were the best ecologists, working on what was the best-studied coral reef in the world, and we got it 100% wrong," Jackson recalled.

The vividly colored reef, which had nurtured a wealth of fish species, never recovered.

"Why did I get it wrong?" Jackson asked. He now sees that the quiet creep of environmental decay, occurring largely unnoticed over many years, had drastically altered the ocean.

As tourist resorts sprouted along the Jamaican coast, sewage, fertilizer and other nutrients washed into the sea. Overfishing removed most of the grazing fish that kept algae under control. Warmer waters encouraged bacterial growth and further stressed the corals.

For a time, these changes were masked by algae-eating sea urchins. But when disease greatly reduced their numbers, the reef was left defenseless. The corals were soon smothered by a carpet of algae and bacteria. Today, the reef is largely a boneyard of coral skeletons.

Many of the same forces have wiped out 80% of the corals in the Caribbean, despoiled two-thirds of the estuaries in the United States and destroyed 75% of California's kelp forests, once prime habitat for fish.

Jackson uses a homespun analogy to illustrate what is happening. The world's 6 billion inhabitants, he says, have failed to follow a homeowner's rule of thumb: Be careful what you dump in the swimming pool, and make sure the filter is working.

"We're pushing the oceans back to the dawn of evolution," Jackson said, "a half-billion years ago when the oceans were ruled by jellyfish and bacteria."

The 55-foot commercial trawler working the Georgia coast sagged under the burden of a hefty catch. The cables pinged and groaned as if about to snap.

Working the power winch, ropes and pulleys, Grovea Simpson hoisted the net and its dripping catch over the rear deck. With a tug on the trip-rope, the bulging sack unleashed its massive load.

*Plop. Splat. Whoosh.* About 2,000 pounds of cannonball jellyfish slopped onto the deck. The jiggling, cantaloupe-size blobs ricocheted around the stern and slid down an opening into the boat's ice-filled hold.

The deck was streaked with purple-brown contrails of slimy residue; a stinging, ammonia-like odor filled the air.

"That's the smell of money," Simpson said, all smiles at the haul. "Jellyballs are thick today. Seven cents a pound. Yes, sir, we're making money."

Simpson would never eat a jellyfish. But shrimp have grown scarce in these waters after decades of intensive trawling. So during the winter months when jellyfish swarm, he makes his living catching what he used to consider a messy nuisance clogging his nets.

It's simple math. He can spend a week at sea scraping the ocean bottom for shrimp and be lucky to pocket \$600 after paying for fuel, food, wages for crew and the boat owner's cut.

Or, in a few hours of trawling for jellyfish, he can fill up the hold, be back in port the same day and clear twice as much. The jellyfish are processed at the dock in Darien, Ga., and exported to China and Japan, where spicy jellyfish salad and soup are delicacies.

"Easy money," Simpson said. "They get so thick you can walk on them."

Jellyfish populations are growing because they can. The fish that used to compete with them for food have become scarce because of overfishing. The sea turtles that once preyed on them are nearly gone. And the plankton they love to eat are growing explosively.

As their traditional catch declines, fishermen around the world now haul in 450,000 tons of jellyfish per year, more than twice as much as a decade ago.

This is a logical step in a process that Daniel Pauly, a fisheries scientist at the University of British Columbia, calls "fishing down the food web." Fishermen first went after the largest and most popular fish, such as tuna, swordfish, cod and grouper. When those stocks were depleted, they pursued other prey, often smaller and lower on the food chain.

"We are eating bait and moving on to jellyfish and plankton," Pauly said.

In California waters, for instance, three of the top five commercial catches are not even fish. They are squid, crabs and sea urchins.

This is what remains of California's historic fishing industry, once known for the sardine fishery attached to Monterey's Cannery Row and the world's largest tuna fleet, based in San Diego, which brought American kitchens StarKist, Bumble Bee and Chicken of the Sea.

Overfishing began centuries ago but accelerated dramatically after World War II, when new technologies armed industrial fleets with sonar, satellite data and global positioning systems, allowing them to track schools of fish and find their most remote habitats.

The result is that the population of big fish has declined by 90% over the last 50 years.

It's reached the point that the world's fishermen, though more numerous, working harder and sailing farther than ever, are catching fewer fish. The global catch has been declining since the late 1980s, an analysis by Pauly and colleague Reg Watson showed.

The reduction isn't readily apparent in the fish markets of wealthy countries, where people are willing to pay high prices for exotic fare from distant oceans — slimeheads caught off New Zealand and marketed as orange roughy, or Patagonian toothfish, renamed Chilean sea bass. Now, both of those fish are becoming scarce.

Fish farming also exacts a toll. To feed the farmed stocks, menhaden, sardines and anchovies are harvested in great quantities, ground up and processed into pellets.

Dense schools of these small fish once swam the world's estuaries and coastal waters, inhaling plankton like swarming clouds of silvery vacuum cleaners. Maryland's Chesapeake Bay, the nation's largest estuary, used to be clear, its waters filtered every three days by piles of oysters so numerous that their reefs posed a hazard to navigation. All this has changed.

There and in many other places, bacteria and algae run wild in the absence of the many mouths that once ate them. As the depletion of fish allows the lowest forms of life to run rampant, said Pauly, it is "transforming the oceans into a microbial soup."

Jellyfish are flourishing in the soup, demonstrating their ability to adapt to wholesale changes — including the growing human appetite for them. Jellyfish have been around, after all, at least 500 million years, longer than most marine animals.

In the Black Sea, an Atlantic comb jelly carried in the ballast water of a ship from the East Coast of the United States took over waters saturated with farm runoff. Free of predators, the jellies gorged on plankton and fish larvae, depleting the fisheries on which the Russian and Turkish fleets depend. The plague subsided only with the accidental importation of another predatory jellyfish that ate the comb jellies.

Federal scientists tallied a tenfold increase in jellies in the Bering Sea in the 1990s. They were so thick off the Alaskan Peninsula that fishermen nicknamed it the Slime Bank. Researchers have found teeming swarms of jellyfish off Georges Bank in New England and the coast of Namibia, in the fiords of Norway and in the Gulf of Mexico. Also proliferating is the giant nomurai found off Japan, a jellyfish the size of a washing machine.

Most jellies are smaller than a fist, but their sheer numbers have gummed up fishing nets, forced the shutdown of power plants by clogging intake pipes, stranded cruise liners and disrupted operations of the world's largest aircraft carrier, the Ronald Reagan.

Of the 2,000 or so identified jellyfish species, only about 10 are commercially harvested. The largest fisheries are off China and other Asian nations. New ones are springing up in Australia, the United States, England, Namibia, Turkey and Canada as fishermen look for ways to stay in business.

Pauly, 60, predicts that future generations will see nothing odd or unappetizing about a plateful of these gelatinous blobs.

"My kids," Pauly said, "will tell their children: Eat your jellyfish."

The dark water spun to the surface like an undersea cyclone. From 80 feet below, the swirling mixture of partially treated sewage spewed from a 5-foot-wide pipe off the coast of Hollywood, Fla., dubbed the "poop chute" by divers and fishermen.

Fish swarmed at the mouth — blue tangs and chubs competing for particles in the wastewater.

Marine ecologist Brian Lapointe and research assistant Rex "Chip" Baumberger, wearing wetsuits and breathing air from scuba tanks, swam to the base of the murky funnel cloud to collect samples. The effluent meets state and federal standards but is still rich in nitrogen, phosphorous and other nutrients.

By Lapointe's calculations, every day about a billion gallons of sewage in South Florida are pumped offshore or into underground aquifers that seep into the ocean. The wastewater feeds a green tide of algae and bacteria that is helping to wipe out the remnants of Florida's 220 miles of coral, the world's third largest barrier reef.

In addition, fertilizer washes off sugar cane fields, livestock compounds and citrus farms into Florida Bay.

"You can see the murky green water, the green pea soup loaded with organic matter," said Lapointe, a marine biologist at Harbor Branch Oceanographic Institution in Fort Pierce, Fla. "All that stuff feeds the algae and bacterial diseases that are attacking corals."

Government officials thought they were helping in the early 1990s when they released fresh water that had been held back by dikes and pumps for years. They were responding to the

recommendations of scientists who, at the time, blamed the decline of ocean habitats on hypersalinity — excessively salty seawater.

The fresh water, laced with farm runoff rich in nitrogen and other nutrients, turned Florida's gin-clear waters cloudy. Seaweed grew fat and bushy.

It was a fatal blow for many struggling corals, delicate animals that evolved to thrive in clear, nutrient-poor saltwater. So many have been lost that federal officials in May added what were once the two most dominant types — elkhorn and staghorn corals — to the list of species threatened with extinction. Officials estimate that 97% of them are gone.

Sewage and farm runoff kill corals in various ways.

Algae blooms deny them sunlight essential for their survival.

The nutrients in sewage and fertilizer make bacteria grow wildly atop corals, consuming oxygen and suffocating the animals within.

A strain of bacteria found in human intestines, *Serratia marcescens*, has been linked to white pox disease, one of a host of infectious ailments that have swept through coral reefs in the Florida Keys and elsewhere.

The germ appears to come from leaky septic tanks, cesspits and other sources of sewage that have multiplied as the Keys have grown from a collection of fishing villages to a stretch of bustling communities with 80,000 year-round residents and 4 million visitors a year.

Scientists discovered the link by knocking on doors of Keys residents, asking to use their bathrooms. They flushed bacteria marked with tracers down toilets and found them in nearby ocean waters in as little as three hours.

Nearly everything in the Keys seems to be sprouting green growths, even an underwater sculpture known as Christ of the Abyss, placed in the waters off Key Largo in the mid-1960s as an attraction for divers and snorkelers. Dive-shop operators scrub the bronze statue with wire brushes from time to time, but they have trouble keeping up with the growth.

