The Rise in Toxic Tides

What's behind the ocean blooms?

By CHRISTINE MLOT

In 1984, a small herd of cows in Montana collapsed and died 10 minutes after drinking from a pond coated with a pea green film.

In 1987, three people died and more than 100 became ill after eating blue mussels from Prince Edward Island.

In 1996, 149 manatees perished mysteriously off the coast of Florida. Autopsies of these endangered marine mammals revealed biological poisons in their brains and other tissues.

In the last 2 months, thousands of fish have sickened and died in tributaries of the Chesapeake Bay. The kills resemble a decade-long pattern in North Carolina estuaries, where a billion or more crabs and fish, especially menhaden, have been killed.

Researchers and the news media have recorded an increasing number of water-related poisonings of both wildlife and people worldwide since the 1970s. The culprits have turned out to be potent toxins produced by any of several single-celled aquatic organisms—some well known, others completely new and dumbfounding in their biology.

A droplet of pond or ocean water contains myriad numbers and species of these organisms. They live in an ancient microscopic realm that is neither wholly bacterial nor animal nor plant, even though they are often classified with algae.

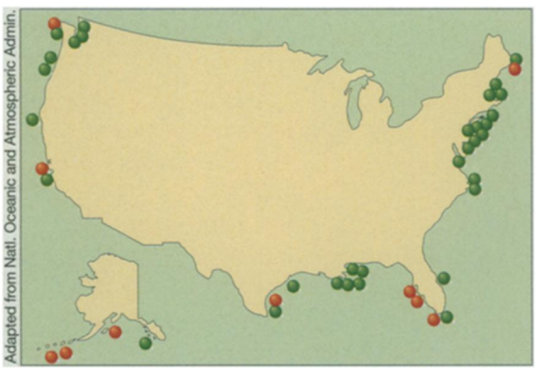
"There's clearly been an increase in both the frequency and extents of harmful algal blooms in coastal waters," says Frances M. Van Dolah of the National Marine Fisheries Service in Charleston, S.C.

The question is, why?

The toxins causing the Chesapeake and North Carolina fish kills have come from *Pfiesteria*, an organism that has attracted the attention of scientists only in this decade. Its treacherous ways have recently caught the public's attention as well. Last week, in an interim report, a medical team appointed by Maryland Governor Parris N. Glendening linked intensive exposures to toxic *Pfiesteria*-containing waters with memory and health problems in 13 people.

Yet *Pfiesteria* is only one of the toxin producers that are dramatically making their presence known. These organisms have traditionally been called algae or plankton, specifically phytoplankton. When they reproduce into large populations, they are informally known as tides or harmful blooms. Recent textbooks call most of these single-celled microorganisms protists. During evolution, protists gave rise to macroscopic plants and animals.

Pfiesteria, with its 24-stage life cycle, defies neat categorization. At some stages, it swims about powered by two flagella and so is considered a dinoflagellate.



Adapted from Natl. Oceanic and Atmospheric Admin.

Increase in toxin-producing blooms in U.S. coastal waters from before 1972 (red) to 1997 (green).

Dinoflagellates are key players in aquatic ecosystems. Large numbers of them live only in the pores of ice, for example, where they photosynthesize and provide food for other organisms. *Pfiesteria* can photosynthesize, but only if it has stolen the green organelles called chloroplasts from true algal cells. It uses a hoselike attachment to acquire these "kleptochloroplasts."

Although *Pfiesteria* can subsist in this way, says JoAnn M. Burkholder of North Carolina State University in Raleigh, it changes its eating habits depending on what's available. When fish are around, it can turn into a predator. It abandons its usual swirling swim pattern and makes a beeline for its prey in response to an unknown cue, perhaps in fish oil or excrement.

Then *Pfiesteria* churns out its toxic cocktail. It emits at least one compound that seems to kill the fish and another that opens up the fish's skin, allowing *Pfiesteria* to feed on the tissue inside (SN: 9/6/97, p. 149). Burkholder, a codiscoverer of *Pfiesteria*, has personally experienced its toxic effects

Finding *Pfiesteria*

When fish suddenly die or develop lesions, it's no simple matter to learn the cause. In the first major report on *Pfiesteria*, in the July 30, 1992 NATURE, JoAnn M. Burkholder and her colleagues called it a "phantom" dinoflagellate because it disappears into the mud after killing fish.

Even when a water sample captures the cell in its toxic state, definitive identification as a species of *Pfiesteria* remains a challenge. Researchers first have to use a detergent bath to strip the cell of its outer membranes. This reveals the cellulose plates that *Pfiesteria* wears like armor. Next, a researcher must fix the cell for examination with an electron microscope. Several views are required to count all the plates and study their arrangement.

