Toxic Tides

In June 1990, after collecting shellfish from a beach, an Alaskan fisherman carried butter clams to a fishing boat where he steamed and ate 25–30 of them. Within an hour of the meal he complained of numbness around his face and fingers. Just two hours later he died. The fisherman had eaten shellfish contaminated with the toxic algae *Alexandrium,* and suffered a condition in which nerve impulses do not reach the muscles. Without the nerve impulses, the diaphragm and fine structures of the lungs do not work, which can lead to respiratory failure, according to Patricia Tester, a marine biologist at the National Marine Fisheries Service in Beaufort, North Carolina.

This deadly organism is among dozens of toxic algae wreaking havoc around the world. Clams, mussels, scallops, oysters, and other shellfish filter toxic algae from the water, and the toxins accumulate in their tissues, frequently without great effect on shellfish health. But people who eat algae-contaminated seafood can suffer gastrointestinal disorders, respiratory problems, confusion, memory loss, and, in rare cases, death. In some cases, one clam or mussel can contain enough poison to kill a human being. What makes such toxins especially dangerous is that they are tasteless and colorless, and even cooking the shellfish often won't destroy the toxins. Moreover, one type of algal toxin can be aerosolized by surf and then carried inland by breezes, and cause respiratory problems in people who breathe it in.

Still, scant information exists about the prevalence of marine seafood poisonings. Globally, about 60,000 cases of toxic seafood poisoning are reported each year, with a 0.15% death rate. But the majority of cases are not reported or are misdiagnosed, experts say. Health agencies also lack data on chronic effects and vulnerable populations for poisonings due to inadequate surveillance systems. It appears, however, that marine seafood poisonings are increasing along with interstate and international shipping of seafood. International travel has exploded as well, with greater numbers of people eating seafood in exotic places. But in the United States, government monitoring of coastal waters for algae and toxins has significantly minimized the risk of consuming tainted shellfish.

Still, algae with at least some type of harmful effect inhabit the waters of nearly all U.S. coastal states. Along the West Coast and in Alaska, state officials have closed hundreds of miles of coastline to shellfish harvesting due to toxic algae. In New England, harmful blooms over the past 20 years have killed shellfish, lobsters, fish, and marine mammals. In 1988 alone, algae blooms killed vast numbers of scallops in New York State waters, causing a $2 million loss to the shellfishing industry. Since 1991, a toxic dinoflagellate, *Pfiesteria piscicida,* has caused fish kills in North Carolina, Maryland, Virginia, and Delaware, and has been implicated in health problems among fishermen heavily exposed to infested waters. Combined economic costs of harmful algae have been serious with about $40 million per year in damages to U.S. fisheries, public health, and tourism over the past seven years, says Donald Anderson, a senior marine scientist at the Woods Hole Oceanographic Institution in Massachusetts.

The number of harmful algae seem to be growing internationally, and their geographic distribution is spreading as well. "Toxic blooms are occurring in places where they haven't been seen before," says Tester. Of several thousand marine algae species, about 60–80 are toxic, according to Theodore Smayda, an oceanographer at the University of Rhode Island Graduate School of Oceanography in Narragansett. A decade ago, only about 25 toxic species had been identified, but scientists continue to discover harmful species. Scientists are also finding formerly unidentified toxins, says Anderson. These newly recognized poisons may be the least potent on a per-milligram basis but their effects on human health, including long-term memory loss, appear to be more insidious and longer-lasting than ones previously known.

History and Causes

The first recorded fatal cases of shellfish poisoning occurred in 1793 after Captain George Vancouver and his crew landed along the northwestern coast of North America. Some of Vancouver's sailors ate shellfish from an area known today in British Columbia as Poison Cove. Later, Vancouver learned that local Indians would not eat shellfish during dinoflagellate blooms, which reddened the waters.