Lapointe began monitoring algae at Looe Key in 1982. He picked the spot, a 90-minute drive south of Key Largo, because its clear waters, colorful reef and abundance of fish made it a favorite site for scuba divers. Today, the corals are in ruins, smothered by mats of algae.

Although coral reefs cover less than 1% of the ocean floor, they are home to at least 2 million species, or about 25% of all marine life. They provide nurseries for fish and protect oceanfront homes from waves and storm surges.

Looe Key was once a sandy shoal fringed by coral. The Key has now slipped below the water's surface, a disappearing act likely to be repeated elsewhere in these waters as pounding waves breach dying reefs. Scientists predict that the Keys ultimately will have to be surrounded by sea walls as ocean levels rise.

With a gentle kick of his fins through murky green water, Lapointe maneuvered around a coral mound that resembled the intricate, folded pattern of a brain. Except that this brain was being eroded by the coralline equivalent of flesh-eating disease.

"It rips my heart out," Lapointe said. "It's like coming home and seeing burglars have ransacked your house, and everything you cherished is gone."

The ancient seas contained large areas with little or no oxygen — anoxic and hypoxic zones that

could never have supported sea life as we know it. It was a time when bacteria and jellyfish ruled.

Nancy Rabalais, executive director of the Louisiana Universities Marine Consortium, has spent most of her career peering into waters that resemble those of the distant past.

On research dives off the Louisiana coast, she has seen cottony white bacteria coating the seafloor. The sulfurous smell of rotten eggs, from a gas produced by the microbes, has seeped into her mask. The bottom is littered with the ghostly silhouettes of dead crabs, sea stars and other animals.

The cause of death is decaying algae. Fed by millions of tons of fertilizer, human and animal waste, and other farm runoff racing down the Mississippi River, tiny marine plants run riot, die and drift to the bottom. Bacteria then take over. In the process of breaking down the plant matter, they suck the oxygen out of seawater, leaving little or none for fish or other marine life.

Years ago, Rabalais popularized a term for this broad area off the Louisiana coast: the "dead zone." In fact, dead zones aren't really dead. They are teeming with life — most of it bacteria and other ancient creatures that evolved in an ocean without oxygen and that need little to survive.

"There are tons and tons of bacteria that live in dead zones," Rabalais said. "You see this white snot-looking stuff all over the bottom."

Other primitive life thrives too. A few worms do well, and jellyfish feast on the banquet of algae and microbes.

The dead zone off Louisiana, the second largest after one in the Baltic Sea, is a testament to the unintended consequences of manufacturing nitrogen fertilizer on a giant scale to support American agriculture. The runoff from Midwestern farms is part of a slurry of wastewater that flows down the Mississippi, which drains 40% of the continental United States.

The same forces at work in the mouth of the Mississippi have helped create 150 dead zones around the world, including parts of the Chesapeake Bay and waters off the Oregon and Washington coasts.

About half of the Earth's landscape has been altered by deforestation, farming and development, which has increased the volume of runoff and nutrient-rich sediment.

Most of the planet's salt marshes and mangrove forests, which serve as a filter between land and sea, have vanished with coastal development. Half of the world's population lives in coastal regions, which add an average of 2,000 homes each day.

Global warming adds to the stress. A reduced snowpack from higher temperatures is accelerating river discharges and thus plankton blooms. The oceans have warmed slightly — 1 degree on average in the last century. Warmer waters speed microbial growth.

Robert Diaz, a professor at the Virginia Institute of Marine Science, has been tracking the spread of low-oxygen zones. He has determined that the number is nearly doubling every decade, fed by a worldwide cascade of nutrients — or as he puts it, energy. We stoke the ocean with energy streaming off the land, he said, and with no clear pathways up the food chain, this energy fuels an explosion of microbial growth.

These microbes have been barely noticeable for millions of years, tucked away like the pilot light on a gas stove.

"Now," Diaz said, "the stove has been turned on."

In Australia, fishermen noticed the fireweed around the time much of Moreton Bay started turning a dirty, tea-water brown after every rain. The wild growth smothered the bay's northern sea-grass beds, once full of fish and shellfish, under a blanket a yard thick.

The older, bottom layers of weed turned grayish-white and started to decay. Bacteria, feeding on the rot, sucked all of the oxygen from beneath this woolly layer at night. Most sea life swam or scuttled away; some suffocated. Fishermen's catches plummeted.

Most disturbing were the rashes, an outbreak often met with scoffs from local authorities.

After suffering painful skin lesions, fisherman Greg Savige took a sealed bag of the weed in 2000 to Barry Carbon, then director-general of the Queensland Environmental Protection Agency. He warned Carbon to be careful with it, as it was "toxic stuff." Carbon replied that he knew all about cyanobacteria from western Australian waters and that there was nothing to worry about.

Then he opened the bag and held it close to his face for a sniff.

"It was like smearing hot mustard on the lips," the chastened official recalled.

Aboriginal fishermen had spotted the weed in small patches years earlier, but it had moved into new parts of the bay and was growing like never before.

Each spring, *Lyngbya* bursts forth from spores on the seafloor and spreads in dark green-and-black dreadlocks. It flourishes for months before retreating into the muck. Scientists say it produces more than 100 toxins, probably as a defense mechanism.

At its peak in summer, the weed now covers as much as 30 square miles of Moreton Bay, an estuary roughly the size of San Francisco Bay. In one seven-week period, its expansion was measured at about 100 square meters a minute — a football field in an hour.

William Dennison, then director of the University of Queensland botany lab, couldn't believe it at first.

"We checked this 20 times. It was mind-boggling. It was like 'The Blob,' " Dennison said, recalling the 1950s horror movie about an alien life form that consumed everything in its path.

Suspecting that nutrients from partially treated sewage might be the culprit, another Queensland University scientist, Peter Bell, collected some wastewater and put it in a beaker with a pinch of *Lyngbya*. The weed bloomed happily.

As Brisbane and the surrounding area became the fastest growing region in Australia, millions of gallons of partially treated sewage gushed from 30 wastewater treatment plants into the bay and its tributary rivers.

Officials upgraded the sewage plants to remove nitrogen from the wastewater, but it did not stop the growth of the infernal weed.

Researchers began looking for other sources of *Lyngbya*'s nutrients, and are now investigating whether iron and possibly phosphorous are being freed from soil as forests of eucalyptus and other native trees are cleared for farming and development.

"We know the human factor is responsible. We just have to figure out what it is," Dennison said.

Recently, *Lyngbya* has appeared up the coast from Moreton Bay, on the Great Barrier Reef, where helicopters bring tourists to a heart-shaped coral outcropping. When the helicopters depart, seabirds roost on the landing platform, fertilizing the reef with their droppings. *Lyngbya*

now beards the surrounding corals.

"*Lyngbya* has lots of tricks," said scientist Judith O'Neil. "That's why it's been around for 3 billion years."

It can pull nitrogen out of the air and make its own fertilizer. It uses a different spectrum of sunlight than algae do, so it can thrive even in murky waters. Perhaps its most diabolical trick is its ability to feed on itself. When it dies and decays, it releases its own nitrogen and phosphorous into the water, spurring another generation of growth.

"Once it gets going, it's able to sustain itself," O'Neil said.

Ron Johnstone, a University of Queensland researcher, recently experienced *Lyngbya's* fire. He was studying whether iron and phosphorous in bay sediments contribute to the blooms, and he accidentally came in contact with bits of the weed. He broke out in rashes and boils, and needed a cortisone shot to ease the inflammation.

"It covered my whole chest and neck," he said. "We've just ordered complete containment suits so we can roll in it."

Fishermen say they cannot afford such pricey equipment. Nor would it be practical. For some, the only solution is to turn away from the sea.

Lifelong fisherman Mike Tanner, 50, stays off the water at least four months each year to avoid contact with the weed. It's an agreement he struck with his wife, who was appalled by his blisters and worried about the long-term health consequences.

"When he came home with rash all over his body," Sandra Tanner said, "I said, 'No, you are not going.' We didn't know what was happening to him."

Tanner, a burly, bearded man, is frustrated that he cannot help provide for his family. Gloves and other waterproof gear failed to protect him.

"It's like acid," Tanner said. "I couldn't believe it. It kept pulling the skin off."

Before the *Lyngbya* outbreak, 40 commercial shrimp trawlers and crab boats worked these waters. Now there are six, and several of them sit idle during fireweed blooms.

"It's the only thing that can beat us," Greg Savige said. "Wind is nothing. Waves, nothing. It's the only thing that can make us stop work. When you've got sores and the skin peels away, what are you going to do?"

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*Times staff writer Usha Lee McFarling contributed to this report.*

## **Resources**

More information about endangered oceans is available at these educational and governmental websites:

<http://scripps.ucsd.edu>

<http://cmbc.ucsd.edu/>

<http://www.hboi.edu/>

<http://www.initrogen.org/>

<http://www.millenniumassessment.org>

<http://www.epa.gov/owow/estuaries/guidance/>

<http://www.hboi.edu/>

<http://www.initrogen.org/>

<http://www.seaaroundus.org>

PART TWO  
ALTERED OCEANS

## **Sentinels Under Attack**

**Toxic algae that poison the brain have caused strandings and mass die-offs of marine mammals — barometers of the sea's health.**

By Kenneth R. Weiss, Times Staff Writer  
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After the last patient of the day walked out the front of Raytel Medical Imaging clinic, veterinarian Frances Gulland slipped an oversized animal crate through the back door.

Inside was a California sea lion. The animal was emaciated, disoriented and suffering from seizures.

A female with silky, caramel-colored fur, wide-set eyes and long whiskers, she was named Neuschwander, after the lifeguard who had found her six weeks earlier, comatose and trembling under a pier at Avila Beach near San Luis Obispo.

Taken to the Marine Mammal Center near Sausalito, Neuschwander showed signs of recovery at first. Her eyes began to clear and focus. She frolicked in the small pool in her chain-link enclosure and wolfed down mackerel at feedings. Then she relapsed.