"It's tedious," says Karen Steidinger of the Florida Marine Research Institute in St. Petersburg. She is one of only a handful of researchers expert in recognizing the cells.

Consequently, researchers have been developing techniques to identify *Pfiesteria* based on its molecular characteristics.

Parke A. Rublee of the University of North Carolina at Greensboro is working on a fluorescent probe to recognize *Pfiesteria*. He and his colleagues have found eight ribosomal DNA regions that seem to be unique to *Pfiesteria*. The researchers are currently testing their approach on samples from the recent Chesapeake fish kills. —*C.M.*

H. Glasgow and Burkholder

Dead menhaden bearing sores from toxic Pfiesteria.

and knows the organism inside out. "It's plant-*and* animal-like," she says.

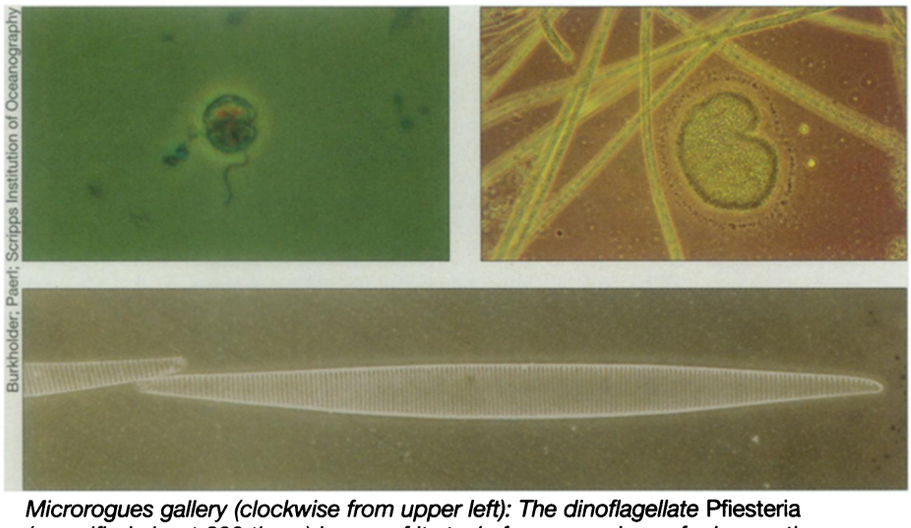
The dinoflagellates responsible for so-called red tides behave more like plants. The pigments they use in photosynthesis can tint the water red during a bloom. Beachcombers notice red tides in other ways—airborne toxins sting the insides of their noses and throats.

Red tides have been around at least since biblical times. In Exodus, a plague turned the water bloodred and destroyed fish. In recent times, such tides have become more frequent and more noticeable. In 1972, New England experienced its first red tide, with devastating effects on the shellfish industry. In Florida, where red tides usually last from 3 to 5 months, one persisted for 18 months, culminating in the manatee deaths in 1996.

Another group of plankton, surprisingly, was responsible for the Prince Edward illness. Canadian researchers traced the outbreak to a toxin, domoic acid, produced by a diatom. Until then, diatoms had been known mainly as benign photosynthesizers. Lacking flagella, they tumble about in the surf or waves, protected by often spectacular filigrees of silica.

In 1991, dozens of California pelicans and cormorants died after feeding on anchovies found to contain the toxin from these diatoms. The toxic diatoms have since been found around the world.

The cows' demise was less mysterious. They were felled by toxins from the oldest photosynthesizers on earth, cyanobacteria, formerly called blue-green algae. They are not always blue-green. One kind blooms frequently in the Red Sea and is probably responsible for its name. Other cyanobacteria grow into bright green films, like the one on the lethal lake in Montana.



Burkholder; Paerl; Scripps Institution of Oceanography

Microrogues gallery (clockwise from upper left): The dinoflagellate Pfiesteria *(magnified about 600 times) in one of its toxic forms; a colony of microcystin-producing cyanobacteria (magnified about 400 times) with a halo of associated bacteria; and the toxic diatom* Pseudonitzschia *with its silica coat (colorized and magnified about 1,000 times).*

Brown tides: Nontoxic but still killers

Red tides are the work of dinoflagellates. Green films are cyanobacteria. Brown tides are formed by still another stripe of cell: marine plankton called chrysophytes, also known as golden-brown algae.

Unlike cells in the red and green blooms, brown tide cells do not produce a neurotoxin; however, their chocolaty blooms are no less devastating. The tiny cells grow to incredible densities—1 million to 2 million cells in a milliliter—and shade the plant life in shallow bays. The effects rattle the food chain.