About 75% of the known toxic algal species are dinoflagellates, writes Smayda in the July 1997 issue of *Limnology and Oceanography*. Dinoflagellates are microscopic, single-celled algae with flagella, or tails, that enable them to travel by spinning through the water. Some dinoflagellate species are photosynthetic, some eat other organisms, and some do both. While the overwhelming majority of dinoflagellate species are not harmful, some species can grow rapidly, accumulating near the sea surface and discoloring the water in a phenomenon called a "red tide." While red tides usually have benign effects, some species produce toxins as they redden the sea. Other algal species produce toxins but do not discolor the sea at all, thus providing no advance warning of their effects.

The growth of harmful algae is part of a larger water quality problem in many U.S. estuaries, some scientists say. In numerous cases, nontoxic and toxic algal blooms are increasing due to excess nutrients from human sources, especially synthetic nitrogen fertilizers from agriculture and nitrogen oxides discharged by cars and factories. Other sources of excess nutrients include aquaculture facilities, urban runoff, and sewage treatment plants. Excess nutrients spur growth of aquatic plants that eventually die, sink, and decay, depleting the water's oxygen supply and thereby suffocating many kinds of sea life. Recent surveys by the National Oceanic and Atmospheric Administration (NOAA) note that, at some point each year, 53% of U.S. estuaries experience hypoxic or low dissolved-oxygen conditions, and 30% of these estuaries experience periods of anoxia, or no dissolved oxygen.

For example, researchers have delineated a gigantic "dead zone" of low-oxygen waters in the Gulf of Mexico at depths of 0.5–20.0 meters. Nutrient overenrichment is a major contributor to the problem, according to NOAA scientists. Indeed, after the Great Mississippi Flood of 1993, which poured huge amounts of agricultural nutrients from Midwest farms into the Gulf, the size of the dead zone doubled from 3,500 square miles to 7,000 square miles.

Nutrient overenrichment is an international concern, as well. Globally, people add between 7 million and 35 million metric tons of nitrogen and between 1 million and 4 million metric tons of phosphorus to the environment each year, says Walter V. Reid, vice president for programs at the World Resources Institute, a nonpartisan research organization in Washington, DC. "Humans now have a huge impact on chemical cycles," he notes.

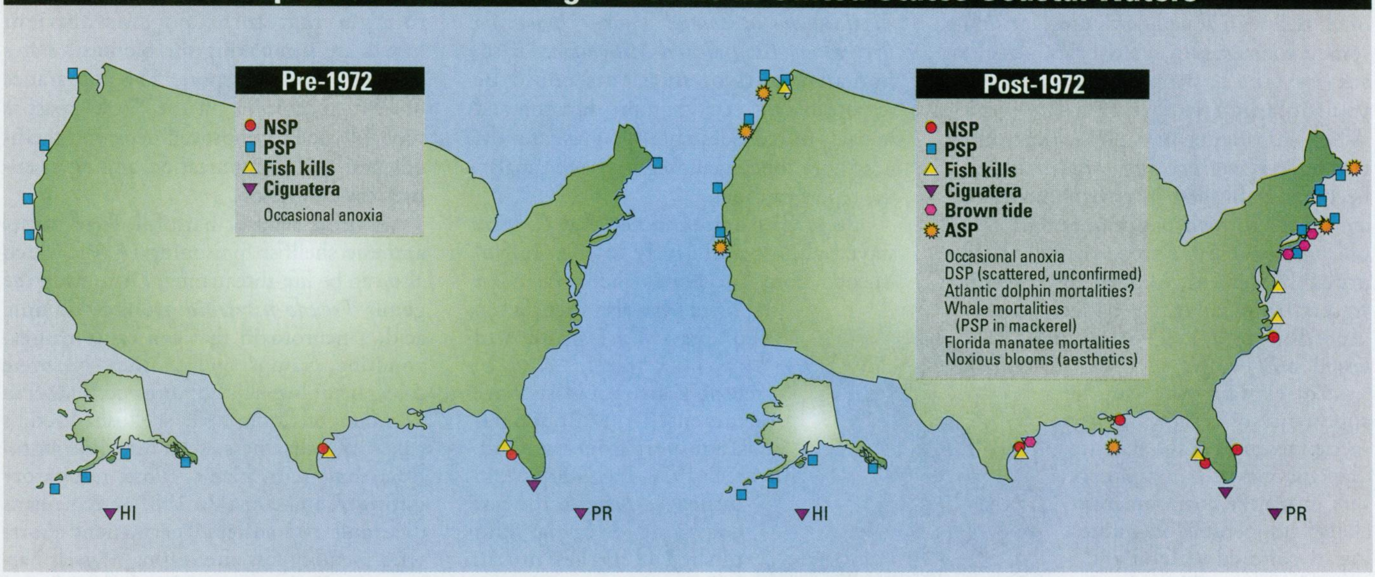
In 1997, the Ecological Society of America and the international Scientific Committee on Problems of the Environment (SCOPE) called nitrogen pollution a "preeminent problem." Robert Howarth, a biogeochemist at Cornell University in Ithaca, New York, who is cochair of SCOPE, argues that synthetic fertilizers, fossil-fuel emissions, and other human sources are responsible for at least 60% of all nitrogen available to plants on land each year. And of that amount, about 20% flows into rivers, and then into estuaries and the coastal ocean. "In the coastal ocean off the northeast United States, nutrient loads are 5- to 10-fold higher than they were a century ago, and in the Gulf of Mexico they are 3-fold higher," he says.