She quit eating and lost 40 pounds. Her sunken eyes darted around, as if tracking a phantom just outside the cage. Her head bobbed and weaved in erratic figure eights.

Neuschwander was loaded into a crate at the nonprofit center, the world's busiest hospital dedicated to the care of wild marine mammals, and trucked across the Golden Gate Bridge. Gulland, the center's director of veterinary science, wanted to scan Neuschwander's brain at the imaging clinic.

After sedating the sea lion, Gulland and four assistants lifted the animal onto a gurney. They inserted a breathing tube into her throat and rolled the gurney into the great thrumming MRI machine.

Gulland, an upbeat, 46-year-old native of Britain, took a last look at Neuschwander as the

machine closed around her. She hoped the sea lion could be saved.

Neuschwander was exhibiting the classic symptoms of domoic acid poisoning, a condition that scrambles the brains of marine mammals and causes them to wash ashore in California as predictably as the spring tides.

They pick up the acid by eating anchovies and sardines that have fed on toxic algae. Although the algae have been around for eons, they have bloomed with extraordinary intensity along the Pacific coast for the last eight years.

The blooms are part of a worldwide pattern of oceanic changes that scientists attribute to warming waters, excessive fishing, and a torrent of nutrients unleashed by farming, deforestation and urban development.

The explosion of harmful algae has caused toxins to move through the food chain and concentrate in the dietary staples of marine mammals.

For the last 25 years, the federal government has tracked a steady upswing in beach strandings and mass die-offs of whales, dolphins and other ocean mammals on U.S. coasts.

More than 14,000 seals, sea lions and dolphins have landed sick or dead along the California shoreline in the last decade. So have more than 650 gray whales along the West Coast.

In Maine two years ago, 800 harbor seals, all adults with no obvious injuries, washed up dead, and in Florida the carcasses of hundreds of manatees have been found in mangrove forests and on beaches.

The surge in mortality has coincided with what Florida wildlife pathologist Greg Bossart calls a "pandemic" of algae and bacteria. Although some of the deaths defy easy explanation, telltale biotoxins have turned up in urine, blood, brains and other tissue.

Sometimes the toxins kill animals outright, such as the manatees found dead in Florida, blood streaming from their noses.

In other cases, they kill slowly by promoting tumor growth or compromising immune systems, leaving marine mammals vulnerable to parasites, viruses or bacteria. Scientists believe the episodic die-offs of bottlenose dolphins along the Atlantic and Gulf coasts that began in the late 1980s may stem from toxic algae that weaken the animals and enable a virus related to canine distemper to attack the lungs and brain.

Sea turtles in Hawaii have been found with fist-sized tumors growing out of their eyes and mouths and behind their flippers. Scientists say the growths are the result of a papilloma virus and an ancient microorganism called *Lyngbya majuscula*, which appears as a hairy weed that has been spreading in tropical and subtropical waters. The tumors doom the turtles by inhibiting their ability to see, eat or swim.

As they watch the oceans disgorge more dead and dying creatures, scientists have come to a disquieting realization: The proliferation of algae, bacteria and other microbes is making the oceans less hospitable to advanced forms of life — those animals most like humans.

"Marine mammals share our waters, eat some of the food we eat and get some of the same diseases we get," said Paul Sandifer, chief scientist for the Oceans and Human Health Initiative of the National Oceanic and Atmospheric Administration.

"If environmental conditions are not good for these sentinels of the sea, you can believe it won't be good for us either," Sandifer said. "What we allow to flow into the sea will come back to bite

us. You can bet on it."

Marine algae, or phytoplankton, occur naturally and make up the first link in the oceanic food chain. A quart of seawater typically contains hundreds of thousands of phytoplankton and millions of bacteria, viruses and protozoans, all in concentrations that keep each other in check.

That equilibrium can be upset when certain types of algae overwhelm their competitors. The change is most pronounced in coastal waters, and scientists believe it is tied to nutrient pollution from a variety of human activities.

Toxic algae thrive on the same elements that turn lawns green and make crops grow — nitrogen, phosphorus and iron.

California, the nation's most populous state with more than 36 million people, sends billions of gallons of partially treated human waste into the ocean every day. Sewage treatment cuts down on disease-causing bacteria but does little to remove nutrients.

Seasonal rains carry enormous loads of urban and agricultural runoff into the ocean, much of it down drainage canals and rivers from the dairies, orchards and farms that make California the nation's largest agricultural producer.

The destruction of coastal wetlands, which filter nitrogen and other nutrients, also plays a role, as does over-harvesting of shellfish and sardines, menhaden and other algae-eating fish.

Climate change is another factor. Warmer seawater speeds up microbial growth and allows aggressive algae and bacteria to move into areas once too cold for them. Commercial ships can help the spread, transporting the algae in ballast water.

The type of algae that poisoned Neuschwander began blooming riotously in California waters in 1998.

It has the tongue-twisting name *Pseudo-nitzschia* (SUE-doh NICH-e-yah). A fraction of the thickness of a human hair, this javelin-shaped, single-cell organism slides through seawater on a coating of mucus and churns out domoic acid, a neurotoxin.

*Pseudo-nitzschia* blooms all along the West Coast, especially around bays and estuaries fed by major rivers. Unlike some other toxic blooms, which are often called red tides, these aren't visible because their greenish-brown coloring blends into the seawater.

Researchers studying *Pseudo-nitzschia* off the mouth of the Mississippi River have unearthed evidence in the seafloor that agricultural runoff from the nation's heartland triggers the outbreaks.

Scrutinizing core samples from five locations in the Gulf of Mexico, they found thick layers of microscopic silica shells of *Pseudo-nitzschia* that coincided with a deposit of nitrates and sediment that had flowed down the Mississippi.

The evidence is preserved in strata that resemble a layer cake. It shows that *Pseudo-nitzschia* didn't proliferate until the 1950s, when grain farmers began widespread use of chemical fertilizers.

In contrast to the Mississippi Delta, such telltale clues cannot be seen in marine sediments off the Pacific coast because the seafloor is constantly being churned up.

As a result, West Coast scientists have been looking for chemical signatures that would directly link river discharges to the toxic blooms.

For the last three years, USC researchers David A. Caron and Astrid Schnetzer have focused on a "hot zone" of *Pseudo-nitzschia* spanning 155 square miles of coastal waters off the mouths of the Los Angeles and San Gabriel rivers.

The researchers are still looking for the link. But one thing is clear, said Caron, a biological oceanographer: "There is a big dose of nutrients."

Knowing about the effects of domoic acid, scientists wonder whether algae blooms explain the freakish behavior of coastal wildlife observed periodically over the years.

Some speculate that *Pseudo-nitzschia* caused the onslaught of crazed seabirds near Capitola, Calif., in 1961 that inspired Alfred Hitchcock's movie "The Birds." Hitchcock, who was living in nearby Scotts Valley, read a newspaper story about sooty shearwaters "wailing and crying like babies," crashing into streetlights and windows, nipping at people and vomiting up anchovies.

In 1998, sailors in Monterey Bay began bumping into dark objects in the water. They thought they were floating logs. They weren't. They were the bodies of sea lions.

That year, more than 400 washed ashore, dead or dying, victims of neurotoxic poisoning.

California's five marine mammal rehabilitation centers were overwhelmed. Every year since, they have been crowded with sea lions trembling with seizures.

This spring, the Marine Mammal Care Center at Ft. MacArthur in San Pedro was often as busy as an inner-city emergency room. Ailing sea lions were packed into chain-link cages. Rescue workers kept bringing in new patients in pickup trucks. The animals needed injections of anti-seizure medicine or had to be hooked up to saline drips to flush the neurotoxin from their systems.

On one typical day, listless sea lions were flopped on their sides, flippers tucked in, too exhausted to lift their heads. One was agitated, head weaving to and fro, grunting and snorting. Another chewed obsessively on a flipper.

All were females found comatose or acting strangely on the beach. Many were pregnant and had seizures just after giving birth.

"A California sea lion has as warm and strong of a maternal instinct with a newborn as you can see in any animal," said Robert DeLong, a government ecologist who has studied sea lions in their Channel Islands rookeries for 35 years.

Domoic acid can destroy that maternal bond.

Sea lions suffering from neurotoxic poisoning usually show no interest in their young. Some that previously cared for their pups shun them after suffering seizures or even attack them when they try to suckle.

"I came in one day and pieces of the pup were everywhere," said Jennifer Collins, a veterinarian who worked at the Marine Mammal Care Center in San Pedro. "We initially thought someone had broken in and macerated one of the animals. Then we pieced it together and realized that a mother had done it to her own pup."

Scientists first became aware of domoic acid and its toxicity in 1987, when three people died and at least 100 others were sickened after eating contaminated mussels from Prince Edward Island in Canada. Nineteen people were hospitalized with seizures, comas and unstable blood pressure.

Many of the patients never recovered gaps in their memory, lending this malady a new name:

amnesic shellfish poisoning. An examination of brain tissue from the three people who died showed severe loss of nerve cells, mostly in the hippocampus, a part of the temporal lobe that resembles a seahorse and plays a key role in memory and navigation.

Reported cases of the illness are rare in North America because health authorities closely monitor shellfish for toxins and because such seafood makes up a tiny fraction of most people's diets. But for animals that consume little else, domoic acid is a recurring danger.

The acid mimics a neurotransmitter, overstimulating neurons that retain memory. The acid prompts nerve cells to fire continuously until they swell and die.

During spring and summer, when *Pseudo-nitzschia* blooms off the California coast, male sea lions don't eat. They are too busy guarding their breeding territory on the Channel Islands, where females mate soon after delivering pups.

The females, in contrast, are ravenous feeders while pregnant and while nursing. They gorge on anchovies and sardines that have fed on toxic algae. Domoic acid doesn't appear to affect the fish, but sea lions eat anchovies in such quantities that they accumulate a toxic load.