In 1985, the first known brown tide appeared off Long Island, N.Y., and destroyed the local bay scallops industry. In 1989, the bloom of another golden-brown species appeared off part of Texas' Gulf Coast—remarkably, it hasn't left yet. That bloom has destroyed the beds of seagrass that act as a nursery for fish larvae.

Although brown tides kill by a different means than other algal blooms, researchers suspect that they are also linked to an increased flush of nutrients into coastal waters.

In the October GLOBAL CHANGE BIOLOGY, Julie LaRoche and her colleagues from Brookhaven National Laboratory in Upton, N.Y., describe 11 years of monitoring the ebb and flow of brown tides around Long Island. The key seems to be the flow of groundwater. The researchers suggest that low groundwater, from sparse rainfall, increases the amount of organic nitrogen available, favoring brown tides. —*C.M.*

As efficiently as the cows were killed, they were hardly the bacteria's intended target, says Hans Paerl of the University of North Carolina at Morehead City. Almost nothing threatens these bacteria. "The cyanobacteria are not worried about cows, they're not worried about humans, they're not worried about anything except the microbes that they're very intimately associated with."

Like gardeners, cyanobacteria cultivate some bacteria and weed out others by leaking certain compounds, including some that happen to be toxic to animals, Paerl says. One such cyanobacterial toxin is microcystin. It locks onto and shuts down phosphatase enzymes, which are common to all organisms. Some toxic marine dinoflagellates target the same phosphatase enzymes.

Red tide dinoflagellates produce toxins that target a protein channel in muscle and nerve cells that allows signals to be passed along. Called brevetoxins, they are long, sinuous molecules of connected carbon rings—what Daniel G. Baden of the University of Miami calls "polychicken wire." They conform to specific receptors on the channels and keep them open too long, resulting in paralysis.

Other dinoflagellates that live in association with seaweeds on coral reefs produce ciguatoxin, which takes a similar shape and attacks the same channel. Small reef-dwelling fish ingest the toxin, which becomes concentrated in large predators, such as barracuda, further up the food chain.

The increasing popularity of snapper, amberjack, and other reef fish in temperate markets is widening the risk of ciguatera poisoning. The Food and Drug Administration and other groups are working on ways of detecting this powerful poison. A single dinner of fish can bring on the gastrointestinal and neurological effects of ciguatera, but it takes 170 kilograms of fish to extract just 100 micrograms of the toxin—about a sesame seed's worth from a dinghy full of fish.

Mussels and other shellfish that feed on diatoms and dinoflagellates can accumulate toxins with no apparent effect, but when people eat shellfish harvested during a toxic tide, the result can be unpleasant—even lethal. The usually colorless toxins are difficult to detect, and they withstand the heat of cooking. They can produce gastrointestinal effects, dizziness and confusion, memory loss, or paralysis.

Researchers understand in exquisite detail the molecular workings of these powerful toxins once they're ingested. They know far less about why the microorganisms produce them and what, if anything, can be done to suppress toxic blooms. In August, the National Institute of Environmental Health Sciences in Research Triangle Park, N.C.,

sponsored a meeting that may signal new support for investigation of the environmental and ecological aspects of the toxin-producing organisms.

For now, researchers have a handful of possible explanations for the increase in toxic tides.

At least some of the toxin producers seem to be responding to increases in the amount of nitrogen (SN: 2/15/97, p. 100), phosphorus, and other nutrients washing off the land from fertilizers and animal wastes. As Hong Kong experienced a sixfold increase in population between 1976 and 1986, the concentrations of nutrients in its harbor more than doubled, and the annual count of red tides increased from 2 to 18.

Pfiesteria outbreaks, too, seem to be connected to nutrients, which stimulate the growth of the algae that *Pfiesteria* feed on, says Burkholder. In North Carolina, "75 percent of the kills that we've observed have occurred in nutrient-overenriched areas."

At the same time, some of the toxin producers seem to respond to pollution controls. In Japan's Seto Inland Sea 4 years after sewage and effluent controls were implemented, the number of red tides leveled off at about half their peak of 300.

In other places, dams may contribute to changes in nutrients. In the March 27 NATURE, European researchers reported that a dam on the Danube River has altered the Black Sea's chemistry, in turn skewing the major species in the plankton community from diatoms to dinoflagellates.

Some researchers believe that a global change in the complex interaction of climate, ocean, and temperature is affecting marine plankton (SN: 9/30/95, p. 220), as well as other organisms (SN: 4/6/96, p. 218).

Increased traffic on the world's oceans may be another factor in seeding new blooms, according to several scientists. Water used as ballast in ships has transported and introduced animals into new waters; exotic microorganisms are probably being introduced as well, says Fred C. Dobbs of Old Dominion University in Norfolk, Va.