Ocean warming, moreover, has combined with nutrient enrichment to create larger, more frequent algal blooms around the world, some scientists argue. Satellite images have confirmed increases in the size and scope of algal growth during the 1980s and early 1990s. El Niño-precipitated events that bring heavier rainfall and regional warming have been "associated with the emergence or resurgence of harmful blooms, especially at higher latitudes," says Paul Epstein, associate director of Harvard University Medical School's Center for Health and the Global Environment. Other environmental stresses that encourage blooms include overharvesting of fish that feed on plankton and destruction of wetlands that filter nitrogen and phosphorus, he says.

In at least one case, nontoxic plankton blooms have encouraged a toxic species to proliferate. In North Carolina, giant livestock farms have polluted coastal rivers as millions of gallons of manure, rich in nutrients, have spilled from farm ponds and run off fields into waterways during heavy rains. Plankton feed on these nutrients, and in turn, *Pfiesteria*, which feeds on the plankton, thrives, notes JoAnn Burkholder, an aquatic botanist at North Carolina State University in Raleigh.

Harmful algal species, though, are not all alike. They can bloom or become toxic under various conditions and stimulants. In fact, scientists cannot clearly link many kinds of destructive and poisonous algae to

Spread of Harmful Algal Blooms in United States Coastal Waters



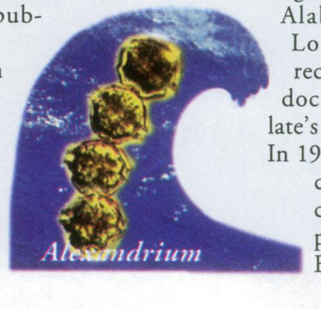
Source: National Office for Marine Biotoxins and Harmful Algal Blooms, MS #32, Woods Hole Oceanographic Institution, Woods Hole, MA 02543 USA.

greater nutrient loads from human sources, especially in the United States, argues Anderson. And he disputes the idea that nutrient levels from human sources have boomed recently in U.S. waters. "During the past 20 years, there have been slightly elevated levels of nutrient pollution, providing some stimulation of harmful algae. But overall, our coastal waters are in pretty good shape."

It's true that excess nitrogen and phosphorus in U.S. waters have not become dramatically worse since the 1970s, when pollutant loads began leveling off, says Howarth. Water quality in many U.S. estuaries, in fact, was notably enhanced by Clean Water Act initiatives of the 1970s. In Tampa Bay, Florida, for example, water quality was very poor from the 1960s until the late 1970s, when advanced sewage treatment facilities were constructed, says Holly Greening, a senior scientist with the Tampa Bay Estuary Program in St. Petersburg. "There was vast improvement in water quality, largely due to reducing nitrogen by 90% from what had been discharged during the '60s and mid-'70s," she says. And while excess nutrients have clearly encouraged marine plant growth globally, Howarth agrees that their effect on specific harmful species is "fairly convoluted" and difficult to prove. In fact, some of Florida's worst and most persistent red tides have occurred in the last 10 years, since the water quality has improved.