Frances Gulland and other researchers have been collecting miscarried sea lion fetuses and stillborn pups on San Miguel Island. To their surprise, domoic acid has turned up in the urine of these pups.

The neurotoxin is typically flushed from an animal in about four hours. But Gulland found that domoic acid can penetrate the placenta, bathing a developing fetus in the neurotoxin for days.

California sea lions have a keen sense of direction. Although their habitat ranges from British Columbia to Baja California, they return to the same breeding beaches on the same islands year after year.

But after attaching satellite transmitters to the animals, Gulland and other researchers found that many victims of domoic acid poisoning — even those that appeared fully recovered — lost their way.

Some swam hundreds of miles out to sea and were never seen again, bizarre behavior for creatures that spend their lives in coastal waters.

Others washed up again on beaches, too addled to make it on their own. One swam in tight circles up the Salinas River.

Neuschwander was one of those who could not find their bearings.

After spending a month at the Marine Mammal Center near Sausalito last summer, the sea lion was eating voraciously and seemed so vigorous that Gulland thought she was ready to fend for herself again. She was released back into the ocean in San Mateo County.

A week later, Neuschwander was found stranded again. This time, she was more than 100 miles inland from her natural home along the coast. She had traveled up rivers and drainage canals and ended up on a hillside near Sacramento International Airport.

She had an enormous gash running from her chest to her back, possibly from a run-in with a barbed-wire fence. She snapped at anyone who came close.

Back at the Marine Mammal Center, Neuschwander wouldn't eat and began weaving her head again in endless figure eights.

Gulland and her staff shaved a wide band of fur off the sea lion's head, attached a dozen electrodes and hooked them to an electroencephalogram to measure brain activity. The needle jumped up and down, a sign that Neuschwander was continuing to have seizures, though there were no visible tremors.

"The damage to the hippocampuses will help trigger seizures, and further seizures will cause further cell damage," Gulland said. "You get into this whole vicious cycle."

So Neuschwander was driven across San Francisco Bay and put into the MRI machine at Raytel Medical Imaging, a clinic near UC San Francisco Medical Center. After the magnets whirled, a computer screen displayed cross-section images of her brain.

Dr. Jerome A. Barakos, a clinical professor and director of neuro-imaging at the clinic, appeared in his white coat. He was there to interpret the 250 images that spooled out of the machine.

"The anatomy of a sea lion is not too dissimilar to the human anatomy," Barakos said. He confirmed Gulland's fear. On the right side of Neuschwander's brain, the hippocampus was severely atrophied. It looked less like a seahorse than like a withered tail.

Gulland paced around the lab, then pulled aside one of her assistants, Michelle Caudle.

"So do we euthanize her? Do we take her home and see how she does?" Gulland asked.

The two women shifted uncomfortably, arms folded across their chests. They talked about how the animal was losing weight and drifting in and out of delirium.

At 140 pounds, Neuschwander was 60 to 80 pounds lighter than a healthy adult female.

Caudle recalled how she wouldn't eat the "happy fish," laced with sedatives, that sea lions normally gulp down. Neuschwander shredded it, then spat it out.

"She looks terrible," Gulland said. "I didn't realize how thin she was. I mean, how much do we make her go through?"

Gulland got a faraway look in her eyes. Her face drooped.

"I'm OK with it," Caudle said.

"I am too. That's why we do it, right?"

To end the suffering.

Gulland blinked back tears. She took a deep breath and rejoined the group to announce the decision.

The team took five vials of blood for future studies. Then Gulland filled an enormous syringe with clear pink liquid, pressed the plunger and shot 15 ccs of sodium pentobarbitone, an overdose of the anesthetic, into a neck vein.

Neuschwander let out one last, rasping breath.

Gulland laid her hands on the sea lion's body. The heart fluttered for a long two minutes.

Then it stopped.

## **Dark Tides, Ill Winds**

**With sickening regularity, toxic algae blooms are invading coastal waters. They kill sea life and send poisons ashore on the breeze, forcing residents to flee.**

By Kenneth R. Weiss, Times Staff Writer  
August 1, 2006

LITTLE GASPARILLA ISLAND, FLA. — All Susan Leydon has to do is stick her head outside and take a deep breath of sea air. She can tell if her 10-year-old son is about to get sick. If she coughs or feels a tickle in the back of her throat, she lays down the law: No playing on the beach. No, not even in the yard. Come back inside. Now.

The Leydons thought they found paradise a decade ago when they moved from Massachusetts to this narrow barrier island, reachable only by boat, with gentle surf, no paved roads and balmy air that feels like velvet on the skin.

Now, they fear that the sea has turned on them. The dread takes hold whenever purplish-red algae stain the crystal waters of Florida's Gulf Coast. The blooms send waves of stinking dead fish ashore and insult every nostril on the island with something worse.

The algae produce an arsenal of toxins carried ashore by the sea breeze.

"I have to pull my shirt up and over my mouth or I'll be coughing and hacking," said Leydon, 42, a trim, energetic mother of three who walks the beach every morning.

Her husband, Richard, a 46-year-old building contractor, said the wind off the gulf can make him feel like he's spent too much time in an overchlorinated pool. His chest tightens and he grows short of breath. His throat feels scratchy, his eyes burn, and his head throbs.

Their symptoms are mild compared with those of their son, also named Richard. He suffers from asthma and recurring sinus infections. When the toxic breeze blows, he keeps himself — and his parents — up all night, coughing until he vomits.

If the airborne assault goes on for more than a few days, it becomes a community-wide affliction. At homeowners' meetings, many people wear face masks.

On weekends, the Leydons escape inland. They drive three hours to Orlando so their son can play outside without getting sick. They go to a Walt Disney World resort with water slides, machine-generated currents and an imported white sand beach.

"It's a shame to leave this beautiful place and go to a water park," Richard Leydon said. "But we don't have much choice. We have to get away from it."

Harmful algae blooms have occurred for ages. Some scientists theorize that a toxic bloom inspired the biblical passage in Exodus: "... all the water in the Nile turned into blood. And the fish in the Nile died, and the Nile stank, so that the Egyptians could not drink water from the Nile. There was blood throughout all the land of Egypt."

What was once a freak of nature has become commonplace. These outbreaks, often called red tides, are occurring more often worldwide, showing up in new places, lasting longer and intensifying.

They are distress signals from an unhealthy ocean. Overfishing, destruction of wetlands, industrial pollution and climate change have made the seas inhospitable for fish and more

advanced forms of life and freed the lowliest — algae and bacteria — to flourish.

A scientific consensus is emerging that commercial agriculture and coastal development, in particular, promote the spread of harmful algae. They generate runoff rich in nitrogen, phosphorous and other nutrients that sustain these microscopic aquatic plants. In essence, researchers say, modern society is force-feeding the oceans with the basic ingredients of Miracle-Gro.

Yet there is debate among Florida scientists over the precise causes of local outbreaks. Red tides date back at least 150 years, before the state became one of the nation's most populous. Some scientists say their increased intensity is part of a natural cycle.

People who have spent many years on Little Gasparilla Island and in other Florida Gulf Coast communities say red tides used to show up once in a decade. Now, they occur almost every year and persist for months.

Red tide announced its arrival this summer by dumping dead tarpon and goliath grouper on the beaches. Soon after, coastal residents were coughing and sneezing.

The previous bloom, which ended in mid-February, peppered Florida's western coast with its fiery breath for 13 months, stubbornly refusing to dissipate despite three hurricanes.

The culprit is a microorganism known as *Karenia brevis*. Each *Karenia* cell is a poison factory pumping out toxins collectively known as brevetoxin.

During red tides, they can be absorbed into the food chain by scallops, oysters and other popular seafood and can cause neurotoxic shellfish poisoning. The effects range from gastrointestinal illness to seizures, loss of muscle control and unconsciousness.

Brevetoxin also gets into the air. It collects on the surface of bubbles and concentrates in sea foam and on dead fish.

When the bubbles burst, brevetoxin is flung into the air and carried by the wind. If inhaled, most particles lodge in the nose and throat, but some are drawn deep into the lungs. People don't have to set foot in the ocean or even on the beach to experience a red tide. It comes to them.

Most of those affected feel as if they have a cold or an allergy. But researchers reported last year that red tides coincided with outbreaks of severe respiratory ailments.

They compared emergency admissions at Sarasota Memorial Hospital during three months of red tide with the same period a year later, when there was no toxic algae.

During the red tide, admissions for pneumonia, bronchitis, asthma, sinus infections and similar afflictions rose 54%. No such increase was reported inland.

"You can tell when it's a bad red tide," said Dr. Brian Garby, the hospital's chief of emergency medicine. "The waiting room is filled with people coughing and they don't know why."

Most alarming was a 19% increase in cases of pneumonia, a leading cause of death among the elderly.

Brevetoxin doesn't cause those maladies directly. Instead, researchers believe, it makes people vulnerable by inflaming their sinuses and suppressing their immune systems, allowing bacteria and viruses to flourish.

Boxy air filters stationed around Sarasota have detected the wind-borne neurotoxin three miles

from the coast, said Barbara Kirkpatrick, a researcher at Mote Marine Laboratory, a private research institute in the city. "The public health message has been, 'If you leave the beach, you'll be OK.' Now we know better. People who are window shopping or eating in outdoor restaurants are still being exposed to the toxins."

Hundreds of visitors from the Midwest and New England have posted questions and complaints on websites, seeking to learn why, after a short beach vacation on the west coast of Florida, they suffered weeks of coughing, bronchial infections, dizziness, lethargy and other symptoms.

Researchers are hearing a growing number of complaints about neurological symptoms.

Ruth DeLynn, a 79-year-old retired biologist and volunteer curator at Mote Marine Laboratory, was hospitalized for five days last year with respiratory distress during a particularly virulent red tide. DeLynn also experienced numbness and a burning sensation in her legs that made it difficult to walk. She and her doctor believe the toxin triggered a resurgence of peripheral neuropathy that had been dormant for 15 years.