Finally, the increased frequency of the blooms may be partly an effect of heightened interest in these events, expanding fish farming, or improved methods of detecting toxins that had previously gone undiagnosed or unnoticed.

"There are toxic and nontoxic blooms all the time," says Jeffrey L.C. Wright of the National Research Council of Canada in Halifax, Nova Scotia. "If you don't have blooms, you don't have life. They are part of the natural ocean processes."

Today's oil deposits in the North Sea and elsewhere are the remains of bygone blooms that settled and accumulated into massive amounts of carbon on the ocean floor.

The causes of the increase may be the focus of study and debate, but there is one thing on which researchers agree: Other, as-yet-undetected microorganisms or their toxins will eventually make their presence known.

Of the rash of blooms and poisonings in the last 2 decades, several have involved unknown toxins or organisms (see sidebar, p. 203). When farm-raised salmon died recently in Washington State, researchers found microcystin, but they have yet to find the producer.

In the case of *Pfiesteria*, the most infamous of the newly discovered microrogues, researchers are trying to figure out how its toxins act. The secrets of the organism itself haven't been completely cracked either (see sidebar, p. 202). *Pfiesteria* seems to be a complex of at least four species, according to Burkholder, although only *P. piscicida* has been named.

The water world these organisms occupy is huge, much of it unexplored, and they've been concocting toxins for eons. "In terms of biological interactions and biological warfare, they've seen it all," says Paerl.

Through a range of activities, humankind has simply waded into the crossfire. □

Behavior

Meds may give attention a lasting boost

An estimated 1 in 50 school-age children in the United States receive stimulant medication to help quell inattentiveness and hyperactivity. A month or two of this treatment helps many youngsters, although researchers have yet to show that stimulants exert benefits over the long haul.

Now, a study conducted in Sweden indicates that an amphetamine given to kids diagnosed with attention-deficit hyperactivity disorder (ADHD) often reduces their core behavior problems during and after the treatment. About one in seven children taking the medication did not improve or dropped out of the study because of severe side effects, report psychiatrist Christopher Gillberg of the University of Göteborg and his coworkers.

The investigation, published in the September ARCHIVES OF GENERAL PSYCHIATRY, consisted of 52 boys and 10 girls treated at one of four sites. Youngsters ranged in age from 6 to 11. They displayed severe problems with inattention, hyperactivity, and impulsiveness. More than half had a developmental or behavioral disorder in addition to ADHD, a pattern frequently noted in prior studies.

Each child received amphetamine treatment for 3 months so that a proper dosage could be established. The children were then assigned at random to receive either the amphetamine or an inactive substance for 1 year, followed by 3 months of the inactive substance for everyone.

The scientists found at the end of the program that behaviors typical of ADHD had subsided to a much greater extent, both at home and at school, in kids who had taken the medication. Intelligence test scores also improved for the amphetamine group.

Still, the study found no conclusive evidence of stimulants' unique long-term benefits in treating ADHD, remarks Michael Rutter of the Institute of Psychiatry in London in an accompanying comment. The study did not, for example, examine whether the benefits of amphetamines exceed those of a psychological intervention, such as training families and teachers to deal with a child's behavioral problems.

A study now under way in the United States is examining 7- to 9-year-olds diagnosed with ADHD during 14 months of medication alone, a comprehensive counseling and training program alone, a combination of both, or no treatment; it will follow them for the subsequent 10 months as well. —*B.B.*

From poverty to undernutrition

Poor women in many countries have access to free food supplements for their babies and young children. Yet a large minority of these children still suffer from a lack of protein and calories known as undernutrition (which falls short of malnutrition). In psychologically vulnerable women, the stresses of poverty may trigger a breakdown in their ability or willingness to care for a child, thus fostering undernutrition, says psychologist Marta Valenzuela of the University of Quebec in Montreal.

"Intervention efforts need to extend beyond food supplements to support infant-mother relationships as a means to prevent [chronic undernutrition]," Valenzuela writes in the September DEVELOPMENTAL PSYCHOLOGY.

She studied 85 poor mothers who regularly attended health clinics in Santiago, Chile, with their 18-month-old infants. All of the babies had a normal weight at birth, but 42 had been underweight since about age 3 months.

Cases of infant undernourishment clustered among mothers who showed little availability, acceptance, responsiveness, or affection toward their children in interactive laboratory tasks, Valenzuela says. Those mothers may, for whatever reasons, recoil emotionally and physically from infants who are initially unresponsive and whose frustrating traits grow increasingly worse due to undernutrition, she theorizes. —*B.B.*