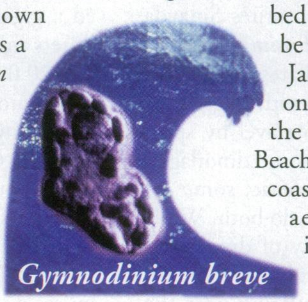
Another possible explanation for the spread of some harmful algae is that they are being transported from estuary to estuary by ship ballast water. Merchant ships routinely draw ballast water into their holds to provide additional weight, making them ride lower and offering greater stability in the open ocean. This ballast water is often rich with aquatic creatures, including some toxic algae. In many cases, algae can survive in a ship's hold during a transoceanic trip lasting a few weeks. When ships enter new ports, they dump the ballast water, and organisms can become established in environments that are similar to their native ones. For example, two species of toxic dinoflagellates probably were introduced to Australian waters from Japan via ballast water, according to a 1993 study published in *Phycologia*.

To explain the sudden appearance of certain harmful species, researchers also point to dramatic increases in aquaculture in marine environments, along with increased monitoring of cultured seafood and coastal waters. This closer monitoring has revealed toxic algae that probably always existed, experts say.


Alexandrium

Classes of Blooms

Several kinds of harmful algal blooms have wreaked havoc in coastal waters around the United States. The oldest known toxic species in North America is a dinoflagellate, *Gymnodinium breve*, that causes neurotoxic shellfish poisoning (NSP). After people eat contaminated shellfish, they can suffer numbness, tingling, cramps, nausea, vomiting, diarrhea, chills, and sweats. In blooms, this dinoflagellate's toxins also kill fish, invertebrates, birds, and marine mammals. NSP blooms may also become aerosolized in surf, and can cause respiratory problems in people who breathe them.


Gymnodinium breve

NSP is the best-documented illness caused by a harmful algal species. Centuries ago, Tampa Bay Indians and Spanish explorers noticed fish kills in certain seasons when coastal waters turned red. In 1880, shellfish poisonings were reported along the west coast of Florida, and in 1916 the first complaints about respiratory problems in association with algal blooms were recorded. In 1946, *G. breve* was discovered to be the cause of NSP.

G. breve grows naturally offshore, on the continental shelf, consuming low levels of nutrients. But *G. breve* blooms are also transported inshore by currents. In coastal bays, the blooms may last longer if provided with additional nutrients from manmade sources. "Evidence suggests that dense blooms inshore cannot be sustained without inputs of 'new' nutrients," states a February 1997 NOAA report, *Harmful Algal Blooms in Coastal Waters: Options for Prevention, Control and Mitigation*. "If so, human inputs of nutrients could be responsible for extending the duration and impacts of red tides once blooms enter the nearshore zone, including bays and canals," the report cautions.

Researchers once believed that *G. breve* stayed almost exclusively in the Gulf of Mexico from Yucatan to the Texas coast (sightings have also occurred in Alabama, Mississippi, and Louisiana waters). But in recent years, scientists have documented the dinoflagellate's transport from the Gulf. In 1987–1988, the Gulf Stream carried *G. breve* to the east coast of Florida and pushed it farther north. Eventually, toxic blooms reached North Carolina for the first time, and shellfish beds were subsequently closed for months. "We had a public health crisis, with 48 documented cases of illness from shellfish poisoning," says Tester. The regional economic impact of the shellfish-bed closing was estimated to be $25 million, she says. In January 1998, *G. breve* was once again transported from the Gulf of Mexico to Palm Beach County on Florida's east coast. In the surf, the toxins aerosolized and wafted inland with breezes, and caused breathing problems for people living near the ocean.

A second category of harmful algal blooms occurs when one of several related species of dinoflagellate in the genus *Alexandrium* grows rapidly and contaminates shellfish. Paralytic shellfish poisoning (PSP), which can be life-threatening, occurs when people eat the contaminated shellfish. Symptoms include tingling, numbness, drowsiness, fever, and in the most severe cases, respiratory arrest within 24 hours after the victim has eaten contaminated shellfish. *Alexandrium* species can also kill fish, birds, and marine mammals.