"If this is going to continue this way," said DeLynn, who lives on a barrier island near Sarasota, "I'm thinking of moving inland."

Neurological symptoms usually flare only with high levels of exposure, said Dr. Lora Fleming, a University of Miami epidemiologist and physician. "It's all about dose."

Fleming isn't persuaded that people on the beach can inhale enough to suffer serious neurological effects, but she thinks surfers may be more vulnerable.

John Purdy, a former Manatee County lifeguard, was paddling his surfboard over a wave last fall when some sea foam lifted off the water and into his mouth just as he was gulping for air.

"I felt like I inhaled a garbage bag," said Purdy, 33, a former high school swimming champion. "It locked up my lungs and throat like a paralysis." The seconds ticked by. "I was thinking, 'Is this the way it's going to end?' "

Eventually, he managed to sneak in a little air. It was like sucking through a cocktail straw. He made his way to shore but didn't feel much better until emergency medical technicians hooked him up to oxygen. "It was the closest thing I've had to a near-death experience," he said.

Unlike surfers, marine mammals can't seek refuge on land. Last year's red tide took the lives of at least 88 manatees, some weighing more than a ton. Hundreds of these massive sea cows have succumbed during outbreaks in previous years.

Greg Bossart, a veterinarian and pathologist at Harbor Branch Oceanographic Institute in Fort Pierce, dissected the tissue of manatees and determined that many died from inhaling brevetoxin-laden air just above the ocean's surface. The result was a cascade of nerve and tissue damage that filled their lungs with blood.

"The manatees are gassed to death," Bossart said. "They die of toxic shock."

Bossart considers the manatee a sentinel for human health, or, as he puts it: "Florida's 2,000-pound canary. We've opened a Pandora's box of health issues."

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The oceans are awash in microscopic algae, or plankton. But of the thousands of different kinds,

only about 100 produce toxins.

About 60,000 people in the United States are poisoned each year by algae blooms. Most get sick by eating fish and shellfish that concentrate neurotoxins from the vast quantities of algae they consume.

The Centers for Disease Control and Prevention estimates that only 2% to 10% of all cases are reported to health authorities — usually those that involve numbness, paralysis, coma or other severe symptoms. Cases of nausea, cramping and diarrhea tend to go unreported.

Estimates of algae-related illness don't include the many thousands of people in Florida and other Gulf Coast states who suffer from inhaling airborne brevetoxin.

Nearly every coastal region has outbreaks of harmful algae or bacteria.

For the second summer in a row, shellfish beds in New England are being closed because of toxic algae that cause paralytic shellfish poisoning. These blooms that typically begin in the Gulf of Maine were rare until the 1970s. Now, they appear almost every year, often spreading down the coast as far as Cape Cod.

California and other West Coast states periodically have banned shellfish harvesting because of toxic algae, including *Pseudo-nitzschia*, which wasn't identified until 1987. That was when it killed three people who ate contaminated mussels in Montreal. Since then, it has left California's coastline littered with dead and dying marine mammals and seabirds.

Marine biotoxins are among the most potent biological poisons ever discovered. Saxitoxin, which causes paralytic shellfish poisoning, is listed among chemical agents banned under a United Nations compact on weapons of mass destruction. As with other algae-produced neurotoxins, there is no known antidote.

People help spread harmful algae by fertilizing them with sewage and farm runoff, transporting them in the ballast water of ships, dredging harbors or warming seawater through climate change.

Patricia M. Glibert, a marine scientist at the University of Maryland, has found that the worldwide spread of paralytic shellfish poisoning has closely tracked the expanding use of urea, a nitrogen fertilizer.

Glibert estimated that fertilizer use will rise 50% this decade "in parts of the world that are already saturated with nitrogen and frequently plagued by harmful blooms."

Donald Anderson and colleagues at Woods Hole Oceanographic Institution in Massachusetts traced the origin of a strain of algae responsible for a 1998 outbreak of paralytic shellfish poisoning on France's Mediterranean coast. Analyzing DNA and shipping records, they concluded that it hitched a ride from Japan in the belly of a ship.

Disturbance of the seafloor by dredging is believed to help promote the growth of algae that cause ciguatera fish poisoning. About a million people a year show signs of ciguatera poisoning — such as gastrointestinal distress, numbness, weakness, vertigo and coma — after eating fish from tropical waters.

Cruise ship passengers who ate raw oysters from Alaskan shellfish beds became violently ill two years ago in an outbreak that medical researchers tied to the bacterial pathogen *Vibrio*, common in the Gulf of Mexico. Researchers realized the strain had moved 600 miles farther north than ever before, as Alaskan waters warmed above the 59-degree threshold that limited the bacterium's range.

A University of Miami marine biologist, Larry E. Brand, examined water samples dating to 1954 and found that outbreaks of *Karenia brevis* off Florida's Gulf Coast are getting stronger, lasting longer and spreading farther.

"When you look at it statistically, red tides are 10 times more abundant than they were 50 years ago," Brand said. Once, "the peak time was in the fall.... Now we have blooms continuing on and lasting into the winter and spring."

The highest concentrations of algae, he said, were along heavily developed shorelines and around the mouths of rivers that disgorge nutrient-laden waters from sugar-cane fields and sediment from phosphate mines.

Brand said that was no coincidence. It reflects "a huge increase in sewage, runoff from lawns and golf courses, mining and agriculture," he said.

State officials say Brand may be misinterpreting the water samples. Cynthia Heil, a senior state scientist, said the data do not support the conclusion that pollution from agriculture or development spawns red tides, although she said it may intensify or prolong the outbreaks.

Heil said there is compelling evidence of blooms that originate out at sea, far from coastal concentrations of man-made pollutants.

She and a team of university scientists in Florida have published a study theorizing that iron-rich dust from Africa's Sahara Desert drifts across the Atlantic and triggers a natural process that stimulates harmful algae blooms off Florida's Gulf Coast.

"The timing sure matches up with blooms," Heil said. "We know it has to contribute to enriching seawater with iron and nitrogen."

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A television suspended from the ceiling at Mote Marine Laboratory in Sarasota plays a public service announcement sponsored by state and federal agencies, offering hints for dealing with red tide.

"If you are going to the beach for a short trip, go to your local drugstore and buy a face mask, like the ones painters wear," the narrator says. "But remember, these masks are only effective for a short time.

"People with asthma should also be sure to take their inhalers to the beach and use them as prescribed. If your inhaler is not providing relief, seek immediate medical attention."

Tourist officials point out that red tides come and go and vary in intensity, and that the airborne toxins don't trigger health problems unless there is an onshore breeze. Beachgoers on one stretch of coast can get a heavy dose, while others a few miles away aren't affected.

Last fall's red tide was one of the worst on record.

Tourists bailed out of hotels and motels, said Dianne Manspeaker, manager of the Gulf Surf Resort Motel in Nokomis. "People come to check in and say, 'I can't stay here, I can't breathe.' "

Manspeaker is sympathetic to tourists who feel ill and refunds their money. She lives inland, and when the wind blows brevetoxin onshore, she stays home and tends to business by phone. "If I have to be here," she said, "I wear a mask."

A few miles up the coast, Sarasota County lifeguard Mike Zanane listened to a familiar chorus of coughs, throat-clearing, sneezes and nose-blowing from hundreds of beachgoers.

It was a typical day at the beach during red tide, Zanane said. The die-hards lie in the sun and cough all day. They won't leave. Nor will they venture into the surf, and Zanane doesn't blame them.

"Sometimes," he said, "you go out there and you feel like you've been Maced."

Red tides have become a staple of the daily reports on surf conditions posted on the lifeguard tower. The sign read: "Some Red Tide = Coughs. Sneezes. Dead Fishes." A few extra words were scribbled in chalk in the margin: "Can't do anything about [it]."

Not that people haven't tried.

In one experiment, researchers from Mote Marine Laboratory sprayed a slurry of clay onto the murky water in an effort to smother and sink the offending organisms. Another experiment in the works would sterilize algae patches with injections of ozone. Such remedies can be problematic. Not only do they kill the harmful algae, they wipe out every living thing in the vicinity.

Jim Patterson, a past mayor of Longboat Key next to Sarasota, would have been satisfied just to rid the beach of the stench of dead fish.

A retired Army general, Patterson took the fight to the fish. He hired a boat and crew and set out to chop up the carcasses with a fish shredder before they could reach the shore.

The results were disappointing for Patterson and his nonprofit group, Solutions To Avoid Red Tide. Instead of whole fish, Longboat Key was littered with decaying fish chunks.

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Buddy Gaines invited a visitor to look out at the Gulf of Mexico from his oceanfront house built on stilts on Little Gasparilla Island. "You can see why we love it here," the retired filmmaker said. "It's a shame we cannot go outside."

Gaines and his wife, Laurie, don't let their dogs — a pair of Hungarian vizslas — outside either. Not during the bloom of a red tide. It's a costly lesson the couple learned a couple of years ago.

Their younger dog, Olivia, was a gregarious puppy who loved to frolic in the sand, splash in the warm surf and follow joggers down the beach.

One morning, after eating a few small fish that had washed up, she arrived home staggering and stumbling. By the time the Gaineses got her to a vet, Olivia couldn't see. She was vomiting and convulsing.

"It was heartbreaking to watch," Laurie Gaines said. "We didn't think she was going to live."

Veterinarian Amanda Schell didn't know what to make of the symptoms.

"Did she eat rat poison?" the vet asked. "Did she get into antifreeze?"

Schell ran blood tests, looking for West Nile virus and canine distemper. Finding no clear answers, she sent the couple to a specialist in Tampa.

The next day, local veterinarians treated 16 dogs — all twitching, vomiting and suffering from seizures. One died.

Buddy and Laurie Gaines embarked on a monthlong odyssey to save Olivia that took them to clinics, animal hospitals and finally Tufts University's veterinary school in North Grafton, Mass. The couple camped in the parking lot in their motor home while Olivia was cared for inside.

"Sometimes I think I'm the biggest fool in the family to have spent \$22,000 on this dog," said Buddy Gaines, 70, sitting on his couch with Olivia. "I had to take out a second mortgage. But I don't care. I love this dog."

Olivia, now 3 years old, appears fully recovered, except for her incessant drooling. Veterinarians suspect it's a sign of residual neurological damage.

A half-mile down the beach, Susan and Richard Leydon were keeping their dog, a sheltie, inside, along with their son, Richard. The air conditioner was going full blast.

Richard's bedroom is at the seaward side of the house with a picture window overlooking the gulf. "I have the best room," he announced.

It's the best room until the wind begins to blow hard off the ocean. Then it's the first to get dosed with toxin-laden air, coming through the cracks and electrical outlets. It leaves a vague metallic taste on the back of the tongue.

The family has taken to wearing surgical masks on windy red tide nights. It's not enough to keep Richard from coughing. His parents also move him into a room on the other side of the house.

Richard has spent nearly his entire life on the island and was among the first residents to develop symptoms. His most common ailment is a dry cough, which he says makes him sound like a barking seal.

The airborne irritants have also triggered recurring sinus infections and asthma. On a few occasions, during intense and prolonged red tides, Richard has been diagnosed with bronchitis and even pneumonia, which kept him out of school for more than a month.

The Leydons said they have consulted with specialists and spent thousands of dollars on tests trying to figure out if something other than red tide was making their son sick. Doctors couldn't pinpoint anything.

The couple worry about the price their son is paying for their decision to move to Florida.

"Is Richard is going to have lung scarring and long-term problems?" his father asked. "I need to know."

The conversation in the Leydon household focused on two topics, as it often does during red tide outbreaks. One was where to flee for the weekend. The other was whether they should move, for good.

"Do we have to sell our house because paradise is killing us?" Susan Leydon asked.

**PART FOUR**  
ALTERED OCEANS

## **Plague of Plastic Chokes the Seas**

**On Midway Atoll, 40% of albatross chicks die, their bellies full of trash. Swirling masses of drifting debris pollute remote beaches and snare wildlife.**

By Kenneth R. Weiss, Times Staff Writer  
August 2, 2006

MIDWAY ATOLL — The albatross chick jumped to its feet, eyes alert and focused. At 5 months, it stood 18 inches tall and was fully feathered except for the fuzz that fringed its head.

All attitude, the chick straightened up and clacked its beak at a visitor, then rocked back and dangled webbed feet in the air to cool them in the afternoon breeze.

The next afternoon, the chick ignored passersby. The bird was flopped on its belly, its legs splayed awkwardly. Its wings drooped in the hot sun. A few hours later, the chick was dead.

John Klavitter, a wildlife biologist, turned the bird over and cut it open with a knife. Probing its innards with a gloved hand, he pulled out a yellowish sac — its stomach.

Out tumbled a collection of red, blue and orange bottle caps, a black spray nozzle, part of a green comb, a white golf tee and a clump of tiny dark squid beaks ensnared in a tangle of fishing line.

"This is pretty typical," said Klavitter, who is stationed at the atoll for the U.S. Fish and Wildlife Service. "We often find cigarette lighters, bucket handles, toothbrushes, syringes, toy soldiers — anything made out of plastic."

It's all part of a tide of plastic debris that has spread throughout the world's oceans, posing a lethal hazard to wildlife, even here, more than 1,000 miles from the nearest city.

Midway, an atoll halfway between North America and Japan, has no industrial centers, no fast-food joints with overflowing trash cans, and only a few dozen people.

Its isolation would seem to make it an ideal rookery for seabirds, especially Laysan albatross, which lay their eggs and hatch their young here each winter. For their first six months of life, the chicks depend entirely on their parents for nourishment. The adults forage at sea and bring back high-calorie takeout: a slurry of partly digested squid and flying-fish eggs.

As they scour the ocean surface for this sustenance, albatross encounter vast expanses of floating junk. They pick up all manner of plastic debris, mistaking it for food.

As a result, the regurgitated payload flowing down their chicks' gullets now includes Lego blocks, clothespins, fishing lures and other pieces of plastic that can perforate the stomach or block the gizzard or esophagus. The sheer volume of plastic inside a chick can leave little room for food and liquid.

Of the 500,000 albatross chicks born here each year, about 200,000 die, mostly from dehydration or starvation. A two-year study funded by the U.S. Environmental Protection Agency showed that chicks that died from those causes had twice as much plastic in their stomachs as those that died for other reasons.

The atoll is littered with decomposing remains, grisly wreaths of feathers and bone surrounding colorful piles of bottle caps, plastic dinosaurs, checkers, highlighter pens, perfume bottles, fishing line and small Styrofoam balls. Klavitter has calculated that albatross feed their chicks about 5 tons of plastic a year at Midway.

Albatross fly hundreds of miles in their search for food for their young. Their flight paths from Midway often take them over what is perhaps the world's largest dump: a slowly rotating mass of trash-laden water about twice the size of Texas.

This is known as the Eastern Garbage Patch, part of a system of currents called the North Pacific subtropical gyre. Located halfway between San Francisco and Hawaii, the garbage patch is an area of slack winds and sluggish currents where flotsam collects from around the Pacific, much like foam piling up in the calm center of a hot tub.

Curtis Ebbesmeyer has been studying the clockwise swirl of plastic debris so long, he talks about it as if he were tracking a beast.

"It moves around like a big animal without a leash," said Ebbesmeyer, an oceanographer in Seattle and leading expert on currents and marine debris. "When it gets close to an island, the garbage patch barfs, and you get a beach covered with this confetti of plastic."

Some oceanic trash washes ashore at Midway — laundry baskets, television tubes, beach sandals, soccer balls and other discards.

Nearly 90% of floating marine litter is plastic — supple, durable materials such as polyethylene and polypropylene, Styrofoam, nylon and saran.

About four-fifths of marine trash comes from land, swept by wind or washed by rain off highways and city streets, down streams and rivers, and out to sea.

The rest comes from ships. Much of it consists of synthetic floats and other gear that is jettisoned illegally to avoid the cost of proper disposal in port.

In addition, thousands of cargo containers fall overboard in stormy seas each year, spilling their contents. One ship heading from Los Angeles to Tacoma, Wash., disgorged 33,000 blue-and-white Nike basketball shoes in 2002. Other loads lost at sea include 34,000 hockey gloves and 29,000 yellow rubber ducks and other bathtub toys.

The debris can spin for decades in one of a dozen or more gigantic gyres around the globe, only to be spat out and carried by currents to distant lands. The U.N. Environment Program estimates that 46,000 pieces of plastic litter are floating on every square mile of the oceans. About 70% will eventually sink.

Albatross are by no means the only victims. An estimated 1 million seabirds choke or get tangled in plastic nets or other debris every year. About 100,000 seals, sea lions, whales, dolphins, other marine mammals and sea turtles suffer the same fate.

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The amount of plastic in the oceans has risen sharply since the 1950s. Studies show a tenfold increase every decade in some places. Scientists expect the trend to continue, given the popularity of disposable plastic containers. The average American used 223 pounds of plastic in 2001. The plastics industry expects per-capita usage to increase to 326 pounds by the end of the decade.

The qualities that make plastics so useful are precisely what cause them to persist as trash.

Derived from petroleum, plastics eventually break down into carbon dioxide and water from exposure to heat and the sun's ultraviolet rays.

On land, the process can take decades, even centuries. At sea, it takes even longer, said Anthony L. Andrady, a polymer chemist at the Research Triangle Institute in North Carolina who studies marine debris. Seawater keeps plastics cool while algae, barnacles and other marine growth block ultraviolet rays.

"Every little piece of plastic manufactured in the past 50 years that made it into the ocean is still out there somewhere," Andrady said, "because there is no effective mechanism to break it down."

Oceanographers have counted on beachcombers around the world to help them plot the course of plastic flotsam as it circumnavigates the globe. Ebbesmeyer has found that some debris gets hung up for decades in gyres before being spun out into different currents, flung ashore or picked up by animals.

A piece of plastic found in an albatross stomach last year bore a serial number that was traced to a World War II seaplane shot down in 1944. Computer models re-creating the object's odyssey showed it spent a decade in a gyre known as the Western Garbage Patch, just south of Japan, and then drifted 6,000 miles to the Eastern Garbage Patch off the West Coast of the U.S., where it spun in circles for the next 50 years.

The Hawaiian archipelago, which stretches from the Big Island of Hawaii westward for 1,500 miles to Kure Atoll, acts like 19 unevenly spaced teeth of a giant comb, snagging debris drifting around the Pacific. Most of the archipelago's atolls are awash in plastic junk, as are some beaches on the main islands.

Native Hawaiians, seeking wood for dugout canoes, used to go to Kamilo Beach at the southernmost tip of the Big Island to collect enormous logs that had drifted from the Pacific Northwest. Now, locals like Noni Sanford pick through the debris for novelties to enter in a trash-art show in Hilo every fall.

Sanford, 58, a free-spirited great-grandmother with long gray hair pulled back in a ponytail, once won second place for a mobile fashioned out of fishing line, floats and a colorful palette of plastic toothbrushes.

As a lifelong beachcomber, she is fascinated and horrified by the transformation of Kamilo Beach since she first set foot there in 1959. She was searching for driftwood with her father, a sculptor.

She remembers seeing a few tires back then. Now, plastic debris litters the crescent-shaped beach for more than a mile.

"This is nothing," Sanford said, stepping over a pile of twisted lines and nets. "This used to be 8 and 10 feet high. Of course, that was three or four cleanups ago."

Sanford and her husband, Ron, have joined in regular cleanup efforts, organized most recently by Bill Gilmartin, a retired wildlife biologist who studied monk seals.