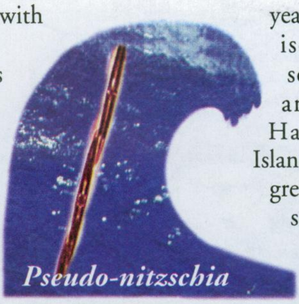
PSP occurs along more coastline in the United States than any other harmful algal problem. On the East Coast, PSP recurs frequently from Maine to Massachusetts, and occasionally farther south to New Jersey. Since 1991, PSP has recurred on the West Coast each year from northern California to Alaska.

Researchers believe that nutrients from human sources probably are not driving these blooms. *Alexandrium* can grow in "relatively pristine waters, and it is difficult to argue that anthropogenic nutrient inputs are stimulating the blooms," states the 1997 NOAA report. The appearance of PSP since 1991 on the West Coast is probably due to improved detection methods and to communication among scientists, says Anderson.

A third class of harmful algae causes amnesic shellfish poisoning (ASP), which also can be life-threatening. Diatoms in the genus *Pseudo-nitzschia* produce domoic acid, a neurotoxin that can cause nausea, vomiting, cramps, and diarrhea. In severe cases, neurological symptoms occur within 48 hours of eating toxic shellfish. Victims can suffer dizziness, seizures, disorientation, short-term memory loss, respiratory difficulty, and coma. In 1987, 4 Canadians died and 105 suffered permanent short-term memory loss after eating mussels harvested off the coast of Prince Edward

Island that were contaminated with toxic diatoms.

Toxic *Pseudo-nitzschia* species are also found on the West Coast of the United States. In 1991, toxins concentrated to dangerous levels in razor clams and Dungeness crabs on the Oregon and Washington coasts. In western Washington alone, the economic impact of the 1991 toxic bloom was estimated at $15–20 million. A few people became ill in Washington State after consuming razor clams, with mild, short-lived symptoms including gastrointestinal disorders and memory loss. At some point each year between 1992 and 1995, toxin levels in razor clams, which are harvested recreationally, have been above regulatory limits in Washington, says Vera Trainer, a research oceanographer with the Northwest Fisheries Science Center in Seattle. To protect public health, the state has temporarily closed some shellfish beds. But some harvesters have complained that regulators exaggerate the toxin risk and that the state is "meddling in something that's gone on for many years," Trainer says. In a few instances, regulators have had to put up roadblocks to prevent harvesters from reaching shellfish beds. Most *Pseudo-nitzschia* blooms have not been linked to nutrient pollution but instead to natural events, including spring and summer changes in currents, temperature, and salinity.

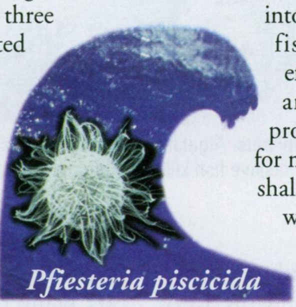


In the tropics and subtropics, toxic dinoflagellates living on coral reefs are eaten by fish herbivores, which in turn are eaten by larger carnivores. The poisons moving up the food chain cause ciguatera fish poisoning (CFP), a fourth category of harmful algae effects. Symptoms include numbness, tingling, cramps, nausea, vomiting, diarrhea, chills, and sweats.

More than 400 different fish species are involved in CFP, including grouper, barracuda, snapper, jack, mackerel, and triggerfish, according to a 1996 report, *Design and Implementation of Some Harmful Algal Monitoring Systems*, by the Intergovernmental Oceanographic Commission, part of the United Nations Educational, Scientific, and Cultural Organization. The toxic algae that cause CFP are a natural phenomenon, with no known link to excess nutrients.

This form of seafood poisoning is probably the most serious public health threat from harmful algae in the United States and its territories, says Anderson. Only a few dozen cases are reported each year in the United States, with isolated poisonings from south Florida to Vermont, and more regular ones in Hawaii, the U.S. Virgin Islands, and Puerto Rico. But the great majority of ciguatera poisonings are unreported, says Anderson. An estimated 100 cases of poisonings are unreported for every reported case in Puerto Rico and the Virgin Islands, where many people are "so poor they don't go to the hospital," Anderson says, and three of every four cases are unreported in Florida.