"The rule is, don't pick up anything smaller than your fist," Gilmartin told a team of volunteers. "Otherwise, it'll take forever. We'll never be done."

Noni Sanford reached down, scooped up a handful of beach sand and let it trickle through her fingers. Most of the grainy mix was bits and pieces of plastic. The beach itself, it seemed, was turning into plastic.

Cleanup efforts in Hawaii and elsewhere have focused on "ghost nets," tangles of abandoned fishing lines, nets and traps that snare and kill marine life.

The National Oceanic and Atmospheric Administration dispatches scuba divers every year to cut tons of these deathtraps off Hawaiian coral reefs. It's dangerous and costly work. In July 2005, a 145-foot charter vessel brought in to haul away nets ran aground on the reef at Pearl and Hermes Atoll, about 100 miles from Midway. The ship was lost. The Coast Guard flew the 23 divers and crew 1,200 miles back to Honolulu.

If it were easier to find them, it would make sense to round up the medusas of nets and synthetic lines at sea before they snagged on coral reefs and endangered monk seals and other coastal wildlife.

But the Pacific spans millions of square miles, and even the debris circulating in the Eastern and Western garbage patches is often diffuse and hard to see, bobbing just below the surface.

Connecting the two patches is a ribbon of oceanic highway that stretches 6,000 miles, an extension of Japan's Kuroshio Current heading east. Oceanographers call this the Subtropical Convergence Zone, where the cold, green, heavier waters from the north slide under the warm, blue waters of the south.

A team of scientists working on NOAA's GhostNet Detection Project suspected that flotsam collected along this line, making it an ideal place to concentrate cleanups. Yet they couldn't be sure. They needed to see it.

The team got its chance last year, after persuading NOAA to lend them an instrument-packed, four-engine reconnaissance plane often deployed to study hurricanes. Wearing life jackets while flying 1,000 feet above the ocean's surface, observers were positioned at windows to spot nets and floats. They were to call out each sighting over the plane's intercom. Others were poised to jot down the location of each sighting.

"When we got into it, we couldn't write fast enough," said Tim Veenstra, an Alaskan pilot and private researcher working with government scientists. The meandering line of buoys, nets, life rings, buckets and other castoffs stretched for hundreds and hundreds of miles — until the airplane had to turn back.

"It was sort of a bittersweet feeling," Veenstra said. "Sweet in the fact that what we had postulated was proven true. Bitter in the fact that there was actually that much debris floating around."

Tuna fishermen have long known about the convergence zone and the debris. They know that fish like to congregate beneath anything that floats.

Off the southern tip of the Big Island of Hawaii, recreational fishermen like Guy Enriques will race miles offshore to fish beneath the flotsam.

It's important to get close to the trash, but not too close, Enriques explained, or the nets and lines will wrap around a boat's propeller.

He said the best fishing was around what looked like an enormous metal garage door floating just below the water's surface. Even some charter boat skippers learned of that one, Enriques recalled, and took fishermen there day after day, until it vanished.

But it wasn't a garage door. He and other fishermen were looking at the top of an 8-by-40-foot cargo container that fell off a ship. Such containers can float for as long as nine months. Until they sink, they are the bane of sailors in fiberglass boats who watch for them like icebergs on the high seas.

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Charles Moore, a member of the Hancock Oil family, was on his way home from the Los Angeles-to-Hawaii Transpacific Yacht Race in 1997 when he took a shortcut through the Eastern Garbage Patch. It's a place that sailors usually avoid because it lacks wind.

As he motored through on his 50-foot catamaran, Moore was startled by what he saw thousands of miles from land. "Every time I came on deck, there was trash floating by," he said. "How could we have fouled such a huge area? How could this go on for a week?"

The experience changed Moore's life, turning him from an adventurer into a self-taught scientist and environmental activist.

Two years later, he returned to the garbage patch with a volunteer crew to survey its contents. He knew he would collect plenty of plastic bags, bottle caps, nets and floats.

He didn't expect what turned up in a special net, one with a tight mesh for collecting plankton, the bottom link in the oceanic food chain. Instead of plankton, it was choked with a colorful array of tiny plastic fragments.

"It blew my mind," Moore said. "We are filling up the oceans with this confetti stuff, and nobody cares."

Over the last decade, Moore, 59, who lives in a waterfront home in Long Beach, has spent his own money and some from a family foundation on a quest to track the plume of plastic so he can figure out how to stop it.

On a cloudless spring day, Moore waded up to his knees into the Los Angeles River in Long Beach wearing shorts, sandals and a white hard hat. He was tethered to a volunteer standing on the dry riverbank, in case he slipped on the slick concrete channel.

The Los Angeles River carries enough trash each year to fill the Rose Bowl two stories high, and despite efforts to corral some of it near the river mouth, most slips through to the ocean.

Moore adjusted a trawlnet to collect trash flowing downriver. At Moore's signal, a crane operator lifted the net out of the water. Volunteers swarmed around the trawlnet, extracted the contents and loaded them into more than a dozen jars.

The jars were filled with plastic pellets the size and shape of pills. They come in all colors and are the raw material for a vast array of plastic products, from trash bags to medical devices.

About 100 billion pounds of pellets are produced every year and shipped to Los Angeles and other manufacturing centers. Huge numbers are spilled on the ground and swept by rainfall into gutters; down storm drains, creeks and rivers; and into the ocean.

From his river sampling, Moore estimated that 236 million pellets washed down the Los Angeles and San Gabriel rivers in three days' time. Also known as "nurdles" or mermaid tears, they are the most widely seen plastic debris around the world. They have washed ashore as far away as Antarctica.

The pellets, like most types of plastic, are sponges for oily toxic chemicals that don't readily dissolve in water, such as the pesticide DDT and polychlorinated biphenyls, or PCBs. Some pellets have been found to contain concentrations of these pollutants 1 million times greater than the levels found in surrounding water.

As they absorb toxic chemicals, they become poison pills. Wildlife researchers have found the

pellets, which resemble fish eggs, in the bellies of fish, sea turtles, seabirds and marine mammals.

Over time, plastic can break down into smaller and smaller pieces, eventually turning to powder and entering the ocean in microscopic fragments. Some plastic starts out as tiny particles, such as the abrasives in cleaning products that are washed down the sink, through sewage systems and out to sea.

The chemical components of plastics and common additives can harm animals and humans. Studies have linked the hormone-mimicking phthalates, used to soften plastic, to reduced testosterone and fertility in laboratory animals, and to subtle changes in the genitals of baby boys. Another additive, bisphenol A, used to make lightweight, heat-resistant baby bottles and microwave cookware, has been linked to prostate cancer.

Moore has tried, without success, to get manufacturers to improve their efforts to clean up spills of pellets that wash off lots and into storm drains. He considers beach cleanups a waste of time, except to raise public awareness of the problem. In his view, the cleanup has to start at the source — many miles inland.

To make that point, Moore tromped through rail yards in Vernon and La Mirada. On the side of a rail car a faded decal read "Operation Clean Sweep." It had three check boxes:

"Keep Plastics Off Ground.

"Close and Lock Caps When Outlets Not in Use.

"Pick Up All Spills."

Beneath the sign was a cone-shaped pile of pellets, as white as freshly fallen snow. Moore shuffled his sandaled feet through another drift nearby.

"This is a plastic sand dune," he said. "It's very slippery, very roly-poly. What makes them so good for the factory makes them good for getting into the ocean."

## **PART FIVE** ALTERED OCEANS

### **A Chemical Imbalance**

**Growing seawater acidity threatens to wipe out coral, fish and other crucial species worldwide.**

By Usha Lee McFarling, Times Staff Writer  
August 3, 2006

As she stared down into a wide-mouthed plastic jar aboard the R/V Discoverer, Victoria Fabry peered into the future.

The marine snails she was studying — graceful creatures with wing-like feet that help them glide through the water — had started to dissolve.

Fabry was taken aback. The button-sized snails, called pteropods, are hardy animals that swirl in dense patches in some of the world's coldest seas. In 20 years of studying the snails, a vital ingredient in the polar food supply, the marine biologist from Cal State San Marcos had never seen such damage.

In a brief experiment aboard the federal research vessel plowing through rough Alaskan seas, the pteropods were sealed in jars. The carbon dioxide they exhaled made the water inside more acidic. Though slight, this change in water chemistry ravaged the snails' translucent shells. After 36 hours, they were pitted and covered with white spots.

The one-liter jars of seawater were a microcosm of change now occurring invisibly throughout the world's vast, open seas.

As industrial activity pumps massive amounts of carbon dioxide into the environment, more of the gas is being absorbed by the oceans. As a result, seawater is becoming more acidic, and a variety of sea creatures await the same dismal fate as Fabry's pteropods.

The greenhouse gas, best known for accumulating in the atmosphere and heating the planet, is entering the ocean at a rate of nearly 1 million tons per hour — 10 times the natural rate.

Scientists report that the seas are more acidic today than they have been in at least 650,000 years. At the current rate of increase, ocean acidity is expected, by the end of this century, to be 2 1/2 times what it was before the Industrial Revolution began 200 years ago. Such a change would devastate many species of fish and other animals that have thrived in chemically stable seawater for millions of years.

Less likely to be harmed are algae, bacteria and other primitive forms of life that are already proliferating at the expense of fish, marine mammals and corals.

In a matter of decades, the world's remaining coral reefs could be too brittle to withstand pounding waves. Shells could become too fragile to protect their occupants. By the end of the century, much of the polar ocean is expected to be as acidified as the water that did such damage to the pteropods aboard the Discoverer.

Some marine biologists predict that altered acid levels will disrupt fisheries by melting away the bottom rungs of the food chain — tiny planktonic plants and animals that provide the basic nutrition for all living things in the sea.

Fabry, who recently testified on the issue before the U.S. Senate, told policymakers that the effects on marine life could be "direct and profound."

"The potential is there to have a devastating impact," Fabry said, "for the oceans to be very, very different in the near future than they are today."

The oceans have been a natural sponge for carbon dioxide from time immemorial. Especially after calamities such as asteroid strikes, they have acted as a global safety valve, soaking up excess CO<sub>2</sub> and preventing catastrophic overheating of the planet.

If not for the oceans, the Earth would have warmed by 2 degrees instead of 1 over the last century, scientists say. Glaciers would be disappearing faster than they are, droughts would be more widespread and rising sea levels would be more pronounced.

When carbon dioxide is added to the ocean gradually, it does little harm. Some of it is taken up during photosynthesis by microscopic plants called phytoplankton. Some of it is used by microorganisms to build shells. After their inhabitants die, the empty shells rain down on the seafloor in a kind of biological snow. The famed white cliffs of Dover are made of this material.

Today, however, the addition of carbon dioxide to the seas is anything but gradual.

Scientists estimate that nearly 500 billion tons of the gas have been absorbed by the oceans

since the start of the Industrial Revolution. That is more than a fourth of all the CO<sub>2</sub> that humanity has emitted into the atmosphere. Eventually, 80% of all human-generated carbon dioxide is expected to find its way into the sea.

Carbon dioxide moves freely between air and sea in a process known as molecular diffusion. The exchange occurs in a film of water at the surface. Carbon dioxide travels wherever concentrations are lowest. If levels in the atmosphere are high, the gas goes into the ocean. If they are higher in the sea, as they have been for much of the past, the gas leaves the water and enters the air.

If not for the CO<sub>2</sub> pumped into the skies in the last century, more of the gas would leave the sea than would enter it.

"We have reversed that direction," said Ken Caldeira, an expert on ocean chemistry and carbon dioxide at the Carnegie Institution's department of global ecology, based at Stanford University.

When carbon dioxide mixes with seawater, it creates carbonic acid, the weak acid in carbonated drinks.

Increased acidity reduces the abundance of the right chemical forms of a mineral called calcium carbonate, which corals and other sea animals need to build shells and skeletons. It also slows the growth of the animals within those shells.

Even slightly acidified seawater is toxic to the eggs and larvae of some fish species. In others, including amberjack and halibut, it can cause heart attacks, experiments show. Acidified waters also tend to asphyxiate animals that require a lot of oxygen, such as fast-swimming squid.

The pH scale, a measure of how acidic or alkaline a substance is, ranges from 1 to 14, with 7 being neutral. The lower the pH, the greater the acidity. Each number represents a tenfold change in acidity or alkalinity.

For more than a decade, teams led by Richard Feely, a chemical oceanographer at the National Oceanic and Atmospheric Administration's Pacific Marine Environmental Laboratory in Seattle, have traveled from Antarctica to the Aleutian Islands, taking tens of thousands of water samples to gauge how the ocean's acidity is changing.

By comparing these measurements to past levels of carbon dioxide preserved in ice cores, the researchers determined that the average pH of the ocean surface has declined since the beginning of the Industrial Revolution by 0.1 units, from 8.16 to 8.05.

Geological records show that such a change has not occurred in 650,000 years, Feely said.

In April, Feely returned from a cruise to the North Pacific, where he took pH measurements at locations the team first sampled in 1991. This time, Feely's group found that the average pH in surface waters had dropped an additional 0.025 units in 15 years — a relatively large change for such a short time.

The measurements confirm those taken in the 1990s and indicate that forecasts of increased acidity are on target, Feely said.

If CO<sub>2</sub> emissions continue at their current pace, the pH of the ocean is expected to dip to 7.9 or lower by the end of the century — a 150% change.

The last time ocean chemistry underwent such a radical transformation, Caldeira said, "was when the dinosaurs went extinct."

Until recently, the ocean was seen as a potential reservoir for greenhouse gases. Scientists

explored the possibility that carbon dioxide could be trapped in smokestacks, compressed into a gooey liquid and piped directly into the deep sea.

Then the results of Jim Barry's experiments started trickling in.

A biologist at the Monterey Bay Aquarium Research Institute, Barry wanted to know what would happen to sea creatures in the vicinity of a large dose of carbon dioxide.

He anchored a set of small plastic rings onto the seafloor to create an enclosure and sent a robot down to squirt liquid carbon dioxide into the surrounding water. Then he waited to see what would happen to animals in the enclosures and those that happened to swim through the CO<sub>2</sub> cloud.

Sea stars, sea cucumbers and sea urchins died immediately. Eighty percent of animals within three feet of the carbon dioxide died. Animals 15 feet away also perished in large numbers.

"When they were adjacent to the CO<sub>2</sub> plume, pretty much, it killed everything," Barry said.

Experiments in Germany, Norway and Japan produced similar results. The evidence persuaded the U.S. Department of Energy, which had spent \$22 million on such research, including Barry's, to pull the plug. Instead, the department will study the possibility of storing carbon dioxide in the ground and on decreasing emissions at their source.

Scientists say the acidification of the oceans won't be arrested unless the output of CO<sub>2</sub> from factories, power plants and automobiles is substantially reduced. Even now, the problem may be irreversible.

"One thing we know for certain is it's not going to be a good thing for the ocean," Barry said. "We just don't know how bad it will be."

Scientists predict the effect will be felt first in the polar oceans and at lower depths, because cold water absorbs more carbon dioxide than warm water. One area of immediate concern is the Bering Sea and other waters around Alaska, home to half of the commercial U.S. fish and shellfish catch.

Because of acidification, waters in the Bering Sea about 280 feet down are running short of the materials that corals and other animals need to grow shells and skeletons. These chemical building blocks are normally abundant at such depths. In coming decades, the impoverished zone is expected to reach closer to the surface. A great quantity of sea life would then be affected.

"I'm getting nervous about that," Feely said.

The first victims of acidification are likely to be cold-water corals that provide food, shelter and reproductive grounds for hundreds of species, including commercially valuable ones such as sea bass, snapper, ocean perch and rock shrimp.

By the end of the century, 70% of cold-water corals will be exposed to waters stripped of the chemicals required for sturdy skeletons, said John Guinotte, an expert on corals at the nonprofit Marine Conservation Biology Institute in Bellevue, Wash.

"I liken it to osteoporosis in humans," Guinotte said. "You just can't build a strong structure without the right materials."

Cold-water corals, which thrive in waters as deep as three miles, were discovered only two decades ago. They harbor sponges, which show promise as powerful anti-cancer and antiviral agents; the AIDS drug AZT was formulated using clues from a coral sponge. Scientists fear that these unique ecosystems may be obliterated before they can be fully utilized or appreciated.

Tropical corals will not be affected as quickly because they live in warmer waters that do not absorb as much carbon dioxide. But in 100 years, large tropical reefs — called rain forests of the sea because of their biodiversity — may survive only in patches near the equator.

"Twenty-five percent of all species in the ocean live part of their life cycle on coral reefs. We're afraid we're going to lose these habitats and these species," said Chris Langdon, a coral expert at the University of Miami who has conducted experiments showing that corals grow more slowly when exposed to acidified waters.

Warm-water corals are already dying at high rates as global warming heats oceans and causes corals to "bleach" — lose or expel the symbiotic algae that provide vivid color and nutrients necessary for survival. Pollution, trampling by tourists and dynamiting by fishermen also take a devastating toll. An estimated 20% of the world's corals have disappeared since 1980.

"Corals are getting squeezed from both ends," said Joanie Kleypas, a marine ecologist and coral expert at the National Center for Atmospheric Research in Boulder, Colo.

The question for scientists is whether living things will adapt to acidification. Will some animals migrate to warmer waters that don't lose shell-building minerals as quickly? Will some survive despite the new chemistry? Will complex marine food chains be harmed?

One laboratory experiment showed that a strain of shelled plankton thrived in higher CO<sub>2</sub> conditions. But most research has shown that shelled animals and corals stop growing or are damaged.

"We put a lot of faith in the idea that organisms can adapt," Kleypas said, "but organisms have probably not evolved to handle these big changes."

The best analogy to what is occurring today is in the fossil records of a 55-million-year-old event known as the Paleocene-Eocene Thermal Maximum, when the Earth underwent one of the most abrupt and extreme global warming events in history.

The average temperature of the planet rose 9 degrees because of an increase in greenhouse gases. Balmy 70-degree days were common in the Arctic. The sudden warming shifted entire ecosystems to higher and cooler latitudes and drove myriad ocean species to extinction.

Geologists agree that a great warming occurred as a result of greenhouse gases, but until recently were uncertain about the volume of gas involved or how much the acidity of the oceans changed.

James Zachos, a paleo-oceanographer at UC Santa Cruz, made an important discovery in 2003 by drilling into seabed sediments more than two miles beneath the ocean's surface. This muck contains layers of microscopic plankton shells. Their chemical composition reveals what ocean conditions were like when they formed.

Zachos' international team analyzed sediments from a series of cores taken from the floor of the Atlantic Ocean 750 miles west of Namibia. At the bottom of the cores, the team found normal sediments, rich in calcium carbonate from shells — the sign of a healthy ocean.

But higher up, at a point in geologic history when the last major global warming event occurred, the whitish, carbonate-rich ooze gave way to a dark red clay layer free of shells. That condition, the researchers concluded, was caused by a highly acidified ocean. This state of affairs lasted for 40,000 or 50,000 years. It took 60,000 years before the ocean recovered and the sediments appeared normal again.

In a paper published last year in the journal *Science*, Zachos' team concluded that only a massive release of carbon dioxide could have caused both extreme warming and acidification of ocean waters.

Zachos estimated that 4.5 trillion tons of carbon entered the atmosphere to trigger the event.

It could take modern civilization just 300 years to unleash the same quantity of carbon, according to a variety of projections by researchers.

"This will be a much greater shock," Zachos said. "The change in modern surface ocean pH will be much more extreme than it was 55 million years ago."