Still another category of harmful algae kills farmed and wild fish, but does not directly affect human health. In recent years, New York and Texas coastlines have been besieged by brown tides caused by marine plankton called chrysophytes. Brown tide cells grow to extraordinary densities and shade the plant life in shallow bays. In 1985, the first known brown tide appeared off Long Island and ruined the local bay scallop industry. In 1989, a brown tide bloomed off the Texas coast and remained for eight years.



Researchers hypothesize that a "brown tide toxin influences nerve transmission in shellfish," says Darcy J. Lonsdale, a marine scientist at the State University of New York at Stony Brook. Lonsdale says that brown tide algae could have evolved their toxins to ward off shellfish, one of their main predators. In large concentrations, the toxin may prevent shellfish gills from functioning, so the shellfish can't feed and thus starve. Brown tide species are probably stimulated, at least in part, by excess nutrients from human sources, some scientists say.

Last but not least in the categories of harmful algae is the toxic dinoflagellate *Pfiesteria piscicida*, linked to fish kills and lesions and human health impacts in several coastal rivers in some mid-Atlantic states. In 1991, *Pfiesteria* was implicated in numerous fish kills in North Carolina. In 1995, officials closed a section of the lower Neuse River after *Pfiesteria* outbreaks apparently caused huge fish kills equaling millions of menhaden (a commercially important fish in the herring family). And in 1997, officials closed sections of Maryland's Pocomoke River and two other waterways that flow into Chesapeake Bay after similar fish kills and human health effects were reported. *Pfiesteria*, an ancient life form that has probably existed in these waters for millions of years, seems to favor shallow, poorly flushed, brackish waters. It seems clear that *Pfiesteria* growth is exacerbated by large increases of nutrients in coastal waters, researchers say.

In 1997, researchers at Baltimore's University of Maryland and Johns

Woods Hole Oceanographic Institution

Red seas and dead seas. The dinoflagellate *G. breve* causes red tides and neurotoxic shellfish poisoning in both marine species and humans.

Hopkins University issued a preliminary report noting that people heavily exposed to *Pfiesteria*-infested waters in rivers draining into Chesapeake Bay suffered skin disorders, respiratory irritation, learning disorders, memory loss, and confusion. Burkholder and her research assistant both suffered memory loss and other effects from working with this toxic dinoflagellate. *Pfiesteria*, however, has not been linked to any known poisonings due to eating seafood.

Florida Department of Natural Resources

Empty nets. Algal blooms have increased significantly in recent years in U.S. coastal waters, causing massive fish kills and leading scientists to ponder the cause.

What's Being Done

During last year's *Pfiesteria* outbreak in the Pocomoke River, NOAA and the EPA provided emergency funds to the state of Maryland to establish regular monitoring of the river, analyses of toxins in sediments, and assessments of watershed loads of nutrients and agricultural chemicals. In this federal–state partnership, officials established epidemiological studies for human health impacts of *Pfiesteria*, and outreach programs for medical personnel and the public. This type of coordinated strategy could be used during other harmful algal outbreaks as well, scientists say. In 1997, Congress appropriated $4 million for harmful bloom research, with $3 million targeted toward *Pfiesteria* studies.

Since last fall, scientists have learned more about the complexity of the *Pfiesteria* phenomenon. Scientist Alan Lewitus of the Belle W. Baruch Marine Laboratory in Georgetown, South Carolina, says that the attention on *Pfiesteria* has stimulated research on other small dinoflagellates that resemble *Pfiesteria* in general appearance. Some of these 6–8 so-called "*Pfiesteria* look-alikes" are also toxic, but otherwise have different behavior patterns and life cycles. A high priority in *Pfiesteria* research is to develop efficient means of identifying *Pfiesteria* in estuarine waters, and distinguishing it from these other dinoflagellates.

Molecular probes to rapidly detect the presence of *Pfiesteria* and its toxins in water are being developed by Parke Rublee, a biologist at the University of North Carolina at Greensboro, and John Ramsdell, division chief of NOAA's Charleston Laboratory marine biotoxin program. Such probes are biochemical tools that can find the presence of molecular traits of specific organisms. The probe for *Pfiesteria* could help researchers determine whether fish kills are actually caused by the organism and could "carry us leaps ahead in linking *Pfiesteria* directly to toxic events," says Lewitus.

To understand how toxic algae affect fish, shellfish, and human health, scientists must learn how the toxins do their damage—specifically, what their life cycles are and at which points in these cycles they are toxic. In research institutions worldwide, scientists have identified the chemical structures of toxins responsible for seafood poisonings including NSP, PSP, ASP, and CFP. Since last fall, scientists at the NIEHS, North Carolina State University, the University of Miami, and the Charleston Laboratory made progress in isolating the *Pfiesteria* water- and lipid-soluble toxins.

In February 1998, to reduce pollution in U.S. waters, President Clinton proposed a Clean Water and Watershed Restoration Initiative, which includes 100 proposals for reducing water quality problems, with a potential cost of $2.3 billion over five years. Some of the proposals would require additional regulations, including new national standards for nitrogen and phosphorus. The initiative would require state and local governments to establish plans to reduce these pollutants. It could impose new restrictions on huge livestock farms, and provide millions of dollars for voluntary programs to reduce the amount of pollution draining into waterways. The voluntary programs would fund the planting of vegetated buffer zones to filter pollutants along 2 million miles of river banks. Block grants and other funds would be targeted to state and local governments to improve water quality. Other funds would be available to private property owners who agree to reduce runoff pollution.

The Clinton initiative, if passed by Congress, could provide crucial funds for pollution reduction to strapped local governments, says Greening. Many localities want to reduce their number of septic systems, which often leak or spill pollution into waterways, by building or improving sewage treatment facilities. But the economic costs of laying sewage pipes and improving treatment plants are just too high, especially for smaller communities, she says.

Any nutrient reduction programs should be designed for entire

Woods Hole Oceanographic Institution

Beach blight. Red tides on the coast of Florida are a health hazard to both man and marine life.

watersheds, a process that has worked effectively in the Chesapeake Bay region, says Tom Schueler, executive director of the Center for Watershed Protection, a nonprofit organization based in Ellicott City, Maryland. "You need to define the watershed, identify the nutrient sources, and then ask for a little bit of reduction from everybody," he says. "You need federal, state, and local government participation, and you need anybody who's going to be regulated or affected economically invited to the table."

To address transport of exotic species in ballast water, including harmful algae, a 1995 international agreement called the Jakarta Mandate encourages ships to dump ballast water from the previous port at sea and then replace it with offshore ocean water. Organisms from the open ocean are unlikely to survive when discharged into estuaries. The United States has similar guidelines. In 1990, Congress passed a law requiring ships to dump ballast water before they enter the Great Lakes. In 1996, Congress passed a law that establishes voluntary guidelines on ballast for ships that enter all U.S. waters. After three years, if voluntary compliance is inadequate to address the problems, then the ballast guidelines will be made mandatory.

Since 1991, *Pfiesteria* outbreaks have increasingly spurred public interest to a spectacular degree, although attention has not been focused on other dangerous algae to anywhere near the same extent. Indeed, *Pfiesteria* is usually treated by the news media as a bizarre, freakish phenomenon without precedent, though this organism is just one part of a national and international problem. For instance, the total Chesapeake Bay fish kill blamed on *Pfiesteria* in 1997 equaled approximately 50,000 fish, but made headlines for months. In contrast, other harmful algae blooms occur under mysterious or natural conditions that are very difficult or impossible for people to predict, much less control, but poisonings due to these toxic blooms are often greatly underreported. For example, one *G. breve* bloom off the coast of Texas killed approximately 40 million fish and was hardly reported. Nevertheless, today's public concern over *Pfiesteria* could encourage lawmakers to establish or improve research and outreach strategies for other harmful algae as well. And it could spur Congress to address once again the nation's chronic water quality issues, thus building on substantial improvements made during the 1970s.

John Tibbetts